SUSTAINABLE DESIGN STRATEGY: ASSESSMENT OF THE IMPACT OF DESIGN VARIABLES ON ENERGY CONSUMPTION OF OFFICE BUILDINGS IN ABUJA, NIGERIA.

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This thesis is submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of the University of Portsmouth

School of Architecture, University of Portsmouth
March, 2015
Title: SUSTAINABLE DESIGN STRATEGY: ASSESSMENT OF THE IMPACT OF DESIGN VARIABLES ON ENERGY CONSUMPTION OF OFFICE BUILDINGS IN ABUJA, NIGERIA.
Abstract

Buildings account for about 40% of global energy consumption and contribute 30% of all CO₂ emissions. This research project investigated extant office building development in Abuja, Nigeria with a view to establishing typical energy performances. Energy end uses were critically analysed to identify energy saving potentials. The research evaluated design variables that can be used to facilitate low energy building design and determine enhanced performances in the Nigerian and regional context.

The research initially adopted a case study approach that involved fieldwork surveys and walk-through energy audits in which 22 office buildings were investigated belonging to four performance based categories developed for the research. Also, based on a building inventory survey form developed for this research, building information obtained included the buildings physical components, energy use management and energy end uses. This enabled typical energy performances of the office building categories to be deduced using three widely used indicators; the Energy Use Index (EUI), the Energy Cost Index (ECI) and the Carbon Emission Index (CEI). Also, disaggregated energy end use showed an average distribution pattern of air conditioning, lighting, equipment and building services in the ratio 59%, 15%, 43% and 4% respectively. This showed the potentials of energy savings by reducing cooling load.

With the aid of computer based simulation (using IES-VE software) the research further evaluated the impacts of nine architectural design variables (identified from design guidance for low energy buildings as well as design recommendations for tropical climates) on building energy consumption using simplified models of the case study office building categories. From all these, an impact hierarchy of the design variables was deduced and the appropriate low energy design strategies were developed. This showed potential energy savings of up to 20% was achievable. Also benchmarks for enhanced building performance targets for all the categories were proposed for the furtherance of a sustainable built environment in a developing world context.
Contents

Title page ............................................................ 1
Abstract .............................................................. 2
Contents ............................................................... 3
Declaration ............................................................ 8
List of Tables .......................................................... 9
List of Figures ........................................................ 10
List of Pictures ....................................................... 13
Acknowledgement .................................................... 14
Dedication ............................................................. 15
Dissemination ......................................................... 16
1. Chapter One: Introduction and Background of study ........ 17
  1.1. Introduction ................................................... 17
  1.2. Study background ............................................. 17
  1.3. Statement of problem ......................................... 19
    1.3.1. Overview of energy in Nigeria ......................... 20
    1.3.2. Electricity in Nigeria .................................. 22
    1.3.3. Electricity and the built environment in Nigeria .... 28
    1.3.4. Prospective future costs of energy in Nigeria .......... 32
  1.4. Aim and objectives .......................................... 35
  1.5. Scope of study ............................................... 36
  1.6. Study approach and outline methodology .................... 37
  1.7. Thesis structure ............................................. 38
  1.8. Significance of study ....................................... 41
  1.9. Study limitations ........................................... 41
  1.10. Summary ..................................................... 42
2. Chapter Two: Energy and the built environment ............... 43
  2.1. Introduction .................................................. 43
  2.2. Energy and global (socio-economic) environment .......... 43
  2.3. Energy and the natural environment ....................... 46
  2.4. Energy consumption in buildings and the environment ...... 50
  2.5. Policy, legislation and regulations on energy use in buildings 53
2.6. Summary .............................................................................................................. 59

3. Chapter Three: Assessment of Energy consumption in buildings ................ 61
3.1. Introduction ........................................................................................................ 61
3.2. Approach to energy consumption analyses in buildings ..................... 61
3.3. Energy use assessment methods for buildings ........................................ 65
3.4. Energy use indicators ...................................................................................... 68
3.5. Evaluation tools for energy use in buildings ............................................. 72
3.6. Factors affecting energy use in buildings .................................................... 75
  3.6.1. Climatic factors .......................................................................................... 76
  3.6.2. Architectural design factors ...................................................................... 80
  3.6.3. Occupant factors ...................................................................................... 89
3.7. Research linkages with architectural works of excellence, .... 95
  3.7.1. Solaris building, Singapore by TR Hamzah and Yeang 2010. ....... 97
  3.7.2. Menara Mesiniaga, Malaysia by TR Hamza and Yeang 1992. ....... 98
  3.7.3. Commerz Bank Frankfurt, Germany by Norman Foster 1997. ...... 100
  3.7.4. Petronas Towers Kuala Lumpur – Malaysia by Ceasar Pelli 1996. .... 103
3.8. Design variables for research analyses ......................................................... 105
3.9. Summary .......................................................................................................... 105

4. Chapter Four: Methodology ............................................................................. 108
4.1. Introduction ........................................................................................................ 108
4.2. Research aim and objectives ......................................................................... 108
4.3. Research methodology ..................................................................................... 109
4.4. Research strategy ............................................................................................... 110
4.5. Research design ................................................................................................. 111
  4.5.1. Case study and field work ......................................................................... 111
  4.5.2. Computer based simulation ....................................................................... 114
4.6. Study limitation................................................................................................. 117
4.7. Confidentiality and ethics ................................................................................. 117
4.8. Summary ............................................................................................................ 118

5. Chapter Five: Energy use and office building development in Abuja .......... 119
5.1. Introduction ........................................................................................................ 119
5.2. General background of Nigeria ........................................ 119
  5.2.1. The geography ....................................................... 119
  5.2.2. The climate .......................................................... 120
  5.2.3. The socio-cultural environment ............................... 122
  5.2.4. The economy .......................................................... 123
5.3. Background of Abuja .................................................. 123
  5.3.1. The geography ....................................................... 124
  5.3.2. The climate .......................................................... 124
  5.3.3. The economic and socio-cultural environment .......... 131
5.4. Establishment and the development of Abuja as a capital city of Nigeria .................................................. 131
  5.4.1. Status of Abuja city development ......................... 133
  5.4.2. Prospective future of Abuja city development .......... 136
5.5. Electricity and energy infrastructure in Abuja ............... 137
5.6. Energy use regulation for the Abuja built environment ..... 138
  5.6.2. Energy use policy and regulations for buildings in Abuja 141
5.7. Office buildings development in Abuja ......................... 143
  5.7.1. Development of office buildings in Nigeria .......... 143
  5.7.2. Development of office buildings in Abuja .......... 151
5.8. Office buildings development in Abuja .......................... 156
  5.8.1. Proposed Performance based office classification ...... 157
    5.8.1.1. Building vertical projection (rise) .............. 157
    5.8.1.2. Budget .......................................................... 157
    5.8.1.3. Other considerations .................................. 158
5.9. Summary .................................................................. 161
6. Chapter Six: Case study and building inventory survey ....... 162
  6.1. Introduction ............................................................. 162
  6.2. Data collection .......................................................... 162
    6.2.1. Building inventory survey form ...................... 162
    6.2.3. Data analyses ...................................................... 169
  6.3. Data and results from case study ............................... 170
    6.3.1. The building physical component .................... 170
    6.3.2. Energy use management and occupancy regimen ...... 177
6.3.3. Energy use audit ................................................. 179
6.4. Statistical performance analyses and discussion ............. 182
   6.4.1. Building design and physical component .................. 182
   6.4.2. Energy performance analyses .................................. 182
   6.4.3. Correlation analyses ............................................. 186
6.5. Limitations .................................................................. 190
6.6. Summary and general findings of statistical analyses ...... 191
7. Chapter Seven: evaluation of design variables using computer simulation ......................................................... 192
   7.1. Introduction .................................................................. 192
   7.2. Computer based simulation .......................................... 192
      7.2.1. The simulation tool .................................................. 193
      7.2.2. Software validation .................................................. 193
   7.3. Performance of architectural typologies ...................... 196
      7.3.1. The simulation constants ......................................... 197
      7.3.2. Simulation performance outputs ................................. 197
   7.4. Performance evaluation of independent (architectural variables) input for enhanced building performance .......... 201
      7.4.1. Wall construction .................................................. 203
      7.4.2. Roof construction .................................................. 204
      7.4.3. Type of glazing ..................................................... 206
      7.4.4. Ground floor ....................................................... 208
      7.4.5. Floor to ceiling height ............................................. 209
      7.4.6. Orientation .......................................................... 210
      7.4.7. Glazing ratio ....................................................... 212
      7.4.8. Ventilation strategy ................................................ 213
      7.4.9. Building form ....................................................... 215
      7.4.10. Selected design variables ....................................... 215
   7.5. Enhanced performance of architectural typologies ......... 216
   7.6. Discussions and results on energy performances of design variables and architectural building typologies ........... 217
      7.6.1. Performance of building typologies ........................... 217
      7.6.2. Independent architectural design variables ................. 220
   7.7. Architectural design variables and improved performance benchmarks for low energy office buildings .................. 228
   7.8. Limitation.................................................................... 232
8. Chapter Eight: Professional reflections ............................................................ 234
   8.1. Introduction .................................................................................................. 234
   8.2. Research linkages and works of excellence .............................................. 234
       8.2.1. Building regulations ............................................................................ 234
       8.2.2. Conscious low energy building design ............................................. 236
       8.2.3. Occupants’ load factor ....................................................................... 241
   8.3. Summary ....................................................................................................... 242
9. Chapter Nine: Conclusions ............................................................................... 243
   9.1. Introduction .................................................................................................... 243
   9.2. General discussions, findings and conclusions .......................................... 243
   9.3. Contributions and significance of study .................................................... 249
   9.4. Recommendations and further research ................................................... 251
   9.5. Summary ....................................................................................................... 253
Appendices ............................................................................................................. 254
   Appendix A0: Building inventory survey data form ........................................... 255
   Appendix A: Ethical Review Approval Documentation (FO:07/11-0051) .............. 259
   Appendix A01: Building forms examined .......................................................... 265
   Appendix B: Monthly thermal performance of wall types .................................. 266
   Appendix C: Simulation data entry and monthly thermal performances for roof construction ................................................................. 274
   Appendix D: Simulation data entry and monthly thermal performances for glazing types ................................................................. 282
   Appendix E: Simulation data entry and monthly thermal performances for ground construction ................................................................. 290
   Appendix F: Simulation data entry for window opening control profile ............. 304
   Appendix G: Thermal performances of orientation with glazed façade ............... 305
   Appendix H: Design of sustainable office buildings in Nigeria, ....................... 307
   Appendix I: Scenario of office buildings energy consumption in Abuja. ............ 318
   Appendix J: Promoting Energy Use Regulations for a Sustainable Built Environment in Nigeria ................................................................. 328
References .............................................................................................................. 334
Declaration

‘Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.’

Name: Mu’azu, Abbas Ibrahim
Date: 24th March 2015

Signature:
List of Tables

Table 1-1: Outline research methodology ......................................................... 38
Table 3-1 Table showing selected design variables for the research interrogation ........................................................................................................... 105
Table 4-1: Summary of research methods ......................................................... 109
Table 6-1: Table showing case study buildings .............................................. 171
Table 6-2: Summary of physical components of case study buildings 176
Table 6-3: Summary of energy use management and end use audit . 181
Table 6-4: Summary of energy performances of case studies ........... 183
Table 6-5: table showing results of correlation analyses between design variables and energy consumption (low-rise) ........................................... 187
Table 6-6: table showing results of correlation analyses between design variables and energy consumption (high-rise buildings) .............. 188
Table 7-1: Table showing type of glazing evaluated in the simulation 207
Table 7-2: Table showing different ground floor types evaluated in simulation ......................................................................................................................... 208
Table 7-3 Comparative energy performance of building typologies using EUI as indicator ........................................................................................................... 216
List of Figures

Figure 1-1: Total energy consumption in Nigeria 2011 (by source) ...................................................... 21
Figure 1-2: Graph showing comparative electricity consumption in (Kwh/capita) ................................................................. 23
Figure 1-3: Electricity generation in Nigeria 1970-2008 ................................................................. 24
Figure 1-4: Projection of electricity generation in Nigeria ................................................................. 24
Figure 1-5: Chart showing electricity tariff adjustments in Nigeria ......................................................... 33
Figure 1-6: Chart showing petroleum price fluctuation in Nigeria ......................................................... 34
Figure 1-7: Outline of thesis structure ........................................................................................................ 39
Figure 1-8: Distribution of studies on life-cycle assessments of buildings .................................................. 65
Figure 3-1: Comparison of energy benchmarks for four categories of office buildings in the UK ................................................................. 73
Figure 3-2: Impact of street width factor on urban heat traps ................................................................. 85
Figure 4-1: Flow of research methods components .................................................................................. 109
Figure 5-1: Map of Nigeria showing Abuja at the centre ....................................................................... 120
Figure 5-2: Climatic map of Nigeria ........................................................................................................ 121
Figure 5-3: Map of Abuja .......................................................................................................................... 124
Figure 5-4: Average monthly rainfall (mm) in Nigerian cities ............................................................... 125
Figure 5-5: Average monthly temperatures of Nigerian cities ............................................................. 126
Figure 5-6: Average monthly direct solar radiation in Nigerian cities (MJ/m²) ........................................ 127
Figure 5-7: Wind rose diagram for Nigerian cities .................................................................................... 130
Figure 5-8: Map showing phases of Abuja city project development ...................................................... 133
Figure 5-9: Distribution of electricity consumption (by sector) in Abuja (2010) .......................................... 139
Figure 6-1: Chart showing distribution of building orientation ............................................................. 172
Figure 6-2: Chart showing distribution glazing ratio ............................................................................... 174
Figure 6-3: Chart showing the distribution of compactness ratio ............................................................ 175
Figure 6-4: Chart showing the distribution of building form factor ....................................................... 175
Figure 6-5: Chart showing distribution of energy consumption ............................................................. 177
Figure 6-6: Daily average duration of electricity availability (%) ......................................................... 178
Figure 6-7: Chart showing distribution of electricity cost (by source) ..................................................... 178
Figure 6-8: Chart showing distribution of energy consumption by end use .............................................. 180
Figure 6-9: Energy use performance for office building categories (EUI) ................................................ 184
Figure 6-10: Carbon emission performance of office building categories (CEI) ........................................ 185
Figure 6-11: Energy cost performance of office building categories (ECI) .............................................. 186
Figure 7-1: Building model used for software validation ........................................................................ 194
Figure 7-2: Validation model reproduced in software .............................................................................. 195
Figure 7-3: Simulation Weather data showing monthly minimum and maximum temperature distribution for Abuja ................................................. 197
Figure 7-4: Table showing performance comparison between fieldwork and simulated results .............................................................. 198
Figure 7-5: Simulated Energy performance of office buildings ...... 199
Figure 7-6: Simulated Carbon emission performance of office buildings ...................................................................................... 199
Figure 7-7: Simulated Energy cost performance of office buildings ... 200
Figure 7-8: Chart showing thermal performances of wall types...... 204
Figure 7-9: Thermal performance of roof types ............................. 206
Figure 7-10: Chart showing thermal performance of glazing types ... 207
Figure 7-11: Thermal performance of ground floor construction ...... 209
Figure 7-12: Thermal performance of floor to ceiling heights (FCH)... 210
Figure 7-13: Thermal performance of orientation on one glazed facade .............................................................................................. 211
Figure 7-14: Thermal performance of orientation on two opposite glazed facades ........................................................................ 211
Figure 7-15: Thermal performance of glazing ratio ....................... 212
Figure 7-16: Thermal performance of glazing types ..................... 212
Figure 7-17: Thermal performance of open window ventilation strategy .................................................................................................. 214
Figure 7-18: Thermal performance of profile window ventilation strategy ............................................................................................ 214
Figure 7-19: Thermal performance of two side profile window...... 215
Figure 7-20: Typical peak day energy consumption of office building categories ................................................................................ 219
*Figure 7-21: Comparative peak day performance of typical and improved simulation of office building categories ........................................ 220
Figure 7-22: Impact of wall type on energy gain of office building categories ......................................................................................... 221
Figure 7-23: Impact of roof type on energy gain of office building categories ......................................................................................... 223
Figure 7-24: Impact of glazing type on energy gain of office building categories ......................................................................................... 224
Figure 7-25: Impact of ground floor type on energy gain of office building categories ................................................................. 225
Figure 7-26: Impact of glazing ratio on building energy consumption 227
Figure 7-27: Impact of design variables on energy consumption (low energy) building design in Abuja ..................................................... 228
Figure 7-28: Improved EUI of office building categories ............ 229
Figure 7-29: Comparison between typical and improved EUI of office building categories ............................................................. 230
Figure 7-30: Improved CEI of office building categories .......... 230
Figure 7-31 Comparison between typical and improved simulated CEI of office building categories ......................................................... 231
Figure 7-32: Improved ECI of office building categories .......... 231
Figure 7-33: Comparison between typical and improved simulated ECI of office building categories ......................................................... 232
Figure 8-1: Proposed performance benchmarks for office buildings in Abuja...
List of Pictures

Picture 1-1: Private electricity generators used by tailors in open streets. ................................................................. 26
Picture 1-2: typical 2-stroke engine generator (I pass my neighbour) ................................................................. 27
Picture 1-3: Generators for private residential electricity provisions ................................................................. 27
Figure 1-4: Electricity consumption trend in the residential, commercial and industrial sectors 1970-2005 ................................................................. 29
Picture 3-1: Solaris Building, Singapore ................................................................. 98
Picture 3-2: Menara Mesiniaga, Malaysia ................................................................. 100
Picture 3-3: Commerzbank, Frankfurt-Germany ................................................................. 103
Picture 3-4: Petronas Towers, Malaysia ................................................................. 104
Picture 5-1: Solar movement between two geographical locations .......... 128
Picture 5-2: Picture showing solar angles for Abuja location .......... 129
Picture 5-3: Sun path diagram for Nigerian cities ................................................................. 129
Picture 5-4: Satellite images showing timeline of construction development ................................................................................. 134
Picture 5-5: Pictorial progress of construction development in Abuja 135
Picture 5-6: Traditional office building in Nigeria ................................................................. 145
Picture 5-7: Colonial style building in Nigeria ................................................................. 147
Picture 5-8: Modern architecture style building in Nigeria ................................................................. 149
Picture 5-9: Post-modern architecture style building in Nigeria ................................................................. 151
Picture 5-10: Early phase architecture style buildings in Abuja ................................................................. 152
Picture 5-11: Contemporary phase architecture style building in Abuja ................................................................................. 153
Picture 5-12: Design of future prospective office building design in Abuja ................................................................................. 154
Picture 5-13: World trade centre project (pictured above) in progress ................................................................. 155
Picture 5-14: Abuja Centenary Project - the New Financial Hub ................................................................................. 155
Picture 6-1: Description of site context ................................................................................. 163
Picture 6-2: Description of plan layout ................................................................................. 164
Picture 6-3: Description of compactness ratio ................................................................................. 164
Picture 6-4: Description of building form factor ................................................................................. 165
Picture 6-5: Description of glazing ratio ................................................................................. 165
Picture 6-6: Examples of shading devices ................................................................................. 166
Picture 6-7: Picture showing different end use energy applications in selected case study office buildings ................................................................................. 181
Picture 0-1: Thermal performance of orientation using one glazed facade ................................................................................. 305
Picture 0-2: Thermal performance of orientation using two opposite fully glazed facades ................................................................................. 306
Acknowledgement

I would like to thank my Director of Studies and supervisors Roger Tyrrell, Dr Brett Martinson and Tim Goodhead for their advice and guidance throughout the project as well as enabling a good basis for the present thesis.

I am grateful to my family, friends and colleagues for all the emotional support, camaraderie, entertainment, and caring they provided. I am indebted to my parents, family, in-laws, the Principals and staff of Deenarc Consultants, Purple Rose Limited and PCD Associates that were particularly supportive.

I would like to thank all the people that contributed with their expertise, critique and jokes in the realisation of this research particularly Dr. Issac Boateng, Dr. Zeynep Aygen, Dr. Tony Ogbonna, Dr Ali Sarki Na’ibbi, Dr Teslim Giwa, Mahmood Abdulkareem, Jamila Kabir, Adamu Kuta, Ahmed Hussain and many more too numerous to mention.

Finally, I wish to thank my wife and friend, Dr. Rabia Batagarawa (my Mercedes) for helping me get through the difficult times, and providing an enabling environment in which to work.
Dedication

To the glory of the one and only true God, Allah (SWT)

Who makes all things possible.
**Dissemination**


1. Chapter One: Introduction and Background of study

1.1. Introduction

This chapter provides a synopsis of some contemporary issues to set the context for the research and then defines the local problems, which the research addressed. The chapter clarifies the research aims, the objectives and the significance of the study. The chapter provides descriptions of the research methodology and its limitations. The structure of the study in terms of the thesis presentation is also described.

1.2. Study background

Since the emergence of the UN’s Sustainable Development discourse (Agenda 21) in 1992, the construction industry has come under increasing scrutiny due to its adverse impacts on the environment. The discourse presents status of global consumption in relation to resource limitations, related inter-generational consequences, greenhouse gas emissions, resource depletion and distortion of ecosystems (amongst others) have been identified as pivotal concerns that require urgent mitigation and appropriate adaptations. (Gyoh & Hugo, 2013; IPCC, 2007; Uher, 1999).

In terms of resource depletion for example, it was identified that the built environment and the construction industry account for one-sixth of the world’s freshwater withdrawals, one-quarter of its wood harvest and two-fifths of its material and energy flows (Ebohon & Rwelamila, 2001; Roodman & Lenssen, 1995).

Similarly, it has been shown that buildings consume an average of 40% of total energy production in many parts of the world, including the USA, UK and China, and accounts for a significant proportion of respective greenhouse gas emissions (Kasozi & Tutesigensi, 2007; Li & Yao, 2009; Scrase, 2001).
Thus, energy consumption in the built environment has become a significant element in sustainable development discourses not only because of its adverse environmental effects but due to a projected and continued rise in demand (King, 2008b; Roaf, Crichton, & Nicol, 2005). This also suggests that when viewed from another perspective, the built environment sector harbours potential for significant reduction of, and savings in energy consumption towards the development of a more sustainable environment.

Generally, high energy consumption in buildings tends to be more conspicuous in large or corporate buildings which also serve as symbolic architectural icons throughout the world (Abu-Ghazalah, 2007; Boussora, 1990; Mahgoub, 2004). Although, energy demand in buildings is influenced by a matrix of complex interrelations between several variables relating to the building itself, the climatic environment and other socio-economic factors, it has been established that the occupancy phase (overall building’s use period) accounts for the highest amounts of energy consumed in a building life-span (Heiselberg, 2012a; Horsely, 2004).

This has necessitated the evolution of various proactive measures targeting reduction in the built environment energy consumption, particularly during the occupancy phase, as a means towards a sustainable built environment (Dempsey & Jenks, 2005; Jenks, 2000; McLennan, 2004). These measures occur in both voluntary and involuntary forms (Lam & Yeang, 2009; Lee & Yik, 2004). Collectively, these include numerous substantive initiatives and instruments in addition to institutional frameworks, regulations and regulatory bodies, established at local, regional, and national and trans-national levels (Ebohon & Rwelamila, 2001; Raynsford, 1999). Some examples include the EU’s Energy Performance Directive (EPBD), Energy Performance Certificates (EPC), European Standards EN 15232, 15251, the US Leadership in Energy and Environmental Design (LEED) rating system, UK’s Code for Sustainable Homes and numerous Green
Building Councils such as those in Canada, Australia, Japan, Argentina, Colombia and South Africa.

However, these frameworks are prevalent primarily amongst the developed nations (Ebohon & Rwelamila, 2001; Iwaro & Mwasha, 2010; Janda, 2009).

Notwithstanding, the introduction of these regulations in general, has led to a paradigm shift from that of a supply dependency to a demand reduction philosophy. Consequently, buildings are expected to fall within one framework of compliance or another, designed to facilitate low energy consumption, energy efficiency and environmental responsibility. This imposes a significant impact on the way buildings are designed, built and used today, and into the future (Heerwagen & Zagreus, 2005; McLennan, 2004). It has therefore become increasingly important for architects, stakeholders and indeed all those involved in the construction industry, to understand the implication of their design decisions on the eventual energy demand of the building.

1.3. Statement of problem

In relation to the development discussed above, it is noted that Africa’s stance towards sustainable development commitments is rather discouraging or at best described as pessimistic (Adeba, 2010; Dybenko, 2010; Newman, 2010). Perhaps this explains why issues encapsulated in the global debate towards the achievement of a sustainable built environment achieves only low ranking in the strategic priorities of many African countries. Generally, the continent is largely depicted by endemic problems of poverty, disease, political instability and poor infrastructure (Moyo, 2009). Although mineral/natural resources and human capital abound within the continent, there is little evidence of translation of these finite resources into significant socio economic development as would have been expected (Davidson et al., 2003).
In addition, the pressure exerted by rapid urban and population growths and the demand for immediate solutions to these problems tends to undermine the development of a coherent and effective sustainable development strategy that is in alignment with the UN’s Agenda 21. It is noted that the challenges regarding the realisation of sustainable development are embedded in imported socio economic solutions based on Western paradigms (du Plessis, 2005; Ofori, 2000). Inadvertently, this only results to poor outcomes due to insufficient or inappropriate comprehension of the African context in which it is applied. This illustrates a marked distinction between the developed countries and their developing counterparts in their ability to deal with environmental and socio-economic problems; let alone the development of a sustainable built environment in particular (Ebohon & Rwelamila, 2001).

Abuja, the capital city of Nigeria which typifies the above scenario will be the focus of this study. The sub sections below describe specific issues related to Nigeria in general so as to place the research in context.

### 1.3.1. Overview of energy in Nigeria

Nigeria has an abundant energy resource that includes crude oil, natural gas, hydropower, coal, and numerous renewable energy potentials such as solar, wind, and biomass. However, exploited energy is mostly dominated by oil and gas; making it the economic mainstay of the country that accounts for over 85% of export earnings and government revenue (CBN, 2012). Nigeria is the 9th largest oil exporter in the world and holds the largest natural gas reserve in Africa (OPEC, 2013). As a consequence, Nigeria has experienced numerous budget surpluses owing to international oil price fluctuations since the crises of the 1970’s and more recent ones; hence increasing its GDP/per capita from $510 to $1,535 in 2003 and 2012 respectively (WorldBank, 2013a). In addition, fuel energy is largely available locally at a low cost,
(through government subsidies) in comparison with international prices.

Despite these budget surpluses, there is little evidence of substantial growth and development, particularly in areas such as energy and other infrastructural development. For example, less than 50% of the country’s nearly 160 million population has access to electricity; of which the availability is characterised as unstable and unreliable 50% of the time (Aliyu, Ramli, & Saleh, 2013; Oseni, 2012; Suberu, et al., 2013). As a consequence, fuelwood remains an important energy resource (as shown in Figure 1.1 below) used mainly for cooking in rural areas and parts of the urban areas due to poor access to modern energy infrastructure (gas and/or electricity).

*Figure 1-1: Total energy consumption in Nigeria 2011 (by source)*

![Figure 1-1: Total energy consumption in Nigeria 2011 (by source)](image)

Source: US Energy Information Administration EIA (2011)

Figure 1.1 shows distribution of energy consumption in Nigeria categorised by source. It is clear that fuelwood usage exceeds that of electricity, which is usually generated through hydro, natural gas or oil. This situation is already resulting in significant deforestation and
desertification; and the rate of forest depletion is considered unsustainable due to lack of appropriate policy and implementation strategies to ensure forest recovery (Bugaje, 2006). Undoubtedly, this will negatively impact upon the capacity for carbon sequestration through natural cycles.

Other energy sources including nuclear, solar and wind are hardly present in the national energy equation due to their negligible proportions (0.7%) and contribute little to the national grid (Shaaban & Petinrin, 2014; Suberu, et al., 2013). Perhaps, the financial gains associated with oil have overtaken other energy sources within the governmental strategic thinking despite their potential enhanced sustainability credentials (Akinlo, 2012; Bazilian et al., 2013; Gaber & Morales, 2011). Furthermore, this positioning is at odds with recent global initiatives towards conscious sustainable development.

1.3.2. Electricity in Nigeria

In Nigeria, electricity is provided largely through the Power Holding Corporation of Nigeria (PHCN), an ailing government agency that has enjoyed a historic monopoly over electricity generation, transmission and distribution in Nigeria (Aliyu, et al., 2013). It has nine generation plants, comprising three hydro and six thermal plants, across the country that are operating significantly below optimum capacities (Oseni, 2011). These generating plants have a collective installed capacity of 6,910MW produced mainly from hydro, and fossil fuel (oil and natural gas) sources at a ratio of 27.9% and 67.2% respectively (AfDB, 2011; NEPP, 2011). In its operations, generated electricity from transmission stations is delivered to District Business Units (BU) where the final distribution to end users/customers takes place. Each BU is responsible for billing/metering, collection and other customer services.

Although total electricity consumption in Nigeria has more than doubled since 2000, making it the highest consumption per capita in West Africa, it still lags behind most North African countries including Egypt and South Africa. A comparative chart of electricity consumption
in Figure 1.2 shows how far Nigeria is trailing behind amongst its peer countries globally. In fact, with Nigeria’s per capita energy consumption at 120.5 kWh, it is more than 10 times below that of the global average. Comparatively speaking, Brazil and Pakistan, two countries with similar population sizes, generate 24 times and 5 times more power than Nigeria, respectively; and Bangladesh, a country slightly smaller in population and with a lower gross domestic product (GDP) than Nigeria, produces nearly twice as much electricity as Nigeria (EIA, 2012).

**Figure 1.2 Graph showing comparative electricity consumption in (Kwh/capita)**

Despite the recent Government’s Reform on Energy and the associated investments expended between 1999 - 2012, as well as attempts to decouple the PHCN through licensing of other independent electric energy providers, electricity supply has not significantly increased as projected in the past two decades (Aliyu, et al., 2013; Thomas, 2013). As shown in Figure 1.3, installed capacity has virtually stagnated and generated electricity often fluctuates and now averages about 3,200MW in more recent years (Oseni, 2011).
Furthermore, demand outstrips supply in a ratio of 3:1 and it is projected that electricity supply has to increase by nearly 100% annually until 2035, to meet local demand (Sambo, 2008). Sambo (2008) further illustrates that this is a prerequisite to the government’s aspiration to attain the status of a developed nation by 2020. Figure 1.4 shows Nigeria’s energy supply projections up to the year 2020.

Figure 1-4: Projection of electricity generation in Nigeria

However, Wolfram, Shelef and Gertler (2012), argue that energy demand projections in developing countries are underestimated because frequently it does not capture the improvement in purchasing power of the poor population who historically had limited access to energy. This
suggests that the gap between demand and supply projections may be wider, having further negative impact on time and investment levels projected towards resolving the electricity crises.

In addition, the unavailability and lack of supply certainty of electricity has adversely affected the socio-economic environment with various sectors having to cope with shortages due to constant pressures from an increasing population and urban growth. Consequently, a supply side solution attracts attention in which the use of individual generators, through private provision is widely used in bridging the supply gap regardless of the associated cost implications. For example, in supplementing the electricity shortages, it is estimated that 60million residents in Nigeria have individual generators, costing N1.56trillion (£61.55bn) per annum to maintain (ECN, 2009). These costs are met in addition to costs of electricity from the national grid. Undoubtedly, this is a significant amount of money to expend on electricity provisions particularly in a country where 50% of its population are living below the poverty line (less than $1/day).

Meanwhile, with an annual electrification growth rate of 0.9% (Oseni, 2012), the status of those without the financial capacity to accommodate these costs of private electricity provision are likely to remain static, pending a substantive energy supply solution. Perhaps this explains why only 50% of Nigeria’s population have access to electricity, and the dominance of fuelwood energy usage.

Additionally, it is shown that 12-13million litres of fuel is consumed daily by generator use at a cost of N1.80billion (£7.10m)/week, within the manufacturing sector alone. This cost has considerable impact upon the economy increasing the cost of production; hence, making the Nigerian manufacturing sector relatively non-competitive in the context of global market position (Alby, Dethier, & Straub, 2013; Fadare, Bamiro, & Oni, 2010; Olayemi, 2012). This indicates an unattractive economic environment for investors, resulting to eventual loss of potential job opportunities. The extent of these challenges have equally
affected the local crafts industry as captured in Picture 1.1 below, which shows local tailors using generators to provide electricity to their sewing machines.

Picture 1-1: Private electricity generators used by tailors in open streets.

In addition, the trend for private electricity provision has emerged as a form of status-symbol, within the Nigerian social context (Adebamowo, Sangowawa, & Godwin, 2013). Presently, the ownership of the smallest size generator set popularly referred to (in West African pidgin English) as “I pass my neighbour” (meaning the attainment of a better economic status as compared to one’s neighbour) is now a common denominator for economic success amongst the middle and low income class (Adamu, 2011; Mensah, 2011). Picture 1.2 below shows the popular simple 2-stroke engine generator (I pass my neighbour) while Picture 1.3 shows various generators, belonging to residents, lined up along perimeter walls and within compounds of the owners.
Generator clusters as shown in Picture 1.3 are very common in shared houses and compounds. The concentration of exhaust fumes from these clustered generators cannot be devoid of health and environmental implications. Apart from contributing to CO$_2$ emissions to the atmosphere, there have been reported incidents of deaths as a result of CO poisoning in such congested compounds (Adamu, 2011; Amstrong-Ogbonna, 2011; Awofeso, 2011; Stanley, Mbmali, & Dania, 2011).

Although the electricity supply solutions are imperfect in the extreme, there are some emerging initiatives promoted by the private sector to curb the dependence on generators as an alternative source of electricity and to embrace more sustainable remedies. These include the
use of solar panels, inverters (local battery storage for electricity) and even generation by wind power (Gyoh, 2013; Oseni, 2012; Stephen, et al., 2012). However, these initiatives are yet to make significant impacts within the Nigerian energy market. This can be attributed to cost of these technologies which remains relatively high and largely out of reach for most people (ECN, 2012). In addition, these alternatives still have to compete in a market saturated with cheap generators from many parts of the world particularly China (Trovalla & Trovalla, 2013).

In addition, there is a political dimension to the electricity challenge which lies in the actual political-will to resolve the electricity generation and supply situation by enacting appropriate policies, attracting and obtaining the required investments and funding as well as developing a target driven implementation programme for electricity delivery. This has been undermined by antagonists, in the form of lobbyist from diesel supply and generator manufacturing groups, who strive to ensure satisfaction of corrupt and selfish interests (Akinnuoye, 2013; Olugbenga, Jumah, & Phillips, 2013; WorldBank, 2013b). Perhaps, only time will tell if the government is able to withstand the pressure from such corrupt and selfish-interest groups in favour of wider public interest and national development.

As a result of the economic, social, environmental and political challenges delivering stable and adequate electricity delivery, it can be understood why a sustainable or energy conscious energy-use strategy as presently encouraged globally, has little constituency in Nigeria.

1.3.3. Electricity and the built environment in Nigeria

There are mainly three major types of consumers (sectors) in Nigeria according to Power Holding Company of Nigeria (PHCN - the primary utility provider) classification. These are residential, commercial and industrial sectors, and in some cases the municipal sector is also included. Although the transport sector is often considered in the overall energy consumption of the country, it does not feature as a PHCN customer/sector due to the absence of electricity driven transport...
systems in Nigeria. In Figure 1.4 electricity consumption trends among the consumers identified above is illustrated. It is evident that the combined effect of residential and commercial sectors far exceeds that of the industrial sector. It also illustrates rise in commercial sector electricity consumption, (which includes office buildings) since the early 1990s such that independently, it exceeds that of the industrial sector.

*Figure 1-4: Electricity consumption trend in the residential, commercial and industrial sectors 1970-2005*

A more noticeable increase in commercial sector electricity consumption is observed post 2000, the period when electricity consumption by commercial sectors begins to exceed that of industrial sector can be traced to 1992. This coincides with the periods when Abuja became a substantive new capital city of Nigeria in 1991. Periods after that can be characterised by the presence of two commercial hubs in the country, since the old capital Lagos still remained an important commercial centre. This presents three noteworthy issues.

First, it shows that the built environment energy consumption is on the increase despite limited supply. Secondly, it presents both residential and commercial buildings as sectors where energy savings could be explored, and lastly, it suggests that energy consumption within the
built environment sector in Nigeria depicts scenarios applicable to
global conditions where it is demonstrated that buildings consume a
significant proportion of generated energy.

However, in addition to the pressure exerted by the built environment
on the fragile energy infrastructure, it is identified that Nigeria has an
annual population growth rate in urban areas reaching 3.7% and
urbanisation is now at 50% particularly in its major cities and
increasingly focused upon the new capital, Abuja (UN-HABITAT, 2009).
The combined effect of these pressures and other local issues has
resulted in a mixture of competing national priorities clouding issues
relating to energy consumption in the built environment. For example,
in describing the cost implication of implementing the master plan of
the new capital Abuja (which was designed according to paradigms
drawn from developed countries) Take (1984) noted the government’s
resolve towards gaining regional/global acknowledgement but with a
disregard to costs. Clearly, this provided an enabling platform to
develop buildings in a manner Tyrrell (2007) termed “architecture of the
fantastic”. Thus, building development was not necessarily embarked
upon with strategies of low energy, energy efficiency or any sustainable
issue at its core (Obia, 2013).

Most of such buildings (and office buildings in particular) have been
built with limited climatic adaptations such that the need for cooling is
required in a largely hot humid environment (Fadamiro & Ogunsemi,
2004; Gyoh & Hugo, 2013; Osasona, 2011). It is envisaged that such
buildings will fail in enabling their functionality, services and being
conducive to human habitation, because the rate of building increase
has not been matched in improvements to electricity infrastructure that
is expected to service them (Diribe, 2011; Imaah, 2004a).

In addition, development in the built environment is progressing amidst
limited advances in regulatory instruments for energy use in buildings
in contrast to what is mandatory in most developed countries (Adegbile,
2012). As a result, a supply side remedial approach continues to be
vigorously used in bridging the supply gap regardless of the associated costs and environmental implications. Bello, et al (2007) described the ensuing trend in the built environment as an emergence of architectural anarchy.

However, in acknowledgement of the debilitating energy situation in the country, the Government has since 2003, instituted Energy Reforms to ensure stable and adequate electricity supply. At the core of this Reform, is the enabling of Independent Power Providers (IPP) such that the monopoly enjoyed by PHCN can be neutralised (PTFP, 2013). Also, this will allow electricity to be competitively marketed as a commodity as exemplified in the telecommunications sector and energy sectors within developed nations.

Although the Reforms are still in the implementation stage, an all-encompassing solution will also require a comprehensive knowledge of the energy consumption behaviour for different sectors of the built environment as well as the need to address current end user inefficiency (Ikeme & Ebohon, 2005; Mu'azu, 2011). Therefore it is important to assess the impact of contemporary design of buildings on energy, particularly in a location experiencing significant construction activities but without the requisite building energy regulations such as Abuja.

As a new capital city, the master plan of Abuja was designed in phases so that an orderly urban growth can be achieved because the scale of the project, at that time, was unprecedented in new-city planning terms (Take, 1984). With this, the phased development can absorb changes and accommodate technological improvements as the project progresses. The entire project is divided into 4 phases, with phase I completed and Phase II still in progress (Adeponle, 2013; FCDA, 1979; Ikoku, 2004). Perhaps, a study of this nature can be useful in the development of energy conscious and sustainable buildings in its subsequent Phases. Also with movements for the establishment of a national green building council as well as associated policy formulation
for energy use in buildings (Adegbile, 2012; Ogunsote, et al., 2011) a study of this nature is timely.

1.3.4. Prospective future costs of energy in Nigeria.

Generally, low energy costs have prevailed for decades in Nigeria due to government subsidies on delivered energy products (Alby, et al., 2013). For example, electricity tariffs have remained low because the government provides a subsidy on electricity tariffs due to its sole ownership of the only electricity utility facility. More often, the government gets away with subsidising electricity in favour of popular pro-poor opinion even though at the detriment of national budget in which oil revenues are used to support the subsidy expenditure.

However, this is drastically changing with the current Energy Reforms as well as unstable government revenues. In part, the Energy Reform targets liberalisation of the sector through unbundling of the electricity supply structure in order to facilitate participation of other independent utility providers (Balouga, 2012). Such market liberalisation forthwith creates the much needed conducive environment for investors, devoid of government intervention that favours only one competitor to the detriment of others. This is considered necessary for any healthy competition governed by market forces where investors can realise their return on investments (Emodi & Yusuf, 2015; Ofoegbu & Emengini, 2013).

The resultant effect of this has been a steady increase in tariffs which can be easily noticed since 2003 when the policy implementation took effect as illustrated in Fig 1-5 below. In fact, to prevent a total price shock on consumers, the intervention of the National Electricity Regulatory Commission (NERC) had to facilitate a gradual process which enabled a more tolerable and steady increases (Ering & Akpan, 2012).
Furthermore, the current energy reform which has enabled private company participation in providing electricity; a new billing regime has been introduced to ensure investors recoup their returns on investment. Hence, new digital (automated/pay as you go) billing method is gradually replacing the flat rate and analogue billing methods. This not only prevents revenue leakages, but also ensures that consumers pay for what they use.

Similarly, the prevalent use of fuel-based generators as alternative energy supply is also under threat due to the recent implementation of subsidy removal on fuel products including petrol, diesel and kerosene. Although it is a laudable initiative in progressive development terms, it has not been a popular issue among the Nigerian population. For example, in 2012 the government attempted complete withdrawal of subsidies but were forced to retract and adopt a systematic withdrawal following a mass protest across its major cities (Ering & Akpan, 2012; Zaccheus, 2012). The systematic withdrawal programme is currently implemented in phases and scheduled to be completed by the end of 2016.
Notwithstanding, the price of fuel in Nigeria remains comparatively low across the region (Rice, 2012). Nonetheless, petroleum products have seen more price increases than decrease locally in the past two decades as shown in Fig 1-6 below.

*Figure 1-6: Chart showing petroleum price fluctuation in Nigeria*

![Chart showing petroleum price fluctuation in Nigeria](image)

Source: Ering & Akpan (2012)

However, a prospective future cost of energy in Nigeria is most probably going to be higher than what the current values reflect particularly when the energy reforms are fully implemented (Rice, 2012).

Similarly, the price of petroleum remains a volatile phenomenon globally, where this is accentuated by the recent drop which is very much similar to the experiences of the 1970’s price fall. This price volatility further galvanises the government’s resolve to withdraw subsidies in both electricity and petroleum products since the luxuries of oil boom prices are not dependable. Obviously, this diminishes the government’s capacity to support any subsidy expenditure (Balouga, 2012).
Consequently, these key changes which include withdrawal of subsidy regime, implementation of energy reforms and rising cost of fuel/tariffs as well as billing regimes will surely affect the future price of delivered electricity to consumers. Certainly, consumers will not only pay more for grid electricity, but also have to cope with higher cost to support any fuel based/generator alternative power supply. This suggests that consumers will adapt various strategies in order to maintain/achieve their electricity needs.

One potential option available to consumers is a conscious energy use such that the cost implication is often borne in mind. The above scenario is already having an impact on household electricity usage where it was noted that house owners only switch on their air conditioners when operating on grid electricity supply and not when the generator is in use due to the simple awareness of the cost implication to run on the latter compared to the former (Alby, et al., 2013; Bazilian, et al., 2013).

Another demonstrable effect of these consequences is the Nigerian Energy Support Programme inaugurated partly for energy efficiency awareness in acknowledgement of the impending consumer/end user adjustments required to cope with the rising energy tariffs.

Furthermore, this provides the impetus for clients to pursue buildings with low energy demand implications. Subsequently, this can further propagate efficient energy use in buildings, energy efficient building designs, enactment of energy use regulations for buildings as well as development of local green building councils and other similar initiatives that support manifestation of sustainable built environments.

1.4. **Aim and objectives**

This study investigates the impact of design on the energy consumption of office buildings in order to appraise appropriate energy efficient design approach in the context of a demand side management approach and solution to the endemic energy supply crises in Nigeria. The aim of
the research is to evaluate the most important design variable(s), which can facilitate energy efficient office building design. This is directed towards informing regulatory frameworks and development of a sustainable built environment in Nigeria.

The objectives of the research are:
1. to review relevant literature on sustainable and low energy design for office building development with critical appraisals of key design elements/variables, energy use assessment methods, tools and indicators;
2. to critically examine office building development and associated energy use regulations in Abuja;
3. to evaluate energy end uses and examine energy performance of office buildings in Abuja; in order to disaggregate energy and uses and establish baseline energy performances for office buildings in Abuja.
4. to quantify the implication of different design variables on building’s energy consumption;
5. to develop enhanced energy performance targets and propose benchmarks that can be used by architects to develop low energy buildings as well as serve as base-line information for further development of energy efficiency regulatory framework for sustainable office development in Abuja, Nigeria.

1.5. Scope of study

This research focuses on government office building developments for a number of reasons. Firstly because office buildings are often associated with very significant energy consumptions, as such one office building probably consumes an equivalent of many residential buildings put together. Secondly and more importantly, office buildings are often associated with symbolism. This is of particular interest in the context of Abuja where symbolism essentially underpins the development of the capital city (as will be discussed in Chapter 5.) Therefore, any demonstration of government’s commitment towards sustainable
initiatives using its own premises in the capital city will naturally attract national interest.

Furthermore, energy provisions in this research context refer to electricity which is the main source of energy for buildings that is made available through the national grid.

In addition, only buildings whose design is based on mixed mode ventilation strategy is covered. Essentially, mixed mode ventilation strategy refers to the application of both naturally and mechanically aided ventilation. Therefore since part of the aim is to reduce dependence on air conditioning, building designed solely as air condition dependent are not considered.

1.6. Study approach and outline methodology

Broadly, three methodological components are applied in this research which includes exploratory, descriptive and predictive methods.

The research applied multiple methods to achieve the set research objectives. Secondary data was also obtained and examined to establish a theoretical framework adopted for the study.

The research of this nature was in part a fact-finding mission which required some exploratory elements. Hence, in order to investigate the office built environment of Abuja, the research adopted a case study approach due to paucity of data in the literature. A survey data form was developed by the researcher for the case-study field-work component of the research, which included a walk-through audit, to examine building and its energy end uses. The building’s performances were then determined. The descriptive approach presented information on the building status quo in terms of its physical component, disaggregated energy end uses and performances.

A quantitative approach was then applied using a dynamic computer based simulation with the aid of IES-VE computer programme to re-evaluate the building performances and assess design impacts and energy saving potentials within the virtual environment. This method
was chosen because it is able to deduce an abstraction of real life, hence it is effective and requires less time as compared to actual construction of buildings for assessment.

Table 1-1: Outline research methodology

<table>
<thead>
<tr>
<th>Research Objective</th>
<th>Method</th>
<th>Chapter</th>
<th>Content</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Review of relevant literature on sustainable and low energy design for office building development.</td>
<td>Literature review (secondary data)</td>
<td>2 and 3</td>
<td>Appraise sustainable and low energy design principles. Identifies important design variables, methods and indicators.</td>
<td>Insights on status and direction on office building designs in global and local context. Examine related literature on Nigeria and/or other tropical locations. Examine appropriate research evaluation and analyses.</td>
</tr>
<tr>
<td>3. To evaluate energy end uses and examine energy performance of office buildings in Abuja.</td>
<td>Descriptive and statistical methods Case study (primary data)</td>
<td>6</td>
<td>Examination of current building designing Abuja. Energy use management. Energy end use distribution.</td>
<td>To examine and disaggregate energy consumption trend and end use patterns. Establish baseline energy performances.</td>
</tr>
<tr>
<td>4. To quantify the implication of different design variables on building’s energy consumption.</td>
<td>Predictive and quantitative methods Computer simulation (primary data)</td>
<td>7</td>
<td>Impact assessment of design variables. Examination of recommended design approaches for hot humid climates.</td>
<td>To examine maximum energy savings potentials. To optimise low energy design. To develop enhanced energy performance targets.</td>
</tr>
<tr>
<td>5. To develop and propose enhanced energy performance targets.</td>
<td>Reflections on from the literature review, fieldwork and simulation. Recommendations and conclusions.</td>
<td>8 and 9</td>
<td></td>
<td>To draw lessons linkages between research works so carried out.</td>
</tr>
</tbody>
</table>

1.7. Thesis structure

The thesis is presented in nine chapters as presented in Figure 1.7 and explained below:
1. Chapter 1 – Introduction and background of study: this presents the background of the study, with the research aims and objectives. It highlights the challenges of electricity supply shortages, rapid urbanisation and vibrant construction activities in Nigeria’s major cities. Hence, it begins to contextualise the research, which questions the sustainability of the emerging built environment.

2. Chapter 2 – Energy and the built environment: is a thematic chapter which discussed issues on sustainability at the global level and described how these developments have affected building design and development. Particularly, the literature review highlights the paradigm shift from a supply led situation to a demand side management regime driven by the need to reduce energy consumption in buildings and its impact on the environment.

3. Chapter 3 – Assessment of energy use in buildings: the chapter is a literature review to examine approaches to building energy use evaluation. It acknowledges the occupancy phase which accounts for the highest energy consumption in a buildings life span. Methods, tools and indicators used in assessing building energy consumption are also reviewed. In addition interactions between factors affecting energy consumption in buildings are examined. Discussions on exemplar projects designed to achieve significant reduction in energy consumption was provided. Collectively, this enabled the identification and selection of important design variables, methods and indicators adopted in this research.

4. Chapter 4 - Methodology: this chapter provides an outline of the methodology applied in the research to address the set objectives.
This includes a literature review of secondary data, exploratory method using case study, descriptive method to analyses the data and predictive methods using computer-based simulation for impact assessment.

5. Chapter 5 – Energy use and the Nigerian built environment: using secondary data, the chapter presents an analysis of the statutes of energy in Abuja, it examines local building regulation to identify energy use control mechanism applicable to buildings. The chapter also examines progression in office building development with particular interest to changes in design morphology and energy use information. It presents proposed performance based office typologies to be evaluated in the research.

6. Chapter 6 – Architectural/building research and fieldwork: this chapter presents the results of the field-work conducted in this research. It detailed the methods applied in case study approach, the building selection, data collection and analyses methods applied. The chapter concludes with results findings from the research and presented important findings.

7. Chapter 7 - Simulation: The chapter discusses the computer simulation undertaken. It provided discussion on the software, its capabilities and validation undertaken. It highlights the methods applied in setting the base case scenario and how the impacts of the design variables were quantified. The chapter presents the results of the iterations carried out, while providing discussions and conclusions on key findings.

8. Chapter 8 – Professional reflections: the chapter synthesises the research findings from literature review, fieldwork and simulation in order to draw lessons learnt on how to achieve low energy buildings in Nigeria.

9. Chapter 9 - Conclusion: the chapter provides a summary of conclusions discussions and recommendations and key findings in the research.
1.8. **Significance of study**

The study demonstrated the impact of design variables on office buildings energy consumption. This facilitates the exploration of design strategies with low energy demand consequences in a context original to the study area. This enables the deduction of an appropriate design strategy with minimal implications on buildings energy consumption that is specific to the study area.

The study output can be useful to support efforts to establish energy conscious/sustainable building initiatives as well as policy formulation whose need has been well emphasised and acknowledged (Ogunsote, et al. 2011). The study further challenges architects and stakeholders in the construction industry on the awareness and implications of their design decisions on building energy consumption.

In addition, cost savings accruing from the adoption of proposed strategies can be used to fund other development projects particularly in a country with millions of people living below the poverty line.

Similarly, the study contributes towards further research on energy use in other sectors to consolidate efforts towards efficient energy use in improving the sustainability of the Nigerian built environment and its wider global interconnections.

1.9. **Study limitations**

Study limitation is been instituted by the theoretical framework adopted from the literature review. There from, case study and simulation evaluations were based on only design variables adopted for the research. This also applied to the methods and performance indicators used in the study. The study is further limited to office buildings as defined in the study scope above.

Further study limitations are discussed in the Chapter 6 and 7.
1.10. Summary

This chapter has presented the background information, the problems and the aims and objectives of the study. The chapter highlights concerns associated with building energy consumption, adverse environmental consequences and resultant remedial solutions developed that tend to ensure future sustainable environments.

It showed that most of the applicable global solutions are lacking in the emerging built environment in Abuja and Nigeria at large. The aim of the research was set out and objectives of the study were defined and a summary of the research methodology/study approach, limitation and structure of the thesis presentation were provided.

The next chapter presents detailed discussions on energy and the built environment issues at large to show the inter relationship between building design and energy consumption.
Chapter Two: Energy and the built environment

2.1. Introduction

This chapter discusses the relationship between energy and economic development, within the natural and built environments. The chapter establishes the challenges upon which this research is built, and as such situates the importance of its intended outcome in both the macro and micro economic sense.

The chapter begins with a discussion on energy, the continued rise in demand as well as the quest for energy supply security emanating largely due to socio economic development often associated with energy use. It further discusses sustainability issues, the concerns for reduction in greenhouse gas emissions at a global level in relation to energy use, development and the built environment.

Also discussed is the impact of the built environment on global resource depletion and greenhouse gas emissions. The chapter concludes with discussions on the ensuing policy legislation and regulations developed to curb the built environment’s negative impact on the natural environment. Exemplars are drawn mostly from developed countries where considerable progress has been made; while highlighting the positioning of developing countries and the consequential challenges.

2.2. Energy and global (socio-economic) environment

Energy is a fundamental tool in human and economic development throughout the world (Karekezi, 2002; van Beeck, 2003). It characterises the change from the world’s largely agrarian economy to an industrial and technology driven economy. Although energy is available in various forms, its availability in the form of electricity is a significant achievement in global development (Ferguson, Wilkinson, & Hill, 2000). The availability of energy in the form of electricity, (and other forms such as oil, often regarded as high quality energy as compared with earlier traditional forms such as fuel-wood, also regarded as low quality energy), tend to be a contemporary preference in
the modern world. In fact, the widespread applications of energy in this form have become pivotal such that it is a universal template for the development of other technologies, development and human enhancement initiatives (Iwayemi, 2008; Simpson 1969). However, despite the acknowledged improvement in quality of life associated with high quality energy use, there still remains wide global variation in both the quality of life and living standard experienced due to unequal access to and/or distribution of, such energy forms (Iwayemi, 2008; Jackson, 2009).

Much research has attempted to uncover the relationship between development and energy use. For example a simultaneous causal relationship between energy consumption and economic growth has been demonstrated in countries including Canada, India, Indonesia, Thailand and the Philippines (Asafu-Adjaye, 2000; Ferguson, et al., 2000; Ghali & El-Sakka, 2004; Paul & Bhattacharya, 2004). Also, Ebohon (1996) confirmed this relationship in his research using Nigeria and Tanzania as case studies. He concluded that insufficient energy supply hinders economic growth and development in these countries.

Similarly, Ferguson et al (2000) showed that wealthy countries have a stronger correlation between electricity use and wealth creation than do poor countries; and that, for the global economy as a whole, there is a stronger correlation between electricity use and wealth creation than there is between total energy use and wealth. This demonstrates that the quality of energy consumed is more significant for economic development than just the quantity consumed. This suggests and perhaps explains the prevalence of poverty, low standards of living and limited economic development (in comparison with developed countries) in Africa where access to high quality energy is still low.

Perhaps, the claim that “the average American consumes five times more energy than the average global citizen, 10 times more than the
average Chinese, and nearly 20 times more than the average Indian” succinctly describes the energy limitation scenario (Sawin, 2004). This comparison implies that the average American consumes 30-40 times more than the average African equivalent; considering that electricity consumption in Africa account for only 4% of global electric energy availability (EIA, 2008; Gardner, Assadourian, & Sarin, 2004; Wolde-Rufael, 2006). In fact, only 65%, 40%, 33% and 5% of the populations in South Africa, Kenya, Nigeria and Mali respectively, have access to electricity (Bugaje, 2006). Instead, low quality energy source, fuel-wood in particular, remains the primary source of energy for over 2.4 billion people in such developing countries (Bugaje, 2006; Karekezi & Kithoyama, 2006; Naibbi & Healey, 2013).

However, recent studies suggest a neutral hypothesis in the relationship between development and energy consumption in which case the occurrence of relationships showing positive uni-directional causality, a negative causality and a bi-directional relationship running from GDP to energy consumption have been demonstrated in both developing and developed countries (Wolde-Rufael, 2006; Wolde-Rufael & Menyah, 2010). Nonetheless, the role of energy in the recent growth and development experienced in countries around the world as exemplified by the Chinese economy, where electricity consumption alone has tripled in the past 15 years, cannot be overemphasised (EIA, 2010a).

Thus, it can be understood why energy constitutes an important economic development factor globally (and for individual nation states) and the potential tensions surrounding its demand and supply mechanism. In this regard, while it can be said that some of the main energy concerns among developed countries includes sustainability and supply security; there is a recognition that the continued exploration and exploitation of natural resources to supply continued rise in energy demand is not devoid of environmental consequences. Further
discussions on these environmental concerns are presented in the next section (2.3).

Conversely, for most developing countries and Africa in particular, there is little evidence to suggest concerted efforts towards resolving the energy supply and demand conundrum. Apparently, this is beclouded by other challenges that includes but is not limited to, challenges of poverty, healthcare, poor infrastructure and political instability. In fact for any required development to be attained by the African continent, the challenges mentioned above must be addressed as identified in the goals of the UN's Millennium Development Goals (MDGs) and the New Partnership for Africa's Development (NEPAD).

Therefore, unless the goals mentioned above are achieved in the two international programmes, the reliance on electricity and other forms of high quality energy to alleviate poverty and ensure economic development in the developing countries will either remain a rhetoric or be explored in environmentally adverse and unsustainable methods.

2.3. Energy and the natural environment

Since the United Nation’s World Commission on Environment and Development (WCED) commonly referred to as Brundtland Report of 1987 (Our Common Future), the world’s attention has been drawn to two important issues. The first draws attention to concerns on resource depletion at a rate beyond its natural recovery. The second, asserts that greenhouse gas emissions resulting from human activities particularly those associated with the use and manufacture of high quality energy, are increasing in such a way that it adversely affects the climate (Stern, 2008). The Report calls for responsible human activities that will ensure the survivability of present and future generations in which two main lines of action were identified – sustainable development and reduction in greenhouse gas (GHG) emissions (Campbell-Lendrum & Corvalán, 2007; Glavic & Lukman, 2007; Nordhaus, 2007).
In response, there has been a global concordance towards the reduction of GHG emissions, which was marked since the Kyoto Protocol of 1997 and its subsequent progressive conventions (UNFCCC, 2010). Most of these reductions were targeted towards industrialised (developed) countries that account for substantial amounts of the global GHG emissions. This positioning strengthens initiatives for the development of energy through renewable sources, considered to have little or no detrimental effect to the environment; in addition to the formation of numerous “green movements/organisations” as well as the review of energy policy/regulation in many countries across the world (King, 2008b; McLennan, 2004).

Conversely, climate change sceptics challenge the inconclusive nature of the data, the magnitude of GHG emission capable of causing catastrophic consequences associated with global warming, or if at all responsible for climate change (Idso, 1998; Inhofe, 2003; McAleer & A, 2009; Monckton, 2007). Inhofe (2003), in particular, was of the opinion that it is a political stratagem to contain growth in the US economy. They also argued that the feared temperature fluctuations are natural climatic occurrences that are bound to result in global cooling or warming. From these sceptical points of view, it can be said that reduction of GHG emissions through reduced or regulated industrial activities, or indeed reduction in energy consumption may not be completely necessary.

However, in acknowledgement of the relationship between energy and development given in section 2.2., it can be asserted that an increase in energy demand from both developed and developing countries is inevitable. Such perceived increase have already been exhibited in many countries. For example, in the US alone, demand for energy doubled from 1950-2000, doubled in Canada and quadrupled in India and China from 1980 - 2007(EIA, 2009a, 2010b). But despite these increases, there remains a shortage in energy delivery and/or
accessibility. For example, it is claimed that more than 400 million people in India still have no access to electricity (Luthra, 2011; Maitra, 2009). More so, most of Africa is trapped in energy poverty due to poor infrastructure and energy accessibility (Bazillian et al, 2012; Mohammed et al, 2013).

Given the standpoints discussed above, it is clear that energy debates are viewed differently between and amongst developed and developing countries. For developed countries, the obvious concerns are geared towards energy security, sustainable energy exploitation and safeguarding the environment on the long term economic growth and environmental sustainability. For most developing countries however, the drive is to secure sufficient energy supply by all means and with limited attention towards issues of sustainability and energy security in contrast to developed countries.

However, this standpoint may not be due to any scepticism, but perhaps due to the inherent challenges that have been facing such countries. In most of sub Saharan Africa for example, the issue of poverty, poor health care, poor and/or absence of basic infrastructure and the widespread fuel-wood usage, remain the primary concerns that are yet to be fully resolved (Karekezi & Kithoyama, 2006; Moyo, 2009). This suggests that initiatives that do not contribute to resolving these local concerns, whether directly or indirectly may not necessarily attract the desired commitment (du Plessis 2001). Perhaps this explains the reasons for the limited enthusiasm expressed towards the reduction of GHG emissions through regulated industrial activities and reduction in energy consumption in regions where these barely exist (Black, 2009).

In addition, there is no doubt that Africa’s position will be further complicated due to the economically viable discoveries and exploitation of oil reserves in Ghana, Angola, Sudan, Cameroon, Nigeria, Libya, Sao Tome and Principe. Across the countries, a lowest production output
averages about 110,000 barrels a day and generating over $500,000. These seem plausible in terms of energy supply security for the continent as well as the potentials for “transformational development” as experienced in the Gulf States due to oil wealth. This has the potential to undermine the efforts towards energy conservation and renewable energy exploration.

Notwithstanding the diverse views on these debates, real-time changes experienced in many parts of the world tends to support proponents of climate change and the need for sustainable development. For example, it is reported that India has experienced an unprecedented rise in atmospheric temperature in the last decade and an increase of up to 2°C is expected within the next decade (Seetharaman, 2010). The report also projects increases in precipitation and rise in sea levels, similar to what was recently experienced in Pakistan and Tuvalu. Declines in farm outputs are also projected. More so, the rate of increases in global population, rapid urbanisation and rural development, food shortage projections and deforestation still constitute serious concerns.

Furthermore, it has been reported that the magnitude of fuel-wood demand in Africa is responsible for significant deforestation and desertification (Bugaje, 2006; Munslow, et al., 1988). Evidently, this adversely contributes in the depletion of carbon sinks required to reduce GHG emission levels through natural cycles of carbon capture. In addition, this supports assertions in the Stern’s Review that developing countries will account for more increases in GHG emissions in the near future. As such, they will become contributors to the adverse state in global climate and not mere victims or spectators anymore.

Thus, it can be said that it is no longer acceptable to dwell on the differences in views on GHG emissions, energy use and all other associated issues in the sustainable development debate while the
pressure exerted on the environment and its resources through increasing global population and urbanisation are still on the rise. Rather, the focus should be on the appropriate action plan for progressive development, which considers the dichotomy between developed and developing countries and balances their priorities, without compromising the environment.

2.4. Energy consumption in buildings and the environment

In the global efforts to reduce energy consumption and associated GHG emissions, research has shown that energy consumption in buildings has exceeded that of the industrial and transport sectors in many parts of the world (Brown, 2010; Perez-Lombard, Ortiz, & Pout, 2008). For example, in the US, buildings consume as much as 48% and 76% of total energy and electricity respectively (Architecture 2030, 2010). Within countries of the EU, buildings consume up to 40% total energy (Bowman et al., 1997; Ürge-Vorsatz, Koeppel, & Novikova, 2006). Similarly, buildings consume more than 50% of energy in Saudi Arabia, Bahrain, Egypt and Dubai (Al-Rabghi, Al-Beirutty, & Fathalah, 1999; Said, Habib, & Iqbal, 2003).

Though it may suggest that such increase in energy consumption should simply translate to development as indicative of correlation studies described earlier (in 2.2); it does indicate that buildings are equally accountable for significant amounts of GHG emissions. It has been reported that in the UK and the USA, buildings account for up to 50% of their GHG emissions (Kasozi & Tutesigensi, 2007; King, 2008a; McLennan, 2004) while CO₂ emissions exceeding 2000kgCO₂/m² from buildings in many parts of the world have also been reported (Gonzalez & Garcia Navarro, 2006; Rolfsman, 2002; Suzuki & Oka, 1998).

This positioning places significant challenges on the already existing buildings, new developments, the projected increase in buildings needed to accommodate the expanding population, occupancy
schedules and activities that have given rise to such energy demand in the first place. With an annual growth rate of 1.3% and projections that total global population will near 9 billion by 2030 of which up to 50% will live in urban areas (Burgess, 2000; Jenks, 2000; UNFPA, 2010; USCB, 2010), population growth can be said to be an important factor influencing building demand. This population pressure tends to deplete the time needed to restructure and evaluate the existing buildings’ energy demand statuses, not to mention the new developments. Hence, the challenge posed appears to be that of a prompt response towards achieving a balance in the provision of the human necessity of shelter along with the aspirations that come with it. As such, attention to its impact on energy and the environment tend to be relegated.

Notwithstanding, various schemes have been developed which attempt to reduce energy consumption in both existing and new buildings as a whole. In the case of existing buildings, various alteration and retrofit approaches have been proposed and widely used, particularly in developed countries, to incorporate new low energy technologies (Streicher et al., 2007). However, this concept is not without financial implications despite the seemingly long term benefits (Mazria, 2010). Potentially, this can limit the extent and commitments to which building owners and governments/stakeholders can retrofit.

For new building developments, however, “the compact city solution” or “the densification models” attract vigorous promotions as sustainable urban models for the future (Breheny, 2001; Rogers & Burdett, 2001; UNFPA, 2010). While proponents of this paradigm accept susceptibility of their model to high energy consumption, they argue that, such models are actually more energy efficient, sustainable and low in transport cost when considered as a whole system rather than viewed as individual buildings. They also argue that with the model, more valuable land is made available for agricultural use.
However, trends in technological advancements which facilitate diverse activities such as e-commerce, distance learning, shopping and social networking to take place within the comfort of our homes or workspace suggests another dimension of longer building occupational use (Perez-Lombard, et al., 2008) regardless of the adopted urban development model. This can automatically translate to extended hours of energy use, hence increasing carbon emissions from the built environment.

Furthermore, the demand for iconic buildings suggests that modern buildings may aesthetically adhere to dictates of global mores (2007) This is often epitomised in glazed high-rise buildings. In fact, this paradigm is overwhelmingly popular particularly in developing countries where buildings play an important role in expressing economic relevance and contemporary identity of international style reckoning (Abu-Ghozalah, 2007; Uduku, 2006; Van Tassel, 2006). Building projects such as the Petronas Towers in Malaysia, the Burj Khalifa in Dubai, the Hope-city in Ghana, the world Trade centre in Nigeria and the Financial Tower in Angola exemplifies this phenomenon. Each of these projects costs in excess of $1bn. Arguably, these funds could have been better spent on social, services and technological projects (Al-Kodmany & Ali, 2012b). In Nigeria for example, basic provision of steady electricity, which is required to service these buildings, can at best described as erratic. Hence it is no wonder that the success of those building typologies is questioned in such locations (Imaah, 2004a). Indeed, Rapoport and El Sayegh (2003) described that for most developing world, modernisation is nothing but westernisation. Perhaps this disillusionment in itself enables the pursuit of building development while dissipating energy and environmental conscious reflections.

In sub Saharan Africa, the demand for building is further complicated by significant shortages in housing and other building types, where the population growth rate, rapid urbanisation, poor infrastructure and
limited energy alternatives still loom large (Burgess, 2000; Dambisa Moyo, 2009; UN-HABITAT, 2008; UNFPA, 2007). In Nigeria alone, it is estimated that there exists a 17 million housing units (Amao et al., 2013). Similar projections have also been estimated in numerous African countries including Angola, Zambia, Ghana and South Africa (UN HABITAT, 2012). These socio economic pressures has undermined the importance of strategic energy planning in the overall development plan for developing countries (Foell, 1985).

Notwithstanding the dichotomy between developed and developing countries on energy, buildings and environment, it is apparent that it is increasingly becoming a fundamental challenge to develop low energy and environmentally responsive buildings. Oliver-Taylor (1993), envisioned the challenge facing building development and construction in general as that of achieving a design balance between the consumption entailed and resultant environmental quality.

This will require a drastic change that may traverse orthodox design paradigms so as to incorporate all the tenets of sustainability (McLennan, 2004). Thus, a new approach is required, which encapsulates good understanding of buildings’ inter-relationship with energy, energy use regulations as well as comprehensive interdisciplinary collaboration (McLennan 2004; King 2008).

2.5. Policy, legislation and regulations on energy use in buildings

The challenge to reduce energy consumption in buildings has been increasing since the global concordance to reduce GHG emissions and subsequent research that showed the impact of buildings on global energy consumption. Understandably, emerging energy policies have been extended to include buildings in order to ensure a coherent approach in GHG mitigation approaches. However, even before development of energy policy at the global level as such, countries such as Sweden and Germany have been proactive in energy policies on
buildings since the oil crises of the 1970s and the environmental agenda that followed (Nilsson, 2005; Wüstenhagen & Bilharz, 2006). Although their policy concerns were predominantly that of energy security, emphasis was also made on the need to conserve energy in the event of energy shortage in the future.

Although, according to Tomain (1990), “it is a mischaracterisation to apply the phrase energy policy/law to any period prior to the mid 1970’s”. He asserted that the oil supply crises following the Arab embargo in 1973 and the Iranian revolution in 1979 precipitated into a corpus of laws, forming pioneer templates for energy policies today. Also, the overarching transition in the evolving forms of energy can be said to delineate energy policy progressions (EIA, 2009a; Tomain, 1990). For example, regulations on public and private ownership of energy delivery system as well as price control mechanism became the initial sets of energy policy drivers (Santa Jr & Beneke, 1993; Tomain, 1990). Then, the oil crises in the 1970’s, and ensuing tensions around major energy suppliers around the world as well as other issues of industrial air pollution and increased automobile use, caused a paradigm shift in energy policy towards energy security and independence (Hudson & Jorgenson, 1974; Lovins & Thorndike, 1978; Williams, 2008). In the 1990’s, issues of resource depletion and discourse on sustainability focused policy attention towards environmental responsiveness (Joskow, 2001; Kraft & Vig, 2006; Sabatier, 1993).

More recently, the discourse on climate change, renewable energy and low carbon future dominate the energy policy domain (Armaroli & Balzani, 2007; Berndes, Hoogwijk, & van den Broek, 2003; Doukas, et al., 2009; Goldemberg, 2007; Nilsson, 2005; Wüstenhagen & Bilharz, 2006).

“Energy policy is multi-faceted and context driven” (Helm, 2005, 2007). That is, the process of its planning and formulation is governed by the stakeholders’ priorities and vision; shaped in response to the dictates of
a prevalent milieu whether political, economic or environmental. The UK’s white paper “Meeting the Energy Challenge - 2007” and the consultation document on “Renewable Energy Strategy- 2008” (Mitchell & Connor, 2004) are examples. In these scenarios, the UK government’s renewable energy agenda was developed in response to address environmental issues on climate change. Another example of such policy response includes the German Green Energy Policy which was initiated since 1974, in response to oil shortages, to enable energy independence (Wüstenhagen & Bilharz, 2006). Also, it can be observed that the issues related to climate change, sustainability and resource depletion are pivotal energy policy drivers in the present times.

Furthermore, policy formulation can take place at various levels of government, from local to international, and framed in accordance to varying implementation time scales. In most of the developed world today, the dynamics of environmental sustainability and renewable energy are prime policy drivers; hence making low carbon future, carbon trading/sequestration, carbon footprint and the likes, commonplace in contemporary international energy policy vocabulary.

Most frameworks used to facilitate reduction in energy consumption of buildings were voluntary. The Energy Star programme developed in the US is among pioneer initiatives to explore energy saving potentials, in which up to 30% savings on office equipment was illustrated (Nordman, et al., 1998). Also, there is the Leadership in Energy and Environmental Design (LEED) rating system, a sustainability assessment framework for buildings operating in the USA. Though it remains a voluntary scheme, its fast growth and widespread application tends to acclaim it as a national template to evaluate the sustainability credentials of buildings. Other countries have emulated such movements by creating National Green Building Councils. These include Canada in 2002, New Zealand and UAE in 2006, Germany and UK in 2007, Netherlands in 2008 and Russia in 2009 among others (WGBC 2010).
More recent energy policies show coherence with the need to reduce GHG emissions by reducing energy consumption. For example the UK’s “zero carbon home” policy introduced in 2008 is targeted to reduce the carbon emissions from buildings to zero by 2016. King (2008a) asserted that perhaps UK has the most ambitious policy to reduce energy use and carbon emissions throughout Europe. Nonetheless, it can be said that if such frameworks are not in place then energy use reduction can neither be achieved nor enforced.

Furthermore, the Energy Performance of Buildings Directive - EPBD, an EU legislation which came into force in 2002 was designed to support policies on energy and carbon reduction. It aims to improve awareness of energy use and to stimulate investments on energy efficiency measures in buildings. The directive binds all EU member countries to enforce the Directive where each country can further develop its own measures and energy reduction methodological framework depending on local needs. This indicates a shift from voluntary schemes to enforceable policy/regulations. Another important aspect of the Directive is the issue of building energy certificates. This ensures buildings’ compliance with certain minimum energy conservation requirements such that clients/building owners/stakeholders are aware of energy use and sustainability credentials of their building investments; hence making it attractive to occupants and buyers.

Again the UK exemplifies proactive responses to these developments in its review of the Part L of the Building Regulations as well as the development of a Code for Sustainable Homes.

From a broad perspective, most of the policy targets to enhance energy saving potentials are essentially a promotion of a “controlled-demand paradigm” or what can be referred to as a “demand side management approach” (Laughton & Kult’ck, 2004; Strbac, 2008) in building
development that will apply to both new and existing buildings. But, a critical look at buildings and the construction process suggest that buildings will continue to be developed following known traditions of design, construction and then occupation. It may then be questioned, where will the energy savings be made or how does the demand control mechanism come into play? Could this be in building material manufacture process, the construction process or indeed from the occupational use of the building?

It is these types of questions, that have necessitated the review of the definition of the term zero energy buildings often used rather loosely (Basir & Basir, 2012; Torcellini, et al., 2006) where buildings that subscribe to this paradigm demonstrate a continued energy consumption. However, various sustainable approaches to design, construction and material selection have been illustrated by such models, while other examples show how buildings can be designed or situated such that the physical enclosure itself can contribute in making buildings partly or fully self-sufficient (including onsite independent energy provisions) (Næss, 2001; Basir & Basir, 2012; Roaf, Crichton, & Nicol, 2009). Perhaps, it is these types of approaches that should be vigorously pursued instead of relying heavily on power grid provisions.

Clearly, the ensuing policies and regulations are designed to force a re-evaluation of all the potential adverse consequences of buildings on energy and environment in the context of the durability and relative permanence of extant built environment. Therefore, architects and planners are increasingly forced to consider energy consumption and the environmental impact of their building designs (Schlueter & Thesseling, 2009).

Conversely, there is limited evidence of similar initiatives (in terms of both the awareness and development of policy and regulations) to
deliver energy conscious and sustainable buildings among developing countries particularly in Africa (Iwaro and Mwasha 2010). In most of sub Saharan Africa for example, the demand for instant solutions to energy provision and economic development are major influences on energy policy and planning. Rapid urbanisation, deforestation due to fuel-wood usage and the recent oil discoveries across the continent are all potential conflicting issues in energy policy formulation. Van Beeck (2003) provided a framework for energy policy and planning development and proposed a new approach towards local energy policy and planning in developing countries. The proposal adopted the use of modular approach to quantify future energy demand that entails a concise appraisal of energy demand in terms of quantity, purpose and type. But, accurate data are difficult to obtain in developing countries (Koolhaas and van der Haak, 2003). Furthermore, poor accessibility and intermittent energy availability suggests a suppressed demand scenario, and the lack of digital records allows for error in the manual collection and analyses processes. Cumulatively, these question the reliability of the data and the required accuracy appropriate for a specific energy planning and policy formulation. Although Van Beeck’s approach is not entirely exclusive of other known schemes, it is designed to enable developing countries to make informed decisions on viable and sustainable energy choices since no substantive commitment has been made towards any energy model.

Meanwhile, in the parts of the world where limited building energy use regulation exist, lies a vigorous pursuit in building developments (to mitigate housing and other building typology shortages) and infrastructural provisions amidst a continued rise in population. This is already evident in places such as Abuja, Nigeria’s capital city. This suggests an adverse situation in the sense that whatever positive environmental strategy is applied in the developed world may be counteracted through construction activities subsequent emissions amongst the developing countries, demonstrating a non-congruent
effort between the developed and developed countries in the global agenda to combat energy issues and climate change.

The discussions above illustrate how energy availability, security and sustainability shape the dynamics in energy policy as well as the seeming dichotomy between developed and developing countries in their approach towards energy and environmental issues. Obviously, for most of the developing world, particularly sub Saharan Africa, a rigorous and proactive energy policy is required which must encapsulate the impacts of buildings (and construction activities in general) on energy and all associated environmental issues. This should satisfactorily recognise political, socio-economic and technological contexts; and the complex interplay of sustainability and the global environment.

2.6. Summary

The chapter highlighted the importance of energy in global socio-economic development where continued demand for energy is on the increase, to satisfy an unbalanced access, distribution as well as the desire for better standards of living. The chapter also discussed the negative impact of resources exploitation for energy development on the global environment, highlighting the need for reduction in energy consumption or/and rationalised energy activities.

In addition, the chapter presents research that has uncovered the significance of the built environment sector which accounts for significant global energy consumption and greenhouse gas emissions. It illuminates concordance towards rationalised energy demand in global responses to combat this scenario, thus necessitating a paradigm shift from supply led to demand led approaches. It explains in summary the ensuing policies and measures designed to regulate energy consumption in buildings.

Within the this chapter, the literature highlighted a lack of congruency between the developed and developing countries in their respective
approach to addressing energy, buildings energy consumption and environmental issues. The dichotomy between developed and developing countries indicates that while numerous advances in policies, regulation and enforcement are in place among developed countries; complementary resolve from developing countries is hindered by their numerous socio-economic challenges.

The literature concluded that in spite of these challenges, it is particularly important that developing countries take proactive measures in addressing energy consumption in buildings and environmental issues bearing in mind the current rapid building developments, with little or no energy use regulations.

This research examines the impact of evolving office building designs in Abuja and the impacts it has on the building energy consumption as means towards enabling energy conscious buildings and its wider interconnections. The next chapter discusses factors affecting energy consumption in the buildings and design principles that have been applied to achieve low energy buildings.
3. Chapter Three: Assessment of Energy consumption in buildings

3.1. Introduction
This chapter focuses on examining current practice in the assessment of energy consumption of buildings. It evaluates available methods, indicators and tools applied in assessing the energy consumption of buildings, particularly during the occupancy phase that accounts for the highest levels of energy consumption within a built life cycle. In addition, it identifies the factors that underpin energy consumption in buildings in order to examine potentials for reduction in energy demand. It examines design variables from an architectural perspective that have been applied to achieve low energy buildings and cites demonstrable exemplar projects alongside. It also identifies methods and indicators applied in assessment of energy consumption in buildings.

The chapter elicits from literature a theoretical, methodological and conceptual framework adopted in conducting the research. The chapter provided a summary, highlighting key issues taken into account to formulate the research framework.

3.2. Approach to energy consumption analyses in buildings
Buildings have become research objects in order to assess the quantity of energy they consume, potential consumption patterns and evaluation of energy demand reduction strategies (Kohler & Hassler, 2002). However, the complexity of the processes involved in building development makes it difficult to assess energy consumption (Haapio & Viitaniemi, 2008). Notwithstanding, a popular approach applied in assessing buildings energy consumption since the early 1990’s is the life cycle assessment/analyses (LCA) (Adinyira, Oteng-Seifah, & Adjei-Kumi, 2007; Crawley & Aho, 1999). In the LCA, emphasis is laid upon potential energy and environmental impacts of a product/object irrespective of location or use (Crawley and Aho, 1999).
In the assessment, early LCA studies attempted to identify key stages in a buildings cycle that account for significant energy and environmental impacts, but were fairly ambiguous in categorising the phase developments of buildings due to the complexity of the building development processes, and had to rely on other inter-industry relations (Keoleian, 1993; Oka, Suzuki, & Konnya, 1993). As such, a conventional building development phase in its entirety was applied. This included mainly material manufacture, construction, occupation/operation and decommissioning phases in which energy use were assessed.

For example, Suzuki and Oka (1998) estimated energy consumption and CO₂ emissions in 10 office buildings built between 1976 and 1987 in Japan using LCA approach, the breakdown of the building development phases included construction, operation, renovation and demolition. Similarly, Cole and Kernan (1996) determined the energy consumption implication of different building materials (using steel, wood and concrete) on a generic 3 storey office in two locations in Canada, using the LCA approach. The building development phases were defined as initial embodied energy (IEE - energy consumed for manufacturing processes) recurring embodied energy (REE - energy consumed for material replacement, refurbishment and maintenance) operational energy (OE - energy consumed for services during building occupation) and demolition energy (DE - energy consumed in building decommissioning, dismantling, carting away and off-site transport, recycle). In both research studies, the OE, that is the occupational period of the building, accounted for the highest amounts of energy consumed.

Suzuki and Oka (1998) showed that the operation phase ranked top with 82% energy consumption followed by the construction phase with 15%. While Cole and Kernan (1996) showed that OE accounted for between 80% and 90% of energy consumed for all the materials in the
two locations while both IEE an REE accounted for less than 10% energy consumption for the entire 50 year time frame that was considered.

Norman, Maclean and Kennedy (2006) widened the research to an urban scale by comparing the impacts of urban density on energy consumption and associated CO₂ emissions using the LCA approach. The study concurred with previous studies showing the dominance of the operational phase/energy that accounted for 60% and 80% of total energy consumption in low and high density developments respectively. But in terms of overall GHG emissions, transportation had the highest causal effect accounting for 61% and 43% of total emissions for low and high-density developments respectively.

Recent LCA studies show very similar energy distribution patterns within the phases of building development processes with the dominance of occupational/operational phase over other phases for office and residential buildings in many parts of the world (Cabeza, et al., 2014; Eskin & Türkmen, 2008; Ramesh, Prakash, & Shukla, 2010). These assert the significance of energy savings potentials during the operational (occupancy/use) phase.

Conversely, Yohanis and Norton (2002) argued that there could be a potential variation in energy distribution towards embodied energy rather than that of building operations due to lack of consistencies in parametric considerations. They demonstrated potential increase in IEE in a 30 year period compared to a 60-year assessment timeframe. They also demonstrated how design can have implications by comparing IEE of buildings with varied glazing ratio.

Thormark (2002) and Kofoworola and Gheewala (2009) acknowledged the prospects of an increase in IEE, but indicated that with increasing environmental awareness, the concept of recycling will still reduce potential increase in IEE on the long term. Despite this counteracting
prospect, other researchers still contend the non-negligible impact of embodied energy when longer building span is considered as well as the impact of other off-site production of building components (Junnila, Horvath, & Guggemos, 2006; Nässén, et al., 2007). However, the complexity and variety of available building products poses significant challenges on the availability of a widely acceptable template to assess embodied energy (Dixit, et al., 2010).

Notwithstanding, more recent LCA studies show a two pronged direction applied in the studies (Cabeza, et al., 2014; Singh, et al., 2010). These include mainly the life cycle energy analysis (LCEA) and the life cycle cost analysis (LCCA). The LCEA, very much like the main stream LCA, accounts for all energy inputs right from manufacturing through to end use while the LCCA takes into account all costs incurred in the process of acquisition, maintenance and disposal of building. Also, the review by Cabeza et al (2014) which covered 167 publications around the world shows in the Fig. 3.1, that the concentration of LCA studies lies in Europe and North America, followed by Oceania and Asia while there is hardly any studies in Africa and South America except for one found in Brazil.
This suggests that research of this nature is likely to be challenged by paucity of relevant literature on the related field for the study location. However, in view of this research energy consumed during the operative/occupancy phase of the building will be taken into cognisance due to its iterative occurrence as the dominant phase in terms of total energy consumption as evidenced in aforementioned literature as well as the inherent potential it harbours for energy savings. More so, from an architectural perspective, it is the phase in which building design can be applied to mitigate energy consumption.

Therefore, the evaluation of buildings conducted in Chapter 7 will consider the occupancy phase of the building in its analyses.

3.3. Energy use assessment methods for buildings

Assessment of energy use in buildings can be as complex as the development of the building itself and the dynamics surrounding its use compound the complexity as indicated in the discussions above. In
order to mitigate the impact on energy and the environment, building energy performance assessment is often undertaken both at inter-building and intra-building sense to illustrate its performance in relation to other buildings and the wider built environment respectively (Douglas, 1996). The performance status quo is used to define what is regarded as typical. This forms the benchmark upon which better performance is sought.

The assessment methods have developed from early simple approaches that involved surveys, monitoring, metering, observations simple walk through/detailed energy audits (Cole, 1998; Krarti, 2012) to more advanced methods as captured in three broad methodologies categorised by Olofsson et al (2004). These include the Aggregated Statistics Approach – ASA, the Simulated Data Approach – SDA and the Expert Knowledge Approach – EKA. The ASA is based on statistical computation of parametric variables using statistical models from which analysis and conclusions can be inferentially deduced. In this approach, actual energy use data (usually from surveys) constitute the initial sets of data used in the evaluation and are still essential in present methodologies (Tavil & Lee, 2005; Zmeureanu, et al., 1999). Such data mostly covers yearly durations and can be obtained from design data, actual measurements/direct metering, energy bills, predictive formulas or model-based extrapolated estimates (Saidur & Masjuki, 2008)

The SDA is a computer based method where buildings energy performances is predicted based on controlled data input (Al-Homoud, 2001). Interpolation of various scenarios is carried out to evaluate a buildings performance in response to these parametric inputs, often using either a prototypical or actual model. Suitability of the method is preferable at design stage where it provides a close visualisation of reality and it can also be used to determine possible improvement to occupied buildings. Validity tests and detailed SWOT analyses of the most common applications have been dealt with (Attia & De Herde,
2011; Crawley, et al., 2008), but without a definite conclusion on the most accurate programme. However, the comparison can be useful in providing a quick guide for the selection of appropriate application to suit various design evaluation. However, one important weakness identified in the analyses is the difficulty to adequately incorporate occupational influence and other useful energy use data. Simulation applications used in this method are discussed in section 3.5.

The EKA simply takes into account experts’ opinion to make predictions and projections of performances on specific building systems. This can be useful both at design and post occupancy stages in determining the best building services suited for a particular purpose with minimal energy purchase implications. However, it can be subjected to limitations of expert’s knowledge on other available systems; and hence questioning the definition of “expert”.

In recent studies, Zhao and Magoules (2012), expanded the categories of methodology to five groups. These included the engineering methods, which is a hybrid method that employs expert knowledge of building physics and computer aided simulations (combined SDA and EKA discussed above) in making evaluations and predictions. The statistical method, which very much like the ASA discussed above, employs the use statistical regression models to predict energy implications as well as to correlate energy consumption with influencing variables. The Artificial Neural Network (ANN) method is based on artificial intelligence model and is effective in solving nonlinear complexities found in building energy analyses. The last two of the groups include special vector machines (SVM) and grey model which are based on complex algorithms such that building energy consumption that can be predicted even with limited input data. These are relatively new in the field and have not been extensively applied.

Oyedele et al, (2011) also proposed the ‘total building performance’ - TBD method which examines both the building performance using a walk-through audits as well as incorporating an aspect to examine the
occupants level of satisfaction with their the building which is often not captured in many assessment methods. However, their experiment was limited to a portion of an existing office building and the application of their model has not been widely extended.

Olofsson et al (2004) concluded that there is no wrong or right method since all the methods have different limitations. They suggested a hybrid category, which consists of a combination of any/all the methods such that one method can remedy the rigour of another.

This research adopted the use of the ASA in which a field study was necessary to obtain historical data sets due to paucity of available literature and provides an opportunity to investigate the area in innovative ways. This method is applied in the examination of the Abuja built environment as will be discussed further in Chapter 6.

Also, the SDA is adopted to test the implication of architectural interventions to reduce buildings energy demand as will be discussed in Chapter 7.

3.4. Energy use indicators

For successful evaluation and assessment of energy use in buildings, certain criteria or indicators either assumed or established are required and Poel et al (2007) and Cody (2009) provided some direction in their definitions of energy efficient buildings. Poel et al (2007) described the efficiency of a building in terms of “the amount of energy actually consumed or estimated to meet the different needs associated with a standardized use of the building”. While Cody (2009) posits that “energy efficiency is the relationship between the quality of internal thermal environment in a building and the amount of energy consumption required to maintain this environment”.

These two criteria define the need for quantification of delivered energy (energy consumed), though they differ slightly in the specificity in terms of occupants’ deliverables. It may seem simplistic to conclude that in a
standardised manner, buildings that consume lesser amount of energy to deliver its designed function, have better performance.

Hence, the need for this standardisation makes it essential that certain parameters such as, floor area or fuel type are taken into account to facilitate objective comparative analyses; otherwise a misleading conclusion can be arrived at (Deng & Burnett, 2000). This suggests that for an effective assessment, a responsive approach will be required which adequately evaluates energy use in ways peculiar to the building or sets of buildings in question. One important step is to identify or categorise the built environment using criteria such as purpose in which case its constituent sectors may include residential, institutional, industrial, educational, recreational and commercial etc. after which, further sub categorisation can be sought. A close examination of such standardised disaggregation of the built environment reveals that office buildings in particular consume huge amounts of energy despite their seemingly low proportion (Lam, et al., 2010; Perez-Lombard, et al., 2008). For example, in Canada office buildings are the 3rd highest energy consumer with 13% consumption of total energy. Same was the case in the USA, where office energy consumption has been the highest sector since 2003; thus disposing office buildings to pioneer various emerging assessment initiatives (EIA, 2009b). The performance of most office buildings in Europe, Hong Kong and China display similar characteristics (Li, 2008; Ürge-Vorsatz, et al., 2006).

Furthermore, such classifications serve as benchmarks to examine sectorial energy consumption profiles viz a vis other considerations and the UK’s Energy Consumption Guide (ECG19) provides appropriate accounts of the considerations to be taken in classifying office buildings.

One important primary indicator widely employed in buildings energy use assessment in the spatial context is Energy Use Intensity/Index – (EUI) (Baker & Steemers, 1996b; Chung, Hui, & Lam, 2006). This is a
summation of total amount of energy consumed per unit floor area of condition space, often expressed over an annual period.

Hence; \( EUI = \frac{\text{KWh}}{m^2/a} \)

Where \( EUI \) = Energy Use Index  
KWh = Total annual energy consumption in Kilowatt Hour  
\( m^2 \) = Total floor area of building  
\( a \) = per annum

Numerous EUI results for offices and other buildings in many parts of the world have been reported (Deng & Burnett, 2000; Li, 2008; Perez-Lombard, et al., 2008; Saidur & Masjuki, 2008). Although there is no established global threshold for energy consumption in buildings, it is useful at individual country or community level for energy use comparison and evaluations have been applied in building rating systems. This suggests importance of a localised application which can have a significant impact in developing specific energy use evaluation frameworks.

Furthermore, energy performance indicators have also been extended to include the amount of \( CO_2 \) emissions produced by a building referred to as carbon emission index (CEI) with units in kg\( CO_2 \)/KWh.yr or KgC/m\(^2\). Similarly, this considers the quantity of carbon emission in a spatial context. Standard conversion factors for various fuel types are available in the UK's Energy Consumption Guide for Office buildings (ECG19). This is also another important indicator widely applied among developed and other industrialised countries where the application of carbon reduction strategies tends to concentrate.

In addition, Zmeureanu et al (1999) and Momodu et al, (2010) suggest that an economic dimension ought to be factored as a performance indicator. They suggested that monetary indicators such as running costs may be appropriate, particularly in context of developing countries. The energy cost indicator (ECI) can express not only energy saved but also potential financial gains through savings from utility bills. It may be self-evident that this economic dimension will provide
better incentive to steer commitments towards sustainable built environments much more than the amounts of carbon emissions would, particularly in most of sub-Saharan Africa and developing countries at large, where endemic social challenges undermine the much needed commitment towards climate change adaptations.

Again, from the indicators given by Poel et al (2007) and Cody (2009) at the beginning of this section, an occupant impact was identified. Cody specifically related the occupant need to thermal comfort. In this regard, the ‘degree day’ has been deduced as an appropriate indicator (Day, et al., 2003; Hyde, 2000). Essentially, this accounts for the duration (number of days/hours) a space or building will require heating or cooling within a year or any specified time. The principle behind this is that the fewer the days, suggests the lesser the reliance on energy dependent mechanisms to create comfortable interior. This is an important indicator in various climates that present extremities in outdoor environments.

In the context of this research, focus is on government office buildings and emphasis is laid on energy consumption during the occupancy phase of a buildings life as aforementioned. In the study, the EUI is considered and was applied to evaluate the case studies as well as provide an insight of the extant conditions. The ECI is considered equally important since it gives an immediate awareness of monetary implications better comprehended in a developing world context, hence applicable to the study area. Similarly, the CEI was adopted to evaluate the building in terms of carbon emission due to the limited attention such an area has attracted locally (Akinbami & Lawal, 2009). The three indicators identified above were applied to examine energy performance of office buildings in Abuja (as discussed further in Chapter 6) since it relies upon historical energy use data of the buildings examined.
However, using the concept of design degree day, the thermal comfort indicator is equally applied in parts of the simulation the computer based simulation. This method is appropriate for evaluation of naturally ventilated buildings or passive systems (Hyde, 2000; Nicol, Humphreys, & Roaf, 2012). This enables the identification of the design variable impacts on building energy loads due to cooling demand.

3.5. Evaluation tools for energy use in buildings

Numerous templates to evaluate energy consumption in buildings have been developed in the past two decades; in response to the implementation of building energy use legislations. Building energy performance evaluation has been undertaken using benchmarks. These benchmarks are usually products of building audits and surveys to establish what is typically obtainable or extant conditions (Krarti, 2012; Vaezi-Nejad, et al., 2003). The general understanding is that if the status quo is responsible for climate change or deemed unsustainable, then the aim is to design that which consumes less energy or produces a lower carbon emission. Thus, the typical can be considered as a benchmark or a worst-case scenario.

Having set these benchmarks, the evaluation process requires that buildings are designed to achieve minimal prescription of the benchmarks or more. For example, in the UK’s Energy Consumption Guide for office buildings (ECG19) sets energy benchmarks that are representative values for common office building types are provided against which comparison of a building’s actual performance can be undertaken as shown in the Figure 3.2.

It can be observed that the benchmarks are given using a standardised EUI as an indicator. Based on field surveys of occupied buildings carried out in the mid-1990s an energy consumption baseline labelled “typical” was obtained. New buildings are then required to meet or improve upon the minimum requirement thresholds labelled “good practice”- these are proven examples where significant reduction in energy use have been achieved; but not below the typical. The Guide
also provides benchmarks for energy costs and carbon emissions in GBP£ and KgC (kilograms of carbon) respectively.

Figure 3-2: Comparison of energy benchmarks for four categories of office buildings in the UK

<table>
<thead>
<tr>
<th>Category</th>
<th>Annual (kWh/m²) of useful floor area (UFA)</th>
<th>Annual £/m² of useful floor area (UFA)</th>
<th>Annual KgC/m² of treated floor area (TFA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>Good practice</td>
<td>Typical</td>
<td>Good practice</td>
</tr>
<tr>
<td>Office</td>
<td>Good practice</td>
<td>Typical</td>
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<td>Office</td>
<td>Good practice</td>
<td>Typical</td>
<td>Good practice</td>
</tr>
</tbody>
</table>

Figures 1 to 3 show annual energy use indices (EUIs), energy cost indices (ECIs) and CO₂ emission indices (CEIs). CEIs are quoted in terms of kilograms of carbon per square meter treated area (kG/m²) emitted annually as CO₂. The data used to construct these graphs is in appendix B.

In figures 2 and 3 the segments of the graphs for heating and hot water are a smaller percentage of the whole than in figure 1, because a kWh unit is less expensive and incurs fewer CO₂ emissions compared with a unit of electricity which would commonly be consumed for the other energy uses. This puts a strong emphasis on the need for electrically heated buildings to be particularly efficient. Such buildings should be compared with the CO₂ benchmarks rather than delivered energy.

It might be thought that the relative costs of gas and electricity are similar to the relative CO₂ emissions, and superficially figures 2 and 3 appear alike. However, larger buildings – particularly those with large computer rooms operating continuously – usually pay less per unit of electricity than smaller offices with low voltage supplies and less uniform load profiles. Consequently, the difference between large and small buildings is smaller in cost terms than it is in CO₂.

Source: UK's Energy Consumption Guide for Office buildings
Another energy performance evaluation template is the UK’s Building Research Establishment: Environmental Assessment Method (BREEAM) tool which has developed to include different templates for varying building purposes such as schools, offices, residential, etc. in recognition of the challenges of one generic template to appropriately evaluate a wide variety of buildings and their functions.

From these comparison-based tools, buildings are then ranked to indicate which perform better. Perhaps, the only exception to this common ranking regime used by most benchmarking schemes is the UK Arup’s Sustainability Project Appraisal Routine (SPeAR) which operates by highlighting potentials for more improvement towards sustainability within all its constituent realms. Hence, instead of merely achieving a stipulated benchmark, it drives continuous exploration of ways for improvements.

Other tools are obtainable in CIBSE and ASHRAE standards as well as other templates used in countries including Japan, France Switzerland, and Germany (IEA Report 2009).

Also computer based applications such as, the Standard Building Energy Modelling tool (SBEM) designed to provide analysis of building’s energy consumption in compliance to European standards (CEN) have been developed. A directory of recognised and approved software can be found on the Building Energy Calculation Software Approval Scheme, while more comprehensive lists of all available software comprising over 300 applications can be found on the US DOE energy Modelling Software directory.

There are other self-assessment tools available on-line where the user can input certain building/occupant/equipment/ climate parameters as applicable and an output of selected energy evaluation results is generated. Scholarly analyses of the various evaluation tools have been extensively discussed (Adejuwon, 1999; Crawley & Aho, 1999; Crawley, et al., 2008; McDougall, et al., 2002; Vreenegoor, Hensen, & de Vries,
2008). These illustrate strengths, weakness, opportunities and threats (SWOT analyses) of the various applications under study.

Although the analyses did not single out preferences for any application, it illustrates their potentials to enable effective energy use control as may be required for varying evaluation purposes.

There are other tools developed at various national levels through the world green building council. Despite this, there is yet to be a standard template applicable globally while the development of such template is still limited amongst developing countries (Iwaro & Mwasha, 2010).

In the simulation conducted for this research, IES-VE, one of the leading simulation application packages, was applied. The simulation tool if further discussed in Chapter 7 where the simulation exercise s presented.

3.6. Factors affecting energy use in buildings

Studies discussed above show that buildings consume significant amounts of energy and that the occupational/operational phase accounts for the largest proportion of energy consumed in a building’s life span (Wang, Cheng and Zhang, 2012; Omer 2008). In this section, the main factors that generally underpin energy demand in buildings are discussed.

Buildings can be said to be a social construct which has multi-faceted interaction with its peculiar environment, function, occupants and of course value systems that may ascribed to it. Hence, it can be relatively difficult to discuss its physicality alone without simultaneously discussing any of its associated facets; perhaps not when the energy use during a building’s occupational phase is in question.

However, three iterative factors, namely climate, architectural design and occupants, have been identified as having substantial causal
relationships with energy demand in buildings (N. Baker & Steemers, 1996b; Kanagaraj & Mahalingam, 2011; P Wouters & Loncour, 2005; Zhao & Magoulès, 2012). Below is an attempt to give account of each factor despite their enmeshed nature.

3.6.1. **Climatic factors**

In the provision of shelter, buildings have associated with varying climatic conditions long before the concerns for status, aesthetics and improved environmental quality became prominent (Evans, 2007; Fry & Drew, 1976; Rapoport, 1969); hence remaining a constant preoccupation in architecture throughout history (Fathy, 1986; Oliver, 1987; Oliver, 1997). The association between buildings and the climate can be expressed as sets of positive, negative or even neutral interactions depending on the climatic disposition. These interactions can be seen as the potentials for pulling external conditions into the building (inclusivity/positive), or to counteract the climate (exclusivity/negative) as may be desired depending on what is regarded as conducive climate.

Climate, according to the Oxford Dictionary, is described as the weather conditions prevailing in an area in general or over a long period. The climate of a place can best be described as a function of temperature ranges and precipitation levels of which the Köppen’s world climatic classification is widely referenced (Kottek, et al., 2006; Peel, Finlayson, & McMahon, 2007). Although climate includes other meteorological elements, these two key variables used in climatic classifications are perhaps, the most influential factors on the evolution of buildings.

Givoni (1998a) and Szokolay (1996) pointed out that the sun is the most important climatic element. To a great extent, the sun affects variations in temperature, precipitation and almost all other meteorological elements; hence it has impacts upon the type/level of protection a building is expected to provide. In addition, it provides valuable natural lighting and visual delight. Therefore, assessment of the sun’s availability is a very important component for climate responsive
buildings. On the whole, perhaps it is based on this knowledge that climate control and application strategies in buildings are evaluated. Evidence from vernacular studies of architecture denotes the importance of climate which can be used to explain the resultant variations of different building typologies from the courtyard house of the hot arid regions in North Africa to the compact buildings with thermal hearths in Northern Europe (Evans, 2007; Fathy, 1986; Oliver, 1997). This illustrates the varying responsive approach applied in relation to different climates. However, developments since the industrial revolution through to post-modern architecture, a new paradigm of “one building for all climate” have become widespread (Boerstra, 2010). This paradigm tends to take limited cognisance of the local climate, compared to experiences in vernacular architecture; hence making it predominantly reliant on other secondary systems (such as heating, ventilation and air conditioning - HVAC systems) to create the desired internal climate which in turn consumes energy. Most of these building typologies, epitomised by high rise, highly glazed buildings, tend to demonstrate iconic relevance to a global audience (Abu-Ghøzalah, 2007; Cody, 2005). As a result, they are subsumed in satisfying international standardisation and requirements associated with such buildings. So, when these buildings are inappropriately placed in a particular climate, they consume significant amounts of energy to counteract external environments in order to create desired internal climate.

Perhaps the impact of modernity and globalisation on the built environment energy consumption should be interrogated particularly now that the architecture of symbolism is vigorously pursued with developers’ aiming to break one world record or the other. For example, in 2011 alone 17 new buildings made it into the “tall building” ranks in several global locations (CTBUH, 2011) with no account made on energy
implications for providing building services, lifts and the strict indoor climate specification associated with these types of buildings.

In such contemporary buildings, the wealth of appropriate climatic design knowledge accrued over time and applied globally throughout vernacular and traditional architecture seems to be abandoned. Although, this does not assert that the building and comfort criteria of the past must be viable today; it suggests that there are lessons to be learnt and opportunities to be explored and applied in contemporary buildings such that the reliance on secondary systems for comfort can be significantly minimised. This is the exact response expected of sustainable buildings (Lomas, 2007).

To achieve this objective, numerous approaches have been applied which are contingent upon critical evaluation of local climatic conditions. Terms such as green, passive, eco and bioclimatic architecture amongst others are used to denote such approaches. These approaches encapsulate lessons from architectural history, vernacular architecture as well as post occupancy evaluations where the prevailing local climate dictates the main protective strategy to be applied in buildings (Roaf, Fuentes, & Thomas, 2007).

In tropical climates, which encapsulate the study area for this research, high temperatures due to solar radiation and humidity due to rain are the most influential climatic factors. Hence, for the control of high indoor temperature, solutions based on a three hierarchical theories of prevention, delay and expulsion of solar radiation have been widely applied (Dilshan, Majid, & Ahmad, 2008; Fry & Drew, 1956; Gut & Ackerknecht, 1993). One climatic responsive recommendation is the “umbrella concept” used for a building’s roof with deep eaves which protects driving rains and serves as sun shading devices (Osasona & Hyland, 2006; Oyeniyi, 1997). Also, other approaches such as
incorporating natural ventilation is emphasised to improve good health and wellbeing of inhabitants while reducing cooling loads.

Although most of the concepts used in energy conservation are not entirely new, perhaps the challenge is that of incorporating them in modern buildings such that they combine new knowledge in science and technology. Despite the technological advances, climate still constitutes an important challenge in design and building development particularly in urban centres where it remains difficult to achieve a fully naturally ventilated building particularly due to other challenges such as urban heat island effects divulged by micro climates (Kolokotroni, Giannitsaris, & Watkins, 2006; Short, Lomas, & Woods, 2004).

This situation further complicates an already complex climatic disposition. In this case, other developments in natural ventilation system such as the mixed mode ventilation systems (which incorporates both natural and mechanical systems) can be an essential strategy for future buildings (Lomas, 2007). Also, potential temperature increase due to climate change predictions undermines the certainty and predictability of future climatic conditions with which designers have to constantly contend with (Holmes & Hacker, 2007). This makes climate a permanent factor, yet a dynamic and potentially volatile one.

Thus, the challenge facing architects today is that of creating buildings which positively interact with the current (and potential future) local climate to provide desired internal climate; which satisfactorily meets the needs of client, occupant and have minimal energy demand implications.

In this research, climatic data for the research area were obtained from the Nigerian Meteorological Agency and weather centre (NIMET). Recommended climatic adaptations identified in the literature were taken into account for further evaluation.
3.6.2. Architectural design factors

Man seeks to mediate the climatic conditions through mediums including architecture (Drew and Fry 1976). Significant variations abound in the mediation applied due to climatic extremes. Perhaps caves, shades and clothing would have sufficed in primordial times (Drew and Fry 1976); at present, the complexity of buildings and the built environment, climate and occupant expectations will require a careful and well considered architectural design intervention.

In the development of sustainable and low energy buildings, one key element is to design better buildings (F. Nicol, et al., 2012). Perhaps this is the only tool disposed to architectural manipulation unlike climatic and occupant factors.

3.6.2.1. Design principles for low energy buildings

In tropical climates, the control of high indoor temperature, solutions based on a three hierarchical theories of prevention, delay and expulsion of solar radiation have been widely applied (Fry & Drew, 1956; Gut & Ackerknecht, 1993). These concepts are still applicable today as embodied in “trias energetica” concepts (Brouwers & Entrop, 2005; Dilshan, et al., 2008; Heiselberg, 2012b). This concept has simply expanded the theories above to include aspects of contemporary significance. Thus, its first principle is the attempt to reduce energy demand through deliberate energy conscious design. The second principle is to utilise all renewable energy available within a buildings site and its immediate environment. The last and third principle is to apply efficient use of fossil fuels where its use cannot be avoided.

Also, other approaches which focus on occupants’, emphasises the incorporation of natural ventilation in buildings not only to reduce cooling loads, but also to improve good health and wellbeing of inhabitants. All these are taken in order to minimise energy demand in buildings.
3.6.2.2. Architectural design variables for low energy buildings

Architectural design can be described as the art or science of design of buildings, structures, objects or spaces. It can also be said to be a concept or process that focuses on the components of a structure or system and unifies them into a functional whole. A more elaborate definition by Ching (2007) described architectural design as a problem–solution driven exercise engineered through a conceptual process of a built space with respect to a set of given conditions. In addition to climate, these conditions may include political, economic or social. Also according to Gratia and de Herde (2003), architectural design is a realization which concretizes a microcosm in more or less close connection with the environment to which it belongs. Hence, the goal of the building design is to achieve this microcosm in optimal agreement with its environment. This view indicates the placement of climate at the top of the hierarchy of influential factors and in a way expatiates the enmeshed nature of factors influencing energy demand in buildings; here bringing together design and climate.

Taking climate into account, as a prime factor compelling the need for shelter, its impact on the nature of approach needed to create habitable spaces can be understood. However, when design fails in the manipulation of its constituent variables to create desired habitable and comfortable spaces, HVAC systems have become convenient contemporary remedy to complement and in some cases replace nature-reliant approaches. In turn, this result to a potential increase in the amount of energy a building consumes (Oral & Yilmaz, 2003).

For example, an architectural design variable such as the building envelope which consists of structural materials and finishes that enclose space, separating inside from outside, must balance requirements for ventilation and daylight while providing thermal and moisture protection appropriate to the climatic conditions of the site (Reffat, 2004). The building envelope is often described as a function of
its permissible heat flow or heat resistance (overall heat transfer coefficient) which is described as its \textit{U-value} (Papadopoulos & Giama, 2007; Yu, Yang, Tian, & Liao, 2009). \textit{U-values} have been established for a variety of materials and are available in building standards.

This information allows designers/architects to evaluate material response to climate in relation to their design requirements. For example, Givoni (1998b) examined the effectiveness of a building’s envelope in free flow building using three different levels of mass (low, medium and high) with the same heat loss coefficients for three buildings in the hot humid climate of Sala, San Diego. On the hottest summer day of the research, the high-mass building obtained an indoor temperature of 24.5˚C when outdoor maximum was 34˚C. Shaviv, et al., (2001) and Ogoli (2003) reported similar results where indoor temperatures of up to 4˚C and 7˚C lower than outdoor maximum were obtained using a variety of materials for the building envelope in hot humid and equatorial climates of Israel and Kenya respectively.

Also, in Givoni’s (1998) analyses, the relationship between the indoor maxima and various parameters of the outdoor climate demonstrated that the best correlation exists between the outdoor average and the indoor maximum temperatures.

However, “it is also widely believed that in a hot humid climate, like Florida, it is not recommended to use thermal mass with night ventilation as a passive cooling design strategy” (Shaviv, et al., 2001). This suggests that ventilation strategy other than natural ventilation may have to be employed, because in this case the diurnal temperature swing between day and night is not enough to dissipate heat gains. Collectively, the examples given above demonstrate that the building envelope is an important factor which influences the amount of energy a building will consume during its occupational phase as a result of cooling, heating or lighting demand. It also demonstrates that a solution
for a particular climate may not necessarily be applicable to another. Therefore, a set of particular specifications may be required for every design and location.

Furthermore, in architectural design, the choice of overall building form, orientation, depth, floor to ceiling height of rooms, the size of windows as well as appropriate shading can together affect the eventual energy consumption of a building (Gratia & De Herde, 2003; Monna & Masera, 2010; Zaki, Nawawi, & Ahmad, 2009). Nicoletti (1998), posits that “passive approach to themes of energy savings is essentially based on the morphologic articulations of the constructions”. He argued that it is the building form, which enables the disposition for any material attachment and interaction with the environment such that energy can be saved. The widely used indicator which describes a building’s form is the ratio of the external surface area and the enclosed volume (Cody, 2005; Oral & Yilmaz, 2003).

\[
\text{Building Form Factor} = \frac{A}{V},
\]

Where; \( A \) = total external surface area, \( V \) = enclosed building volume.

Cody (2005), further argued that currently, “form follows energy”. Although he did not uphold any building form as being superior to another in an energy sense, he demonstrated through some examples how the building form and its resultant surfaces are used for both energy conservation as well as generation. Cody (2009) further demonstrated how contemporary building forms are articulated to aid ventilation by redirecting air-flow in sub-tropical climates.

In tropical climates, the use of narrow plans has been recommended and considered appropriate for natural ventilation (Gut & Ackerknecht, 1993; Hyde, 2000). However, in relation to form factor, what constitutes ‘narrow’ in terms of buildings depth remains vaguely described.
Also, the buildings compactness ratio is used to describe the building form (Rajapaksha 2004). In two separate studies involving computational analysis of air flow patterns in buildings, it was observed that the courtyard form offers greater flexibility and potentials for natural ventilation as well as passive climate control than large compact buildings in Queensland Australia and Moratuwa Sri Lanka (Rajapaksha, 2004; Rajapaksha, Nagai, & Okumiya, 2003; Rajapaksha & Hyde, 2005).

Michel and Elsayed (2006) also concurred that a building’s form/geometry has an impact on energy use both at the building and urban scale. At the building scale, the research showed that a building’s geometry affects the radiation balance, wind conditions and heat exchange due to the ratio of its exposed surfaces (walls, roof and windows). This can affect both lighting and thermal comfort in buildings. At the urban scale, the geometry is often very complex resulting in trapped heat from solar radiation within the urban fabric due to street canyons which is mainly affected by height to width factor of the streets and adjoining buildings respectively. Figure 3.3 illustrates the impact of the streets width factor in creating heat traps in urban areas.
Therefore, the configuration of the urban setting can further impact upon the local climatic conditions with which the buildings have to contend. The study which involved 140 buildings located in Cairo and Alexandria in Egypt, concluded that the impact of architectural design variables on a building’s energy consumption has relative importance owing mainly to variations in location.

This suggests that the impact of one design variable on consequent building energy demand varies for different locations. Therefore, it is essential to discuss design variables particular to a climatic location if specific design solutions are to be derived.

Similarly, orientation of the built form also impact upon the energy demand of buildings and have been regarded as key considerations for tropical designs such as in Nigeria. Orientation can be used to either admit or exclude solar radiation, which aids reduction in heating or cooling loads. It is also an important consideration for daylighting and ventilation. For example, Haase and Mato (2006) determined optimum building orientation for natural ventilation where up to 50% of
electricity saving was realised for tropical climates in China. Gratia, et al. (2004), also suggests that the potentials for natural ventilation strategies is largely determined by the buildings orientation. In addition, Hyde and Pedrini (2002) assert that a building’s orientation is a key component in lighting, thermal and ventilation via natural means. This was demonstrated using the thermal zoning concept, which describes the relationship between the building’s spatial organisation and exposed surfaces. For these to be achieved, an understanding of the daily/annual positioning and movement of the sun is essential (Szokolay, 1996). He described the importance of knowing the sun path, the solar altitude and azimuth angles in relation to building location for effective solar design. Geographical cardinal points comprising North, South, East and West and their constituent sub divisions are used in describing building orientation.

More so, the window, which connects the inside to the outside, is also an important design factor that affects energy use in buildings. Windows are desirable for ventilation, lighting and viewing purposes. So, the size of window or glazing needs to be considered for the purposes of lighting and solar radiation control. Therefore it is important to optimise the fenestration sizes in buildings. The transparency ratio or window to wall ratio (WWR) criteria is widely used to denote the relationship between a building’s opacity and its glazed area. The glazing ratio can also be calculated as the dividend of the net glazed area by gross external wall area for daylight designs (Baker & Steemers, 2002).

For tropical climates, recommendations for size of window openings vary greatly from full wall openings to slim and narrow sizes (Fry & Drew, 1956; Givoni, 1994a; Gut & Ackerknecht, 1993; Koenigsberger, et al., 1974).
In some vernacular architecture, buildings with small windows (small glazing ratio) are common practice for mud buildings in Arid zones to reduce solar radiation at the expense of indoor lighting (Al-Temeemi, 1995; Denyer, 1978) and where large windows are used, protection from radiation is paramount. Meanwhile, numerous modern buildings in such climates now have full glazed facades (Abu-Ghozalah, 2007). Although protection to windows and glazed areas can be achieved by simple shading using trees and other forms of vegetation, the complexity of the cityscape and lateral progression of modern buildings tends to undermine this potential. Thus, shading elements in forms of vertical, horizontal and composite shelves (placed internally or externally) are used (Hyde & Pedrini, 2002; Kadiri & Okosun, 2006; Tzempelikos & Athienitis, 2007).

In addition, shading devices can be of flexible modules to allow for adjustments as may be required which offers significant opportunity to optimise day lighting and energy saving potentials due to cooling loads arising from heat gains (Tzempelikos & Athienitis, 2007). Offiong and Ukpo (2004) demonstrated the effects of different window shading approaches on internal temperature and solar heat gain protection using reveals, overhangs and vertical fins with different depth ranges. They showed that window reveals had the best effect in reducing solar gains and lowered internal temperatures, followed by overhangs, then vertical side fins which had the least effects. However, determining appropriate shading remains a complex process due to requisite knowledge and understanding of the sun’s movement in relation to both timing and positioning (Szokolay, 1996).

Nonetheless, technological developments in intelligent building facade architecture have made available different types of glazing with “built-in” shading coefficients and levels of heat and light transmittance such as tinted, reflective, switchable and double emissivity glazing to enable efficient lighting and thermal designs (Hamza, 2008; Lampert, 2003).
Though, the high cost of these advanced materials tends to impede its general application (Saridar, 2004). In addition, this raises question on the impact of the resultant embodied energy demand in the production of these new materials on the buildings LCA.

Despite the capability of these architectural design variables to moderate climate in such a way that it reduces energy consumption, a certain degree of compromises remains inevitable due to the complexity of climate, the building typology and the human expectations thereof. It has also been observed that efficient technologies of today may not necessarily be applicable in the future due to climate change and other potential developments (Chappells & Shove, 2005). But, since buildings from past generations, can still provide comfort today within the context of their own construction; as attested in traditional architecture in numerous global locations (Fathy, 1986; Osasona and Hyland, 2006) it illustrates the significance of architectural design variables as potential and fundamental solution in achieving low energy buildings.

Therefore, it is essential that architects understand the implication of all design decisions on energy demands while also standing up to the challenge of developing buildings that not only meet the aspiration of contemporary times but also ensuring on-going sustainability.

Drawing from these architectural design factors, it can be observed that the orientation, building form and nature of the building envelope (comprising both its visual and thermo physical properties) are very important architectural factors for energy efficient design. However, a priority scale or hierarchy of importance of the variables for decision making purposes was not established due to the relative importance exhibited by the variables which is largely attributed to different climatic locations and design intent. As such, the decision remains that of the architect to manipulate the design variables at will, as it is perhaps the main factor where his control can be fully exercised.
The research takes account of these variables and other design recommendations to evaluate their impacts on energy consumption in office buildings in Nigeria.

3.6.3. Occupant factors

In energy use studies of buildings during the occupational/operation phase, it is logical to examine the impacts of occupants on buildings’ energy demand. This has been largely ignored in the past (Lutzenhiser, 1993). Lutzenhiser argued that occupants behavioural patterns have significant impacts on a building’s energy use and therefore should be a subject of study. More recent studies do confirm that occupants impact on a building’s energy demand is significant (Janda, 2009; Masoso & Grobler, 2010; Orr, 1997). Janda (2009) even argued that, “buildings do not consume energy”, it is people that consume energy particularly in the demand for comfort.

Occupant comfort in buildings is primarily an embodiment of thermal, visual and indoor air quality (Roaf, et al., 2009). And in order to achieve these through associated building services or secondary sources, buildings consume energy (Haase & Amato, 2006; Nicol & Humphreys, 2009). Occupant comfort has a wide variance globally, owing to climate, individual preferences, age, gender, activity (metabolic rate), duration of occupancy and social and cultural mores (de Dear 2010). That is to say, depending on the building’s purpose and climatic location, the energy demand may vary in the fulfilment of the three comfort components named above and other associated energy requirements. However, thermal comfort tends to be of major concern, and in combination with other occupant expectations of their internal spaces, to a large extent determine the amount of energy buildings consume. This is true of tropical climates where the focus of this research is situated. Therefore, occupant factors will be examined with a thermal comfort bias.
3.6.3.1. *Thermal comfort studies*

Various researchers have attempted to explain the human comfort mechanism. Such research demonstrate that thermal comfort is a positive sensation towards the restoration of internal body core temperature, and that any *agent* causing sensation against this restoration, can cause discomfort (De Dear, 2010b). Fanger’s (1970, 1977) seminal research are among the early studies to deduce thermal comfort into scientific equations. He theorised that comfort can be determined using four environmental variables, air temperature, mean radiant temperature, humidity and air velocity; and two personal variables, degree of clothing and level of activity (or metabolic rate). His research proposed the Predictive Mean Vote (PMV) Model that is a range of temperature where by any group of subjects are expected to vote being satisfactorily comfortable with their environment such that the percentage of people dissatisfied (PPD) is not greater than 20%. The votes are calibrated into 7 on a scale as shown in Table 3, with the mid-point (0) set as neutral or comfortable temperature joining a hot and cold axis, each depicting the degree of deviation away from the centre and numerically rated up to +/- 3.

This body of work has earned worldwide recognition, becoming basis the for comfort standards such as the American Society of Heating, Refrigerating and Air-conditioning Engineers, ASHRAE Standard 55 and ISO 7730 (Brager & De Dear, 2000; Chappells & Shove, 2005). Proponents of this theory advocate that, it not only enables global standardisation but also enables a seamless climatic transition particularly now that people engage in timeless travels. In a way, this promotes *conditioning or non-naturally occurring* indoor climate.

Other studies however, question the temperature ranges specified in such standards. Firstly, limitation in the passive and sedentary nature of occupants assumed in such studies does not portray real time experiences where numerous adaptive capabilities and opportunities such as clothing, habituation, acclimatization can be exercised
(Newsham, 1997; Nicol & Humphreys, 1973). Secondly, numerous research based on fieldwork records demonstrate that people can work and live comfortably in temperature ranges well outside these comfort provisions; therefore the model is not representative of true comfort temperature boundaries in unconditioned or naturally ventilated buildings (Cena & De Dear, 1999; Nicol, 2004; Schiller et al., 1988). And thirdly, establishing optimum indoor climates accentuates the need for air-conditioning which increases building’s energy needs, undermining the impacts upon sustainable building development (Nicol & Humphreys, 2009). These have necessitated a standing review of the ASHRAE 55 standard once every decade to incorporate advances in the field (Brager & De Dear, 2000).

Conversely, Humphreys (1970) proposed an alternate derivative equation for thermal comfort; the *adaptive comfort model*. This model acknowledged the adaptive capabilities of a self-regulatory comfort mechanism within the physiological make up of each individual as well as other non-physiological adaptive potential (at the occupant’s disposition) in relation to outdoor climate.

\[
T_c = 0.534 \times (T_{\text{mean}}) + 11.9
\]

Where
- \(T_c\) is Comfort Temperature
- \(T_{\text{mean}} = (T_{\text{max}} + T_{\text{min}})/2\)
- \(T_{\text{mean}}\) is monthly mean outdoor temperature
- \(T_{\text{max}}\)is monthly mean daily maximum outdoor temperature
- \(T_{\text{min}}\) is monthly mean daily maximum outdoor temperature
- \(T_{\text{min}}\) and \(T_{\text{max}}\) are usually available from Meteorological Office Data

The same equation will yield variable indoor temperatures results for different climates since it takes into account localised outdoor temperatures. Although, subsequent research show further variation of the equation (Humphreys & Nicol, 2000), the equation has been generally corroborated in other field studies to conform with indoor comfort temperature ranges for unconditioned and naturally ventilated buildings (De Dear & Brager, 1998; Givoni, 1994a; Roaf, et al., 2007). In addition, Brager and de Dear (2000) noted that it can be useful to
incorporate the PPD component of Fanger’s PMV model to underscore the level of satisfactory comfort expected within temperature ranges determined by the adaptive model.

This research considers the adaptive comfort model as a credible comfort approach because it demonstrates the importance of flexible temperature ranges rather than strict adherence to rigid comfort boundaries. This will allow occupants to adjust and take control of their indoor climates accordingly with the aid of both their physiological and non-physiological mechanism without having to rely on energy driven secondary sources. This tends to comply with tenets of sustainability in a conscious energy use sense in addition to boosting occupant comfort through natural means (Milne, 1995). It should be noted that this does not undermine the importance of the PMV comfort model particularly in fields of air travel and such other transient environments, which have to provide comfort for a multitude of occupants drawn from worldwide climatic locations.

3.6.3.2. Energy use in buildings and thermal comfort
For low energy buildings, the primary approach remains to encourage naturally ventilated buildings; and in the case where this is not achievable, mixed mode/ hybrid ventilation systems should be the next option before an all-out air-conditioning is sought (Lomas 2007). This can be viewed as a proactive approach towards sustainable development.

Clearly, this provides an important opportunity that is applicable in both the developed and developing worlds’ contexts. For the developed world, this provides an opportunity to reduce energy use which can enable meeting their commitment in mitigating carbon emissions. In the developing world, where the luxury of air-conditioning is not yet widespread due to poor energy infrastructure; building development along sustainable paths can be encouraged. Importantly, funds can also
be made available, through the reduction of the use of high cost air conditioning systems, to tackle other important social problems.

In addition to comfort demand, there is also an occupant attitudinal imperative which influences high energy use in buildings (Lutzenhiser, 1993). To amplify this point, Kempton and Montgomery (1982) made a contrast with a scenario of how consumers purchase commodities in a supermarket. They explained that occupants indulge in wasteful use of energy because the immediate awareness of energy requirement or its financial implication is not easily obtainable as will have been the case with shopping at a supermarket where items carry price tags. The lack of such immediate indicators that prompts the cost and quantity awareness makes it difficult to determine the amount of energy required for our everyday tasks in quantifiable terms resulting to an unknowing energy usage.

More recent works confirm wasteful energy use due to occupant attitude. Masoso and Grobler (2010) surveyed six randomly selected commercial buildings in South Africa and Botswana and an energy audit was carried out for up to a year taking into account HVAC, power load and lighting. The results revealed that energy consumed after working hours was greater than that consumed during working hours. The reason behind this was that many types of equipment were left switched on. This shows that when occupants do not use buildings as designed, it will limit the ability of the incorporated design or technology to ensure reduction in energy use (Bordass, Cohen, & Field, 2004; Siddall, 2010). Masoso and Glober (2010) advocated a golden rule: “if you don’t need it, don’t use it!”

Furthermore, affluence, life style and expectations also encourage wasteful energy use (Kempton & Montgomery, 1982; Schipper, 1996; Schipper, et al., 1989). This is evident in many glazed international corporate buildings, which are underpinned by prestige (Abu-Ghozalah,
2007), rather than any energy performance rationale. This also brings into perspective the phenomenological concepts of occupants’ perceptions of their buildings or clients demands of how they want their buildings to be. Because these concepts are dependent upon occupants background and social value systems (Rudofsky, 1972), it becomes increasingly difficult to establish an empirical assessment of how such values affect occupant response to energy use in buildings constituting a limitation in that context.

Also, while acknowledging the importance of design solutions towards low energy usage in buildings, Janda (2009) and Orr (1997) argued, that current approaches to address energy usage in its entirety are not adequate, and that perhaps the next step should incorporate occupant sensitisation programme on an energy conscious building use protocol. This suggests that architects should explicate the design intent in relation to user expectations during the buildings occupancy phase. But yet again, this approach may potentially be confronted by another limitation due to the dynamics of occupants. For example, in schools, where students graduate every year and other buildings, which have significant variation in occupants’ versatility, only periodic enlightenment programmes on building use will suffice with each change in occupants.

From the above discussions, it is evident that occupants have a significant impact in the dynamics of buildings energy use. Occupant’ attitudes and expectations are crucial in the success of any architectural or technological stratagem. The impacts of occupant’ factors on buildings energy use is becoming more crucial with potential rise in occupancy durations aided by technology where endeavours such as learning, shopping and even dating are facilitated online within the comfort of homes and offices. In addition, with forecasts in temperature rise due to climate change, the ability to provide comfort for indoor habitation is further challenged. However, only if building
occupants are truly concerned with buildings sustainability and that of the wider environment, then perhaps it should be expected that occupants engage in what can be termed as sustainable occupancy/occupation (Coley, 2009; Deuble & de Dear, 2010).

In this research the building’s occupancy regimen was considered as part of the occupant factors influencing energy consumption in buildings. This takes into account the duration of occupancy, occupant density and any energy conscious management strategy that may be in place in the buildings. Also the Humphery’s adaptive comfort model was preferred to predict internal comfort ranges following review of some fieldworks conducted in Nigeria where the Humphrey model’s prediction compared favourably to the actual fieldwork results obtained (Ogbonna & Harris, 2008). This provides comfort boundaries for naturally ventilated offices as well as determining the threshold at which the application of air-conditioning that may be deemed necessary.

3.7. Research linkages with architectural works of excellence.
It is important to acknowledge that office building is the most visible tangible index for economic activity, of social, technological and financial progress the world over (van Meel, 2000) where tall buildings and skyscrapers have become key elements for cultural signification. This phenomenon is more evident in developing countries as exemplified in Nigeria’s capital city Abuja; as will be discussed in Chapter 5. Most of the concerns within the built environment, is not the development of the buildings per se, but the inappropriate transplantation of international style building designs of the US and temperate Europe into tropical climates (Bay & Ong, 2007). The consequences are that they are often climatically incompatible, have poor thermal performance and very importantly demand high energy inputs.
Yeang (2008) acknowledged that the abandoning of the concept of having skyscrapers and tall buildings is unlikely and predicts an increase in its propensity into future. He describes the skyscraper as generally disposed to being non-green and un-ecological building and argues that designers must devise means to design them in such a way that their environmental impacts are reduced to the minimum while still fulfilling their socio-economic role.

Van Meel (2000) posits that the root of sustainable design lies in context that drives the project. He cited an example of national context with the German’s resistance to skyscraper development in many parts of their cities such as Munich, Hamburg and Berlin to preserve and retain traditional patterns of urban design while maintaining relevance of historic buildings ensuring that they are not dwarfed by new developments. This safeguards the identity of the city. Perhaps the few exceptions are those cities significantly destroyed during World War 2 such as Frankfurt where buildings exceeding 150m can be found; which are not really skyscrapers judged against international criteria.

Featured projects discussed below demonstrates the application and manipulation of design variables to achieve modernity in the built environment in ways away from convention such that impact of product is less severe or damaging as would have been if conventional approaches are employed.

Although attempts to select projects in very comparative context within the research were made, project selection was indeed random and their presentation did not follow any particular hierarchy or ranking. Moreover, there is no attempt to single out the work of one architect/design team above others but rather to applaud their understanding of sustainable practices and celebrate its design synthesis within a sustainable construct. Furthermore, it is noted that these are high end or expensive typologies; they do represent the typologies sought after in the new capital city development. From this,
further design variables/considerations that are relevant in the Nigerian development contexts can be drawn.

3.7.1. Solaris building, Singapore by TR Hamzah and Yeang 2010. This project is located in Singapore. Its location near the equator and tropical climate is comparative to Nigeria, thus it is beneficial in context and holds potentials for knowledge/technology transfer. In the design of this office project, its shape and form is completely different from conventional shapes or pinnacle developments seen elsewhere. The building consumes 38% less energy compared to conventional office buildings and has received Platinum certification, the highest ranking in Singapore’s GreenMark programme (CTBUH, 2014). This project was selected for design features that have accorded it numerous global prizes. Key lessons to be derived from this project include:

a. Emphasis on natural ventilation was high. The building adapts a window opening and closing profile to aid thermal comfort regulation of the central core and most of the building, using louvers, which played an important role in regulating percentage of operable area. This allows significant reduction in terms of energy that would otherwise have been expended on air conditioning. This also shows the impacts of occupants’ behaviour on buildings energy usage.

b. The design made critical consideration of solar orientation where shading in a largely East-West solar axis was applied in order to reduce heat gain and eventual consequences of energy demand for cooling.

c. There is a deliberate design integration of natural lighting. Apart from daylight admitted from the external sides of the building, a light trough is introduced piercing through the core of the building. This was obviously thought of before artificially supported lighting. In fact, the choice of a motion/luminance sensor activated lighting should be applauded not only because of its benefits of switching on automatically when daylighting falls below desired levels but also its
ability to switch-off. Therefore addressing potentials of occupant forgetfulness in switching off when not needed. In equatorial climates such as Nigeria where the sun is nearly vertically overhead and averages 11 hours of daylight all year round, asserts the potential to harness and reduce energy due to lighting loads.

There are other important design considerations which are outside the scope of this research but are worth mentioning because of their contribution to a truly sustainable building. Such features include water harvesting that is being incorporated into the design for watering of plant gardens at different levels of the building.

*Picture 3-1 Solaris Building, Singapore*

Source: Council on Tall Buildings and Urban Habitat (CTBUH) 2013

3.7.2. **Menara Mesiniaga, Malaysia by TR Hamza and Yeang 1992.**

The project is an office building modestly rising to 15 floors high. It is one of the first projects of its kind which also received an AGA Khan award in 1995. The project is of importance because it can be said to be the first project that has successfully incorporated into a multi-storey
building most of the known theories in bioclimatic architecture within the context of a tropical climate (Jahnkassim & Ip, 2006). Key lessons to be taken from this project include:

a. The external façade is used as an environmental filter which provides less of exposed surfaces to solar orientation (Anholts, 2012). Unlike conventional office buildings with relatively smooth rising surfaces, this building is deliberately punctured with sky courts which houses plantation gardens (vertical gardens). With this, ecosystems that could have been conventionally confined to ground levels are elevated to grow with the building’s vertical progression. This also aids the improvement of indoor air quality through the natural symbiotic relationships that exists between human respiration and plants photosynthesis. In addition, one empirical study showed that vertical greenery aids temperature reduction in buildings in tropical climates (Tan, et al., 2012).

b. Windows with most exposure to the sun along the East and West axis are adequately shaded with external louvers while those with lesser direct solar radiation, to the North in particular, have fully glazed facades using coated float glass. This maximises the daylighting and external view potentials. This equally exposes the importance of window shading in climates with high/intense direct solar radiation.

This project demonstrates further ingenuity in the manipulation of the building form to create sustainable high rise buildings. Hence, suggesting that limitation of built form to particular energy disposition perhaps lies only with limitation of creativity inherent in its designer.
Most of Yeang’s bioclimatic designs are facilitated by testing known low energy design principles and other design recommendations in small scale prototypes to evaluate their performance within the given climate of the project’s location. This approach from test models have developed in to actualised building projects. This demonstrates the importance of building simulation in the prediction of building performance analyses as will be discussed and applied in Chapter 7.

3.7.3. Commerz Bank Frankfurt, Germany by Norman Foster 1997.
Although this project is a development located in a very different social, economic and climatic context from the focus of this research, it is discussed due to the exemplary qualities it contains. It is the world’s first ecologically sustainable high rise office building which is still considered innovative today (Barkkume, 2007; Shrift, 2010). Furthermore, it emphasise to the developing world audience the viability of low energy and sustainable buildings as applicable in developed worlds; from where most of their building typologies are
drawn. The Commerzbank building plan is simplistic and takes a triangular shape with an atrium in the centre. The building also performs more effectively than all the German energy benchmarks, consuming 30% less energy compared to similar buildings (Wood & Salib, 2013). Key lessons to be taken from this project include:

a. The capability of operable windows for inhabitants to control their micro climate at such an elevation is one of the important feature of this building (McCallum, 1997; Shrift, 2010). This provides occupants the flexibility to adjust their environment to achieve thermal comfort without any energy demand implication. It also shows the application and importance of window opening profile, controlled by occupants in the maintenance of indoor thermal comfort. In comparison with reliance on air conditioning, this is a very economic and simple technology.

b. The building’s full height atrium, rising 160m high, inter-connects a four storey high garden alternately arranged on the buildings three sides. Although other scholars contend that the arrangement of the gardens wasted space (Yang, Brandon, & Sidwell, 2008), it creates and enables useful stack effect ventilation all the way to the top where the air is expelled to the outside with gardens improving indoor air quality.

c. The floor plates of each wing of the building are narrow in plan. This allowed all workstations to have a direct view to the outside, with those to the inner parts having their view from atrium through the intelligently located garden troughs. Although the German regulation requiring all workstations to have a view to the outside was seen as a limitation then (Davies & Lambot, 1997), in the context of this research, it asserts the importance of a sound and coherent building regulations in facilitating sustainable designs. Such regulations should take cognisance of all tenets of sustainability including both issues of major concerns such as energy use/efficiency, but also other factors to improve occupants’ wellbeing. The building’s post
occupancy study showed improved productivity of employees (Shrift, 2010; van Meel, 2000).

However, in Nigeria building regulations are uncommon, incoherent and its scope is mostly focuses on structural stability and limited in terms of energy use or occupants wellbeing as discussed in Chapter 5.

d. In achieving good external view, the project architect worked with the glass manufacture to ensure desired product performance (Shrift, 2010). The result of this collaboration saw the development of a laminated clear glass that excludes solar radiation and heat, admittance of optimal daylight and unhindered view to the outside. This kind of commitment shows that architects are potentially drivers in the development of more efficient and sustainable building products. Although it may not be practical to push the boundaries all of the time, the product exercise undertaken on this project shows the potentials of achieving positive results.

The Petronas Towers is arguably one building that has thrust Malaysia onto the global stage. The combination of twin rising towers makes it a unique project. Key lessons to be derived from this project include:

a. From a contextual point of view, the client’s intent was clear on the need to fully incorporate and integrate socio cultural aspects in the design. The result was expressed firstly in the adaptation of Islamic geometric form (in plan) which is two interlocking squares with eight pointed pinnacles (Al-Kodmany & Ali, 2012a). In a largely Muslim dominated country, this is a positive socio-cultural design consideration. Also, the building finishes reflect local crafts in the wall, screen and tiling patterns. In this project, it is clear that despite the desire for global recognition through development of the world’s
tallest building in Asia, focus regarding deliberate inclusion of social context was not lost.

b. The building applied both concrete and steel components in its structural design. It also applied a special vision glass which was designed to provide extra protection against the tropical sun in order to provide both good view and enhanced thermal comfort. All these were as a result of critical evaluation of the building design, material and methods (Thornton, Hungspruke, & Joseph, 1997). The evaluation included social, economic and performance perspectives amongst others.

c. The building design is truly iconic in the sense that it can be used to denote Malaysia as does the Eifel Tower in Paris or the Opera House in Sydney. As such, it defines place in a globalised context and does not accentuate placelessness (Al-Kodmany & Ali, 2012a).

*Picture 3-4: Petronas Towers, Malaysia*
3.8. **Design variables for research analyses**

From the above discussions, design variables were selected to form unit of inquiry in the analyses of various office building types found in Nigeria. The design variables are largely categorised into four components as further discussed in chapter 6.2.2.1. Summarily, these categories are the site, building configuration, building envelope properties and shading devices. The table below provides the constituents of the categories.

*Table 3-1 Table showing selected design variables for the research interrogation*

<table>
<thead>
<tr>
<th>BUILDING PARAMETER</th>
<th>VARIABLE NAME</th>
<th>VARIABLE FORMULAR</th>
<th>DEFINITION OF UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Orientation</td>
<td>N/S, E/W, NE/SW, NW/SE</td>
<td>N=North, E= East, W=West, S=South</td>
</tr>
<tr>
<td></td>
<td>Set backs</td>
<td>m</td>
<td>Lengths in meters, distance away from fence, building line and other buildings.</td>
</tr>
<tr>
<td>Building Configuration</td>
<td>Building Form Factor</td>
<td>A/V</td>
<td>A = total external surfaces; V = enclosed building volume</td>
</tr>
<tr>
<td></td>
<td>Compactness Ratio</td>
<td>P²/4A</td>
<td>P = total building perimeter; A = building floor area</td>
</tr>
<tr>
<td></td>
<td>Glazing Ratio or WWR</td>
<td>A_G/A_W</td>
<td>A_G = total area of glazing/window; A_W = total area of wall/opacity</td>
</tr>
<tr>
<td>Building Envelope</td>
<td>Heat Resistance</td>
<td>U Values</td>
<td></td>
</tr>
<tr>
<td>Shading Device</td>
<td>Depth of Shading</td>
<td>m</td>
<td>Lengths in meters</td>
</tr>
<tr>
<td></td>
<td>Type of Shading</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.9. **Summary**

Without question, energy plays a vital role in development processes throughout the world and the impact of buildings energy consumption on climate change is well documented. Consequently, policies and regulatory frameworks on energy use in buildings have been formulated all over the world but remain limited in developing countries; particularly sub Saharan Africa. These regulatory frameworks harness the understanding of buildings operations to elicit a proactive agenda.
for future low energy and sustainable buildings. Life cycle energy use analyses have shown that the operational/occupancy phase consumes the highest amount of energy, in comparison to other building development phases, and so are subject to potentials for energy savings investigations.

In identifying these potentials, critical analyses that demonstrate the underlying factors that necessitate energy use in buildings during the occupancy stage have been undertaken. These factors include climate, architectural design and occupant factors, all inter-related in a complex matrix with each element affecting the other significantly. The constituent variables of these factors can be manipulated in a variety of ways to harness a low energy building in relation to its microcosmic contexts as exemplified in vernacular architecture and ancient civilisation in architectural history.

Despite this body of knowledge, in addition to advances in science and technology, energy consumption in buildings remains high. This has accentuated the need to evaluate building performances such that energy saving potentials can be optimised. Thus, numerous templates and approaches have evolved to examine buildings energy performance. However, the complexity of buildings, use, climatic variation and technological dynamism all challenge the compatibility of today's innovation with future energy demands in buildings as well as its evaluation.

Hence, it potentially limits a global application of any particular evaluation template. In this chapter, important climatic, architectural design and occupant aspects have been identified. These aspects, along with other local and regional design recommendations will be applied to evaluate office building performances in Abuja using survey data, statistical and computer simulation methods identified from the literature.
Notwithstanding, the challenge remains to design sustainable buildings that incorporate the occupancy aspiration of this and future generations, provide low energy consumption and provide minimal environmental consequences.
4. Chapter Four: Methodology

4.1. Introduction

The chapter highlights the methodology applied in this research in order to fulfil the set objectives. In doing so, it recalls the research aim and objectives as well as the theoretical framework adopted from the literature and describes the structure of the thesis. It then reviews the general research approach, research strategies, analyses, the inherent limitations as well as justifications for the applied methods. As such a full description of the research methods and scope of study is provided. Finer details of the methods are provided where they are applied particularly in Chapters 6 and 7 where discussions on case study fieldwork and computer simulation are given respectively.

4.2. Research aim and objectives

The research aim and objectives have been discussed in Chapter 1 and hereby reiterated in order to relate how they are addressed respectively.

1. To review the relevant literature on sustainable and low energy design for office building development with critical appraisals of key design elements/variables, energy use assessment methods, tools and indicators.
2. To critically examine office building development and associated energy use regulations in Abuja.
3. To evaluate energy end uses and examine energy performance of office buildings in Abuja; in order to disaggregate energy and uses and set baseline energy performances for office buildings in Abuja.
4. To quantify the implication of different design variables on building’s energy consumption.
5. To develop enhanced energy performance targets and propose benchmarks that can be used by architects to develop low energy buildings as well as serve as base-line information for further development of energy efficiency regulatory framework for sustainable office development in Abuja, Nigeria.
The table below provides a summary of the methods applied to achieve the research objectives.

**Table 4-1: Summary of research methods**

<table>
<thead>
<tr>
<th>Research Objective</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To review of relevant literature on sustainable and low energy design for office building development.</td>
<td>Literature review</td>
</tr>
<tr>
<td>2. To critically examine office building development and associated energy use regulations in Abuja.</td>
<td>Literature review</td>
</tr>
<tr>
<td>3. To evaluate energy end uses and examine energy performance of office buildings in Abuja.</td>
<td>Case study field work Statistical analyses</td>
</tr>
<tr>
<td>4. To quantify the implication of different design variables on building’s energy consumption.</td>
<td>Computer simulation</td>
</tr>
<tr>
<td>5. To develop performance targets a propose benchmarks for low energy building design framework towards a sustainable office development in Abuja, Nigeria.</td>
<td>Recommendation from findings above</td>
</tr>
</tbody>
</table>

### 4.3. Research methodology

This research adopts a typical framework applied within academic realms which involves problem identification, the review of relevant literature & theories, research design & methods, data collection, analyses and conclusions. Although this is often expressed in a linear diagram, researchers concur that the processes is indeed reiterative or perhaps cyclic in nature to facilitate furtherance of research and feedback into the academic loop (Groat & Wang, 2002).

**Figure 4-1: Flow of research methods components**
Identifying the research problem was motivated during the researcher’s time working in architectural practice. Challenging issues on building design and development in relation to energy use was identified during the researcher's involvement in a number of construction projects. This played an important role in relating the challenges confronted at project/local level to what is obtainable within sustainable buildings issues in a global and regional context. Trochim (2006) observed that such formulation of research ideas stemming from personal experiences is important in solving practical problems in the field. Challenges on achieving low maintenance (low energy use) in office buildings and the implication of architectural design on energy consumption of buildings in Nigeria were identified as the main issues which the research attempts to resolve.

4.4. Research strategy

Literature review in Chapters 2, and 3 fulfilled the objective 1 of the research, and indicated paucity in literature on energy use studies in in Nigeria. A further review in Chapter 5 confirms the paucity of literature on office buildings and issues relating to their energy consumption; therefore the research strategy was largely exploratory. This provided primary data for the research, while also acknowledging useful secondary data from the literature review. In general, the methods applied in the research include exploratory and descriptive, analytical and predictive methods.

1. Exploratory and descriptive: this provides information on the extent of the office built environment in Abuja and their energy consumption profiles. The method required case study and field work which is discussed in 4.5.1

2. Analytical: examines relationships between office building developments in Abuja, their energy consumption and end use trends. It involves using statistical methods of analyses further described in 4.5.1.3
3. Predictive: quantitatively analyse the potential impacts of design on buildings energy demand. This involved computer based simulation further discussed in 4.5.2

4.5. Research design
The research design applied the following methods to address the rest of the research objectives.

4.5.1. Case study and field work
A case study approach was adopted for this study because sourcing information has been identified as an invaluable task and difficult in most developing countries (Koolhaas, 2003). This is attributed to poor database framework, data management system and lack of regular update (Van Beeck, 2003).

The research adopted a case study framework from Noor (2008) which involves site selection and then selection of particular cases. The framework is simple, replicable and devoid of ambiguity in implementation.

The case study approach provided a unique opportunity to examine the study area in a way that has been largely unexplored (descriptive strategy). The process involves situation report/analysis, survey or observation of the area understudy. The case study research method as an empirical inquiry that investigates a contemporary phenomenon within its real-life context (Yin, 2009). Eisenhardt (1989) noted the strength of this approach in its flexibility to address issues by incorporating mainstream research methods including those descriptive, exploratory and analytical in nature. It also allows for the application of mixed methods in its inquiry, data collection and all facets of the research that otherwise may not have been adequately captured in other approaches (Tellis, 1997; Yin, 2009).
4.5.1.1. Study site/area

Abuja was chosen because it epitomises the concentration of government office buildings as envisioned in its master plan (Mabogunje, 2001), and its positioning as the capital city offers a wide range of cases while also serving as a prime location for intervention programmes as a result of heavy government presence.

With only Phase 1 of the four phase project completed (Ikoku, 2004), it offers an opportunity to evaluate the performance of what currently exists. Importantly too, it provides an opportunity to demonstrate government support in the development of a sustainable environment through successful exemplars of low energy buildings which can be replicated in the subsequent Phases of the Abuja development plan. Thus, it is deemed as an ideal vehicle towards promoting energy efficient buildings.

Abuja also offers a unique geographical climate which shows a confluence of the hot-dry and hot-humid climates predominantly confined to the Northern and Southern parts of the country respectively. According to Koppen’s climatic classification, Abuja falls within the equatorial climates (Au) which features a tropical wet and dry climate. The Abuja climate is further discussed in Chapters 5.3.2 where climatic issues of importance are highlighted. As such it can serve as a national design standard and basis for other local derivations. Also the central location of Abuja which is approximately equidistant from its boundary edges makes the site accessible as shown in Chapter 5.

4.5.1.2. Building selection criteria

Although a case study approach is not the same as sampling technique used in social science research (Tellis, 1997), selective or purposive method was applied in selection of the buildings for the case study. Since the selected buildings constitute the unit of assessment, it is essential that there is a wide variation for appropriate typology analyses, but with applied control in some aspects (Lam, Wan, & Yang,
Otherwise comparative analysis of the energy performances can be misleading. A performance based control mechanism was proposed and adopted in the research which gave rise to four categories. Other controls applied in the building’s selection includes function, occupancy and fuel/energy types (ECON19, 2003). The control criteria adopted in the building selection are further discussed in Chapter 5.8.

4.5.1.3. Data collection

Yin (2009) described six sources that can be used for data collection in the case study protocol. These include documentation, archival records, interviews, direct observation, participant observation, and physical artefacts. Tellis (1997), noted that no single source has a complete advantage over the others; rather, they may be complementary to each other and could be used in tandem.

In this research, a building inventory survey form was developed by the researcher to record information on the building’s physical properties (architectural design variables identified in Chapter 3) and to obtain energy consumption data for the building. The method has been applied in the works of Deng and Burnett (2000), Saridar (2004), and Ogbonna (2008). The form developed in this research, was divided into three sections A-C. Section A dealt with the physical characteristics of the building while Section B and C examined the energy use status and end use profile of the building. Further details of the form and administration of the survey is provided in Chapter 6.

4.5.1.4. Data analyses

Data from the case studies was processed using standard statistical analyses functions (mean, median and mode) to describe the categories of the case studies. This provided descriptive presentation of the extant office built environment, its disaggregated energy end use and energy performances using indicators identified in Chapter 3.

The data so generated are used to evaluate performance of the adopted building typologies. Furthermore, the derived data is considered as
performance baseline for office buildings; hence serving as a threshold for the exploration of building design improvements using computer based simulation.

4.5.2. Computer based simulation

To achieve objective 4 and 5, a predictive strategy using computer simulation was applied. The simulation enabled the redevelopment of the case study typologies for their performance revaluation. It also provided validation for the simulation and fieldwork data. Furthermore, evaluation was carried out to quantify energy implication of design variables on the building typologies as a means towards enabling low energy improvements.

Although this method requires some level of expertise in both running the simulation and result interpretation, it was considered appropriate as it is inexpensive and it is less time consuming compared to real-time construction of the buildings and monitoring the results of different design interventions.

The computer simulation programmes contain sets of mathematical models that seek to explain quantitatively how each component of a building behaves under given circumstances (Lam, et al., 2008; Tzempelikos & Athienitis, 2007). This enables designers to evaluate appropriate design options and building performance. Many software packages have been used for energy simulations around the world. Comparative studies of the most popular software have been undertaken to highlight their strengths, weakness and reliability (Attia, et al., 2009; Bazjanac, 2004; Crawley, et al., 2008; Forsyth & Crewe, 2006).

Schlueter and Theseling (2009) posits that architects are mostly non-experts in the performance simulation paradigm. That is to say, as generalists they do not know about precisely every parameter necessary to run an expert simulation. However, Schlueter and Theseling (2009)
conceded that architects are well informed about form, materials and technical preferences of building systems for their design.

For most architects, it is this type of information that forms the basis of their capacity to evaluate building performance. Hence, simulation undertaken in this research is hinged upon this disposition due to the researcher’s background in architectural discipline. Therefore, all analyses will bear this architectural bias as against core engineering physics often associated with building simulation.

Although simulation programmes attempt to replicate real life situations in the virtual sense, it is acknowledged that the results are rarely completely accurate and are liable to misinterpretation (Williamson, 2010). Despite this, Siddall (2010) opined that it is better to be partly correct than to be absolutely wrong when it comes to low energy designs. Nevertheless, computer simulations are still strongly explored in building design decision processes and are becoming part of the curriculum in architectural studies (Crawley et al., 2001; Hamza, 2010; Jones, 2010; Pollock, et al., 2009).

4.5.2.1. The simulation tool

The Integrated Environmental Solution Virtual Environment, IES-VE software chosen for this research, is a package that has evolved as one of the leading packages for building energy use analyses used by architects (Attia, et al., 2009). The package was readily available to the University, while expertise support was also acquired. Essentially, the software is capable of evaluating building design compliance to prevailing environmental requirements particularly energy consumption and carbon emissions. Another of the software’s strength is its capacity to incorporate many aspects of occupant factors including thermal comfort and occupancy schedule. However, the capacity of the interface of constructing the building model to be evaluated has been identified as one of its weakness. This is compensated in its compatibility with
models generated from other CAD software including AutoCAD, Revit and Google Sketch-Up.

Software validation is available in numerous verified simulation results that have been undertaken elsewhere (Attia, et al., 2009; Hammad & Abu-Hijleh, 2010; Roderick, et al., 2009). However, there was none conducted within similar climate and social contexts to this research. Hence, software validation exercise conducted for this research is provided in Chapter 7.2.2.

4.5.2.2. Simulation data input/output
After the software validation, representative models of the building typologies were simulated to analyse their energy performances (using mainly EUI as performance indicator) with that derived from the field work. Energy performances for the different typologies were evaluated from the results to establish typical baseline performance thresholds.

To determine potential improvement and energy reduction strategy, a base-case scenario is established upon which independent variables are iterated to examine their impacts on dependent variables (Hensen, 2004; Pollock, et al., 2009). In this case, the model used for software validation (described in Chapter 7) was initially used to examine impact of all the variables, with the best performing output identified and carried forward to the next iteration until the variables are exhausted. In this section of the simulation, the thermal comfort was used as a performance indicator because of its impacts on building cooling demand which has been identified as the highest energy end use in office buildings. Hence, presents the highest potentials for energy savings.

The impacts of these selected variables on the energy performance of the case study were then evaluated using simplified building models of the building categories. From this improved performances were evaluated and benchmarks were proposed.
The independent variables (input) comprise the architectural design variables and related low energy design concepts for office buildings in tropical climate. Categories of these variables include those obtained from case studies, Nigerian regulation (where applicable), tropical and design recommendation. Fixed parameters include the location which is Abuja, occupancy schedule and simulation weather file. This was obtained from NIMET because it was not available in the software database for that location.

4.6. Study limitation
The research was confronted with limitations from the literature review with paucity of data on both areas of office building development and energy use in office buildings in Nigeria. Although this research enables bridging knowledge gap therein, it did constitute a limitation in the course of developing this research. However, more limitations were faced during the case study fieldwork phase as well as simulation phase as detailed in Chapter 6 and 7.

4.7. Confidentiality and ethics
Ethical approval was sought from the University of Portsmouth through a completed application form and guidance from the supervisory team. Ethical approval documentation is provided in Appendix A. The main highlight of the process was to assess potential risk or harm and eliminate them accordingly. As a matter of procedure, it was required that consent be sought from all personnel involved in providing building information. This was achieved through formal notification and introduction. The participants were made aware of the information required and were allowed to decide whether to participate or not.

Anonymity of the personnel was ensured by not disclosing their identity in the event that their participation or the information provided may endanger them in their work places in future. Due to political tension during the course of the study data confidentiality on public buildings was deemed important, therefore only outline of building plans from site maps were provided and detailed building plans were not presented.
4.8. Summary

The chapter provided a summary of methods adopted in this the research. The research strategy employs an orthodox framework involving problem identification, review of relevant literature, research design, data collection, analyses and conclusions. To achieve objective 3 of the research, a case study approach was applied. This enabled an investigation of the research area in its context; hence facilitating findings that are specific. The case study was guided by a survey/inventory data form developed by the research to elicit the required building information. This comprised both physical and social aspects including a walk through energy audit which is often regarded as an important prelude to any effective energy efficiency regimen (Ekpenyong, 2008).

For objective 4 of the research, a computer based simulation to evaluate their impacts on the buildings total energy consumption was adopted using IES-VE simulation software. Further details of the methods and limitations thereof are provided in Chapters 6 and 7.

The next chapter examines the extant of office building development in Abuja in relation to issues concerning energy consumption in buildings.
Chapter Five: Energy use and office building development in Abuja

5.1. Introduction
This chapter provides background information on Nigeria as a whole, and Abuja in particular in order to provide the context for the research. The geography, climate, people, social and economic environment of Nigeria and Abuja are also discussed. The challenges confronting the energy infrastructure in relation to increasing growth of the built environment and developments in building codes/regulation for energy use in buildings at the national level and Abuja in particular is evaluated. A chronological commentary of office building development in Abuja is exposed to highlight trends in the built environment.

5.2. General background of Nigeria
This section describes Nigeria as a whole to reflect the dynamics of its political environment and socio-economic challenges to enable an understanding of how these contexts affect local urban development, energy demand and associated energy policies and regulations.

5.2.1. The geography
The Nigerian state is located in West African sub region as shown in Figure 5.1. It has a total land area of 923,768 km², whose borders are defined by Niger Republic to the North, Cameroon to the East, Chad to North-East, Benin to the West and a coastline southwards to the Gulf of Guinea as shown on the African map inset of Figure 5.1. Nigeria lies between Lat 4° and 14° E and between Long 2° and 14°N. Its water body covers about 13,000 km² with the River Niger entering the country in the northwest and flows southward through tropical rain forests and swamps to its delta in the Gulf of Guinea where it discharges into Atlantic Ocean. The topography varies from Southern lowlands, central hills and plateaus, mountains in SouthEast and plains in the North. Its lowest point is 0m at the Atlantic Ocean boundaries while its highest point is 2,419m at Chappal Waddi to the Far East near the Cameroonian
border. Abuja, which will be discussed in more detail later in the chapter is shaded in pink.

Figure 5-1: Map of Nigeria showing Abuja at the centre

5.2.2. The climate
Based on a broad climatic description, Nigeria lies within the tropical zone having wide variations in different regions across the country as illustrated in Figure 5.2. The Figure shows that at least five different climatic types are obtainable within the Nigerian boundary. Near the shores of the Atlantic Ocean, to the south of the country, the seasons are not sharply defined. Temperatures rarely exceed 32°C (90°F), but humidity is very high and nights are hot. Inland, there are two distinct seasons: a wet season from April to October, with generally lower temperatures, and a dry season from November to March, with midday temperatures that surpass 38°C (100°F) but relatively cool nights, and sometimes dropping as low as 12°C (54°F). To the western midlands on the Jos Plateau, temperatures are more moderate while temperatures are quite high reaching 41°C towards the Northern border.
Figure 5-2: Climatic map of Nigeria

Average rainfall along the coast varies from about 180 cm (70 in) in the west to about 430 cm (170 in) in certain parts of the east. Further inland, it decreases to around 130 cm (50 in) over most of central Nigeria and only 50 cm (20 in) in the extreme north.

Two principal wind patterns are prevalent in Nigeria. The trade winds, from the northeast, is hot and dry and carries a reddish dust from the desert while the southwest monsoon winds from the Atlantic coast is moist and humid; with each having its influence on the microclimate. Sunshine and day-light periods are experienced for an average of 6-7 hours daily throughout the year.
5.2.3. The socio-cultural environment

The Nigerian state is an amalgamation of British West African colonies of 1914 comprising three protectorates with distinct cultural mixes of Hausa, Yoruba and Igbo ethnic groups to the North, South West and South East regions respectively (Geary, 1927). Although English is the official language, the diversity of the country is accentuated by the 250 other local dialects which are still spoken. With a population of over 170 million and annual growth rate of 3.2% according to the 2006 National Census, it is easily regarded as the most populous African country accounting for 47% of West Africa’s population; and 48% of the population live in urban areas (World Bank, 2012). Muslims, Christians and indigenous beliefs form 50%, 40% and 10% of the population respectively.

Although its regional monarchical rule gradually gave way to democracy which was introduced by the British, the monarchy still plays a significant role in the country’s political administration (Afigbo, 1991; Odeyele, 2010). However, resource inequality and perceived corruption of the electoral and political process led in 1966 to several military coups. This sequence of events led to an increase in ethnic tension and violence that precipitated the civil war in 1967. Since then, the county has experienced series of border partitioning from its three regional configurations leading to its present 36-state matrix as shown in Figure 5.1 (Mabogunje, 1999).

This is indicative of the challenges facing the government in developing policies that are adequately representative of a relatively new nation-state as well as being capable of meeting the needs of its diverse indigenous population.
5.2.4. The economy

Nigeria was renowned for its rich agrarian economy that was exploited during the British Colonial era through plantation agriculture. Since the discovery of oil in the late 1950s, its economy is now largely oil-based. During the oil crises of the 1970s, and other more recent events, Nigeria experienced significant increase in earnings from the oil sector resulting to budget surpluses; thus, providing funds for significant development projects. More recently, oil revenues account for 95% of total foreign exchange earnings and 80% of source of budgetary revenues (AfDB, 2011; NBS, 2012).

However, in relation to the accrued wealth from the oil trade, the infrastructural base still remains poor and grossly inadequate with electricity still marginally available (Moyo, 2009; Sambo 2008).

In addition, the over-dependency on oil revenues and relatively frequent occurrences of windfall earnings, have undermined the relevance of agriculture and other sectors to the economy, resulting in neglect, decline and near collapse of other sectors (Ake, 1996; Ogwumike & Ogunleye, 2008; Sala-i-Martin & Subramanian, 2003). However, the telecommunication sub sector, comprising few private transnational firms, is making significant in-roads into the local economy with approximately 87 and 44 million people having access to mobile telephone and internet respectively (AfDB, 2011; NBS, 2012).

5.3. Background of Abuja

Abuja is the new capital of Nigeria. It is located at the centre of the country, making it almost equidistant to all its boundaries and as such a complete contrast from the former coastal capital Lagos. The sections below attempt to provide an overview of the context.
5.3.1. The geography

Abuja is located within Lat 7° 25' N and 9° 20' North and Long 5° 45' E and 7° 39' E of Greenwich Meridian (AGIS, 2006). The new capital was carved out of adjoining states and is located in the centre of the country. Its topography is characterised by Savanah grass land to the north with fertile agricultural soils while the rest southwards is undulating and sandwiched by mountains and rock outcrops.

Figure 5-3: Map of Abuja

5.3.2. The climate

The climate of Abuja falls near the borders of the essentially humid south and sub humid north of the country. In other words, its weather and climatic conditions are transitional in nature. The high altitudes and undulating terrain of the city also act as moderating influence on the weather of the territory. This positioning makes the climate of Abuja particularly unique from the rest of the generalised climatic groups in Nigeria.
Its main climatic conditions can be described as a hot-humid rainy season and a hot dry season. In between the two seasons, a short harmattan period is experienced occasioned by the North East Trade Wind, with the main feature of dust haze, intensified coldness and dryness. This occasions climatic conditions in Abuja, which is sometimes similar to the north and southern parts of Nigeria, a median of both or completely contrary.

For example, the hot-humid appreciable amount of rain begins around March and runs through October with an annual total rainfall in the range of 1100 mm to 1600 mm. In Figure 5.4 a comparison of annual average rainfall between Kano and Lagos (two cities depicting typical climatic conditions of the sub humid north and humid south respectively - see Fig 5-1 for their locations relative to that of Abuja) and Abuja is shown. It will be noted that rain begins later than Lagos but earlier than Kano. Also duration of monthly rainfall distribution intensities (above 150mm) varies across the three cities.

This impacts upon humidity ranges in which average humidity range in Abuja falls between 60-70%, providing a more preferable comfort range as compared to a rather more humid coastal city of Lagos or the dry and harsh North (Akande & Adebamowo, 2010; Sangowawa, Adebamowo, & Godwin, 2008).

*Figure 5-4: Average monthly rainfall (mm) in Nigerian cities*
Similarly, mean daytime temperatures reach 28-30°C and night time lows hover around 22-23 °C between March to October. Meanwhile, the dry season reigns between October and March, with recorded daytime temperatures reaching as high as 40°C and night time temperatures reducing up to 12°C, resulting in chilly evenings. Even the coldest nights can still be followed by daytime temperatures well above 30°C. Fig 5.5 shows temperature ranges for the three locations. Often, this period uniquely records higher temperatures than both the northern and southern climates of Nigeria. However, it can be noted that the range of diurnal daily temperature swings is wider than Lagos but narrower than Kano.

*Figure 5-5 Average monthly temperatures of Nigerian cities*

![Graph showing temperature ranges for Kano, Abuja, and Lagos.](source)

Furthermore, an average of 11-12 hours of daylight and 7 hours of sunshine is experienced all year round in most of Nigeria. The variation is mostly within a 30minutes range. The levels of such high day time temperatures more often demand for air conditioning due to the nature of the building’s design as will be discussed in 5.7. Although the application of thermal mass design recommendations for tropical climate may not be effectively applied in Lagos as shown in studies of similar climate (Shaviv, 2001), the large temperature swing between day time and night time temperatures presents the potential application of thermal mass design concepts. Similarly, the amount of direct solar radiation varies slightly as shown in Fig 5.6 except for Kano, which understandably shows higher levels of direct solar radiation, owing to limited cloud cover. This has further implication on resultant monthly average number of days with very high recorded temperatures.
Figure 5-6: Average monthly direct solar radiation in Nigerian cities (MJ/m²)

Obviously this has impact on daily temperatures, diurnal temperature swings as already discussed above. This also shows the potential for applying design concepts of insulation due to apparent high solar radiation. This can be important where the building surfaces are susceptible to high conductive heat gains. Also, the intensity of the direct solar radiation will impact indoor climate particularly in low rise building where the roof space is directly part of the habitable space below. In this case, green roofs may be applied as shown in the Solaris building in Chapter 3. Consequently, these further impacts upon any design decisions in building developments. Without question, building materials response towards providing thermally cool and comfortable interiors becomes the focal point of any successful building development.

More so, the disposition of daylight durations and direct solar radiation in this climate is quite different from what is obtainable in the UK, with the main difference being a resultant of relationships between geographical location and solar movement.
Picture 5-1 Solar movement between two geographical locations

As shown in Picture 5.1, locations in the northern hemisphere, seasonal solar angles vary from as low as 16.5° – 63.5° while for locations close to the equator, solar angles are largely close to 90° with the lowest being 66.5°. Therefore, this necessitates different approach to design in the two locations, and indeed any other location with dissimilar climatic dispositions.

Shading of fenestrations is a common design recommendation for climates with this character as discussed in Chapter 3. Also, the design decisions to exclude solar heat gains, through maximising building orientation, insulation and even roofing materials have been propagated. More detailed discussions on this are provided in previous chapters (Chapter 3) and particularly their applications in architectural works of excellence in tropical climates.

Fig 5.7 shows a section of a building detailing its relationship with overhead seasonal location of the sun. Some of the inferences that can be drawn from this are; that the roof is exposed to constant solar radiation and almost as much are the East, South and West facades of the building enclosure. Furthermore, the North façade receives less amount of direct solar radiation compared to other elevations. Similarly, predominant wind directions are from northerly and southerly directions. Thus, the orientation of openings along these wind directions can aid desired ventilation.
In addition, Picture 5.3 provides a clear sun path diagram for the three locations. It can be noted that the peak solar angles occur around March – June and again between July – September and it is not exclusively to the south (i.e. the Equinoxes). This suggests not only intense direct solar radiation, but also higher temperatures as already confirmed above in the temperature charts. However, the occurrence of intensified rainfall in June through to October tends to lower temperatures in the September equinox, while the lack of it exacerbates temperatures during the March Equinoxes.
Furthermore, Figure 5-7 shows windrose diagrams for the three locations. It can be noted that Abuja is actively influenced by both the North East Trade winds as well as the South West Monsoon winds. This is quite unlike the generalised climates of Kano and Lagos which has dominant influence of one wind source. Maximum and average wind speeds for Kano, Abuja and Lagos are 12.6mph, 7.2mph and 5.3mph and 4.6mph, 4.5mph and 4.4mph respectively.

*Figure 5-7: Wind rose diagram for Nigerian cities*

<table>
<thead>
<tr>
<th></th>
<th>KANO (sub humid North)</th>
<th>ABUJA (transitional hot humid)</th>
<th>LAGOS (humid south)</th>
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</thead>
<tbody>
<tr>
<td><strong>ALL YEAR</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(January – December)</td>
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<tr>
<td><strong>DRY SEASON</strong></td>
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<tr>
<td>(November – April)</td>
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<tr>
<td><strong>RAINY SEASON</strong></td>
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<tr>
<td>(May – October)</td>
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</tbody>
</table>

Source: Raymond (2015)

However, the undulating terrain of Abuja also plays a role in the wind speed variations associated with this location. Nonetheless, the combined effect of the prevailing wind direction and terrain disposess
Abuja to calm wind speeds and potentials for application of cross ventilation strategies often recommended for tropical climates.

Hence, this unique climatic disposition of Abuja will require a distinct design approach in achieving comfortable indoor working environments that is different from two broadly categorised tropical climates of Nigeria.

5.3.3. The economic and socio-cultural environment

Prior to establishment of Abuja as the new capital city of Nigeria, the Gbagyi tribe were its main inhabitants (Mai & Shamsuddin, 2008). Its local people used to thrive on subsistence agriculture, cultivating yam and other food crops (FCT, 2011). But most of this has changed due to the convergence of its current national identity as a Federal capital which has overshadowed previous ethnic presence (Obia, 2013).

Abuja is a cosmopolitan settlement in Nigeria drawing upon cultures from all over the country. This gives it a rich blend of all the ethnic groups found elsewhere in the country. As a seat of government, most of its demographic composition is made up of civil servants and a host of other service oriented businesses which support the administrative structure (FCT, 2011). More so, it was conceived to accommodate very limited commercial and industrial activities in its planning. Perhaps for this reason, most of the economic activities are services based, to support a population dominated by people in public sector.

5.4. Establishment and the development of Abuja as a capital city of Nigeria

The new capital of Nigeria - Abuja, was conceived since the 70’s and substantively relocated from Lagos in 1991. It is located almost exactly at the centre of the country. The idea of the new capital was conceived for the following reasons that evolved and galvanised the need for relocation.
Firstly, the congestion, overcrowding and squalid environment evolving in Lagos were deemed not befitting of the country’s capital and the cost of land around government establishments and that of neighbouring suburbs was too high for government to embark on local expansion (Salau, 1977).

Secondly, there was a need to locate the capital in an area that is neutral to all parties following disunity created by coup plots and civil war experiences, to a place that portrays inclusion and readily accessible to all; unlike the old coastal capital Lagos (Moore, 2008; Salau, 1977). Then, the elaborate scheme for the new capital was soon backed by unprecedented revenue precipitated by the oil boom. There was also a drive to assert the state of independence by doing away with inherited colonial structures through creating something genuinely indigenous (Obia, 2013).

The Abuja project design was led by a consortium of international planners and architects and local architects (Mousalli, 1999; Olomola, 1999). Due to the scope and cost of the Abuja project, it was regarded as the biggest project of its time (Take, 1984). The city accounts for nearly 1% of the country’s total land mass with a total planned area of 8,000km² (Kurfi, 1999; Mabogunje, 1999). Execution of the projects is planned in four phases as shown in the Figure 5.8.
It had a projected population of less than 250,000 and not exceeding 3.2 million upon completion of Phase 1 and Phase 4 respectively (Olomola, 1999).

5.4.1. Status of Abuja city development

The Abuja project development commenced in earnest in 1981 and the Phase 1 was planned to be completed in 1996, but for political expediency, physical occupation came sooner in 1991 (Obia, 2013). This presented new challenges to the project where infrastructural development has been struggling to catch up with building development (Galadima, 1999).

Picture 5.4 shows satellite images depicting a chronology of the Abuja physical development from 1985-2010. From 1985-1991, outline of transport networks are more visible while building development was limited. Whereas from 2006-2010, increases in construction and building development are noticeable all-over the city.
With only the Phase 1 completed, the population of Abuja has increased from barely 400,000 inhabitants in 1991 to over 1.4 million from 2006, indicating more than a 300% increase (National Census 1991, 2006).

Also, Picture 5.5 elaborates more on the scale of this urban growth. It shows a pictorial documentary from a bird's eye view of a particular location near the central mosque within the central business district during construction from 1991 to a relatively recent status in 2010. A sharp contrast depicting the scale of the urban growth is well noticed.
This is the scale and rate of development that is observed in most locations in Abuja as earlier indicated in Picture 5.4.

*Picture 5-5: Pictorial progress of construction development in Abuja*

In the city’s master plan, office buildings are located at the core of each construction Phase with in-fill of supporting services and surrounded by residential buildings. However, relocating the seat of government earlier than schedule in 1991, and the ultimatum for all its departments and agencies to follow suit by 1996 came with
consequences (Obia, 2013). Many government offices had to be temporarily accommodated in buildings designed as residential buildings pending when their substantive offices were completed/constructed. In addition to increase in urban population and consequent building demand, the city is experiencing shortages in housing provisions (Aluya, 2008). This has resulted in the development of sub-standard housing in the city's suburbs (Obia, 2013).

The combined effects of these urban and population growths further pressurises the infrastructure and its electricity supply has already been adversely affected (Galadima, 1999). This suggests that unless there is an appropriate increase in energy supply (or diminution in demand), the city will be faced with a significant energy shortage upon completion of the subsequent phases of development.

Additionally, there were cases of abuse of the master plan where distortions in the form of change of land use was evident. Of great importance was the allocation of parks and green areas for private/commercial developments. This has necessitated an outright demolition exercise on all defaulting properties in order to protect the master plans intent and safeguard against such practices in future (Daramola & Aina, 2004). This corrective measure has had negative cost implication on the city and had eroded time that could have been used to further develop infrastructure.

5.4.2. Prospective future of Abuja city development

In response to the challenges facing the city, and in its renewed vision to be among the top 20 leading cities in the world by 2020, the city is in a determined pursuit towards the completion of the next phases. Concerns about poor transportation networks were addressed by awarding an $850 million light rail transport network connecting all major city nodes supported by a plethora of public buses (Awofeso, 2010; Davies, 2011). This is further complemented by accelerated mass housing projects through a public private partnership known as the
Land Swap scheme, which allows private developers to contribute to housing development in exchange for undeveloped land, hence reducing the burden on government to provide housing.

However, it is noted that the Abuja development was not planned as a sustainable city, perhaps because it was too early then to incorporate such concepts into the project (Obia, 2013). Nonetheless, experts and professional bodies have raised concerns regarding the unsustainable urban growth largely from an environmental perspective and in terms of resource use and subsequent depletion (Gyoh, 2011; Ogunsoye, et al., 2011; Olotuah, 2011).

Notwithstanding, urban development, urban growth and projects of national significance such as the grand city gate project, the Abuja Mall, National Cultural Centre and the World Trade Centre amongst others, are all progressing despite the challenges.

5.5. Electricity and energy infrastructure in Abuja

Abuja city, like most cities in Nigeria obtains electricity from the national supply grid. It is therefore affected by all supply the shortfalls, which characterises electricity supply in Nigeria (discussed in chapter 1). Also, as a urban area, serving as the new capital of Nigeria, the modern city relies substantially on electricity, but with lesser proportion of its population relying on fuelwood as found elsewhere in major cities of Nigeria (Naibbi & Healey, 2013) accentuating the competition for the electricity.

At some point, energy supplies to neighbouring settlements had to be diverted often, in order to complement energy shortages in the capital (Galadima, 1999). Galadima (1999) pointed out that electricity shortage is imminent unless there is increase supply to accommodate the urban growth. At present, Abuja accounts for over 10% of the consumption of the total annual electricity delivered from grid, making it the 4th highest consumer conurbation and ranking ahead of other older established cities including Port Harcourt, Kaduna and Kano (Oseni, 2012). This is
substantial considering that these are old cities predating independence and have populations greater than that of Abuja by multiple folds.

5.6. Energy use regulation for the Abuja built environment

In Chapters 2 and 3, a global movement towards the development of sustainable built environment was discussed with emphasis on energy use regulations for buildings in order to mitigate their energy demand impacts. In this section, the Abuja built environment is evaluated to elicit the impact of office buildings energy consumption on the cities energy infrastructure as well as regulatory measures in place to ensure mitigation.

5.6.1. Energy use in the Abuja built environment

Establishing the electric energy consumption profile of Abuja is not a simple task, owing to numerous factors. Firstly, the total energy allocations according to states were not obtainable at the time of this writing; which is was due to lack of a central statistical pool for energy data and record which has been identified as a challenge and common occurrence in most developing countries (van Beeck, 2003). Secondly, the formation of Abuja necessitated the alteration of neighbouring states and regional boundaries (Galadima, 1999). In that process, utility districts initially linked to other state electricity grids were now under the administration of the new capital. This also constituted a bureaucratic hiatus in the collection and collation of energy data. And thirdly, available records often provide incomplete data series and insufficient level of disaggregation and consistency. Nonetheless, extracted energy allocations compiled from data files of 11 electricity distribution units servicing Abuja is shown in Figure 5-9.
Figure 5-9: Distribution of electricity consumption (by sector) in Abuja (2010)

Source: Compiled by researcher from local utility provider (2010)

The figure shows that commercial and residential buildings consume most of the electricity in Abuja accounting for 37% and 61% respectively. However, according to the master plan, the total land allocation for commercial and residential sector developments is 4.21% and 48.97% respectively (Omolola, 1999). This suggests that the commercial building sector has a disproportional impact on local energy demands compared to its small proportion of land allocation; particularly bearing in mind that the Abuja development project is far from finished. The commercial sectors comprise public/civic/private offices and business premises presently accommodates numerous government offices, agencies and notably OPEC’s regional and ECOWAS head offices.

However, the format in which energy data records are presented inhibits the extraction of appropriate information with the required level of disaggregation into its constituent groups (Price, et al. 1998; Van Beeck
2003). Despite this difficulty, PHCN data files show that more than 10% of commercial buildings are categorised as ‘maximum demand’ customers (MDs). These are described as customers with high energy demands such that they are provided with dedicated transformers; most government and ministerial buildings fall into this category.

Akinbami and Lawal (2009) and Ajibola (2001) noted that office buildings in Nigeria consume significant amount of energy, attributing this to cooling requirements of the buildings. Presently, numerous public office buildings use generators as the immediate electricity back up. The practise is fast becoming part of the common architecture within the built environment (Akarakiri, 1999). Imaah (2000) posits that unless the prevailing electricity shortage is addressed, it will remain impossible to develop and maintain international standard high-rise and corporate buildings as often prescribed within the Abuja master plan.

Graham and Marvin (2001) lamented that in the development of urban centres around the world, architects have confined themselves to the spaces they design while paying little or no attention to the networked infrastructure that service them. Such an acknowledgement is certainly appropriate for a place largely characterised by electricity shortages. Thus, in response to particular energy situation it would be expected that energy conscious building designs will evolve rather than replicating what prevails now.

From the above discussions, it is clear that an energy conservation and demand side management approach have been marginalised in the reduction of energy use in buildings due to dominance of a supply side remedial approach to the electric energy shortages. Therefore, it is very important to strategically rationalise the use of energy in buildings since electricity is the primary energy source available for buildings in general and in particular the office building typology under study.

~ 140 ~
5.6.2. Energy use policy and regulations for buildings in Abuja

To control urban development within the Abuja master plan, requires guidelines for construction endeavour that are contained in two distinctive documents. These are the Abuja Development Control Manual and the Nation Building Code. Below are accounts of their features with particular focus on regulation on buildings energy use.

a. **Development Control Manual (DCM):** This is a building regulatory document developed at the city/local level. The first DCM was developed in 1976 shortly after the Abuja master plan design team was commissioned. It presents guidelines relating to all categories of building development in Abuja, and requirements for obtaining planning/building permission on all intended projects as a means of urban development control mechanism.

Perhaps, because it was the first of its kind at the time, most of its content was derived from elsewhere in Bexley Council, a London suburb in the UK. It is unknown why this location was of particular interest since they hardly share any commonality. Though it is a known practice where policies from developed countries are exported to developing countries without appropriate adaptation to local considerations; hence often resulting to undesired result (du Plessis, 2001).

The DCM was reviewed in 2007 following government’s action to review the master plan as a result of physical distortions that have taken place within the city development. In the preambles to the revised DCM, it noted categorically that the revised DCM focused on environment quality and sustainability amongst others. In the energy efficiency section dedicated to this reads “the Department will encourage improved energy efficiency in all new buildings, conversions and land use”; with no more mention of anything anywhere else in the rest of the document.
This clearly shows a ‘lip service’ regulation, if at all. Hence, architects and developers will have to introduce measures as they see fit and do not have to comply with any pre-defined tangible benchmarks.

The rest of the documents regulation was biased towards the approval process itself, specifying submission requirements. Perhaps due to prevailing concern around the restoration of the original master plan, the DCM has laid more emphasis in controlling “where” should “what” be built, but with limited or no acknowledgement of the sustainability or energy performance of “what” is built.

b. **National Building Code (NBC):** The first NBC was introduced and passed into law in 2006, although the first draft was developed since 1987. The NBC was developed largely due to incessant building collapse that was plaguing major cities including Abuja, Lagos, Kaduna and Port Harcourt (Mbamali & Okotie, 2012). In that context, the emphasis was on structural stability and safety (Dahiru, Abdulazeez, & Abubakar, 2012).

The NBC is a national document and is expected to compliment any local regulation such as the DCM for Abuja. Though NBC contained specific guidelines that were more detailed compared to the DCM, it did not contain any clear/specific regulations towards the development of energy efficient and sustainable built environment (Dahiru, et al., 2012). Additionally, guidelines related to design issues were sometimes loosely defined. Of particular interest, regulation on ventilation for office buildings was simply to provide natural and/or mechanical ventilation. Again, this is an open-ended regulation with the architect/developer having discretion to design either a low energy or energy intensive building.
Other regulations, again rather open-ended, include that of the external wall and roof construction. Regulation for roof construction stipulates that *roof design is done in conventional manner with minimum pitch of 30°.*

Although, the enactment of the NBC is widely applauded, researchers have uncovered its shortfalls and have recommended its review such that buildings energy efficiency, sustainability issues and performances thresholds/indicators are incorporated (Dahiru, et al., 2012; Mu'azu, 2011; Ogunsote, et al., 2011).

This clearly shows that current building regulation is not adequate to facilitate the evolution of a sustainable built environment. Hence, a study of this nature is envisioned to recommend valuable inputs for consideration from a performance perspective alongside the review of the NBC. This research holds potential to inform the development of local and national regulatory frameworks appropriate to Nigeria and possibly further informing such developments in similar contexts.

### 5.7. Office buildings development in Abuja

Office building development in Abuja has a relatively short history compared to Nigeria and various other international capital cities, owing to its very recent formation. It is therefore important to provide an overview of the historical evolution of office building development in Nigeria before providing finer details of what is obtainable in Abuja.

#### 5.7.1. Development of office buildings in Nigeria

The framework of the timeline of phased developments applied in this study closely matches the political events in Nigeria as often adopted by other researchers in the urban evolution of the country (Odeyale, 2010; Oduwaye, 1998; Osasona & Hyland, 2006; Ozo, 2009; Prucnal-Ogunsote, 2001; Uduku, 2006). This approach is useful because it is these sets of socio-political events that have given rise to office building development and so should provide a contextual outline of progression.
Although present day Nigeria was discussed within the boundaries of its 1914 amalgamated state, references to earlier times were made in order to appreciate the original state of development and its societies which are often ignored (Ekeh, 1975; Thomas-Emeagwali, 1989). This is to enable a fuller understanding of progressive synergies towards what is obtainable today.

Although most of the literature discussed the Nigerian architecture in general, only the aspects that discussed office buildings in particular are emphasised. Based on these adaptations and while acknowledging the inherent overlaps in the timeline, four broad classifications are outlined. These include the traditional architecture, the colonial architecture, modern architecture and post-modern architecture. In periodic terms in relation to political events, these are congruent with pre-colonial, colonial and post-independence eras and contemporary times in Nigeria. The time spans in brackets are merely approximate estimates.

5.7.1.1. Traditional architecture phase (before 1700 circa)

Nigerian architecture prior to colonial contact was purely vernacular and peculiar to its locality (Aradeon, 1984). Traditionally, the three distinct regions (of North, East and West) that form Nigeria were governed by independent monarchical head who exercises authoritarian leadership over the political, military, traditional and spiritual affairs of the people including land administration (Forde & Jones, 1967; Nevadomsky, 1993; Paden, 1973). The traditional urban landscape had a tripartite, framed structure comprising the palace, the worship centre and the market place encapsulating a wide expanse of royal court (Forde and Jones, 1967; Oduwayne, 1998). According to Ozo (2009), “the prominence of the palaces in these courts, had their corollaries in urban development which became veritable features in the cultural urban landscape of Nigerian traditional cities”. Hence, the palace is regarded as the “office building” in the context of this research.
Below are some of basic features of this architectural style and Picture 5-6 is an example of such building archetype.

Design/building features include:

a. Built forms were basic both in terms of construction (round/circular and rectangles), technology (made by hand) and spatial distribution.
b. Building materials were organic, locally obtainable with relative impermanence.
c. Spatial order and design manifests from accumulated knowledge and mastery in craft, climate and social structure.
d. Energy demand for electricity can be said to be zero (as it was not available in the first place) as were many buildings around that time.

*Picture 5-6: Traditional office building in Nigeria*

Above is a photograph of house that belonged to a district head in Kano, now *retrofitted* and used as cultural exchange office.

Source: photograph by researcher (2011)
5.7.1.2. Colonial architecture phase (1700-1960)

The regional amalgamation of three regions along the Gold Coast of West Africa in 1914 by the British to form the Nigerian state fundamentally reshaped the mode of governance and the Nigerian community at large; and by extension the importance of traditional palaces in its government/administrative make up. (Afigbo, 1991; Ballard, 1971; Davis & Kalu-Nwiwu, 2001; Ibrahim, 2006).

The Colonial phase saw the development of *alien* buildings used to house the new administrative machinery. Understandably, what the British built resembled buildings in Britain. This may be attributed to the building technology familiar to the British administration or perhaps, an attempt to establish a domineering physical presence as practiced amongst other colonial powers in those days (Osasona & Hyland, 2006). Below are some of basic features of this architectural style and Picture 5-7 is an example of such building archetype.

Design/building features include:

a. Introduction of British styled architecture.

b. Replacement of traditional building materials and technology which mainly included cement and corrugated iron roofing.

c. The style expressed symmetry, large windows, arches, verandas and deep eaves.

d. From an energy use perspective, it can be said that there was minimal consumption, where it was used for lighting and ceiling fans (Sangowawa, et al., 2008).
Although modern architecture may be well suited to define this phase, the term ‘tropical architecture’ has been used to denote the same period (Qurix, 2007; Uduku, 2006). The architectural development in this phase started in response to the demand for regional development by the indigenous members of the native authorities during the colonial government in a shift away from resource exploits only. This provided an exotic client for the architectural profession largely dominated by foreign or foreign trained architects; notably Maxwell Fry and Jane Drew amongst others (Le Roux, 2004; Uduku, 2006).

There were conscious attempts by their designers to adopt the buildings to local climate although the results were little different from a modernist approach as obtainable internationally at that time (Qurix, 2007). There was some emphasis on passive cooling, cross ventilation and sun shading; where brise-soliel, sun breakers and concrete/aluminium sun shading devices were extensively used.
However, this trend did not last long for reasons suggested by other researchers. One is that the buildings became very expensive due to foreign expertise requirements, technology of prefabrication, use of concrete and other foreign materials and shading components applied in the construction; in addition to poor recognition of the social and cultural nature of the occupants (Aradeon, 1981; Prucnal-Ogunsote, 2001; Uduku, 2006). Most importantly, the political climate was no longer conducive to support such expensive ventures and there was political pressure for indigenous architects to replace those from overseas (Uduku, 2006). Below are some of basic features of this architectural style and Picture 5-8 is an example of such building archetype.

Design/building features include:

a. Climate responsive attempts with emphasis on passive cooling.

b. Extensive use of cement, glazing, aluminium and prefabricated elements.

c. Buildings had an international style outlook, despite local climatic considerations.

d. Vertical progression with buildings several floors high.

e. Buildings were expensive, due construction costs and expertise.
5.7.1.4. Postmodern (contemporary) phase (1970 – till date)

Post Modern architecture in Nigeria can be said to have begun following the discovery of oil in Nigeria and windfall earnings resulting from the oil crises that characterised the 1970’s (Qurix, 2007). This economic context provided funds to embark upon numerous construction projects such as the national universities projects across the country, hosting of the Second World Festival of Black Arts and Culture (FESTAC) 1977 and the numerous mass housing schemes were perhaps the most notable. It was also during this period that the decision to relocate the capital from Lagos to Abuja was resolved. The Abuja project was deemed the largest project of the century at that time and was estimated at $15bn (Salau, 1977; Take, 1984).

Buildings in this phase embraced high-maintenance style architecture with glazing and air conditioning (Uduku, 1996). Perhaps, the government subsidy on energy mitigated reflections on long-term cost
implications of maintenance and cost-in-use. Issues such as climate, environmental awareness, and local consultation were notably absent in the discussion of the architecture and philosophy of the era (Uduku, 2006). However, for the building clients, such buildings were essential because socially, it represented progress (Prucnal-Ogunsote, 2002). From this time onward, this style became the dominant contemporary architectural style representing over 30% of the built environment (Prucnal-Ogunsote, 2001). This is particularly the case in Abuja whose development started afterwards and with modernity in mind in a way much to the liking of a global audience rather than a local one. Below are some of basic features of this architectural style and Picture 5-9 is an example of such building archetype.

Design/building features
a. Disregard for climate and social imperatives.
b. Emergence of open floor plan offices.
c. Free use of geometric forms with curtain walls, parapet walls and flat roofs.
d. Extensive use of concrete, glazing, aluminium and prefabricated elements.
e. Buildings have an international style outlook and required high maintenance.
f. The buildings are several floors high.
5.7.2. Development of office buildings in Abuja
As an administrative city by design, numerous office buildings and corporate head offices of government, private and international agencies characterise its urban landscape. But due to its relatively short existence of barely two decades, it is difficult to group its architectural styles, which evolve overtime, into any meaningful categories. Also, in the absence of any relevant literature to have addressed this, the research will attempt to categorise office building development in Abuja based on political precedents as previously applied in the context of Nigeria. However, it is noted that the ensuing urban development in Abuja is largely post-modernists in outlook due to the impacts of occurrence elsewhere around the country (Qurix, 2007).

The categories proposed in this research are as follows:

Construction work on the new capital city began 1981, while the seat of government relocated from Lagos to Abuja in 1991 and with an ultimatum for the rest of its departments and agencies to do same by
1996. Within the periods of 1991 -1998, the country was governed by military regimes and is described as early phase of the city. The construction work period spanning 1981-1990 is not considered due to limited occupancy.

The early phase saw the development of significant landmark buildings that were of national importance such as the ECOWAS secretariat shown in Picture 5-10 and the International conference centre (which hosted the OAU conference in 1991) alongside other office developments.

Design/building features

a. Built to satisfy political exigencies, and hence depicted aura of economic/political relevance.

b. Use of geometric forms was basic and simplistic.

c. Extensive use of imported materials.

d. Construction activities were dominated by foreign construction firms providing expertise that ensured timely project delivery.

e. High project/construction costs

f. Some office building designs bore climate responsive emphasis as found in modern Architecture of Nigeria discussed above.

*Picture 5-10: Early phase architecture style buildings in Abuja*

ECOWAS head office, Abuja, - Source: LaKriz (2010)
**5.7.2.2. Contemporary phased (1999 – till date)**

The year 1999 marked the beginning of a stable democratic government in Nigeria that have survived military intervention to-date unlike in previous periods. In this period, the civilian democratic government have consolidated the positioning of its agencies in the new capital while also propagating modernity in all aspects of its project delivery. This period also witnessed an exposition to a globalised world through the advent of digital information technology and mobile telecommunication. Below are some of basic features of this architectural style and Picture 5-11 is an example of such building archetype.

Design/building features

a. There is a confluence of various architectural styles but mostly postmodernist (contemporary) style.
b. Emphasis on vertical progression much more than in previous phases
c. Extensive use of glazed façade.
d. Free use of geometric forms with curtain walls, parapet walls and flat roofs.
e. Application of central air conditioning.

*Picture 5-11: Contemporary phase architecture style building in Abuja*

Central Bank of Nigeria, Abuja.
Source: Interstate Architects Limited (IAL) (2013)
5.7.2.3. Future prospects

In 2010, receipt of tender began for construction of the Abuja City center project popularly referred to as Abuja Boulevard (Iroegbu, 2010). In the vision to modernise the city, this project comprises high-rise office buildings, hotels, conference centres and parks along four axial roads traversing the city – each 6.5km long. The project is compared with Rodeo Drive in Los Angeles USA.

Another project of national interest is the World Trade Center project shown in Picture 5-12. This comprises an office node housing the Trade Center tower and other office buildings and flanked by residential nodes. The $1.3bn 37 storey project is currently in progress as shown in Picture 5-13.

Other such post modernists project includes the Abuja centenary village shown in Picture 5-13, The Abuja City Gate project to mention two.

*Picture 5-12: Design of future prospective office building design in Abuja*
Picture 5-13: World trade centre project (pictured above) in progress

World Trade centre project in progress. Source: Tbite (2013)

Picture 5-14: Abuja Centenary Project - the New Financial Hub

Source: Suarez and Pons (2013)
It is apparent that there is a continued demand for urban growth in Abuja. From most project proposals and those already under construction, key features indicate precedents drawn from non-African contexts, a sustained drive towards vertical progression, extensive use of glazed façade, central air conditioning and a style attuned to placeless modernity.

One other important concern is that of the likelihood of the replication of this paradigm in other urban centres in the country. Lagos, is already illustrating this.

It therefore becomes more important not only to rationalise energy use in buildings, but also to actively pursue a demand side management regime in the design of buildings.

5.8. **Office buildings development in Abuja**

It will be noted that the office buildings in Abuja as discussed above have been developed within a rather short time frame in comparison to other historical narratives accustomed to urban/architectural developments. Also, the project implementation delays as discussed has somewhat given rise to different building typologies evolving simultaneously when going by project completion dates. As such, it becomes rather difficult to conduct a robust building energy performance analysis of such building clusters earlier discussed in 5.7.2.

Hence, in this research a new approach of building typology classification is proposed and adopted for the energy performance analyses (Chapter 6 and 7). This typological classification aims at bringing together very similar buildings in the most objective approach. The bases for the selection are discussed in the following sections.
5.8.1. Proposed Performance based office classification

In the absence of any local regulation, the following considerations towards achieving the proposed performance based classification are:

5.8.1.1. Building vertical projection (rise)
Two categories of buildings are proposed based upon the vertical projection of the buildings using number of floors as criteria. Although there is no office building classification in any relevant building development regulatory documents in Nigeria, local regulations on the provision of lift services in buildings provided guidance for the component of the proposed typology.

Within local regulations, buildings in excess of four suspended floors are required to have lifts services, while it is not necessary for buildings of less than for floors.

Hence, adaptations in the typology herewith are:

Low Rise (LR) = buildings of four floors and below
High Rise (HR) = buildings above four floors

5.8.1.2. Budget
The budgetary criteria considered the dividend between the capital value (estimated construction costs) of the building and total floor area. This was applied because most of the office buildings were government owned, and as such a rental value was not readily obtainable. The capital value was derived from an average of valuation feedback from randomly selected quantity surveyors in Abuja who are familiar with the selected case study buildings. Thus, accounts of the buildings locations, services and finishes were considered.

It also took into cognisance construction costs thresholds adopted by the local guild of surveys in determining/projecting project qualities based on some assumed standards. Such quality gradation includes categories such as basic, standard, high quality, premium etc. In this research a mark-up N150,000/m² is assumed for high quality buildings.
Building rate = \( x = \frac{\text{capital value (in Naira)}}{\text{total floor area (sqm)}} \)

Low budget = \( x \leq N150,000/m^2 \); High budget = \( x \geq N150,000/m^2 \)

Thus, the ensuing groups from these two considerations are as follows:

a. LBLR – Low Budget Low Rise
b. HBLR – High Budget Low Rise
c. LBHR – Low Budget High Rise
d. HBHR – High Budget High Rise

5.8.1.3. Other considerations

Additional consideration to enable a robust energy performance based classification, as obtainable in other best practises, are given below:

1. **The location** of the buildings was in Central Business District CBD nodes of the metropolis. This forms the main area planned to accommodate office buildings (Mabogunje, 2001).

2. **The Building’s function** depicts the kind of services/activity in a building. Wide variance in the type/levels of activities should be avoided. All the buildings considered are single use/occupancy office buildings.

3. **The occupancy durations** conformed with official working hours in Nigeria which is between 0800hrs to 1600hrs Monday – Friday. The occasional eventuality of extended-stay or overtime-stay was also taken into account.

4. **Architectural styles** were modern and post-modernist in style as discussed in Chapter 5.7.2. The design types selected accounts for significant proportion of office buildings in Nigeria (Prucnal-Ogunsote, 2001).

5. **HVAC strategy** was based on mixed mode ventilation which is a combined strategy of natural and mechanical ventilation systems.

6. **The fuel type** was electricity provided primarily from the national grid. Unlike many developed countries where both electricity and gas
are used, it was a relatively straightforward position to resolve in the case of Nigeria. Power Holding Corporation of Nigeria (PHCN) remains the primary source. In addition, diesel fuel powered generators were identified as the general alternative source of energy.

30 buildings were identified as potential case studies. Amongst the 30, 4 were inaccessible due to heightened security situation and political sensitivities while another 4 were discarded due to incomplete information leaving a total of 22 buildings. These are shown in table 5-1.
Table 5.8-1: Selected case study of office buildings in Abuja

<table>
<thead>
<tr>
<th>Classification by Performance Level</th>
<th>High Budget High Rise (HBHR)</th>
<th>Low Budget High Rise (LBHR)</th>
<th>Low Budget Low Rise (LRLR)</th>
<th>Early Period (1940-1960)</th>
<th>Contemporary Period (1991-Till Date)</th>
<th>Classification by Date</th>
</tr>
</thead>
</table>
5.9. Summary

This chapter discussed the importance of buildings in fulfilling the role of Abuja as an important capital city of international reputation. It discussed the impact of socio economic pressure and rapid urban growth on its infrastructure. The strain on electricity, building's only source of energy, is demonstrated and the impact of commercial (including office) buildings on the city’s overall energy consumption is highlighted. The shortfall in electricity has resulted to an uncoordinated search for energy supply sources, alternatives currently dominated by the use of generators.

The chapter also indicated that the increasing pressure to catch up with global development has disabled the development of a coherent energy conscious regulation for the developments as found in many developed countries. The literature also suggests that the prevailing direction of office building development remains energy intensive despite the city's energy infrastructure predicament.

In view of these challenges, it has become essential for architects to understand the impact of their design decisions on long-term energy demands in order to achieve a sustainable and responsible built environment. The chapter proposed a performance based classification of office building development within which the status of their energy performances can be evaluated.

The next chapter presents the fieldwork on the case study.
6. Chapter Six: Case study and building inventory survey

6.1. Introduction

This chapter presents the case study field work conducted in Abuja. Data collected was guided by the building inventory survey developed by the researcher. This covered architectural design and energy use aspects of the building. Conducting the case study was predicated by the literature review presented a paucity of data for the evaluation of office building design and development and the energy implications thereof. This case study is an attempt to elicit the status of the office built environment in this context. Therefore, characteristics of the Abuja office built environment is provided while the distribution of energy end use and energy performances were deduced. An attempt to elicit an understanding of potential relationships between design and energy consumption of office buildings in Abuja using statistical correlation is discussed.

6.2. Data collection

Data from the case study was collected based on the information requirements contained in the building survey data form developed for this research as discussed in Chapter 4.5.1.3.

6.2.1. Building inventory survey form

The form developed in this research, was divided into three sections A-C. Content of each section is given below. The inventory survey form is attached in Appendix A0.

6.2.1.1. Section A - Building physical component

Section A dealt with the physical characteristics of the building discussed in Chapter 3.6.2. The section set out to evaluate current design of office building in Abuja in relation to key design parameters that have been applied either to achieve low energy buildings, recommended for tropical climates or requirements contained in local
building regulations. The architectural design variables examined fall under four categories as follows:

1. The Site: At the site level, the situated building is examined within an urban context. This considers the building's orientation and set back. Orientation refers to the relationship between the building's façade and the geographical directions (North, South, etc). This is important as it relates the building mainly to the location of the sun which is a source of solar heat gain and useful for lighting as well. The setback refers to the distance between the building and property/fence line, which is expected to be in compliance with set local regulations. This largely ensures proper lighting and ventilation in the building.

   Picture 6-1: Description of site context

   ![Diagram of site context]

   a₁, a² = setback distances between building and fence/boundary.
b¹ = distance between main building and adjoining property

   ____ = main axis of orientation, is a reference to the geographical cardinal points where greater proportion of the building façade is facing.
Example, main building orientation axis is East/West
Adjoining building orientation is North/South

2. Building configuration: This examines the building design in general. It describes the plan layout, which can be of narrow plan (NP), compact plan (CP), deep plan (DP), courtyard plan (CY), composite/compact spread (CS) or covered atrium plan (AT) as shown in Picture 6-2. Also, Pictures 6-3 and 6-4 shows
description of building compactness ratio and form factor respectively.

*Picture 6-2: Description of plan layout*

*Picture 6-3: Description of compactness ratio*

Compactness ratio, \( CR = \frac{P^2}{4A} \)
Where, \( P \) = perimeter; \( A \) = floor area
Therefore, \( CR = \frac{P^2}{4A} \),
\[ = \frac{(2l + 2b)}{4(l \times b)} \]
3. Building Envelope Properties: This examined the constituents that make up the building fabric. These included the wall construction material, roof construction, type of glazing, as well as the thermo physical properties of the glazing and opaque components of the wall, which is their U-values measured in W/m² °C. These are obtainable in numerous manufactures and building specification manuals. Meanwhile, the glazing ratio is shown in Picture 6-5 and be described as:

*Picture 6-5: Description of glazing ratio*

Glazing Ratio = $GR = \frac{\text{Net Glazing Area}}{\text{Gross Wall Area}}$

This can be expressed as a fraction or in percentage (%)
4. Shading devices: This examined the type of shading devices applied in the building design, its projections and orientation of elevations in which they are applied. Of key importance is the projection distance off the wall. Shading devices can be horizontal (H), vertical (V) a combination of both (HV) or in a form of recess wall (RW).

*Picture 6-6: Examples of shading devices*

Vertical shading  horizontal shading

6.2.1.2. *Section B - Building energy management and occupancy schedule*

Section B examined energy use management in the building. This covered primary and alternative sources of energy, cost and maintenance of energy supply infrastructure, occupancy regimen and any deliberate management system or policy applied towards efficient energy usage in the buildings. These were grouped under three headings. These are:

1. Energy resource: this examined all sources deployed to provide energy to the building. These were mainly the primary grid utility source (PHCN) and generators as shown in the literature review. Billing and fuel records for primary energy source and generator were obtained for a year period respectively. Approximate average daily supply duration from each source was also obtained from the building manager.
2. Energy management: this examined building energy management system with particular attention to any energy efficiency policy deployment, general maintenance and funding mechanism.

3. Occupancy schedule: this examined the occupant density and in particular building occupational duration (daily working hours) and incidents of any extended occupancy.

From the data derived, energy performance status of current office building practice can be determined. The energy use index (EUI), a widely used indicator, is applied to describe the energy performance of the buildings. Also, performance in terms of economic and environmental implication using Energy Cost indicator (ECI) and Carbon Emission indicator (CEI) respectively were determined. Details of these performance indicators are provided in Chapter 3.4.

**6.2.1.3. Section C - Building energy end use (audit)**

Section C examined end use profile of the building using a walk through audit. Main building end uses comprising lighting, office equipment, air-conditioning and other building services of a typical floor was taken into account. This is to ascertain energy end use distribution and establish the highest end use where energy savings can be made. Researchers have indicated that significant energy use is due to cooling, but with limited attempt to establish the actual end use distribution for most building typologies in Nigeria (Fadamiro & Ogunsemi, 2004; Imaah, 2004b).

**6.2.2. Administration of survey form**

Prior to the commencement of the survey, a formal ethical review was conducted at the university and an approval granted. Details were discussed in Chapter 4.7 and the ethical review documentation is attached in Appendix A.

The field work began with a pre notification and reconnaissance visit to the office buildings selected as case studies. Building Management
Heads were approached by the researcher to intimate them about the research and the information required from them.

In Section A, empirical data collected include building plans/as-built drawings where available, otherwise measured or estimated sketch plans were reproduced by the researcher. Pictures of the building elevations were also taken and recorded for each building as provided in the survey form to cover design variable aspects that were discussed above.

Section B examined the building energy use management system in general. It checked for any policy implemented towards conscious energy usage in the building. Energy costs for both primary and secondary sources were also obtained. Energy consumption data from monthly metered energy bills were obtained for a year time series. Direct sub metering was not undertaken due to the availability of these energy meters. In addition to the challenging process, unstable electricity supply and the potentials of power-surge made a measured energy protocol (direct sub-metering) unsuitable for these buildings. More so, the time required for robust sub metering was beyond the scope of this research. Energy costs were obtained from receipts.

Section C comprised an audit of energy end uses. A simple-walk through audit and an inventory of energy end use appliances was conducted together with the building’s management team/personnel. This involved recording observed end use appliances, number of units, power rating etc. as contained in the audit section of the inventory survey form. However, due to constraints of access time granted to the research a typical floor was identified for each of the buildings. The building end uses were categorised into HVAC, lighting, equipment load and building services as often encapsulated in literature (Omer, 2008; Schlueter & Thesseling, 2009). Due to time and cost implication of direct metering, calculation methods using mathematical formulas have been devised as an alternative method for calculating disaggregated energy end uses (Batagarawa, Hamza, & Dudek, 2011; McLoughlin,
Duffy, & Conlon, 2013; Rosenberg, 2014). In this research Batagarawa, Hamza and Dudek (2011), was selected because it was applied in context similar to this research and discussed in 6.2.3.

6.2.3. **Data analyses**

Data from case study was analysed based on statistical and mathematical models in order to achieve objective 3 of this research.

6.2.3.1. **Descriptive analyses**

Data from the case studies was processed using standard statistical analyses functions (mean, median and mode) to describe the categories of the case studies from a design perspective using the examined architectural variables. Also, the energy performances were derived using the indicators highlighted above.

6.2.3.2. **Disaggregated energy end use**

Energy end uses were disaggregated using a mathematical model adopted for this research as discussed above. The equations of the model are expressed below:

\[ Q_a = \text{energy rating} \times \text{quantity} \times \text{duration of use (hours)} \ldots \text{equation(1)} \]

Where \( Q_a \) is the quantity of energy consumed by appliance; obtained from manufacturers label/maintenance manual

\[ Q_A = Q_{a1} + Q_{a2} + Q_{a3} + \ldots Q_{an} \ldots \text{equation(2)} \]

Where \( Q_A = \) total energy consumed by appliance
\( Q_{a1}, Q_{a2}, \ldots Q_{an} = \) different appliances

The same equation (2) is applied for air conditioning \( Q_C \) (cooling) and lighting, \( Q_L \)

Hence,

\[ Q_C = Q_{c1} + Q_{c2} + Q_{c3} + \ldots Q_{cn} \ldots \text{equation(4)} \]

\[ Q_L = Q_{l1} + Q_{l2} + Q_{l3} + \ldots Q_{ln} \ldots \text{equation(5)} \]

So total energy consumption (\( Q_T \)),

\[ Q_T = Q_A + Q_C + Q_L \ldots \text{equation(6)} \]

Also, total energy supply (\( Q_S \)),

\[ Q_S = Q_P + Q_G \ldots \text{equation(7)} \]

Where \( Q_P \), energy from primary source, and \( Q_G \) energy from generator

~ 169 ~
6.2.3.3. Correlation analyses
A correlation analyses using Pearson’s model was carried out on the data obtained from the case study to evaluate the occurrence of potential statistically significant correlation between the design variables and energy use of the buildings surveyed. Disaggregated energy end use due to cooling was examined in particular.

6.3. Data and results from case study
6.3.1. The building physical component
In the first part of the survey empirical data collected include building plans/as-built drawings where available, otherwise measured or estimated sketch plans were reproduced by the researcher to deduce parametric details of the built form. Pictures of the building elevations were also taken and recorded for each building as provided below for visual contextualisation. Also google map images for the case study sites were obtained for each building to demonstrate how it is situated within the urban context. In Table 6-1, the photographic documentary is given with buildings falling into their respective categories (LBLR, HBLR, LBHR and HBHR as adopted in Chapter 5.8) and in particular showing their site contexts. While a summary of the case study is provided highlighting their design variables (selected from literature) is shown in Table 6-2.
Table 6-1: Table showing case study buildings

<table>
<thead>
<tr>
<th>ID</th>
<th>SITE</th>
<th>BUILDING</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A02</td>
<td>LBLR</td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A04</td>
<td>HBLR</td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A05</td>
<td>LDHR</td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H04</td>
<td></td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B01</td>
<td></td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B02</td>
<td></td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B03</td>
<td></td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B04</td>
<td></td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B05</td>
<td></td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B07</td>
<td></td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B08</td>
<td></td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B09</td>
<td></td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B10</td>
<td></td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B11</td>
<td></td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B12</td>
<td></td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B13</td>
<td></td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B14</td>
<td></td>
<td>SITE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BUILDING</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
a. Site: All the buildings complied within the minimum regulatory requirement of set-backs distances away from the property line or fence. This positioning shows potentials to maximise natural ventilation and views due to unimpeded surroundings.

b. Building orientation: Figure 6-1 shows distribution of the building orientations amongst the constituents. It shows that consideration for building orientation seems to be dependent upon the layout of the existing access road. This is often the case in most residential buildings such that the access to building is facing the road directly (Mike Adebamowo & Ilesanmi, 2012). Although this can be understood in a residential building context due to spatial constrains; the land allocation for most of the office buildings is in excess of 5000m². This suggests the potential to maximise façade orientation.

Figure 6-1: Chart showing distribution of building orientation

```
<table>
<thead>
<tr>
<th>Orientation</th>
<th>No of buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/S</td>
<td>1</td>
</tr>
<tr>
<td>NNE/SSW</td>
<td>1</td>
</tr>
<tr>
<td>NE/SW</td>
<td>2</td>
</tr>
<tr>
<td>NEE/SW</td>
<td>1</td>
</tr>
<tr>
<td>E/W</td>
<td>1</td>
</tr>
<tr>
<td>NWW/SEE</td>
<td>1</td>
</tr>
<tr>
<td>NW/SE</td>
<td>5</td>
</tr>
<tr>
<td>NWW/SSE</td>
<td>3</td>
</tr>
</tbody>
</table>

Legend: LBLR, HBLR, LBHR, HBHR
```

c. Plan layout: Plan layout of the buildings varied widely. This ranged from narrow plan (NP) often recommended for tropical climates to enable cross ventilation. There were plans with open court yard which is an adaptation from traditional architecture (CY) and a few with atriums (AP). Also used, were compact plans
(CP), deep plans (DP), while other large buildings were spread out with adjoining compact forms (CS).

d. Total floor area: total floor area of surveyed buildings was 162,577 m² in which the typologies LBLR, HBLR, LBHR and HBHR account for 10,613 m², 20,454 m², 14,688 m² and 122,402 m² respectively. Average total floor areas were 2,653 m², 4,091 m², 7,344 m² and 11,127 m² for the LBLR, HBLR, LBHR and HBHR typologies respectively.

e. Floor to ceiling height (FCH): floor to ceiling averaged 3.1 m, exceeding the local minimum regulation of 2.4 m. In fact only one building actually had 2.4 m FCH, with the highest reaching 4.0 m.

f. External wall: All external walls of the case study buildings were made of the basic 225 mm hollow block wall as per regulation, but clad in different ways. These ranged from simple plaster to both internal and external faces (PW), plaster to the internal with the external face having either facing brick (PWB) or tiled (PWM). Other more prestigious buildings had marble tile finishes both to internal and external faces of the wall (PWMM).

g. Type of glazing: All the buildings have single pane glazing. This was either clear (SCG), coloured or tinted (STG) or reflective (SRG) glass.

h. Glazing ratio/percentage glazing: Percentage glazing of the buildings external façade ranged between 20-70%. Generally, glazing ratio averaged around 50% as shown in Figure 6-2.
Shading: Only 8 of the buildings surveyed had shading device components which included horizontal, vertical and composite shading device types. These were limited to the high-rise buildings, while none of the low rise buildings had any shading at all.

Building form (Compactness Ratio - CR and Building Form Factor - BFF): the typologies showed a rather similar distribution in both the CR and BFF as shown in Figure 6-3 and 6-4.
Figure 6-3: Chart showing the distribution of compactness ratio

![Compactness Ratio Distribution](chart1.png)

Figure 6-4: Chart showing the distribution of building form factor

![Building Form Factor Distribution](chart2.png)
| BUILDING ID | CLASSIFICATION | YEAR OF COMPLETION | PLAN LAYOUT TYPE | BASE FLOOR AREA (m²) | TOTAL FLOOR AREA (m²) | NO. OF FLOORS | FLOOR TO CEILING HEIGHT (m) | FLOOR TO CEILING HEIGHT (m) | COMPACTNESS RATIO | BUILDING FORM FACTOR | OPAQUE WALL MATERIAL | WALL U-VALUE | TYPE OF GLAZING | GLAZING U-VALUE | PERCENTAGE GLAZING | MAIN AXIS OF FACADE ORIENTATION | TYPE OF SHADING | APPROXIMATE DEPTH OF SHADING DEVICE (m) |
|-------------|----------------|--------------------|------------------|----------------------|-----------------------|--------------|---------------------------|--------------------------|-------------------|---------------------|-------------------|--------------|--------------|-----------------|-----------------------------|----------------------|----------------------------------|
| A02         | DP             | 1991               | CP               | 270                  | 540                   | 2            | 2.4                       | 66                        | 0.217             | PW                  | SCG               | 2.725       | SRG          | 4.91            | 30%            | NNE/SS                    | NW/SE          | 0                                |
| A08         | CP             | 1999               | CY               | 926                  | 2,783                 | 3            | 3.1                       | 240                      | 0.28              | PW                  | SCG               | 2.725       | STG          | 5.391           | 60%            | NW/SE                    | N              | 0                                |
| B12         | CP             | 2009               | NP               | 624                  | 1,248                 | 2            | 3.1                       | 122                      | 0.167             | PWMM                | STG               | 2.689       | SRG          | 5.391           | 20%            | NW/S                     | N              | 0                                |
| B13         | CP             | 2009               | NP               | 231                  | 462                   | 2            | 2.9                       | 64                       | 0.172             | PW                  | SCG               | 2.725       | STG          | 5.025           | 60%            | NW/SE                    | N              | 0                                |
| A01         | CP             | 1991               | DP               | 2,040                | 6,120                 | 3            | 3.1                       | 240                      | 0.28              | PW                  | STG               | 2.689       | SRG          | 5.391           | 40%            | NW/SE                    | NW/SE          | 0                                |
| A06         | CP             | 1998               | CP               | 2,256                | 6,750                 | 3            | 3.1                       | 113                      | 0.167             | PWMM                | STG               | 2.689       | SRG          | 5.025           | 60%            | NW/SE                    | N              | 0                                |
| A07         | NP             | 1998               | NP               | 672                  | 2,688                 | 4            | 3.5                       | 116                      | 0.071             | PWMM                | STG               | 2.689       | SRG          | 5.391           | 40%            | NW/SE                    | N              | 0                                |
| B14         | CP             | 2009               | CP               | 932                  | 3,728                 | 4            | 2.8                       | 132                      | 0.089             | PWMM                | STG               | 2.689       | SRG          | 4.91            | 70%            | NE/SE                    | N              | 0                                |

**Table 6.2: Summary of physical components of case study buildings**

- **Legend**
  - Meaning
  - Abbr
  - Deep Plan: DP
  - Compact Plan: CP
  - Courtyard Plan: CY
  - Narrow Plan: NP
  - Compact Spread: CS
  - Atrium Plan: AP
  - Plastered Wall: PW
  - Plastered wall with brick cladding: PWB
  - Plastered wall with marble tiled cladding: PWM
  - Plastered wall with marble tiled cladding externally and internally: PWMM
  - Single clear glass: SCG
  - Single tinted glass: STG
  - Single reflected glass: SRG
  - Recessed wall: RW
  - Horizontal: H
  - Horizontal and vertical: H/V
  - None: N

- **General Building Parameters**
  - Plan Layout Type
  - Base Floor Area (m²)
  - Total Floor Area (m²)
  - No. of Floors
  - Floor to Ceiling Height (m)
  - Perimeter (m)
  - Compactness Ratio
  - Building Form Factor

- **Building Envelope Properties**
  - Opaque Wall Material
  - Wall U-Value
  - Type of Glazing
  - Glazing U-Value
  - Percentage Glazing

- **Shading**
  - Main Axis of Facade Orientation
  - Type of Shading
  - Approximate Depth of Shading Device (m)
6.3.2. Energy use management and occupancy regimen

Sections B and C dealt with issues relating to energy use. Sectioned B examined the building energy use management system in general while Section C examined end use distribution. Section B checked for any policy implemented towards conscious energy usage in the building and details of parameters examined are given alongside observations made during the data collection. The table at the end of this section presents a summary of data obtained for these sections.

a. Energy use sources: In addition to the primary source form the national grid (PHCN), all the buildings used diesel powered generators of varying makes, models and capacities. Only one building adopted solar panels but was limited to external lighting.

Figure 6-5; Chart showing distribution of energy consumption (by source)

b. Duration of electricity availability: Average daily durations of electricity varied between 3-6hours in a day. Power interruptions are experienced on a daily basis and generators are used to supplement the shortage. Office buildings occupancy duration conformed to standard official working hours in Nigeria and there was no incidence of work over the weekends but there were periodic
extended office work not exceeding 3hrs and requiring less than 10% of the staff strength.

Figure 6-6: Daily average duration of electricity availability (%)

Figure 6-7: Chart showing distribution of electricity cost (by source)

c. Energy costs: Energy costs for primary source was straightforward as these were readily available from the bills collected or payment receipts. Costs of diesel supply were also obtained and collated data is shown below.
d. Energy management: there was no specific document regulating or providing guidance in terms of energy usage in the buildings. However, in a different initiative commissioned by the government to enhance public service delivery (SERVICOM) a simple rule has been adopted by some offices which reminds staff to switch off their computers at the close of work. This is seen pasted on office doors. There is no penalty for non-compliance.

More so, financing of electricity provisions comes directly from the government. This contained within ministerial budgets where there are no limits on energy expenditure, no incentives for energy efficiency initiatives and no penalty for energy waste (Akinbami & Lawal, 2009).

6.3.3. Energy use audit
Section C comprised an audit of energy end uses. Result of end use energy distribution from simple-walk through audit and an inventory of energy end use appliances is discussed below. The building end uses were categorised into HVAC, lighting, equipment load and building services as encapsulated in literature (Omer, 2008; Schlueter & Thesseling, 2009).

a. Heating Ventilation and Air Conditioning: Window, split and standing units are the most common while the use of large central air conditioning was limited. The use of fans was very limited and this may not be unconnected to cultural imperatives where the use of air conditioning denotes a status symbol (Adebamowo, et al., 2013).

b. Lighting: Lighting fittings are mostly ceiling mount white light emitting fluorescent lamps. Cases of both normal and low energy compact bulbs usage have been observed.

c. Equipment: Office equipment comprises mostly computers, then printers and copiers. The use of fridges and kettles was also recorded, though this occurrence was mostly observed in higher ranking or senior staff offices. Other appliances include television in waiting lounges, stereo sets and cold water dispensers.
d. Building services: Building services energy consumption was minimal. This included mostly elevators. These are provided in buildings exceeding three floors according to local building regulations. Other building service energy use includes water pumps to boost water pressure in upper floors.

*Figure 6-8: Chart showing distribution of energy consumption by end use*

Also, the use of electricity stabilisers was common and a few even had electric surge protectors attached to all plug loads.
Table 6-3: Summary of energy use management and end use audit

<table>
<thead>
<tr>
<th>Building ID</th>
<th>Classification</th>
<th>Average Monthly Electricity Consumption from Primary Source (Kwh)</th>
<th>Percentage of Total Monthly Charges (NGN)</th>
<th>Total Annual Electricity Consumption (Kwh)</th>
<th>Costs of Generation Charges (NGN)</th>
<th>Average Monthly Cost of Electricity (NGN)</th>
<th>Approximate Number of Occupants (per person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>CLASS B</td>
<td>1,000</td>
<td>3</td>
<td>7,811,000</td>
<td>1,566,000</td>
<td>20,275</td>
<td>600</td>
</tr>
<tr>
<td>B2</td>
<td>CLASS B</td>
<td>1,200</td>
<td>6</td>
<td>30,000</td>
<td>13,300</td>
<td>7,112</td>
<td>45</td>
</tr>
<tr>
<td>B3</td>
<td>CLASS B</td>
<td>1,600</td>
<td>12</td>
<td>8,000</td>
<td>1,800</td>
<td>5,400</td>
<td>10</td>
</tr>
<tr>
<td>B4</td>
<td>CLASS B</td>
<td>3,400</td>
<td>40</td>
<td>2,480,000</td>
<td>141,400</td>
<td>683,600</td>
<td>15</td>
</tr>
<tr>
<td>B5</td>
<td>CLASS B</td>
<td>16,000</td>
<td>190</td>
<td>12,000</td>
<td>4,500</td>
<td>675</td>
<td>25</td>
</tr>
<tr>
<td>B6</td>
<td>CLASS B</td>
<td>20,700</td>
<td>45</td>
<td>1,768,000</td>
<td>892</td>
<td>1,500</td>
<td>30</td>
</tr>
<tr>
<td>B7</td>
<td>CLASS B</td>
<td>32,400,000</td>
<td>3,600</td>
<td>3,730,000</td>
<td>3,620</td>
<td>2,178,800</td>
<td>15</td>
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<tr>
<td>B8</td>
<td>CLASS B</td>
<td>181,600</td>
<td>2,178,800</td>
<td>6,819,000</td>
<td>1,968,000</td>
<td>2,480,000</td>
<td>15</td>
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<td>CLASS B</td>
<td>45,800</td>
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<td>476,500</td>
<td>4,500</td>
<td>675</td>
<td>15</td>
</tr>
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<td>B10</td>
<td>CLASS B</td>
<td>13,300</td>
<td>159,200</td>
<td>132,800</td>
<td>150</td>
<td>124,000</td>
<td>10</td>
</tr>
<tr>
<td>B11</td>
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<td>20,000</td>
<td>225,000</td>
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<td>200</td>
<td>196,300</td>
<td>15</td>
</tr>
<tr>
<td>B12</td>
<td>CLASS B</td>
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<td>5,900</td>
<td>1,800</td>
<td>450</td>
<td>15</td>
</tr>
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<td>B13</td>
<td>CLASS B</td>
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<td>5,400</td>
<td>16,600</td>
<td>5,400</td>
<td>140,000</td>
<td>15</td>
</tr>
<tr>
<td>B14</td>
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<td>301,600</td>
<td>301,600</td>
<td>301,600</td>
<td>200</td>
<td>15</td>
</tr>
</tbody>
</table>

~ 181 ~
6.4. Statistical performance analyses and discussion

6.4.1. Building design and physical component

All the office building typologies have shown similar disposition in terms of site context, building orientation and building plan forms. All the buildings show compliance with regulations in terms of building set backs away from the property line. Therefore, this allows enough space for air circulation and visual appeal to the outside. However, it is noted that buildings tend to be oriented towards the access road into the building site; potentials of building orientation is not optimised.

More so, the different types of building plans examined are common to all of the typologies.

The building components also showed much commonality in terms of the external wall types. Although the high budget walls were clad with more expensive materials, the basic component in most of the buildings remains the hollow sandcrete blocks.

Three types of glazing were found among the case studies and have been applied across all categories. There was also a similarity in terms of glazing ratio. However, the high budget buildings showed higher glazing ratio distributions.

6.4.2. Energy performance analyses

The case study buildings were analysed using three performance indicators as discussed in Chapter 3. These are Energy Use index (EUI), Energy Cost Index (ECI) and Carbon Emission Index (CEI). The results are shown in Table 6-4.
Table 6-4: Summary of energy performances of case studies

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>ENERGY COST INDEX ECI (NGN/m²/yr)</th>
<th>CARBON EMISSION INDEX (KgCO₂/KWh)</th>
<th>ENERGY USE INDEX (KWh/m²/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBLR</td>
<td>3,640</td>
<td>3,000</td>
<td>38.3</td>
</tr>
<tr>
<td></td>
<td>1,780</td>
<td>119,000</td>
<td>141.0</td>
</tr>
<tr>
<td></td>
<td>6,260</td>
<td>65,000</td>
<td>241.3</td>
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<td></td>
<td>1,210</td>
<td>3,000</td>
<td>39.0</td>
</tr>
<tr>
<td></td>
<td>980</td>
<td>92,000</td>
<td>49.5</td>
</tr>
<tr>
<td></td>
<td>1,470</td>
<td>69,000</td>
<td>37.7</td>
</tr>
<tr>
<td></td>
<td>5,860</td>
<td>2,000</td>
<td>45.4</td>
</tr>
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<td></td>
<td>5,020</td>
<td>61,000</td>
<td>126.4</td>
</tr>
<tr>
<td></td>
<td>2,900</td>
<td>33,000</td>
<td>42.0</td>
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<td>159,000</td>
<td>66.4</td>
</tr>
<tr>
<td></td>
<td>1,420</td>
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<td>4,420</td>
<td>133,000</td>
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<td></td>
<td>2,380</td>
<td>225,000</td>
<td>122.9</td>
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<tr>
<td></td>
<td>660</td>
<td>218,000</td>
<td>29.5</td>
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<td>62.3</td>
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<td>559,000</td>
<td>226.8</td>
</tr>
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<td>2,080</td>
<td>1,203,000</td>
<td>306.2</td>
</tr>
<tr>
<td></td>
<td>2,000</td>
<td>1,761,000</td>
<td>358.1</td>
</tr>
<tr>
<td></td>
<td>2,000</td>
<td>160,000</td>
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</tr>
<tr>
<td></td>
<td>2,880</td>
<td>62,000</td>
<td>76.9</td>
</tr>
</tbody>
</table>

a. Energy Use Index EUI: Average across the detailed typologies was not well delineated. However, when broadly viewed, average EUI for the low-rise and high-rise buildings show 85kWh/m²/a and 145kWh/m²/a respectively. However, Figure 6-9 shows actual derived performance for each of the respective categories examined.
The EUI values shows a wide variation range across the categories, but typical performance behaviour denoted by their medians occur in within a narrower range. Accordingly, typical EUI for the LBLR, HBLR, LBHR and HBHR categories are 90.0 kWh/m²/a, 45.4 kWh/m²/a, 57.6 kWh/m²/a and 134.0 kWh/m²/a respectively. Perhaps this suggests the design impact across the categories is fairly comparative from an energy stand point. Although the derived typical energy performance values are comparative to other global reporting (Batagarawa, et al., 2011; Perez-Lombard, et al., 2008); on a case by case basis, some of the EUI are relatively low with values well below 100 kWh/m²/a as shown in Table 6-4 above.

b. Carbon Emission Index (CEI): There was a clearer distinction in terms of CEI amongst the two broad typologies and even the sub groups. Accordingly, typical CEI for the LBLR, HBLR, LBHR and HBHR categories are 34,000 kg CO₂/kWh, 61,000 kg CO₂/kWh, 111,500 kg CO₂/kWh, 225,000 kg CO₂/kWh respectively. Figure 6-10
shows actual derived performance for each of the respective categories examined.

Figure 6-10: Carbon emission performance of office building categories (CEI)

However, it is noted that such high values of derived EUI is not unconnected with on-site energy generation due to use of generators and potential inefficiencies of such systems.

c. Energy Cost Index (ECI): Accordingly, typical ECI for the LBLR, HBLR, LBHR and HBHR categories are 2,710NGN/m²/a, 2,900NGN/m²/a, 1,340NGN/m²/a and 2,000NGN/m²/a. Figure 6-11 shows actual derived performance for each of the respective categories examined.
The ECI values suggest that, energy provisions in high rise office buildings is more cost efficient. Again, this may not be unconnected to on-site energy generation using generators. A further evaluation of this potential shows that typical capacity of generators in low rise and high rise buildings are 700KVa and 1,00KVa respectively. Obviously, these largely oversized generating capacities for some of the buildings have significant impact on the energy running costs. Furthermore, with increase in electricity tariffs as discussed in 1.3.4 will impact upon the future ECI.

Notwithstanding, these results provided an insight on the performance status of office building in Abuja. The typical performance benchmarks so generated will be further analysed in the simulation in the next Chapter.

### 6.4.3. Correlation analyses

This section attempts to determine if energy consumptions in the building surveyed can be attributed to any of the architectural design
variable of the building using Pearson’s correlation analyses. The variables were correlated with total energy and the disaggregated end uses, with particular attention to energy for cooling since it accounts for the highest energy consumed. Results of the correlation are as shown in Table 6-5 below.

For both categories of low-rise buildings, there was no statistically significant correlation between any design variable and the total energy consumption at the 0.05 and 0.01 levels of significance.

However, there was statistically significant correlation between the external wall (wall u-value) and the energy due to cooling at the 0.01 levels of significance. This is quite an important outcome. As we have seen in the literature review, the external wall essentially acts as a medium for climate control, excluding/mediating the transition between external climatic conditions with the internal spaces. In this regard, it suggests that external wall has an impact on the resultant energy consumption for cooling in office buildings.
Similarly, the correlation analyses showed statistically significant correlation between the building form factor (BFF) and the energy due to lighting at the 0.05 levels of significance. Also, this shows the importance of the relationship between the general buildings configuration and arrangements in order to optimise naturally occurring climatic conditions that are beneficial in indoor building climates such as lighting and ventilation. In Chapter 3, for example natural lighting and ventilation optimisation by adapting the building’s shape and openings were provided.

Table 6-6: table showing results of correlation analyses between design variables and energy consumption (high-rise buildings)

<table>
<thead>
<tr>
<th></th>
<th>TOTAL ENERGY</th>
<th>WALL UVALUE</th>
<th>GLAZING UVALUE</th>
<th>GLAZING RATIO</th>
<th>COMP RATIO</th>
<th>BFF</th>
<th>FCH</th>
<th>DOC</th>
<th>TFA</th>
<th>OCCUPANT DENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL ENERGY</strong></td>
<td>Pearson</td>
<td>-0.588*</td>
<td>0.271</td>
<td>0.167</td>
<td>0.171</td>
<td>0.171</td>
<td>0.259</td>
<td>0.319</td>
<td>0.322</td>
<td>0.179</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>Correlation</td>
<td>0.034</td>
<td>0.37</td>
<td>0.586</td>
<td>0.576</td>
<td>0.576</td>
<td>0.393</td>
<td>0.289</td>
<td>0.283</td>
<td>0.558</td>
</tr>
<tr>
<td>N</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td><strong>PEU</strong></td>
<td>0.512</td>
<td>-0.339</td>
<td>-0.091</td>
<td>-0.083</td>
<td>0.058</td>
<td>0.156</td>
<td>0.09</td>
<td>0.214</td>
<td>0.42</td>
<td>-0.055</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>Correlation</td>
<td>0.074</td>
<td>0.257</td>
<td>0.767</td>
<td>0.788</td>
<td>0.85</td>
<td>0.611</td>
<td>0.77</td>
<td>0.482</td>
<td>0.153</td>
</tr>
<tr>
<td>N</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td><strong>LIGHT</strong></td>
<td>-0.635*</td>
<td>0.597*</td>
<td>0.212</td>
<td>-0.363</td>
<td>-0.039</td>
<td>0.191</td>
<td>0.073</td>
<td>0.165</td>
<td>0.438</td>
<td>-0.02</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>Correlation</td>
<td>0.02</td>
<td>0.031</td>
<td>0.487</td>
<td>0.222</td>
<td>0.9</td>
<td>0.531</td>
<td>0.812</td>
<td>0.591</td>
<td>0.135</td>
</tr>
<tr>
<td>N</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td><strong>EQUIP</strong></td>
<td>-0.249</td>
<td>0.227</td>
<td>0.36</td>
<td>-0.09</td>
<td>0.156</td>
<td>0.065</td>
<td>0.043</td>
<td>0.171</td>
<td>0.397</td>
<td>-0.085</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>Correlation</td>
<td>0.412</td>
<td>0.455</td>
<td>0.227</td>
<td>0.769</td>
<td>0.61</td>
<td>0.834</td>
<td>0.89</td>
<td>0.578</td>
<td>0.179</td>
</tr>
<tr>
<td>N</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td><strong>EUI</strong></td>
<td>0.034</td>
<td>-0.237</td>
<td>-0.509</td>
<td><strong>0.588</strong></td>
<td>0.283</td>
<td>0.497</td>
<td>-0.01</td>
<td>0.272</td>
<td>0.221</td>
<td>0.252</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>Correlation</td>
<td>0.912</td>
<td>0.435</td>
<td>0.075</td>
<td>0.035</td>
<td>0.349</td>
<td>0.084</td>
<td>0.974</td>
<td>0.368</td>
<td>0.468</td>
</tr>
<tr>
<td>N</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).**

Conversely, in the high-rise building categories, there was statistically significant correlation between only one building design variable (the wall u-value) and the total energy consumption at the 0.05 levels of significance. This further suggests the influence of the building fabric upon the buildings energy consumption. However, there was no statistically significant correlation between the rest of the design variables with either the total energy consumption or any of the disaggregated energy end uses at the 0.05 and 0.01 levels of significance.
This is in contrast to the research's hypothetical expectations in cognisance with the literature review which suggests that, most, if not all, of the variables will have some level of correlations with the buildings energy consumption. In these analyses, it was expected that variations in their respective levels of significance will be obtained. This would have hinted the level of importance or enabled the deduction of a hierarchical order of importance of the variables impacts on building energy consumption.

In an attempt for comparison and cross validation of the result of statistical evaluation approach, other known correlation tests comprising Kendall Tau’s and Spearman Rho’s methods were used to analyse the same data sets. The results of both methods were in concordance with that of Pearson’s. Furthermore, regression analyses from scatter diagram generated from the fieldwork data as shown in Fig 6-12 was rather in conclusive as it was not possible to draw fit lines of the research hypothesis.

Figure 6-12: Scatter diagram on EUI and design variables of case study office buildings.
This leaves questions on the data sets used in the analyses. This may suggest the presence of subtle errors in the variables since most of them are computed using adopted parametric definitions obtained from literature.

6.5. Limitations
The case study limitations are as follows:

1. In the absence of local regulations, a performance based building typological classification was developed for the research as defined by the researcher. Hence, from the onset, classification was limited to the typologies so formed.

2. Access to some of the buildings of interest was not possible due to security and political sensitivity issues. This affected the sample size that was evaluated.

3. Inadequacy of energy use data was prevalent. This was observed for both primary and secondary energy sources. For primary sources, billed data of up to one year was difficult due to difficulty in obtaining historical energy data. The cost of energy from the secondary source comprises costs of equipment, maintenance and diesel supply. According to Osuagwu, Agbkwuru and Chinedu (2011) diesel costs accounts for 97.3% annually in overall management costs of generator. Therefore, in the research, only diesel supply was considered while cost of equipment and maintenance was ignored.

4. The wide variation of energy end uses, their energy ratings and efficiency of equipment made accurate disaggregation of end use difficult. For example, a building can have many air condition units of different brands and acquired over a long period of time. To contend with these potential errors, a typical end use distribution of one floor was adopted for the whole floors of the building.
6.6. Summary and general findings of statistical analyses

1. Case study involving a total of 22 office buildings, of which 4, 5, 2 and 11 belong to LBLR, HBLR, LBHR and HBHR typologies of office building development in Abuja respectively was conducted. Essentially, that is 9 and 13 were low-rise and high-rise respectively.

2. Both typologies showed similarities in terms of the design variables analysed particularly in terms of the external wall construction and glazing ratio.

3. Buildings in both typologies face the same energy supply challenge where a supply side management remedial approach using diesel generators has been applied.

4. End use energy distribution show energy consumption due to air conditioning to be more significant than that of lighting, equipment and building services, hence identifying the potentials for energy savings by reducing cooling needs.

5. Energy performances using EUI, ECI and CEI indicators for the buildings have been obtained and reported, showing the extant of the office built environment in Abuja. However, further comparative analyses of energy performances were not possible due to limited literature on energy performance of built environment in similar climatic and socio-economic context.

6. Furthermore, only the wall u-value showed statistically significant correlation with buildings energy consumption. However, all of the other architectural design variables evaluated did not exhibit correlations of statistical significance with the buildings total or disaggregated end use energy consumption.
Chapter Seven: evaluation of design variables using computer simulation

7.1. Introduction

This chapter re-evaluates the energy performances of case study buildings using simplified models in a virtual environment. It then evaluates the impact of design variables in achieving low energy buildings using computer simulation. A combination of the best design variables, providing the most comfortable indoor climate whilst reducing energy consumption due to cooling (the highest building energy end use from disaggregated energy consumption obtained in the previous chapter), is determined. The impact of the select design variables on energy consumption is examined across the office building typologies. From these, improved performances are analysed in relation to derived typical energy use benchmarks.

7.2. Computer based simulation

From the case study analyses in Chapter 6, typical performance status of office buildings in Abuja has been derived from fieldwork data. In this section, the building typologies were recreated in a virtual environment to re-evaluate the performances in an attempt to establish typical performance benchmark for the respective building typologies. The EUI was used as the main performance indicator (as discussed in Chapter 3.4). Prior to this, a short software validation exercise is provided to demonstrate and ascertain the software’s capability of abstracting real life scenario in the context of the case study area.

In the next stage of the simulation, the impact of architectural design variables on internal thermal comfort is examined. This is important because it will make little sense to have a desired low energy building that does not meet essential occupational requirement of the user. More so, it has been identified from literature review and further substantiated in the case study fieldwork that cooling requirement is significant and accounts for the highest end use energy consumptions

~ 192 ~
for office buildings in Abuja. Hence, it presents significant potentials for energy savings by reducing the cooling requirements of the building.

The variables examined have been deduced from design recommendation for the tropics as well as general design approaches for low energy building design (previously discussed in Chapter 3.8). The design variables showing best performances were then identified and selected for further evaluation.

The models were then improved upon through simulation iterations to examine the impact of the selected design variables on the buildings energy performance as well as to determine improved performance benchmarks.

### 7.2.1. The simulation tool

In 4.5.2.1, the simulation software used in this study was identified as IES VE. One of the considerations for its selection is the capability of the software to conduct energy load deductions due to numerous factors including heat gains, design alterations etc. Furthermore, the simulation tool contained a module known as Macroflo which deals with bulk air flow movement. The module adopts zonal airflow calculations to estimate bulk air flow movement in and within the building, driven by wind and buoyancy induced pressure. As such air movements and associated temperature responses can be deduced. This was sufficient from an architectural perspective, to analyse infiltration and natural ventilation gains in buildings.

Otherwise, a detailed numerical simulation of fluid flow and heat transfer process used in computational fluid dynamics would have been required. This level of understanding in building physics and engineering is beyond the scope of the researcher and this research.

### 7.2.2. Software validation

Validation of software in numerous verified simulation results are obtainable but none was observed for Nigeria and related tropical climates (Attia, et al., 2009; Hammad & Abu-Hijleh, 2010; Roderick, et
al., 2009) therefore a validation exercise for this research needed to be undertaken. This was carried out in the following ways;

1. Validation of building physics: In the first validation conducted, acclaimed capabilities of the software were tested using known building physics principles of air flow movement. A single room rectangular building box was developed. A single window opening was introduced. Both scenario of with and without window were simulated. A change in the internal room temperature and air flow movement is noticed between the two models. The material appendage of the model was further varied by replacing walls with glass to evaluate its sensitivity to solar heat gain. Simulation results showed responsiveness to solar heat gain. Lastly, an elongated model was developed with two opposing windows, with the point of inlet at the lower level facing the windward direction and the outlet point at a higher level on the opposite side. Results obtained confirmed the effect of buoyancy and air flow within the building.

2. Validation of existing model: This was conducted since there was no literature indicating application or validation of the simulation tool in a tropical Nigerian climate. A real life experiment carried out at Imo State University Owerri in Nigeria was reproduced (Odim, 2008). The experimental research involved the construction of two single room buildings to evaluate the effect of orientation on internal thermal comfort. The building’s dimension is as provided in the diagram below.

*Figure 7-1: Building model used for software validation*
The building construction was made up of sandcrete hollow blocks, zinc roofing sheets on wooden roof trusses and asbestos ceiling. Two opposite windows measuring 1200mm x 1200mm with single pane clear glass are provided on North/South and East/West facades for models M1 and M2 respectively. Mean internal temperature collected for the two rooms over a period of 2 years were 28.27°C and 29.63°C for models M1 and M2 respectively.

The model was reproduced based on the as-built parameters as shown below. The mean internal temperatures obtained for the N/S and E/W orientations were 28.72°C and 28.92°C. These results were closely comparative to the real life observations.

Figure 7-2: Validation model reproduced in software

It should be noted however, that results from the real life experiments were collected for a duration of 24 months while in the simulation the maximum calculation period of 12 months duration was used. This demonstrated the capacity and degree of accuracy of the of the simulation to predict the real life scenario.

3. The software was also subjected to sensitivity analyses to examine its response to iteration inputs that will be conducted. Varying cooling set points were input to determine threshold when
airconditioning can be introduced. The output of the building energy loads were all proportionately different showing positive response to any slight modification in input data.

7.3. Performance of architectural typologies

In this section, energy performance of selected office buildings from each of the typological classification (which included both cellular and open-plan configurations) was undertaken. Simplistic models of each building was regenerated in Google Sketchup and imported to IES-VE as shown in the Table 7-1. In IES-VE, particular attention was made on the input data entry to replicate the building construction properties as obtained in the fieldwork case study. However, certain elements (discussed in 7.3.1.) remained the same throughout the simulation.

Table 7-1: Simplified models of case study office buildings
7.3.1. The simulation constants

Abuja was selected as the site location and the simulation weather files obtained for Abuja, as shown in Fig 7-3, was input into the model and made constant throughout the simulation. Occupancy profile, which is the duration investigated was also made constant. This reflected official working hours of 0800-1700hrs daily from Monday to Friday throughout the year culminating to a total of 2340hrs.

*Figure 7-3: Simulation Weather data showing monthly minimum and maximum temperature distribution for Abuja*

7.3.2. Simulation performance outputs

With the developed models above and having assigned to each building the construction appendages as obtainable in the field work case study, the model were then simulated in IES-VE to determine the energy consumption implications of each building. This was analysed using the EUI as a performance indicator alongside derived fieldwork data. This aided comparative typological analyses of energy consumption of the respective buildings. Table 7-4 shows performance comparison between the fieldwork and simulation results. The sections after the table discussed the simulated performance using the three adopted indicators.
a. Energy Use Index: Table 7-4 shows that actual simulated figures for total energy consumption for most of the buildings were proportionately comparative within reasonable range. For most of the buildings, the simulated values were slightly higher than that of the fieldwork. This may be due to stable and uninterrupted energy flow in the building simulation as against the daily interruption/alteration between generator and mains supply observed in the fieldwork. However, there were outliers mainly in the HBHR category having significantly high values. Notwithstanding, similar high values were equally obtained from the fieldwork. This suggests that the buildings actually do consume energy in such high proportions. Figure 7-5 shows typical simulated EUI for the LBLR, HBLR, LBHR and HBHR categories as 53.5kWh/m²/a, 73.3kWh/m²/a, 48.5kWh/m²/a and 105.8kWh/m²/a respectively.
b. Carbon Emission Index: The values derived for the carbon emission were proportionate to the values of total energy consumption in the buildings. However, the results were not true reflection of the fieldwork results owing to potential inefficient on-site generation using the generators.

Figure 7-6: Simulated Carbon emission performance of office buildings
Figure 7-6 shows typical CEI for the LBLR, HBLR, LBHR and HBHR office building categories as 31,500kgCO₂/kWh, 182,000kgCO₂/kWh, 327,600kgCO₂/kWh and 624,100kgCO₂/kWh respectively.

c. Energy Cost Index: The values derived for the energy costs were mostly less than the fieldwork results. This can be largely due to a stable singular source with a unified tariff across all the buildings. Meanwhile, the higher costs in the fieldwork may not be unconnected to the volatile price of diesels or simply additional cost due to outsourcing from black markets during fuel shortages/scarcity.

Accordingly, typical simulated ECI for the LBLR, HBLR, LBHR and HBHR categories are 1,000NGN/m²/a, 1,400NGN/m²/a, 900NGN/m²/a and 2,000NGN/m²/a respectively as shown in Table 7-7.
7.4. Performance evaluation of independent (architectural variables) input for enhanced building performance

In order to design improved or enhanced performance of the office building categories, this simulation was conducted to determine the impact of the independent architectural design variables on the buildings energy demand. However, it can be recalled that air conditioning load due to cooling demand accounts for more than 50% of energy consumed in the field work as shown in Figure 6.8 and discussed in section 6.3.3. This shows that reduction in cooling demand has a significant potential in reducing building energy consumption.

Hence, the objective of the simulation in this section was to identify design variables with the best thermal performance, and consequently, minimal energy implication to the building but without compromising the occupants essential thermal comfort requirements.

Using the validation model to test the impact of the design variables, a thermal performance indicator was adopted as a measure of building performance at this point. The evaluation of the thermal comfort is based on design degree day methods (see Chapter 3.4). In this method, base-case temperature is identified and the total duration with cooling or heating requirement (to achieve comfort) is calculated (Day, et al., 2003). Due to climatic disposition of Abuja, only cooling degree days CDD are examined because of the prevalent high temperature which negates the demand for heating throughout the working hours as discussed in Chapter 5.3.2.

Also, the Humphery’s adaptive thermal comfort model (see Chapter 3.6.3.2) was chosen because it suits buildings designed based on natural ventilation strategy (Yang, Yan, & Lam, 2014). Though there exists a few variations in the adaptive thermal comfort model, Humphrey’s formula was adopted in this research because result from fieldwork aimed at developing thermal comfort indices for various locations in Nigeria corroborate the adaptive model (Adunola, 2014;
Ogbonna & Harris, 2008). It is also considered that when mean external temperature range between 10°C and 30°C, then adaptive thermal comfort is applicable in the design of naturally ventilated building (Humphreys, Rijal, & Nicol, 2013).

Nicol, Humphery and Roaf (2012) showed that the adaptive thermal comfort temperature can range from +/-2°C to as high as +/-7°C depending on the adaptive options available to the occupants. However, in this research the more conservative temperature range of +/-3°C is applied to enable gradual acclimatisation for the occupants already accustomed to air-conditioned offices. According to this model, adaptive thermal temperature range for Abuja is between 24.0°C and 28.5°C while mean annual comfort temperature is 26.1°C. Therefore impact of design iterations (output) will be aimed at achieving maximum duration of temperature ranges between 22°C and 29°C.

The simulation undertaken for the architectural variables follows the order of the listing above. The best performing parameter obtained is then adopted and carried forward to the next simulation. Each variable contained a minimum of three iterations. This considered occurrence of the variable within local building regulation, obtained from case study survey, design recommendation for tropical climates, or simply contemporary occurrence of interest.

a. Wall construction (Wall U-values)
b. Roof construction (Roof U-values)
c. Type of glazing (Glazing U-values)
d. Ground floor construction (ground construction U-values)
e. Floor to ceiling height (FCH)
f. Orientation
g. Glazing ratio
h. Ventilation strategy
i. Building form (Building forms evaluated are provided in Appendix A01)
### 7.4.1. Wall construction

Wall categories examined in this section are shown in Table 7-2

*Table 7-2: Table showing simulation wall types*

<table>
<thead>
<tr>
<th>Wall 01</th>
<th>General description</th>
<th>Sectional diagram</th>
<th>Wall 05</th>
<th>General description</th>
<th>Sectional diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brick wall, with plastered internal face</td>
<td></td>
<td></td>
<td>block wall with insulation to the external and plastered on both faces</td>
<td></td>
</tr>
<tr>
<td>Wall 02</td>
<td>Block wall with plastered internal face, and tile clad external face</td>
<td></td>
<td>Wall 06</td>
<td>Double wall with insulation in between and plastered on both faces</td>
<td></td>
</tr>
<tr>
<td>Wall 03</td>
<td>block wall with plastered internal face, and aluminium clad external face</td>
<td></td>
<td>Wall 07</td>
<td>Double wall with cavity in between and plastered on both faces</td>
<td></td>
</tr>
<tr>
<td>Wall 04</td>
<td>block wall with insulation to the internal and plastered on both faces</td>
<td></td>
<td>Wall 08</td>
<td>lightweight wall made of wood board to the external and gypsum board to the internal.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig 7.8 show the thermal performance of all the walls types with the thermal comfort durations expressed in percentages of occupied hours. The chart also shows performances during hot months which spans from January – June months and throughout the year. A detail of monthly performance analyses of each wall type is provided in Appendix B.

7.4.2. Roof construction
It was noted that there was no local regulation regarding roof construction in Nigeria. The roof types evaluated are shown in Table 7-3. Also, from the previous simulation, the best performing wall (Wall 04) was adopted for the building envelope while the roof types were altered.
### Table 7-3: Table showing simulation roof types

<table>
<thead>
<tr>
<th>Roof 01</th>
<th>General description</th>
<th>Sectional diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional concrete roof with no insulation (typical practice from survey)</td>
<td></td>
</tr>
<tr>
<td>Roof 02</td>
<td>Externally insulated concrete roof</td>
<td></td>
</tr>
<tr>
<td>Roof 03</td>
<td>Externally and internally insulated concrete roof</td>
<td></td>
</tr>
<tr>
<td>Roof 04</td>
<td>Aluminium sheet roof (typical practice from survey)</td>
<td></td>
</tr>
<tr>
<td>Roof 05</td>
<td>Insulated aluminium sheet roof</td>
<td></td>
</tr>
</tbody>
</table>

~ 205 ~
A description of roof input data in the software and monthly performance is provided in Appendix C. It should be noted however, that the effect of roof is essentially limited to the upper most floor.

### 7.4.3. Type of glazing

Similar to building’s roof, there is no regulation on the use of glass in Nigeria’s building regulation/codes. Thus, examples of what is obtainable within common practice, as observed in the fieldwork, were examined. In carrying out the simulation of this variable, the entire building was clad in glass except for the roof. The roof was made of the best performing roof (Roof 03) from the previous simulation. The glazing types evaluated are tabulated below:
Table 7-4: Table showing type of glazing evaluated in the simulation

<table>
<thead>
<tr>
<th>Simulation code</th>
<th>Description of glazing type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glaze 02 Single pane clear glass</td>
</tr>
<tr>
<td>2</td>
<td>Glaze 02a Single pane reflective glass</td>
</tr>
<tr>
<td>3</td>
<td>Glaze 02c Single pane anodised glass</td>
</tr>
<tr>
<td>4</td>
<td>Glaze 02d Single pane low-e glass</td>
</tr>
<tr>
<td>5</td>
<td>Glaze 01 Double low-e glazing</td>
</tr>
<tr>
<td>6</td>
<td>Glaze 03 Triple low-e glazing</td>
</tr>
</tbody>
</table>

Glaze type 02, 02a and 02c were types obtain from the survey (common practice). Details of monthly performance are provided in Appendix D.

Figure 7-10: Chart showing thermal performance of glazing types
7.4.4. **Ground floor**

The variations evaluated in this study are shown in Table 7-5

*Table 7-5: Table showing different ground floor types evaluated in simulation*

<table>
<thead>
<tr>
<th>Simulation code</th>
<th>Description of ground construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Grndfloor 01</td>
<td>Insulated concrete floor with wood finish</td>
</tr>
<tr>
<td>2 Grndfloor 02</td>
<td>Uninsulated concrete floor with carpet</td>
</tr>
<tr>
<td>3 Grndfloor 02a</td>
<td>Uninsulated concrete floor without carpet</td>
</tr>
<tr>
<td>4 Grndfloor 02b</td>
<td>Concrete floor insulated to ground-no carpet</td>
</tr>
<tr>
<td>5 Grndfloor 02c</td>
<td>Concrete floor insulated to screed-no carpet</td>
</tr>
<tr>
<td>6 Grndfloor 02d</td>
<td>Carpeted concrete floor insulated to ground</td>
</tr>
<tr>
<td>7 Grndfloor 02e</td>
<td>Carpeted concrete floor insulated to screed</td>
</tr>
<tr>
<td>8 Grndfloor 02-raised</td>
<td>Raised/suspended uninsulated concrete floor with carpet</td>
</tr>
<tr>
<td>9 Grndfloor 02a-raised</td>
<td>Raised/suspended uninsulated concrete floor without carpet</td>
</tr>
</tbody>
</table>

Type 2 and 3 (Grndfloor 02 and 02a) were the types obtained from the survey (common practice). The others are custom configurations adopted from common practices elsewhere. The raised floor construction had a clearance of 1m above ground. In this simulation, all the glazing was removed and simulation continued with wall construction (wall 04). Full description of ground construction input data in the software and monthly thermal performance is provided in Appendix E. However, the impacts of ground floor construction are limited to the ground floor.
7.4.5. Floor to ceiling height

The building regulation in Nigeria stipulates a minimum FCH of 2.5m for all habitable spaces. In this simulation, the office space FCH is evaluated by an increment of 500mm until the FCH reached 5m. That is six steps as listed below.

1. FCH 2500mm
2. FCH 3000mm
3. FCH 3500mm
4. FCH 4000mm
5. FCH 4500mm
6. FCH 5000mm
7.4.6. Orientation
In the simulation tests for orientation, the north facing façade was replaced with a fully glazed single pane clear glass. The angle of rotation for the building is then calibrated in 10° increment due west from the North direction (000), ie anticlockwise, until a full circle is completed. Hence, 000, 090, 180 and 270 represent north, west, south and east respectively. Further details of orientation performances are provided in Appendix G.
The simulation further evaluated two opposite facades of the building; that is the north and south facing façade. Same sequence of rotation as above is repeated. The results obtained are as shown below.

*Figure 7-14: Thermal performance of orientation on two opposite glazed facades*
7.4.7. Glazing ratio

Glazing ratio of a single façade facing north and using clear glass was analysed. A glazing ratio of 10% was used as baseline for the simulation with increment of 10% until a full glazed façade was reached on one elevation facing north.

*Figure 7-15: Thermal performance of glazing ratio*

Furthermore, comparative impacts of glazing was evaluated on main orientations of North(000), East(270), West(090) and South(180) for both reflected glass (rg) and clear glass (cg) although reflective glass showed better performance in a fully glazed scenario.

*Figure 7-16: Thermal performance of glazing types*
7.4.8. **Ventilation strategy**

Part of the research analyses is to evaluate how a building can be designed to provide comfortable thermal environment based on natural ventilation strategy in order to reduce the need for air conditioning. Two concepts of natural ventilation are analysed. The first was based on an uncontrolled open window which allows free flow of air at all times. The second was based on a window opening control profile.

In both cases, a window opening of 10% glazing ratio was adopted based on glazing performance of same size as evaluated earlier. The window façade was examined on key orientations starting from North and then calibrated to 45° increment due west until a full circle is completed.

The second ventilation strategy was based on a controlled window opening profile. The window opening algorithm is designed such that windows are opened when the room temperature exceeds the upper thermal comfort threshold provided that external air temperatures are lower than room air temperature (see Appendix F for simulation data input). This is based on assumption that occupants play active roles in controlling their thermal environment in an adaptive thermal comfort model. The results obtained are shown below.
Figure 7-17: Thermal performance of open window ventilation strategy

Figure 7-18: Thermal performance of profile window ventilation strategy
Furthermore, a two sided profile window to facilitate cross-ventilation was also analysed. The results obtained are shown below.

*Figure 7-19: Thermal performance of two side profile window*

7.4.9. **Building form**
Different building forms with same floor area were developed and analysed. Results showed no marked distinction in the thermal performances of the forms analysed. However, the results confirm that buildings with narrow plans show better performance as advocated for tropical climates (Givoni, 1994b).

7.4.10. **Selected design variables**
From the above thermal performance simulation the architectural variables showing the best performances were selected and applied in the next simulation phase. These include:

a. wall04,
b. roof 03
c. Glaze 02a
d. groundfloor 02
e. Orientation (020°)
f. Ventilation strategy (profile window modulation)

The FCH and building form of the case study buildings were maintained because they showed very negligible impact on the simulations carried out above. Also the glazing ratios of the buildings were maintained as obtained in the fieldwork to determine their typical performance scenario.

7.5. Enhanced performance of architectural typologies

In this section, the case study buildings were further analysed within the IES-VE simulation to examine the impact of adapting appropriate design strategies on the buildings energy consumption. This aimed at reducing the building’s total energy consumption mainly through reduction in cooling loads; the highest building energy end use.

The case study generic building construction input data was substituted with the design components that showed the best performance (see 7.4.10).

Table 7-6 shows the comparative energy performances between the field work data, simulated data and the improved performances after adoption of the selected design variables.

Table 7-6 Comparative energy performance of building typologies

<table>
<thead>
<tr>
<th></th>
<th>LBLR</th>
<th>HBLR</th>
<th>LBHR</th>
<th>HBLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA/B</td>
<td>A02</td>
<td>B13</td>
<td>A01</td>
<td>A07</td>
</tr>
<tr>
<td>TOTAL</td>
<td>FIELD</td>
<td>21,000</td>
<td>18,000</td>
<td>303,000</td>
</tr>
<tr>
<td></td>
<td>SIMUL</td>
<td>33,000</td>
<td>21,000</td>
<td>366,000</td>
</tr>
<tr>
<td></td>
<td>IMPROV</td>
<td>27,746</td>
<td>19,653</td>
<td>310,769</td>
</tr>
<tr>
<td>EUI</td>
<td>FIELD</td>
<td>38.3</td>
<td>39.0</td>
<td>49.5</td>
</tr>
<tr>
<td></td>
<td>SIMUL</td>
<td>61.4</td>
<td>45.6</td>
<td>59.8</td>
</tr>
<tr>
<td></td>
<td>IMPROV</td>
<td>51.4</td>
<td>42.5</td>
<td>50.8</td>
</tr>
<tr>
<td>% IMPROV</td>
<td>16.3</td>
<td>6.7</td>
<td>15.1</td>
<td>22.7</td>
</tr>
<tr>
<td>CEI</td>
<td>FIELD</td>
<td>3,400</td>
<td>2,900</td>
<td>91,800</td>
</tr>
<tr>
<td></td>
<td>SIMUL</td>
<td>30,600</td>
<td>32,400</td>
<td>338,000</td>
</tr>
<tr>
<td></td>
<td>IMPROV</td>
<td>25,638</td>
<td>30,265</td>
<td>288,378</td>
</tr>
<tr>
<td>ECI</td>
<td>FIELD</td>
<td>3,640</td>
<td>1,210</td>
<td>980</td>
</tr>
<tr>
<td></td>
<td>SIMUL</td>
<td>1,170</td>
<td>870</td>
<td>1,140</td>
</tr>
<tr>
<td></td>
<td>IMPROV</td>
<td>976</td>
<td>809</td>
<td>965</td>
</tr>
</tbody>
</table>

Despite the difficulty in relating actual measured result and simulated results, it will be noted that EUI simulation results concur within reasonable ranges relative to the actual fieldwork. Perhaps, this buttresses the validation of the simulation. Although it can be noticed...
that simulation results of improved building performances are generally lower than most of the field work, the results show improved performance in all of the typical/baseline simulation.

Also in the table, the percentage improvement (energy reduction) obtained for each of the building in the simulation conducted are highlighted. In the discussions below, a summary of the performances of the categories is given below. Also, deduced reasons for variations in percentage EUI improvement in the case study buildings are discussed to provide an understanding of the impacts of design variables on the building energy consumption.

7.6. Discussions and results on energy performances of design variables and architectural building typologies

7.6.1. Performance of building typologies
The performance of four office building categories in Abuja was evaluated simulation and summary of their performances using the three adopted indicators are given in Table 7-7.

Table 7-7: Summary of performances for office building categories.

<table>
<thead>
<tr>
<th></th>
<th>LBLR</th>
<th>HBLR</th>
<th>LBHR</th>
<th>HBR</th>
<th>LBLR</th>
<th>HBLR</th>
<th>LBHR</th>
<th>HBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELDWORK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EUI</td>
<td>90.0</td>
<td>34,000</td>
<td>2,710</td>
<td>43.7</td>
<td>50,800</td>
<td>2,190</td>
<td>57.6</td>
<td>112,000</td>
</tr>
<tr>
<td>CEI</td>
<td>32,000</td>
<td>1,020</td>
<td>73.3</td>
<td>182,000</td>
<td>1,400</td>
<td>48.5</td>
<td>328,000</td>
<td>900</td>
</tr>
<tr>
<td>ECI</td>
<td>141,000</td>
<td>900</td>
<td>56.7</td>
<td>283,000</td>
<td>800</td>
<td>41.9</td>
<td>504,000</td>
<td>1,780</td>
</tr>
</tbody>
</table>

7.6.1.1. Low Budget Low Rise (LBLR)
This category showed that typical EUI from the fieldwork was higher than the simulated results as shown in Table 7-7. This may be due to inefficient energy misuse or other occupant factors. Nonetheless, with the implementation of low energy design strategy, a performance improvement of up to 16% was obtained.

However, CEI results were relatively comparative between the field work and the simulation. This may be because buildings in this category had the least application of on-site generation from generators (see Fig 6-6). The ECI also indicates a very significant potential for energy cost savings.
7.6.1.2. High Budget Low Rise (HBLR)
This category showed that typical EUI from the fieldwork was lower than the simulated results as shown in Table 7-7. Unlike, the LBHR category, the HBLR category was significantly dependent on onsite generation to supplement energy shortage. Perhaps, time loses due to this interruptions may account for lower EUI. Nonetheless, with the implementation of low energy design strategy, a performance improvement of up to 22.6% was obtained; the highest across the categories.

However, CEI from the field work results were significantly lower than the simulated results despite high level of application of onsite generation. Also, the ECI also indicates a significant potential for energy cost reductions.

7.6.1.3. Low Budget High Rise (LBHR)
This category showed that typical EUI between the fieldwork and the simulated results was within reasonable comparative range as shown in Table 7-7. With the implementation of low energy design strategy, a performance improvement of up to 13.6% was obtained.

However, CEI results were significantly lower than the simulated results despite much reliance on onsite generation. Also, the ECI also indicates a significant potential for energy cost reductions.

7.6.1.4. High Budget High Rise (HBHR)
This category showed that typical EUI between the fieldwork and the simulated results was within reasonable comparative range similar to the LBHR. With the implementation of low energy design strategy, a performance improvement of up to 11.6% was obtained; the lowest impact across the categories.

However, CEI results were significantly lower than the simulated results despite extensive application of onsite generation, the highest across all the categories. Also, the ECI also indicates a significant potential for energy cost reductions.
Although, a reduction in energy consumption of all the building categories was observed as a result of improved design (enabled by the adoption of selected design variables), Fig 7-20 presents a peak day energy consumption obtained in the typical simulated performances scenario within the occupied periods across the building categories in order to enable relative comparison of their energy consumption patterns.

*Figure 7-20: Typical peak day energy consumption of office building categories*

Also Fig 7-21 shows comparative peak day energy consumption obtained between the typical simulated performances and improved design scenario within the occupied periods in B13, A07, B02 and B08 being representative of the LBLR, HBLR, LBHR and HBHR building categories.
The section below provides an understanding of the impact of the design variables on the building energy consumption in making sense of the variation in percentage/level of improvement observed across the building categories.

### 7.6.2. Independent architectural design variables

#### 7.6.2.1. The external wall construction

In the eight walls analysed, wall04 which had embedded insulation to the internal face of the wall showed best performance. This demonstrates that insulated walls perform better than common local practice of cavity walls. Although, the use of insulated buildings is beginning to attract advocacy in some parts of Nigeria (Adebamowo, et al., 2013) it has not attracted wide application as observed from the case study. Nonetheless, simulation results confirm that wall04 has better performance than current local practice and concrete wall (thermal mass). This suggests better performance in reducing conductive heat gain, thus a better implication on the building energy consumption.
Fig 7-22 shows the impact of wall04 on building conductive energy gains. The wall has the highest impact on the HBHR building. Also it had similar impacts on the HBLR and LBHR, while it had limited impact on the LBHR buildings. Understandably, the HBHR had the highest total external wall area coverage and its base-case wall (granite cladding to both its internal and external faces) harboured a thermal mass effect, hence resulting in higher conductive heat gain. The HBLR and LBHR were largely the same while the LBLR had the minimum wall area coverage.

However, the higher cost implication of Wall04 may be a hindrance to its wide application. The energy cost reduction as shown in Table 7-7 indicates approximately 70% savings when wall04 is used. This can be
used to supplement any increase in construction cost while effectively reducing energy costs over the building life cycle.

Furthermore (though outside the scope of this study), it is important to note that the insulated walls are likely to have more energy implications over the course of a life cycle (LCA) when embodied energy is taken into account.

7.6.2.2. The roof construction
Five roof types have been evaluated and generally, the results show that the flat roofs performed better than the pitched or aluminium roofs. In particular, Roof03 showed the best performance and Fig 7-23 shows its impact on the energy consumption of the building categories. The impact of this is more significant on the HBLR and LBHR buildings that had pitch/aluminium roofs. But in the LBLR, whose base case building had an uninsulated flat roof and having the lowest roof coverage area, the impact was not very significant. All these corroborate the results obtained in the thermal performance analyses of the different roof types. More importantly, this indicates potentials for energy performance improvement since the roof is the building element that is completely exposed to solar heat gain.
However, estimated cost of the improvements from conventional uninsulated concrete roof to the insulated concrete roof, increased the roof cost from approximately NGN23,000/m² to NGN31,000/m²; and for the aluminium roof it was NGN4,500/m² to NGN12,000/m². This accentuates the potential impediments which cost implication constitutes towards low energy building design. But, perhaps the average 35% energy cost savings from this improvement may also serve as an incentive to pursue its wider application.

### 7.6.2.3. The type of glazing

Six independent glazing types have been evaluated. Results show that among the current common practice glazing types, reflective glazing had the highest performance. The multiple glazing types performed lower than the single glazing types. However, Fig 7-24 shows that the
difference in performance between the glazing types was quite minimal particularly in buildings with high glazing ratios.

Figure 7-24: Impact of glazing type on energy gain of office building categories

<table>
<thead>
<tr>
<th>LBLR</th>
<th>HBLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>B13</td>
<td>A07</td>
</tr>
</tbody>
</table>

7.6.2.4. Ground construction
Nine types of ground floor construction have been evaluated. In Fig 7-25, shows limited, but similar pattern of impact of the selected ground floor type across all the building categories. Nonetheless, current local practices of ground floor construction show best performance.
**Figure 7-25: Impact of ground floor type on energy gain of office building categories**

<table>
<thead>
<tr>
<th>LBLR</th>
<th>HBLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>B13</td>
<td>A07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LBHR</th>
<th>HBHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>B09</td>
<td>B08</td>
</tr>
</tbody>
</table>

### 7.6.2.5. Floor to ceiling height

Six levels of FCH were examined and the results in the thermal performance evaluation showed a maximum improvement of 1.4% between the best and worst FCH. Therefore, evaluating its impact on the buildings energy consumption was ignored. It is also acknowledged that pursuing any FCH improvement in building will most likely be ignored due to its negligible impact particularly when the cost implication of the improvement is considered.

### 7.6.2.6. Building orientation

108 iterations of building façade orientation were evaluated deducing optimum angles for building façade orientations. Main axis of building orientations up to 30° due west from North show best performances.
while up to 20° due east from North showed best thermal performances. The result corroborates recommended orientation for tropical climates.

With varying orientation disposition of the case study buildings, up to 20% of energy savings was observed with improved orientation. It must be noted however, that the impact of orientation is further influenced by the glazing ratio as discussed in 7.4.7.

7.6.2.7. *Glazing ratio*

Using clear glass on one building façade facing North orientation, ten glazing ratios from 0 to 100% with 10% increments were evaluated. The results showed a steep decline in performance as glazing ratio is increased. For example, performance declined from 80.8% with a 10% glazed façade to 22% with a 100% glazing. Furthermore, the impact of the glazing ratio is dependent upon the façade orientation on which the glazing is located as well as the distribution of the glazing on the facades.

Generally, the results show that the more the glazing ratio the lower the performance, though an improvement of up to 5% is obtainable with the correct type of glazing. However, the impact of glazing type reduces with increase in glazing ratio.

It should be noted that in the energy impact simulation analyses, the buildings were evaluated with their respective glazing ratios as obtainable from the field work. The results showed that buildings with higher glazing ratios recorded lower performance improvements as earlier shown in Table 7-6. A further cross examination where windows sizes of an improved building design (B13) was reduced by 50%, the building energy performance increased where a proportionate reduction of almost 50% in the building solar energy gain was observed as shown in Fig 7-26.
This poses concerns on the energy performance prospects of the proposed office building projects (discussed in Chapter 5.7.2.3) that are in favour of fully glazed façades. Based on this result, there is no doubt about the negative energy implications these proposed developments will pose. Therefore, an understanding of the implication of glazing ratio is important to enable appropriate low energy design of buildings.

### 7.6.2.8. Ventilation strategy

In a naturally ventilated building, three ventilation strategies were evaluated. These included a simple open window, always closed window and a profile window (open and close on demand). Though the ventilation strategy is positively influenced by orientation, profile window strategy showed the best performance and most suitable for effective natural ventilation strategy. This also demonstrates the importance of simple open and close technology in enhancing energy saving potentials and occupant impacts on the buildings energy demand mitigation. It was also determined that ventilation strategy showed best performance along the 30° of building main orientation axis. This concurs with the Abuja wind directions discussed in Chapter 5.
### 7.6.2.9. Building form

Building form was ignored in the simulation as results of generic building forms showed limited performance impacts. All buildings were therefore examined within the contexts of their existing building forms as obtained from the fieldwork.

### 7.7. Architectural design variables and improved performance benchmarks for low energy office buildings.

From further evaluation of the results obtained above, a hierarchy of importance of the variables in facilitating low energy building design was deduced. The results are presented in Fig 7-27 below.

*Figure 7-27: Impact of design variables on energy consumption (low energy) building design in Abuja*

![Diagram showing the impact of design variables on energy consumption](image)

Although the statistical analyses conducted did not show much statistically significant correlation, the computer based simulation evaluation has shown that most of the variables have some level of impacts on buildings energy consumption. In this case, the combination of building orientation and glazing has the highest impacts on office building’s energy demand in the tropical climates of Abuja. Although
this may not be absolute to other building typologies and contexts, it is reflective of the occurrence across all the typologies evaluated in this research context.

Furthermore, improved performance benchmarks are presented below.

a. Energy Use Index: Figure 7-28 shows improved simulated EUI for the LBLR, HBLR, LBHR and HBHR categories as 47.0kWh/m²/a, 56.7kWh/m²/a, 41.9kWh/m²/a and 93.2kWh/m²/a respectively.

*Figure 7-28: Improved EUI of office building categories*

Also, Fig 7-29 shows the comparative levels between the typical and improved simulated EUI for the office building categories.
b. Carbon Emission Index: Figure 7-30 shows improved simulated CEI for the LBLR, HBLR, LBHR and HBHR categories as 28,000kgCO₂/kWh, 141,000kgCO₂/kWh, 283,000kgCO₂/kWh and 504,000kgCO₂/kWh respectively.
Also, Fig 7-31 shows the comparative levels between the typical and improved simulated CEI for the office building categories.

*Figure 7-31: Comparison between typical and improved simulated CEI of office building categories*

<table>
<thead>
<tr>
<th>Office building categories</th>
<th>CEI Improved</th>
<th>CEI Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBLR</td>
<td>283,000</td>
<td>504,000</td>
</tr>
<tr>
<td>LBHR</td>
<td>141,000</td>
<td>328,000</td>
</tr>
<tr>
<td>HBLR</td>
<td>28,000</td>
<td>182,000</td>
</tr>
<tr>
<td>LBLR</td>
<td>32,000</td>
<td>624,000</td>
</tr>
</tbody>
</table>

**c. Energy Cost Index:** Figure 7-32 shows improved simulated CEI for the LBLR, HBLR, LBHR and HBHR categories as 890NGN/m²/a, 1,080NGN/m²/a, 800NGN/m²/a and 1,780NGN/m²/a respectively.

*Figure 7-32: Improved ECI of office building categories*
Figure 7-33: Comparison between typical and improved simulated ECI of office building categories

Also, Fig 7-33 shows the comparative levels between the typical and improved simulated ECI for the office building categories. It is easily observed that there is significant energy cost savings in the improved design owing to the buildings reduced energy demand. Perhaps the impact of the energy cost savings will be more pronounced and appreciated when the building energy costs is examined in a long term scenario. However, application of energy cost benchmark will be limited to prevailing energy tariff obtainable during the evaluation.

7.8. Limitation
The limitations are as follows:

1. Most simulation packages do not have adequate data for developing countries particularly weather files. Weather files are integral to virtual simulation of real world environments. Hence necessitating the use of weather files obtained from NIMET for the study location. However, the capacity for weather files to capture real time developments and challenges of climate change which suggests an ever changing climatic scenario can be challenged (Kim and Chung, 2011). Although most weather files do not fully address future
climate occurrence, it is assumed the principle of developing the TMY makes it a more equipped weather file for simulation analyses (Levermore and Parkinson, 2006; Jiang, 2010).

2. The simulation also ignores the effect of micro climates particularly urban heat island effects due to the contextual setting of the buildings, which are all stand alone and independent buildings.

3. The air flow computation in the model was limited to Macroflo module of the simulation engine which provides average internal air temperature without stratification of potential vertical differences.

4. Case study performance analyses were limited to the data obtained from the field work.

7.9. Summary

The chapter presented the computer simulation conducted to evaluate the impact of design variables on buildings energy demand. IES-VE software was validated and adopted as the simulation tool. The chapter provided methodological details of the simulation in which nine design variables, involving over 400 iterations were evaluated to determine the appropriate low energy building design. Three major indicators (EUI, CEI and ECI) were adopted to evaluate and derive simulated typical and improved building performances benchmarks for all the office building categories. Consequent impact of design strategies on the buildings energy consumption was evaluated across the categories was also deduced.

The next chapter evaluates outcomes of the case study, simulation and the literature review to establish synergies or otherwise.
8. Chapter Eight: Professional reflections

8.1. Introduction
This chapter draws lessons across the thesis development on how purposeful design decisions can be coordinated to develop low energy and sustainable office buildings in Abuja without compromising other desired modern, aesthetic, occupant requirements.

8.2. Research linkages and works of excellence
In the wake of globalisation, tall buildings and skyscrapers have become important elements for cultural signification. Thus, it is important to acknowledge that office building is the most visible tangible index for economic activity, of social, technological and financial progress the world over (van Meel, 2000) and particularly in developing countries as exemplified by Abuja in Chapter 5. However, the literature review showed that consequences of such building developments are often climatically incompatible, poor thermal performance and very importantly demand high energy inputs for their effective operations.

It is therefore paramount that architects devise means to design buildings that are compatible with global sustainable environments while still fulfilling their socio-economic role. Although there is no globally applicable template, the research narrative shows that this is achievable as cited. Drawing from the lessons learnt from the research narrative, an attempt to demonstrate how this can achieved in the context of the research area will be discussed in the headings below.

8.2.1. Building regulations
The enactment of building regulations, largely, have become drivers or tools that buttresses the pursuit for sustainable, low energy or green buildings as may be referred. Most of these are clearly evident within the developed world contexts but limited in most developing countries. Notwithstanding, in places where such building regulations are entrenched, buildings compete for the highest environmental recognition. Hence compliance certifications and awards are now common place for various types of performances and innovations. This

~ 234 ~
is envisaged to propagate the development of a global sustainable environment.

However, in Nigeria, as the literature review showed, there is no evidence of any building regulations that is compatible with any global sustainable environmental goal. Consequently, this has allowed the development of buildings with unchecked/unguided energy consumption and other environmental implications.

Conversely, all the case study buildings demonstrated compliance in terms of what the local building regulations contained. For example, guidance on setbacks, floor to ceiling height, type of wall construction, minimum size of window openings and provision of lift services were all adhered to in the buildings. This demonstrates that if regulation on buildings energy use components constituted part of the regulation, there is the potential that it will be complied to as well.

Nonetheless, this research provides a starting point that can be further developed to establish localised performance benchmarks and targets despite the limited number of case studies and paucity of building energy use data. Notwithstanding, the case studies provided an insight in terms of building design typologies obtainable in the capital city as well as the scenario of their energy performances. Energy performance of the buildings was evaluated from the case study fieldwork data and using computer based simulation. From this exercise, the typical energy performances of the building categories were derived. This approach is not only widely used, but was also applied in the development of Menara Mesiniaga, the first project that has successfully incorporated into a multi-storey building, most of the known theories in bioclimatic architecture within the context of a tropical climate (see Chapter 3.7.2).

Within this method, the impact of various design variables on the buildings energy was evaluated in order to determine appropriate design improvements involving low energy design principles and other design recommendations applied on the remodelled case study buildings within the virtual environment. The results showed that a reduction in
the buildings energy consumption of up to 20% as achievable which is quite a significant reduction bearing in mind that in global exemplar low energy building such as the Commerz Bank building, an energy reduction of 30% was achieved as cited in Chapter 3.

Furthermore, the simulation tool was able to show the level carbon emissions generated from the building. Although building’s carbon emission has not attracted much attention as building energy use in Nigeria (Emodi and Yusuf, 2015), the results show that the office buildings do account for a significant amount of carbon emissions contribution into the atmosphere.

Hence, to complement the development of a sustainable built environment for the benefit of a wider global interconnection, it becomes paramount that Nigeria pursues similar regulatory compliance in office buildings, particularly owing to its own peculiar energy predicaments as presented in Chapter 5.

8.2.2. Conscious low energy building design

From the research narrative, it is evident how essential it has become for architects to understand the implication of their design decisions on energy demands while also fulfilling the challenge of developing buildings that not only meet the aspiration of contemporary times but also ensure development of sustainable environment. This means that the architect’s creative liberties are not infringed upon, but they are expected to include environmentally responsive judgements within their overall design considerations. This appears easy to bring together particularly where building regulations are obtainable to provide guidance and other required environmental deliverables.

Furthermore, exemplar works of architecture have been discussed in Chapter 3 where appropriate design strategies have been applied to achieve buildings with low energy implications, without compromise to any attached socio economic role. The resultant building developments were borne either due to its designer’s awareness of sustainable
environmental demands or in compliance to local building energy use and environmental regulations. Most of these exemplars were deliberate extracts of tropical climates elsewhere which demonstrate that such achievements can equally be replicated in the tropical climates of Abuja and Nigeria at large. However, the success of any energy conscious design lies in a collaborative synergy between the understanding of the climate and appropriate design strategy.

However, their intertwined nature necessitates their discussions in tandem. In terms of design, the variables are numerous (though this research focused on nine important ones as obtained from literature review in Chapter 3), in which the deployment of any design strategy has to satisfy the buildings intent. In terms of climate, the sun (its movement, solar radiation, altitude etc.) and wind direction can be said to be the most influential in tropical locations. This is so because the sun is responsible for high temperatures and heat gain while the wind can be harnessed for occupants comfort. This is well demonstrated in Solaris building (discussed in 3.7.1.) where the design showed the application of louver windows in the windward directions. This played an important role in regulating percentage of operable area and allowing significant reduction in terms of energy that would otherwise have been expended on air conditioning. Significantly too, the design made critical consideration where shading in a largely East-West solar axis was applied.

At this point it will be useful to point out that from the case studies carried out in this research, most of the buildings where not placed along recommended orientation axis for tropical climates. Meanwhile, in the results of the simulation, an increase in performance was observed when the main axis of the building orientation was placed such that the window openings were exposed towards range of NE/SW orientation. This result corroborates the climate information as contained in the wind directions of the wind rose chart for Abuja (Pic 5-4, Chapter 5.3.2). This also shows the importance of articulated synergy between
appropriate design and climatic understanding in the development of low energy and sustainable buildings.

Also notable was the sparse application of shading devices despite the high solar radiation. Consequently, this potentially exposes the buildings to high levels of solar heat gains. Perhaps the disregard for this contributes to poor energy performance of some of the buildings.

Furthermore, in terms of glazing, type of glazing was generally limited to what was readily available in the market as demonstrated in the case studies. However, the simulation showed approximately 7% improvement in performance when single pane clear glass was replaced by single pane reflective glass. More so, the simulation results also showed steep decline in building performance when glazing ratio was increased. In the case study models simulation, the buildings with high glazing ratio showed low rates of improvement (3-7%) on energy performances when other design variables construction were improved upon. This also reaffirms that glazing ratio has a significant impact on the energy performance of buildings.

Although the desire of glazing in modern architecture of Nigeria can be understood, at this point it is important to recall the work on Commerz bank, the world’s first ecologically sustainable high rise office building (discussed in 3.7.3).

From that project, at least two lessons can be learnt and corroborated in the research findings herewith. The first is on the type of glazing. The architects ensured the appropriate type of glazing was obtained resulting to a laminated clear glass that excludes solar radiation and heat, admittance of optimal daylight and unhindered view to the outside. The second is on ventilation strategy. The building was designed with capability of operable windows for inhabitants to control their micro climate even at such an elevation. The combination of this
largely un-orthodox approach of designer-manufacturer synergy and the ventilation strategy has enabled the development of a building that consumes 30% less energy compared to similar buildings (Wood & Salib, 2013).

In addition to the above, the simulation results also explored other design strategies often recommended for tropical climate such as thermal mass. Although the use of thermal mass as a design strategy is not new in Nigeria, its use has been gradually discarded in favour of modern materials particularly where modern urban buildings are involved (Osasona and Hyland 2008, Ogunsoye 2010). Notwithstanding, the simulation evaluated the performance of thermal mass made of concrete walls. The results showed a decline in performance by 13% in comparison to an insulated wall. Further analyses showed that within the building climatic context, conductive heat gain of the building was almost five times greater than radiant solar heat gain in the thermal mass building. However, in using the insulated wall type (Wall 04), the ratio between the conductive and radiant heat gain reduced to 3:1. This suggests that insulated walls is more effective in reducing building cooling load and performs better than thermal mass in the climatic context of Abuja. In fact other earlier works have demonstrated poor thermal performance of numerous modern construction materials in Nigeria including concrete base thermal mass wall construction (Aradeon 1984).

Similarly, the same applies in terms of flat concrete roof constructions. However, the main difference is that roof has more effect in low rise buildings or limited to upper floors carrying the roof. In terms of the roof, a minimum of 10% performance improvement was recorded when insulation is introduced. Even the conventional aluminium roof showed better performance with the introduction of insulation. Also, in the Solaris and Menara Mesiniaga buildings discussed in Chapter 3, roof gardens were applied to aid further insulation.
On the whole, it is clear that application of the appropriate design strategy can enable the reduction of buildings energy consumption. With the understanding of how these design variables impact upon the building energy demand; architects can make informed decisions as they develop their various design schemes. Also, design improvements due to appropriate application of some of these strategies have resulted to appreciable energy use improvements across the building categories. These can easily be energy performance targets for architects in office building designs.

Hence, the benchmarks proposed in Fig8-3 below are provided to formulate such performance targets. This was derived by reducing the improved performance levels by a factor of 15%. This is considered conservative in relation to the 30% improvements obtained in the exemplar buildings discussed earlier. Furthermore, a performance factor of more than 10% has been generally achieved in the improved simulation for all the building categories. Also, it is considered that such levels should be tolerable and acceptable in a society where issues on sustainability attracts limited attention due to various other pressing socio-economic impediments.

*Figure 8-1: Proposed performance benchmarks for office buildings in Abuja*
Although the benchmark values may seem conservative, it is indeed representative of the building typology performances derived from the fieldwork and simulation. More so, the gradual calibration conforms to what is applicable in best practices. This is quite useful in the achievement of a sustainable built environment in Nigeria and its wider global interconnections.

8.2.3. Occupants’ load factor

Although it is acknowledged that the architect has limited control over climate and occupants (discussed in 3.6), occupants are still considered here as an integral part of any sustainable design strategy. In the discussions provided, it was noted that buildings actually do not consume energy; and that it is essentially occupants that consume energy in their search for a desired indoor quality. Whenever the building design fails to achieve or deliver these indoor qualities (which are largely visual and thermal comfort requirements) occupants seek redress through means that are energy dependent.

For example, in the exemplar buildings discussed in 3.7, it was demonstrated how louvers and operable windows were used to regulate indoor thermal comfort such that energy required for air conditioning is significantly reduced. Similarly, in the simulation conducted, it was shown that a thermally comfortable duration of over 60% can be achieved in a window profile strategy where occupants can open or close the window as dictated by their thermal preferences.

Essentially, this simplistic participatory approach is required to enable any designed energy saving potential of the building. Other participatory approaches include the occupants’ moderation of their personal/individual clothing to suit their thermal comfort requirements and switching off equipment when not required.

Hence, a buildings low/efficient energy design can be compromised by occupants’ misuse. However, awareness programmes are often
encouraged to enable occupants’ participation to achieve reduction in buildings energy demand. It is recommended that this should be conducted periodically due to the transient nature of occupants as well as to serve as a constant reminder. This type of awareness programmes will equally be required in Abuja and Nigeria as a whole in order to have an effective sustainable low energy design strategy that is all encompassing.

8.3. Summary
The Chapter discussed how low energy office buildings can be achieved in Abuja and Nigeria as whole. In the discussions provided, it draws lessons derived from the literature review, fieldwork, simulation and exemplar tropical design recommendations. It also presents useful building performance information of the case study buildings establishing what is obtainable in typical local practice while also proposing improved benchmarks both in terms of energy and carbon emissions.

The next Chapter presents the research conclusions and recommendations.
9. Chapter Nine: Conclusions

9.1. Introduction
This chapter provides recommendations and conclusions for the entire research work. It highlights the issues the research attempted to address, providing a general discussion on the research findings and conclusions therefrom. The chapter further discussed new contributions the research has made to the existing body of knowledge while exploring potential application of the research findings in the real world. The chapter also provided recommendations and further research opportunities.

9.2. General discussions, findings and conclusions
In recognition of developments on global sustainable environment agenda, this study investigated the impact of architectural design on the energy consumption of office buildings in order to appraise appropriate energy efficient design approach in the context of a demand side management solution to the endemic energy supply challenges in Nigeria. Hence, the aim of the research is to evaluate the importance and impacts of design in achieving low and energy efficient office building. This is directed towards informing regulatory frameworks for energy use in buildings and the development of a sustainable built environment in Nigeria.

The research set out five objectives to achieve its aims and the discussions set forth below are presented with these objectives in mind.

1. Discourse on sustainable development is now a global phenomenon in which the need to reduce buildings energy consumption due to associated environmental impacts, have become focus (Perez-Lombard, et al., 2008). Researchers have supported the need to rationalise energy consumption in buildings through a wide array of mediums including government regulations, as well as other voluntary and involuntary approaches (Persily and Emmerich, 2012; Bull, Chang and Flemming, 2012). Much of this research project has
concentrated on the buildings occupancy/operational phase, which accounts for the highest proportion of energy consumed by buildings. But owing to complexities and wide spectrum of the constituents of the built environment, in addition to climatic and occupant factors, it has not been possible to apply a globally generic regulatory template. Therefore, measures have been developed and applied at various regional, national and local levels.

However, for a consistent and coherent global outcome, certain aspects contained in the methods have been standardised. For example, energy performance indicators such as energy use index (EUI), carbon emission index (CEI) and energy cost index (ECI), adopted in this research, have been applied globally to assess performance and sustainability targets in buildings despite the multiplicity in available methods and approaches.

Driven by such targets towards a sustainable built environment, the global direction in building design is shifting towards a demand-led paradigm in which reduction in building energy consumption being expected. A further review of factors affecting energy demand in buildings revealed three influential factors to account for, namely climate, architectural design and occupants (Roaf, Horsley, & Gupta, 2004). But to a great extent, the architect has limited control over climate and occupants. Therefore architects have freedom to deploy their creativity in manipulating certain architectural design variables to achieve low energy building design. These included building orientations, building form, building envelope and shading devices, which were identified from the literature and have formed the basis of evaluation of building design in this research.

Nonetheless, an understanding of both climatic and occupants disposition is required such that the architect’s design can be
developed in symbiotic relationship with these factors in order to deliver low energy buildings.

Notwithstanding, the onus of building design remains that of the architects and therefore, should be required to have a comprehensive understanding of the interactions between the buildings they design, the consequential energy implications and impacts on the environment. The design of exemplary buildings where balance between achieving these targets, current aspiration of modernity and higher standards of living have been acknowledged.

2. The literature reviewed showed that these developments and design methods exists only amongst developed countries in comparison with their developing counterparts (Iwaro & Mwasha, 2010; Janda, 2009). This positioning is gradually attracting concerns; not because of the imbalanced divisions, but also due to an increase in urbanisation and building construction activities amidst limited or poor energy supply infrastructure (du Plessis, 2005; Ebohon & Rwelamila, 2001).

The study examined office buildings in Abuja which typifies many developing countries particularly in sub-Saharan African (in the contexts of urbanisation growth rates, construction activities and energy infrastructure) in order to ascertain whether the local considerations on building development is complementary or contradictory to current global building response towards sustainable built environment. Hence, the study underscored the prevailing aspirations in office building design and development, local building regulations regarding building energy use and practices to combat prevailing energy supply shortages.

The study confirmed rapid growth rates of urbanisation, construction activities and unstable energy infrastructure in Abuja. It highlighted the predominance of current office building
development towards a modernist and post-modernist architectural style (Qurix, 2007). Largely, these buildings have been developed with limited climatic, social and cultural considerations. Hence they come with attendant challenges of poor performance. This necessitates the need for cooling and resultant increase in buildings energy demand in a place characterised by unreliable and unstable energy infrastructure (Imaah, 2004b; Oseni, 2011). This also confirmed the disconnection between architects in the design of their buildings and prevailing socio economic environment (such as access/availability of networked infrastructure) in which they are located (Graham & Marvin, 2001).

Furthermore, the review showed the absence of energy regulatory mechanism at national and local levels (Gyoh, 2011; Ogunsote, et al., 2011). Therefore, contrary to the global direction in combating issues relating to building energy use, a supply led paradigm dominates the approaches applied in bridging the energy supply gap, where the use of diesel fuel generators has become widespread despite its economic and adverse environmental implications (Olukoju, 2004).

Although, it has been reported that commercial sector energy consumption has exceeded that of industrial sector at the national level (Babatunde & Shuaibu, 2010), it has not been possible to obtain detail disaggregated energy consumption across the built environment in Abuja. A snap shot of energy distribution obtained from a few energy distribution units in Abuja show an energy distribution of 61% and 37% between the residential and commercial sector of the built environment respectively.

This suggests that the commercial sector has a significant impact on energy supply, particularly when the proportion of commercial buildings is compared to that of residential buildings. In fact, commercial buildings (including office buildings) and the residential
sector accounts for 4.9% and 48.7% of total land allocation according to the Abuja master plan (Olomola, 1999).

With only the Phase 1 completed, and the rest of the Phases of the 4-Phase Abuja development project underway, trend in office building development, based on current design proposals examined, suggest a continued inclination towards post-modernist and international architectural style developments characterised mainly by fully glazed facades. Meanwhile, despite current government programme to boost energy supply through the national grid, there is limited evidence to suggest successful implementation of the programme in line with its set targets up to the year 2020 (Akinbami & Lawal, 2009; Oseni, 2011). The above scenario suggests the prevalence of supply led regime in the near future aided by diesel fuel generators; pending substantive solutions to the energy supply predicaments.

3. The research methodology applied a case study approach to further explore office building design and development in Abuja, its application of energy use regulation, energy performance and distribution of end uses. This approach provided the research with primary information on office building development in ways previously not reported. Although, no literature was found that specifically categorised office building development in Abuja, the case study confirmed the development of office building, based on modernist and post-modernist architectural styles as prevalent in other major Nigerian cities. Whilst acknowledging the timeline historic documentary applied for buildings in Nigeria, a performance based classification was proposed. This included the LBLR, HBLR, LBHR and HBHR building categories. This new classification was to enable a robust performance analyses across comparative sets of buildings.

Furthermore, there was no evidence of any energy use regulation applied in either the design or the management of the buildings.
Similarly, most of the buildings relied upon diesel fuel generators as alternative source to supplement the grid supply shortages; with the cost of energy from alternative source being greater than that of primary source not to mention the increase and negative environmental impacts.

With data obtained from a walk through audit, disaggregated energy distribution was deduced using a model adopted for this study. The average energy end use distribution shows that air conditioning, lighting and office equipment account for 59%, 14% and 23% of total energy consumption in the buildings examined, while building services including lifts, account for a negligible proportion of the energy distribution. This indicates greater potentials for energy savings in reducing cooling demand.

Furthermore, typical building performances using EUI, ECI and CEI indicators were derived for the different office building categories. Though the result is comparable with limited known reporting of a similar sector (Batagarawa, et al., 2011), this study provides energy performance values for a more comparative set of buildings in approaches similar to that obtained globally (Perez-Lombard, et al., 2008).

However, further analysis of the implication of the building’s design on its energy consumption using Pearson’s correlation model did not show correlation results of statistical significance acceptable within research realms that would have suggested having any impact on the buildings energy consumption. Only the wall u-value showed statistically significant correlation with building energy consumption across the categories.

4. In the search of appropriate low energy design for office buildings in Abuja, the study evaluated nine architectural design variables
(identified from the literature review) that can be manipulated to achieve low energy and sustainable buildings. These included the external wall, roof, type of glazing, ground floor construction, building orientation, glazing ratio, ventilation strategy and building form. The research adopted the use of computer based simulation with IES-VE for the iterations of the design variables. Over 400 iterations were evaluated to determine appropriate design strategy.

From the simulation, the research identified orientation and glazing ratio as having the highest impacts on buildings energy consumption. The simulation also showed the potentials for reduction in cooling requirement through mechanical user operated means of simple window opening control mechanism in the modification of thermally comfortable internal spaces. It also applied these variables to determine resultant performance improvements.

5. The research demonstrated that the current office building development in Abuja and the built environment in Nigeria is lacking in terms specific energy regulations for buildings. The study also brings forth an energy performance perspective of office buildings in Abuja which have been largely unexplored. The research was able to provide in quantifiable terms the impacts of different design on buildings energy consumption in Abuja. And hence, proposed potential performance targets to enable building designs with improved energy performances.

9.3. Contributions and significance of study
1. This research has examined current initiatives and approaches applied in the global domain towards the achievement of low energy buildings and sustainable built environment in Nigeria. The research has demonstrated a dichotomy between developed nations and Abuja, an exemplar city within developing countries in their approaches towards sustainable and energy conscious built environment. It also exposed the gap that developing countries are
lagging behind and will need to do more to compliment global trend in building energy use regulation if a truly global sustainable building and environmental agenda is to be achieved.

2. The study confirms the absence, and in some cases poor or incoherent, construction and environmental policies among developing countries identified as requisite drivers for any effective implementation as exemplified in many developed countries (du Plessis, 2001; Ebohon & Rwelamila, 2001). It highlighted the shortfalls contained in current practices and local building regulations in relation to energy use for buildings. To some extent, the study ameliorates the paucity of data in this field of research. The study proposed a performance based classification based on which the office buildings were evaluated. This can further be developed to enable performance based classifications for the rest of the built environment composition in Nigeria.

3. The study derived typical office building performances for all the categories under study using globally acknowledged indicators. The research output demonstrate the need to rationalise energy use in a society where supply-led paradigms dominate. Though development of an adequate energy supply infrastructure tend to be among top government priorities, any viable, responsive and sustainable environment outcome should encompass a comprehensive assessment of all sectors in the built environment as well as curbing end-use inefficiencies (Ekpenyong, 2008). A study of this nature has identified the impact these buildings can pose on the local energy supply. Information such as that is vital in the development of an informed energy use policy (van Beeck, 2003).

4. The research, through the simulation conducted, was able to quantify the impact of design variables on buildings energy demand such that a hierarchy of importance can be deduced and applied in
low energy design decision making process. The research applied these strategies on simplified models of the case study buildings to determine energy saving potentials in which up to 20% in energy savings was observed in comparison to derived typical performances. The research was able to test and ascertain the appropriateness of recommended tropical design and local regulations in the delivery of low energy buildings in Nigeria. Hence, the research was able to examine sustainable design within its own context, rather than simply adopting other internationally acknowledged standards as commonly practiced in Africa (du Plessis, 2005).

5. From the above, benchmarks for enhanced performance targets were proposed for all the office building categories. It is envisioned that application of these benchmarks can be reflected in the regulatory/policy formulation for energy use in buildings. The Building Research Standards of the Nigerian Institutes of Architects (NIA) and the National Building and Road Research Institutes (NBRRI) are two institutions that can further engage government in the development of appropriate regulatory mechanisms for energy use in buildings (Ogunsote 2011). Other agencies that can benefit from this study include the ministries of environment, energy, housing and urban development. The study template can also be adopted to evaluate other sectors of the built environment in order to have an all-encompassing scope to aid a comprehensive policy.

9.4. Recommendations and further research
1. The literature review has demonstrated a paucity of data in the study area. Hence research concentration should be broadened to reduce the unbalanced nature of the current literature. Perhaps this should be pursued to ensure an all-encompassing goal towards a sustainable global environment. Graham and Marvin (2001) pointed out the spread of numerous aspects of the urban concepts in globalised world such that what seem to be confined in one locality
developed countries) is more than likely to replicate itself elsewhere (developing countries).

2. The study is limited to the urban development in Abuja where a significant amount of construction activity exists. While the analyses of the Abuja office built environment was based on the 22 case studies, a more comprehensive study involving more buildings will be required to include other sectors of the built environment. As such a nationwide study may be relevant in order to develop a comprehensive national policy on building energy use.

3. In obtaining end use energy data collection, the calculation method based on mathematical model applied in the research did not take as much time as direct sub metering would have probably required. However, the complexity of access limitation to building constituted challenge in obtaining detailed energy end uses in all spaces. As such typical floor areas was applied. In addition, future energy end use should also account for extended uses such as staff bringing their electronic equipment to recharge in the office. Other aspects observed is that of external lighting either to the buildings surrounding or as independent standing external lighting. These are usually left switched on overnight but also add to the total amount of energy consumed by the building.

4. In the building simulation, there was no in-depth evaluation of shading device components, so it should be considered in future research. However, this should be treated as an independent aspect due complex aspects associated with it such as nature of sun positioning throughout the year and the different types of shading devices available both externally and internally. Hence numerous hourly iterations would be required for a robust evaluation. Also, the simulation weather file only considered a typical metrological year. With the current climate change discourse, it may be useful to
evaluate office building performance using projected climate data that captures temperature rise predictions.

9.5. Summary

The chapter presented a summary of the background information and the aim of the study. The chapter also presented summary of discussions and conclusions in relation to the objectives set out to achieve the research aim. Concerns associated with building energy consumption have been highlighted and the adverse environmental consequences and resultant remedial mechanisms developed which tend to ensure future sustainable environments at global level. The study has evaluated energy use in buildings in the Nigerian context with focus on office buildings in Abuja.

The chapter also presented summary of key findings from the evaluation of existing office building development in Abuja as well as the computer based simulation undertaken to evaluate design impacts on buildings energy consumption.

This provided primary information and an insight on energy performance data on the existing stock of office building in Abuja where typical and enhanced building performances were provided. Proposed performance targets for the office building categories were also provided. The study concluded with recommendations and highlighted areas for future research.
Appendices
Appendix A0: Building inventory survey data form

### BUILDING INFORMATION

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### SECTION A: BUILDING’S PHYSICAL COMPONENT

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<td>E</td>
<td>SE</td>
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### Building Configuration

| Description of Layout      |     |
| Total Floor Area           |     |
| Number of Floors           |     |
| Plan Layout Type           |     |
| Floor to Ceiling Height    |     |
| Building Form Factor       |     |
| Compactness Ratio          |     |

### Building Envelope Properties

| Wall Material               |     |
| Type of Glazing             |     |
| Transparency Ratio          |     |
| U- Value of Opaque Material (W/m²°C) |     |
| U – Value of Glazing (W/m²°C) |     |

### Shading Device

| Type of Shading Device      |     |
| Projection Depths of Shading Device |     |
| Facade Application of Shading Device |     |
|                            | N   | NE  | E   | SE  | S   | SW  | W   | NW  |
## SECTION B: BUILDING ENERGY MANAGEMENT AND OCCUPANCY SCHEDULE

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<td>Extended Operational Hours</td>
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<td>Percentage of Staff During Extended Hours</td>
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## SECTION C: BUILDING ENERGY END USES

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<td>Types of fans</td>
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<td>% Total energy consumption</td>
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<td>Types of fittings</td>
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<td>Lighting system</td>
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<td>% Total energy consumption</td>
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<td>Equipment Types</td>
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<td>Type of equipment/appliance</td>
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Appendix A: Ethical Review Approval Documentation (FO:07/11-0051)
Faculty of Creative and Cultural Industries
Application for Research Ethics Review

This front sheet should be completed for every application.

Application for: Exemption from Full Review □  Full Review □  Checklist only □

Applicant Details:

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<thead>
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<th>Name of researcher:</th>
<th>Mu'azu, Abbas Ibrahim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status: (please tick)</td>
<td>□ Postgraduate Student</td>
</tr>
<tr>
<td></td>
<td>□ Staff</td>
</tr>
<tr>
<td></td>
<td>□ Other (please state)</td>
</tr>
<tr>
<td>Email address:</td>
<td><a href="mailto:elabbas77@yahoo.com">elabbas77@yahoo.com</a></td>
</tr>
<tr>
<td>Contact address:</td>
<td>6c Landport Terrace</td>
</tr>
<tr>
<td></td>
<td>Southsea, Portsmouth</td>
</tr>
<tr>
<td></td>
<td>PO1 2RG</td>
</tr>
<tr>
<td>Telephone number:</td>
<td>07738082105</td>
</tr>
</tbody>
</table>

If a student then also:

<table>
<thead>
<tr>
<th>Details of study: (please tick)</th>
<th>□ PhD</th>
<th>□ MPhil</th>
<th>□ MA</th>
<th>□ Other (please state)</th>
</tr>
</thead>
</table>

| Name of supervisor:           | Roger Tyrrell |

Project Details

Project funded by: Partial Sponsorship by Petroleum Technology Development Fund (PTDF) Nigeria

Title and summary of proposed research:

Sustainable Low Energy Design: A Case Study of Public Office Buildings in Abaja, Nigeria

Research Synopsis

In cognisance to dwindling resources across the world, sustainable development has become pertinent. As such, huge energy consumptions in buildings have attracted concerns that demands better building performances without compromising occupant comfort. This research undertakes an historical review of office building development in tropical climates of Nigeria to examine changes in the architectural design and associated energy consumption using SPSS based correlation analyses. A prototypical office building model is simulated using IES-VE to evaluate the impact and relative importance of design variables on internal comfort and associated cooling load. This can be useful to architects in understanding the relationship between their design decisions and energy use implications in the context of a developing country where the energy infrastructure is grossly inadequate.
Faculty of Creative and Cultural Industries

RESEARCH ETHICS REVIEW CHECKLIST

Name: Mu'AZU, Abbas Ibrahim

If you are unsure about any of the following questions, please contact your local representative on the CCI FEC for advice.

For the named research project, as far as you can identify at the present time:

<table>
<thead>
<tr>
<th>Question</th>
<th>No</th>
<th>Yes</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Will you be involving human participants in your study?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If you answer NO to this question, please go to Q 16.</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>2. Will the study involve recruitment of patients or staff through the NHS or Councils with Social Services responsibility (CSSRs)?</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>If you answer YES to this question then there is no need to continue with this checklist. See point 2 below.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Will the participants be exposed to any physical or psychological stress or anxiety, or be caused harm or negative consequences greater than those encountered in their normal lifestyle?</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>4. Will the participants be exposed to any non-standard hardware or any non-validated instruments?</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>5. Will the study involve participants who are in any way vulnerable or may have any difficulty giving consent?</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>6. Will the study require the co-operation of a gatekeeper for initial access to the groups or individuals to be recruited? (E.g. students at school, people with a learning disability, or people who may be deemed to lack Mental Capacity and therefore unable to make a reasoned decision).</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>7. Will it be necessary for participants to take part in the study without their full knowledge and consent at the time? (E.g. covert observation of people in public places.)</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>8. Will the study involve the use of questionnaires, surveys, or observational studies, or any other means of collecting primary personal data?</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>9. Are drugs, placebos or other substances to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Question</td>
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<td>Yes</td>
<td>Unsure</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>----</td>
<td>-----</td>
<td>--------</td>
</tr>
<tr>
<td>10. Will financial inducements or any other incentives (other than</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reasonable expenses and compensation for time) be offered to participants?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>11. Does the research methodology use deception? (e.g. participants will</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>not be told the true reason for the study.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Will you be in a position of authority or influence over any of the</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>participants?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Is there any reason why the participants will NOT be provided with</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sufficient details of the study at an appropriate level of understanding?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. After the study, is there any reason why participants will NOT be</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>provided with feedback about their involvement and be able to ask any</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>questions they may have about this involvement?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Is there any reason why the data collected from the participants will</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOT be stored and/or published in an anonymous form, or securely</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>disposed of?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Are there any potentially socially sensitive issues involved? (e.g.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sexual, political, legal/criminal or financial.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Will your study involve the natural/physical environment and/or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cultural/historical features or anything else that may be ethically</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sensitive?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Will the study involve the investigator and/or any participants, in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>activities that could be considered contentious, unacceptable, or illegal,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or in any other way harmful to the Faculty of Creative and Cultural</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industries or the University of Portsmouth?</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

You should send this completed form to the Faculty Ethics Committee and take a copy for your own records.

1. If you have answered no to questions 1, 16, 17 and 18, then you should probably apply for exemption from the full ethical approval process. However, if you are unsure, please contact your local representative on the FREC for advice.

2. If you have answered yes to Q2, then you should apply to the appropriate LREC for ethical approval.

3. If you have answered yes or unsure to any of the other questions you will need to describe more fully how you plan to deal with the ethical issues raised by your research. When the occasion arises, you will need to answer the questions in the Full Ethical Approval Review for Researchers form addressing the ethical issues raised by your proposal. Please ensure that the completed form is sent to the Faculty Ethics Committee.

Please note that it is your responsibility to follow the University’s Ethics Policy and any relevant University, academic or professional guidelines in the conduct of your study.
Any significant change in the question, design or conduct of the research over the course of the project should be notified to the Faculty Ethics Committee.

Please sign and date the following to verify that you have read and understood the questions contained in the Research Checklist above.

**Academic Research Staff**

<table>
<thead>
<tr>
<th>Principal Investigator: print name</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator: signature:</td>
<td></td>
</tr>
<tr>
<td>Date:</td>
<td></td>
</tr>
</tbody>
</table>

**Postgraduate Researchers**

<table>
<thead>
<tr>
<th>Print name:</th>
<th>Abbas Mu'azu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signature:</td>
<td>[Signature]</td>
</tr>
<tr>
<td>Date:</td>
<td>19.01.11</td>
</tr>
<tr>
<td>Supervisor's name:</td>
<td>Roger Tyrell</td>
</tr>
<tr>
<td>Supervisor's signature:</td>
<td>[Signature]</td>
</tr>
<tr>
<td>Date:</td>
<td>19.01.11</td>
</tr>
</tbody>
</table>

**Committee Use Only.** Ethical Review Code:

Signed:

Comments:
21st September 2011

Dear Abbas,

I apologise for the delay in reviewing your application. This was due to many of the committee taking annual leave across the summer break.

I am pleased to inform you that the CCI Faculty Ethics Committee, based on the information you have provided in your initial application and your additional responses to our questions, has given your application for the study entitled 'sustainable low energy design: A case study of public office buildings in Abuja, Nigeria', a favourable opinion.

This opinion has been given for this study only, and any changes in the conditions of the study may require you to re-apply for ethical review.

Although the Committee has given a favourable opinion, the final responsibility for the ethical conduct of this work lies, as always, with the researcher(s).

Please note that the Committee reserves the right to re-review this application should any concerns be raised about it in the future.

Your ethical review number is FO:07/11-0051

If you have any questions about this, please let me know.

[Signature]

Wendy Powell
(Chair, CCI FEC)
## Appendix A01: Building forms examined

<table>
<thead>
<tr>
<th>Description</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>(L \times B \times H) = 5 \times 10 \times 30</td>
<td><img src="image1.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(L \times B \times H) = 5 \times 60 \times 5</td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(L \times B \times H) = 15 \times 20 \times 5</td>
<td><img src="image3.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(L \times B \times H) = 12 \times 25 \times 5</td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(L \times B \times H) = 10 \times 30 \times 5</td>
<td><img src="image5.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>
Appendix B: Monthly thermal performance of wall types

<table>
<thead>
<tr>
<th>Description</th>
<th>Wall ID: WALL – 01</th>
<th>Thermo physical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material composition (outside to inside)</td>
<td>Thickness (mm)</td>
<td>U-value (W/m²K)</td>
</tr>
<tr>
<td>Common Brick</td>
<td>230.0</td>
<td></td>
</tr>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermal performance (%)</th>
<th>Too cold &lt;21°C</th>
<th>Comfortable Between 21°C and 29°C</th>
<th>Too hot &gt;29°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>0</td>
<td>78</td>
<td>22</td>
</tr>
<tr>
<td>Hot months (Jan-Jun)</td>
<td>0</td>
<td>67</td>
<td>33</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date: Fri 01/Jan to Sun 31/Jan</th>
<th>Date: Mon 01/Feb to Sun 28/Feb</th>
<th>Date: Mon 01/Mar to Wed 31/Mar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date: Thu 01/Apr to Fri 30/Apr</td>
<td>Date: Sat 01/May to Mon 31/May</td>
<td>Date: Tue 01/Jun to Wed 30/Jun</td>
</tr>
<tr>
<td>Date: Thu 01/Jul to Sat 31/Jul</td>
<td>Date: Sun 01/Aug to Tue 31/Aug</td>
<td>Date: Wed 01/Sep to Thu 30/Sep</td>
</tr>
<tr>
<td>Date: Fri 01/Oct to Sun 31/Oct</td>
<td>Date: Mon 01/Nov to Tue 30/Nov</td>
<td>Date: Wed 01/Dec to Fri 31/Dec</td>
</tr>
<tr>
<td>Description</td>
<td>Wall ID: WALL – 02</td>
<td>Thermo physical properties</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Material composition</td>
<td>Thickness (mm)</td>
<td>U-value (W/m²K)</td>
</tr>
<tr>
<td>Granite</td>
<td>15.0</td>
<td>2.0814</td>
</tr>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Hollow Concrete block</td>
<td>230.0</td>
<td></td>
</tr>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermal performance (%)</th>
<th>Too cold (&lt;21°C)</th>
<th>Comfortable between 21°C and 29°C</th>
<th>Too hot (&gt;29°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>80</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Hot months (Jan-Jun)</td>
<td>63</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

- **Date: Fri 01Jul to Sun 31Jul**
- **Date: Mon 01Feb to Sun 28Feb**
- **Date: Mon 01Mar to Wed 31Mar**
- **Date: Thu 01Apr to Fri 30Apr**
- **Date: Sat 01May to Mon 31May**
- **Date: Tue 01Jun to Wed 30Jun**
- **Date: Thu 01Jul to Sat 31Jul**
- **Date: Sun 01Aug to Tue 31Aug**
- **Date: Wed 01Sep to Thu 30Sep**
- **Date: Fri 01Oct to Sun 31Oct**
- **Date: Mon 01Nov to Tue 30Nov**
- **Date: Wed 01Dec to Fri 31Dec**

~ 267 ~
### Wall ID: WALL – 03

<table>
<thead>
<tr>
<th>Description</th>
<th>Material composition (outside to inside)</th>
<th>Thickness (mm)</th>
<th>U-value (W/m²K)</th>
<th>R-value (m²K/W)</th>
<th>Mass (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum sheet cladding</td>
<td>5.0</td>
<td>1.5992</td>
<td>0.4482</td>
<td>554.1</td>
<td></td>
</tr>
<tr>
<td>Cavity</td>
<td>75.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hollow Concrete block</td>
<td>230.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Thermo physical properties

<table>
<thead>
<tr>
<th></th>
<th>Too cold &lt;21°C</th>
<th>Comfortable Between 21°C and 29°C</th>
<th>Too hot &gt;29°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>0</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Hot months (Jan-Jun)</td>
<td>0</td>
<td>62</td>
<td>38</td>
</tr>
</tbody>
</table>

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![Graphs showing temperature data over different dates and months]
### Wall ID: WALL-04

<table>
<thead>
<tr>
<th>Material composition (outside to inside)</th>
<th>Thickness (mm)</th>
<th>U-value [W/m²K]</th>
<th>R-value (m²K/W)</th>
<th>Mass (kg/m²)</th>
<th>Thermophysical properties</th>
<th>Comfortable range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td>0.0807</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hollow Concrete block</td>
<td>150.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>100.0</td>
<td>12.2154</td>
<td></td>
<td>393.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermal performance (%)</th>
<th>Too cold &lt;21°C</th>
<th>Comfortable Between 21°C and 29°C</th>
<th>Too hot &gt;29°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>0</td>
<td>88</td>
<td>12</td>
</tr>
<tr>
<td>Hot months (Jan-Jun)</td>
<td>0</td>
<td>77</td>
<td>28</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Material composition</th>
<th>Thickness</th>
<th>U-value [W/m²K]</th>
<th>R-value (m²K/W)</th>
<th>Mass (kg/m²)</th>
<th>Thermal performance (%)</th>
<th>Comfortable range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date: Fri 01Jul to Sun 31Jul</td>
<td>Plaster 10.0</td>
<td>0.0807</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date: Mon 01Feb to Sun 28Feb</td>
<td>Hollow Concrete block 150.0</td>
<td>12.2154</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date: Mon 01Mar to Wed 31Mar</td>
<td>Insulation 100.0</td>
<td>393.0</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Date: Thu 01Apr to Fri 30Apr</td>
<td>Plaster 10.0</td>
<td>0.0807</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Date: Sat 01May to Mon 31May</td>
<td>Hollow Concrete block 150.0</td>
<td>12.2154</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date: Tue 01Jun to Wed 30Jun</td>
<td>Insulation 100.0</td>
<td>393.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date: Thu 01Jul to Sat 31Jul</td>
<td>Plaster 10.0</td>
<td>0.0807</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Date: Sun 01Aug to Tue 31Aug</td>
<td>Hollow Concrete block 150.0</td>
<td>12.2154</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Date: Wed 01Sep to Thu 30Sep</td>
<td>Insulation 100.0</td>
<td>393.0</td>
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<tr>
<td>Date: Fri 01Oct to Sun 31Oct</td>
<td>Plaster 10.0</td>
<td>0.0807</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date: Mon 01Nov to Tue 30Nov</td>
<td>Hollow Concrete block 150.0</td>
<td>12.2154</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date: Wed 01Dec to Fri 31Dec</td>
<td>Insulation 100.0</td>
<td>393.0</td>
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<td></td>
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</table>
### Thermo physical properties

<table>
<thead>
<tr>
<th>Description</th>
<th>Wall ID: WALL - 05</th>
<th>Thermo physical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material composition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside to inside</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Thickness (mm)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td>0.0807</td>
</tr>
<tr>
<td>Insulation</td>
<td>100.0</td>
<td>12.2154</td>
</tr>
<tr>
<td>Hollow Concrete block</td>
<td>150.0</td>
<td>393.0</td>
</tr>
<tr>
<td><strong>Plaster</strong></td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td><strong>U-value (W/m²K)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R-value (m²K/W)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mass (kg/m³)</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **Thermal performance (%)**  |                    |                            |
| Too cold <21°C               |                    |                            |
| Comfortable Between 21°C and 29°C |                   |                            |
| Too hot >29°C                |                    |                            |

**Annual**

| Hot months (Jan-Jun)         | 0                  | 87             | 13             |

| Hot months (Jan-Jun)         | 0                  | 75             | 25             |

**Date:** Fri 01Jan to Sun 31Jan

**Date:** Mon 01Feb to Sun 28Feb

**Date:** Mon 01Mar to Wed 31Mar

**Date:** Thu 01Apr to Fri 30Apr

**Date:** Sat 01May to Mon 31May

**Date:** Tue 01Jun to Wed 30Jun

**Date:** Thu 01Jul to Sat 31Jul

**Date:** Sun 01Aug to Tue 31Aug

**Date:** Wed 01Sep to Thu 30Sep

**Date:** Fri 01Oct to Sun 31Oct

**Date:** Mon 01Nov to Tue 30Nov

**Date:** Wed 01Dec to Fri 31Dec
<table>
<thead>
<tr>
<th>Description</th>
<th>Wall ID: WALL – 06</th>
<th>Thermo physical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(outside to inside)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td>U-value (W/m²K)</td>
</tr>
<tr>
<td>Hollow concrete block</td>
<td>150.0</td>
<td>R-value (m²K/W)</td>
</tr>
<tr>
<td>Insulation</td>
<td>100.0</td>
<td>Mass (kg/m²)</td>
</tr>
<tr>
<td>Hollow concrete block</td>
<td>150.0</td>
<td>Thickness (mm)</td>
</tr>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td>U-value (W/m²K)</td>
</tr>
<tr>
<td>U-value (W/m²K)</td>
<td>0.0787</td>
<td></td>
</tr>
<tr>
<td>R-value (m²K/W)</td>
<td>12.5364</td>
<td></td>
</tr>
<tr>
<td>Mass (kg/m²)</td>
<td>1106.0</td>
<td></td>
</tr>
</tbody>
</table>

### Thermal performance

- **Too cold:** < 21°C
- **Comfortable:** Between 21°C and 29°C
- **Too hot:** > 29°C

**Hollow concrete block**

- Thickness: 150.0 mm
- U-value: 0.0787 W/m²K
- R-value: 12.5364 m²K/W
- Mass: 1106.0 kg/m²

**Plaster**

- Thickness: 10.0 mm
- U-value: 0.0787 W/m²K
- R-value: 12.5364 m²K/W
- Mass: 1106.0 kg/m²

### Hot months

- (Jan-Jun) **0°**
- **87°**
- **13°**
# Description

Wall ID: WALL – 07

## Thermo physical properties

<table>
<thead>
<tr>
<th>Material composition</th>
<th>Thickness (mm)</th>
<th>U-value (W/m²K)</th>
<th>R-value (m²K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaster</td>
<td>10.0</td>
<td>1.1192</td>
<td>0.7164</td>
</tr>
<tr>
<td>Hollow concrete block</td>
<td>150.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass (kg/m²)</th>
<th>Thermal performance (%)</th>
<th>Too cold &lt;21°C</th>
<th>Comfortable Between 21°C and 29°C</th>
<th>Too hot &gt;29°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1097.00</td>
<td>81</td>
<td></td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

### Annual:

<table>
<thead>
<tr>
<th>Hot months (Jan-Jun)</th>
<th>420.0</th>
</tr>
</thead>
</table>

### Diagrams:

- **Jan**: Temperature vs. time for Jan.
- **Feb**: Temperature vs. time for Feb.
- **Mar**: Temperature vs. time for Mar.
- **Apr**: Temperature vs. time for Apr.
- **May**: Temperature vs. time for May.
- **Jun**: Temperature vs. time for Jun.
- **Jul**: Temperature vs. time for Jul.
- **Aug**: Temperature vs. time for Aug.
- **Sep**: Temperature vs. time for Sep.
- **Oct**: Temperature vs. time for Oct.
- **Nov**: Temperature vs. time for Nov.
- **Dec**: Temperature vs. time for Dec.
<table>
<thead>
<tr>
<th>Material composition (outside to inside)</th>
<th>Thickness (mm)</th>
<th>U-value (W/m²K)</th>
<th>R-value (m²K/W)</th>
<th>Mass (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather board</td>
<td>15.0</td>
<td>1.6071</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity</td>
<td>75.0</td>
<td>0.4452</td>
<td></td>
<td>29.2</td>
</tr>
<tr>
<td>Gypsum plasterboard</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermal performance (%)</th>
<th>Too cold &lt;21°C</th>
<th>Comfortable Between 21°C and 29°C</th>
<th>Too hot &gt;29°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>0</td>
<td>62</td>
<td>38</td>
</tr>
<tr>
<td>Hot months (Jan-Jun)</td>
<td>0</td>
<td>52</td>
<td>48</td>
</tr>
</tbody>
</table>

---

### Date: Fri 01Jan to Sun 31Jan

#### Date: Mon 01Feb to Sun 28Feb

#### Date: Mon 01Mar to Wed 31Mar

#### Date: Thu 01Apr to Fri 30Apr

#### Date: Sat 01May to Mon 31May

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#### Date: Sun 01Aug to Tue 31Aug

#### Date: Wed 01Sep to Thu 30Sep

#### Date: Fri 01Oct to Sun 31Oct

#### Date: Mon 01Nov to Tue 30Nov

#### Date: Wed 01Dec to Fri 31Dec

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~ 273 ~
Appendix C: Simulation data entry and monthly thermal performances for roof construction
Monthly Thermal Performance Charts for Roof 01
Monthly Thermal Performance Charts for Roof 02
Monthly Thermal Performance Charts for Roof 03

~ 279 ~
Monthly Thermal Performance Charts for Roof 04
Appendix D: Simulation data entry and monthly thermal performances for glazing types
Monthly thermal performance chart for Glaze 02
Monthly thermal performance chart for Glaze 02a
Monthly thermal performance chart for Glaze 02c
Monthly thermal performance chart for Glaze 02d
Appendix E: Simulation data entry and monthly thermal performances for ground construction
<table>
<thead>
<tr>
<th>Material (outside to inside)</th>
<th>Thickness mm</th>
<th>Conductivity W/(mK)</th>
<th>Density kg/m³</th>
<th>Specific Heat Capacity J/(kgK)</th>
<th>Resistance T.W/(Km)</th>
<th>Apparent Mass (kg/m²)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slug London Clay</td>
<td>750.0</td>
<td>1.4139</td>
<td>1930.0</td>
<td>9900.0</td>
<td>-</td>
<td>-</td>
<td>Sedimentary</td>
</tr>
<tr>
<td>Clay</td>
<td>190.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Sedimentary</td>
</tr>
<tr>
<td>Concrete</td>
<td>150.0</td>
<td>1.1360</td>
<td>2050.0</td>
<td>1000.0</td>
<td>-</td>
<td>-</td>
<td>Concrete</td>
</tr>
<tr>
<td>Wood</td>
<td>50.0</td>
<td>0.3419</td>
<td>1100.0</td>
<td>645.0</td>
<td>-</td>
<td>-</td>
<td>Sawn &amp; Dressed</td>
</tr>
<tr>
<td>Clay Tile</td>
<td>10.0</td>
<td>0.4489</td>
<td>1950.0</td>
<td>890.0</td>
<td>-</td>
<td>230.0</td>
<td>Tile</td>
</tr>
</tbody>
</table>
Monthly thermal performance chart for groundfloor 01
Monthly thermal performance chart for groundfloor 02
Monthly thermal performance chart for groundfloor 02a
Monthly thermal performance chart for groundfloor 02b
Monthly thermal performance chart for groundfloor 02c
Monthly thermal performance chart for groundfloor 02d
Monthly thermal performance chart for groundfloor 02e
Monthly thermal performance chart for groundfloor 02-raised
Monthly thermal performance chart for groundfloor 02a-raised
Appendix F: Simulation data entry for window opening control profile

Windows are open when:

Ta > 29°C & To < Ta

Where, Ta = room temperature and To = outside temperature
Appendix G: Thermal performances of orientation with glazed façade

Picture 0-1: Thermal performance of orientation using one glazed façade
Picture 0-2: Thermal performance of orientation using two opposite fully glazed facades
Appendix H: Design of sustainable office buildings in Nigeria,

Design of Sustainable office buildings in Nigeria

Mu’azu, Abbas I¹, Louis Gyoh²

¹ School of Architecture, University of Portsmouth, PO1 3AH UK
² Department of Architecture, Ahmadu Bello University, Zaria. Nigeria

Abstract
This study examined the impact of architectural design variables on energy consumption in office buildings in Nigeria where 17 office buildings case studies in Abuja were analysed. This was to appraise appropriate building elements design and specification that can be harnessed to achieve sustainable buildings with low energy consumption. Based on Pearson’s model, a correlation analyses was carried out to evaluate the relationship between the energy consumption (of the 17 case studies) and eight architectural design components in order to elicit the most important architectural variable affecting their energy consumption. Only the u-value of the external wall showed statistically significant correlation the buildings energy consumption. The study suggests that external wall material selection/specification is an important design variable in attaining sustainable low energy office buildings in Nigeria. The findings from this study would provide the framework for the development of a multiple decision support toward more energy efficient and environmental sensitive buildings in Nigeria.

Keywords: design variables; energy consumption; office buildings; wall u-value; Nigeria.

1. Introduction
Discourse on buildings energy consumption is now prevalent in numerous sustainable development agenda. This is largely due to their significant impacts on energy resources and the environment at large, which exceed that of other sectors, including transportation, in many parts of the world (Brown, 2010; Perez-Lombard, et al., 2008). In addition, buildings account for a significant proportion of green house gas emissions (P. Kasozi & A. Tutesigensi, 2007; King, 2008b). More so, researches show that commercial buildings and office buildings in particular, account for significant amount of energy consumed by buildings in many parts of the world including the US, Hong Kong, UK and China (Said, et al., 2003) (EIA, 2008; J. S. M. Li, 2008)

Therefore, it has becomes increasingly important that energy consumption in such buildings is rationalised so as to reduce the impacts on energy resources and environment. Subsequently, numerous mechanisms and policies are actively pursued and implemented particularly amongst developed country, which are all geared towards the development of an energy conscious built environment (King, 2008b; J. McLennan, 2004). However, it is noted that such frameworks designed to mitigate energy consumption in buildings are not evident as such in many developing countries (K. Janda, 2009).
Reasons for such positioning has been researched elsewhere (du Plessis, 2001; O. J. Ebohon & Rwelamila, 2001; J. Iwaro & A. Mwasha, 2010). In particular, the lack of institutional frameworks (and failed institutions where they exist) has been identified as the bane of sustainable and energy conscious building development in Africa (du Plessis, 2001; O. J. Ebohon & Rwelamila, 2001). More so, recent studies show an almost nonexistent status of policies and mechanisms employed to mitigate buildings’ energy consumption in developing countries in comparison with the developed countries (J. Iwaro & A. Mwasha, 2010; Kathryn B Janda, 2009). Despite this setback, building development remain on the increase in developing countries, in Africa for example, particularly now that such endeavours can be supported by new found oil wealth in countries including Chad, Niger, Sudan and Ghana.

Therefore, it becomes paramount to examine and pursue other energy conscious measures in the short term, while advocating for a coherent and substantive policies and institutional frameworks on the long term.

It is the aim of this study to examine the impact architectural design in the evolution of modern office building in an attempt to appraise appropriate building elements design and specification that can be harnessed to achieve sustainable buildings with low energy consumption.

2. Architectural design and energy consumption in buildings

Energy consumption in buildings may be linked primarily to three main factors. These are climate, design and occupant factors (N. Baker & Steemers, 1996a; Peter Wouters & Delmotte, 2005). In the provision of shelter, buildings have associated with varying climatic conditions long before the concerns for status, aesthetics and improved environmental quality became prominent (Drew & Fry, 1976; J. M. Evans, 2007; A. Rapoport, 1969); hence remaining a constant preoccupation in architecture throughout history till date (H. Fathy, 1986b; Oliver, 1987; P. Oliver, 1997). These variations in climatic dispositions across the world attract different approach in building development and its consequent demands for energy. For instance, heating and cooling may be required during very cold or hot weather, thus affecting their energy demands respectively.

This clearly indicates the influence climate imposes on buildings and human activities where the occurrence of favourable and unfavourable environment abounds. When the conditions are favourable, we tend to spend time outdoors; the summer periods in most of Europe for example. But when it is unfavourable, man seeks to mediate the climatic conditions through mediums including architectural designs (Drew & Fry, 1976)

Like climate, significant variations abound in architectural design approaches applied to mediate the climatic extremities. Perhaps caves, shades and clothing would have sufficed in primordial times (M. Fry & Drew, 1964); presently, the complexity of buildings and the built environment, climate and occupant expectations will require a careful and well thought architectural design intervention (Boestra, 2010).
Architectural design is a realization which concretizes a microcosm in more or less close connection with the environment to which it belongs (Gratia & De Herde, 2003). Hence, the goal of the building design is to achieve this microcosm in optimal agreement with its environment”. This assertion prioritises climate in the hierarchy of influential factors and in a way expatiates the intertwined nature of factors influencing energy demand in buildings; here, bringing together design and climate.

However, when design fails in the manipulation of its constituent variables to create desired spaces, systems such as lighting and HVAC have become convenient contemporary remedy to complement and in some cases replace nature-reliant (passive) approaches. In turn, this result to a potential increase in the amount of energy a building consumes (M. Haase & A. Amato, 2006; J. Nicol & Humphreys, 2009; G. K. Oral & Z. Yilmaz, 2003).

In spite of the plethora of available design remedies, the way and manner in which the building’s occupants use the buildings, to a great extent affects the buildings energy demand (L. Lutzenhiser, 1993; Orr, 1997). Recent studies confirm that occupants impact on a building’s energy demand is significant (Kathryn B Janda, 2009; Masoso & Grobler, 2010)(Janda, 2009; Masoso and Grobler, 2010). It was further argued that, “buildings do not consume energy”, it is people that consume energy particularly in their demand for comfort(Janda, 2011).

Occupant comfort in buildings is primarily an embodiment of thermal, visual and indoor air quality (R. De Dear & G.S. Brager, 1998; Susan Roaf, David Crichton, & Fergus Nicol, 2009). Occupants’ comfort has a wide variance globally, owing to climate, individual preferences, age, gender, activity (metabolic rate) and duration of occupancy (de Dear, 2010a). That is, depending on the building’s purpose and climatic location, the energy demand may vary in the fulfilment of the three comfort components named above and other associated requirements.

However, it is noted that while the architectural design of buildings can be fully manipulated, it can be understood that, for now, climate remains a relative constant owing only to nature’s dispositions. Similarly, it is a very difficult task to determine or control occupant response/behaviours in buildings(Siddal, 2010). Therefore, architectural design becomes an indispensible mechanism that can be manipulated to achieve sustainable buildings having low energy implications.

Although a broad matrix of design variables exists, this study is limited to selected eight.

These include:

1. Building orientation
2. Building form factor
3. Compactness ratio
4. Floor to ceiling height
5. Transparency ratio
6. U value of wall
7. U value of glazing
8. Depth of Shading device
The parametric definitions of the variables are given in the Table 1 below, while detailed discussion of the variables considered are extensively documented in relevant literature (N. Baker & Steemers, 1996a; Cody, 2005; Givoni, 1998a; S. Monna & G. Masera, 2010; M. Nicoletti, 1998; G. K. Oral & Z. Yilmaz, 2003; Papadopoulos & Giama, 2007; Yu, et al., 2009).

Table 1: Selected architectural design variables affecting building energy consumption

<table>
<thead>
<tr>
<th>DESIGN PARAMETER</th>
<th>VARIABLE NAME</th>
<th>VARIABLE FORMULAR</th>
<th>DEFINITION OF UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>Orientation</td>
<td>N/S, E/W, NE/SW, NW/SE</td>
<td>N=North, E= East, W=West, S=South</td>
</tr>
<tr>
<td>Building Form Factor</td>
<td>Building Form Factor</td>
<td>A/V</td>
<td>A = total external surfaces V= enclosed building volume</td>
</tr>
<tr>
<td></td>
<td>Compactness Ratio</td>
<td>P2/4A</td>
<td>P = total building perimeter A= building floor area</td>
</tr>
<tr>
<td></td>
<td>Floor to Ceiling Height</td>
<td>H</td>
<td>H= Height in meters</td>
</tr>
<tr>
<td>Building Envelope</td>
<td>Transparency Ratio or WWR</td>
<td>A_G/A_W</td>
<td>A_G= total area of glazing/window A_W= total area of wall/opacity</td>
</tr>
<tr>
<td></td>
<td>Heat Resistance of Wall</td>
<td>U Values</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat Resistance of Glass</td>
<td>U Values</td>
<td></td>
</tr>
<tr>
<td>Shading Device</td>
<td>Depth of device</td>
<td>L</td>
<td>L = depth of device/component from wall</td>
</tr>
</tbody>
</table>

3. Methodology

3.1 Study Approach

A case study approach was applied in this study due to the difficulty in obtaining building information in developing countries (Koolhaas & van der Haak, 2003; N Van Beeck, 2003). The case study provides opportunity to examine the study area in a way that remains largely unexplored. Case study approach is widely used approach in the field of social sciences and has been applied in studies of similar nature (Francis, 2001; A. C. Ogbonna, 2008).

3.2 Site selection

Abuja was identified as a suitable study site due its accessibility within the country as well as the ample opportunity it provides for selection of office buildings due to their concentration largely due to heavy government presence.

3.3 Building selection criteria

Government office buildings were particularly selected since governments are key drivers in energy policy formulation for buildings and as such should be
able to demonstrate its commitments towards building energy efficiency/performance initiatives using its own premises.

Also, in the building selection, the UK's office building categorisation as contained in the Energy Consumption Guide 19 for office buildings was adopted for this study in the absence of similar literature specific to the study area. The Guide recommends that office buildings should have a total floor area greater than 2000sqm, which complies with the EU’s EBPD threshold for large buildings deemed capable of having significant energy consumption. This classification ensures that offices housing similar activities and using similar equipments, particularly HVAC, are classified together. The key factors that must be similar are itemised below:

The key selection criteria include:
1. Building function/use – office buildings
2. Architectural style and HVAC strategy – air condition (excluding central air conditioning)
3. Energy/fuel type used in the building – electricity as primary source
4. Occupancy – normal office hours of 8.00am-4.00pm
5. Location – Abuja central business district.

The selected case studies belong to modern buildings, as referred to in the context of Nigeria, which represents over 30% of the built environment (Bogda Prucnal-Ogunsote, 2001).

3.4 Data collection
The case study investigation was conducted via a field study with the aid of a drafted building survey form developed by the researcher, as applied in similar works (S. M. Deng & J. Burnett, 2000; A. Ogbonna & Harris, 2008; Sawsan M Saridar, 2004), to guide and ensure comparable sets of data are obtained across all the buildings. A total of 20 buildings were selected and approached to participate in the study. 17 responded positively, 3 did not respond at all and none declined. Energy bills for yearly time series were obtained. The survey also took records of the energy end uses in the buildings to include mainly lighting, air conditioning and ventilation, equipments and building services (lifts etc). Due to the poor energy supply infrastructure, the study also took account of the diesel based generators widely adopted as alternate energy source to supplement energy shortages.

3.5 Data processing
Data from the survey forms were collated with Microsoft Excel programme. This allowed parametric identity of selected design variables to be computed using the “cell formula” options embedded in the programme. The buildings were also coded to provide anonymity in partial fulfilment of research ethical requirements.

The study applied sensitivity statistical analyses which is commonly used particularly in the field of social science and has also been applied within the architecture discipline (Boubekri, Hull, & Boyer, 1991; Goins, Jellema, & Zhang, 2010; Groat & Wang, 2002; London & Ostwald, 2004). The method was considered for its ease of application, replication and comprehension in a developing world context.

This involved a correlation analyses based on Pearson’s model with the aid of SPSS software as a tool. The analyses considered a two tailed correlation due
to assumption of a non-directional hypothesis (A. Field, 2009). Statistical significance of the correlation analyses were obtained and evaluated.

Hence, the relationship, impact and perhaps the importance of the selected design variables on the buildings energy consumption can be obtained from their respective derived values. From the derived values, a hierarchy of importance or a scale of priority of the variables can be established.

The theoretical underpinning of the statistical significance model is hinged upon assumptions that the results obtained are more unlikely to have occurred by chance (Cowles & Davis, 1982; A. Field, 2009; Goins, et al., 2010; Stigler, 2008). This tends to imply the reliability of the results. From the values of the obtained correlation results, variables with statistical significance were identified and ranked. As such, the degree of importance of the variables was inferred.

4. Analyses and result
The statistical significance of the Pearson’s model is given by $p$ value between 0.05 and 0.01 which is typically adopted and acceptable amongst researchers (A. P. Field, 2009; Groat & Wang, 2002; Stigler, 2008). This implies that there are 1-5% of the results occurring by chance; hence giving the results a level of acceptable reliability for research purposes. Summary of analyses is given in Table 2.

In the analyses of the eight selected variables, only the total floor area and the wall $u$-value showed significant correlation with the buildings’ total energy consumption. This is in contrast to the research’s hypothetical expectations in cognisance with the literature review which suggests that, “most, if not all, of the design variables will show some sort of statistically significant levels of correlations with the buildings total energy consumption” and perhaps exhibiting only slight variations in their respective levels of statistical significance. It was expected that this would have hinted the level of importance or enabled the deduction of a hierarchical order of importance of the variables impacts on building energy consumption.

To further compare and cross validate the result of statistical evaluation, other known correlation tests were used to analyse the same data sets. The results were in concordance with that of Pearson’s.

Similarly, a simple ordinary linear regression statistical analysis was conducted to examine the levels of statistical significance of the variables relationship with the buildings energy consumption. The results obtained were very similar with the outcomes of the correlation analyses; showing only the wall $u$-value with an appreciable level of statistical significance.

At this point the following discussions can be put forward. Firstly, the results tends to give credence to critics that have for long challenged the $P$-value significance theorem (Kaye, 1986; W. R. Rice, 1989; Shaver, 1993; Thompson, 1989). Basis for these arguments is largely hinged upon the assertion that even though its theory puts it that results obtained could have only occurred by a 1-5% chance, the reliability or credibility given to the remaining 95%
(presumed correct probability) may also be subjected to other errors or chance factors that are not accounted for in the model.

It is also argued that the study sample size is important for any meaningful generalisation (Nickerson, 2000; Thompson, 1989). Conversely, Cicchetti (2001) argued strongly that increasing the sample size ($N$) by a predetermined factor may not be necessary. That is to say, the application of the correlation model should not be determined by the sample size. Perhaps this position may not be contradicted, unless if the model has an established threshold for $N$ from which accurate computations and results can be obtained. After all, every research is susceptible to potential sample size limitation.

However, if increasing the size of $N$ is upheld, then perhaps other researches based on these methods will be discredited on the basis of lack of fulfilment for the suggested $N$ value (sample size) requirement. Again, it may not be tenable for various types of research to attain such prescribed size for $N$. In any case, determination of sample size may not be absolutely necessary despite the inherent complementarities with result interpretations (Fan, 2001) in order to affirm the level of significance given by the $p$ value.

Thompson (1997), noted that bulk of the confusion lies with use of language and manner of results reporting notably by asserting that the result is simply “significant” rather than “statistically significant”. And as a result, it potentially leads to misinterpretation or confusion. This could have a potential hazard particularly where generalisation are made and applied to real life situations like in health sciences. However, it is encouraged that researches should be furthered to demonstrate results that can have practical significance in the real world (Kirk, 1996; Thompson, 1999).

This implies that correlation analyses using its $p$ tests, and of course other statistical approaches, are still relevant and applied in research. On the occasion of this research however, the fact that significant correlation results for some certain variables were obtainable, suggests that the sample size for the survey conducted may not necessarily be a factor for the failure of the tool to detect the presumed correlation results in the other variables. From another stand point however, one may ask, whether or not the correlation results will still be challenged or scrutinised had it demonstrated outcomes in favour of the hypothesis. Notwithstanding, if one opts to ignore the number of variables showing significant correlation due to low turnout, then it may be asserted that either the statistical model or the analyses tool (SPSS) is not suitable for this type of analyses.

Conversely, there may be nothing wrong with the statistical model since a comparison and cross validation using Spearman Rho’s and Kendall Tau’s model also yielded very similar results. If at all, that leaves questions surrounding the calculation engine embedded in the SPSS programme itself.

More so, if the above assumption is remains challenged, then the data sets used in the analyses may be questioned. This may suggest the presence of subtle errors in the variables since most of them are computed using adopted parametric definitions obtained from literature. For example, the results
showed positive results in variables that are quite straightforward to obtain such as the floor area.

Notwithstanding, this may not absolutely be the case because no significant correlations were obtained for other straightforward variables such as orientation and floor to ceiling heights. Notwithstanding, from the results the u-value of the wall remains an important design variable with significant correlation with the building energy consumption for climates like that of Abuja - Nigeria as attested by other researches (H. Fathy, 1986a; M. Fry & Drew, 1964; M. K. Singh, Mahapatra, & Atreya, 2009).

5. Recommendation and conclusion
The study examined the relationship of eight selected architectural design variables and the total building’s energy consumption from a case study of 17 of government office buildings in Abuja using a correlation analyses based on Pearson’s model. The u-value of the building’s opaque material (wall) is the only design variable to exhibit statistically significant correlation with the buildings total energy consumption while the rest of the variables evaluated did not exhibit correlations of statistical significance with the buildings energy total energy consumption. The study suggests that the specification of the external building fabric is vital in any energy conscious building design in Nigeria. Further research would be required in determining the energy and environmental performance of the major building material in use in the Nigerian construction industry. This knowledge would provide a framework for the possible development of an energy design compliance best practice guide in the short to medium term in Nigeria.
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Appendix I: Scenario of office buildings energy consumption in Abuja.


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Abstract — The study investigated energy consumption of office buildings in Abuja, Nigeria to elicit their status, impacts and performance on the city’s energy supply. The study provided a general synopsys on status of energy in Nigeria and highlights of its evolving built environment via a vis its electricity infrastructure. The study confirmed that commercial buildings (including office buildings) have a significant impact on the energy supply of the city. The study also confirmed the prevalence of a suppressed energy demand scenario due to shortages in energy supply. Using the Energy Use Indicator – EU as a building energy performance indicator, the study reported a derived EUI ranging between 18.5 kWh/m² a – 38.4 kWh/m² a which is significantly lower than other global reporting. This was attributed to prevalent suppressed energy supply. Energy saving opportunities was identified while an energy conscious building design and development is encouraged to enable a sustainable built environment.

Keywords: office buildings, energy consumption, EUI

1. INTRODUCTION

Energy consumption in buildings has become a focal point in global discourses towards sustainable development and its wider interconnections with the environment. Studies have shown that energy consumption of the built environment exceeds that of other sectors, including transportation, in many parts of the world [1, 2]. For example, in the US, buildings consume as much as 48% and 76% of total energy and electricity respectively [3]. In addition, buildings account for a significant proportion of greenhouse gas emissions [4, 5]. More so, researchers show that commercial buildings and office buildings in particular, account for significant amount of energy consumed by buildings in many parts of the world including the US, Hong Kong, UK and China [6-8]. Thus, it has become paramount that energy consumption in such buildings is rationalised so as to reduce the potential adverse environmental impacts.

In this regard, numerous mechanisms and policies have been proposed and implemented particularly amongst developed countries, all geared towards energy conscious building development [5, 9]. Though, initial policies such as the EU’s Energy Performance of Buildings Directive (EPBD) and the UK’s Energy Consumption Guidelines targeted large buildings such as office buildings which have been identified as having significant energy consumption; current policies encapsulate virtually all sub-sectors of the built environment.

In contrast to the above developments, the lack of similar institutional frameworks has been identified as the bane of sustainable and energy conscious building development in Africa [10, 11]. More so, recent studies show an almost nonexistent status in the development of such policies and mechanisms employed to mitigate buildings’ energy consumption in developing countries in comparison with their developed counterparts [12-14].

However, this does not come as a surprise because many developing countries, sub Saharan Africa in particular, are characterised by poor energy supply infrastructure [15]. For example, electricity consumption in Africa accounts for only 4% of global electric energy availability [8]. In fact, only 65%, 40%, 33% and 9% of the populations in South Africa, Kenya, Nigeria and Mali respectively, have access to electricity [16]. To a large extent, this energy supply deficits undermines a purposeful development of a sustainable modern built environment [17].

Despite these setbacks, building development remains on the increase in Africa, due to pressure of housing and other building demands, particularly now that such activities can be supported by new found oil wealth across the continent, including Chad, Niger, Sudan, Angola and Ghana. For example, Nigeria with a population of over 140 million, is observed to have an annual population growth rate in urban areas reaching 3.7% and rapid urbanisation is at 50% in its major cities [18]. This is epitomised in the new capital, Abuja, with its master plan designed according to paradigms found in developed countries [19-21].

Thus, it becomes paramount to examine energy consumption in the evolving built environment in a developing world context and pursue energy conscious measures in the short term, while advocating for a coherent
and substantive policies as well as institutional frameworks on the long term.

This study examined energy consumption of office buildings in Abuja, the largest urban centre in Nigeria, characterised by significant government and corporate body presence as well as rife construction activities, in an attempt to elicit the status, performance and the impacts of office buildings on energy in Abuja as an exemplary microcosm of the other African urban cities.

II. STATUS OF ELECTRIC ENERGY IN NIGERIA

Nigeria has abundant energy resources, mostly dominated by oil and gas; making it the economic mainstay of the country accounting for over 85% of export earnings and government revenue [22]. Nigeria is the 9th largest oil exporter in the world and holds the largest natural gas reserve in Africa [23]. It also boasts of other energy sources including coal, nuclear, solar and wind which are rarely accounted for in the national energy mix due to their negligible proportions in comparison to oil and gas.

Despite this abundance of energy resources, only 49% of the population has access to electricity and are mostly located in the urban areas [16]. Reports also showed that electricity contributes less than 3% to the national GDP owing to low supply and competing demand from a high population [24].

Meanwhile, firewood remains an important energy resource used mainly for cooking in rural and even parts of the urban areas; resulting to significant loss of forests and desertification [16]. Fig. 1, below shows the distribution of energy consumed in Nigeria categorised by source, but excludes firewood. Also Fig. 2 below shows the same energy distribution including firewood sources. A sharp contrast depicting the dominance of firewood over other prevalent sources is easily noticed. However, this also indicates the degree of level of competition for limited resources particularly in areas solely dependent on electricity.

Figure 1: Total energy consumption in Nigeria (excluding firewood)

Through total energy consumption in Nigeria has more than doubled from 0.8 quadrillion BTU in 1980 to 1.13 quadrillion BTU in 2002, making it the highest in West Africa, it lags behind most North African states including Egypt, with 2.4 quadrillion BTU as well as South Africa with 3.8 quadrillion BTU [23].

Figure 2: Total energy consumption in Nigeria including firewood.


Recently, the government has introduced reforms which primarily involves neutralizing the monopoly enjoyed by the then, government owned single electric energy Power Holding Corporation of Nigeria (PHCN), through introducing other independent electric power providers in addition to injecting huge investments in the sector to boost electricity supply.

Despite, the more recent investment spanning from 1999 till date, electricity supply has not significantly increased as projected in the past three decades, with production still fluctuating between 1500-3000MW annually [25-28] as shown in Fig. 3. The supply itself has virtually stagnated as shown in Fig. 3 in addition to being sporadic, inadequate and inefficient [29, 30]. Hence, the discourse on electricity has been a vexed issue in Nigeria particularly in urban areas where electricity is the main source of energy [31].

Figure 3: Electricity Supply in Nigeria 1970-2008

More so, it is shown that demand outstrips supply in a ratio of 3:1 and projected that electricity supply has to increase by nearly 100% in every 5 years until 2030 (see Fig. 4), otherwise local demand cannot be met [28]; let alone meet the Millennium Development Goals (MDG) target which is envisaged to enable Nigeria attain the status of a developed nation by 2015. Also, it is argued that the

~ 319 ~
energy demand projections are underestimated because it does not capture the improvement in purchasing power of the poor population who generally have limited access to energy [32]. Although the projection shown in Fig. 4 was made almost a decade ago, it remains uncertain if the country is capable of overcoming its electricity supply predicaments [26, 33]. Thus, it can be said that not only is there a suppressed energy demand in Nigeria, but also all sectors including buildings will have to cope with this shortage due to constant pressure from an increasing population and urban growth, in the interim pending a substantive energy supply solution.

The idea of the new capital was conceived for two reasons. First, the congestion, overcrowding and squashed environments existing in Lagos were deemed not befitting of the country’s capital [21, 34, 35]. Secondly, there was a need to locate the capital in an area that is neutral to all parties following tensions and disunity caused by coup plots, and a place readily accessible to all; unlike the old coastal capital Lagos [34, 35]. The Abuja project design was led by a consortium of international planners and architects and some local architects as well [26, 37]. At the beginning of the project, it was regarded as the biggest project of that time [20]. The planned development of the main city was phased into four as shown in Figure 6.

III. ENERGY CONSUMPTION IN THE BUILT ENVIRONMENT OF ABUJA

Abuja is the new capital of Nigeria, conceived since the 70’s and substantively relocated from Lagos in 1991. It is located within Lat 7° 25' N and 9° 20' North and Long 5° 45' E and 7° 3' E of Greenwich Meridian making it almost exactly at the centre of the country and almost equidistant to all its boundaries as shown in Fig. 5.

Figure 5: Map of Abuja
(with planned city development shaded in white colour)

The city accounts for just under 1% of the country's total land mass (with a total planned area of 8,000km²) and it is increasingly becoming an important urban settlement on the Nigerian landscape [21]. It had a projected population of less than 250,000 and not exceeding 3.2 million upon completion of Phase 1 and Phase 4 (all the phases) respectively [37].

However, with only the Phase 1 barely completed, the population of Abuja has increased from 400,000 inhabitants to over 1.4 million from 1991 to 2006, indicating more than a 100% increase [37-39]. Although it is assumed that the real figures are higher than what the Census figures depict due to circumstances in which the census was conducted, the city's urban growth rate is said to be between 20-30% annually [22, 24].

The trend of these growth rates in the capital suggests a significant adverse impact of the development on the infrastructure, particularly if the infrastructural growth rates do not match that of the population and urban growth. For example, in terms of energy supply, it was envisaged that a supply shortage was imminent if the infrastructure base was not improved [40]. Thus, energy supplies to neighbouring settlements had to be diverted often, in order to complement energy shortages in the capital [40]. This indicates that unless there is an appropriate increase in

~ 320 ~
energy supply, the city will be faced with a significant energy shortage upon completion of the subsequent phases.

At present, such energy shortages are supplemented by the use of largely diesel powered generators despite the inherent potential adverse environmental implications [29, 31, 41]. In fact, it is claimed that, almost 12-13 million litres of fuel are consumed daily on generators used to supplement the electric energy shortages [42] with all sectors including commercial, industrial and residential sectors, actively pursuing this indulgence.

Figure 7: Electricity consumption trend in the residential, commercial and industrial sectors 1970-2005
Source: Babatunde and Shonibare (2011)

![Electricity Consumption Chart](image)

Fig. 7 above shows energy consumption trends in Nigeria. The figure also shows the impacts of buildings generally on the country’s total electricity consumption. It also illustrates a significant rise in commercial sector energy consumption (which includes office buildings), since the early 1990s such that it exceeds that of the industrial sector. The periods where significant increase in energy consumption by commercial sectors is observed (from 1990) also coincides with the periods when Abuja became a substantive capital. However, it is noteworthy to mention here that despite the relocation of the capital from Lagos to Abuja, Lagos remained an important commercial centre. Thus, that period can be characterised by the presence of two commercial hubs in the country. Unlike Lagos and other major cities in Nigeria, the Abuja urban centre can be characterised by the dominance of office buildings which can largely be attributed to the role of the city as the country’s administrative capital, and a preferred location of corporate head offices and foreign missions. Therefore, it can be said that office buildings, as a subset of commercial buildings, have an impact on the country’s energy consumption.

But, establishing the electric energy consumption profile of Abuja is not a straightforward task owing to numerous factors. Firstly, the total energy allocations according to states were not obtainable at the time of this writing; which is due to lack of a central statistical pool for energy data and record. Such occurrence has been identified as a common challenge in most in most developing countries [43]. Secondly, the formation of Abuja necessitated the alteration of neighbouring states and regional boundaries [40]. In the process, utility districts initially linked to other

state electricity grids were now under the administration of the new capital. This also constituted a bureaucratic hiatus in the collection and collation of energy data. And thirdly, available records often provide incomplete data series and insufficient level of disaggregation and consistency. Nonetheless, extracted energy allocations compiled from the 11 Business Units (electricity distribution office) data files comprised in Abuja for 2009 are shown in Fig. 8.

![Energy Consumption Profile Chart](image)

Fig 8: Energy Consumption Profile in Abuja (by Sector) 2009

<table>
<thead>
<tr>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Municipal</th>
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<tr>
<td>61%</td>
<td>37%</td>
<td>1%</td>
<td>1%</td>
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</table>

Source: PHCN Energy Consumption Data file 2008-2009 for Abuja (Compiled by Researcher)

Also, the constant alterations in the master plan, particularly the addition of more ministerial buildings to the original plan was forecast to further complicate the energy demand situation in Abuja [40]. At present, Abuja
accounts for over 10% of the total annual electricity delivered from grid, making it the 4th highest consumer and ranking ahead of other older established cities including Port Harcourt, Kaduna, Kano and Jos [33].

In addition, commercial buildings (including offices) and residential buildings account for 4.2% and 48.97% of total load allocation in Abuja’s master plan respectively[37]. Nonetheless, commercial buildings consume up to 37% of electricity in Abuja as shown in Figure 8 above. This suggests that the commercial building sector has a significant impact on local energy demands despite its seemingly smaller proportion.

Also, according to the PHCN data file, more than 10% of commercial buildings are categorised as Maximum Demand consumers (MDs). These are described as consumers with very high energy demands, such that they are provided with dedicated transformers; these are mostly government and ministerial office buildings. Most of the energy demands for such buildings are often attributed to the need for cooling [44, 45].

But with an increasing shortage in electricity supply, numerous public office buildings use generators as the immediate electricity back up. The practice is fast becoming part of the vernacular architecture within the Nigerian built environment [29]. It postulated that unless the prevailing electricity shortage is addressed, it will remain impossible to develop and maintain international standard high-rise and corporate buildings as often prescribed in the Abuja master plan [17].

In fact, such energy use imbalances for buildings have stimulated a movement for the establishment of a Green Building Council and related energy use standards for buildings in Nigeria under the auspices of Architects Registration Council of Nigeria (ARCON) [46-49].

From the above discussions, it is clear that an energy conservation and demand side management approach have been marginalised in the mitigation of energy use in buildings due to dominance of a supply side remedial approach to the energy shortage. Therefore, it becomes important to rationalise the use of energy in buildings since electricity is the primary energy source available for buildings in general and in particular the office buildings typology under study.

IV. METHODOLOGY
The study employed a case study approach where Abuja was identified as a suitable study site due to its accessibility within the country. It also boasts of a wide array of office building types, hence providing sufficient case study opportunities. Case study approach is widely used approach in the field of social sciences and has been applied for studies of this nature [30, 31].

The UK’s office building categorisation as contained in the Energy Consumption Guide 19 for office buildings was adopted for the study, in view of the absence of similar literature specific to the study area. As recommended in the Guide, all the office buildings selected should have a total floor area greater than 2000m², which complies with the EU’s EBPD threshold for large buildings deemed capable of having significant energy demand. The selected case studies falls into category 2 and 3 of the Guide’s classification as shown in Figure 9. This classification ensures that offices housing similar activities and using similar equipment, particularly HVAC, are classified together.

Figure 9: Classification of Office Buildings in the UK for Energy Consumption Assessment


Another important consideration was the fuel type (source/type of energy servicing the building which in this case is electricity).

In this study, government office buildings were particularly selected since governments are key drivers in energy policy formulation for buildings and as such should be able to demonstrate their readiness and commitment towards building energy efficiency/performance initiatives, using their own premises. The selected case studies belong to modern buildings, as referred to in the context of Nigeria, which represents over 30% of the built environment [52].

The selected buildings are mostly not jointly occupied and operate normal official working hours of 8.00am to 4.00pm (Monday – Friday), with not more than 10% of staff working no more than additional 4 hours daily of overtime. The buildings: are between 3 to 9 floors high though up to 22 floors is allowed within the Abuja CBD, but with varying floor to ceiling high heights. The location
of the office buildings largely lies within the CBD of the city, as shown in Figure 10, where the highest concentration of office can be found and accounts for areas where the planned developments have been completed.

The case study investigation was conducted via a field study with the aid of a drafted building survey form as applied in similar works [53][54][51], to guide and ensure comparable sets of data are obtained across all the buildings.

A total of 20 buildings were selected and approached to participate in the study. 17 responded positively, 3 did not respond at all and none declined. Key officials dealing with the buildings management were identified and were served pre notification letters prior to the dates of the survey. Energy bills for yearly time series were obtained. The survey also took records of the energy end uses in the buildings to include mainly lighting, air conditioning and ventilation, equipment and building services (lifts etc.). Due to the poor energy supply infrastructure, the study also took account of the diesel based generators widely adopted as alternate energy source to supplement energy shortages.

V. ENERGY USE INDEX (EUI) FOR OFFICE BUILDINGS IN NIGERIA

EUI was calculated for the studied offices. The EUI is a widely used energy use indicator, as well as a basis for energy use comparisons of similar buildings [2, 7, 53]. It is derived by dividing the annual total energy consumption by the gross total floor area. Time series utility bills for 2009 and 2010 from the site survey and energy audits fieldwork exercise were used to compute the annual energy consumption.

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<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUI</td>
<td>15</td>
<td>13.50</td>
<td>134.30</td>
<td>58.6667</td>
<td>45.19113</td>
</tr>
<tr>
<td>Valid N</td>
<td>15</td>
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</table>

The EUI indicated is very low compared to other global reporting [2, 55]. This may not be unconnected to the fact that there is a suppressed energy consumption scenario [28]. This was substantiated by the percentage availability duration of electricity from the primary source discussed above. In addition, the study's limitation considered only energy consumed from PHCN while energy consumption from generator use was not integrated into the overall energy consumption.

Total gross floor area of individual offices studied ranged from 2300-27500m² with a combined total of 142228m². The scatter diagram in Fig. 11 did not indicate a concise pattern of relationship between the EUI and gross total floor area. Although it can be said that the buildings with total gross floor area greater than 10000m² lied more within region of higher EUI expect for the lone building to the extreme left of the diagram which has the highest gross total floor area of 27500m² and a corresponding lowest EUI of 13KWh/m² annum.

Fig 12 shows a scatter diagram of the EUI and the buildings date of construction. The year of construction of the office buildings studied spanned from 1991 (when Abuja officially assumed status of the Nigeria’s capital city) to 2009. No apparent relationship was drawn from the scatter diagram. However, EUI of buildings in the early
1990s was substantially low, and then there appears to be an increase in EUI in the mid 1990s until 2000. A decrease in EUI was noticed between 2000 and 2005 while more recent buildings from 2006 to 2009 showed a significant increase in EUI.

VI. DISCUSSIONS

Arguably, the buildings studied cannot be said to have good energy performance as suggested by the derived EUI due to already established suppressed energy supply scenario. In fact, the obtained building energy information shows that the buildings experienced frequent sporadic electricity supply fluctuations, with daily average availability durations electricity from primary source (PHCN) lasting for 2.8hrs of the working hours (i.e. 47.5%).

Figure 12: EUI vs Date of Construction of Government Office Buildings in Nigeria

In part, this situation made the quantification of energy consumption of the building with the aid of direct metering equipment unsuitable in this study. Meanwhile, each office has diesel powered generators as backup with an average daily usage of 4.9hrs of the working hours (i.e. 61.25%). Installed generator capacity vary from 350-1800Kva across the offices with an average of 1140Kva.

However, there are numerous energy saving opportunities. For example, Abuja, like most of Nigeria enjoys an average of 10hrs daylight and 6hours sunshine all year round. It is therefore important that this potential is harnessed to reduce energy consumption due to lighting. This can provide up to 15% reduction in overall energy consumption.

Also, the end use energy audit shows that cooling accounts for an average of 60% of energy consumed in all the buildings. The need for air conditioning can be well understood due to the climatic disposition of the study area. Abuja is famed with temperatures averaging 29°C all year round. Perhaps this explains the high percentage of energy consumption as a result of air conditioning. The buildings had many types of air-conditioning installations ranging from window units, split package, mini central and central air conditioning systems all of varying capacities.

Other variations of cooling strategies should be explored from passive design to enduse applications such as water cooled air conditioners. Similarly the application of fans should be considered since it is sufficient to provide conducive indoor climate [56].

Also, offices should be encouraged to use only energy efficient equipments. Appropriate rating systems of energy labels such as the Energy Star should be identified and made available for use. This can be tied to the development of enforceable building energy codes, whose absence contributes to manifestation of energy inefficient buildings [10]. This should be able to prescribe the appropriate energy requirement for buildings.

Monitoring and benchmarks to cap energy consumption. Also, reward and penalties should be applied for compliance and default respectively.

Lastly, occupant awareness should be incorporated because end users also have a significant impact on a buildings energy use [57]. Basic principle such as ‘Don’t
switch it if you don’t use it” can be an important forward step [55].

VII. CONCLUSIONS

The study examined the status and impact of commercial buildings (including office buildings) in Abuja. While acknowledging the country’s abundant energy resources, the study established a suppressed energy demand scenario particularly for the urban built environment where electricity is its main source of energy. As such, widespread use of diesel powered generators have been necessitated to make up the supply shortages. This study showed that commercial and residential building sector accounts for 37% and 61% consumption of the energy supply respectively. This confirmed that commercial buildings have a significant impact on the city’s energy supply. Thus, the study examined the energy performance of 17 government office buildings using the EUI as an indicator. Derived EUI ranged between 13KWh/m²a – 134 KWh/m²a which is significantly lower than other global reporting. Sporadic energy availability is considered as an important factor for this positioning. The examined building’s total floor area as well as the date of their construction was evaluated alongside the derived EUI, but without any apparent correlation established. Energy saving potentials covering both end uses as well as building operational regimen was identified together with other recommendations.

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PROMOTING ENERGY USE REGULATIONS FOR A SUSTAINABLE BUILT ENVIRONMENT IN NIGERIA

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Abstract
There have been growing concerns on energy supply, resource depletion and sustainable development owing to rapid growth in energy use, particularly within the built environment. To this effect, building energy standards have been developed and are persistently implemented across the world in order to achieve sustainable energy efficient buildings. However, it is noted that most of these initiatives seem to be confined to developed countries. Whilst most developing countries tend to be lagging behind, others seem not to be pursuing similar objectives. This highlights a potential gap between the aspirations for sustainable energy efficient buildings and the development of building design in developing countries. In this paper, building standards and regulations in Nigeria is reviewed. It illustrates the challenges to tackle endemic local issues while aspiring to move in tandem with the rest of the world.

Keywords: building code, building regulations, energy efficiency, energy use, sustainable buildings.

INTRODUCTION
In response to dwindling energy resources and subsequent adverse environmental consequences, energy use has become an important policy issue across the world. In particular, the built environment has come under much scrutiny due to the huge amounts of energy consumed and resultant carbon emissions which it accounts for (Kasozi & Tutesigensi, 2007; McLennan, 2004; Perez-Lombard, Ortiz, & Pout, 2008). As such, building standards and other regulatory frameworks have been developed and enforced to ensure a sustainable and energy efficient building stock. The UK’s Code for Sustainable Homes, Energy Consumption Guide for Office Buildings (ECON 19), Israel Standard 5282 and the National Energy Code of Canada for Buildings (NECB) are some examples of existing energy codes for buildings.

While most developed nations are aggressively pursuing this vision, there is limited documentation of the developing world’s effort in this regard (Iwaro & Mwasha, 2010). Meanwhile, there are evidences of significant building development projects in developing countries particularly those in Africa, which at present is experiencing sporadic wealth dispositions precipitated by oil discoveries in countries such as Cameroun, Ghana, Angola, Sudan, Chad, Libya and even diamonds in Zimbabwe.

To this effect it is important to evaluate energy use regulatory mechanisms applied in the context of developing countries. This should bear in mind the endemic poverty and health issues which abound, as well as local aspiration to progress into the developed world’s status. This study critiques the situation in Nigeria as a prototypical case study of a sub Saharan African country which in many ways is an important exemplar to the rest of the African continent.

GLOBAL STATUS OF BUILDING ENERGY CODES
Building energy use regulations exists in three broad categories namely; economic incentives (e.g. taxes), informational programmes (e.g. awareness programmes) and regulatory requirements (e.g. building codes and standards) (Lee & Yik, 2004). Its application occurs either in voluntary, mandatory requirement or mixed forms. More recently, the use of building energy codes/standards has become widespread due to increase in public-private participation. The application of the Leadership in Energy and Environmental Design (LEEDS) rating scheme for buildings in the US and the emergence of organisations such as the Green Building Councils in countries around the world including the UK, US, Canada and Japan (King, 2008; McLennan, 2004) are examples of such public-private participations that tends to promote a sustainable energy use agenda for the built environment.
Building’s energy use standards/regulation, often referred to as codes are obtainable as a single document, or parts of several other documents or simply subsumed in broader regulatory handbooks, guidelines, laws or legislations all channelled towards reducing energy consumption in buildings.

An early survey of world status on building energy codes development involving 57 countries revealed that only 38 had some form of substantive documents while only 6 have made such proposals (K. B. Janda & Busch, 1994). An update of a similar survey involving 81 countries, indicated an increase which showed that 61 and 11 countries had substantive energy codes and proposed codes respectively (K. Janda, 2009). An analysis of these surveys revealed that most of the countries with any form of energy code for buildings belonged to the developed world category. In their survey, Moisan and Bosseboeuf (2005) confirmed that all of the European countries had one form of mandatory energy code or the other for the built environment.

In contrast, only one country (Tunisia) of the 6 African countries (of the existing 52 countries in Africa) captured in the surveys mentioned above had a mandatory code.

A more recent survey on the status of building energy code development involving 60 developing countries revealed that 42% of developing countries have none in place, 20% have mandatory, 22% have mixed and 16% have made proposals (Iwaro & Mwasha, 2010). It also revealed that 70% of the African countries (including Nigeria) involved in the survey did not have any code in place. While 5% have a mandatory code, 10% have mixed and 15% have proposed codes.

AN OVERVIEW OF BUILDING DEVELOPMENT AND THE ENERGY SCENARIO IN NIGERIA

Without doubt, Nigeria is the most populous country in Africa with an estimated population of over 150 million people and an annual growth rate of 3%. However, the notion that Nigeria is the giant of Africa seems to be expressed only in population figures and not reflective of local infrastructure and energy accessibility issues. In fact it does not fare well compared to other continental energy giants like Egypt and South Africa where more than 70% of their population have access to electricity. Whereas in Nigeria less than 45% of the population have such privileges (Bugaje, 2006).

Currently, Nigeria is the 12th largest petroleum producer in the world and holds the largest natural gas reserve in Africa (EIA, 2010; OPEC, 2009). Thus, it is no surprise that the economy is fuelled by oil revenues which in turn supports its rapid urban development. It is noted that most of these developments are underpinned by the need to reflect national economic relevance to regional and international community’s (Take, 1984; Uduku, 2006). Hence numerous buildings are developed attuned to international style typologies which turn out to be high maintenance buildings due to their significant energy consumption (Adegoroye, 1997; Imaah, 2004).

Meanwhile, the electric energy supply infrastructure in Nigeria (monopolised by the Power Holding Corporation of Nigeria - PHCN) which is the only primary source of energy to buildings, have been characterised by endemic instability, inadequacy and unreliability, such that Government Reforms since 2001 had to be initiated (Ikeme & Ebohn, 2005; Okoro & Chikuni, 2007; Olukoju, 2004). This aimed at neutralising the monopoly enjoyed by the PHCN over the generation, transmission and distribution of electricity across the nation in order to enable other Independent Power Providers (IPP) to participate in energy supply delivery. However, ten years afterwards, there remain little changes in the availability and accessibility of electricity across the nation in comparison to designed projections (Akinwumi, Obioh, Momodu, & Akinbami, 2009; Sambo, 2008).

Consequently, fuelwood have been generally used to bridge the energy supply gap with more prevalence amongst rural communities even though it applies to many parts of the urban centres. For most urban communities, the energy supply gap is bridged through the use of fuel based generators (Akarakiri, 1999; Oluba, 2008) which is widespread such that it is fast becoming part of the vernacular architecture.

This positioning is not devoid of environmental repercussions in addition to cost/maintenance implications. Yet it seems a veritable option to consumers, perhaps owing to available fuel subsidies. This trend is likely to persist unless the electricity predicament is resolved or some form of energy use regulation is enforced.
Although initiatives such as researches on energy conservation in buildings, energy use awareness programmes, and solar energy exploration and utilisation are vigorously pursued by the Energy Commission of Nigeria - ECN (Sambo, 2008; Zarma, 2008) it seems to have limited application to street lighting. The initial cost of these solar energy equipments in addition to petro-diesel subsidies enjoyed in the country, perhaps undermines the thrust towards renewable energy utilisation. More so, the Commission’s new Centre for Energy Efficiency and Conservation Research is still at its infancy to make an impact unto the public domain.

Other notable contributors to energy conservation awareness include government agencies such as the National Electricity Regulatory Commission (NERC) as well as nongovernmental organisations such as Energetic Solutions, Environmental Rights Action/Friends of the Earth Nigeria (ERA/FoEN) and Community Research and Development Centre (CREDC).

BUILDING REGULATIONS AND ENERGY USE IN THE NIGERIAN BUILT ENVIRONMENT

Building regulation and urban development planning have existed in Nigeria since pre colonial times as evidenced in walled cities, fortresses and the tripartite urban configuration (comprising the place, market and shrine) across the regions of the country. However, it can be said that the input from the British Research Institute (BRI) which provided British architects who operated along the Gold Coast, technical support and advice regarding materials and environmental design for the tropics (Le Roux, 2004; Uduku, 2006) formed initial templates that developed into early reference documents for building regulations in Nigeria. Although these regulations were more concerned with the spatial context of urban planning to suit colonial aspirations, its derivates continued to be adopted for post-colonial projects such as the Abuja urban development.

The Federal Capital Development Authority (FCDA) which was charged with the responsibility of planning and developing the new capital relied on such documents and experiences gained from the old capital, Lagos. It was until 1996 that the new capital published its own set of building development regulations. However, a review was necessitated in 2006 due to significant distortions in the master plan. There was also the need to avoid a repeat of the Lagos experience, characterised by traffic congestions, development of slums and squalor settlements. Hence, the regulation focused on strict adherence to spatial designs, infrastructural development, and scenic environment that befits the new capital.

About the same time, the first National Building Code – NBC was established in 2006 amidst the prevailing rapid urban sprawl. Though the code had existed in a Draft form since 1987, it was reviewed in 1989 and last reviewed in 1991; where it remained yet again in a Draft form (NBC, 2006). It was until in 2005 that the government revisited the code owing to increasing pressure to tackle widespread building collapse particularly in its two main cities, Lagos and Abuja. This was attributed to the demand for speedy project delivery particularly because of the directive to relocate the seat of government and its associated administrative mechanisms to Abuja.

Although the directive itself is not the cause for the building collapse, it can be argued that it stimulated an already vibrant property development sub-sector such that developers changed building’s use to that other than which it was designed for in order to meet the growing building demands. Meanwhile, some developers simply compromised standard building procedures at the expense of speedy project delivery (Olabosipo & Adedamola, 2010). However, analysts contend that the use of poor quality building materials play a critical role in building collapse (Dimuna, 2010; Olajumoke, Oke, Fajobi, & Ogedengbe, 2009). Furthermore, the infiltration of nonprofessionals (quacks) already operating within the construction industry also complicates the situation (Ede, 2010).

Hence the swift response to address these concerns of building collapse, perhaps explains the limited attention given to energy efficiency and contemporary sustainability issues in the NBC. The NBC is primarily divided into four parts. The first part titled “Administration” discusses housekeeping issues; providing definitions, interpretations and meaning of abbreviations. Most importantly, it clearly states the pivotal reasons behind the evolution of the NBC as listed below:

1. Poor towns and cities planning
2. Incessant building collapse, fire, built environment decay and abuse
3. Dearth of referenced design standards and professionals
4. Use of non-professionals
5. Use of untested products and materials
6. Lack of adequate regulations and sanctions against offenders

The second part describes building categorisation that were referred to in the code while the third part discusses the entire building construction processes whilst expressing responsibilities of all associated building professionals at each stage in relation to the type of building in question. In the last section, details on the code’s enforcement procedure are provided with accompanying form samples that confirms all professional instructions/actions taken on any construction work.

Generally, the code extensively deals with issues on structural integrity as well as occupant health and safety as entailed within the perspectives of building professionals in any project delivery (Tolulope, 2006). For example, the code emphasised the importance of a thermally comfortable environment in order to ensure healthy well-being of occupants. However, the code provided a largely general prescriptive requirement for building openings. Though it indicated the need for adequate ventilation, it did not assert any preference on the ventilation strategy, whether natural or mechanical; let alone the consequent energy requirement thereof.

Also, there was no mention to suggest U-values for walls as may be expected in building thermal comfort performance requirements. Instead, focus was on minimum requirements for block/brick sizing, compactness of aggregates, compressive strengths and fire resistances durations. Perhaps this explains the indiscriminate use of glazing, light/heavy weight materials for building fabric, in addition to widespread use of air-conditioning systems. Similarly, the same kind of non prescriptive approach was applied to issues concerning lighting requirements.

While these may have positive implications that suggests design liberty and unhindered creativity within the realms of architecture, it indicates the absence of any tool or design measures that recognise the endemic limited energy supply situation.

Conversely, in countries where substantive energy codes for building exist, such as the UK, definitive guides for building types are available. For example, the Energy Consumption Guide 19 (ECON 19) focuses on office buildings and has recommended energy use benchmarks for all categories of office building types according to its classifications. It recommends baseline EUI’s (Energy Use Index - that is total annual energy use/gross floor area) and suggests energy use benchmarks for broad end uses including heating and hot water, office equipment, lighting and cooling.

Thus, it may have been appropriate to develop certain standards/statutory measures that indicate minimum ventilation rates, energy use per person and even energy ratings for appliances for buildings in Nigeria. Although this task may seem beyond the jurisdiction of architects and Architectural Practices, it is a potentially useful area to imbibe an intra disciplinary collaborative research amongst professionals engaged in the building industry. The Nigerian Institute of Architects’ (NIA) Building Research and Standards (BRS) Committee and the National Building and Road Research Institute (NBIRI), amongst others may find the challenge worthwhile.

CONCLUSIONS

“The construction industry is an indispensable service industry that contributes immensely to the process of the development of the environment. Therefore, the industry plays a key role in the development and degradation of the environment depending on the outcome of the actions at stake” (Fadamiro & Ogunsemi, 2004).

Without doubt, building energy use regulation plays a critical role in the development of energy efficient buildings as well as ensuring sustainable development of the wider environment. However, the advancement of these regulations seems to be aggressively pursued within developed countries, while very little can be said of the developing countries.

Understandably, the pressure from local challenges underlies the neglect towards energy consciousness as a requisite requirement in the development of building’s energy use regulation in developing countries as evident in the case of Nigeria.

Although in Nigeria the developments in building regulations are equally plausible in addressing local challenges, a wider intra disciplinary collaboration is necessary to push forward an enforceable sustainability agenda for the built environment. Other synergies should also be enabled at regional and
international levels such that the generic microcosmic solutions are in such concordance with other initiatives to safeguard the macrocosmic environment.

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