EVALUATING PASSIVE COOLING STRATEGIES FOR ENERGY EFFICIENCY IN THE DESIGN OF SENATE BUILDING FOR FEDERAL UNIVERSITY KASHERE, GOMBE STATE

By

Abdulhamid YAHUZA B.Sc. Arch (ABU ZARIA, 2014)
P13EVAT8045

A DISSERTATION SUBMITTED TO THE SCHOOL OF POST GRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF A

MASTERS OF SCIENCE DEGREE IN ARCHITECTURE

DEPARTMENT OF ARCHITECTURE
FACULTY OF ENVIROENMENTAL DESIGN
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

APRIL, 2018

DECLARATION

I declare that the work in this dissertation entitled “Evaluating Passive Cooling Strategies For Energy Efficiency In The Design Of Senate Building For Federal University Kashere, Gombe State" has been performed by me in the Department of Architecture. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project dissertation was previously presented for another degree or diploma at any university.

Yahuza Abdulhamid		April, 2018
Name of student	Signature	Date

CERTIFICATION

This dissertation entitled “EVALUATING PASSIVE COOLING STRATEGIES FOR ENERGY EFFICIENCY IN THE DESIGN OF SENATE BUILDING FOR FEDERAL UNIVERSITY KASHERE, GOMBE STATE" by Abdulhamid YAHUZA meets the regulations governing the award of the degree of Master of Science in Architecture of Ahmadu Bello University, and is approved for it contribution to knowledge and literary presentation.

Chairman, Supervisory Committee Dr. M.O. Gafar	Signature	Date
Member, Supervisory Committee Prof. M. L. Sagada	Signature	Date
Head of Department Dr. A.S. Salisu	Signature	Date
Dean, School of Postgraduate Studies Prof. S. Z. Abubakar	Signature	Date

ACKNOWLEDGEMENT

I am grateful to Almighty Allah, the sustainer who out of his mercy made it possible for me to conduct this research and also for being there for me through all odds of life.

To my major supervisor, Dr M.O Gafar, I would say Special thanks to you for supervising this dissertation, encouragement and support. I am very grateful for his commitment in ensuring the success of this dissertation, you are simply amazing sir. Also, the role played by my minor supervisor Dr. H. T. Kimeng is very commendable. He has been very committed in ensuring standard was followed in the conduct of this research.

I pray that Almighty Allah grant my late father, Malam Yahuza Dahiru *Jannatul Firdaus* who died around fourteen years now, he would love to see me reaching this milestone in life but Allah knows best.

To my mother who merged the roles of the father and the mother together, she identified my talent and supported me until I come to this level. May Almighty Allah reward her abundantly, give her long and healthy life, wealth and wisdom to carry on.

I am short of words to express how grateful I am to my role model and also a father, Alhaji Salisu Muhammad Gombe, who shared my academic burden right from time, he supported me, encouraged me; Sir I appreciate everything you did to me and I hope we build on where stop.

To all my family members especially the most senior brother in the family, Alhaji Aliyu Yahuza and my dear wife, I appreciate you for being there for me, your prayers, assistance and encouragement.

My colleagues in the department of architecture and everywhere especially those that provided me with some materials and encouragement like Abdullahi Usman Muhammad, I say thank you, God bless you all.

ABTSRACT

Apparently, Nigeria is struggling with the developmental issues of the incessant power outage and lack of energy services. The primary sources of energy for office building are from national grid and gasoline generators. However, the former is not reliable and the latter is unsustainable; hence, the need to explore energy efficiency strategies to cut down the energy demand for cooling office building in Nigeria is unavoidable. This dissertation aimed to assess the energy efficiency or performance index of the Nigerian Universities' senate buildings in the north-eastern region (dry sub-humid climate). The research employed a case study approach, construction of baseline model with the Revit architecture software and applied Autodesk's Ecotect building analysis software to evaluate the energy performance of the senate building as built. Three local case studies and one foreign case study were selected such as university administrative building of Modibbo Adama University of Technology, Yola (MAUTECH), senate building of Abubakar Tafawa Balewa University, Bauchi (ATBU), university administrative building of Gombe State University, Gombe (GSU) and the Chancellery office building of University Kebangsaan (UKM), Malaysia. Although, operating appliances release heat to interior spaces of the building but the scope of the study deals with the performance of the building envelope as a whole. In terms of adherence to the checklist, MAUTECH senate and ATBU some scored 65%, GSU got 78% while UKM got 94%. The simulation results show that in MAUTECH, as high as 141.4kwh/m^2 of heating/cooling required per annum; ATBU senate got 127.3kwh/m2; GSU senate had 97.4kwh/m^2; UKM had 20.5kwh/m^2 Annual Energy. These results have indicated that more efforts should gear towards exploring energy efficiency strategies in office building designs

because the results are far away from the British standards of 15kwh/m2 for energy efficient office buildings. Then, the proposed senate building incorporated sustainable design features such as deciduous trees, double glazing, void, screen walls, horizontal and vertical shading devices, water surfaces, etc.; after the simulation, it was found out that 22.67kwh/m^2 Annual energy which is very closer to the stipulated British standard of *15wh/m^2* and 68.92% reduction was achieved. Therefore, research implication is that it is essential for the architects and engineers to incorporate more proactive energy efficiency strategies in the design of office buildings in Nigeria.

TABLE OF CONTENTS

Title Page……...ii

Declaration……ii

Certification iii

Acknowledgement iv

Abtsract v

Table of Contents……...……..……...…...vii

List of Tables xii

List of Figures xii

List of Plates xvii

List of Appendices xviii

Abbreviations xix

1.0 INTRODUCTION 1

1.1 Background of the Study 1

1.2 Problem Statement 3

1.3 Justification of Study 3

1.4 Aim and Objectives of Study 4

1.5 Research Questions 5

1.6 Scope……..……5

1.7 Significance 6

2.0 LITERATURE REVIEW 7

2.1 Energy Efficiency 7

2.2 Situation of energy supply in Nigeria **7**

2.3 Energy Efficiency in Buildings **8**

2.3.1 Selection of site 10

2.3.2 Building shape and size 11

2.3.3 Use of building 11

2.3.4 Fenestration and orientation 11

2.3.5 Energy and building form 12

2.3.6 Effect of solar radiation on building's orientation 13

2.3.7 Effect of building height solar shading 15

2.3.8 Effect of solar radiation on height to width ratios 16

2.3.9 Energy and Building Materials 18

2.3.10 Insulation used as a resistance to heat flow; Mechanism of thermal mass 21

2.4 Status of Passive Cooling Developments in Dry Sub-Humid/Bsh Subtropical Steppe **23**

2.5 Contemporary Methods of Passive Cooling **23**

2.5.1 Solar and heat protection techniques 24

2.5.2 Modulation of heat gains 25

2.5.3 Heat dissipation technique (*Remove internal heat)* 26

2.6 The need for Senate Building in Federal University Kashere, Gombe **31**

2.7 Summary of Findings from Literature Review **31**

3.0 RESEARCH METHODOLOGY **33**

3.1 Preamble **33**

3.2 Research Population **33**

3.3 Sampling Technique 33

3.4 Case Study Approach 34

3.4.1 Case Study Selection Criteria 34

3.4.2 Selected Cases to be studied 34

3.5 Research Design 35

3.6 Dependent and Independent Variables 35

3.7 Methods of Data Collection 36

3.7.1 Visual survey 36

3.7.2 Computer Simulation 36

3.7.3 Selecting Energy Analysis Computer Programs 40

3.8 Analysis 41

3.8.1 Parametric analysis with computer simulations 42

4.0 RESULTS 43

4.1 Preamble 43

4.2 Findings from Case Study A: Modibbo Adama University of Science and Technology (MAUTECH) Administrative Building 43

4.2.1 Passive cooling techniques 43

4.3 Findings from Case Study B: Abubakar Tafawa Balewa University, Bauchi (ATBU) Senate Building 51

4.3.1 Passive cooling techniques 51

4.4 Findings from Case Study C: Gombe State University (GSU) Senate Building 61

4.4.1 Passive cooling techniques 61

4.5 Preliminaries for simulation 69

4.6 Environment for the Experiment **70**

4.7 Monthly heating/cooling Loads **70**

4.7.1 Monthly heating/cooling loads for MAUTECH senate building **71**

4.7.2 Monthly heating/cooling loads for ATBU senate building **73**

4.7.3 monthly heating/cooling loads for GSU senate building **76**

4.8 Discussions of Findings **78**

4.8.1 Discussion of findings from visual survey 78

4.8.2 Comparing the results of monthly energy load for ATBU, MAUTECH and GSU senate buildings 81

4.8.3 International Case Study: The Chancellery Building of University of Kebangsaan, Malaysia (UKM) 84

4.8.4 comparing the results of the three local case studies with the foreign Case Studies 86

5.0 DESIGN REPORT **87**

5.1 The Site **87**

5.1.1 Study Area 87

5.1.2 Site Selection Criteria 87

5.1.3 Site Location 88

5.2 Site analysis **89**

5.2.1 Site physical characteristic 89

5.3 Climatic Data Analysis **90**

5.3.1 Temperature 90

5.3.2 Wind 91

5.3.3 Precipitation 92

5.4 Services 92

5.5 Site Zoning 93

5.6 Simulation Results of Proposed Building 94

5.6.1 Wall 94

5.6.2 Roof 98

5.6.3 Window/Glazing 100

5.6.4 Presence of vegetation 102

5.6.5 Orientation 103

5.6.6 Building Form 103

5.7 Combination of Various Strategies 104

5.3.1 Energy savings with proposed combinations of strategies 104

6.0 CONCLUSION AND RECOMMENDATIONS 107

6.1 Conclusion 107

6.2 Contribution to Knowledge 107

6.3 Recommendations 108

6.4 Areas of Further Research 109

REFERENCES 110

APPENDICES 115

LIST OF TABLES

Table 2.1 Wall Characteristics used in Simulation. 22

Table 2.2 Climate and Suggested Design Responses 23

Table 3.1 General Information on Case Studies 37

Table 4.1a Result of Checklist used for the assessment of passive cooling Strategies on MAUTECH administrative building……..49

Table 4.1b Analysis of Checklist used for the assessment of Passive Cooling Techniques on MAUTECH Administrative Building……..……...50

Table 4.2a Checklist used for the assessment of passive cooling Techniques on ATBU Senate Building……..……..59

Table 4.2b Checklist used for the Assessment of Passive Cooling Techniques on ATBU Senate Building.....60

Table 4.3a Checklist used for the Assessment of Passive Cooling Techniques on GSU Administrative Building……67

Table 4.3b Checklist used for the Assessment of Passive Cooling Techniques on GSU Administrative Building…….……...68

Table 4.4 Summery of Level of Reflection of Checklists……...79

Table 5.1 Composition of Simulated Wall Types……...96

Table 5.2 The Proposed Roofs……99

Table 5.3 The Proposed Glazing……...100

Table 5.4 Energy Savings Annual Cooling Loads for Various Combination of Strategies.....105

Table 5.5 The Difference in Each of the Five Studied Variables 106

LIST OF FIGURES

Figure 2.1 Figure 2.1 The structure of Nigerian National Electricity Grid 8

Figure 2.2 Triangle for low energy building design 9

Figure 2.3 Factors governing energy consumption 10

Figure 2.4 Continuum of building climate response..... 12

Figure 2.5 Different forms of shape..... 13

Figure 2.6 Site considerations 14

Figure 2.7 Sun protection on all sides of the building..... 15

Figure 2.8 Various Shading Pattern 16

Figure 2.9 Solar radiation for different H/W ratios 17

Figure 2.10 Light shelves..... 18

Figure 2.11 Solar gain in opaque surface 19

Figure 2.12 Transmission of solar radiation through glass..... 19

Figure 2.13 Solar striking glass; the transmission of far infrared through glass 20

Figure 2.14 Stabilizing effect of chapter on internal temperature 21

Figure 2.15 Contemporary Methods of Passive Cooling..... 24

Figure 2.16 Evaporative Coolers (Swamp Coolers)…….27

Figure 2.17 Concept of wind driven cross ventilation system Source..... 28

Figure 2.18 Concept of buoyancy driven stack ventilation system 29

Figure 2.19 Concept of single-sided ventilation system..... 30

Figure 2.20 Research Theoretical Frame Work..... 32

Figure 4.1 Orientation of MAUTECH Administrative building 44

Figure 4.2 Ground floor plan of MAUTECH administrative building..... 45

Figure 4.3 Orientation of ATBU Senate Building..... 52

Figure 4.4 Floor Plan of ATBU Senate Building 52

Figure 4.5 Section across the Building Showing Natural Ventilation Methods..... 58

Figure 4.6 Site plan of GSU Administrative Building..... 62

Figure 4.7 Ground floor plan of GSU Administrative Building..... 62

Figure 4.8 Baseline model of MAUTECH Administrative Building 69

Figure 4.9 Visual Analysis of heating/cooling Loads of MAUTECH Administrative Building……71

Figure 4.10 Visual Analysis of Monthly heating/cooling Loads of MAUTECH Administrative Building's VC's Office……..72

Figure 4.11 Visual Analysis of Monthly heating/cooling Loads for Cooling MAUTECH Administrative Building; Council Chamber……..72

Figure 4.12 Baseline Model of ATBU Senate Building..... 73

Figure 4.13 Visual Analysis of Monthly heating/cooling Loads of ATBU Senate..... 74

Figure 4.14 Visual Analysis of Monthly heating/cooling Loads for Cooling ATBU Senate Building; VC's Office……74

Figure 4.15 Visual Analysis of Monthly heating/cooling Loads for Cooling ATBU Senate Building; Council Chamber 75

Figure 4.16 Baseline Model of GSU Administrative Building 76

Figure 4.17 Visual Analysis of Monthly heating/cooling Loads of GSU Administrative Building……...76

Figure 4.18 Visual Analysis of Monthly heating/cooling loads for Cooling GSU Administrative building; VC's Office……...77

Figure 4.19 Visual Analysis of Monthly heating/cooling loads for Cooling GSU Administrative building; Council Chamber……78

Figure 4.20 Level of Reflection of Passive Cooling Techniques on the Buildings.... 80

Figure 4.21 Monthly Energy Loads for ATBU, MAUTECH and GSU senates 81

Figure 4.22 Monthly Energy Loads for Council Chambers of MAUTECH, ATBU and GSU Senate Buildings……...……....83
Figure 4.23 Monthly Energy Loads for VC's Offices of MAUTECH, ATBU and GSU Senate Buildings……..…...…….…....84
Figure 4.24 Input and Output of Foreign Case Study…….84
Figure 4.25 Summary of Results of the four Case Studies…….86
Figure 5.1 Site Selection Criteria……..88
Figure 5.2 Site Location……88
Figure 5.3 Monthly temperature, average and extreme of Gombe……....91
Figure 5.4 Average daily wind speed……...……..91
Figure 5.5 Monthly precipitation amount……...92
Figure 5.6 Services 93
Figure 5.7 Site Zoning 93
Figure 5.8 Various Walls configuration 94
Figure 5.9 Percentage of energy reduction of various walls..... 97
Figure 5.10 Roof colours 98
Figure 5.11 Heating/cooling loads of various roof types..... 99
Figure 5.12 Heating/cooling loads of various roof types..... 101
Figure 5.13 Simulation with/without trees 102
Figure 5.14 Heating/cooling loads of various roof types..... 102
Figure 5.15 Heating/cooling loads of various roof types..... 103
Figure 5.16 Continuum of building climate response (Loonen, 2013)..... 104
Figure 5.17 Energy Savings annual cool load for various combination of strategies 106

LIST OF PLATES

Plate I Administrative building facing east with asphalt drive and few shrubs..... 45

Plate II Asphalt finished open space linking the three semidetached complexes.... 46

Plate III Soft landscape used from the south view..... 46

Plate IV Garden in the west elevation for cool breeze 47

Plate V North view of the building showing landscape features. 53

Plate VI East view of the building showing vegetation and grass cover. 54

Plate VII West view of the building showing trees shading some part of parking Spaces……...54

Plate VIII Use of balconies and recesses to provide shade for ATBU senate building 55

Plate IX Deciduous trees used to provide shading 55

Plate X Floor finish of ATBU senate building 56

Plate XI Exterior view from east elevation showing landscape features..... 63

Plate XII View from the courtyard showing landscape grasses and growing trees.... 63

Plate XIII Exterior view from east elevation showing projected wall as vertical shading device, roof overhang and window recess……..…...64

Plate XIV *Abuja brown* paint as wall finish……65

Plate XV Arcade in front of offices in GSU Senate building…….……66

Plate XVI Site Vegetation..... 90

LIST OF APPENDICES

APPENDIX I Project Information of the Baseline Model in Ecotect 115

APPENDIX II Daily Schedule of Activity for University Senate Building..... 115

APPENDIX III General Zones setting in ECOTECT 116

APPENDIX IV Thermal Properties of zones settings for Energy Simulation 116

APPENDIX V Monthly Heating/Cooling Loads of MAUTECH Admin. Building……..117

APPENDIX VI Monthly Heating/Cooling Loads of VC's Office of MAUTECH…….117

APPENDIX VII Monthly Heating/Cooling Loads of ATBU Senate Building 118

APPENDIX VIII Monthly Heating/Cooling Loads of VC's Office of ATBU 118

APPENDIX IX Monthly Heating/Cooling Loads of GSU Senate Building 119

APPENDIX X Monthly Heating/Cooling Loads of VC's Office of GSU 119

APPENDIX XI Monthly Heating/Cooling Loads of Council Chamber of ATBU…….120

APPENDIX XII Monthly Heating/Cooling Load of Council Chamber of GSU . 120

APPENDIX XIII Results of Monthly Heating/Cooling Loads for MAUTECH ATBU & GSU Senate Buildings……...121

APPENDIX XIV Results of Monthly Heating/Cooling Loads for the Council Chambers of MAUTECH, ATBU & GSU Senate Buildings…121

APPENDIX XV Results of Monthly Heating/Cooling Loads for the VC's Offices of MAUTECH, ATBU & GSU Senate Buildings……122

APPENDIX XVI Results of Monthly Energy Loads of Various Walls 122

APPENDIX XVII Heating/Cooling Loads in each of the Simulated Roofs 123

APPENDIX XVIII Heating/Cooling Loads in each of the Proposed Glazing 124

APPENDIX XIX Variable Cooling Loads for Vegetation..... 125

APPENDIX XX Energy Savings Annual Cooling Loads for Orientation 125

APPENDIX XXI Site Plan.……....…….…….126

APPENDIX XXII Ground Floor Plan…….…….…….…….126

APPENDIX XXIII First Floor Plan…….…….....…….127

APPENDIX XXIV Second Floor Plan…….…….…..…….127

APPENDIX XXV Third Floor Plan…….…..…...…..128

APPENDIX XXVI Fourth Floor Plan…….....…128

APPENDIX XXVII Fifth Floor Plan……..…...…..129

APPENDIX XXVIII Sixth Floor Plan…….…129

APPENDIX XXIX Roof Plan…….……130

APPENDIX XXX East and West Façade……..……...….130

APPENDIX XXXI South and North Façade……..…...….131

APPENDIX XXXII Section X-X and Section Y-Y……...……...…..131

APPENDIX XXXIII Summary of Sustainable Materials Used in the Proposed Senate Building……...……..……...132

APPENDIX XXXIV Perspectives View 1…….……...132

APPENDIX XXXV Perspective View 2……...……...133

APPENDIX XXXVI Perspective View 3……...…....133

APPENDIX XXXVII Perspective View 4……..……134

APPENDIX XXXVIII Perspective View 5…….....……..134

ABBREVIATIONS

ASHRAE	American Society of Heating Refrigerating and Air Conditioning Engineers
A/V.	Area to Volume ratio
BTU	British Thermal Unit
CIBSE	Chartered Institute of Building Services Engineers
CRD	Climate Responsive Design
FSEC	Florida Solar Energy Centre
HVAC	Heating Ventilation and Air Conditioning
HVM	Hostile Vehicle Mitigation
H/W	Height to Width ratio
MRT	Mean radiant temperature
PMV	predicted Mean Vote

1.0 INTRODUCTION

1.1 Background to the Study

It is a common fact that electricity is the fundamental energy source for industrial, commercial and domestic activity in the modern world. Presently, there are more than 150 million people living in Nigeria (McDonald, Green, Balk, Fekete, Todd & Montgomery, 2011). Also, the installed capacity of Nigeria's power sector is only capable of generating around 8000 MW of electricity, out of which only 4000 MW is operable and less than 2000 MW available to generate energy (Ogunleye, 2017). This is well below all economic projections and the country's consumer and business needs, despite government investment of around USD1 billion annually in the sector (Brimmo, Sodiq, Sofela & Kolo, 2017). The World Bank estimates that in Nigeria the per capita electricity consumption is 120.5 kWh; Compared to the annual world average of 2803 kWh in 2009 ((Brimmo et al., 2017).

Samuel, Katende, Daramola & Awelewa, (2014) noted that in Nigeria, the transmission lines are radial and are overloaded. The switchgears are obsolete while power transformers are poorly maintained. Overall transmission and distribution losses are in the range of 30–40%. The grid structure itself is unstable and vulnerable to sabotage.

Moreover, some buildings are said to consume more energy than others; office buildings consume a great deal of energy. Sadrzadehrafiei, Sopian, Mat, Lim, Hashim & Zaharim, (2012) asserted that about 70-300kwh/m^2 of energy is consumed by office buildings in Nigeria. The amount of energy used usually depends on region or climate and the appliances that are used.

Therefore, reduction in the quantity of energy consumed is inevitable; reduction of energy consumption in buildings can be achieved by simple methods and techniques using an appropriate building design and energy-efficient system and technology, such as passive cooling system (Ahmed, Khan, Than & Rasul, 2014)

Design strategies that minimize the need for mechanical cooling systems include proper window selection and orientation and day lighting design, selection of appropriate varnishing for windows and skylights, proper shading of glass when heat gains are not desired, use of light-colored materials for the building envelope and roof, careful sitting and orientation decisions and good landscaping design (Ahmed et al., 2014).

On the other hand, if the existing institutional structures in Nigerian universities were designed with least focus on energy efficiency in the past, built environment professionals especially practicing architects, engineers and students can still change the direction of the practice to a more efficient way of energy conservation. Also, Federal University Kashere (FUK), Gombe State, the location of this research is one of the newly established federal universities where researches can be explored and research findings can be put to practice.

University Senate Building is a structure built to serve the central administrative function in university campuses, design to accommodate offices, exhibition hall, senate chamber, governing council chamber and other necessary facilities. The university senate is the agency for the articulation and representation of the views of the faculty (Kentucky, 2011)

However, despite the numerous benefits of passive cooling strategies practicing Architects still linger between theory and practical application. As a result of that,

this research intends to evaluate passive cooling strategies as an intervention for energy efficiency in the university senate buildings in Dry Sub-humid climate; this dissertation also intends to create awareness within the built environment professionals to accept contemporary measures of reducing energy consumption in university senate buildings.

1.2 Problem Statement

Due to the incessant unstable nature of power supply by the Power Holding Company of Nigeria (PHCN), most people rely on gasoline generators for power. This has made buildings especially offices to resort to alternative sources of energy which increases their running cost. This also harbors other negative effect such as air and noise pollution. Buildings in Nigeria are mostly poorly designed in terms of utilizing passive design strategies (Jibrin, 2016) which lead to increase of the building running cost; the extensive use of gasoline generators as an alternative source of power poses a great threat to the environment (Daroda, 2011; Jibrin, 2016).

On the account of the above, this research intends to evaluate passive cooling strategies as an intervention for energy efficiency in the design of university senate building in Dry Sub-humid climate.

1.3 Justification of Study

The outcome of this research will aid government policy in curbing the continuous loss of energy due to inefficient usage; now that government is battling to ensure stable power supply, researches should focus more on how to conserve the existing energy output.

In addition, the findings will be of immense importance to Federal University Kashere (FUK), Gombe state of Nigeria as a newly established institution in the area of research development. Built environment professionals especially architects and engineers will also benefit from the research and should take the major findings of the research as a priority in handling all subsequent projects of the university. Finally, the end users will benefit from the research because at the end, the occupants will have a thermally comfortable environment.

1.4 Aim and Objectives of Study

The aim of this research is to evaluate passive cooling strategies as an intervention for energy efficiency in the design of university senate building in Dry Sub-humid climatic zone of Nigeria. The specific objectives of the study are:

i. To investigate the contemporary passive cooling strategies for energy efficiency in office building
ii. To identify energy efficiency assessment criteria in accordance with passive cooling techniques for office buildings in Dry Sub-humid climatic region of Nigeria
iii. To assess and simulate selected senate buildings for energy efficiency based on passive cooling criteria within the Dry Sub-humid climatic zone of Nigeria.
iv. To compare the results of selected senate buildings in the Dry Sub-humid climatic zone of Nigeria.
v. To demonstrate the research findings in the design of an energy efficient university senate building in Dry Sub-humid climatic zone of Nigeria

1.5 Research Questions

The research questions for this dissertation are as follows:

i. What are the contemporary passive cooling strategies for energy efficiency in office buildings?
ii. What is the energy efficiency assessment criteria based on passive cooling strategies in office building in Dry Sub-humid climatic zone of Nigeria?
iii. What are the energy efficiency performance ratings of existing senate buildings in Dry Sub-humid climatic zone of Nigeria?
iv. Which of the simulated senate buildings is the most energy efficient?
v. How best could passive cooling strategies be demonstrated in the design of university senate building.

1.6 Scope of the Study

The geographical area of Nigeria is so large that it is not easy for the researcher to conduct a comprehensive research on all the university senate buildings in Nigeria; moreover, as it is known that geographical considerations do affect practice, segmenting this study could, to a large extent enhance the reliability of its findings. Thus, this study has been delimited to some university senate buildings located within the Dry Sub-humid zones, North-east of Nigeria. Data will be collected through the case study approach with the help of visual survey, checklist and simulation.

1.7 Significance

There were several researches about overall energy saving methods for buildings and there are various researches about energy simulations focusing on various particular passive energy saving measures. However, there is a lack of such studies in terms of Dry Sub-Humid Climate. So the research highlights the environmental design of University Senate Buildings in the said climate in an attempt to find solutions for improving energy conservation. In addition, the research will help to establish better understanding about the interactive relationship between the building envelop, shape and the surrounding environment. Also the research helps to provide reasonable results, as it depends on using simulation program in order to optimize building energy performance.

2.0 LITERATURE REVIEW

2.1 Energy Efficiency

Energy efficiency is defined largely as cost-effective ways to reduce energy consumption through existing and improved technologies as well as through sound energy use practices (Batagarawa, 2013). The idea behind energy efficiency is quite simple - if people consume less energy, there will be less emission of greenhouse gases as a result of the burning of fossil fuels. This is especially useful in developing countries where there are frequent power outages as well as lack of energy services. Therefore, the utilization of energy is meant to be efficient, sensible and wise so that the purpose of sustainable development will become manifest.

It is important for Nigeria's building industries to organize its development in a sustainable way now that recent researches centered toward reducing the level of energy consumption owing to the substantial growth of the building industries (Aliyu, Dada & Adam, 2015). In the next sections of this chapter, energy efficiency, thermal comfort, passive cooling strategies among others, are discussed in the following sub sections.

2.2 Situation of energy supply in Nigeria

The energy crisis, which has engulfed Nigeria for almost four decades, has been enormous explains the quantity of electricity generated, transmitted and distributed in Nigeria (Nnaji, 2010) see Figure 2.1. The megawatts are certainly too low, to be dependent upon, it is in this regard that this research proposes energy efficient model for office building.

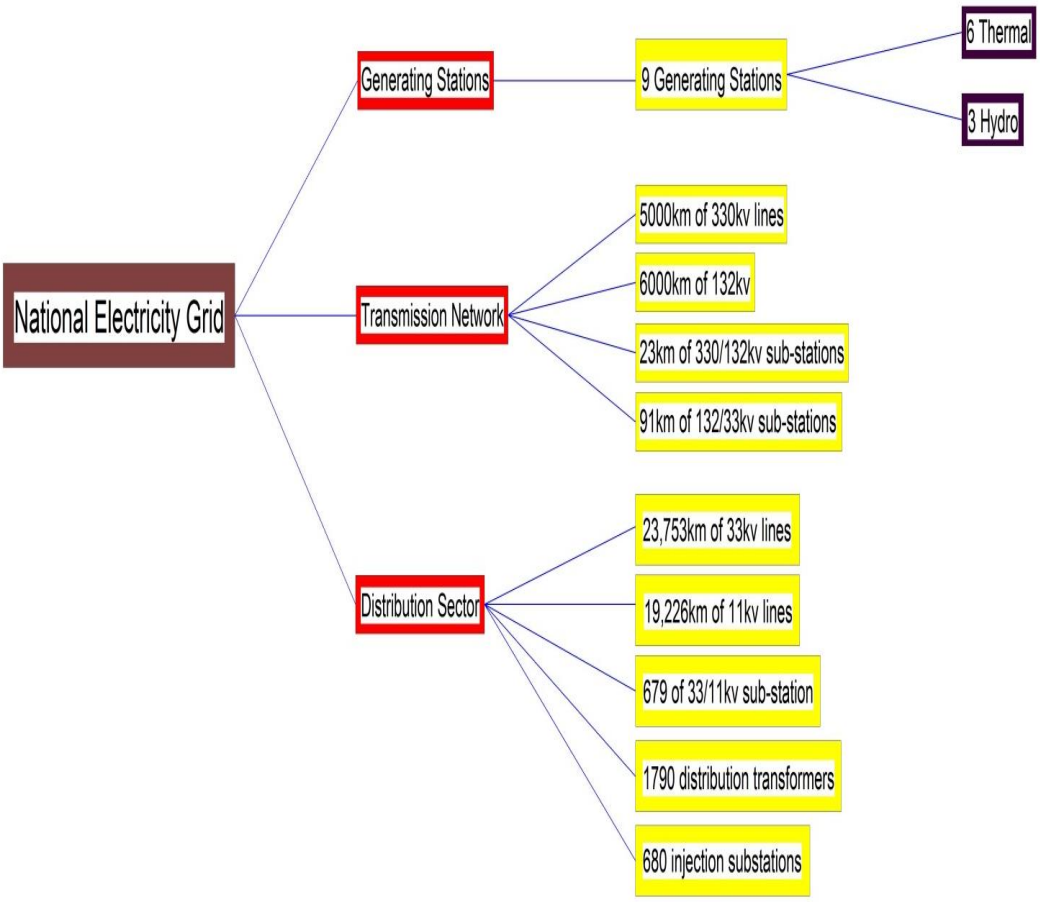


Figure 2.1 The Structure of Nigerian National Electricity Grid

(source: Nnaji, 2011)

discussed above, there are only two alternatives for building occupants: using gasoline generators or passive techniques. Thus, this dissertation is dedicated toward evaluating passive cooling techniques, which is safer, sustainable and energy efficient.

2.3 Energy Efficiency in Buildings

The triangle for low energy building design is shown in Figure 2.2. Energy savings in Nigeria will lead to personal income saving; reducing the building of more power stations allowing the funds to be spent on other sectors of the economy; improve access to energy; and decrease load shedding.

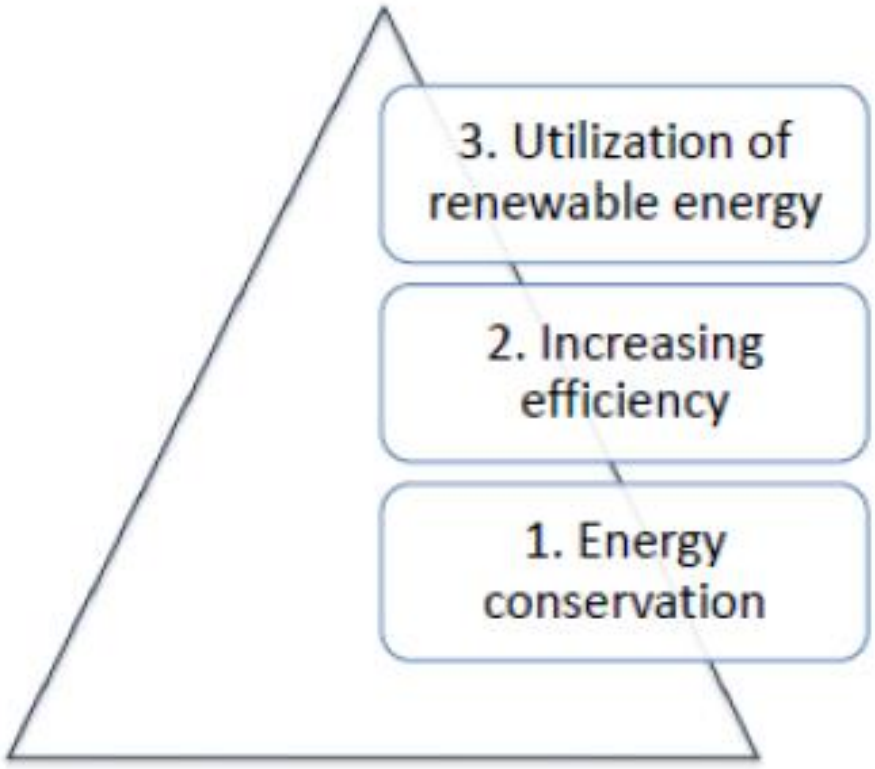


Figure 2.2 Triangle for Low Energy Building Design (source: Haase and Amato, 2006)

As earlier stated buildings contribute more than one third of total global greenhouse gas emissions and consume more than 50% of energy in Nigeria; therefore, Architects should explore and apply the existing research findings that optimize passive cooling. Elaiab (2014) looked at some factors, which govern energy consumption in buildings in which he believed designers need to consider carefully in order to reduce energy consumption; these factors are illustrated in Figure 2.3 and are briefly described in the next subsections.

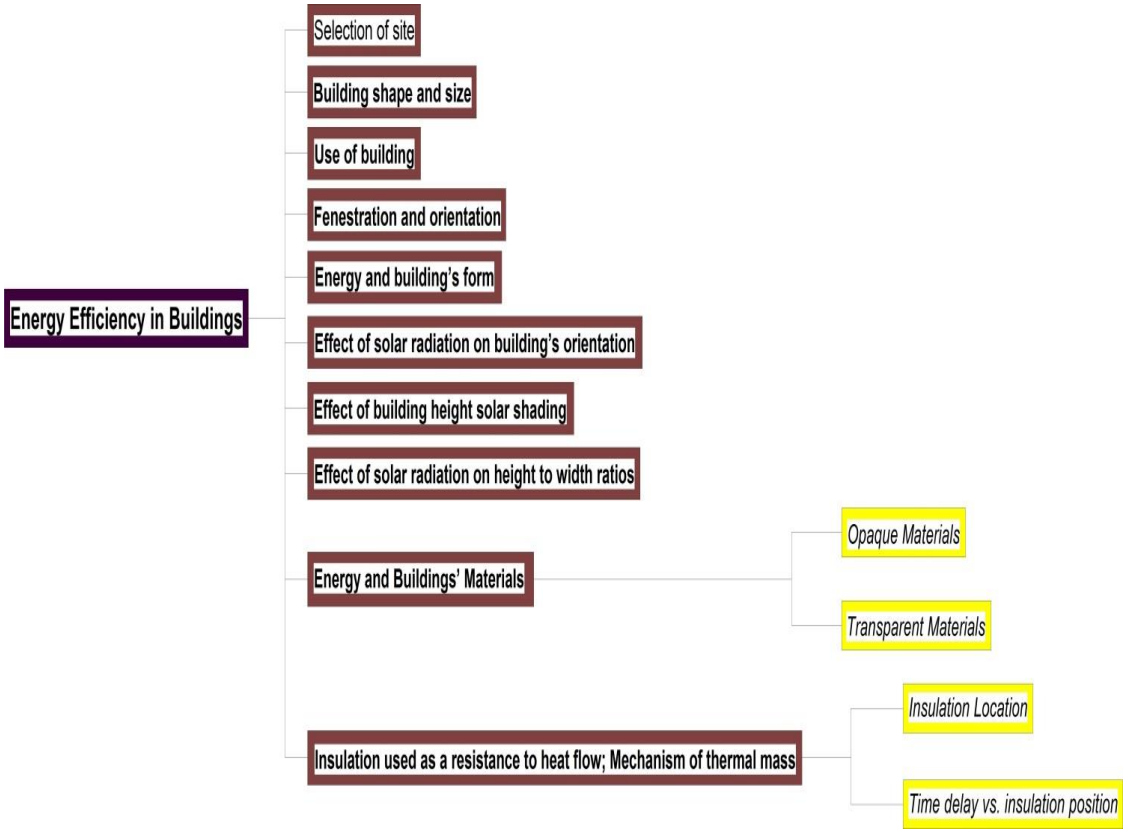


Figure 2.3 Factors Governing Energy Consumption (source: (Elaiab, 2014)

2.3.1 Selection of site

Town planners control this factor while the architects are rarely able to have much influence on allocated sites for development (Usman, 2015); this is debatable because architects as the chief designers of the built environment, should be in the forefront in selecting site for every proposed building. For example, an exposed site with increase wind speed can increase ventilation rates and decrease surface resistances (Givoni, 2011). Over 20% increase in energy consumption may result if the wind speed is high throughout the year, also elevated sites will be colder and more subject to rain and mist (Bonan, 2015).

2.3.2 Building shape and size

The bigger surface area to volume the quicker it will lose heat, as it has a bigger surface where the heat can rise and travel out from. If the volume is the same but the surface area is smaller, heat will stay in for longer as there is only a small area for the heat to escape from, meaning that the heat that is lost does not account for the mass.

The product of this research will incorporate the above explanation which means that the proposed senate building should have relatively big surface area to volume ratio in order to make the building lose heat as soon as possible.

2.3.3 Use of building

Reduced internal temperature, which may require the occupants to wear more clothes, can save a considerable amount of energy (Usman, 2015). The explanation deals with people in the temperate regions, thus it is the opposite that concern people in the tropics.

2.3.4 Fenestration and orientation

Unobstructed windows facing south which are curtained at night gain approximately as much heat from the sun during the hot seasons as they lose. On other orientations, the gain is very much reduced and there is a net heat loss (Jibrin, 2016). The importance of fenestrations in relation to orientation cannot be ignored in the product of this dissertation in order to optimize passive cooling in the proposed senate building.

2.3.5 Energy and building form

Loonen, (2013) states three forms of building type in response to climate, from climate responsive through combination to climate rejecting (Figure 2.4). Moore believes that in the past architects had to utilize the building envelope as the principle mediator between exterior and interior environmental conditions.

This research is concerned with a form of buildings that described as a selective mode which work with the environment even so it is not easy to achieve all the points listed in his mode.

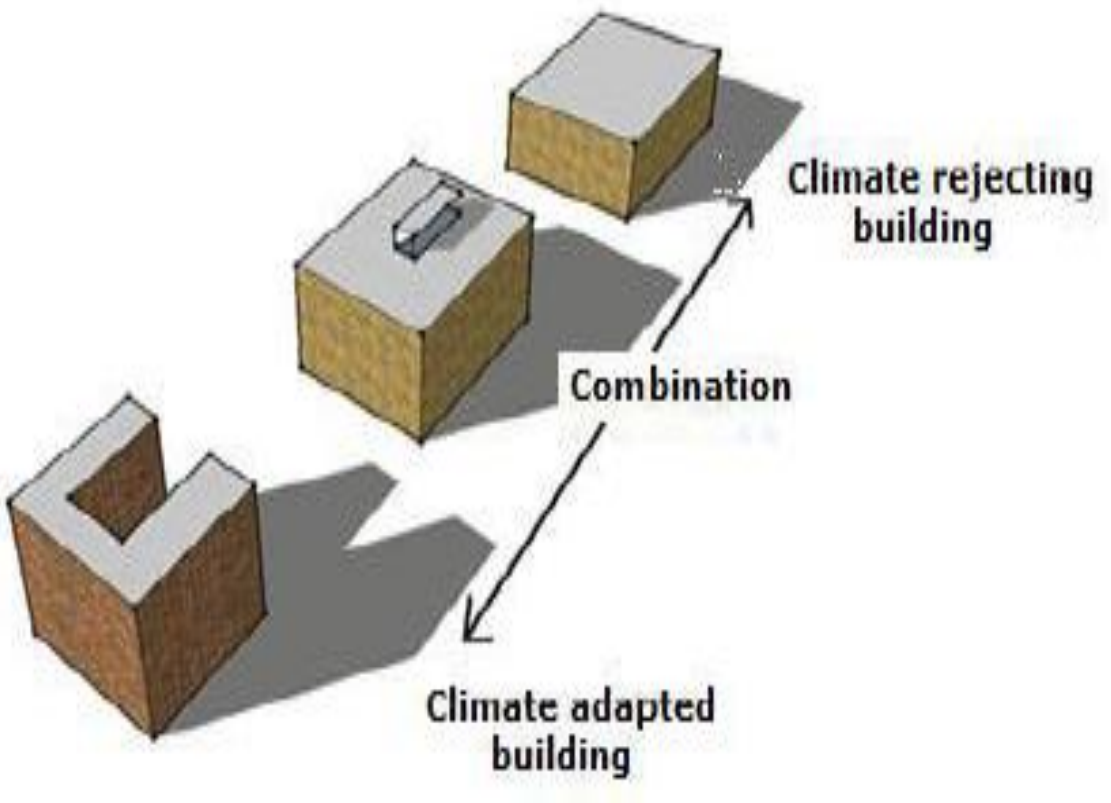


Figure 2.4 Continuum of Building Climate Response (Loonen, 2013)

Nevertheless, Moore's research seems to have not covered a wider range of different verities of building forms. Central Public Works Department reviewed and developed a more detailed format of building forms and their corresponding

effects based on surface area to volume ratio of the building form as illustrated in Figure 2.5.

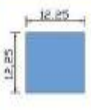
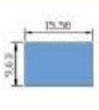
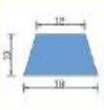
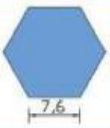
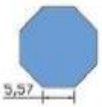
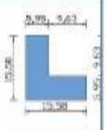
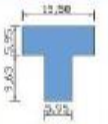
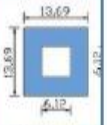
Shape	circular	Square	Rectangular	Trapezoid	Pentagon	hexagon	Heptagon
Perspective							
Plan							
Perimeter	43.41618	48.9898	50.4145	50.8806	46.685	45.588	44.9736
Surface	410.49708	443.9388	452.487	455.2836	430.11	423.528	419.8416
S/V	0.456107866	0.493265333	0.503	0.506	0.478	0.47	0.466
Shape	Octagon	L Shape	T Shape	Cross Shape	H Shape	U Shape	Court Shape
Perspective							
Plan							
Perimeter	44.5816	62.3148	62.3148	62.3148	73.482	73.482	79.2664
Surface	417.4896	523.8888	523.89	523.89	590.892	590.892	625.598
S/V	0.464	0.582098666	0.582	0.582	0.656	0.656546666	0.695

Figure 2.5 Different Forms of Shape (Loonen, 2013)

2.3.6 Effect of solar radiation on building's orientation

Radiation and temperature are both acting together to produce the heat experienced by the surface. Therefore, architects must consider the direction of their building in relation to the predominant climate. For example, in the hot zones under conditions of excessive heat, the orientation of building should decrease the undesirable solar impact and in turn reduce the air conditioning requirements (Alsousi, 2011)

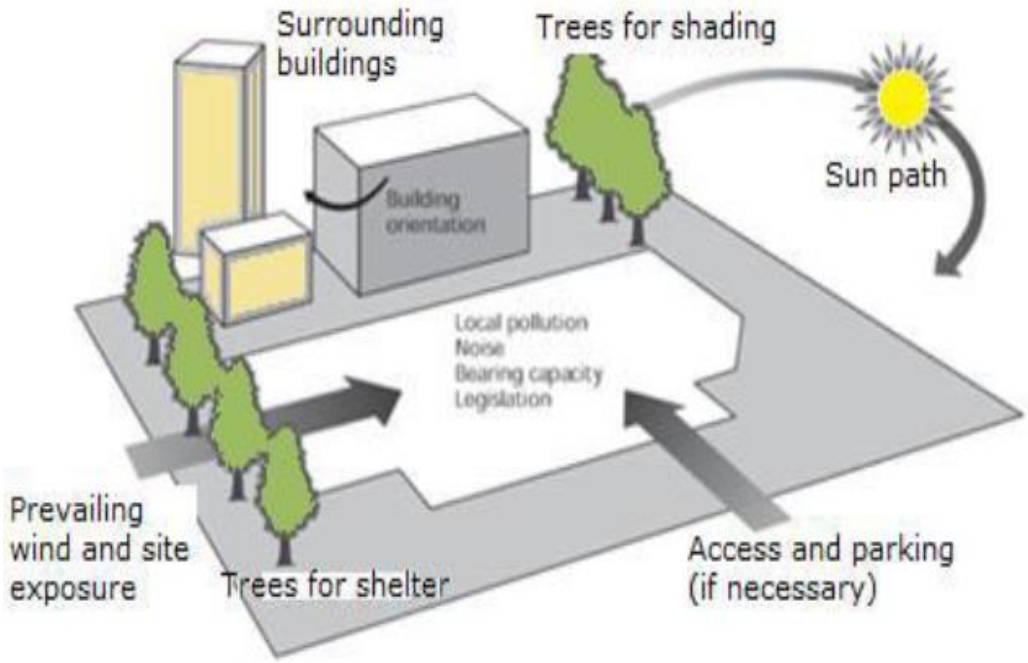


Figure 2.6 Site considerations (Usman, 2015)

Figure 2.6 illustrates the importance of site orientation in relation with energy gain/loss in buildings. Vegetation and landform can complement passive solar design. However, if poorly positioned in relation to buildings, tall vegetation will reduce solar gain by overshadowing, and obstructing sunlight. Here are some key principles in dry regions:

i. Shelterbelts should be orientated to the south-west of development and distanced 3-4 times their mature height from south facing elevations.
ii. Trees that will grow above the shadow line should be deciduous as they allow sunlight to pass through when at a low angle in cold season and provide beneficial shading in hot season.

The proposed senate building will take into account the different types of trees and shrubs in relation to achieving indoor thermal comfort while at the same not creating obstruction due to shadows. The Shelterbelts should be orientated to the south-west of development and distanced 3-4 times their mature height from south

facing elevations. Also Trees that will grow above the shadow line should be deciduous as they allow sunlight to pass through when at a low angle in cold season and provide beneficial shading in hot season. On the other hand, the longer side of the building will be along east-west direction and the shorter side along North-South direction.

2.3.7 Effect of building height solar shading

Potential shading of the building caused by structures in its locality needs to be examined during the initial design stage. In an urban environment, it might not be necessary to provide sun protection because neighboring buildings shield off the sun see Figure 2.7, depending on different heights of the neighboring buildings (Waheeb, 2005).

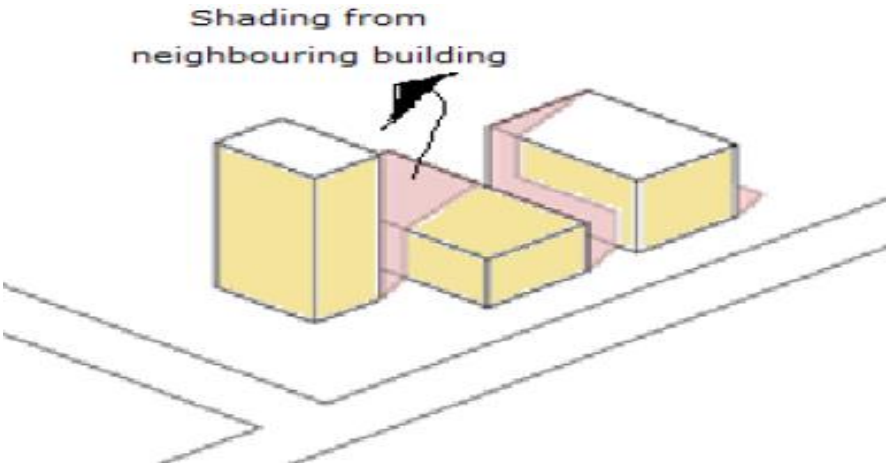


Figure 2.7 Sun Protection on all Sides of the Building (Haase & Amato, 2006)

Muhaisen (2005), Hyde (2000), Loonen (2013), Givoni (2011) and (Evans, 1988) approved that easiest orientations for solar shading are south and north, while the hardest orientations for solar shading are east and west surfaces that because sun angles are low. Figure 2.8 describe the different types of shading patterns.

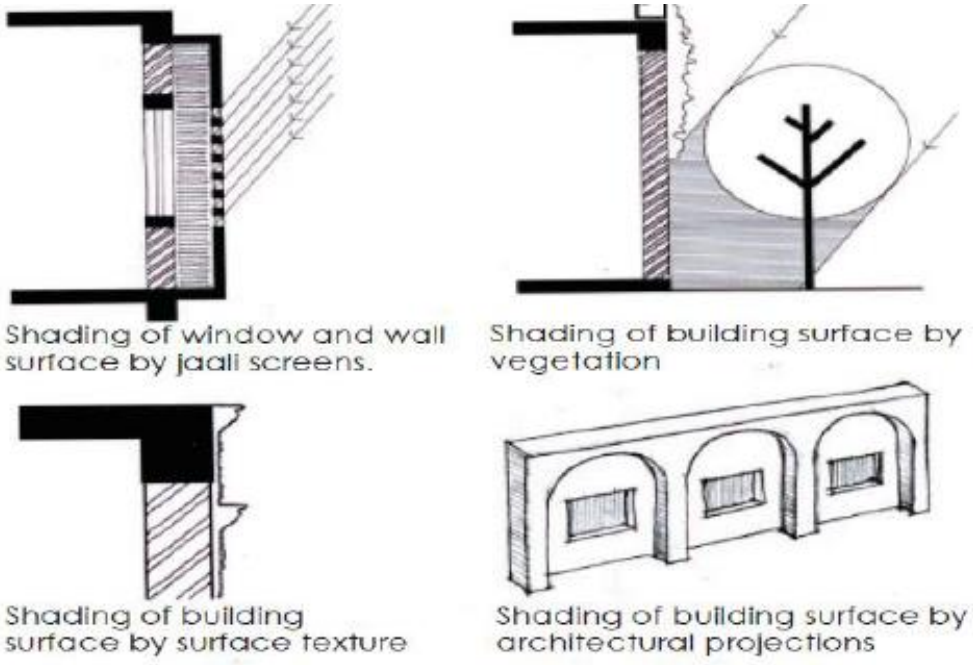


Figure 2.8 Various Shading Pattern (Source: Loonen, 2013)

The product of this dissertation will incorporate all of the different types of shading ranging from screen wall, vegetation, surface texture and architectural projections depending on the circumstances.

2.3.8 Effect of solar radiation on height to width ratios

In a study by Breshears & Ludwig (2010) explain, illustrates solar radiation for different Height to Width ratios (H/W), see Figure 2.9. On the flat plan, most of the absorbed solar radiation is re-radiated to the sky as long-wave radiation. In a medium density of H/W= 1, most of the reflected solar radiation hits other buildings, as well as the ground, until it is absorbed near or at the ground. For higher densities of H/W= 4, most of the absorption takes place at a high level of the canyon, reducing the amount of radiation that reaches the ground.

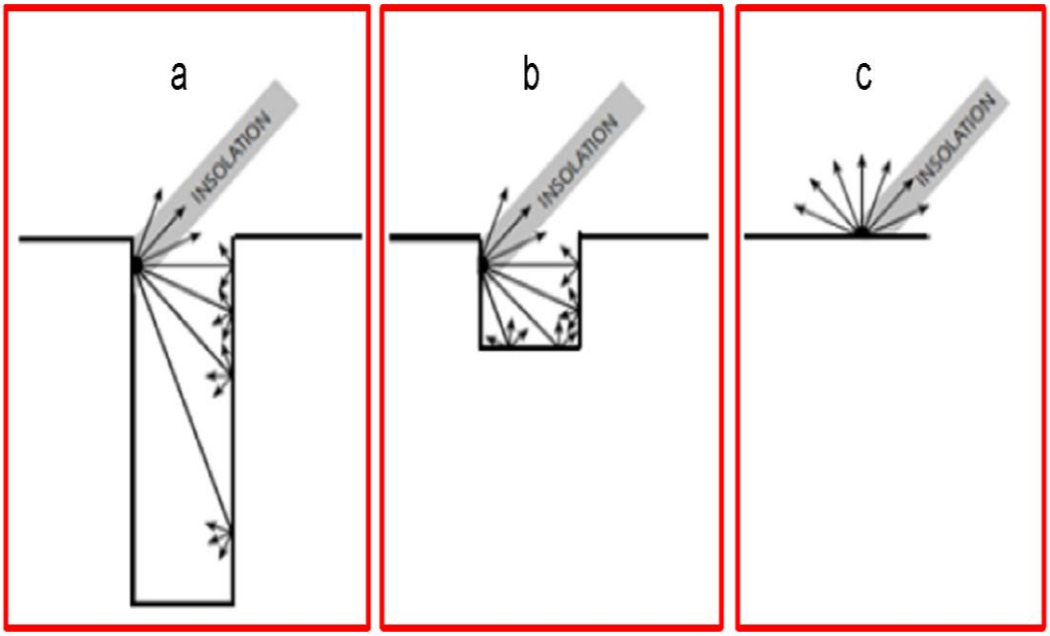


Figure 2.9 Solar Radiation for Different H/W ratios (Breshears & Ludwig, 2010)

The *compartment c* is the best, therefore this research will harness that because for higher densities of H/W= 4; most of the absorption takes place at a high level of the canyon, reducing the amount of radiation that reaches the ground. The proposed senate building will tentatively be painted white or with very light colors, because much of the incident radiation can be reflected away from the surface as described below above. In case of any surface on the proposed senate building that is exposed to high levels of solar radiation in hot season should be well insulated to reduce the transfer of heat.

An integrated design approach utilizes indirect radiation for day lighting and avoids the heat of direct radiation by use of light shelves as shown in Figure 2.10.

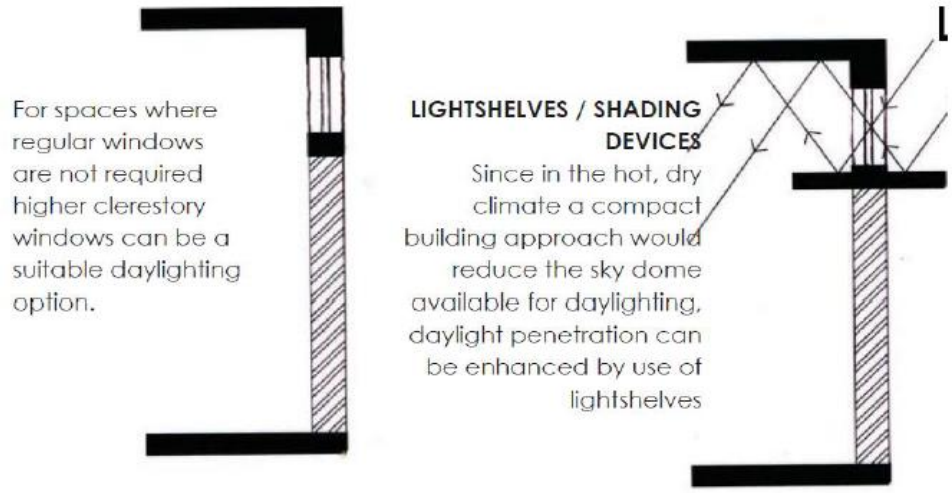


Figure 2.10 Light Shelves (Source: Susilawati & Al Surf, 2011)

2.3.9 Energy and Building Materials

The materials of construction should provide adequate insulation and appropriate thermal response and it can be divided into two namely:

i. Opaque Materials

For comfort, air movement is essential and internal surface temperatures should be kept as low as possible during the day and the night (Alsousi, 2011). Figure 2.11 shows the route of sun heat into an opaque surface, this route is different if the surface (wall or roof) is insulated. On other hand, if the surface (wall or roof) is un-insulated, and if the element is thermally massive, it will absorb the solar energy striking it and delay the entry of this energy into the room for a number of hours. If there is sufficient thermal mass, it may delay the entry of energy until night time when cooler outside air can be used to cool the structure. Yet, if the element is thermally light the solar energy heats up the external surface and this energy is quickly transferred through the structure resulting in rise in internal air temperature.

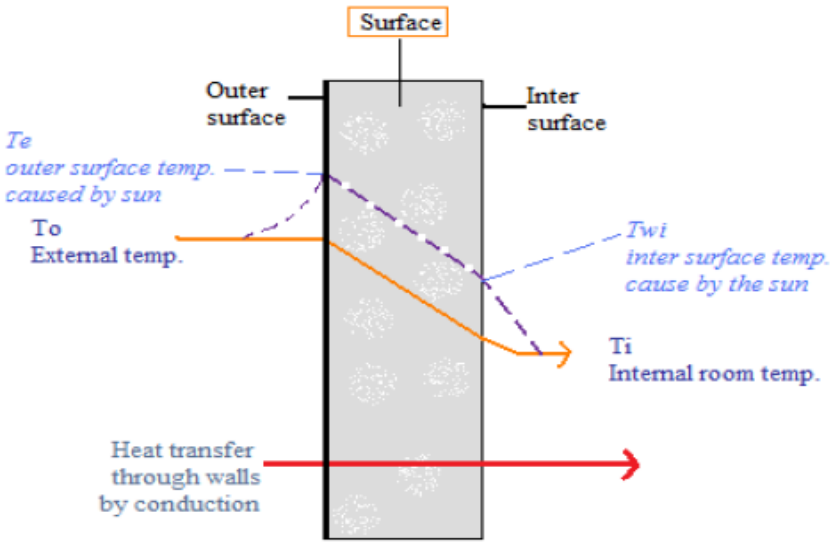


Figure 2.11 Solar Gain in Opaque Surface (Breshears & Ludwig, 2010)

ii. Transparent Materials

The issue is compounded by the fact that windows do not let all of this radiation into the building. Figure 2.12 illustrates how glass indirectly transmits far infrared from a heated room. The thermal radiation from the room is absorbed by the surface of the glass.

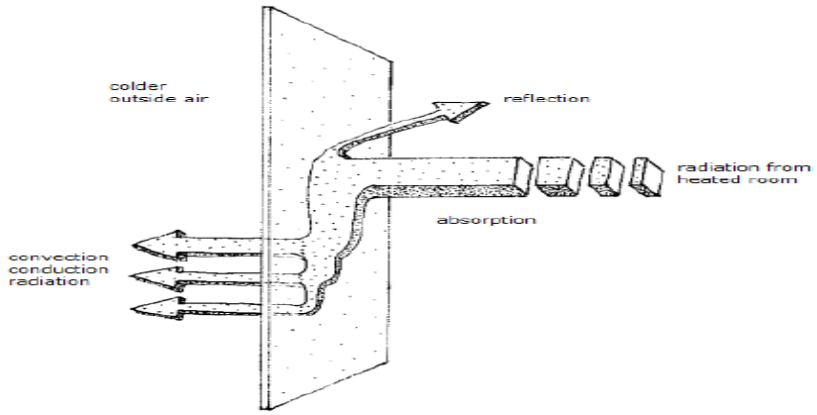


Figure 2.12 Transmission of Solar Radiation Through Glass (Breshears & Ludwig, 2010).

The transmission of solar radiation through standard window glass is illustrated in Figure 2.13. Some of the solar radiation incident on the glazing is reflected. The fraction absorbed by the glass is dependent on the thickness and absorption

coefficient of the glazing. The absorbed radiation is converted to heat, which raises the temperature of the glass.

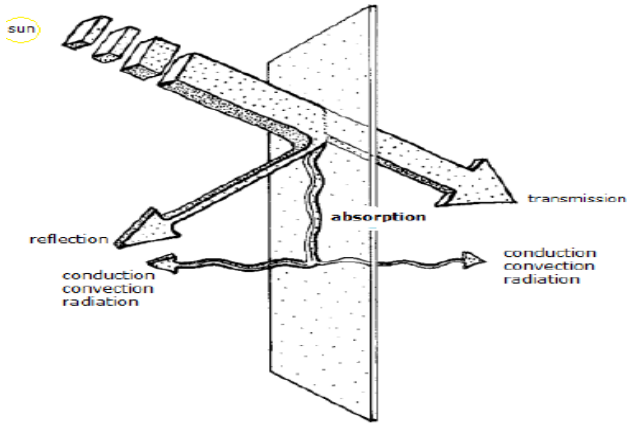


Figure 2.13 Solar Striking Glass; the transmission of far infrared through glass (Breshears & Ludwig, 2010)

However, the above process is also affected by different windows' types and window/blind systems. CIBSE also has provided the importance of the glazing role on thermal comfort to a building's occupants, this role can be underlying as principles briefly outlined below:

Comfort criteria dictate that there should not be more than 4K between any surface and air temperature. Outside of this margin, extra heat is needed to compensate for the increased feeling of discomfort.

i. In a building where the walls are well insulated the temperature difference between the wall surface and room temperature is minimal, but the temperature differences between glazing and room temperature (assuming an indoor room temperature of 21 K) can be significant according to glazing type: Between single glazing and air temperature can be around 20° C.

ii. Between double-glazing and air temperature will be around 8° C.

iii. Between triple glazing and air temperature will be around 4° C (i.e. within the comfort zone).

2.3.10 Insulation used as a resistance to heat flow; Mechanism of thermal mass

It is important, to understand the mechanism of thermal mass performance in order to achieve the best possible results. Thermal mass, in the most general sense, describes the ability of any material to store heat (Zandes, 2015). For a material to provide a useful level of thermal mass, a combination of three basic properties is required:

i. High specific heat capacity to maximize the heat that can be stored per kg of material.
ii. High density to maximize the overall weight of the material used.
iii. Moderate thermal conductivity so that heat conduction is roughly in synchronization with the diurnal heat flow in and out of the building.

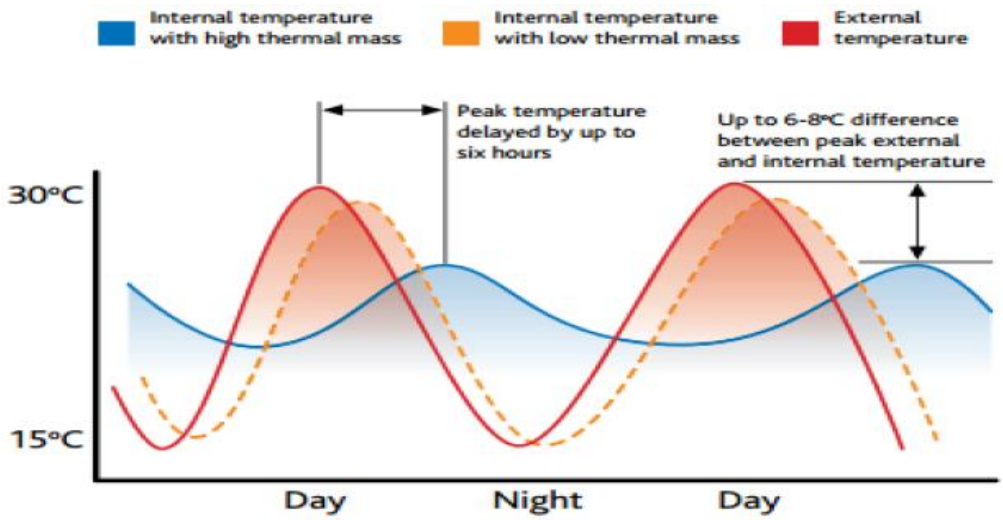


Figure 2.14 Stabilizing Effect of Chapter on Internal Temperature (Zhao, Ma, Xu, Thierno, Zhu & Zhou, 2017)

Heavyweight construction materials such as brick, stone and concrete all have these properties (Zandes, 2015). Some materials, like wood, have a high heat capacity, meaning that their thermal conductivity is low, which limits the rate at which heat is absorbed see Figure 2.14. Steel can also store a lot of heat, but in contrast to wood, steel possesses a very high rate of thermal conductivity, which means heat is absorbed and released too quickly. This can be explained in two ways:

i. Insulation Location

A study by (Byrne & Ritschard, 1985) on three wall configurations. shows that the wall with insulation outside always performed better than the wall with insulation inside of the mass. However, the relative performance of the three wall types changed slightly with climate, building design and total wall U-value, see Table 2.1.

Table 2.1 Wall characteristics used in Simulation (Byrne & Ritschard, 1985).

Wall characteristics	Mass wall with insulation outside	Mass wall with insulation inside	Mass wall with integral insulation
Mass conductivity w/m ^{0}C	0.86	0.86	0.05

ii. Time delay vs. insulation position

Massive construction may provide the full solution, as it may ensure comfortable indoor conditions without any mechanical cooling or night heating. In addition, the location of the insulation relative to the mass layer affects both the time lag of the heat, flux through a wall and the ability of the wall mass to dampen interior temperature swings.

2.4 Status of Passive Cooling Developments in Dry Sub-Humid/Bsh Subtropical Steppe

Köppen Climate Classification System states that climate is classified to Tropical humid, Dry, Mild Mid-Latitude, Severe Mid-Latitude, Polar. Architectural suggestions for this kind of climate have been postulated by (Daroda, 2011) in Table 2.2 Federal University, Kashere (FUK), Gombe state of North East Nigeria, the site of this research belongs to Dry Sub-humid/Bsh Sub-Tropical Steppe climate.

Table 2.2 Climate and Suggested Design Responses (Source: Daroda, 2011)

DRY	SUGGESTED DESIGN RESPONSES
	Use passive solar principles with well insulated thermal mass
	Maximize night time cooling in summer.
	Consider convective (stack) ventilation, which vents rising hot air while drawing in cooler air.
	Build more compact shaped buildings with good cross ventilation for summer.
	Maximize solar access, exposure to cooling breezes and cool air drainage.
	Protect from strong, cold winter and dusty summer winds.
	Shade all east and west glass in summer.
	Provide shaded outdoor living areas. Consider adjustable Shading to control solar access.
	Avoid air-conditioning.
	Use reflective insulation to keep out summer heat.
	Use bulk insulation for ceilings, walls and exposed floors.
	Consider double glazing.
	Use ponds and water in shaded courtyards to provide Evaporative Cooling
	Draught seal thoroughly. Use airlocks to entries.

2.5 Contemporary Methods of Passive Cooling

Passive cooling encompasses techniques for solar and heat control, heat modulation and heat dissipation using naturally driven phenomena such as natural ventilation, radiative cooling, evaporative cooling and ground cooling (Santamouris & Kolokotsa, 2013). Recent review papers (Givoni, 2011; Santamouris & Kolokotsa, 2013) which collated individual studies from a broader

spectrum of climatic regions agree that cooling strategies for buildings should be designed at three levels:

2.5.1 Solar and heat protection techniques

The most effective method to save energy and cool the building in is to keep the heat from building up in the first place (Givoni, 2011). Next sub sections discussed different techniques of solar and heat protection techniques see Figure 2.15.

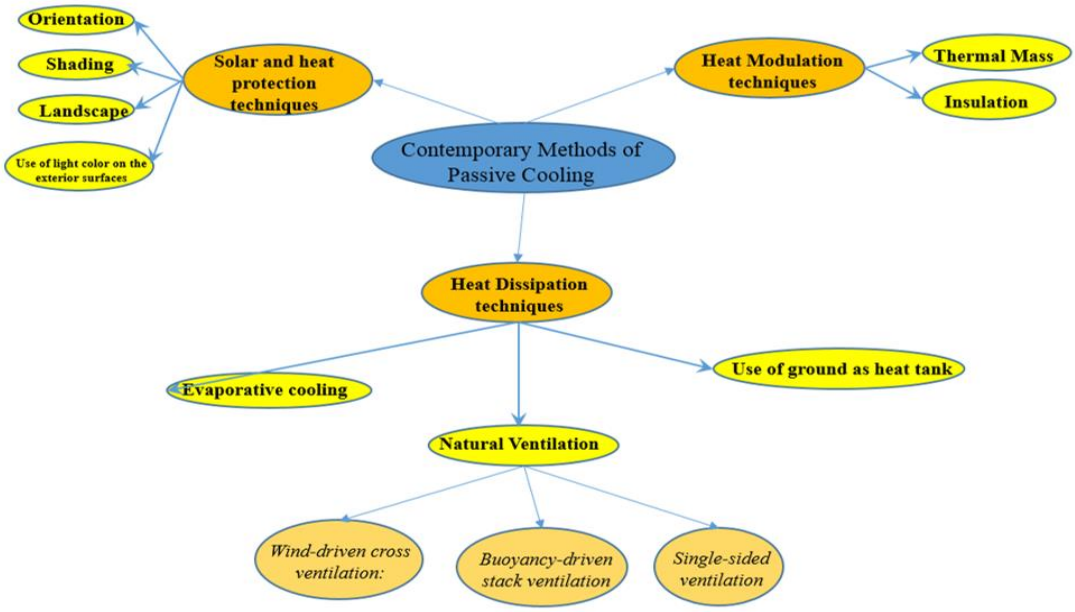


Figure 2.15 Contemporary Methods of Passive Cooling (source: Givoni, 2011; Santamouris & Kolokotsa, 2013)

a) Microclimate

The microclimate of an urban area can be modified by appropriate landscaping techniques, with the use of vegetation and water surfaces, and can be applied to public places, such as parks, play-grounds and streets (Givoni, 2011).

Microclimate can be categorized into:

i. Vegetation

ii. Water surfaces

Despite the numerous advantages of using courtyard for cooling, there is problem of maintenance**;** *Water surfaces within the building if not properly maintained will* erode the *surface* of the paving in the areas. Therefore, this research will carefully harness the advantages of introducing water surface within the building of University Senate Building of FUK to curb those problems.

b) Shading

Among all other solar passive cooling techniques solar shading is relevant to thermal cooling of buildings especially in a developing country owing to their cost effectiveness and easy to implement (Kamal, 2012). This technique was discussed in the previous section.

2.5.2 Modulation of heat gains

Heat modulation is associated with high thermal mass materials, like brick and concrete, in building structures that act as a storage for heat during daytime and cold at night (Rodriguez-Ubinas, Ruiz-Valero, Vega & Neila, 2012).

a. Insulation

The effect of insulation is to reduce heat gain and heat loss. This section was previously discussed. However, it is worthy of note that use of 40 mm thick expanded polystyrene insulation on walls and vermiculite concrete insulation on the roof has brought down space-conditioning loads of the RETREAT building in Gurgaon by about 15% (Haase & Amato, 2006). Air cavities within walls or an attic space in the roof ceiling combination reduce the solar heat gain factor, thereby reducing space-conditioning loads. The performance improves if the void

is ventilated. Heat is transmitted through the air cavity by convection and radiation.

b. Thermal mass

Thermal mass has been discussed previously under insulation. However, it is worthy of notice that, for east facing walls a very short or very long delay is generally best, however the latter requires a very thick wall which may not be practicable. For south facing walls a lag of around 10 -12 hours will delay the midday heat until late evening/night (Givoni, 2011). The same delay or slightly less (8 hours) is also suitable for west facing walls since there are only a few hours to sunset. North facing walls have little need for a time lag as the solar gains are small. For roofs exposed to solar gains all day, the time lag needs to be very long to delay the penetration of heat until the evening. However, this is often impracticable, as it requires very heavyweight construction, so the use of additional insulation is typically a better option.

2.5.3 Heat Dissipation Technique (*Remove internal heat)*

Effective dissipation of the excess heat depends on two main pre-conditions: (a) The availability of a proper environmental heat sink with sufficient temperature difference for the transfer of heat and (b) the efficient thermal coupling between the building and the sink (Givoni, 2011).

i) Evaporative cooling

The air movement over a wetted surface causes some of the water to evaporate. This evaporation results in a reduced temperature and an increased vapor content in the air (Santamouris & Kolokotsa, 2013).

a) *Direct Evaporative cooling:* Typical commercial evaporative coolers have an effectiveness of 50-70%. The following alternatives are proposed in chronological order:

1. An evapo-reflective roof to reduce passive cooling in buildings for hot arid climates has been proposed in (Ben, Hamida & Ammar, 2004)
2. A direct evaporative cooler that operates either with natural wind flow or with wind catchers is described in (Qiu & Riffat, 2006).
3. Water evaporative walls are proposed in (Naticchia, D'Orazio, Carbonari & Persico, 2010) and (He & Akhira, 2010).
4. A wet porous cooling plate as a building wall is proposed in (Chen & Liu, 2010; Chen, 2011) where cooling is performed via evaporation of the porous material.

Therefore, direct evaporative cooling can be considered a very effective solution for hot and arid climatic conditions, see Figure 2.16.

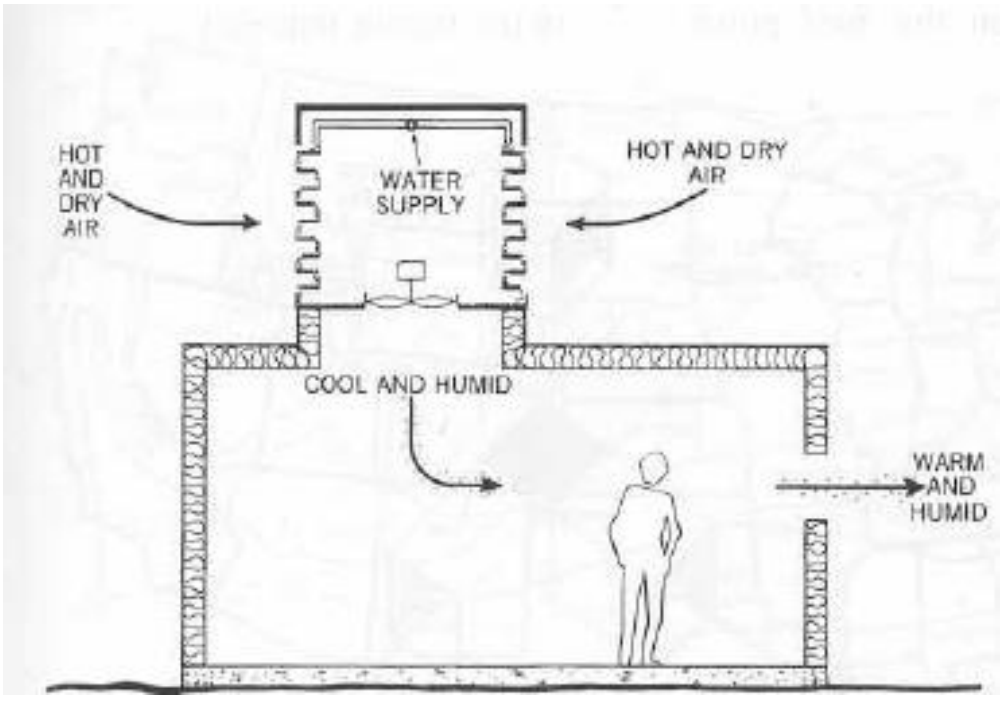


Figure 2.16 Evaporative coolers (Source: Santamouris and Kolokotsa, 2013)

b) *Indirect Evaporative cooling*: Such systems require energy for the fan power for the airflow. On the one hand this fan power can be up to 20% less due to lower air velocities required and on the other hand the main reduction of the energy demand is attributed to the replacement of the conventional air conditioning system.

ii) Natural Ventilation

The successful design of a naturally ventilated building which modern architecture discourages (Geetha & Velraj, 2012) requires a good understanding of the air flow patterns around it and the effect of the neighboring buildings. Natural ventilation is classified as follows:

a- Wind-driven cross ventilation: Wind-driven cross ventilation occurs via ventilation openings on opposite sides of an enclosed space. Figure 2.17 shows a schematic of cross ventilation serving a multi-room building (Givoni, 2011). A significant difference in wind pressure between the inlet and outlet openings and a minimal internal resistance to flow are needed to ensure sufficient ventilation flow.

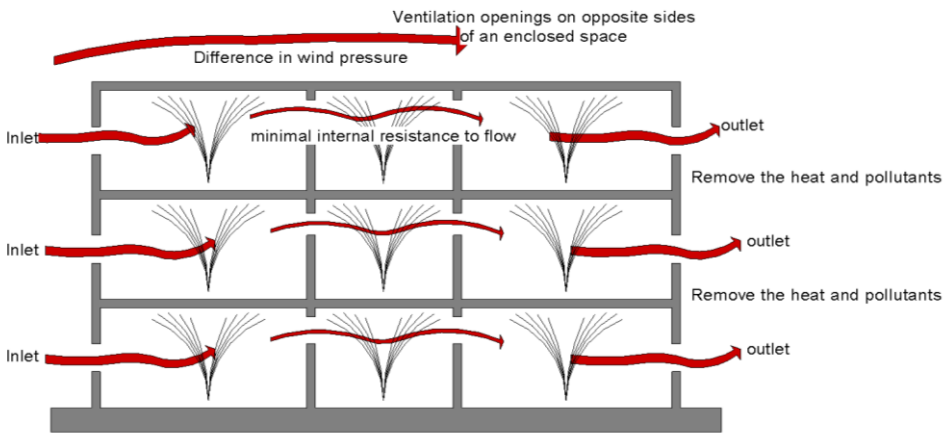


Figure 2.17 Concept of Wind Driven Cross Ventilation System (Source: Kamal 2012)

However**,** wind-driven cross ventilation is associated with challenges such as uncontrollable factors like speed and direction of wind, can bring polluted air into office buildings, strong winds can result to cooler temperature than cannot be controlled.

b- Buoyancy-driven stack ventilation: Buoyancy-driven stack ventilation or displacement ventilation (DV) relies on density differences to draw cool, outdoor air in at low ventilation openings and exhausts (Santamouris & Kolokotsa, 2013). Figure 2.18 shows the schematic of stack ventilation for a multi-storied building. A chimney or atrium is frequently used to generate sufficient buoyancy forces to achieve the needed flow. However, even the smallest wind will induce pressure distributions on the building envelope that will also act to drive the airflow (Kamal, 2012).

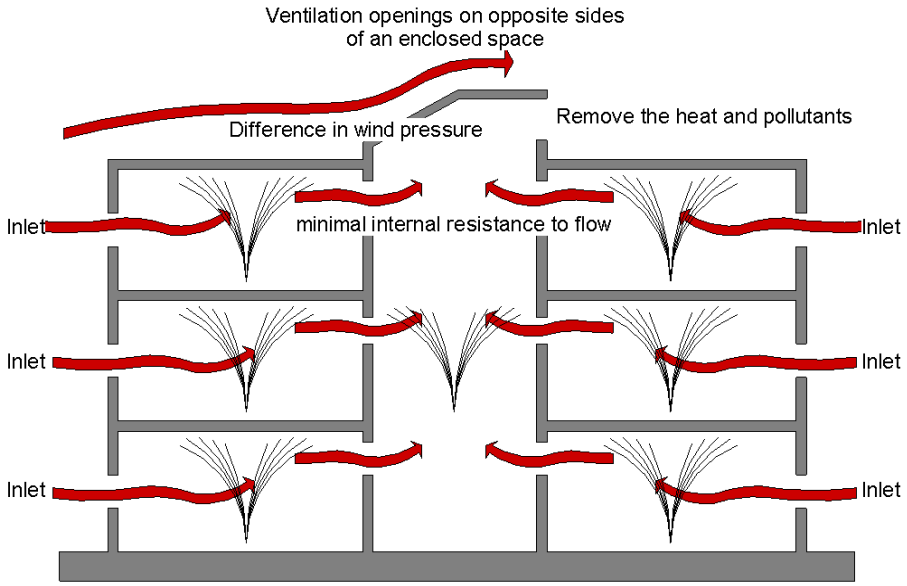


Figure 2.18 Concept of buoyancy Driven Stack Ventilation System (Source: Geetha & Velraj, 2012)

However**,** wind-driven cross ventilation is associated with challenges such as: it cannot control exterior temperature, it brings polluted air into the office buildings.

The proposed FUK senate building will incorporate this type of ventilation because even the smallest wind will induce pressure distributions on the building envelope that will also act to drive the airflow

c- *Single-sided ventilation:* Single-sided ventilation typically serves single rooms, and thus, provides a local ventilation solution. Figure 2.19 shows a schematic of single-sided ventilation in a multi-room building. The ventilation airflow in this case is driven by room-scale buoyancy effects, small differences in envelope wind pressures.

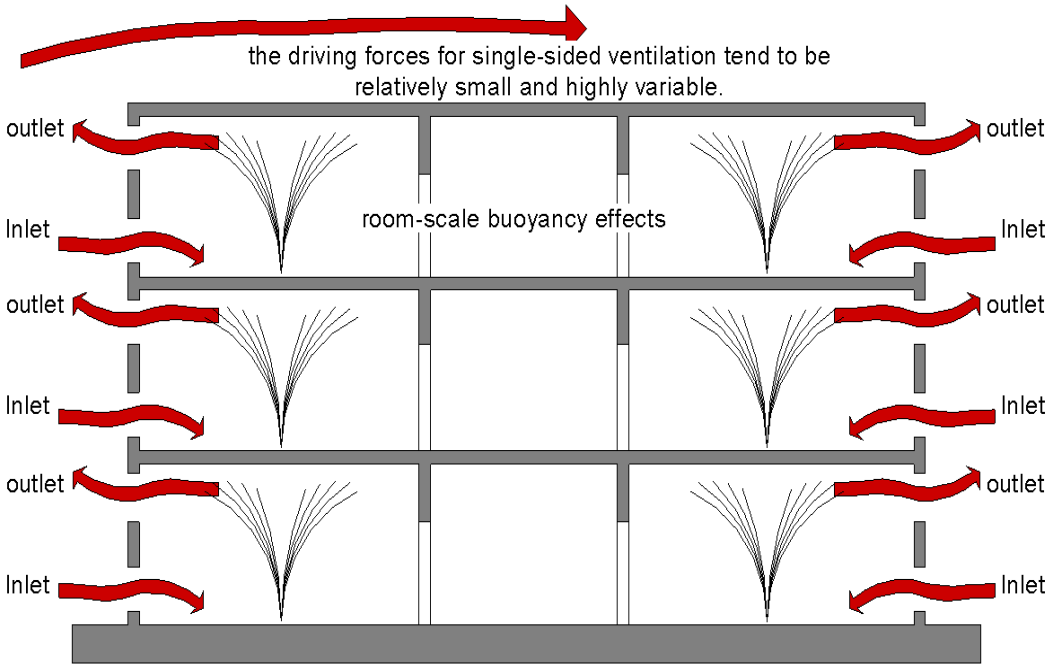


Figure 2.19 Concept of single-sided ventilation system (source: Geetha & Velraj, 2012)

Consequently, the driving forces for single-sided ventilation tend to be relatively small and highly variable. It is worth of notice that, stack ventilation has less disadvantages compared to other types and therefore the proposed senate building for FUK would optimize this type ventilation.

2.6 The need for Senate Building in Federal University Kashere, Gombe

University Senate Building is a structure built to serve the central administrative function in university campuses, design to accommodate offices, exhibition hall, senate chamber, governing council chamber and other necessary facilities. The university senate is the agency for the articulation and representation of the views of the faculty (Kentucky, 2011). Though recent debates suggest that senate building should accommodate just more than offices (Jibrin, 2016), limited recreational spaces should be incorporated for staff refreshment; spaces like gardens, kitchens and so on.

Federal university Kashere (FUK), Gombe is newly established universities with many of its structures remain temporary. The Vice Chancellor and other administrative staff huddled up in small buildings scattered around the campus community. Researches should be realistic and problem solving in the society (Usman, 2015), thus this dissertation intends to answer that call by proposing a climate responsive senate building for FUK.

At the end of this research, the students, teaching and non-teaching staff of FUK will have a loud sigh of relief. The product of this research should be iconic and achieved through research, and creativity; and it should go a long way in bringing about effectiveness and efficiency in the decision-making process of the university.

2.7 Summary of Findings from Literature Review

In sums, chapter two has presented theories, concepts and models of passive cooling strategies as an intervention for energy efficiency in dry sub-humid

climate. It is evident from the above section that energy efficiency in buildings is vital for many reasons. Having justified the needs for energy efficiency it is now important to focus on the basic principles that can bring about energy efficiency in buildings of Kashere, Gombe. An extensive literature review consisting of different journals, books, researches and related websites was undertaken to establish the basic passive principles for designing energy efficient office buildings in dry sub-humid climate.

From the studied carried out we can deduce that, in order to achieve indoor thermal comfort both energy efficiency strategies as well as climate responsive design will have to be incorporated at the design stage.

Based on the discussion presented in the previous chapter, the theoretical frame work for this research could be deduced as in Figure 2.20

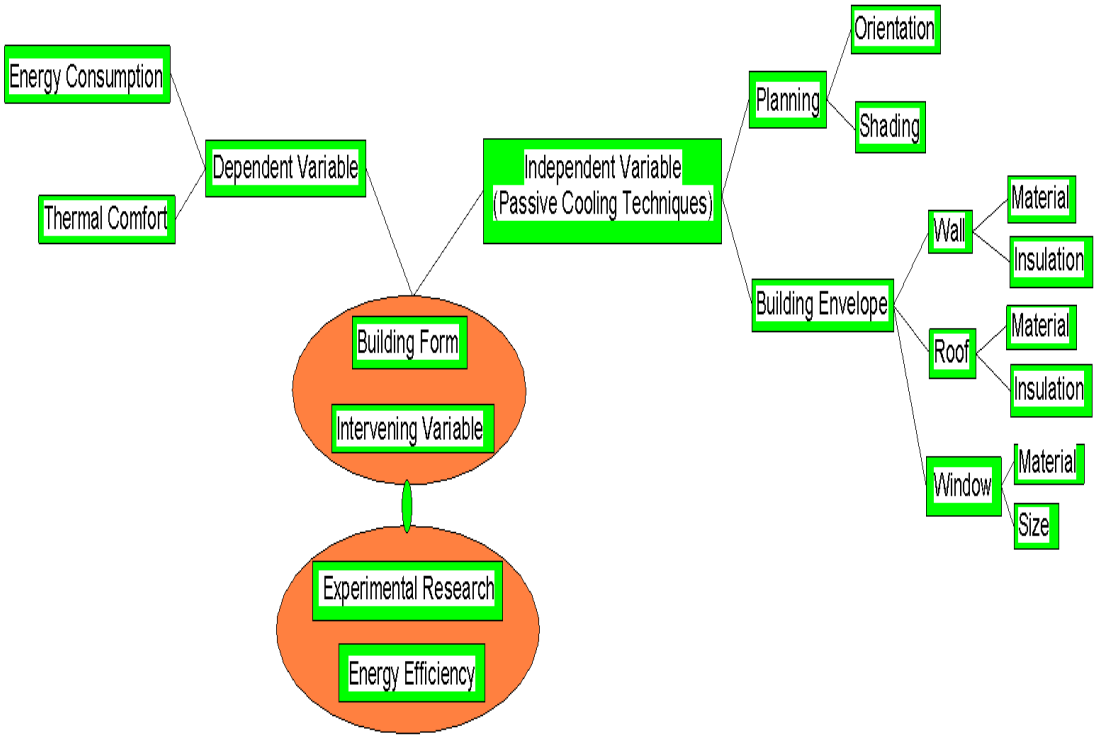


Figure 2.20 Research Theoretical Frame Work (Researcher, 2016)

3.0 RESEARCH METHODOLOGY

3.1 Preamble

This chapter focuses on the methods for collection and analysis of data for the study. Research methodology is the plan, mode or conceptual structure of the research and type or approach adopted in the study (Olaofe, 2010). This chapter therefore, is a clear-cut discussion on the scheme and research method selected and used in conducting the study (Oluigbo, 2011); and arranged under the following headings: Research Population; Sampling Technique; Case Study Approach; Case Study Selection Criteria; Selected Cases to be studied; Research design/Method; Procedure for data collection; Procedure for data analysis; and conclusion.

Multiple methods of data collection will be employed in the case studies using visual survey, observation and simulation.

3.2 Research Population

Orodho (2008) stated that specification of the population, to which the inquiry was addressed, affect decisions that researchers make both about sampling and resources. The target population for this study constitutes all university senate buildings within the Dry Sub-humid zones of Nigeria which is dominantly the North East part of Nigeria, with States having similar climate characteristics. This region includes places like Gombe, Bauchi, and Adamawa.

3.3 Sampling Technique

Oluigbo, (2011) opined that cases are identified for study due to their inherent qualities which were in consonance with the phenomenon under investigation The

sampling method used was purposive, in which the buildings chosen possess some characters under study.

3.4 Case Study Approach

According to Yin, (2013), a case study is an empirical inquiry that investigates a contemporary phenomenon within its real life context using multiple sources of evidences. A case study approach provides a mode of inquiry for an in-depth examination of a phenomenon. The method of study for this research involves a quantitative analysis of cases purposively selected and simulation. Case studies are based on the exploration of passive cooling techniques as an intervention for energy efficiency in university senate building. The assessment will be carried out through visual survey with the help of visual survey checklist, observation and simulation.

3.4.1 Case Study Selection Criteria

Oluigbo (2011) asserted that for a case to be selected it must have certain characteristics that are representative of the phenomenon under consideration. Hence the criteria for selection of cases are based on the university administrative buildings located within the Dry Sub-humid climate zone of Nigeria and with the presence of elements contributing to passive cooling in the tropical climates.

3.4.2 Selected Cases to be Studied

The cases to be studied include:

i. Gombe State University (GSU); Administrative Building.
ii. Abubakar Tafawa Balewa University, Bauchi (ATBU); Senate Building.
iii. Modibbo Adama University of Technology, Yola (MAUTECH); Administrative Building.

The selection of these cases is made in order to address the issues regarding cooling demand in university Senate buildings. The research is focused at reducing the use of HVAC system and suggesting sustainable alternative means through research to assess the effectiveness of passive cooling techniques used, and measures to improve their performance.

3.5 Research Design

This research adopts an exploratory, and experimental approach to frame the answers to its research aim and objectives. These approaches are classified by Morgan, Gliner & Harmon, (2001) into:

i. Individual differences (non-experimental)

ii. Descriptive

iii. Experimental

3.6 Dependent and Independent Variables

The dependent variables predicted are electricity consumption and thermal comfort. Energy consumption is measured in Watt-hours whereas thermal comfort is measured in terms of indoor dry bulb air temperature and operative temperature, both measured in degree Celsius. Dry bulb temperature is the most common index for the specification of comfort (Trebilock & Figueroa, 2014). However operative indoor air temperature combines the effect of surface temperature of the wall surface as well as air temperature and is considered more accurate.

The independent variables examined are classified into two groups. The groups are Planning design variables and Building Envelope design variables. Planning design variables examined are orientation and shading. Building Envelope design

variables examined are Wall, Roof and Window/Glazing. However, each of these variables is categorized based on Material component and Insulation. The details of components of each Independent variable are in Appendix of this research dissertation.

3.7 Methods of Data Collection

The task of data collection begins after a research problem has been defined and research design/plan chalked out. The *primary data* are those which are collected afresh and for the first time, and thus happen to be original in character (Oluigbo, 2011). The *secondary data*, on the other hand, are those which have already been collected by someone else and which have already been passed through the statistical process. The former constitutes method for use in this research.

3.7.1 Visual survey

The use of visual survey in most case study research is due to its ability to obtain inventory of static object (mostly facilities) requisite in understanding a context of phenomenon (Yin, 2013). Visual survey was used to record position of passive cooling techniques in the cases being studied.

3.7.2 Computer Simulation

Experimental investigations; Computer simulation techniques, which grow in popularity each year, were selected using computerized program such as ECOTECT which provide reasonable results. The heating and cooling loads was calculated for each model. The results would be evaluated in order to optimize the thermal behavior of the models.

ECOTECT software is a comprehensive, concept-to-detail sustainable design analysis tool, providing a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs.

Table 3.1 General Information on Case Studies

General Information on Case Studies			
Location	MAUTECH Administrative Building, Yola	ATBU Senate Building, Bauchi	GSU Administrative Building
Latitude & Longitude	$9^0$13’48” N $12^0$27’36”E	$10^0$18’57” N $9^0$50’39”E	$10^0$17’N $11^0$10’E
Activity Period	5 days a week from 08:00am to 05:00pm	5 days a week from 08:00am to 05:00pm	5 days a week from 08:00am to 05:00pm
Occupants’ Activities	Mostly paper based	Mostly paper based	Mostly paper based
Wall composition	sandcrete blocks (225mm); internal and external rendering (12.5mm); finished with medium Ocher Orange paint; 3.11 U-Value; 3.97 Time Constant (Hours)	Light pink sandcrete blocks (225mm); internal and external rendering (12.5mm); finished with vibrant ocher yellow; 3.11 U-Value; 3.97 Time Constant (Hours)	sandcrete blocks (225mm); internal and external rendering (12.5mm); finished with subtle umber natural brown; 3.11 U-Value; 3.97 Time Constant (Hours)
Roofing Material	0.75mm long span corrugated aluminum roofing sheet subtle sun yellow; no roof ventilation; 0.89 U-Value; 7-hour time lag.	0.75mm long span corrugated aluminum roofing sheet subtle spinel yellow; no roof ventilation; 0.89 U-Value; 7-hour time lag.	0.75mm long span corrugated aluminum roofing sheet finished medium spinal mint; with roof ventilation; 0.89 U-Value; 7-hour time lag.
Window material	single clear with blind glazed windows	single clear with blind glazed windows	single clear with blind glazed windows

Online energy, water, and carbon-emission analysis capabilities integrate with tools visualize and simulate a building's performance within the context of its environment. It calculates heating and cooling loads for models and analyze effects of occupancy, internal gains, infiltration, and equipment. Also, it visualizes incident solar radiation on windows and surfaces, over any period. It displays the

sun's position and path relative to the model at any date, time, and location. Guidelines for using Ecotect are as follows:

i. Building energy simulation software

The main goal of this project was to determine the thermal performance of the university administrative building. The most popular and advanced simulation software that can be used for this type of analysis for office buildings are the following: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES/VES, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS.

ii. Choosing an analysis method

The most important step in selecting an energy analysis method is matching method capabilities with project requirements. The method must be capable of evaluating all design options with sufficient accuracy to make correct choices. The following factors apply generally (Rabl, 1988):

a, Accuracy

The method should be sufficiently accurate to allow correct choices. Because of the many parameters involved in energy estimation, absolutely accurate energy prediction is not possible (Waltz & Sharma, 1992). Method of Test for the Evaluation of Building Energy Analysis Computer Programs, was developed to identify and diagnose differences in predictions that may be caused by algorithmic differences, modelling limitations, coding errors, or input errors.

i. *Sensitivity*

The method should be sensitive to the design options being considered. The difference in energy use between two choices should be adequately reflected.

ii. *Versatility*

The method should allow analysis of all options under consideration. When different methods must be used to consider different options, an accurate estimate of the differential energy use cannot be made.

iii. *Speed and cost*

The total time (gathering data, preparing input, calculations, and analysis of output) to make an analysis should be appropriate to the potential benefits gained. With greater speed, more options can be considered in a given time. The cost of analysis is largely determined by the total time of analysis.

iv. *Reproducibility*

The method should not allow so many vaguely defined choices that different analysts would get completely different results.

v. *Ease of use*

This affects both the economics of analysis (speed) and the reproducibility of results.

3.7.3 Selecting Energy Analysis Computer Programs

Selecting a building energy analysis program depends on its application, number of times it will be used, experience of the user, and hardware available to run it.

The first criterion is the capability of the program to deal with the application. For example, if the effect of a shading device is to be analyzed on a building that is also shaded by other buildings part of the time, the ability to analyze detached shading is an absolute requirement, regardless of any other factors.

i- Complexity of input

Complexity of input is largely influenced by the availability of default values for the input variables. Default values can be used as a simple set of input data when detail is not needed or when building design is very conventional, but additional complexity can be supplied when needed. Secondary defaults, which can be supplied by the user, are also useful in the same way. Some programs allow the user to specify a level of detail. Then the program requests only the information appropriate to that level of detail, using default values for all others.

ii- Quality of output

This is another factor to consider. Reports should be easy to read and uncluttered. Titles and headings should be unambiguous. Units should be stated explicitly. The user's manual should explain the meanings of data presented. Graphic output can be very helpful. In most cases, simple summaries of overall results are the most useful, but very detailed output is needed for certain studies and also for debugging program input during the early stages of analysis.

Before a final decision is made, manuals for the most suitable programs should be obtained and reviewed, and, if possible, demonstration versions of the programs should be obtained and run, and support from the software supplier should be tested. The availability of training should be considered when choosing a more complex program.

iii- Availability of weather data

Weather data processing subroutine or program are major features of a program. Some programs include subroutine or supplementary programs that allow the user to create a weather file for any site for which weather data are available.

iv- Auxiliary capabilities

Economic analysis and design calculations, are a final concern in selecting a program. An economic analysis may include only the ability to calculate annual energy bills from utility rates, or it might extend to calculations or even to life-cycle cost optimization. An integrated program may save time because some input data have been entered already for other purposes.

3.8 Analysis

The analysis conducted in this research is by the following methods:

The three techniques commonly used for electricity consumption analysis are statistical (parametric and non-parametric), artificial neural networks and intelligent computer systems techniques (Swan & Ugursal, 2009).

3.8.1 Parametric analysis with computer simulations

The aim of the parametric analysis is to observe the response following a modification in a variable. Parametric analyses are conducted for reasons including the need to determine (Waltz & Sharma, 1992):

I. Which parameters require additional research for strengthening the knowledge base,

thereby reducing output uncertainty?

II. Which parameters are insignificant and can be eliminated from the final model

III. Which inputs contribute most to output variability?

IV. Which parameters are most highly correlated with the output?

V. The consequence of changing a given input parameter

This investigation is concerned with point. Points 1-3 have already been established within the literature review and point 4 is outside the scope of this investigation.

The parametric analysis is used to examine the consequence of changing a given independent variable on electricity consumption and thermal comfort using computer simulations. The steps are:

I. Define the model, its independent and dependent variables. This includes defining the climatic profile

II. Vary the values of each independent variable one at a time, in a rational and

Incremental manner using the whole building energy calculation software EnergyPlus

III. Record the corresponding value of the dependent variable

IV. Assess and compare the influences of each input/output relationship through

Statistical methods.

4.0 RESULTS

4.1 Preamble

The findings from case studies carried out have been discussed under the following Sub-headings: Background information, passive cooling techniques, simulation and discussion of findings.

4.2 Findings from Case Study A: Modibbo Adama University of Science and Technology (MAUTECH) Administrative Building

MAUTECH senate building was designed by PPS department of the university and commissioned in 2003; it is a box design concept where all offices open to the central void in each of the three detached blocks. The building plan comprises of three detached single story office buildings that are linked with a void at the center. The building accommodates offices of staffs, senate chamber, governing council chamber, VC's office and other facilities.

4.2.1 Passive cooling techniques

Passive cooling strategies used in the design of MAUTECH senate building comprises of solar and heat control, heat modulation and heat dissipation using natural phenomena. Assessments of each of the strategies are presented below:

a. Heat prevention techniques

This section is very important because literature reviewed reveals that the first step towards achieving comfort in buildings is to prevent the heat from building up in the first place.

MAUTECH administrative building is assessed in accordance to orientation, shading, landscape and use of light color as illustrated below:

- *Orientation:* The building plan comprises of three detached square office buildings that are linked with an open space at the center see Figure 4.1, half of it faces the solar radiation and the other faces north-south, see Figure 4.2, there is limited apertures in the exposed surface to sun path to prevent heat from solar radiation intensity which causes high level of discomfort and encouraging the use of active cooling systems such as air conditioner (AC) in order to balance the effect due to overheating of the building envelop.



Figure 4.1 Orientation of MAUTECH Administrative Building (Source: google, 2016)

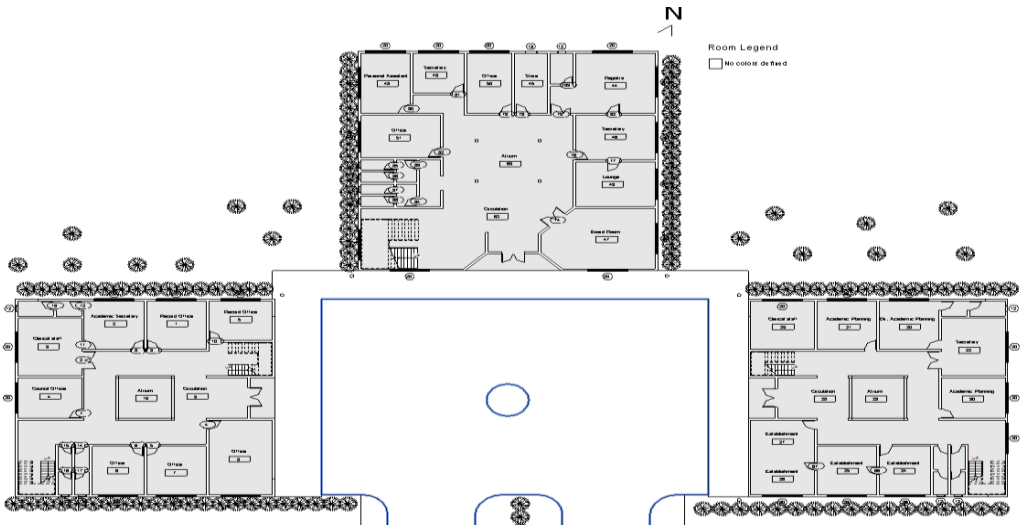


Figure 4.2 Ground Floor Plan of MAUTECH Administrative Building (Source: Field study, 2016)

- *Landscape:* The site landscape is characterized with short trees, growing trees, shrubs, grasses and arrangement of natural stones from the rear, while vehicle parking spaces with brick interlocks, interlocked walkways and driveways as part of the hard landscape. The administrative complex faces the east which is characterized by a dual asphalt drive way and hedges at the center. While vehicle parking spaces, shrubs planted around parking spaces, grasses and interlocked driveway are characteristics of landscape still on east side, see Plate I and II.



Plate I Administrative Building Facing East with Asphalt Driveway and Few Shrubs (Source: Field study, 2016)



Plate II Asphalt Finished Open Space Linking the three Semidetached Complexes (Source: Field study, 2016)

Plate I and II presented the west, north and south elevations of the senate building. Different species of trees and grasses are the landscape features of the site. The presence of vegetation on west side is very important as it diffuses sun radiation from coming directly in to the building and humidifies the surrounding air, see plate III and IV.



Plate III Soft Landscape from the South View (Source: Field study, 2016)

- *Shading:* On all sides of the building, the dominant shading system adopted was projected long roof parapet overhang while tall trees provide shading in the west,

north and south. The solar radiation from angle sun is not blocked from the interior.

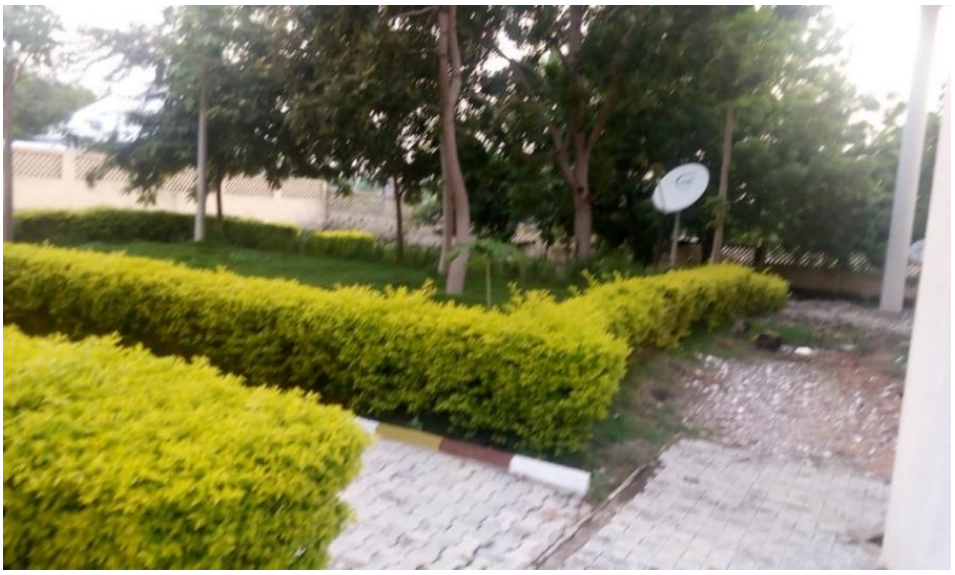


Plate IV Garden in the West Elevation for Cool Breeze (Source: Field study, 2016)

- *Use of light colors on the exterior:* yellow emulsion paint constitutes the color applied at the external wall surface. Light colored material has high reflection and low absorption properties. These properties are required in reducing excess solar gain. The walkways are made from interlocks while the parking spaces and driveway from asphalt

b. Heat modulation techniques

The heat modulation strategies identified in the field comprises of insulation and thermal mass. Assessment of MAUTECH administrative building in accordance to insulation and thermal mass are discussed in the subsections below:

- *Insulation:* The attic space in the roof ceiling of the building of provides insulation for the buildings in other to reduce excess heat gain. Roof structures has larger exposed surface to solar radiation intensity therefore. The exterior walls are made

from hollow sand Crete block with burnt brick finishes covering some part of the building elevation

- *Thermal mass:* The material use for exterior walls are characterize as a low thermal mass material. Sand Crete block has low mass that is subject to absorbing and dissipating heat from the sun to the interior spaces and environment at a very fast rate. Concrete has high thermal mass characterized with of absorption, holding and dissipation of solar heat gain. Concrete is used in decks and long roof overhang.

c. Heat dissipation techniques

Heat dissipation techniques deal with the disposal of the excess heat of a building to a sink characterized by lower temperature. The only heat dissipation strategy used in MAUTECH administrative building is natural ventilation and is discussed below:

- *Natural ventilation:* There is average optimization of natural means of achieving ventilation in the building. The backyard landscape with trees, grass and other soft landscaping elements serve the means for exchange of hot air from the exterior with cool air from the backyard.

Assessments of MAUTECH administrative building in accordance to the checklist established from literature is summarized in table 4.1a and 4.1b. the checklists contain the detailed requirements of each of the three major energy efficiency strategies such as heat protection technique, heat modulation technique and heat dissipation technique

Table 4.1a Result of Checklist used for the Assessment of Passive Cooling Strategies on MAUTECH Administrative Building (Source: Author, 2016)

Passive cooling Principles	Passive cooling Technique	Requirements	Level of Reflection 1	2	3	4	5	Remark
Heat prevention techniques	Orientation	-shorter side of the building Should be exposed to sun path.		X				From assessment based on level of reflection of orientation on passive cooling (A.=8/15)
		-design narrow building forms with longer walls oriented to cooling breezes.				X		
		-adopt east-west orientation.		X				
	Landscape	-extensive use of soft landscape in the environment.		X				From assessment based on level of reflection of landscape on passive cooling (A=11/20)
		- Use of shrubs or other plantings to shade paved areas.		X				
		-Use of tall trees to provide shade for the building against direct solar heat gain.			X			
		-use of grasses as ground cover to improve evaporation.				X		
	Shading	- use of building mass to produce shadow/shade	X					From assessment based on level of reflection of landscape on passive cooling (A=7/20)
		-use of long overhang along sun path.	X					
		-balconies and window recesses.	X					
	Use of light-colored materials.	-use of light-color surface finishes on walkways, driveways and other hard landscape elements.			X			From assessment based on level of reflection of landscape on passive cooling (A=6/20)
		-use of light-colored roofing materials			X			

5=Very Strong 4= Strong 3= Average 2= Weak 1= Very weak

Table 4.1b Analysis of Checklist used for the Assessment of Passive Cooling Techniques on MAUTECH Administrative Building (Source: Author, 2016)

Passive cooling Principles	Passive cooling Techniques	Requirements	Level of Reflection 1	2	3	4	5	Remark
Heat modulation techniques	Insulation	-provide ceilings in all offices to insulate from the heat generated inside roof space.					X	From assessment base on level of reflection of insulation material on passive cooling (A=8/15)
		-provide roof ventilation.		X				
		-use of wall tiles on the external surfaces to maximize wall insulation.	X					
	Thermal mass	-compact planning of buildings to minimize heat gain.			X			The assessment shows level of reflection of thermal mass on passive cooling (A=6/10)
		-use of building material with high thermal mass for construction of external walls on east and west elevations.			X			
Heat dissipation techniques	Natural ventilation	-positioning of openings to take advantage of prevailing wind.			X			The assessment shows level of reflection of natural ventilation on passive cooling (A=18/25)
		-windows should be located for maximum cross ventilation in each room.			X			
		-use of larger openings along south façade.				X		
		-use of large courtyard to provide cool breezes.				X		
		-use of windows with maximum open area.				X		

5= Very Strong 4= Strong 3= Average 2= Weak 1= Very weak

4.3 Findings from Case Study B: Abubakar Tafawa Balewa University, Bauchi (ATBU) Senate Building.

The senate building is a two story structure designed by Capital Projects Consultants built on the university main campus and commissioned around 2008 to serve as the central administrative building. The structure was designed by Capital Projects Consultants to accommodate offices of staff, head of security and senior administrative officers. The council chamber as well as the VCs office is located on the second floor alongside DVC admin, DVC academics and Audit section. Staircases are the main means of vertical transportation.

4.3.1 Passive cooling techniques

Passive cooling strategies used in ATBU senate building comprises of solar and heat control, heat modulation and heat dissipation using natural phenomena. Assessments of each of the strategies are presented below:

a- Heat prevention techniques

Heat prevention techniques assessed in this study comprises of orientation, landscape, shading and the use of light-color surfaces on the exterior as discussed below:

- *Orientation:* The building comprises of four square blocks of offices connected to each other around a central void, see figure 4.3.



Figure 4.3 Orientation of ATBU Senate Building (Source: google earth, 2016)

The square blocks of offices with their shorter sides facing sun path as illustrated in figure 4.4; the sides exposed to the direct sunlight are recessed to provide shading minimizing heat island on the external surrounding which is considered ideal orientation for heat gain prevention in hot climates; it makes use of the air masses in cooling the building in a passive way.

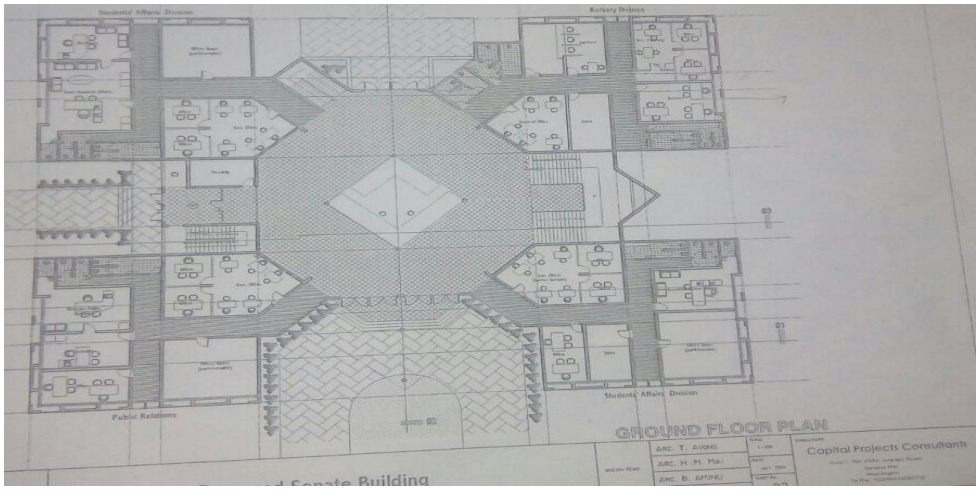


Figure 4.4 Floor plan of ATBU Senate Building (Source: Field study, 2016)

- *Landscape:* On the north elevation of the building, the landscape is characterized with grasses, asphalt driveway and very few deciduous trees shading the offices,

see Plate 4.3; the area of hard landscape will lead to absorption of solar radiation hence heating of air in surrounding causing heat island effect. The green parts of the landscape encourage evaporation and helps in sun shading and cooling of air around the building. From the south view, shrubs and deciduous trees are planted to optimize cool breeze around the building.



Plate V North View of the Building Showing Landscape Features (Source: Field study, 2016)

The east and west sides of the building are characterized with ground cover grasses and deciduous trees to provide shade for the building against direct solar heat gain, this serves insulation purposes as they filter cool breezes before entering into building openings, see plate V.



Plate VI East View of the Building Showing Vegetation and Grass Cover (Source: Field study, 2016)

While paved ways constitute only a small portion of the landscape, see Plate V and VI. Finally, the void provides ventilation with stack effect as elements of passive cooling.



Plate VII West View of the Building Showing Trees Shading Some part of Parking Spaces (Source: Field study, 2016)

- *Shading:* On all sides of the building the only shading element is recess around the apertures see plate VII.

From the front around the council chamber there are balconies and slab projections which constitute the shading for the council chamber, see plate VIII. Generally, these shadow cools the building envelop as the breezes around the walls are been cooled.



Plate VIII Use of Balconies and Recesses to Provide Shade for ATBU Senate Building (Source: Field study, 2016)

Deciduous trees and hedges are used in providing shade for covered parking spaces to minimize the rate of heat gain of surfaces exposed to solar radiation intensity, see plate IX.



Plate IX Deciduous Trees used to Provide Shading (Source: Field study, 2016)

- *Effect of the surfaces finish:* Light pink emulsion paint is used on all surfaces of the external walls and shading devices on walls. Light colors are regarded as cool material characterized by high solar reflectance and infrared emittance values. These properties are the two main factors that control the temperature of a surface.



Plate X Floor Finish of ATBU senate building (Source: Field study, 2016)

The building is roofed with a light milk color aluminum roofing sheet, while the decks are finished with bituminous coating to prevent against moisture leakages. Light colored roofing material has high reflectance and low absorption properties, See Plate X. The roofing structure has high potentials for solar heat gain because it is the most exposed surface to solar radiation intensity. The use of light pink paint instead of dark shades of colors will go a long way in minimizing the rate of heat absorption.

b- Heat modulation techniques

The heat modulation strategies identified in the field comprises of insulation and thermal mass. Assessment of ATBU senate building in accordance to insulation and thermal mass are discussed in the subsections below:

- *Insulation:* The attic space in the roof ceiling of the four blocks of offices provides insulation for the buildings for minimizing excess heat gain. Roof structures has larger exposed surface to solar radiation intensity therefore, providing roof ventilation will greatly maximize the performance of the ceiling
- *Thermal mass:* All matter has thermal mass; however, when used in reference to a building, thermal mass generally means materials capable of absorbing, holding and gradually releasing heat. Heavy, dense building materials with high specific heat like concrete, brick and other masonry have high thermal mass.

  Sand Crete hollow block which is the dominant building material used for the construction of the building has less thermal mass. Concrete projected floors have the ability of absorbing cool night air when the surrounding temperature is less than the interior temperature, holding and gradually releasing and cooling the interior during the day time when surrounding temperature becomes greater than room temperature.

c- Heat dissipation techniques

Heat dissipation techniques deal with the disposal of the excess heat of a building to a sink characterized by lower temperature. The only heat dissipation strategy used in ATBU senate building is natural ventilation and is discussed below:

- *Natural ventilation:*

  The council chamber close to the VC's office in the second floor is well ventilated with larger window openings to the outside, these increases the rate of air movement into the building.

  The office design of all the blocks are double banked with offices opposite each other and a narrow lobby.

The ventilation system adopted was a combination of single-sided ventilation techniques with windows from the external walls and void, while the stacked windows from the lobby provides cross ventilation using stack effect for the offices and also cools the central lobby, see Fig 4.5.

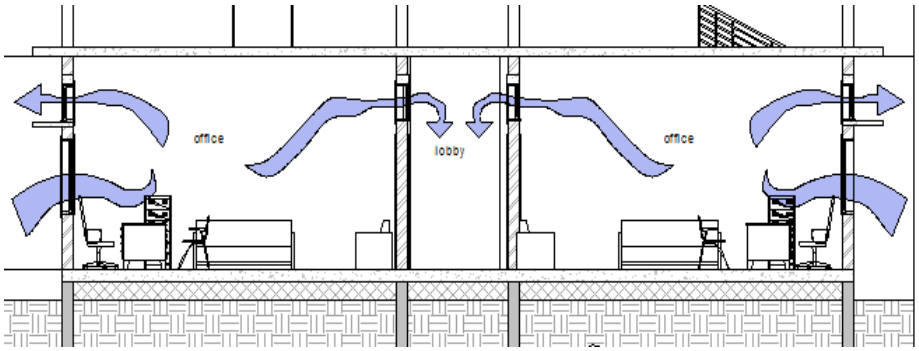


Figure 4.5 Section across the building showing natural ventilation method adopted in the offices (Source: field study, 2016)

Assessments of ATBU senate building in accordance to the checklist established from literature is summarized in table 4.2a and 4.2b. The assessments were carried out the using 1-5 scale in place of very strong to very weak. Eventually, the overall results were analyzed using graphs.

Table 4.2a Checklist used for the Assessment of Passive Cooling Techniques on

ATBU Senate Buildings (Source: Author, 2016)

Passive cooling Principles	Passive cooling Technique	Requirements	Level of Reflection 1	2	3	4	5	Remark
Heat prevention techniques	Orientation	-shorter side of the building Should be exposed to sun path.				X		From assessment based on level of reflection of orientation on passive cooling (B=11/15)
		-design narrow building forms with longer walls oriented to cooling breezes.			X			
		-adopt east-west orientation.	X					
	Landscape	-extensive use of soft landscape in the environment.				X		From assessment based on level of reflection of landscape on passive cooling (B=16/20)
		- Use of shrubs or other plantings to shade paved areas.				X		
		-Use of tall trees to provide shade for the building against direct solar heat gain.				X		
		-use of grasses as ground cover to improve evaporation.				X		
	Shading	- use of building mass to produce shadow/shade			X			From assessment based on level of reflection of shading on passive cooling (B=7/15)
		-use of long overhang along sun path	X					
		-balconies and window recesses.			X			
	Use of bright-colors on the exterior surfaces	-use of lighter colors on external walls.			X			From assessment based on level of reflection of light-color material on passive cooling (B=8/15)
		-use of light-colored roofing materials.	X					
		-use of light-color surface finishes on walkways, driveways and other hard landscape elements.			X			

5= Very Strong 4= Strong 3= Average 2= Weak 1= Very weak

Table 4.2b Checklis**t** used for the Assessment of Passive Cooling Techniques on ATBU Senate Buildings (Source: Author, 2016)

Passive cooling Principles	Passive cooling Techniques	Requirements	Level of Reflection 1	2	3	4	5	Remark
Heat modulation techniques	Insulation	-provide ceilings in all offices to insulate from the heat generated inside roof space.	X					From assessment base on level of reflection of insulation material on passive cooling (B=7/15)
		-provide roof ventilation.	X					
		-use of wall tiles on the external surfaces to maximize wall insulation.	X					
	Thermal mass	-compact planning of buildings to minimize heat gain.				X		The assessment shows level of reflection of thermal mass on passive cooling (B=8/10)
		-use of building material with high thermal mass for construction of external walls on east and west elevations.				X		
Heat dissipation techniques	Natural ventilation	-positioning of openings to take advantage of prevailing wind.			X			The assessment shows level of reflection of thermal mass on passive cooling (B=8/10)
		-windows should be located for maximum cross ventilation in each room.			X			
		-use of larger openings along south façade.				X		
		-use of large courtyard to provide cool breezes.				X		
		-use of windows with maximum open area.				X		

5= Very Strong 4= Strong 3= Average 2= Weak 1= Very weak

4.4 Findings from Case Study C: Gombe State University (GSU) Senate Building

The building is a single floor structure redeveloped by multi-systems consultants LTD in 2004 and commissioned in 2005 the building has semidetached buildings comprising VC's complex, Registry, student affairs, Deanery, etc.

4.4.1 Passive cooling techniques

Passive cooling strategies used in GSU administrative building comprises of solar and heat control, heat modulation and heat dissipation using natural phenomena. Assessments of each of the strategies are presented below:

a, Heat prevention techniques

The heat prevention techniques to be assess in this study comprises of orientation, landscape, shading and the use of light-color surfaces on the exterior.

- *Orientation:* The building is rectangular in shape orientated with longer sides facing north and south, while the shorter sides facing the sun path which is considered to be the ideal, see Figure 4.6.
- *Landscape:* The landscape on the north side of the building is characterized with large surfaces of low grasses, asphalt driveways and very few shrubs.



Figure 4.6 Site Plan of GSU Administrative Building (Source: google earth, 2016)

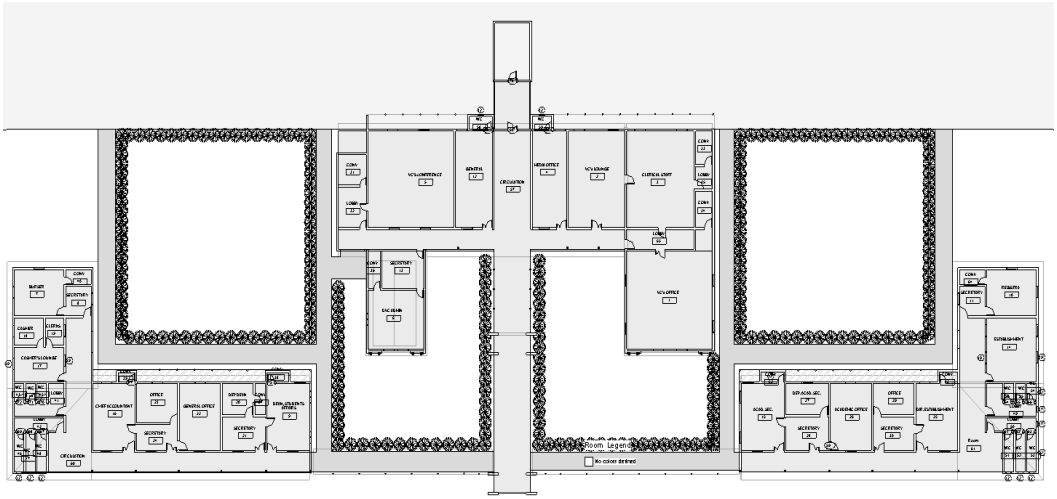


Figure 4.7 Ground Floor Plan of GSU Administrative Building (Source: Field study, 2016)

The green surfaces help in evaporation and in cooling of surrounding air while hard landscape absorbs and radiate heat making the surrounding air hot and interior spaces uncomfortable. On the east and west sides, characterized with surfaces of dense grasses, interlocked walkway and asphalt driveways; see Plate XI



Plate XI Exterior View from east Elevation Showing Landscape Features (Source: Field study, 2016)

The courtyard is landscaped with grasses and growing trees and shrubs to help cool the interior from the micro climate formed by the courtyard, see Plate XII.



Plate XII View from the Courtyard Showing Landscape Grasses and Growing Trees (Source: Field study, 2016)

- *Shading:* The type of shading device used on east and west elevations are basically the vertical projected walls, arcades and long roof overhang. The presence of shrubs, grass cover and growing trees on the external environment allows filtered

solar radiation into the building openings and heat prevention of the building envelops, see Plate XIII.



Plate XIII Exterior View from East Elevation Showing Projected Wall as Vertical

Shading Device, Roof Overhang and Window Recess (Source: Field study, 2016)

- *Use of light colors on the exterior surfaces:* Some parts of the exterior walls are finished with crack stones which more thermal mass than sandcrete blocks whereas the majority of the exterior walls are finished with *Abuja brown* color emulsion paint, see Plate XIV. It reflection of solar radiation is greater than darker colors but less than much lighter colors. It absorption rate is greater when compare with white emulsion paint.



Plate XIV *Abuja brown* paint as Wall Finish (source: Field study, 2016)

On the roof structure, silver color long aluminum roofing sheet is used for the covering, Silver colors are light and has reflective tendencies of solar radiation. The walkways are paved with light bright interlock tiles and driveways with gravel and ash color asphalt.

b, Heat modulation techniques

Heat modulation is associated with high thermal mass materials, like brick and concrete, in building structures that act as a storage for heat during daytime and cold at night.

- *Insulation:* The attic space in the roof ceiling of the building of provides insulation for the buildings in other to reduce excess heat gain. The roof has roof vents. Incorporating roof vents greatly maximizes the insulating performance of the ceiling.
- *Thermal mass:* Apart some portion of the exterior wall which was built of stones, Sand Crete block was used throughout the building construction. Sand Crete block is a low thermal mass building material when compare with concrete and brick blocks. Low thermal mass material absorbs and releases heat from the sun to the surrounding at a very fast rate.

c, Heat dissipation techniques

Heat dissipation techniques deal with the disposal of the excess heat of a building to a sink characterized by lower temperature. The only heat dissipation strategy used in ATBU senate building is natural ventilation and is discussed below:

- *Natural ventilation:* The building attains it natural ventilation by utilizing the courtyard, arcade and overhangs most of the office are designed around central courtyards given the opportunity of having opposite windows in the offices, see plate XV. The orientation of the building also promotes achievement of natural ventilation because the longer side of the building is along direction of cooling breezes.



Plate XV Arcade in Front of Offices in GSU Senate Building (source: Field study, 2016)

Assessments of GSU administrative building in accordance to the checklist established from literature is summarized in Table 4.3a and 4.3b. The checklists contain the detailed requirements of each of the three major energy efficiency strategies such as heat protection technique, heat modulation technique and heat dissipation technique

Table 4.3a Checklist used for the Assessment of Passive Cooling Techniques on GSU Administrative Building (Source: Author, 2016)

Passive cooling Principles	Passive cooling Technique	Requirements	Level of Reflection 1	2	3	4	5	Remark
Heat prevention techniques	Orientation	-shorter side of the building Should be exposed to sun path.	X					From assessment based on level of reflection of orientation on passive cooling (C=15/15)
		-design narrow building forms with longer walls oriented to cooling breezes.	X					
		-adopt east-west orientation.	X					
	Landscape	-extensive use of soft landscape in the environment.	X					From assessment based on level of reflection of landscape on passive cooling (C=16/20)
		- Use of shrubs or other plantings to shade paved areas.	X					
		-Use of tall trees to provide shade for the building against direct solar heat gain.			X			
		-use of grasses as ground cover to improve evaporation.				X		
	Shading	- use of building mass to produce shadow/shade				X		From assessment based on level of reflection of shading on passive cooling (C=13/15)
		-use of long overhang along sun path.	X					
		-balconies and window recesses.				X		
	Use of bright-colors on the exterior surfaces	-use of lighter colors on external walls.				X		From assessment based on level of reflection of light-color material on passive cooling (C=8/15)
		-use of light-colored roofing materials.			X			
		-use of light-color surface finishes on walkways, driveways and other hard landscape elements.			X			

5= Very Strong 4= Strong 3= Average 2= Weak 1= Very weak

Table 4.3b Checklist used for the Assessment of Passive Cooling Techniques on GSU Administrative Building (Source: Author, 2016)

Passive cooling Principles	Passive cooling Techniques	Requirements	Level of Reflection 1	2	3	4	5	Remark
Heat modulation techniques	Insulation	-provide ceilings in all offices to insulate from the heat generated inside roof space.	X					From assessment base on level of reflection of insulation material on passive cooling (C=13/15)
		-provide roof ventilation.	X					
		-use of wall tiles on the external surfaces to maximize wall insulation.			X			
	Thermal mass	-compact planning of buildings to minimize heat gain.		X				The assessment shows level of reflection of thermal mass on passive cooling (A=6/10, B=8/10, C=5/10)
		-use of building material with high thermal mass for construction of external walls on east and west elevations.			X			
Heat dissipation techniques	Natural ventilation	-positioning of openings to take advantage of prevailing wind.	X					The assessment shows level of reflection of natural ventilation on passive cooling (C=20/25)
		-windows should be located for maximum cross ventilation in each room.	X					
		-use of larger openings along south façade.			X			
		-use of large courtyard to provide cool breezes.	X					
		-use of windows with maximum open area.			X			

5= Very Strong 4= Strong 3= Average 2= Weak 1= Very weak

4.5 Preliminaries for simulation

This section presents in detail how the collected data were discussed. First a baseline model was redrawn 'as built' see Figure 4.8. In the second stage, results were observed and recorded. The third stage involves interpretation and presentation of results in various tables and charts.

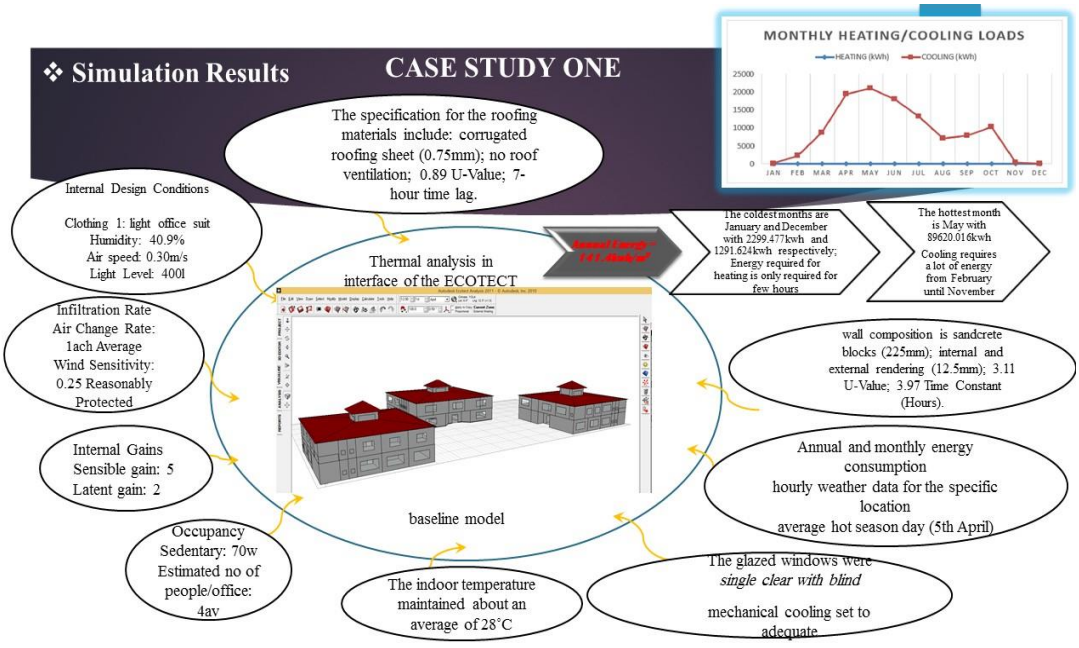


Figure 4.8 Baseline Model of MAUTECH Administrative Building (source: Field study, 2016)

The results of energy consumption presented here are with the mechanical cooling set to adequate. The indoor temperature is therefore maintained about an average of 25˚C. The dependent variable used to examine the thermal performance of the variables is annual and monthly energy consumption. Detail results of the simulation can be found in the appendices of this research. Also hourly weather data for the specific location of this research is also moved to the appendix.

4.6 Environment for the Experiment

Autodesk's ECOTECT is a building analysis software that allows user to easily design and work in 3D; it offers a wide range of analysis options from acoustics to energy efficiency tools. ECOTECT's tool related to energy efficiency can be found under thermal analysis in it interface. For this tool to be used properly, it requires the adherence to some specific principles when constructing the model that will be analyzed, afterwards simulation was ran to observe how these behaved all together in regards energy consumption.

The simulation runs on average hot season day (5th April) also, it is important to note that the general parameters for the simulation are: wall composition is sandcrete blocks (225mm); internal and external rendering (12.5mm); 3.11 U-Value; 3.97 Time Constant (Hours). The specification for the roofing materials include: corrugated roofing sheet (0.75mm); no roof ventilation; 0.89 U-Value; 7-hour time lag. Lastly, the glazed windows were *single clear with blind*.

4.7 Monthly heating/cooling Loads

Heating Cooling loads of air conditioning system working with 95% efficiency and 10m² per person at a state of activity (55W) is considered for the calculations. The thermal comfort zone is chosen as 18-28 ^{0}C for the temperature band that the calculation would take place according to the standards (Schiller Brager & de Dear. (2000); ANSI/ASHRAE (2001) Standard 55-2000R) applied to the Yozgat weather data, 2002. However, due to geographical location and climatic condition of dry sub-humid zone, the total annual energy required for heating is very small (which can be negligible) and it's only required for few hours in the two coldest months of the year which are January and December.

4.7.1 Monthly heating/cooling loads for MAUTECH senate building

The simulation results from Ecotect analysis for the entire MAUTECH administrative building are moved to appendix VI

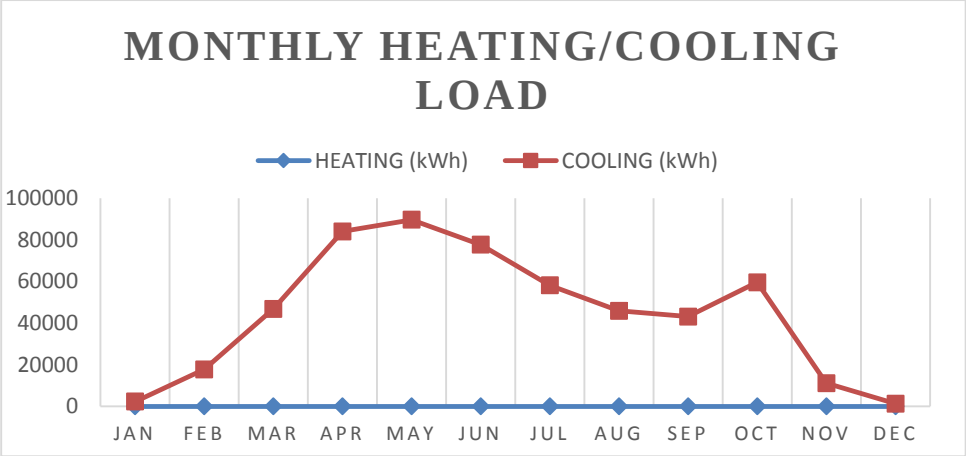


Figure 4.9 Visual Analysis of Monthly heating/cooling Loads of MAUTECH Administrative Building (source: field study, 2016)

The coldest months for MAUTECH administrative building are January and December with 2299.477kwh and 1291.624kwh respectively while the hottest month is May with 89620.016kwh, see Figure 4.9. Energy required for heating is only required for few hours in the two coldest months of the year which are January and December. But cooling the MAUTECH senate building requires a lot of energy starting from February until November. The month with peak energy consumption is May i.e. around middle of the year.

Moreover, the coldest months recorded in the VC's office of MAUTECH administrative building are January and December with 34.683Kwh and 12.866kwh respectively while the hottest month is May with 1622.735kwh.

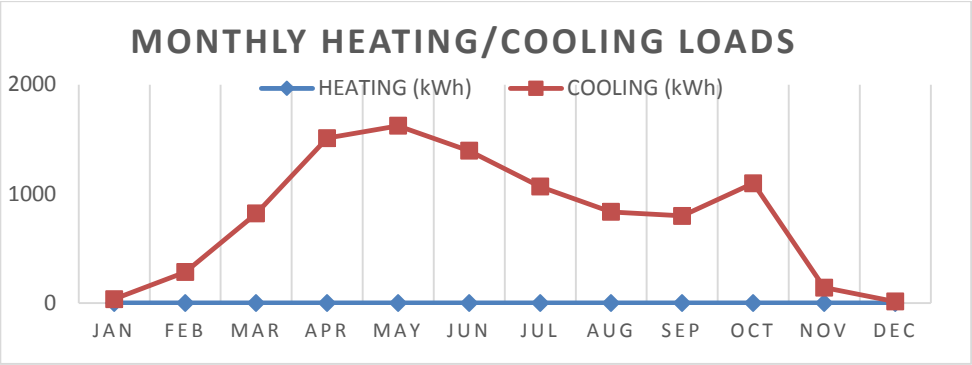


Figure 4.10 Visual Analysis of Monthly heating/cooling Loads for MAUTECH Administrative Building; VC's Office (source: field study, 2016)

Energy for heating is only required for few hours in the two coldest months of the year which are January, November and December. But cooling the VC's office requires a lot of energy starting from February until November. The month with peak energy consumption is May i.e. around middle of the year, see Fig 4.10

Also, the monthly heating/cooling loads for the council chamber of MAUTECH administrative building recorded that the coldest months are January and December with 32.36kwh and 15.405kwh respectively while the hottest month is May with 1789.111 kwh.

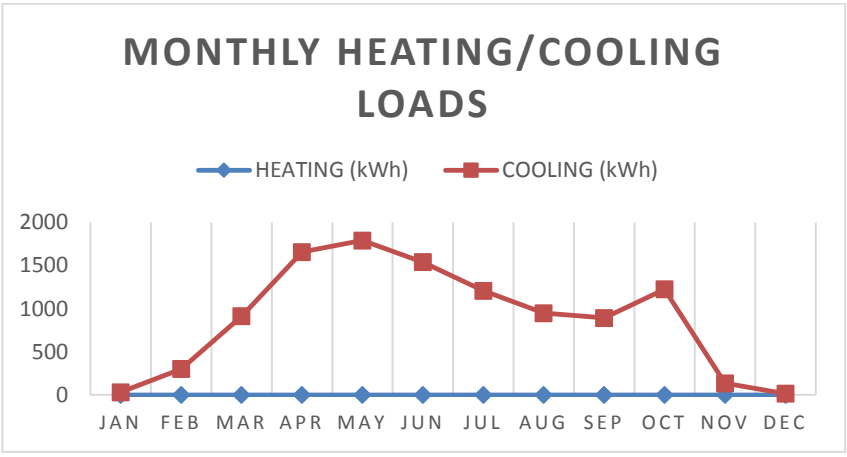


Figure 4.11 Visual Analysis of Monthly heating/cooling Loads for cooling MAUTECH Administrative Building; Council Chamber (source: field study, 2016)

Energy for heating is only required for few hours in the two coldest months of the year which are January, November and December. But cooling the council chamber requires a lot of energy starting from February until October, see Figure 4.11. The month with peak energy consumption is May i.e. around middle of the year.

4.7.2 Monthly heating/cooling Loads for ATBU senate building

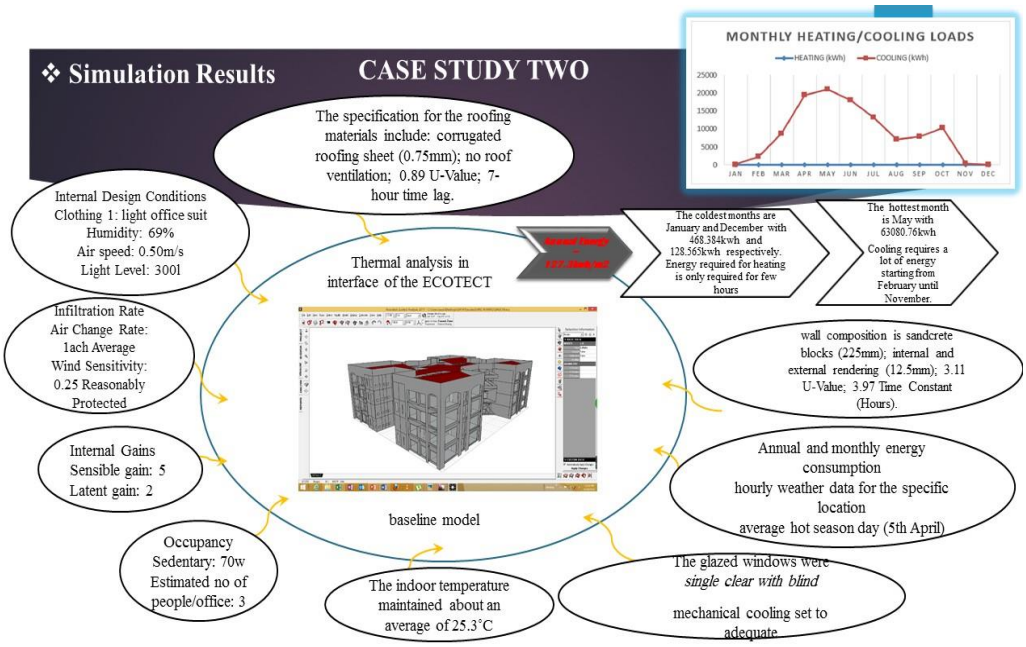


Figure 4.12 Baseline model of ATBU Senate Building (source: Field study, 2016)

The summary of the input data and the simulation results are illustrated in figure 4.12. The simulation results from Ecotect analysis for the entire ATBU senate building are moved to the appendix.

For ATBU senate building, the coldest months are January and December with 468.384kwh and 128.565kwh respectively while the hottest month is May with 63080.76kwh followed by April with 58443.12 and June with 54036 respectively, see figure 4.13

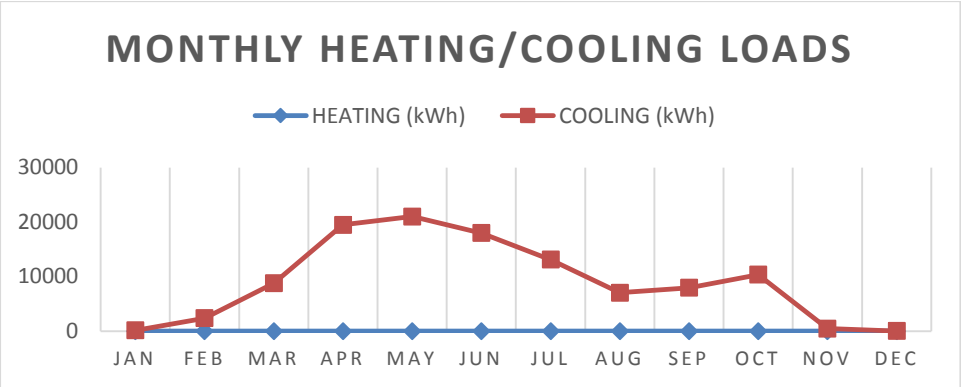


Figure 4.13 Visual Analysis of Monthly heating/cooling Loads of ATBU Senate Building (source: field study, 2016)

Energy required for heating is only required for few hours in the two coldest months of the year which are January and December. But cooling the ATBU senate building requires a lot of energy starting from February until November. The month with peak energy consumption is May i.e. around middle of the year as illustrated in figure 4.13.

The monthly heating/cooling loads for the VC's office of ATBU senate building recorded that, the coldest months in VC's office of ATBU senate building are January, November and December with 0kwh, 0kwh and 0kwh respectively, see Figure 4.14 while the hottest month is May with 715.997kwh.

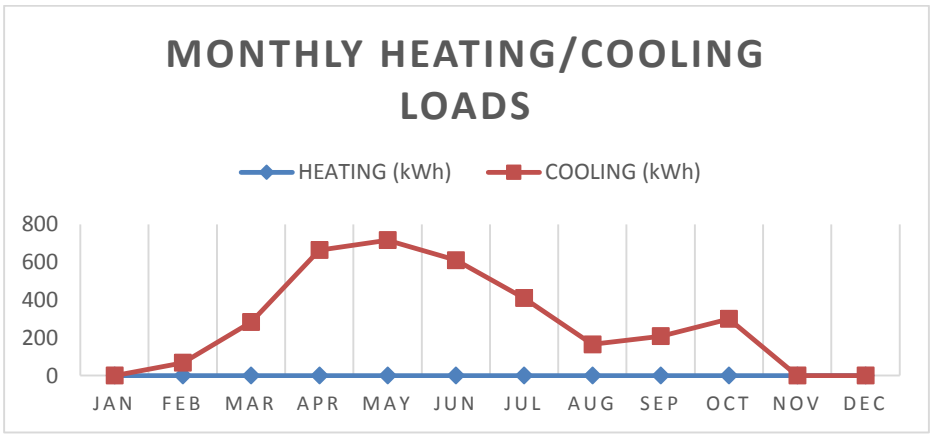


Figure 4.14 Visual Analysis of Monthly heating/cooling Loads for ATBU Senate Building; VC's Office (source: Field study, 2016)

Energy for heating is only required for few hours in the two coldest months of the year which are January, November and December. But cooling the VC's office requires a lot of energy starting from February until October. The month with peak energy consumption is May i.e. around middle of the year.

The monthly heating/cooling loads for the council chamber of ATBU senate building recorded that the coldest months in the council chamber of ATBU senate building are January, November and December with 0kwh, 0kwh and 0kwh respectively. while the hottest month is May with 1111.967kwh.

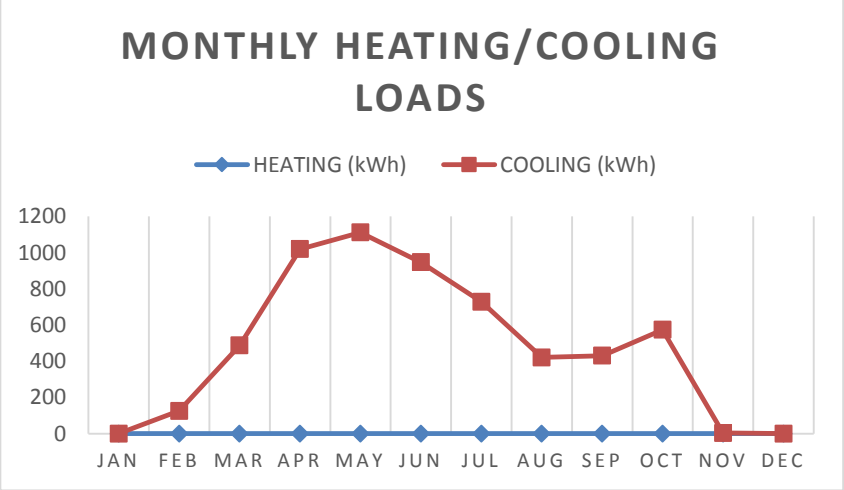


Figure 4.15 Visual Analysis of Monthly heating/cooling of ATBU Senate Building; Council Chamber (source: Field study, 2016)

Energy for heating is only required for few hours in the two coldest months of the year which are January, November and December, see Figure 4.15. But cooling the council chamber requires a lot of energy starting from February until October. The month with peak energy consumption is May i.e. around middle of the year.

The data input and the results obtained are summarized in figure 4.16. the input data were generated from the reviewed literature and the standards provided by Ecotect energy analysis software.

4.7.3 Monthly heating/cooling loads for GSU senate building

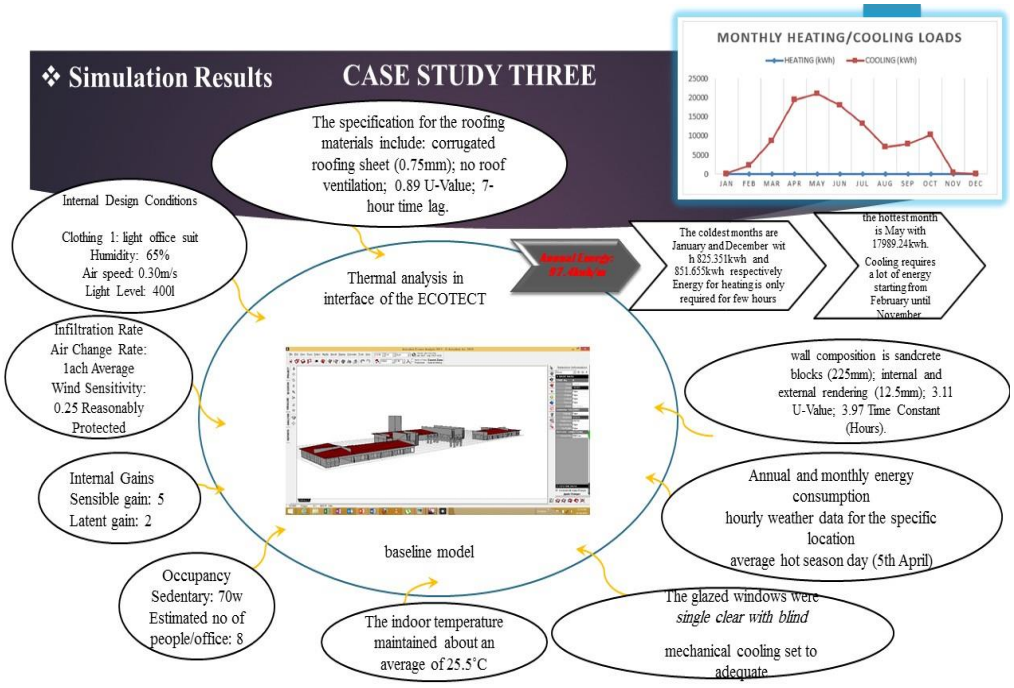


Figure 4.16 Baseline model of GSU Administrative Building (source: Field study, 2016)

The simulation results from Ecotect analysis for the entire GSU administrative building are moved to appendix. For GSU senate building, the coldest months are January and December with 825.351kwh and 851.655kwh respectively, see figure 4.17 while the hottest month is May with 17989.24kwh.

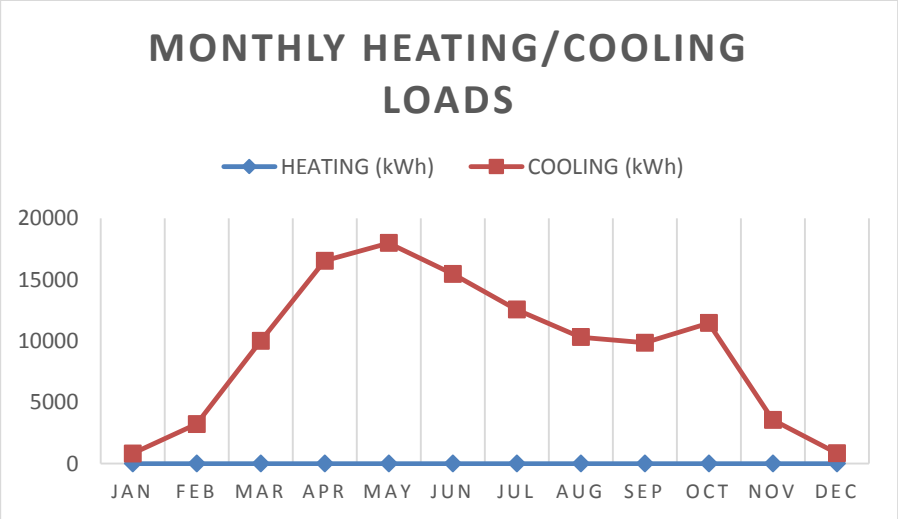


Figure 4.17 Visual Analysis of Monthly heating/cooling Loads of GSU Administrative Building (source: Field study, 2016)

Energy for heating is only required for few hours in the two coldest months of the year which are January and December. Cooling the GSU senate building requires a lot of energy starting from February until November. The month with peak energy consumption is May i.e. around middle of the year.

The monthly heating/cooling loads for the VC's office of GSU administrative building recorded that the coldest months are January and December with 0Kwh and 0kwh respectively while the hottest month is May with 622.844kwh.

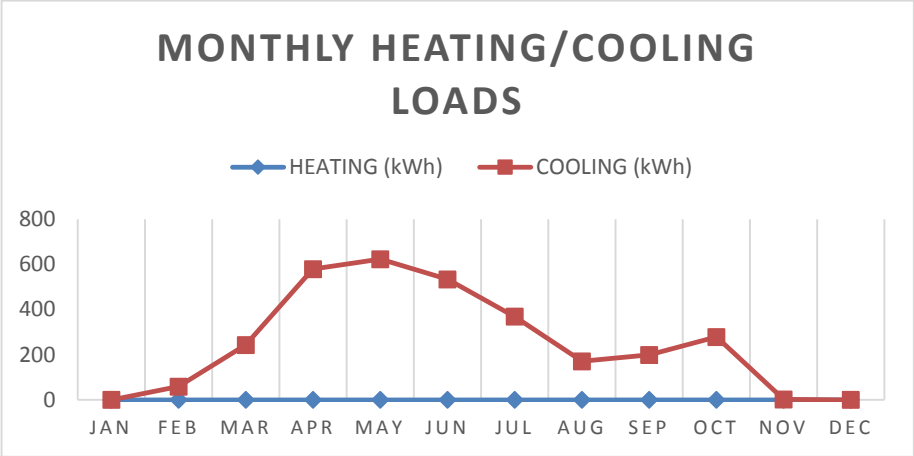


Figure 4.18 Visual Analysis of Monthly heating/cooling Loads for GSU Administrative Building; VC's Office (source: Field study, 2016)

Energy for heating is only required for few hours in the two coldest months of the year which are January and December. But cooling the VC's office requires energy starting from February until November, see figure 4.18. The month with peak energy consumption is May i.e. around middle of the year.

The monthly heating/cooling loads for the council chamber of GSU administrative building recorded that the coldest months are January, November and December with 0kwh, 0kwh and 0kwh respectively while the hottest month is May with 281.697kwh. February and August are relatively very cold with 15.865kwh and 14.218kwh respectively, see figure 4.19.

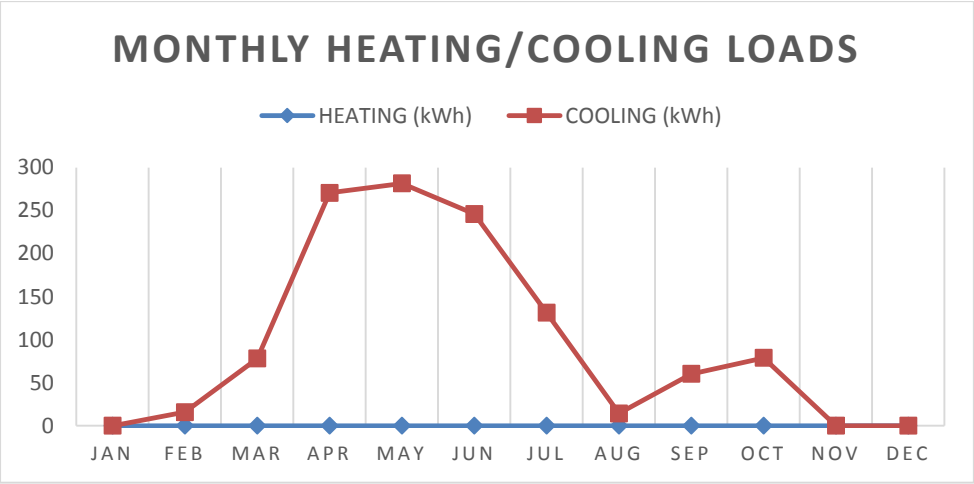


Figure 4.19 Visual Analysis of Monthly heating/cooling Loads for GSU Administrative Building; Council Chamber (source: Field study, 2016)

Energy for heating is only required for few hours in the two coldest months of the year which are January. November and December and averagely very cold months which are February and August. But cooling the council chamber requires energy starting from March to July and September to October. The month with peak energy consumption is May i.e. around middle of the year.

4.8 Discussions of Findings

The methods of data collection for this research comprise of field work and virtual laboratory. The field work was assessed using checklist established from literature review while the virtual laboratory was used to assess monthly energy load of each of the three local case studies

4.8.1 Discussion of findings from visual survey

From Table 4.4 case study C has the highest level of reflection of passive cooling techniques with 90/115 followed by case study B with 75/115 and case study C with 68/115 respectively. This shows that case study C has the highest tendency

of lowest energy load for cooling throughout the year which is testified by energy simulation followed by case study B and case study A respectively.

Table 4.4 Summery of Level of Reflection of Checklists (Source: Author, 2016)

Variable	Case study A	Case study B	Case study C
Orientation	8	11	15
Landscape	11	16	16
Shading	7	7	13
Use of light color	8	8	11
Insulation	8	7	10
Thermal mass	6	8	5
Natural ventilation	18	18	20
Total	75	75	90

Figure 4.20 shows that on heat prevention technique, case study B has its lowest level of reflection on shading; the level of reflections of the landscape is the highest and orientation is very high; and relatively average on use of light colors on exterior surfaces. On heat modulation technique, the lowest level of reflection occurs on insulation; and relatively average on thermal mass. On heat dissipation technique the level of reflection is very high on natural ventilation.

Moreover, on heat prevention technique, case study A has its lowest level of reflection on shading; the level of reflection of landscape and use of light colors on exterior surfaces is very high; and relatively orientation. On heat modulation technique, the lowest level of reflection occurs on thermal mass; and relatively average on insulation average on. On heat dissipation technique the level of reflection of natural ventilation is very high.

In addition, on heat prevention technique, case study C has its lowest level of reflection on use of light colors on exterior surfaces; the level of reflection of landscape and orientation is very high due to the rectangular nature of the building

plan, shorter side of the building is oriented to face sun path while the longer axis along south and north and a lot of landscaped open spaces see figure 4.20

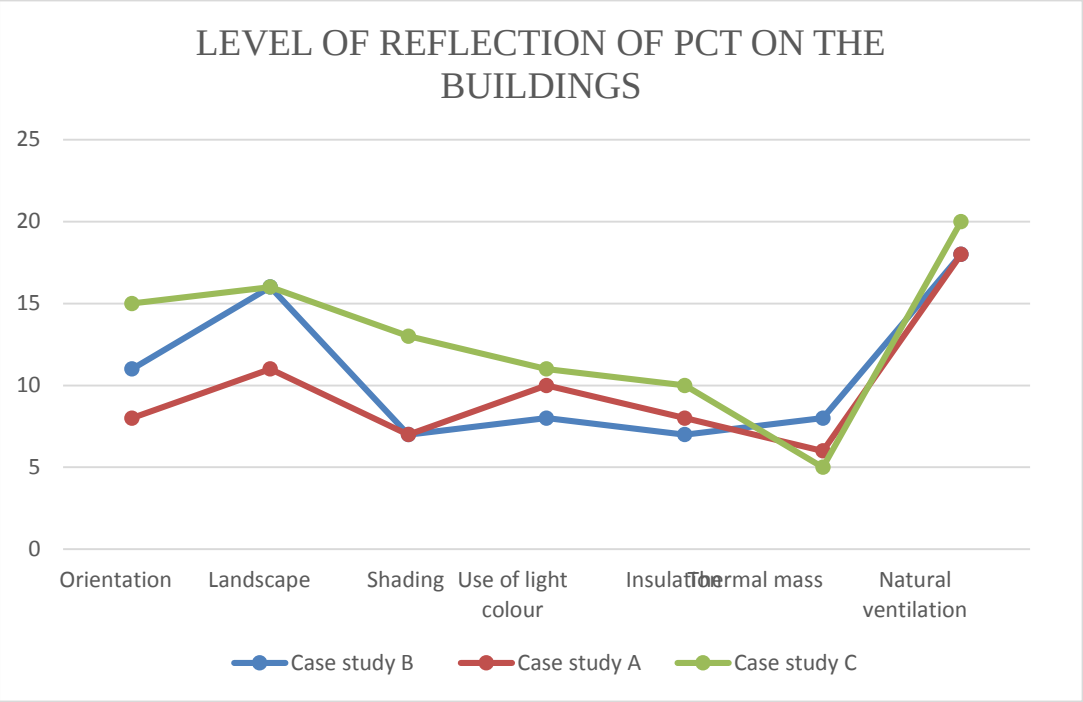


Figure 4.20 Level of Reflection of Passive Cooling Techniques on the Buildings (source: Field study, 2016)

and relatively average on shading. On heat modulation technique, the lowest level of reflection occurs on thermal mass; and relatively average on insulation. On heat dissipation technique the level of reflection of natural ventilation is very high. Comparing results from case studies, it shows that GSU has the highest level of reflection passive cooling techniques followed by ATBU and MAUTECH respectively. The most effective method to save energy and cool the building is to keep the heat from building up in the first place (Givoni, 2011). Therefore, heat prevention techniques should be given adequate attention from the design process.

4.8.2 Comparing the results of monthly energy load for ATBU, MAUTECH and GSU senate buildings

Heating Cooling loads of air conditioning system working with 95% efficiency and 14m² per person at a state of office activity (55W) is considered for the calculations.

The thermal comfort zone is chosen as 18-28 0C for the temperature band that the calculation would take place according to the standards; ANSI/ASHRAE (2001) Standard 55-2000R) applied to the Yozgat weather data, 2002. However, due to geographical location and climatic condition of dry sub-humid zone, the total annual energy required for heating is very small (which can be negligible) and it's only required for few hours in the two coldest months of the year which are January and December. Figure 4.21 describes the monthly heating/cooling loads of each of the three simulated case studies.

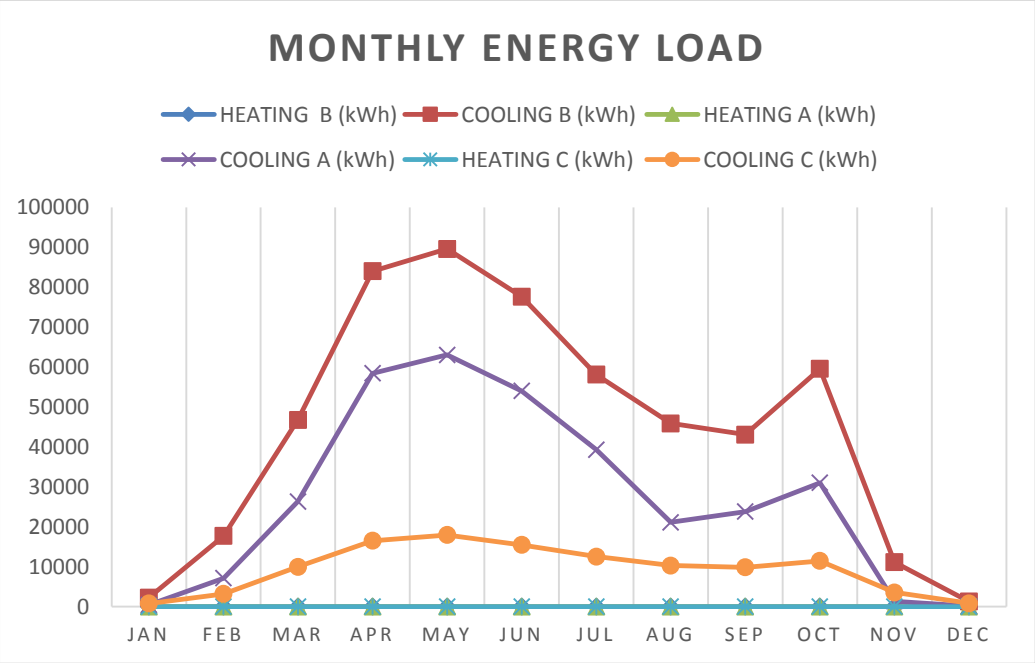


Figure 4.21 Monthly energy load for ATBU, MAUTECH and GSU senates (source: Field study, 2016)

MAUTECH senate building requires more energy load to cool the building throughout the year, see figure 4.21 followed by ATBU and GSU senate buildings respectively. For all the three the senate buildings, the coldest months are January and December while the hottest month is May followed by April and June respectively. with reference to the Figure 4.1 earlier discussed, the possible reasons for MAUTECH senate building to require a lot of energy for cooling may be connected to the fact that the senate building does not have enough shading devices, the landscape are limited to the backyard of the building neglecting walkways, paving to receive and reflect excessive solar radiation and due to the presence of the hard landscapes from the eastern side of the building as well as the harsh weather of Jimeta in Yola town, the temperature therein is very hot.

Secondly, the ATBU senate building is the second in energy consumption, see figure 4.18. The building is compacted and deficient in cross ventilation. It comprises of four square blocks of offices connected by an octagonal atrium, as such the orientation of the building as a whole is relatively good because the longer side faces north and south, however, each block as a compartment is a square and does not optimize cross ventilation, these and the weather data of Gubi in Bauchi may be the reasons for ATBU senate building to consume a lot of energy for cooling throughout the year.

Lastly, GSU senate building is a single floor building with good orientation, landscape, ventilation and shading, see figure 4.1, as such it is expected that the senate building does not consume the same energy as ATBU and MAUTECH senate buildings.

It can be deduced from table 4.9, that MAUTECH senate council chamber requires more energy for cooling followed by ATBU's and GSU's as illustrated in figure 4.22.

This is because the apertures for MAUTECH council chamber face the east and does not have cross ventilation and shading devices

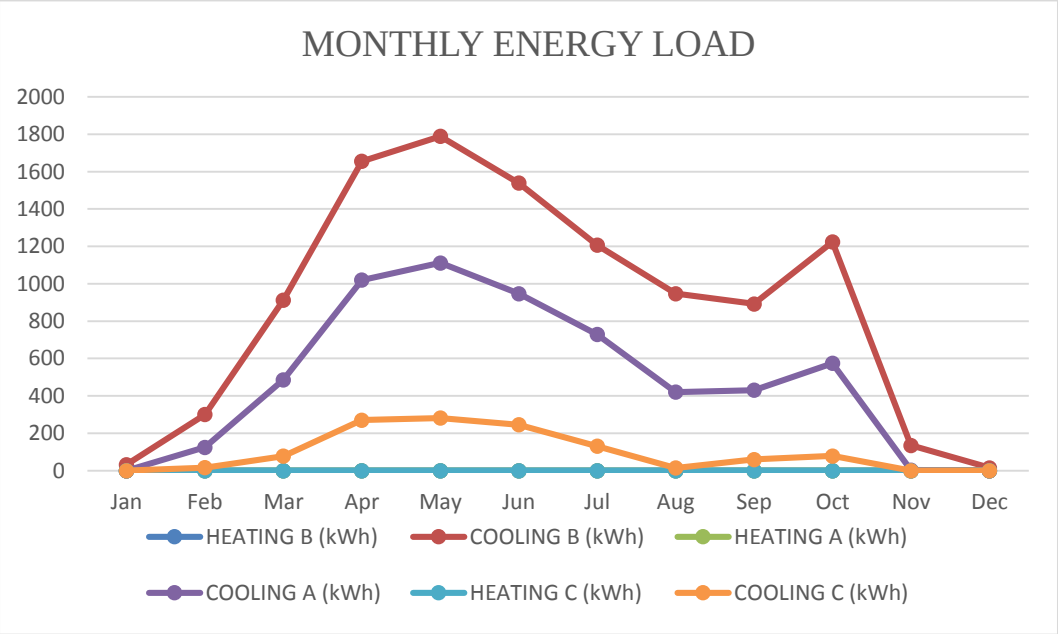


Figure 4.22 Monthly Energy Load for Council Chambers of ATBU, MAUTECH and GSU Senate Buildings (source: Field study, 2016)

ATBU council chamber faces south and has balconies as shading devices as well as deciduous trees from the south elevation. GSU VC's conference has good shading from all sides and cross ventilation.

The VC's office of MAUTECH demands more energy followed by ATBU's, this may be connected to the fact that the VC's office for MAUTECH is oriented on the east and west axis.

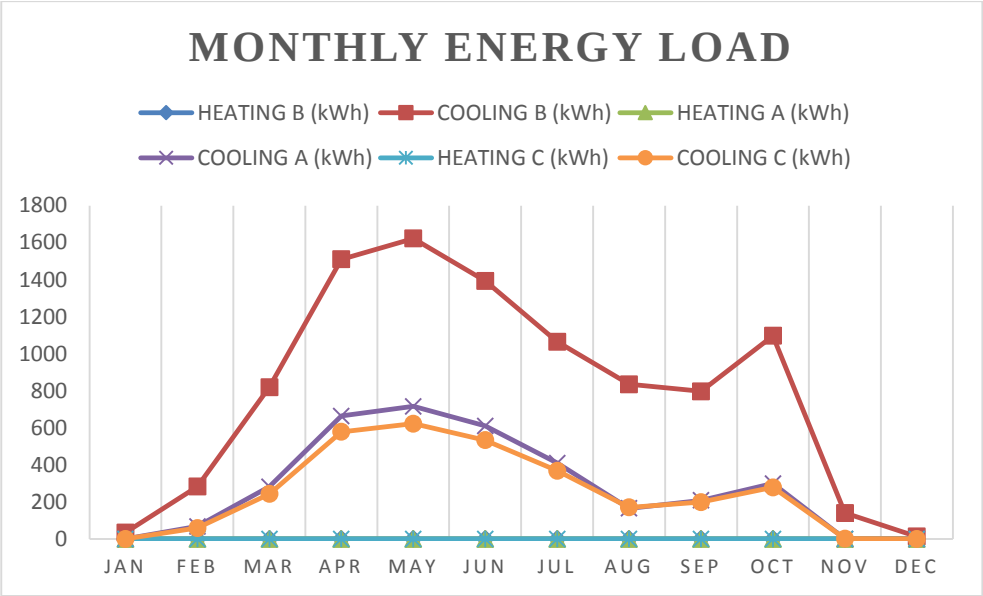


Figure 4.23 Monthly Energy Load for VC's Office of ATBU, MAUTECH and GSU Senate Buildings (source: Field study, 2016)

ATBU VC's office faces south and has recesses as shading devices as well as deciduous trees from the south elevation. GSU VC's conference has good shading from all sides and cross ventilation.

4.8.3 International Case Study: The Chancellery Building of University of Kebangsaan, Malaysia (UKM)

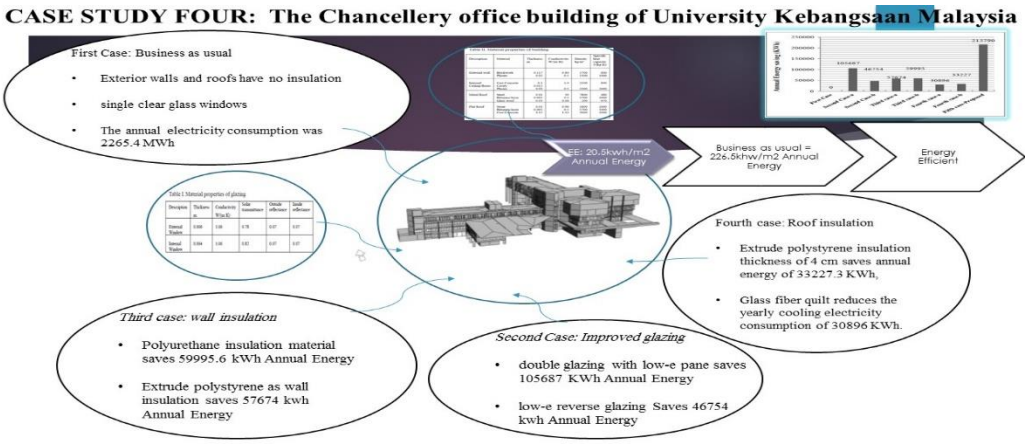


Figure 4.24 Input and Output of Foreign Case Study (source: Field study, 2016)

Four scenarios were set up, see figure 4.24 and simulation at each scenario was run as follows:

- First Case: Business as usual

- Exterior walls and roofs have no insulation
- single clear glass windows
- The annual electricity consumption was 2265.4 MWh

- *Second Case: Improved glazing*

- double glazing with low-e pane saves 105687 KWh Annual Energy
- low-e reverse glazing Saves 46754 kwh Annual Energy

- *Third case: wall insulation*

- Polyurethane insulation material saves 59995.6 kWh Annual Energy
- Extrude polystyrene as wall insulation saves 57674 kwh Annual Energy

- Fourth case: Roof insulation

- Extrude polystyrene insulation thickness of 4 cm saves annual energy of 33227.3 KWh,
- Glass fiber quilt reduces the yearly cooling electricity consumption of 30896 KWh

4.8.4 Comparing the results of the three local case studies with the foreign Case Studies

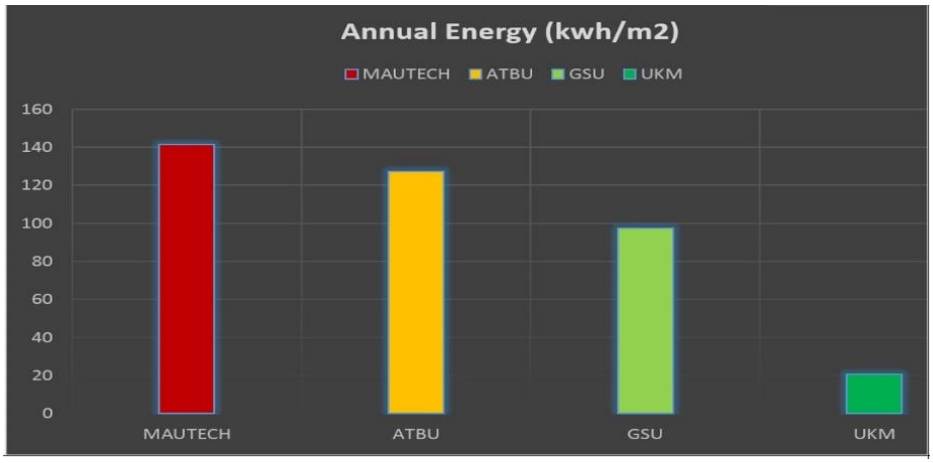


Figure 4.25 Summary of Results of the four Case Studies (source: Field study, 2016)

UKM is the most energy efficient and the least energy efficient was MAUTECH see Figure 4.25. UKM's senate optimized energy efficient materials such as: double glazing, extrude polystyrene on the wall, Extrude polystyrene insulation thickness of 4 cm in the roof.

In the local case studies, MAUTECH senate building requires more energy load to cool the building throughout the year, see figure 4.25 followed by ATBU and GSU senate buildings respectively. The possible reasons for MAUTECH senate building to require a lot of energy for cooling may be connected to the fact that the senate building does not have enough shading devices, the landscape are limited to the backyard of the building neglecting walkways, paving, etc.

5.0 DESIGN REPORT

5.1 The Site

University Senate Building is a structure built to serve the central administrative function in university campuses, design to accommodate offices, exhibition hall, senate chamber, governing council chamber and other necessary facilities. The university senate is the agency for the articulation and representation of the views of the faculty. It should be envisioned generally with some topographic interest, having complete utilities, stable, well-drained soils, excellent road and pedestrian access, protection from excessive weather patterns. The site should be easily accessible and be free of any natural or environmental hazards with ample spaces for future expansion. It would be located in the heart of the university and should be free from undesirable businesses. site selection criteria were used to find suitable site for the proposed senate building.

5.1.1 Study Area

The proposed location is Kashere, Gombe state of Nigeria which is located at the center of north eastern states, it is bordered by Borno and Yobe State to the north and east respectively, Taraba and Adamawa State to the south and Bauchi State to the west. It is located on latitude $10^0$16'N and longitude $11^0$11'E and It covers an area of about 20,265km2 with a population of approximate 2,353,000 people as of 2006.

5.1.2 Site Selection Criteria

The site was selected after analysis of the set down criteria based on literature review and the relevant guidelines for the university senate building design in Nigeria and north-east in particular. The parameters used for site selection criteria are illustrated in figure 5.1

SITE SELECTION CRITERIA



	Criteria	Site A	Site B	Site C	Remark
1	Accessibility	4	5	4	site B is the most accessible site because is closer the newly constructed main gate of the university
2	Good views	2	4	4	site B and site C will give aesthetics views better A because site A is a bit blocked by neighboring buildings
3	Expansion potential	4	5	2	site A and B can be expanded from the eastern and northern parts respectively while site C is constrained from all sides
4	Proximity to faculties	4	3	4	sites A and C are equally closer to faculties than site B
5	Presence of natural/soft landscape to aid cooling	4	4	4	all the tree sites are potentially good interms of landscape as trees and shrubs can be seen from google map and photographs
6	Noise free environment	4	5	3	site C is the noisiest of all the three sites while site B is the most silent of them
7	Location free from wind shadow effect	4	5	3	site B gets ventilation from all directions while site C constrained from three sides
8	Ease of drainage	5	5	5	All the three sites can be chanelled to the campus darinage network
9	Location away from high traffic	2	4	1	site B is the furthest of all the three sites from heavy traffic noise
10	Orientation	3	5	1	site B has best orientation because the longer side faces north-south direction
	Total	37	45	31	

Figure 5.1 Site Selection Criteria (source: Field study, 2016)

Weighing scale excellent 5, Very Good, 4, Strong 3, Week 2, Very Week

5.1.3 Site Location

The proposed site for senate building is located in federal university Kashere, Gombe. Figure 5.2 explains the location of the site on the global map

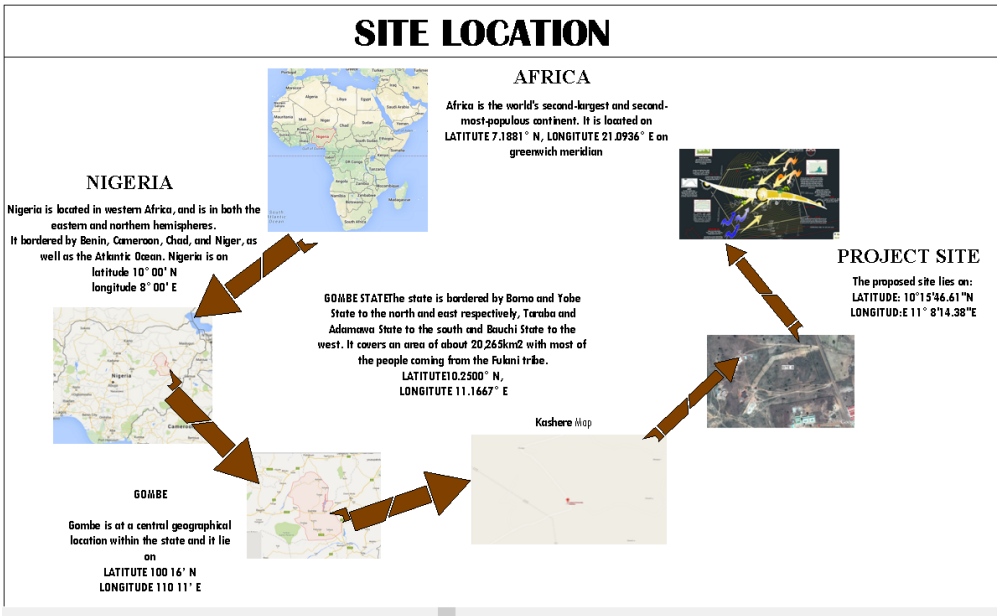


Figure 5.2 Site Location (source: Field study, 2016)

5.2 Site analysis

Site analysis is generally the study of the micro site and it features considering it potentials and threats in an attempt to utilize all the advantages and avoiding the disadvantages. In trying to understand the site, the following parameters were considered and analyzed:

5.2.1 Site physical characteristic

The physical characteristic is composed of all the visible features of the site. This include topography and site vegetation.

a. Topography

The topography of the site is a gentle slope consisting of few number of contours draining toward the eastern part of the site because the site level in the western part of the site is visibly elevated. The site drainage will take advantage of the slope direction so as to make use of natural gravity. The planning of the proposed senate building will take into consideration of the topography at the site as design tool for integrating passive design features in the project.

b. Vegetation

Vegetation of the site is typically that of the Sudan Savannah, characterized by locust trees and shrubs, see Plate XVI. The site has abundant grasses distributed all over the site, hence will help in enhancing the micro climate of the site.

The original vegetation has not been altered by human activities since the site is virgin land. Thus, the planning will make the use of the available trees at the site as means of integrating passive design strategies.



Plate XVI Site Vegetation (source: Field study, 2016)

5.3 Climatic Data Analysis

The study and analysis of the micro climate of the site which include; temperature, wind speed, precipitation, relative humidity, sunshine and it radiation and relate this micro climate to the macro climate of the area with due considerations to the site features.

5.3.1 Temperature

The maximum mean monthly temperature is 35.7 degree centigrade. April and May are usually the hottest months of the year. The extreme minimal temperatures are 28.2 degree centigrade and 18.7degree centigrade in December and January respectively. Figure 5.3 shows the monthly temperature, average and extreme of the region.

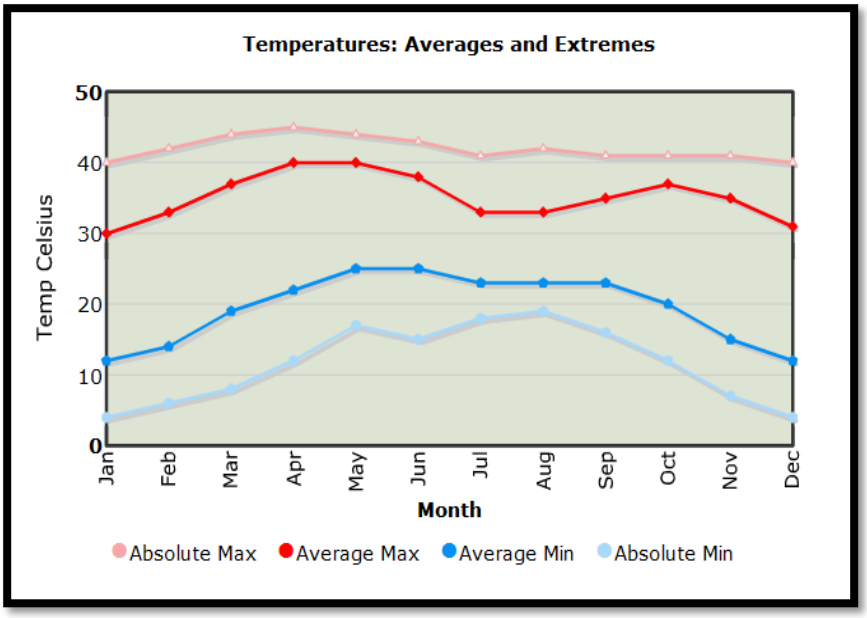


Figure 5.3 Monthly Temperature, Average and Extreme of Gombe Source: (myweather2, 2015)

5.3.2 Wind

The average monthly wind speed and the maximum speed recorded and sustained each month the year, see figure 5.4. The chart will help in choosing durable local available roofing material.

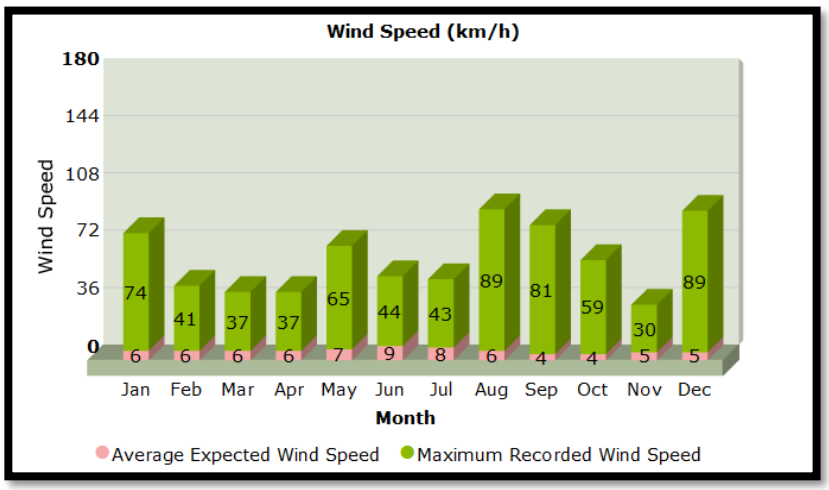


Figure 5.4 Average Daily Wind Speed Source: (myweather2, 2015)

5.3.3 Precipitation

The site experiences conventional and relief rainfall. The minimum monthly rainfall (in march the maximum rainfall (in august) is 163mm, the is more voluminous during this period and its cooling effect is better felt during this period than at other times of the year. at the peak of rainfall gutters will be made to efficiently collect the water from roofs and site towards the lowest point of the site. Figure 5.5 shows the average of rainfall received far month.

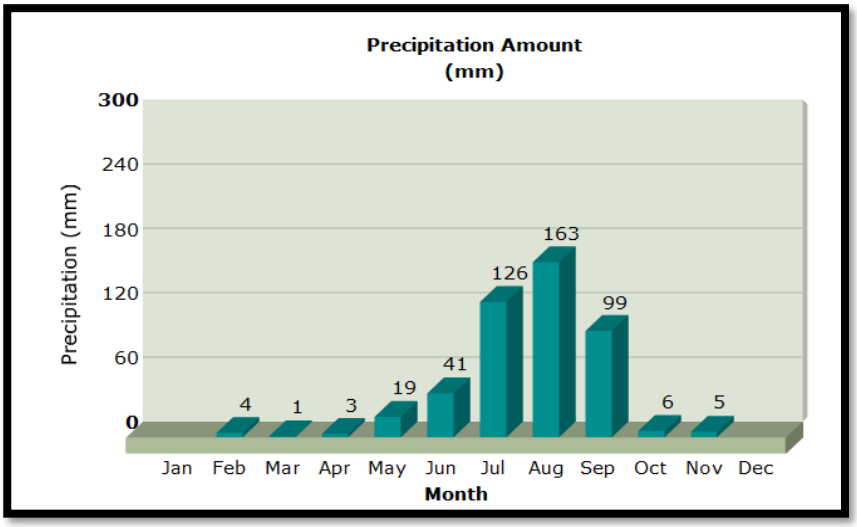


Figure 5.5 Monthly Precipitation Amount

5.4 Services

Services like electricity power lines, water supply lines, telephone services, access roads and pedestrian paths, well designed drainages are all available on site, see figure 5.6. The site is accessed from all angles of the university. Also, high tension electrical cables can also be sited from the site.

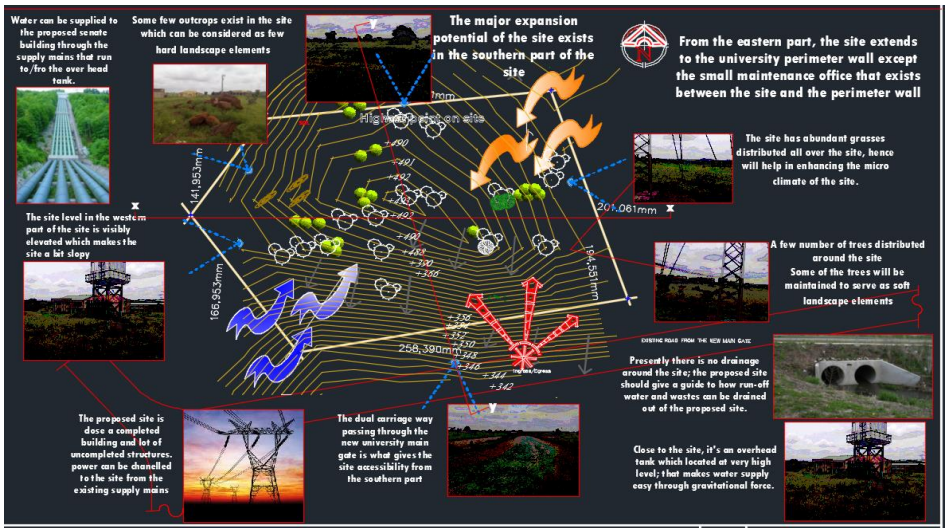


Figure 5.6 Services (source: Field study, 2016)

5.5 Site Zoning

The zoning of spaces was intentionally based security challenges within the country. Preventing unauthorized vehicles from getting too close to, or entering a site or building, and how the integrity of stand-off distances can be maintained remains one of the main considerations of counter-terrorism design. The United Nations recommend a 30M off distance from the main building to Hostile Vehicle Mitigation (HVM) parking, see figure 5.7.

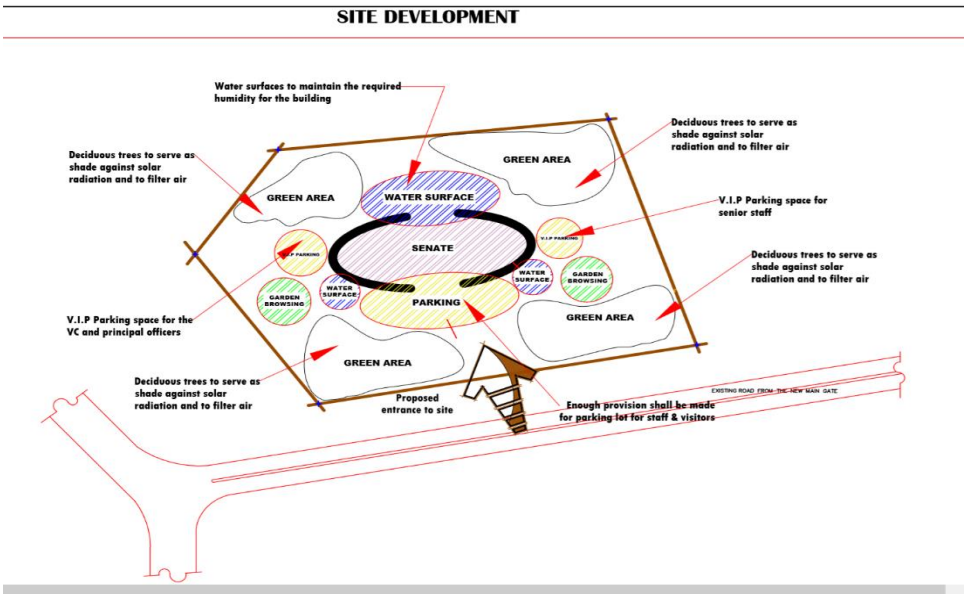


Figure 5.7 Site Zoning (source: Field study, 2016)

5.6 Simulation Results of Proposed Building

The results for simulation are discussed below based on the individual building elements and subsequently the building envelope itself

5.6.1 Wall

As mentioned earlier in the literature review of this dissertation, the effectiveness of capacitive insulation (therma1 mass) is acceptable where the diurnal variation of ambient temperatures exceeds 10 degrees. According to the weather condition of the studied buildings' location, the range between monthly mean maximum and minimum temperature for the 12 months is higher than 10 degrees. Therefore, thermal mass is proposed to be applied for the walls in order to examine its competence in achieving better thermal comfort particularly in the baseline model building. various resistive insulations were proposed because of their ability to control the heat flow through the walls in both directions see figure 5.7. However, using resistive insulation could be appropriate in hot season as the heat loss through walls is significantly higher than heat gain. This means that the thermal performance of walls with higher conductance could be more appropriate for hot season. Therefore, in order to achieve the most effective energy efficient walls t throughout the seasons, various types and thickness of walls were proposed and simulated, see figure 5.8

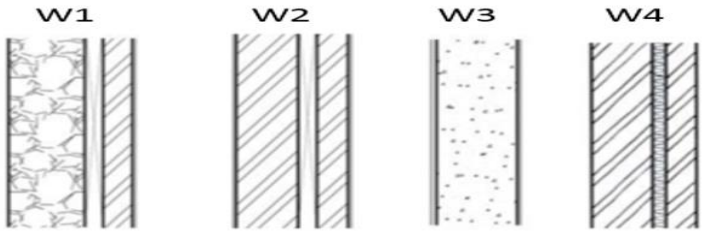


Figure 5.8 Various Walls Configuration (source: Field study, 2016)

The resultant temperature in both a hot season and a cold season day was estimated with the implementation of the various proposed walls and compared with the MRT temperature in the case of the baseline model wall which is W1. Furthermore, the percentages of comfort hours through each season and through the whole year were predicted with the implementation of the proposed walls. Description for the tested walls and the simulation results are provided in the following subsections. The selected materials which built for ECOTECT simulation, the materials chosen based on of U-value as it has been shown that in buildings, the total heating load is usually more sensitive to changes in wall U-value than to changes in the amount of thermal mass. However, total cooling load can often be impacted more by the addition of thermal mass than by wall insulation. W4 types of construction's materials developed or modified were used in this stage; attached each time in different order to find out if this component has an effect on indoor temperature, see table 5.1.

- *Heating and Cooling Energy Load*

Heating Cooling loads of air conditioning system working with 95% efficiency and 10m² per person at a state of activity (55W) is considered for the calculations. The thermal comfort zone is chosen as 18-28 ^{0}C for the temperature band that the calculation would take place according to the ASHRAE standards applied to the Gombe weather data, 2010.

Table 5.1 Composition of Simulated Wall Types (Source: Author, 2016)

Wall Code	Description	Thickness (mm)	U-Value (W/m^2 °C)	Time constant (Hours)
W1	-Outside: external rendering -Hollow concrete block -Internal mortar plaster -Inside: internal paint	-12.5 -225 -12.5	3.11	3.97
W2	- Outside: cement rendering - brick - Internal sand cement plaster - Inside: internal paint	12.5 150 12.5	2.62	4.38
W3	- Outside: mortar plaster - Extruded Polystyrene - Hollow concrete block - Internal sand cement plaster - Inside: internal paint	12.5 50 225 12.5	0.32	10.83
W4	- Outside: cement rendering - Polystyrene - Hollow concrete block - Internal mortar plaster - Inside: internal paint	12.5 75 225 12.5	0.29	12.47

However, due to geographical location and climatic condition of Gombe the total annual energy required for heating is too small (which can be negligible) and it's only required for few hours in the two coldest months of the year which are January and December. Results showing the effect of various walls configuration of the total annual energy reduction on the baseline model are presented in appendix I.

The cold season months (January& December) have the least energy demand while the hot season months (April & May) have the highest energy demand. Various walls were displayed on axes with different tick mark. The vertical scale is in kWh (kilowatt-hours), and the horizontal axis is in months of the year.

The effect of applying various walls (W1 –W4) with their corresponding values of percentage decrease is observed. W1 being the wall used in baseline model has the value of 0% and remaining walls (W2 – W4) shows the percentage decrease with respect to wall W1, see figure 5.9.

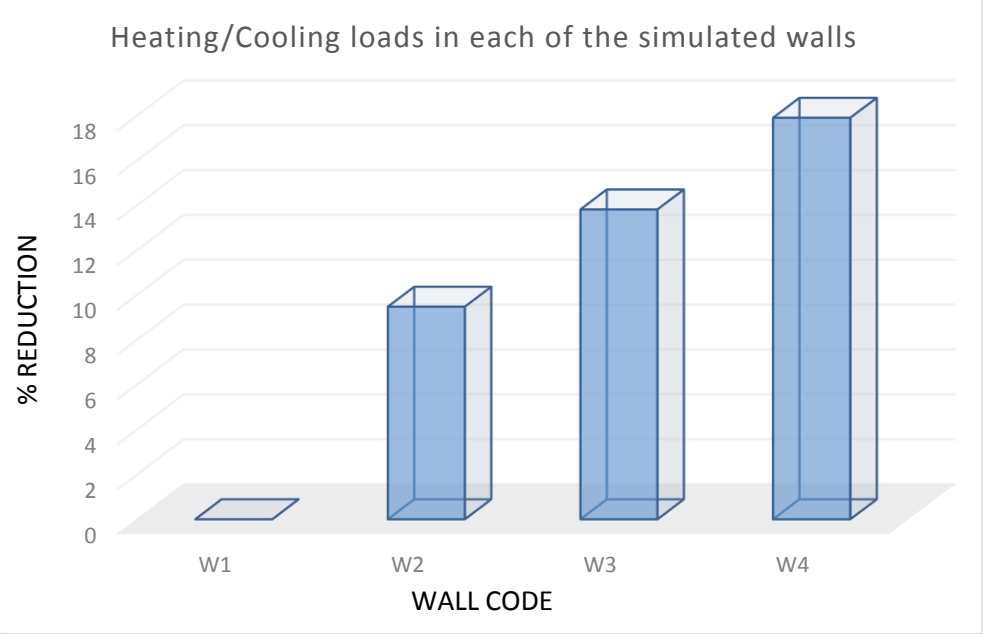


Figure 5.9 Percentage of energy reduction of various walls (source: Field study, 2016)

From the figu.re 5.9 it can be seen that by applying wall W2, a reduction of 9.46% of total heating and cooling energy load required in wall W1 can be achieved. By applying wall W3 a reduction of 17.89% is achieved. This will however, give a clue on the effect of insulation material in the reduction of the energy load in building. Walls W4 show slight improvement in reduction energy load 21.23%, as compared to wall W3 with a value of 0.44% and 0.48%respectively. Also, from

the result it can be observed that Wall W4 shows greater improvement in energy load reduction with a value of 17.89% and Annual Energy of 14695.40kwh

5.6.2 Roof

Roof used in the baseline model is corrugated metal roof type, the roof mainly affects top floor and since heat gain through this type of roofs is constant and independent of building proportion and orientation of building therefore there is need to insert insulation materials within this surface is essential in hot climate countries. Also roof colour contribute to energy consumption and thermal comfort. It was found out that by using light colour with higher reflectance 10% of the total energy load can be saved when using dark colour with lower reflectance value. Figure 5.10 represents brighter color and dark color

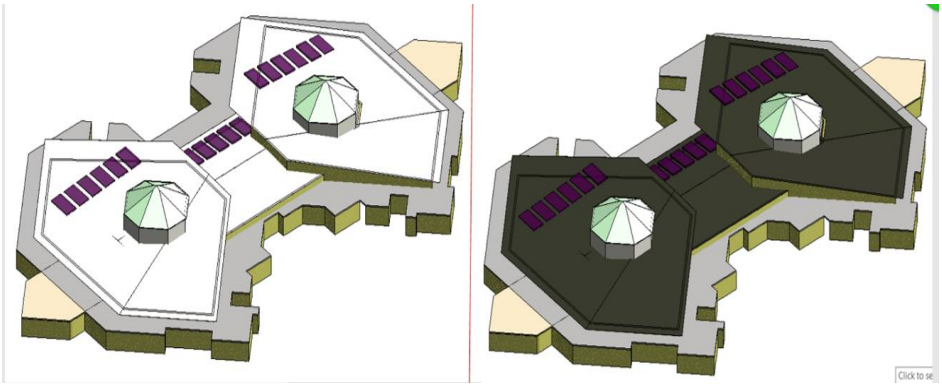


Figure 5.10 Roof Colours (source: Field study, 2016)

In roof simulation different types of insulations were inserted then was run to calculate the possibility reduction that can be achieved by adding these materials, example of these materials are polystyrene and air gap in different thickness.

Results in this research shows a good potential for saving energy by reducing heat flow indoors. This reduction is as a result of using polystyrene materials (100mm) while when polystyrene material used (50mm) a reduction of 60.5% has been

shown that the effect of the thickness of insulation materials. Table 5.2 provides the proposed roofs explaining their layers, thicknesses, and thermal conductance.

Table 5.2 The Proposed Roofs (Source: Author, 2016)

Roof Code	Description	Thickness (mm)	U-Value (w/m^2 ^{0}C)	Time Lag
R1	-Outside: reinforced concrete, cement rendered -Inside: sand cement plaster	150	0.89	7
R2	-Corrugated roofing sheet -No roof vent	0.55	7.14	-
R3	-Corrugated roofing sheet -Glass fiber quilt -Roof vent	50	0.55	4.5
R4	-Corrugate roofing sheet -Extrude polystyrene -Roof vent	50	0.55	4.5

The heating/cooling loads of the various roofs simulated are summarized in figure 5.11. A decrease of 12.34% was recorded in R4 thereby making R4 most preferred choice of roof for the proposed senate building

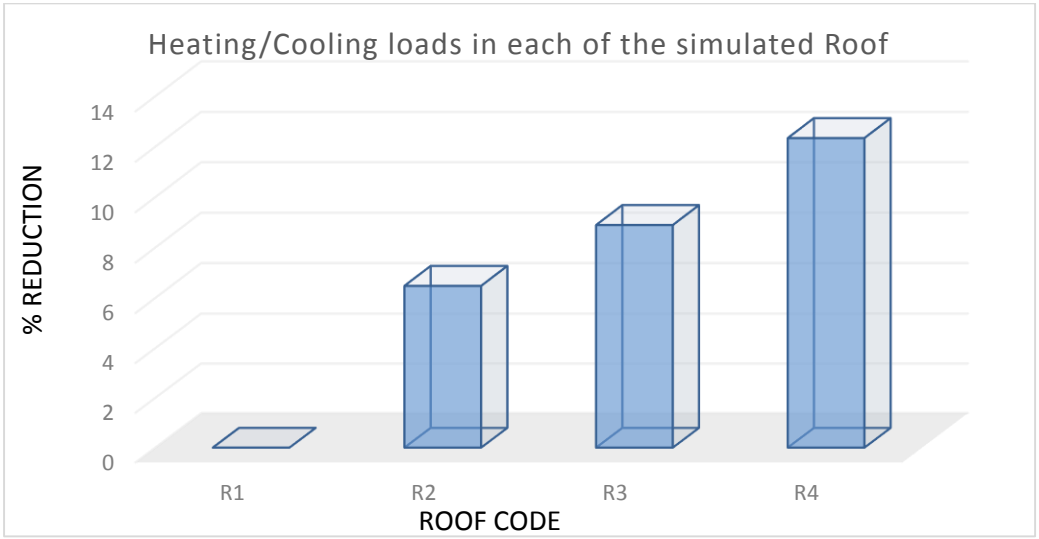


Figure 5.11 Heating/cooling Loads of Various Roof Types (source: Field study, 2016)

The reduction in the yearly electricity energy consumption due to application of extrude polystyrene as roof insulation was observed. The application of extrude

polystyrene insulation thickness of 4 cm demonstrate a 12.3% reduction of the annual energy load, see figure 5.11.

5.6.3 Window/Glazing

Windows are the leading source of heat gain, accounting for nearly 50% of the heat that enters a building. Heat gain through glazing is depending on surface size, orientation and the present of shading devices also depending on glazing type where different types are available around the world from single to multiple layers with or without e-low, however, in third world countries such as Nigeria single type is the most used one which revealed the highest solar heat transferred type (+90% of solar radiation). In this research different types of glazing are simulated to test the potential for reduction heat flow and increase comfort indoors that can be achieved using each type of these glazing. As shown in Table 5.3, there are four forms of glazing used in ECOTECT simulation which applied on the Baseline Model presenting in different types and thickness, from G1 the one applied on the baseline model to G4 the double clear with a blind.

Results illustrate that application of double glazing with low-e pane would yield a saving in annual electricity consumption of 105687 KWh compare to energy consumption when single clear glazing is used.

Table 5.3 The Proposed Glazing (Source: Author, 2016)

Glaze Code	Description	Width (mm)	U-Value ($w/m^2 {}^0C$)
G1	Single clear		6
G2	Single with blind		5.32
G3	Double clear		3.14
G4	Double with internal blind		1.60

The reduction in annual cooling energy used in selected jobs due to changes in the standard glass (clear single) to the Double clear and Double with internal blind studied, reduces the percentage of annual cooling energy consumption in

reference to the annual energy consumed by cooling available when the building uses standard glass. Results shown in figure 5.12 illustrate that application of Double with internal blind low-e pane would be the most preferred glazing type having 19.93% reduction in annual electricity consumption, see appendix III for the simulation results.

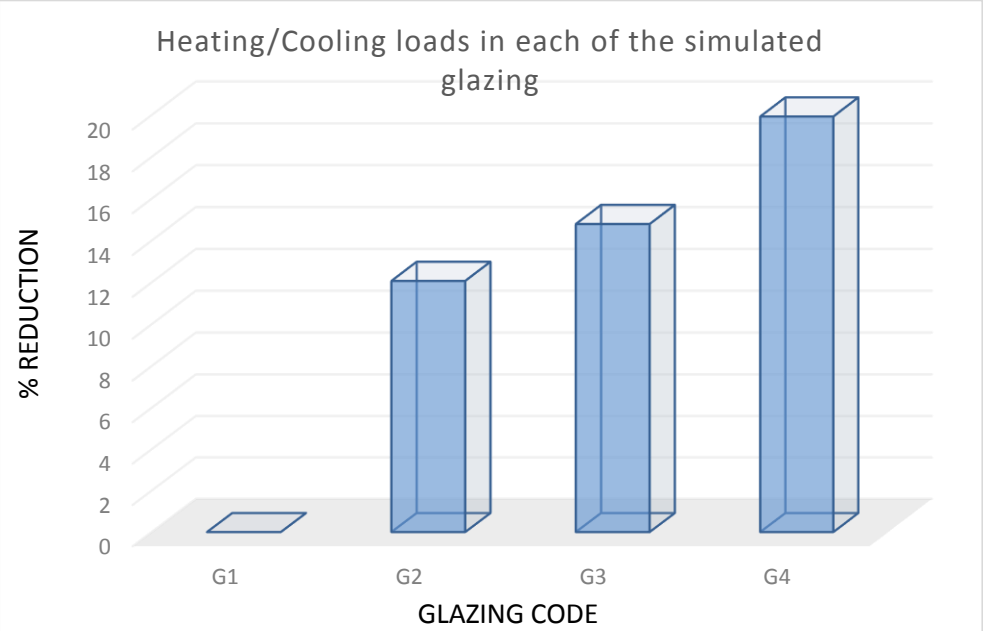


Figure 5.12 Heating/cooling Loads of Various Glazing Types (source: Field study, 2016)

5.6.4 Presence of vegetation

Vegetation reduces building energy use by shading buildings during the summer and consequently lowering temperatures also help to block cool winds in winter. But, they can increase energy use by shading buildings in winter, and may increase or decrease energy use by blocking summer breezes. Thus, proper tree placement near buildings is critical to achieve maximum building energy conservation benefits. The proposed senate building investigated once with a trees row that present in reality just 3 meters away on southeast side and second time was run

without the existing of those trees using Ecotect simulation. The effect of tree shading shows a significant impact on room temperature. It has a shading screen on ground floor between 8:00 am to noon nevertheless the external temperatures still expectable and relatively lower than those of mid-day temperatures where the shading moves to the opposite direction, see figure 5.13.



Figure 5.13 simulation with/without trees (source: Field study, 2016)

The proposed senate building with vegetation yields 10.6% annual energy saving as illustrated in Figure 5.14

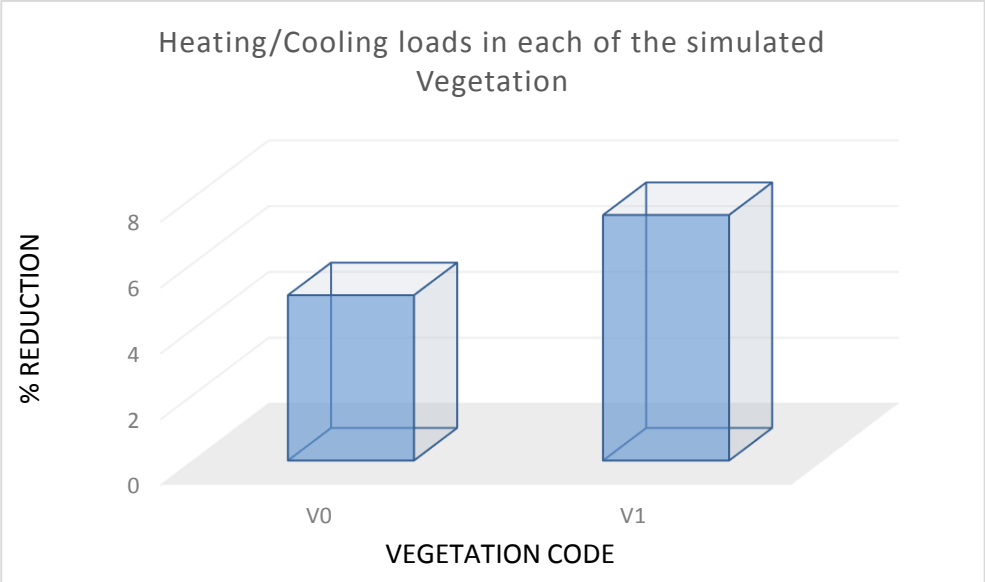


Figure 5.14 Heating/cooling loads of various roof types (source: Field study, 2016)

5.6.5 Orientation

Repeatedly, perform an ECOTECT simulation on the proposed buildings in order to investigate the effect of orientation on energy cooling load. Analysis process includes all the occupant zones excluding bathrooms and toilets as well as other service areas of the building such as staircase, stories, corridor and lifts, figure 5.15 shows that orientation at 90^0 yields 14% annual energy saving, see appendix IV for simulation results. The orientation is such that 0^0 means that the longer side is facing east and west side while 90^0 means that the longer sides are facing north and south.

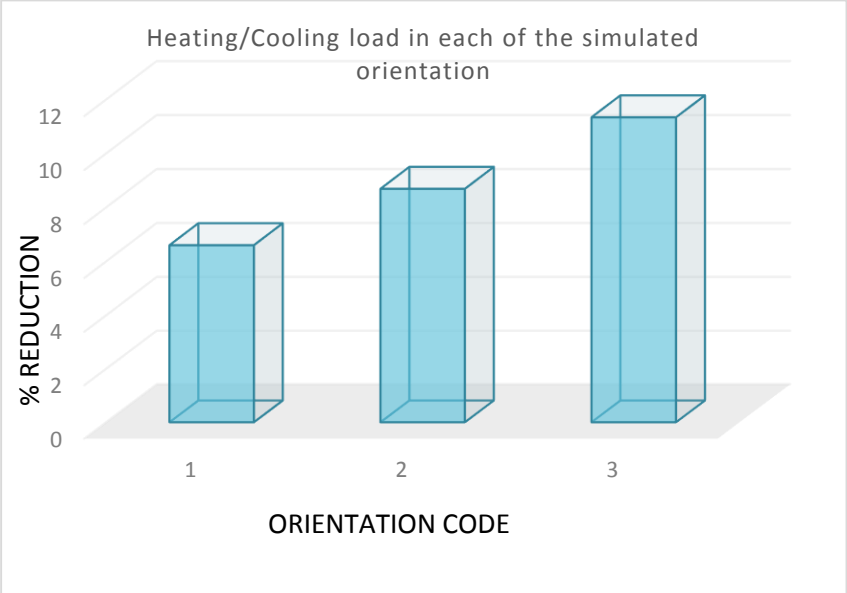


Figure 5.15 Heating/cooling Loads of Various Roof Types (source: Field study, 2016)

5.6.6 Building Form

This research is concerned with a form of buildings that described as a selective mode which work with the environment even so it is not easy to achieve all the points, see figure 5.16.

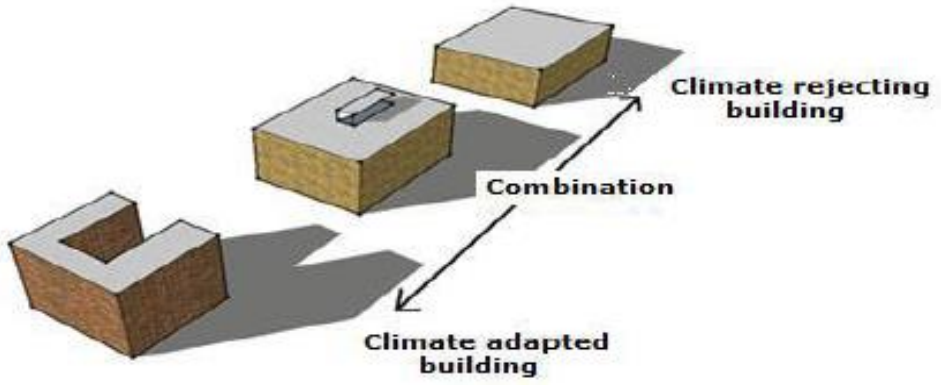


Figure 5.16 Continuum of Building Climate Response (Loonen, 2013)

reviewed and more detailed format of building forms and their corresponding effects based on surface area to volume ratio of the building form in Dry Sub-Humid climate its recommended that office buildings building should have. Scholars have given suggestions on building form of different climates, also particular building form deals with the climate attached to it. On the contrary, orientation and vegetation depend largely on the studied site.

5.7 Combination of Various Strategies

After data collection through software simulation, this section is where all those analysis and results will be translated into action in order to establish new component materials that have the potential to reduce heat gain and indoor temperature. To achieve the goal of this research which is set the comfort level up. The next step of this work was to combine improved materials together, each time a group with different type of walls, vegetation and orientation

5.3.1 Energy savings with proposed combinations of strategies

The energy savings of the proposed fabrics combinations is measured approximately where the baseline model is using air conditioning in order to estimate the annual cooling loads. The results show that by implementing the

fabrics combination (W3, V1, 90^0), a great potential savings in the annual loads could be achieved with the highest saving is obtained by applying (W4, V1, 90^0). Table 5.4 presents these potential saving beside compares these Figures with the situation of the Baseline Model.

Table 5.4 Energy Savings Annual Cooling Loads for Various Combination of Strategies (Source: Author, 2016)

COMBINATION	ANNUAL COOLING EBERGY LOAD(KWH)	COOLING EBERGY LOAD PER M² (KWH)	PERCENTAGE REDUCTION (%)
W1, V0, 0^0 (business as usual	2293487.250	216.786	--
W4, V1, $90^{0,}$ R4, G4 (Most preferred option)	508371.438	22.67	68.92
W3, V1, 90^0 (Second preferred option)	628701.6	59.426	42.59

Although, there is a relatively close possible saving by applying either of second or third option combinations still the (W4, V1, G4, R4 90^0) group shown the highest saving among the other groups in these three combinations with almost 85.62% saving of about 48.052KWH/M²/ year. The results also revealed that by implementing the fabrics combinations of second option a great potential savings in annual load of about 68.92% which is 22.67 KWH/M²/ year. Comparing the results of the improved model with that of the business as usual model, see Table 5.5

Table 5.5 The Difference in Each of the Five Studied Variables.

		Wall	Roof	Glazing	Vegetation	Orientation	TOTAL
Business as Usual	kwh	1592048.52	1382803.4	1882026.94	2072994.44	1801325.57	8731199
	% of Energy	23	20	27	12	18	100
Improved	kwh	1469530	1081352.26	1622028.4	1865695	1401031	7439637
	% Reduction	17.89	12.30	19.93	7.46	11.34	68.92

Figure 5.17 summarizes all the sustainable features incorporated in the design. The sustainable features include: insulated wall extrude polystyrene, sandcrete blocks (225mm); internal and external rendering (12.5mm); 3.11 U-Value; 3.97 Time Constant (Hours); The specification for the roofing materials include: corrugated roofing sheet (0.55mm); roof ventilation; 0.89 U-Value; 7-hour time lag; roof insulation; extrude polystyrene insulation thickness of 4 cm saves annual energy of 33227.3 KWh and several other conditions as enshrined in Figure 5.17

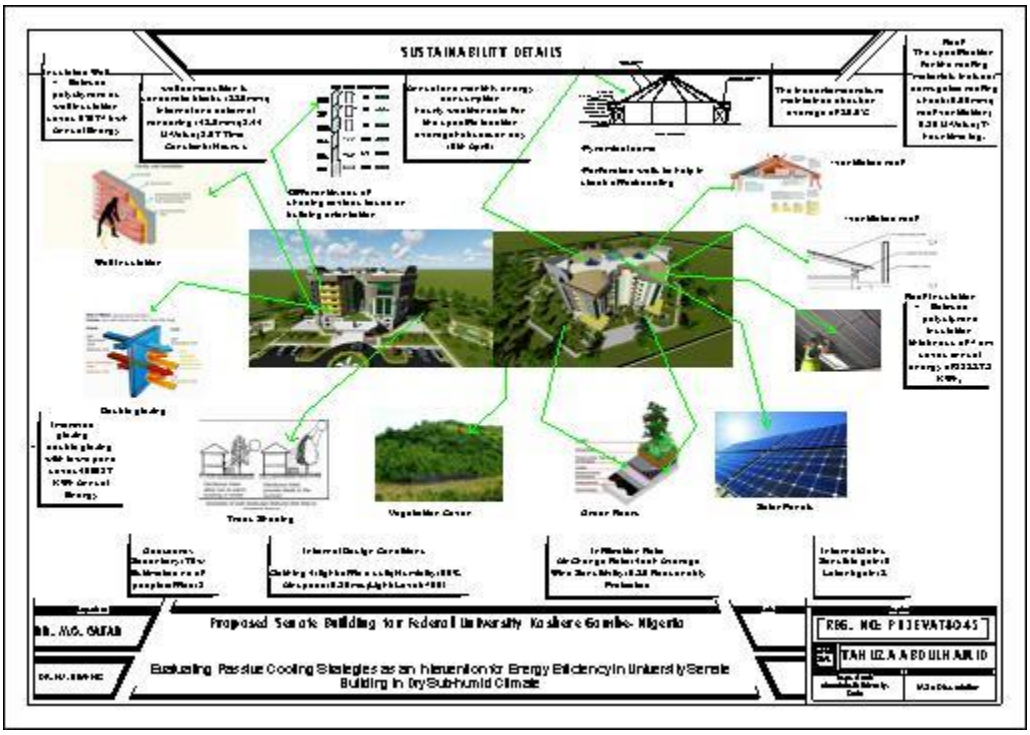


Figure 5.17 Energy Savings Aannual Cooling Loads for Various Combination of Strategies (Source: Author, 2016)

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the design through to operational stages in the proposed university senate building of Federal University, Kashere, Gombe, 80.20% can be reduced simply by adopting climatic strategies.

Climate Responsive Design principles are beneficial right from the design stage because buildings are designed based on natural ventilation, local climate and materials, and using renewable and clean technologies. Climate Responsive Design principles therefore allow buildings to maintain comfort with minimal mechanical support. Adaptive approach was used in evaluating passive strategies to achieve cooling for building users in this research.

Building energy calculation is especially beneficial at the early stage of design to enable designers to make informed decisions on the energy use in the operational stage of the buildings. This will not only prevent poor building performance due to electricity failure, but also adapt buildings to the unstable Nigeria's power sector.

6.2 Contribution to Knowledge

1- From the previously discussed simulation results, it was shown that by using building energy simulation, it is possible to ascertain the reduction in space cooling energy requirement for university senate building in Kashere, Gombe, Nigeria.

2- By applying 100mm thick polystyrene insulation on external walls a total 0f 17.89% percentage of cooling energy demand can be saved in the climate of Gombe.

3- By applying glazing/window double glazed with inter blind which is most preferred option a total of 19.93% of energy can be saved.
4- Glazing/window orientation contribute to the total cooling energy load consumption in building.
5- By applying 50mm polystyrene insulation on bright color roof a total of 12.30% of the energy load is saved.
6- In Gombe 68.92% of cooling energy can be reduced by combining the five different strategies studied.
7- Stipulated British Standard of 15KWH/M² per annum of heating and cooling required by most European countries and America can be adopted in Nigeria especially in dry sub-humid climate zones as this research achieved 22.67KWH/M² per annum.

6.3 Recommendations

I. Owing to the world climatic challenges, it is recommended that sustainable methods such as energy efficiency strategies should be dully applied in building design especially office buildings. Therefore, building professionals should work together in an integrated approach focusing on how to improve the thermal performance of buildings; enforcing environmental and energy efficiency policies and encourage the development of more efficient, integrated and accessible simulation techniques for predicting and improving the future environment.
II. It should be taken into account the micro-climate of Gombe especially to the building's form and configuration as the solar radiation is the most important parameter in this climate.

6.4 Areas of Further Research

This dissertation focused on how to design an energy efficient university senate building in the micro-climate of Gombe. So further research can be;

a- Study on effect of each individual building element such as Glazing by modifying various property of that element to find out the contribution of each property of that element in improving energy performance of a university senate building.

b- There is need to replicate this research on another building typology like library or faculty building to confirm the effect of the used energy efficiency strategies in such building.

REFERENCES

Ahmed, A.F., Khan, M.K., Than, A.M. & Rasul, R.M. (2014). Selection of Passice Cooling Strategy for a Sub-tropical Climate. *International Journal of Mechanical and Material Engineering*, 104, Pp 351-357.

Aliyu, A. S., Dada, J. O., & Adam, I. K. (2015). Current status and future prospects of renewable energy in Nigeria. *Renewable and sustainable energy reviews*, 48, Pp336-346.

Alsousi, M. (2011). *User response to energy conservation and thermal comfort of highrise residential buildings in hot humid region with referring to Gaza.* Nottingham, UK: A PhD thesis submitted to architecture and built environment department at university.

Batagarawa, A. (June, 2013). *Assessing the Thermal Performance of Phase Change Materials in Composite Hot Humid/Hot Dry Climates: an examination of office buildings in Abuja, Nigeria* . Newcastle : Unpublished .

Ben C., Hamida & Ammar B. (2004). Passive cooling by evapo-reflective roof for hot dry climates. *Renewable Energy* , 29 (11): Pp 1877-86.

Bonan, G. (2015). *Ecological climatology: concepts and applications.* Cambridge: Cambridge University Press.

Breshears, D. D., & Ludwig, J. A. (2010). Near-ground solar radiation along the grassland-forest continum: Tall-tree canopy architecture imposes only muted trends and heterogeneity. *Austral Ecology* , 35(1), Pp31-40.

Brimmo, A. T., Sodiq, A., Sofela, S., & Kolo, I. (2017). Sustainable energy development in Nigeria: Wind, hydropower, geothermal and nuclear (Vol. 1). *Renewable and Sustainable Energy Reviews*, *74*, 474-490.

Byrne, S. J., & Ritschard., R. L. (1985). A Parametric Analysis of Thermal Mass in Residential Buildings. *ASHRAE/DOE/BTECC Conference: Thermal Performance of the Exterior Envelopes of Buildings*, (pp. (pp. 1225–1240)). Clearwater Beach.

Chen W. & Liu W. (2010). Thermal Analysis on the Cooling Performance of a Porous Evaporative Plate for Building . *Heat Transfer - Asian Research* , 39(2):127-40 .

Chen, W. (2011). Thermal analysis on the cooling performance of a wet porous evaporative plate for building. *Energy Conservation and Management* , 52(5):2217-26.

CIBSE. (2007). *Guide A.* Norfolk: Chartered Institute of building service engineers.

Daroda, K. S. (2011). Climate Responsive Architecture: Creating Greater Design Awareness Among Architects. *Journal of Environmental Issues and Agriculture in Developing Countries*, Volume 3 Number 1, .

Department, C. P. (2013). *Integrated Green Design for Urban & Rural Buildings in Hot-Dry Climate Zone.* New Delhi: Central Public Works Department.

Elaiab, F. M. (2014). *Thermal comfort investigation of multi-storey residential buildings in Mediterranean climate with reference to Darnah, Libya (Doctoral dissertation.* Nottingham: University of Nottingham).

Evans, M. (1988). *Housing, climate, and comfort.* J. Wiley in London, New York: Architectural Press.

Fanger, P. (1970). *Thermal Comfort: Analysis and Applications in Environmental. Copenhagen.* Danish Technical Press.

Geetha, N.B. & Velraj, R. . (2012). Passive cooling methods for energy efficient buildings with or without thermal energy storage . *Journal of energy, science and research* , 29(2),913-946.

Givoni, B. (2011). Solar Energy. *Indoor Temperature Reduction by Passive Cooling Systems*, 85, 1692-1726.

Givoni., B. (1981). *Man, Climate and Architecture.* London, UK: Applied Science Publishers Ltd.

Haase, M. and Amato, A. (2006). Passive and Low Energy Architecture. *The 23rd Conference on Passive and Low Energy Architecture.* Geneva, Switzerland.

He J. & Akhira H. (2010). Experimental Study of Cooling Effects of a Passive Evaporative Cooling Wall Constructed of Porous Ceramics with High Water Soaking-up Ability. *Building and Environment* , 45(2):461-72 .

Hyde, R. (2000). *Climate responsive design: a study of buildings in moderate and hot humid climates.* UK: Chapman & Hall.

Jibrin, M. A. (2016). *Assessment of Passive Cooling Techniques for the Design of Senate Building Federal University, Lafia.* (Msc Thesis, Ahmadu Bello University, Zaria).

Kahu, R. (2014). *Evaluating Energy Efficiency in the design of Large Scale Office Building in Hot-dry Climate of Nigeria.* (MSc thesis, Ahmadu Bello University, Zaria.

Kamal, M. (2012). An overview of passive cooling techniques in building: Design concepts and Architectural interventions. *Acta Technica Napocensis: Civil Engineering & Architectural*, 55 (1) 84-97.

Kentucky, W. U. (2011). *Charter of University Senate* . Retrieved August 1, 2015 from http://www.wku.edu/senate .

Loonen, R. C. (2013). Climate adaptive building shells: State-of-the-art and future challenges. *Renewable and Sustainable Energy Reviews*, 25, Pp483-493.

Markus, T. A. (1994). *Domestic energy and affordable warmth. London: Watt Committee on Energy by Spon.*

McDonald, R. I., Green, P., Balk, D., Fekete, B. M., Revenga, C., Todd, M., & Montgomery, M. (2011). Urban growth, climate change, and freshwater availability. *Proceedings of the National Academy of Sciences*, *108*(15), 6312-6317.

Morgan, G. A., Gliner, J. A. & Harmon, R. J. (2001). Measurement validity. *Journal of the American Academy of Child & Adolescent Psychiatry,* 40(6), 729-731

Muhaisen, A. S. (2005). *Prediction of the solar performance of courtyard buildings with different forms and in various climates.* Nottingham, UK: A PhD thesis submitted to architecture and built environment department at university.

myweather2. (2015, june 26). Retrieved from http://www.myweather2.com/City-Town/Nigeria/Katsina/climate-profile.aspx

Naticchia B., D'Orazio M., Carbonari A & Persico I. . (2010). Energy Performance Evaluation of a Novel Evaporative Cooling Technique . *Energy and Buildings* , 42(10):1926-38.

Nigeria, C. (2011). *Electricity in Nigeria', The business, trade and investment guide 2010/2011, Corporate Nigeria [Online]*. Available at: http://www.corporatenigeria.com/index/energy/electricity-in-nigeria.html.

Nnaji, C. E. (2010). The role of renewable energy resources in poverty alleviation and sustainable development in Nigeria. *Continental Journal of Social Sciences*, 3, Pp31-32.

Nwoye, M. I. (2011). Privatization of Public Enterprises in Nigeria: The views and counter views . *Journal for Political theory and research on Globalization, Development and Gender*, 2(4), Pp234-251.

Olaofe, I. A. (2010). *Research Writing for Academic Growth.* Zaria: Ahmadu Bello University Press Limited, Zaria, Kaduna State, Nigeria. .

Oluigbo, S. (2011). Context and application of case studies in architectural research. *unpublished*, Zaria.

Ogunleye, E. K. (2017). Political economy of Nigerian power sector reform. *The Political Economy of Clean Energy Transitions*, 391.

Orodho, J. A. (2008). Techniques of Writing Research Proposals and Reports in Education and Social Sciences. Bureau of Educational Research. *Kenyatta University, Nairobi, Kenya:* Kanezja HP Enterprises.

Qiu G.Q. & Riffat S.B. (2006). Novel design and modelling of an evaporative cooling system for buildings. *International Journal of Energy Research*, 30(12):985-99.

Rabl, A. (1988). Parameter estimation in buildings: methods for dynamic analysis of measured energy use. *Journal of Solar Energy Engineering,* 110(1), 52-66

Rodriguez-Ubinas, E., Ruiz-Valero, l., Vega, s., & Neila, J. (2012). Applications of Phase change material in highly energy-efficient houses . *Energy and Buildings*, 50, Pp49-62.

Sadrzadehrafiei S., Sopian K., Mat S., Lim C., Hashim H.S. & Zaharim A. (2012). Enhancing Energy Efficiency in Office Buildings in a Tropical Climate, Malaysia. *International Journal of Energy and Enironment,* 6(2), 209.

Samuel, I. A., Katende, J., Daramola, S. A., & Awelewa, A. A. (2014). Review of System Collapse Incidences on the 330-kV Nigerian National Grid. *International Journal of Engineering Science Invention, 3*, 55-59.

Santamouris M. and Kolokotsa D. (2013). Passive cooling dissipation techniques for buildings and other structures: the state of the art. *Energy and Buildings* , 57, 74-94 .

Standards, A. (2004). *Thermal Environmental Conditions for Human Occupancy. American Society of Heating,Refrigerating and Air-Conditioning Engineers.* Inc.

standards, A. (2009). *ASHRAE Handbook - Fundamentals (I-P Edition). American Society of Heating, Refrigerating and Air-Conditioning Engineers.*

Susilawati, C., & Al Surf, M. (2011). Challenges facing sustainable housing in Saudi Arabia: a current study showing the level of public awareness.

Swan, L. G., & Ugursal, V. I. (2009). Modelling of end-use energy consumption in the residential sector: A review of modellimng techniques. *Renewable and sustainable energy reviews,* 12(8), 1819-1835

Szokolay, S. V. (2008). *Introduction to Architectural science, the basic of sustainable design_ 2ed edition.* Elsevier. USA: Architectural press.

Trebilock, M., & Figueroa, R. (2014). Thermal comfort in primary schools: a field study in Chile. *Counting the cost of comfort in a changing world,* 10-13.

Usman, A. M. (2015). *Application ff Energy Efficiency Strategies in the Design of National Library, Katsina* . Unpublsihed : (MSc thesis, Ahmadu Bello University, Zaria).

Waheeb, S. A. (2005). *Impact of shading devices on indoor sunlight distribution and building energy performance, with reference to Saudi Arabia.* Nottingham, UK: Thesis (PhD), University.

Waltz, J. Y., & Sharma, A. (1994). Effect of long range interactions on the depletion force between collidal particles, *Journal of Colloid and interface science*, 168(2), 485-496

Yin, R. K. (2013). Validity and Generalization in future case study evaluations. *Evaluation, 19(3), 321-332*

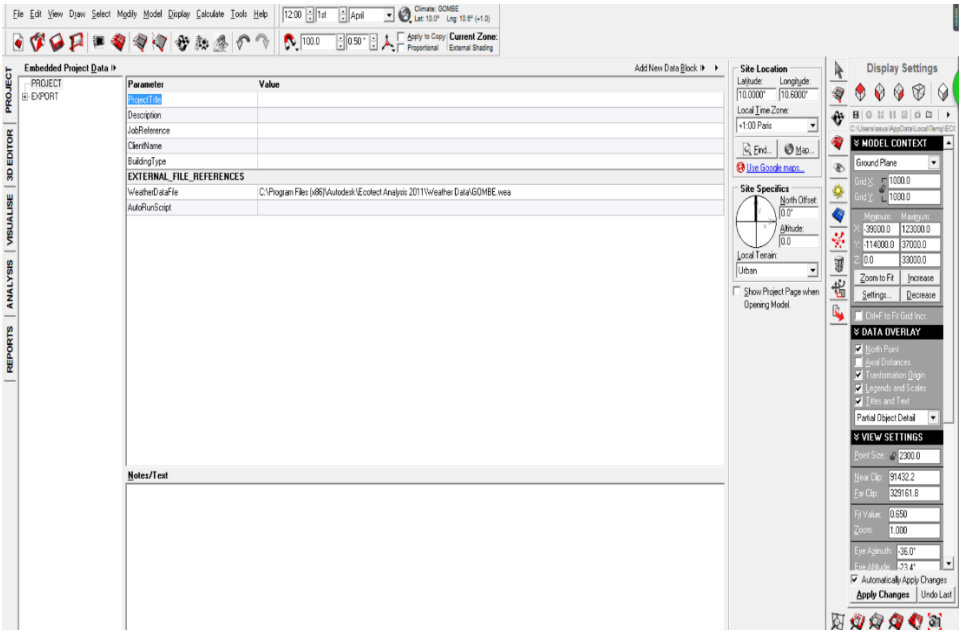
Zandes, T. (2015). *The role of thrrmall mass materials in net-zero energy buildings.* Greece : Markuz Wierner Publishers .

Zhao, X., Ma, X., Xu, P., Thierno, D., Zhu, Z., & Zhou, J. (2017). Cases of Energy System in a Green Building in UK. *Handbook of Energy Systems in Green Buildings*, 1-55.

APPENDICES

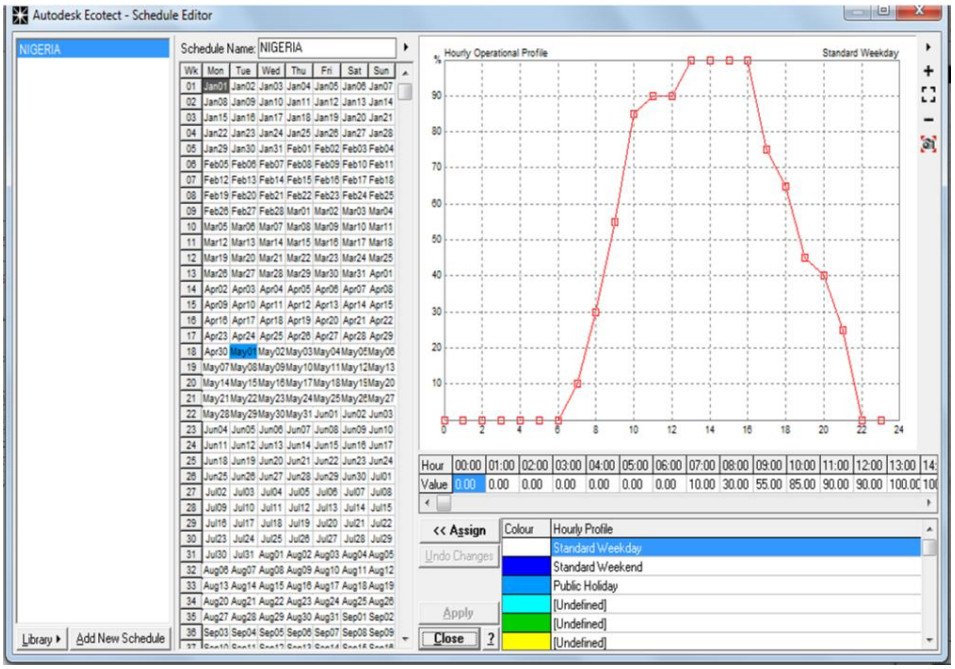
APPENDIX 'I'

Project information of the baseline model in ECOTECT



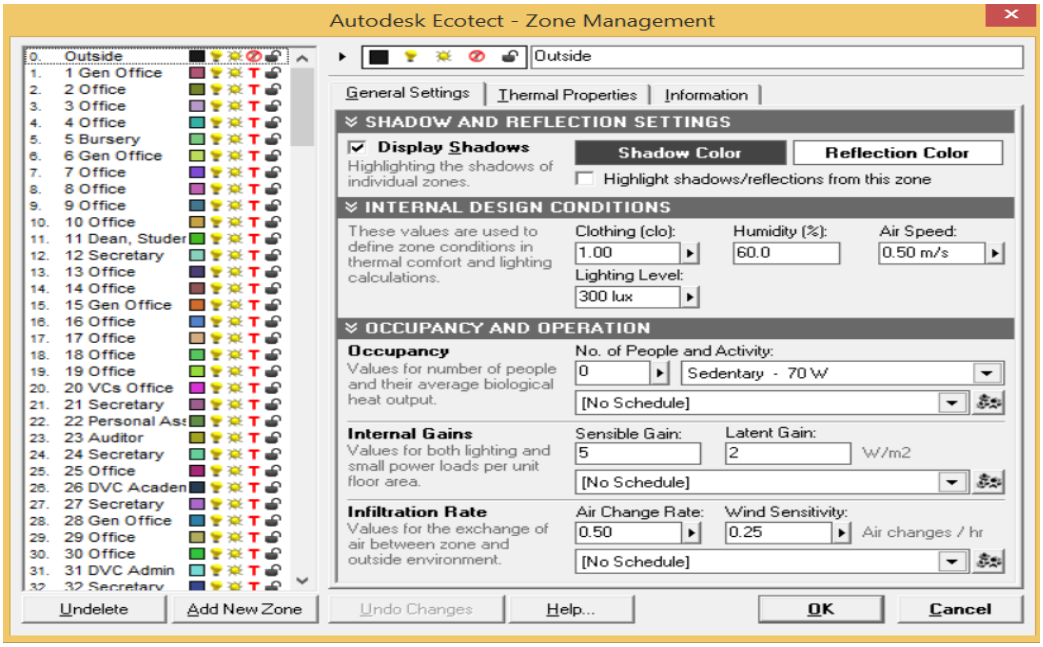
APPENDIX 'II'

Daily schedule of activity for University Senate building



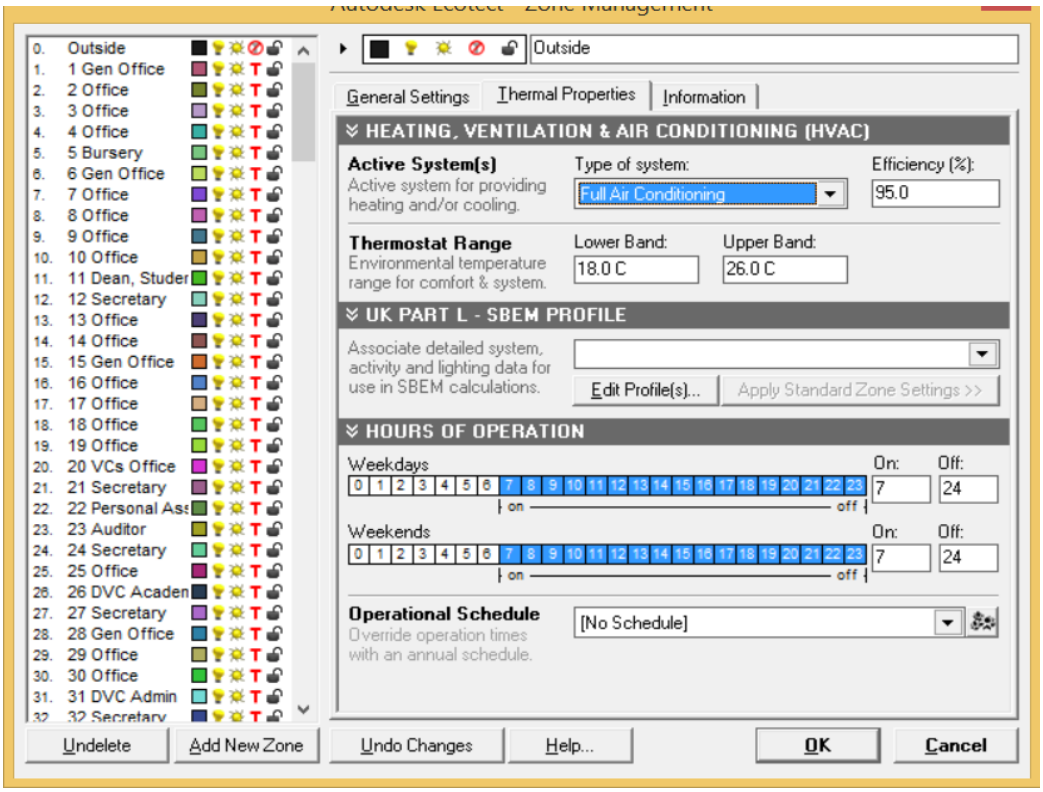
APPENDIX 'III'

General zones settings in ECOTECT



APPENDIX 'IV'

Thermal properties of zones settings for energy simulation



APPENDIX 'V'

Monthly heating cooling loads of MAUTECH administrative building

Max Heating: 0.0 C - No Heating.		
Max Cooling: 658.941 kW at 14:00 on 10th May		
MONTH	**HEATING (kWh)**	**COOLING (kWh)**
Jan	0	2299.477
Feb	0	17730.912
Mar	0	46806.129
Apr	0	84051.719
May	0	89620.016
Jun	0	77672.07
Jul	0	58138.551
Aug	0	45894.27
Sep	0	43102.422
Oct	0	59567.117
Nov	0	11145.439
Dec	0	1291.624
TOTAL	**0**	**537319.75**
Floor Area: 1779.892 m2 *141.4kwh/m^2 of heating/cooling required per annum*		

APPENDIX 'VI'

monthly heating/cooling loads of VC's office of MAUTECH administrative building

	HEATING	**COOLING**
MONTH	**(kWh)**	**(kWh)**
Jan	0	34.683
Feb	0	282.702
Mar	0	819.425
Apr	0	1509.973
May	0	1622.735
Jun	0	1393.821
Jul	0	1065.179
Aug	0	834.885
Sep	0	797.043
Oct	0	1097.303
Nov	0	140.605
Dec	0	12.866
TOTAL	**0**	**9611.218**
Floor Area: 87.091 m2		

APPENDIX 'VII'

monthly heating/cooling loads of ATBU senate building

Max Heating: 0.0 C - No Heating.		
Max Cooling: 169.110kW at 11:00 on 21st June		
MONTH	**HEATING (kWh)**	**COOLING (kWh)**
Jan	0	468.384
Feb	0	7131.288
Mar	0	26365.46
Apr	0	58443.12
May	0	63080.76
Jun	0	54036
Jul	0	39352.02
Aug	0	21149.6
Sep	0	23829.49
Oct	0	31048.23
Nov	0	1381.722
Dec	0	128.565
TOTAL	**0**	326414.6
Floor Area: 1779.892m2		
127.3kwh/m^2 of heating/cooling required per annum		

APPENDIX 'VIII'

monthly heating/cooling loads of VC's office of ATBU senate building

	HEATING	**COOLING**
MONTH	**(kWh)**	**(kWh)**
Jan	0	0
Feb	0	67.624
Mar	0	282.359
Apr	0	663.783
May	0	715.997
Jun	0	610.17
Jul	0	409.508
Aug	0	165.472
Sep	0	208.454
Oct	0	299.573
Nov	0	0
Dec	0	0
TOTAL	**0**	**3422.94**
Floor Area: 86.358 m2		

APPENDIX 'IX'

monthly heating/cooling loads of GSU senate building

Max Heating: 0.0 C - No Heating. Max Cooling: 142.725 kW at 14:00 on 10th April		
MONTH	**HEATING (kWh)**	**COOLING (kWh)**
Jan	0	825.351
Feb	0	3233.117
Mar	0	10004.39
Apr	0	16543.63
May	0	17989.24
Jun	0	15466.72
Jul	0	12561.77
Aug	0	10310.49
Sep	0	9862.721
Oct	0	11467.85
Nov	0	3572.504
Dec	0	851.655
TOTAL	**0**	112689.4
Floor Area: 1538.169m2 *97.4kwh/m^2 of heating/cooling required per annum*		

APPENDIX 'X'

monthly heating/cooling loads of VC's office of GSU administrative building

MONTH	**HEATING (kWh)**	**COOLING (kWh)**
Jan	0	0
Feb	0	58.929
Mar	0	243.094
Apr	0	578.722
May	0	622.844
Jun	0	533.757
Jul	0	368.712
Aug	0	170.516
Sep	0	199.377
Oct	0	278.486
Nov	0	1.907
Dec	0	0
TOTAL	**0**	3056.344
Floor Area: 106.620m2		

APPENDIX 'XI'

monthly heating/cooling loads of council chamber of ATBU senate building

MONTH	HEATING (kWh)	COOLING (kWh)
Jan	0	0
Feb	0	125.403
Mar	0	486.853
Apr	0	1019.876
May	0	1111.967
Jun	0	947.619
Jul	0	729.012
Aug	0	420.783
Sep	0	430.406
Oct	0	574.358
Nov	0	3.082
Dec	0	0
TOTAL	**0**	**5849.358**
Floor Area: 93.430 m2		

APPENDIX 'XII'

monthly heating/cooling loads of council chamber of GSU administrative building

MONTH	HEATING (kWh)	COOLING (kWh)
Jan	0	0
Feb	0	15.865
Mar	0	78.026
Apr	0	270.612
May	0	281.697
Jun	0	246.03
Jul	0	131.379
Aug	0	14.218
Sep	0	60.234
Oct	0	78.937
Nov	0	0
Dec	0	0
TOTAL	**0**	1176.998
Floor Area: 100.000 m2		

APPENDIX 'XIII'

Results of Monthly heating/cooling Loads for MAUTECH, ATBU & GSU Senate Bbuildings

MONTH	HEATING B (kWh)	COOLING B (kWh)	HEATING A (kWh)	COOLING A (kWh)	HEATING C (kWh)	COOLING C (kWh)
Jan	0	2299.477	0	468.384	0	825.351
Feb	0	17730.912	0	7131.288	0	3233.117
Mar	0	46806.129	0	26365.46	0	10004.39
Apr	0	84051.719	0	58443.12	0	16543.63
May	0	89620.016	0	63080.76	0	17989.24
Jun	0	77672.07	0	54036	0	15466.72
Jul	0	58138.551	0	39352.02	0	12561.77
Aug	0	45894.27	0	21149.6	0	10310.49
Sep	0	43102.422	0	23829.49	0	9862.721
Oct	0	59567.117	0	31048.23	0	11467.85
Nov	0	11145.439	0	1381.722	0	3572.504
Dec	0	1291.624	0	128.565	0	851.655
Total		537319.746		326414.64		112689.4

A= ATBU; B= MAUTECH; C= GSU

APPENDIX XIV

Results of monthly heating/cooling loads for the council chambers of MAUTECH, ATBU & GSU senate buildings

MONTHS	HEATING B (kwh)	COOLING B (kwh)	HEATING A (kwh)	COOLING A (kwh)	HEATING C (kwh)	COOLING C (kwh)
Jan	0	32.36	0	0	0	0
Feb	0	300.896	0	125.403	0	15.865
Mar	0	912.891	0	486.853	0	78.026
Apr	0	1655.246	0	1019.876	0	270.612
May	0	1789.111	0	1111.967	0	281.697
Jun	0	1538.775	0	947.619	0	246.03
Jul	0	1206.649	0	729.012	0	131.379
Aug	0	947.293	0	420.783	0	14.218
Sep	0	892.097	0	430.406	0	60.234
Oct	0	1224.386	0	574.358	0	78.937
Nov	0	134.921	0	3.082	0	0
Dec	0	15.405	0	0	0	0
TOTAL		10650.03		5849.359		1176.998

APPENDIX XV

Results of monthly heating/cooling loads for the VCs' offices of MAUTECH, ATBU & GSU senate buildings

MONTHS	HEATING B (kwh)	COOLING B (kwh)	HEATING A (kwh)	COOLING A (kwh)	HEATING C (kwh)	COOLING C (kwh)
Jan	0	34.683	0	0	0	0
Feb	0	282.702	0	67.624	0	58.929
Mar	0	819.425	0	282.359	0	243.094
Apr	0	1509.973	0	663.783	0	578.722
May	0	1622.735	0	715.997	0	622.844
Jun	0	1393.821	0	610.17	0	533.757
Jul	0	1065.179	0	409.508	0	368.712
Aug	0	834.885	0	165.472	0	170.516
Sep	0	797.043	0	208.454	0	199.377
Oct	0	1097.303	0	299.573	0	278.486
Nov	0	140.605	0	0	0	1.907
Dec	0	12.866	0	0	0	0
TOTAL		9611.22		3422.94		3056.344

APPENDIX XVI

Result of monthly energy load of various walls

MONTH	**W1** (kWh)	**W2** (kWh)	**W3** (kWh)	**W4** (kWh)
Jan	74594.77	74336.422	87051.406	87022.016
Feb	105259.9	100729.94	99613.617	99319.586
Mar	174456.7	156633.91	131635.86	130878.54
Apr	211050.7	183809.17	144895.25	143916.89
May	215310.4	188054.98	149060.63	148004.64
Jun	198053.4	173580.42	138679.98	137781.97
Jul	175578.4	157730.58	132786.03	131957.3
Aug	166746	151831.66	131657.42	130802.58
Sep	169330.8	152859.77	129707.72	128802.05
Oct	179453.8	160450.83	133115.88	132195.36
Nov	126484.7	118474.59	108160.54	107647.52
Dec	69375.76	70683.344	91370.352	91202
PER M^2	142.258	128.799	112.677	112.051
TOTAL	1865695	1689176	1477735	1469530
% REDUCTION	0	9.460979	20.79391	21.23396

APPENDIX XVII

Heating/Cooling loads in each of the simulated roofs

MONTH	R1 (kWh)	R2 (kWh)	R3 (kWh)	R4 (kWh)
Jan	74594.77	90046.44	148635.422	87022.016
Feb	105259.9	74595.96	130180.94	99319.586
Mar	174456.7	108515.92	168194.91	130878.54
Apr	211050.7	16825.19	166703.17	143916.89
May	215310.4	92474.10	152060.98	148004.64
Jun	198053.4	106414.44	165053.42	137781.97
Jul	175578.4	102903.60	162492.58	131957.3
Aug	166746	104115.68	163704.66	130802.58
Sep	169330.8	94118.85	153707.77	128802.05
Oct	179453.8	94118.86	153707.83	132195.36
Nov	126484.7	90417.61	150906.59	107647.52
Dec	69375.76	85940.36	145529.344	91202
PER M^2	142.258	128.799	112.677	112.051
TOTAL	1865695	1150077.20	628215.845	1081352.26
% REDUCTION	0	6.480910	8.89301	15.64285

APPENDIX 'XVIII'

Heating/Cooling Loads in each of the Proposed Glazing

MONTH	G1 (kWh)	G2 (kWh)	G3 (kWh)	G4 (kWh)
Jan	87022.016	179635.422	148635.422	87022.016
Feb	99319.586	164184.94	130180.94	99319.586
Mar	130878.54	198104.91	168194.91	130878.54
Apr	143916.89	196003.17	166703.17	143916.89
May	148004.64	182063.98	152060.98	148004.64
Jun	137781.97	196003.42	165053.42	137781.97
Jul	131957.3	192492.58	162492.58	131957.3
Aug	130802.58	193704.66	163704.66	130802.58
Sep	128802.05	183707.77	153707.77	128802.05
Oct	132195.36	183707.83	153707.83	132195.36
Nov	107647.52	180006.59	150906.59	107647.52
Dec	91202	175529.344	145529.344	91202
PER M^2	142.258	128.799	112.677	112.051
TOTAL	1865695	2264214	1356375.12	1622028.4
% REDUCTION	0	12.07170	19.79391	23.27396

APPENDIX XIX

variable cooling load results for vegetation

	WITHOUT TREES V0	WITH TREES VI
MONTH	(kWh)	(kWh)
Jan	74594.77	82562.99
Feb	105259.9	94262.06
Mar	174456.7	124919.1
Apr	211050.7	137487.9
May	215310.4	141698.8
Jun	198053.4	131259.4
Jul	175578.4	125806.7
Aug	166746	125045.4
Sep	169330.8	122946.8
Oct	179453.8	126129.9
Nov	126484.7	102428.3
Dec	69375.76	86484.12
PER M^2	142.258	106.828
TOTAL	18.65695	14.01031

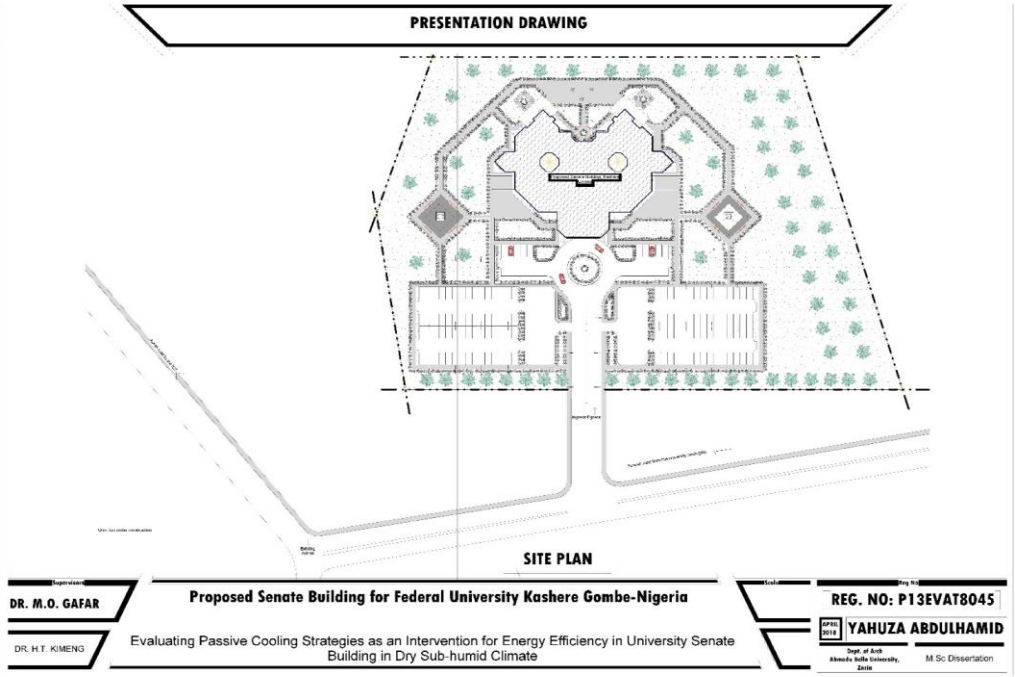
APPENDIX 'XX'

Energy Savings annual cool load for orientation

Degrees	0^0	45^0	90^0
MONTH	(kWh)	(kWh)	(kWh)
Jan	74594.77	87740.2	82562.99
Feb	105259.9	99525.62	94262.06
Mar	174456.7	130715.8	124919.1
Apr	211050.7	143450.3	137487.9
May	215310.4	147544.3	141698.8
Jun	198053.4	137331.7	131259.4
Jul	175578.4	131671.7	125806.7
Aug	166746	130622	125045.4
Sep	169330.8	128620.3	122946.8
Oct	179453.8	131995.3	126129.9
Nov	126484.7	107751.2	102428.3
Dec	69375.76	91795.93	86484.12
PER M^2	142.258	111.993	106.828
TOTAL	1865695	1468764	1401031

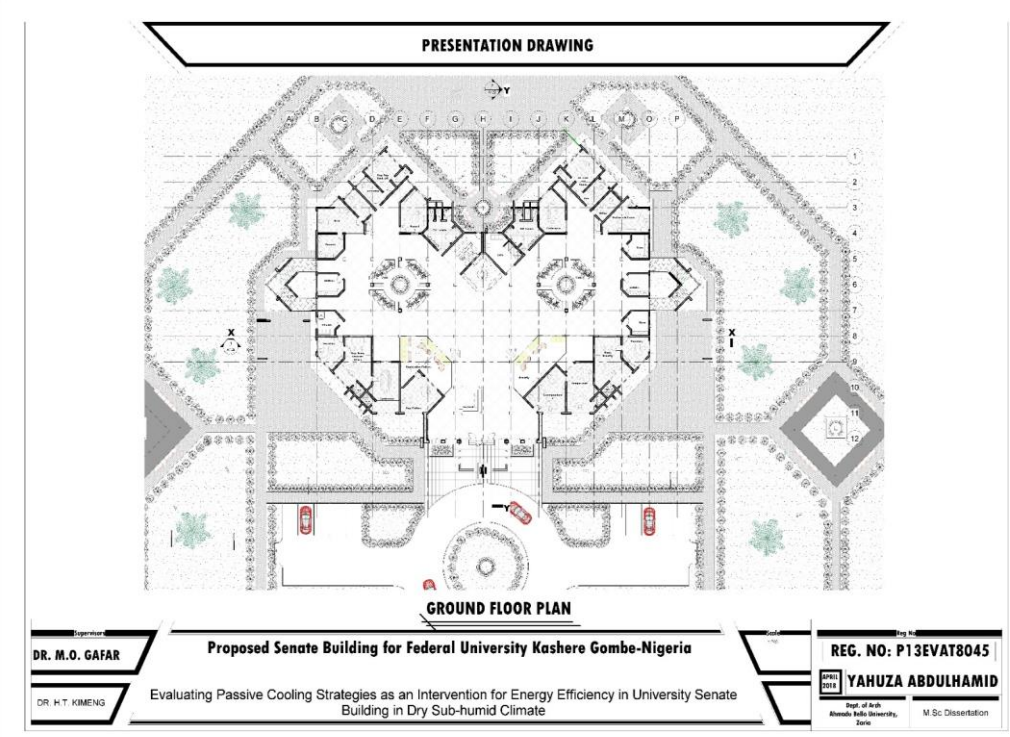
APPENDIX 'XXI'

Site Plan



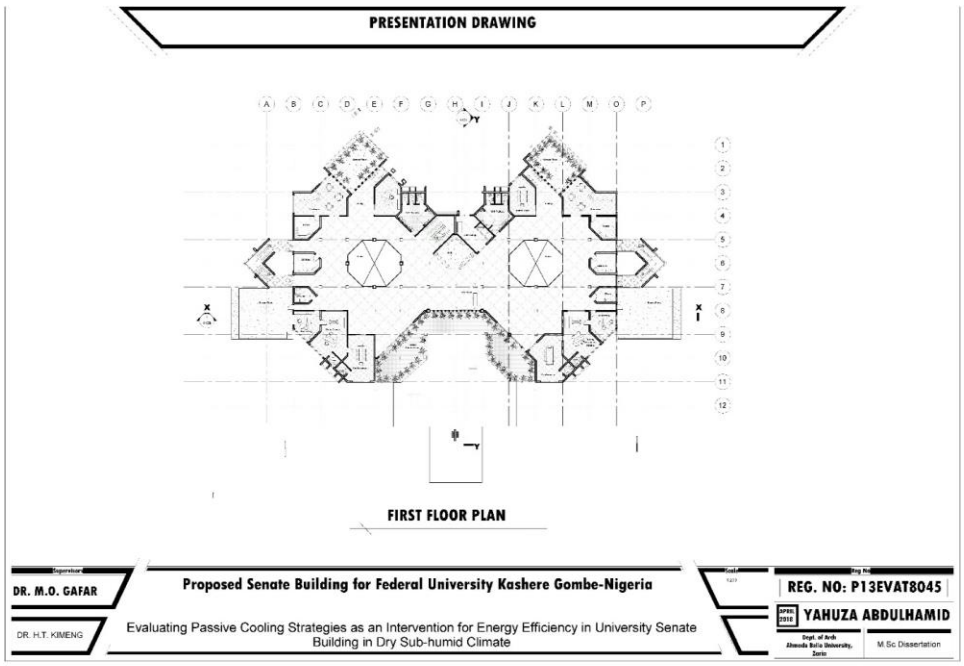
APPENDIX 'XXII'

Ground Floor Plan



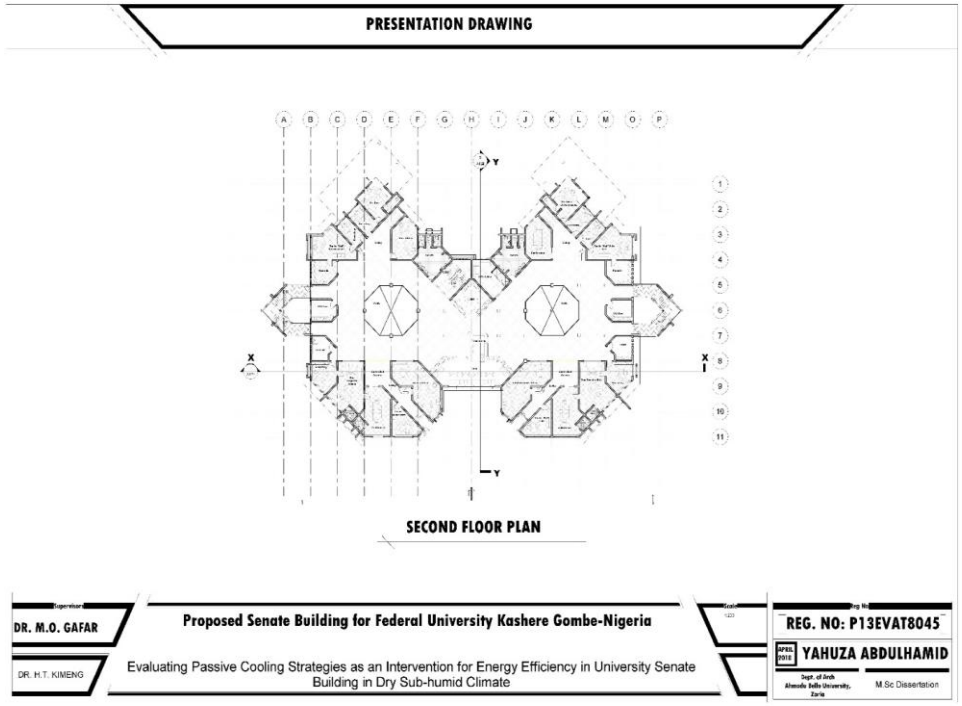
APPENDIX 'XXIII'

First Floor Plan



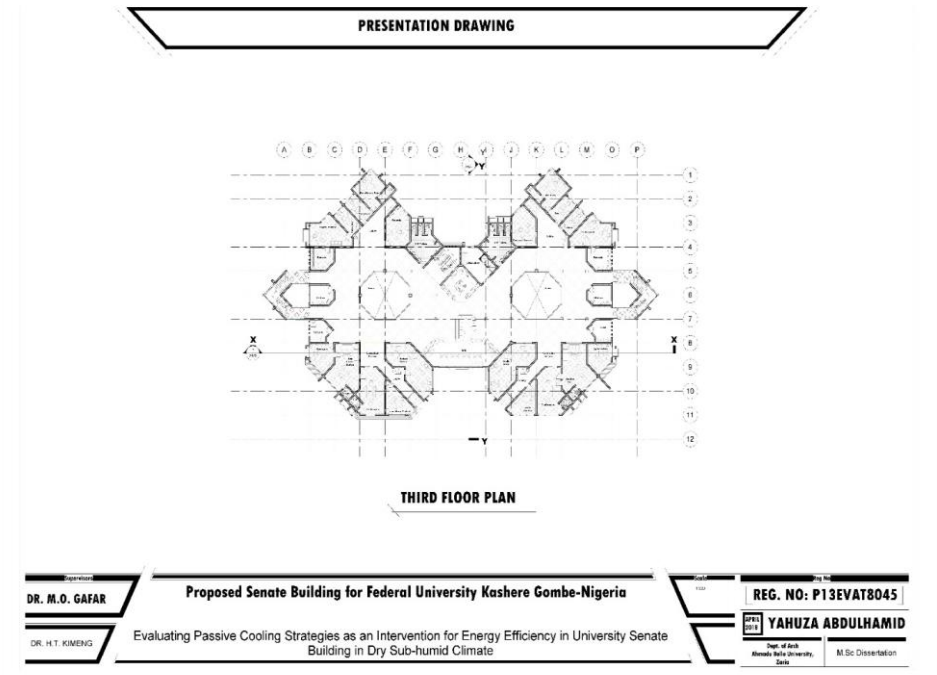
APPENDIX 'XXIV'

Second Floor Plan



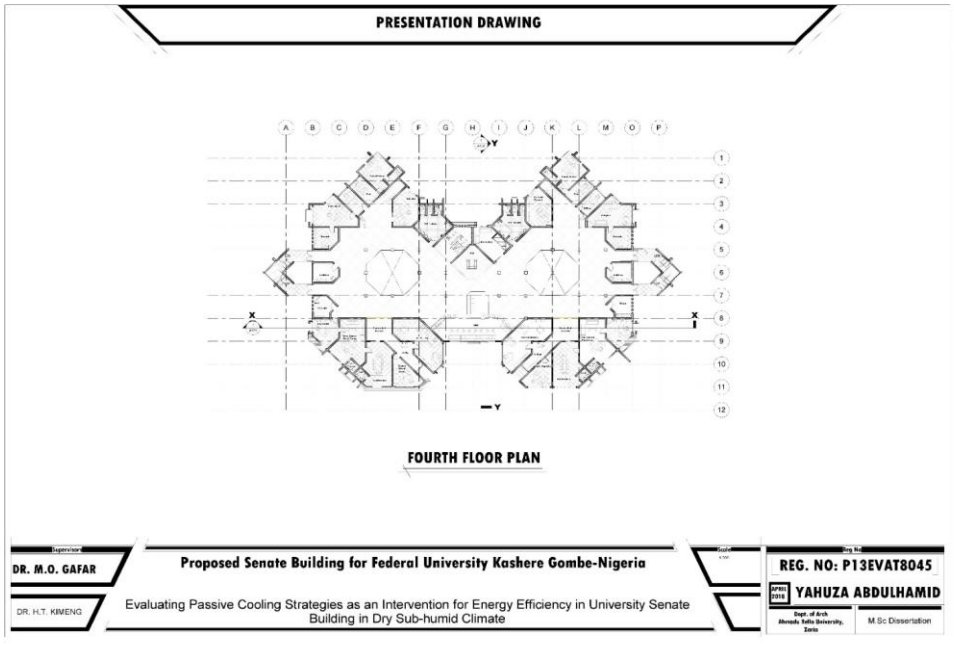
APPENDIX 'XXV'

Third Floor Plan



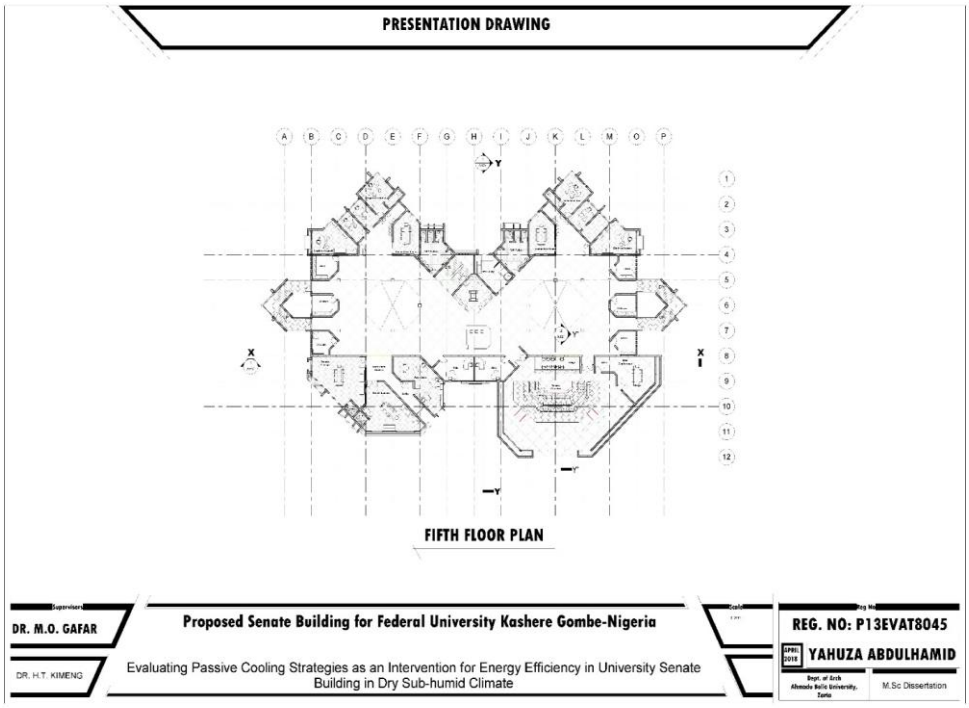
APPENDIX 'XXVI'

Fourth Floor Plan



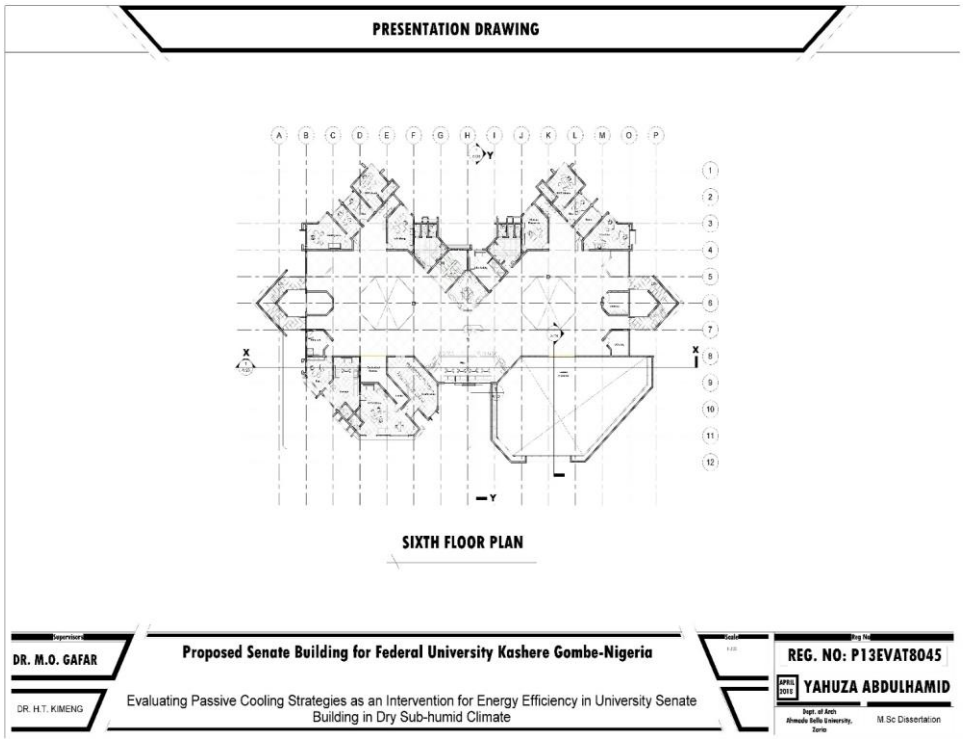
APPENDIX 'XXVII'

Fifth Floor Plan



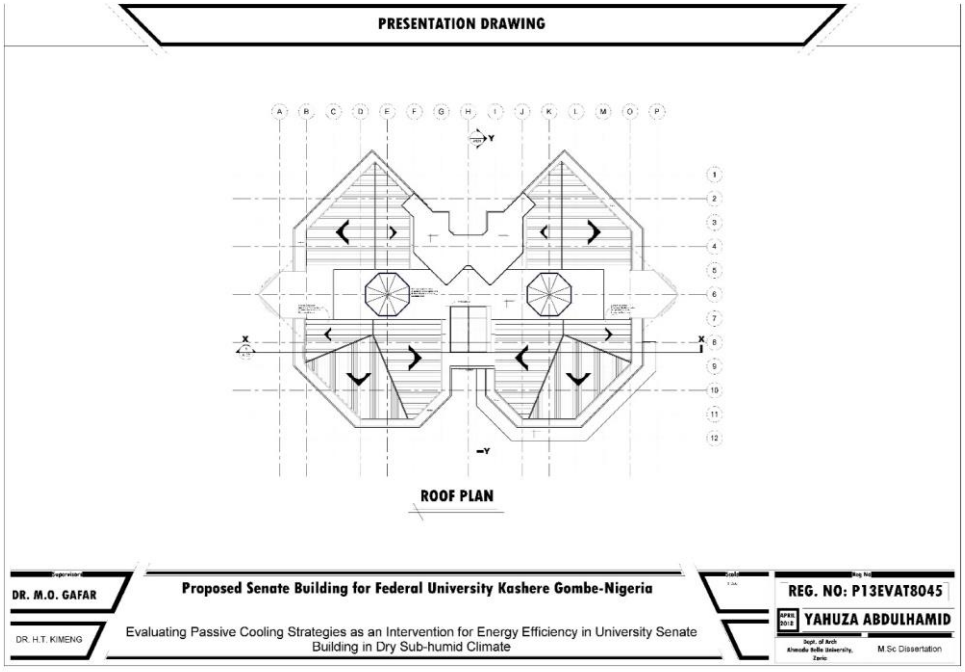
APPENDIX 'XXVIII'

Sixth Floor Plan



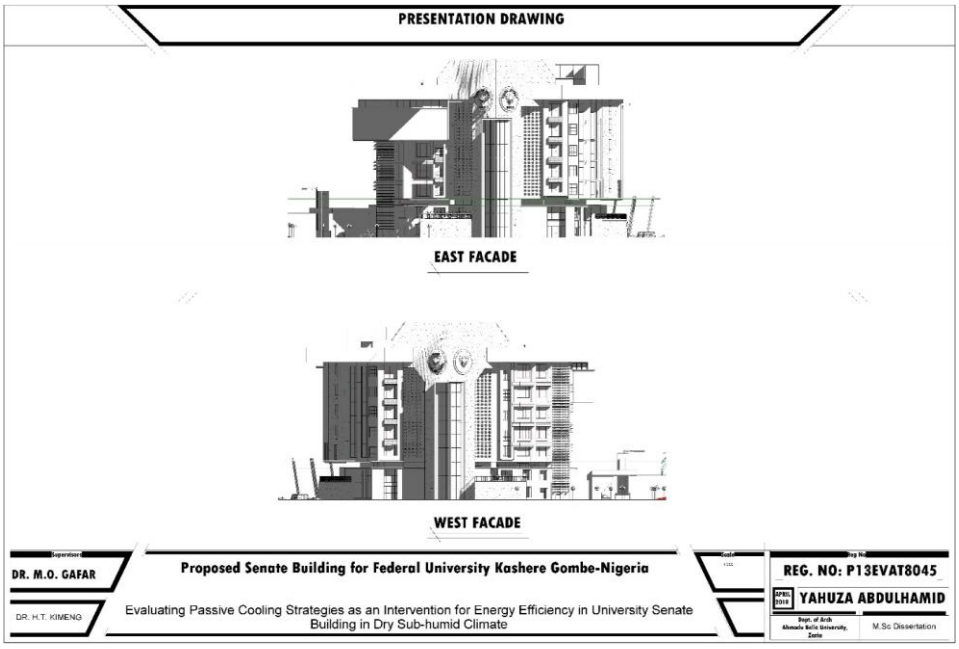
APPENDIX 'XXIX'

Roof Plan



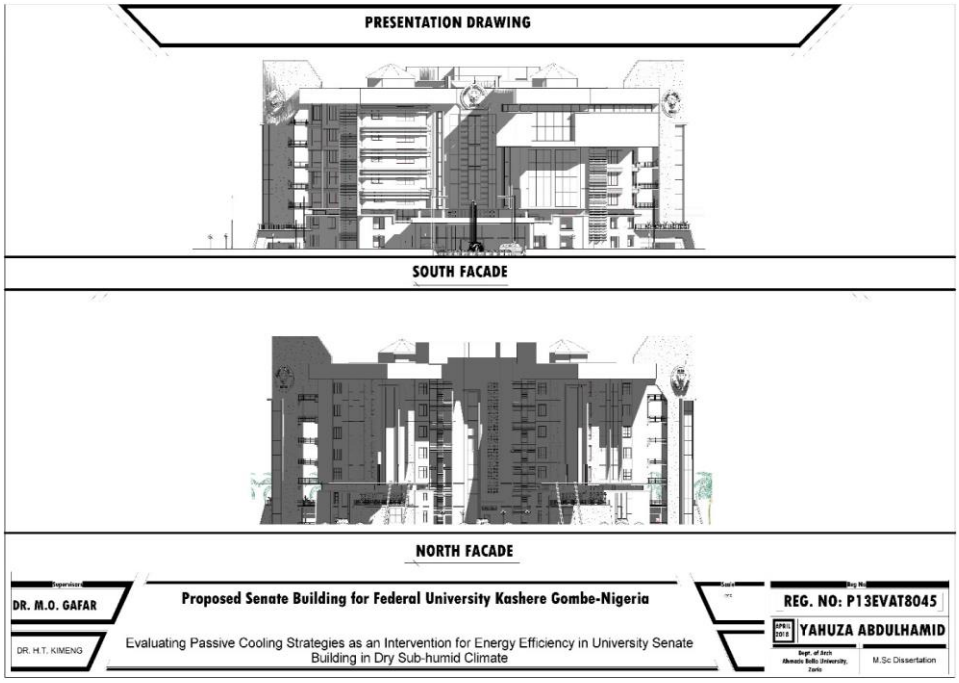
APPENDIX 'XXX'

East and West Facade



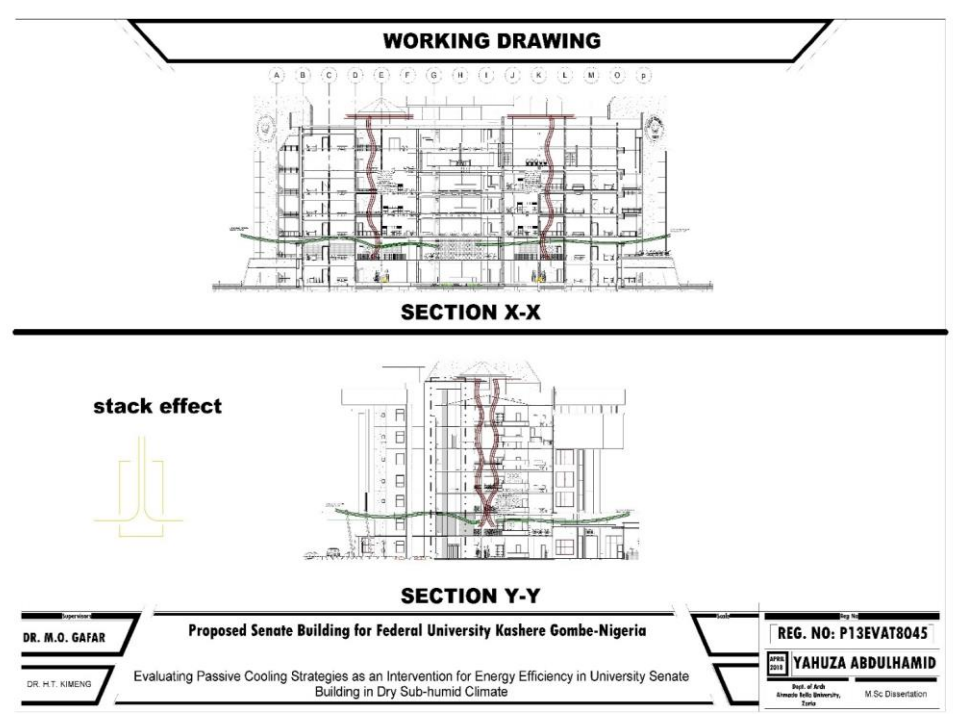
APPENDIX 'XXXI'

South and North Facade



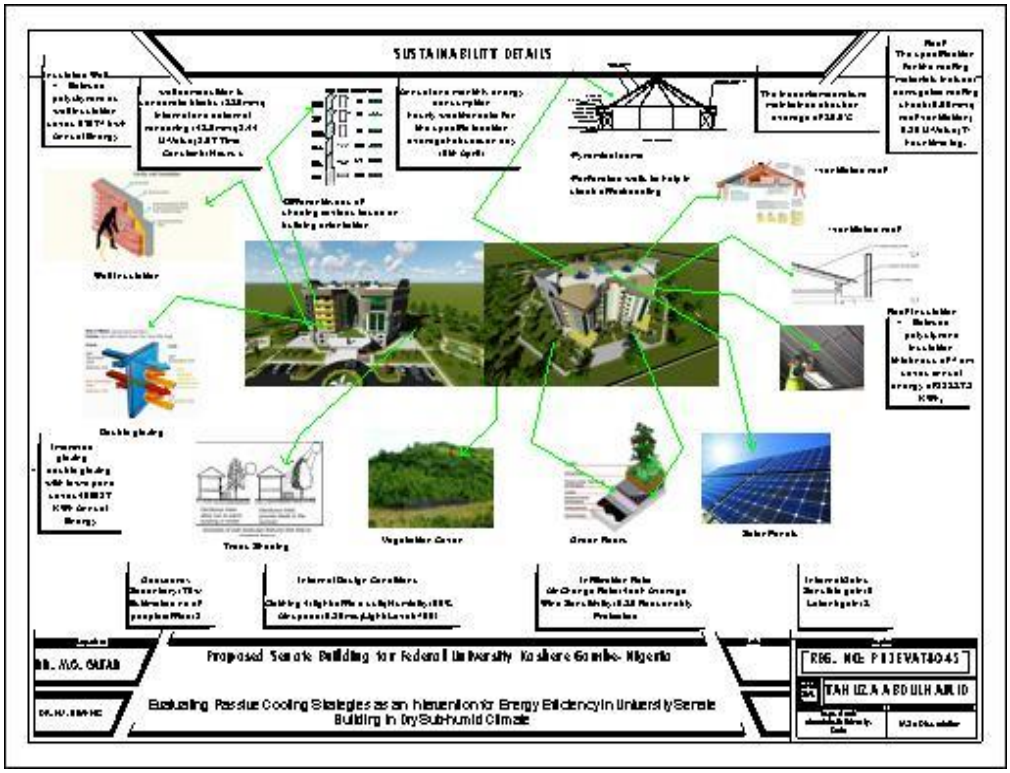
APPENDIX 'XXXII'

Section X-X and Section Y-Y



APPENDIX 'XXXIII'

Summary of Sustainable Materials used in the Proposed Senate Building



APPENDIX 'XXXIV'

Perspective view 1



APPENDIX 'XXXV'

Perspective view 2



APPENDIX 'XXXVI'

Perspective view 3



APPENDIX 'XXXVII'

Perspective view 4



APPENDIX 'XXXVIII'

Perspective view 5

