ASPECT RATIO OF BUILDING FORM AS A TOOL FOR ENHANCING THERMAL COMFORT IN THE DESIGN OF A TELECOMMUNICATIONS OFFICE BUILDING (MAIDUGURI)

By

Ibrahim TAJUDDEEN

P14EVAT8161

DEPARTMENT OF ARCHITECTURE

FACULTY OF ENVIRONMENTAL DESIGN

AHMADU BELLO UNIVERSITY, ZARIA

DECEMBER, 2017

ASPECT RATIO OF BUILDING FORM AS A TOOL FOR ENHANCING THERMAL COMFORT IN THE DESIGN OF A TELECOMMUNICATIONS OFFICE BUILDING (MAIDUGURI)

By

Ibrahim TAJUDDEEN B.Sc. Arch. (ABU 2014), P14EVAT8161

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS DEGREE IN ARCHITECTURE

DEPARTMENT OF ARCHITECTURE
FACULTY OF ENVIRONMENTAL DESIGN
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA.

DECEMBER, 2017

Declaration

I declare that the work in this dissertation entitled "ASPECT RATIO OF BUILDING FORM AS A TOOL FOR ENHANCING THERMAL COMFORT IN THE DESIGN OF A TELECOMMUNICATIONS OFFICE BUILDING (MAIDUGURI)" has been carried out by me in the Department of Architecture. The information derived from the literature has been dully acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

Ibrahim Tajuddeen		15th December,2017
Name of Student	Signature	Date

Certification

This dissertation "BUILDING FORM AS A TOOL FOR ENHANCING THERMAL COMFORT IN THE DESIGN OF A TELECOMMUNICATIONS OFFICE BUILDING IN A HOT-DRY REGION (MAIDUGURI)" by IBRAHIM TAJUDDEEN meets the regulations governing the award of the degree of Master of Science in Architecture of Ahmadu Bello University, Zaria, and it‟s approved for its contribution to knowledge and literary presentation.

Dr. A.J. Ango — Signature _____
Chairman, Supervisory Committee — Date _____

Dr .G. O. Mudashir — Signature _____
Member, Supervisory Committee — Date _____

Dr. A. S. Salisu — Signature _____
Head of Department — Date _____

Prof. S.Z Abubakar — Signature _____
Dean, School of Postgraduate Studies — Date _____

Dedication

Dedicated to the memory of my late father Alh. Muhammad Tajuddeen from whose loss I draw the strength that kept me moving, and to my mother Hajiya Balkis Uzaifah , and to all potential designers and architects, I hope this research work will help to guide them in solving contemporary design problems.

Acknowledgements

First of all, my deepest appreciation goes to the Almighty God for making this thesis a success despite the desperations and challenges involved.

I would never have been able to finish my thesis without the guidance of my supervisory committee members, support from my family members and help from friend.

I would like to express my deepest gratitude to my supervisor, Dr.A.J. Ango, for his good guidance and patience toward editing my work and providing me with a favorable atmosphere for doing the research. I would like to thank Dr. G.O. Mudashir who let me experience the research in its simplistic manner and helping me solve practical issues especially in the design stage of the work, beyond the textbooks.

I would also like to thank my Dearing mother, Hajiya Balkisu, my two elder brothers (Kabir and Nasir) who ensured the sponsorship throughout the course of the program. And their radiant advice and words of encouragement that they gave to me all the time even when I wanted quitting at a point, I sincerely appreciate that.
My gratitude goes to all my brothers and sisters. They were always supporting me and encouraging me with their best wishes.

Finally, my immense appreciation also goes to my good Friends and well-wishers many of whom space will not allow me to mention their names, whose words of inspiration and valuable suggestions made Architecture and whole life really interesting.

ABSRACT

Thermal comfort is recognized as a key parameter for healthy and productive large workspaces found in office buildings. Achieving occupants comfort is a priority that has a great effect on energy demand in buildings, particularly in hot climate zones. The study aims at investigating a suitable aspect ratio of building form that will reduce the costly effects of providing thermal comfort to occupants in buildings in a hot-dry climate of Nigeria.

A case study approach was adopted to study the geometric properties of existing similar office buildings which were chosen purposively and a quantitative research method was used for the collection of data through computer simulation. Firstly, the study examined the thermal performance of different building forms with the same floor area against their volume to surface ratio (V/S). Forms with good thermal performance were optimized with different aspect ratios elongated along east-west orientation. ECOTECT program was used to study the energy performance of the forms on exposed surfaces.

From the deduction of the study, the west and south surfaces are the most exposed (in terms of heat gain and incident light), both the cube and cylinder forms were optimized with various aspect ratios and simulations were conducted to observe the extent to which solar radiation could be reduced on exposed west surfaces during hot periods and maximized on south surfaces during cold periods.

The study showed that a slight change in the volume to surface ratio could have a significant impact in a building's energy performance, and also significant thermal

environment can be attained during both hot and cold periods when optimized with an optimum aspect ratio of (1:1.7) as compared to aspect ratio (1:1). 33% and 28% energy are further saved on south and west surfaces respectively when aspect ratio "1:1.7" (ideal ratio) is compared with aspect ratio "1:1". Also, it was noted that the incident solar radiation decreases from aspect ratio 1:1.7 indicating 71% exposure, 1:1 and 1:2 indicating 72% exposure, 1:2.5 indicating 73% exposure, 1: 4 indicating 77% exposure and 1:3 indicating 78% exposure. Therefore, it could be said that an ideal aspect ratio of 1:1.7 existed for the wide range of ratios from 1:1-1:4. In conclusion, the thermal comfort of the proposed building could be optimized by applying the aspect ratio "1:1.17" of cylindrical/cuboidal form to reduce the effect of west and south solar radiation. It is recommended that prospective designers should go beyond only orienting buildings on east-west axis, rather, effort to experimentally explore different aspect ratios should be considered for befitting alternative.

Table of Contents

Title page.....i

Declaration.....ii

Certification... …….....iii

Dedication …...iv

Acknowledgements……. ….....v

Abstract vii

Table of Contents …...ix

List of Figures…….....xv

List of Tables.....xviii

List of Plates.....…xix

List of Appendices.....xx

Abbreviations, Definitions, Glossary and Symbols..... xxi

1.0 INTRODUCTION..... 1

1.1 Background to study…….…….....1

1.2 Problem Statement.....…….... 4

1.3 Aim and Objectives 4

1.4 Research Questions.....…….....5

1.5 Scope.....5

1.6 Justification.....6

2.0 LITERATURE REVIEW.....7

2.1 Thermal Comfort Conditions.....7

2.1.1 Comfort zones of hot-dry regions.....8

2.2 Energy Conservation in Telecommunication Office Building.....9

2.3 Performance of Building Forms in Enhancing Thermal Comfort.....10

2.3.1 Thermal performance of a Building's Volume to Surface Area Ratio (V/S).....10

2.3.2 Relationship of Aspect Ratio (Width to length ratio) and Solar Radiation……11

2.3.3 Thermal Response of Building Envelope.....11

2.3.4 Relationship of Relative Compactness to the Cardinal Points.....18

2.3.5 Effect of Self – Shading of Building Forms.....22

2.4 Summary of Findings from Literature Review.....24

3.0 METHODOLOGY.....27

3.1 Research Design/Approach.....27

3.1.1 Experimental/Case study Design.....27

3.2 Instruments of Data Collection.....28

3.2.1 ECOTECT (ECOTECT Version 11).....28

3.3 Criteria for Selecting Simulated Building Forms 29

3.4 Dependent and Independent Variables.....30

3.5 Procedure for Data Collection (Parametric Analysis).....31

3.6 Simulation inputs and assumptions 32

3.6.1 Analysis of Internal Heat Gain.....32

3.7 Characteristics of Tropical Hot-dry Climate.....33

3.8 Method of Data Analysis.....33

4.0 DATA ANALYSIS AND PRESENTATION.....34

4.1 Case Study.....34

4.1.1 Case Study I : National Communication Commission (NCC). 34

4.1.2 Case Study II: NITEL Headquarters, Abuja.....37

4.1.3 Simulation Input Information.....39

4.2 Thermal comfort conditions and comfort zone parameters for the simulation…...40

4.3 Analysis of Energy Consumption of the Building Forms 42

4.4 Analysis of incident solar insolation on varying surfaces of cube and cylindrical forms with varying aspect ratios 44

4.5 Total Incident Solar Insolation on the Combined Exposed Surfaces for Overall Orientations.....49

4.6 DISCUSSION OF FINDINGS.....53

5.0 DESIGN PRELIMINARIES.....56

5.1 General Climate Characteristics.....56

5.1.1 Temperature.....57

5.1.2 Relative humidity.....58

5.1.3 Sunshine.....59

5.1.4 Rainfall.....59

5.2 Site Selection Criteria.....60

5.2.1 The proposed site.....65

5.3 Site Analysis.....66

5.3.1 Topography.....66

5.3.2 Vegetation.....67

5.3.3 Services / Infrastructure.....67

5.3.4 Climate.....67

5.4 Summary of Site and Surrounding Analysis.....68

5.5 Design Inferences from the Site Analysis 68

6.0 DESIGN REPORT 69

6.1 Design brief 69

6.2 Functional flow chart.....70

6.3 Spaces of the technical staff area.....71

6.3.1 Network operations room:.....71

6.3.2 Call centre department: 71

6.3.3 Contact centre department:.....72

6.3.4 Communications centre department:.....72

6.3.5 Information security operation department: 72

6.3.6 Geographical Information System (GIS) room:.....73

6.3.7 Interactive Voice response (IVR) room: 73

6.3.8 Transmissions room 73

6.4 Bulk schedule and space grouping 73

6.5 Schedule of Accommodation.....77

6.6 Design Philosophy.....81

6.7 Main Buildings in the Centre.....83

6.7.1 The telecommunication office..... 83

6.7.2 The vocational/technical training unit/restaurant 83

7.0 CONCLUSION AND RECOMMENDATION…….....84

7.1 Conclusion 84

7.2 Recommendation 85

7.3 Contribution to Knowledge 86

REFERENCES 87

APPENDICES 91

List of Figures

Figure 2.1: Impact of building shape on heating load……..…….....10

Figure 2.2: Different plan forms representing mid-size office buildings…...……..……14

Figure 2.3: 3-D images of archetype building……..….16

Figure 2.4: The shapes of Building that were comparison of energy consumption… ... ….19

Figure 2.5: Orientation of buildings to cardinal point in terms of minimizing heating load……..…...19

Figure 2.6: L-type, T-type, H-type, cross shape, U-shape, cross shape, and rectangular office building……...…… 21

Figure 2.7: 3-D - images of the buildings used in application……. 21

Figure 2.8: Depth ratio (a/b) in the self-shading geometries (convex shapes)……...……...23

Figure 3.1 : Parametric framework…….…...29

Figure 3.2: Dependent and independent variables……...….....30

Figure 4.1: NCC Organogram……...35

Figure 4.2:Graphical comparison of monthly cooling loads of all the form ……42

Figure 4.3: Average solar insolation on North, South, East, & West surfaces for different aspect ratios of cube…….....45

Figure 4.4: Average solar radiation on North, South, East, & West surfaces for different aspect ratios of cylinder…….....45

Figure 4.5: Chart representing Month with available highest solar radiation……..….49

Figure 4.6: Graph for total absorbed and incident solar insolation for aspect ratio 1:1…...50

Figure 4.7: Graph for total absorbed and incident solar insolation for aspect ratio1:1.7….50

Figure 4.8: Graph for total absorbed and incident solar insolation for aspect ratio 1:2…...51

Figure 4.9: Graph for total absorbed and incident solar insolation for aspect ratio 1.25….52

Figure 4.10: Graph for total absorbed and incident solar insolation for aspect ratio 1:3….....52

Figure 4.11 Graph for total absorbed and incident solar insolation for aspect ratio 1:4….....53

Figure 5.1: Climate data for Maiduguri……..…..…....57

Figure 5.2: Maximum and minimum temperature for Maiduguri……..58

Figure 5.3: Average relative humidity for Maiduguri…….……...58

Figure 5.4: Average monthly sunshine in Maidguri…….……59

Figure 5.5: Average precipitation in Maiduguri……....60

Figure 5.6: Topographical analysis of the site……..66

Figure 5.7Climatic data analysis…….…….…..67

Figure 6.1: Preliminary design framework…….…….…..71

Figure 6.2: Design strategy for thermal comfort…….……..75

List of Tables

Tab le 2.1 : Acceptable operative temperature ranges based on comfort zone 9

Table 2.2: Shape design parameters ..... .24

Table 2.3: Summary of findings from literature review……...25

Table 4.1: Illustration of primary parameters for the simulation 40

Table 4.2: Description of forms that were simulated 41

Table 4.3: High solar radiation on west and south surfaces for different aspect ratios of cube and cylinder 46

Table 6.1a: Grouping of telecommunications office spaces 74

Table 6.1b: Grouping of telecommunications office spaces……..75

Table 6.1c: Grouping of telecommunications office spaces……...76

Table 6.2a: Schedule of Accommodation of Reception/Technical staff area 77

Table 6.2b: Schedule of Accommodation of Reception/Technical staff area……78

Table 6.3a**:** Schedule of Accommodation of Technical specialists staff rooms 78

Table 6.3b**:** Schedule of Accommodation of Technical specialists staff rooms……..….79

Table 6.4a: Schedule of Accommodation of Administrative staff area 79

Table 6.4b: Schedule of Accommodation of Administrative staff area…….80

Table 6.5: Schedule of Accommodation of Computer and equipment area 81

List of Plates

Plate I: Description of variables studied in the case study 36

Plate II :Approach view of the building 37

Plate III:Side view of the building 37

Plate IV: Satellite image showing approximate diameter of the building 38

Plate V: Approach view of case study showing visual characteristics of the form 39

Plate VI: side view of case study building 39

Plate VII: satellite image showing geometric properties 40

Plate VIII: Google earth image showing Site A 64

Plate IX : Google earth image showing Site B 65

Plate X: Google earth image showing Site C 65

Plate XI: Selected Site for Proposed Design 67

List of Appendices

Appendix I: Thermal comfort conditions and comfort zone settings ……91

Appendix II: Thermal comfort conditions and comfort zone settings……91

Appendix III: Thermal and schedule settings in ECOTECT 2011 92

Appendix IV: Zone management general settings in ECOTECT 2011..... 92

Appendix V: Zone information in ECOTECT 2011..... 93

Appendix VI:Site plan of the proposed office building. 93

Appendix VII: Ground floor plan of the proposed office building..... 94

Appendix VIII:first and second floor plan of the proposed office building 94

Appendix IX: Third and fourth floor plan of the proposed office building..... 95

Appendix X: Fifth and sixth floor plan of the proposed office building..... 95

Appendix XI: South and west elevations of the proposed office building..... 96

Appendix XII: North and east elevation of the proposed office building..... 96

Appendix XIII: Section of the proposed office building 97

Appendix XII: 3-D I of the proposed office building 97

Appendix XIV: 3-D II of the proposed office building..... 98

Appendix XV: 3-D III of the proposed office building 98

LIST OF ABBREVIATIONS, DEFINITIONS, GLOSSARY AND SYMBOLS

ASHRAE	American Society of Heating and Air Conditioning Engineers
GFA	Gross Floor Area
GIS	Geographical Information System
ICIR	International Center for Investigative Reporting
IVR	Interactive Voice Response
LANL	Los Alamos National Laboratory
NATCOM	National Telecommunication Commission
NCC	Nigerian Communication Commission
NITEL	Nigerian Telecommunication Limited
OSHS	Occupational Safety and Health Services
V/S	Volume – Surface Area - Ratio
W/L	Width/Length ratio
WWR	Window – Wall – Ratio

Glossary

Aspect ratio	Aspect ratio is defined as an increase relative to the north – south or east – west axis , which can influence the amount of building form exposed to solar radiation.
Building form	Building form, in general, refers to the measurements related to building configuration and arrangement. In a broader sense, it includes the components of building envelope, such as; walls, roofs, floors, doors, and fenestration, which interact with the exteriors and mediate the difference between outdoor conditions and desired indoor conditions.
Building shape factor	Also called building characteristic length which is defined as the ratio between the heated volume of the building (Vb) and the sum of all heat loss surfaces that are in contact with the exterior, ground or adjacent non-heated spaces.
Relative compactness	Relative compactness of a form is derived in that its volume to surface ratio is compared to that of the most compact form with the same volume .
Volume /surface ratio	Volume/Surface ratio is defined as the ratio of the volume of the form to its surface area, which includes wall surfaces, roof surface, and ground surface.

1.0 INTRODUCTION

1.1 Background to study

Telecommunication office buildings are essential to the economy; however, they are also significant consumers of energy required to maintain thermal comfort. (Creamer Media Reporter, 2015). Thermal comfort is recognized as a key parameter for healthy and productive workplaces, some of which are found in telecommunications building. At the same time, lowering energy use in commercial building is vital if a significant reduction in greenhouse gas emissions is to be achieved. Traditionally thermal comfort has been achieved at the expense of significant energy use for heating and/or cooling (Ismail, Jusoh & Makhtar, 2010). In a major study, Taylor, Fuller & Luther (2008) found that a well-designed building should be able to provide good thermal comfort, while simultaneously having low energy consumption.

The thermal conditions of an office environment are very important with respect to the productivity and success of that office. The excessive cost of energy used to attain occupants‟ comfort could lead to decrease in profits productivity, and if this effect is lasting for a longer period, it could be detrimental to offices" productivity. (Ismail etal., 2010).

Studies have shown that employee satisfaction with the thermal comfort of their workplace plays a significant role in both employee retention and productivity. One study even revealed that employees consider workplace comfort second only to compensation in terms of benefits (American Society of Interior Designers). Since telecommunication office workplaces and cooling need expand, it is as a result of the use of servers and other telecommunication equipment that has spread widely in our society, and their importance as a social infrastructure has been increasing. However, the operation of telecom

equipment generates a large amount of heat and requires year-round air conditioning, so there is a strong demand for reduced power consumption of air conditioning systems. (Yosuke, 2014).

Also, in order to stress the widespread of telecommunication sector that brought about office workspaces and cooling need demand, Olusoji (2000) stated how the Nigerian Telecommunication limited (NITEL) was created from a merger of the Nigerian External Telecommunication and the Telecommunication Departments of the defunct Post and Telecommunication in 1985. Olusoji (2000) further asserted that the main objective of establishing NITEL was to harmonies the planning and co-ordination of internal and external telecommunication development and provide accessible efficient and affordable services.

However, almost 20 years or more down the line the Nigeria Telecommunication Limited had roughly half a million (500,000) lines available to over 100 million Nigerians (Nigeria Business Information, 2005). From a bit above 500,000 NITEL fixed wire line and mobile subscriber in 2001, the industry grew to over 7 million subscribers in 2004; in December 2008, the subscribers in the market grew to 62.99 million, an addition of 22.59 million subscribers in 2008 alone represented 56% annual growth rate. Recent figure as at January 2009 put the subscribers‟ base at 64.16% while G.S.M subscribers are in the range of 57 million, CDMA subscription in Nigeria grew from just 380,000 in 2007 to more than 6 million at the end of 2008. (Nigeria Business Information, 2005).

From the above statistics, it is evident that growth in the telecommunication industry in Nigeria is increasing which in turn requires increase in the number of office facilities as thesame, while putting into cognizance an energy conservation approach in their design as a result of energy they require on air-conditioning.

As a consequence of this, building form was adopted as one of the important design parameters that affect the cooling energy required to attain occupants‟ comfort in a buildings, according to (Erdim & Manioglu, 2011) . Also, Study by (Chia, Mohd, & Dilshan, 2007) in tropical hot-humid region in Malaysia shows that different geometrical forms have the ability to react to thermal comfort differently, due to differences in their geometrical characteristics. Studies by Philip & Alan, (2014) reported that aspect ratio could affect incident solar radiation on the form**.** Ratti, Raydan, Steemers (2003) asserted that in order to achieve good thermal comfort, it is noted that during hotter periods, the sun has a high solar angle thus there is need for maximum shading and minimum exposure while during colder periods the sun has a lower solar angle indicating no need for cooling. Ratti, et.al (2003) further postulated that a building form can possess good thermal properties if it has a low exposed area on maximum incident solar radiation in hotter periods and high exposed area on minimum incident solar radiation in colder periods. This study aimed at examining different aspect ratios of building forms in hot dry region and attempts to suitably enhance thermal comfort, within a large office workspace with minimum amount of energy by reducing heat gain into the building during hotter periods and increasing heat gain into the building during colder periods. Although previous researches have determine the effect of different building forms on energy consumptions in different climatic region, but there are limited study that have investigated the role of

aspect ratio of building forms on energy required for thermal comfort specifically in hot-dry climate of Nigeria.

Therefore, primary design parameters of building should be developed as providing the climatic comfort conditions and minimum energy consumption during the construction and use of the building. Building form is one of the important design parameters affecting the heating and cooling energy consumption in the building.

.

1.2 Problem Statement

Thermal comfort within the modern office (especially those with large workspaces such as telecommunications office buildings) is determined by air conditioning both centrally for the whole building, and locally at room level by the occupants. Air conditioning systems are typically optimized during extreme summer period in hot dry regions. These air conditioning systems require huge amount of energy to attain occupants comfort . This results in unnecessary energy consumption.

It is in line with this that it is significant to provide an optimum architectural approach in the design of buildings with large workspaces that will reduce such effect by exploring different building forms, from which the essential one will be applied in reducing cost on cooling for telecom buildings in hot-dry climates of Nigeria.

1.3 Aim and Objectives

The aim of this research is to investigate the aspect ratio of suitable building form that will reduce the cooling demand required for occupants thermal comfort in a telecommunications office building in a hot-dry region.

The research intends to achieve the aim above through the following objectives;

i. To study the thermal comfort conditions and comfort zones in hot-dry regions.
ii. To study the effect of various building forms toward enhancing thermal comfort.
iii. To optimize the studied building forms with different aspect ratios using solar exposure with a computer simulation.
iv. To demonstrate the research findings in the design of a telecommunications office building in Maiduguri, Nigeria.

1.4 Research Questions

This research seeks to answer the following questions:

i. Which building form reduces energy demand on thermal comfort for a large workspace office building.
ii. In what ways can the research findings be applied in the design of a telecommunication office building?

1.5 Scope

This research is focused on the architectural aspect of telecommunication office building design in hot-dry region, Maiduguri. However, this study will only check and compare different building forms and the extent to which energy demand to attain minimum comfort level could be reduced in such way. And not on the technology aspect which has to do with the energy required to run telecommunication equipment.

1.6 Justification

According to a report from the International Center for Investigative reporting (ICIR), (2015) which stated that Switzerland has promised to partner with countries affected by Boko Haram insurgency in reconstructing ravaged areas and displaced persons. Among the facilities to be reconstructed as noted by the government are telecommunication facilities which have been completely destroyed and require reconstruction and replacements in Maiduguri.

To further justify the reason why telecom building must be undertaken in this research, another report by the African Business Central (ABC), (2014), noted that Nigerian government makes progress in latest attempt to privatize incumbent Telco and its mobile unit Mtel. Investment vehicle National Telecommunications Commission (NATCOM) has emerged as the successful bidder for Nigerian incumbent Ntel and its mobile unit Mtel.

2.0 LITERATURE REVIEW

This chapter gives a review of existing literature that have been undertaken on energy efficient approaches for telecommunications office buildings. It also seeks to review the different building forms that have been applied to several buildings toward conserving energy in different climate. At the end of this chapter, a knowledge gap will be established for energy conservation used for telecom office buildings while also exploring a gap on building form used in office buildings.

2.1 Thermal Comfort Conditions

Thermal comfort is defined in the ISO 7730 (1994) and ASHRAE standards 55-66 as "the condition of the mind that which expresses satisfaction with the thermal environment". Cheung (2003) states that, thermal comfort occurs when there is a thermal equilibrium in the absence of regulatory sweating and the heat exchange between the human body and the environment.

The most commonly used indicator of thermal comfort is air temperature because it is the most easy to use and people can rate it without any difficulty. Although it has vital importance,

however, it is not the only parameter that can be used to define thermal comfort very accurately. According to Khaliq (2009), air temperature should always be considered in relation to other environmental and design factors. Temperature and relative humidity are the two local climatic factors that affect indoor comfort while building envelop,orientation, shading, glazing type and size, vegetation, thermal mass are the design

dependent parameters that contribute to the thermal comfort condition in a workspace building such as a telecommunications centre. Another set of factors affecting thermal comfort are known as the human thermo-regulatory factors. Although these factors are independent to each other, they have collectively a great impact. Thermo-regulatory factors are not considered further in this research, because it is outside the scope of the study.

2.1.1 Comfort zones of hot-dry regions

According to Çakir (2006), thermal comfort in an interior space can be considered as the sum-total of heat or cold sensations experienced by occupants. Further, if the interior space has neither excessive heat nor cold conditions, it is then considered to be thermally comfortable. This reveals that the space is within an occupant‟s comfort zone. Thus, the comfort zone may be defined as a thermal condition in which little or no effort is required by occupants to adjust their bodies to surrounding environmental conditions.

Occupational safety and health services (1997) OSAHS, provided a thermal comfort standard for sedentary occupations applicable in hot-dry climatic zone. According to the standard, most people will be thermally comfortable in the following conditions;

i. Air temperature : heat periods (19ºC-24ºC) cold periods (18ºC-22ºC)
ii. Relative humidity : 40%RH-70%RH
iii. Air speed : 0.1-0.2 m/s, without creating draught
iv. Radiant heat

Below also is the example of acceptable operative temperature ranges based on comfort zone diagrams in ASHRAE Standard-55-2004

Tab le 2.1 : Acceptable operative temperature ranges based on comfort zone
Source: ASHRAE standard 2004

Conditions	Acceptable operative temperatures	
	°C	° F
Summer *(clothing insulation = 0.5 clo)*		
Relative humidity 30%	24.5 – 28	76 – 82
Relative humidity 60%	23 – 25.5	74 – 78
Winter *(clothing insulation = 1.0 clo)*		
Relative humidity 30%	20.5 – 25.5	69 – 78
Relative humidity 60%	20 – 24	68 – 75

2.2 Energy Conservation in Telecommunication Office Building

Previous studies on energy conservation in telecom buildings mainly focused on improvement of efficient air conditioning systems (Nakao, Hayama, & Uekusa, 1988; Maeda, Seshimo, & Okazaki, 2005; Choi, Kim, & Jeon, 2007), indoor airflow optimization (Hayama & Nakao, 1989; Dan & Matti, 2000), use of renewable energy (Makhkamdjanov, 2006), and other energy saving and monitoring techniques (Schmidt & Shaukatullah, 2003).

Building energy efficiency design, which is known as passive cooling technology, is very popular in the traditional buildings and well inherited and applied in the modern buildings in Southern China where the above study was conducted (Zhang, et al. 2008). Compared with the active one, such as air-conditioning, passive cooling technology has notable

advantages on utilizing natural cooling capacities with no or few energy consumption. Many studies report building energy efficiency designs of walls, roof, glazing, shading and natural ventilation for residential buildings (Feng, 2004), institutional buildings (Athanassios, Andreas, & Panagiota, 2007) and high rise apartments (Cheung, Fuller, & Luther), however, no such studied were performed on telecom buildings.

2.3 Performance of Building Forms in Enhancing Thermal Comfort

2.3.1 Thermal performance of a Building's Volume to Surface Area Ratio (V/S)

Gratia & De Herde, (2002) conducted a research to see how V/S area of different shapes are compared to that of the most compact shape (cube). Simulations on five different forms were performed (Figure 2.1) to identify the role of „compactness" on the heating loads of buildings in the context of Belgium. Envelope design and fenestration areas remain fixed for all five forms. Their study turns out with the result that a high C (compactness) form corresponding to the least heating load requirement per year (Figure 2.1). The building with a V/S of 1.24 (highly compact) requires 20.73% less space heating energy while compared to a building with a V/S of 0.84 (the least compact form studied).

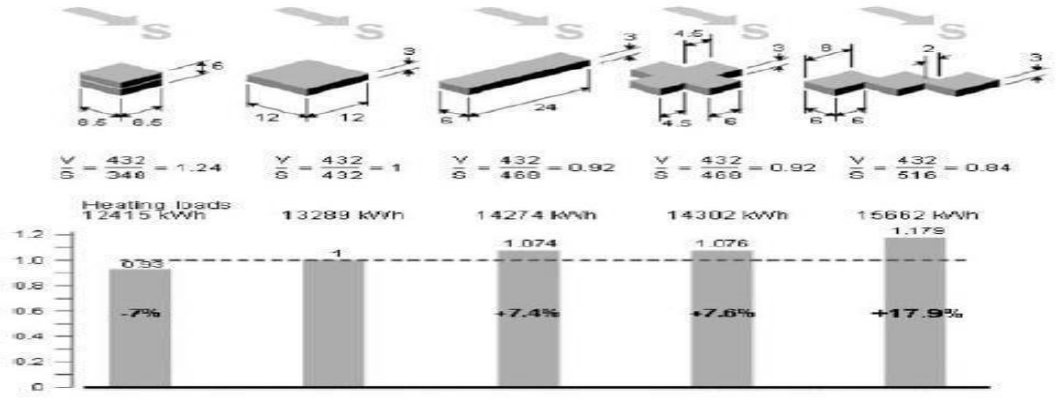


Figure 2.1: Impact of building shape on heating load.

Source: Gratia & De Herde, 2003

2.3.2 Relationship of Aspect Ratio (Width to length ratio) and Solar Radiation

A study by Szokolay (2004) recommends an aspect ratio of 1: 1.3 to 2.0 for elongated buildings depending on the climate and walls with major openings (on the elongated side) to face within 45° of the prevailing wind direction. This is 15° more than what Lauber, (2005), suggested on the above issue. On the other hand, this implies an optimum orientation of the elongated sides facing north or south, and a thermally inappropriate direction of openings facing the western sun.

Koranteng & Abaitey, (2010) assert that for a shape that is elongated, the use of ambient energy and orientation is an important issue; while compact forms tend to minimize the influence of the external environment, thereby ignoring orientation. The more a form is elongated, the larger the surface area and area that could be exposed to solar radiation. Therefore, for such forms, orientation has to be away from the east and west.

A ratio of 1: 1.64 is also recommended by (Watson & Labs, 1983), but orientation ceases to be an issue when thermal resistance of the building envelope increases.

Olgyay,(1963) and Yeang, (1994) also suggested that building form with W/L ratio 1:1.7 and 1:3 are the optimum ratio for tropical climate

2.3.3 Thermal Response of Building Envelope

Behsh, (2002) carried out research on the thermal response of building envelope as a function of its geometric shape in the context of Mediterranean region. His study depicts that the volume to surface area ratio (V/S) is not precise enough for providing a clear understanding of the thermal response of forms with complex shapes; such as: building

with a courtyard, L shape, U shape, and a large number of other forms. He investigates three levels of relations between the forms and the surroundings:

i) The relation between surfaces and volume (V/S)

ii) The relation between the south oriented surfaces to the west oriented surfaces (South/west)

iii) The relation between the roof area and walls (roof/ wall)

A number of different geometries are developed in his work to have similar contained volume, glazing area, and structural properties. The results of the simulation study are discussed in terms of duration of cooling period. It is observed that form with a rectangular shape (elongated on east-west axis) shows better response during the overheated days. In opposite to that, a square form demonstrates better response during the cold days. Therefore, if the compact form is chosen as a design option, the form with a low V/S placed along east-west is the most perfect for the Mediterranean climate. An important result comes out from his research: despite having equal V/S buildings can show different thermal performance. Therefore, the researcher suggests the most relevant factor to analyze their thermal performance would be the south/west oriented surfaces.

Behsh, (2002) also finds that the form with the least roof area of the same total space is mostly recommended as the roof is a major component of a building where it constitutes the

primary source for thermal stress both under the cold and the overheated period. The researcher concludes that, a form with a large size of southerly oriented areas is the most optimal form, as it will receive the lowest amount of heat during summer and the highest amount during winter in the climate of Mediterranean region.

Ross, (2009) similarly conducted a research to determine the influence of decisions taken at the preliminary design stage on the energy intensity of the built project. The researcher analyzes mid-size office buildings with a total floor area of 4662m^2 (with 4 stories, 1165.5m2 per floor) for Toronto climate for five distinct geometries (Figure 2.2). The built forms are specified primarily with the ratio of „façade area: gross floor area (GFA)" and secondly, with the ratio of „surface area (including roof). Three variation of façade layout (with window to wall ratio of 20%, 40%, and 60% respectively) are tested for each form. The thermal resistances of the enclosure are maintained similar in all simulations. When the annual energy intensity is compared, the square form (regardless of window to wall ratio) gave the least energy requirement among others. The most energy intensive is the H-shape regardless of its orientation. It supports that, the building with the highest „façade to GFA" ratio consumes less energy on

an annual basis and the lower the ratio, the greater the energy consumptions. The study concludes that, regardless of the effect of fenestration amount, a building"s energy performance is always determined by the proportions of its surface.

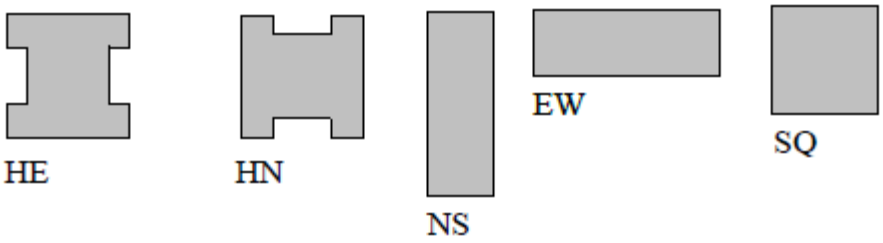


Figure 2.2: Different plan forms representing mid-size office buildings

Source: (Ross, 2009)

Chia, Hamdan, Ahmad, & Dilshan , (2007) investigated different configuration of forms of high-rise buildings in tropical hot-humid region in Malaysia. The study is carried out

using computer simulation (ECOTECT Version 5.2b, 2002) package which has a unique approach to conceptualize building design. According to the study, only the two basic geometric shapes used for high-rise buildings in the region are selected with varied width/length ratio. The researchers based the W/l ratio on studies from (Olgyay, 1963) and (Yeang, 1994) which suggested that building form with W/L ratio 1:1.7 and 1:3 are the optimum ratio for tropical climate.

. The result from Chai et al. (2007), indicated that main factors that determine the relationship between solar insolation level and building shape are W/L ratio and building orientation.

Similarly, Daluku, (2015) simulated different generic shapes of buildings in hot-humid climate of Nigeria using ecotect package. The simulation exercise was focused on building shapes, building orientation, effect of glazing (window to wall ratio), internal heat gain and external heat gain. The result of the simulated shapes (cube, cuboid, cylinder, cone and pyramid) shows that cylinder, which has the most self-shading in hot-humid climate, has the least energy consumption on cooling compared to other generic shapes.

From the above findings of Daluku, (2015) & Chai et al. (2007), it is obvious that cylindrical (circlular) shapes are most effective on energy conservation in hot-humid regions.

Ferdous (2012), also studied the energy performance of five building forms based on their distinct features to contribute to the energy savings of office buildings as investigated by previous researchers. Although to the first priority, simple geometry with comparatively high compactness is chosen by the researcher as highly compact form has less energy use pattern of a building and less affected by external environment. The gross

floor area (GFA) is kept constant as 6000 m2 for all shapes (1200 m2 per floor). To ensure that the building volume remains constant, the total height is kept the same (as 20 m) for all building configurations. The five forms (cube/square, rectangle elongated east-west, rectangle elongated north-south, H-shape, cruciform) as seen in figure 2.3 are modeled as actual office buildings with service zones (restrooms and stairs) and with five consecutive stories.

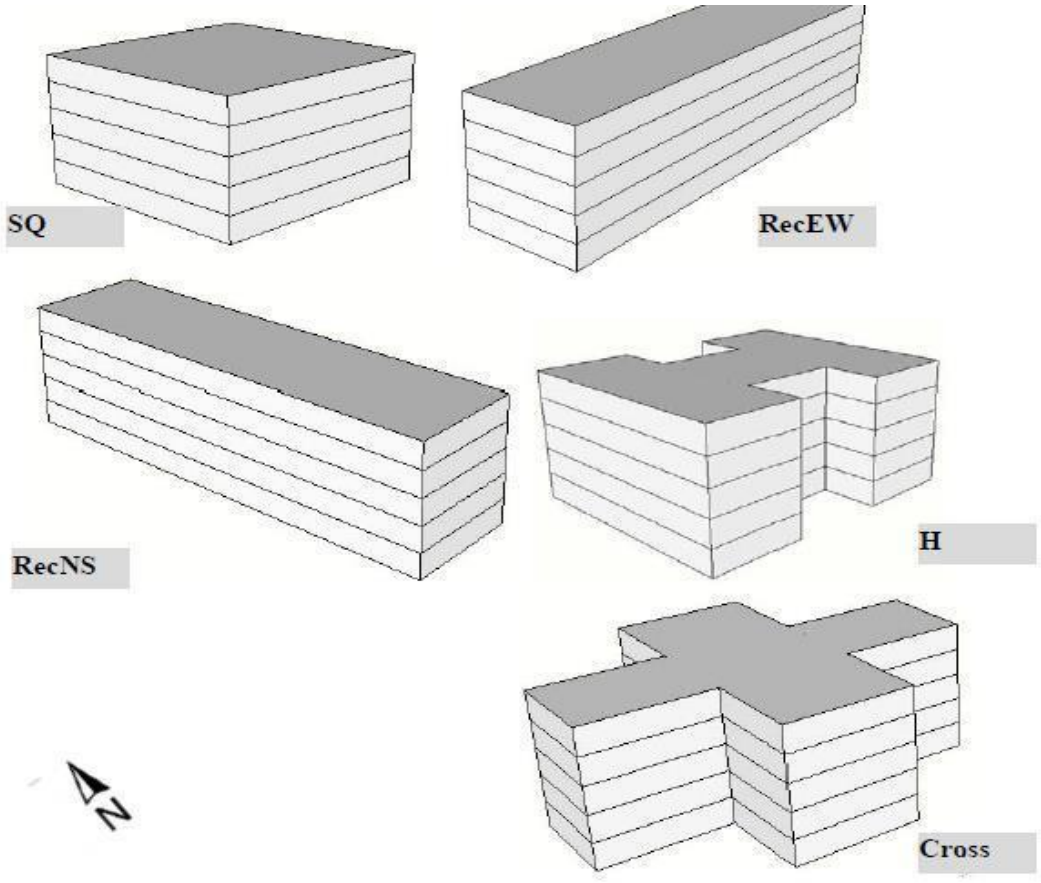


Figure 2.3: 3-D images of archetype buildings.
Source: (Ferdous, 2012)

The researcher provides multi- floor model which would provide more accurate understanding of energy use as it contains a ground contact floor, several intermediate floors, and a roof top. The study area is Toronto, Canada which is identified with cold humid with heating degree days between 4000 and 5000 as Toronto is considered as one of Canada‟s warmer cities. The variables considered in his investigation are:

i. The five forms are examined with WWR of 30%, 50%, 70%, and 80% to observe the impact of fenestration at a low level up to the higher level respectively. To achieve a comparable result, each façade of the form is designed with the same window to wall ratio.
ii. Shading component.
iii. Envelope design, Although exploration of the envelope design on energy use pattern is outside of the domain of his research.

In his research, IES Virtual Environment (IES VE 6.4.0.9) is selected to perform a total of 40 simulations on five archetype buildings. Both internal heat gain and external gains are put into consideration in the simulation process.

The results of the parametric analysis indicate that the impact of building geometry on total energy use depends on primarily two factors: the compactness and the window to wall ratio. Orientation of buildings performs significant role over the energy consumption patterns. Thus, geometry with high east- west oriented surfaces is less preferable in the context of Toronto. According to the findings of this work, external shading is particularly helpful in reducing cooling demand in offices spaces, although the total energy values are found to be higher. To be noted, these observations are only based on a single type (fixed external shading) of shading devices. Therefore, shading devices with different features may show different outcomes than the findings of this project. Shading devices have other

importance for maintaining visual comfort and avoiding glare in the office spaces, especially with high fenestration ratio. From his work, it can be concluded that a greater emphasis should be given to the integration of various design parameters rather than individual components.

Summary of his findings are thus:

i. Geometries are found to follow the definition of compactness: the most compact form has the least total annual energy use.

ii. Square building requires the lowest amount of energy per year. RecEW, RecNS, Cross, and H are found to display a gradual increase in energy consumption. However, the difference in total energy values is relatively small (ranging between 2.2% and 7.5%).

iii. As window to wall ratio increases gradually from 30% to 80%, the total annual energy consumption results in each archetype also increases.

2.3.4 Relationship of Relative Compactness to the Cardinal Points

Gelekta & Sedlakova, (2012), comparatively selected different occurring forms of administrative buildings based on relative compactness(RC), which were simulated in a dynamic simulation program Energy plus. All shapes were compared with the same volume (V= 4287m^3) and the same total heating floor area (S_{pdl} = 12250m^2). The basic shape used in creating the planned shapes of building was cube with dimension 3.5mx3.5mx3.5m. The research focused on the effect of orientation of buildings to the cardinal points, % of glazing on exterior walls, and ratio of rectangular plan effect on the need for heating. They were compared to the three basic shapes of buildings, as well as rectangular with varying aspect ratio ground plan (from 1:1 to 1:8) as shown in figure 2.4.

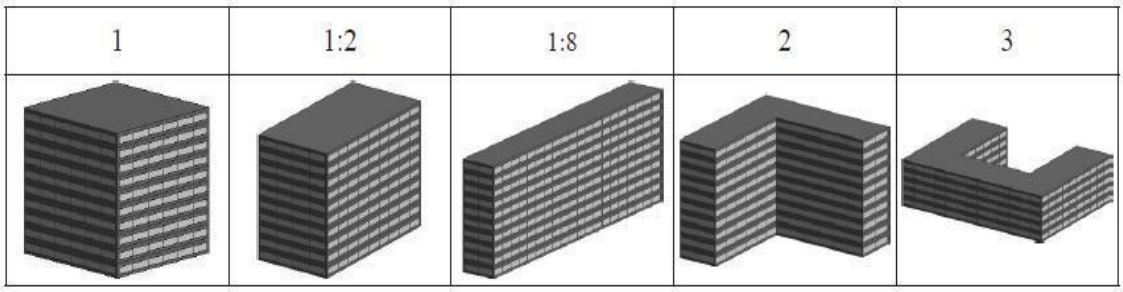


Figure 2.4: The shapes of Building that were comparison of energy consumption

Source: (Gelekta & Sedlakova, 2012)

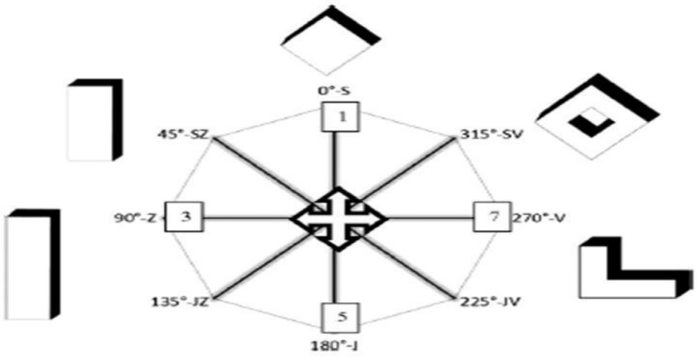


Figure 2.5: Orientation of buildings to cardinal point in terms of minimizing heating load. Source: (Gelekta & Sedlakova, 2012).

The different shapes were simulated at day intervals parametrically for different orientation and for different ratio of glazing to external wall (from 0%-100%). Figure 2.5 presented the orientation of the mentioned buildings to the cardinal point in terms of minimizing heating load, that is, best orientation of building.

The results of the simulation show that the energy use decreases as relative compactness increases. Also, as the relative compactness increases, exterior wall area exposed to ambient conditions decreases.

To support the results of the research by Gelekta & Sedlakova, (2012), a previous study in 2009 on relative compactness of building form was carried out by AlAnzi, Seo, and Krarti.

AlAnzi, Seo, & Krarti, (2009) have proposed a different metric to measure the compactness of a form. Relative compactness (RC) is used in their study as an indicator while assessing the impact of shape on the building energy performance. The authors have developed seven different shapes as representative of prototypical office building in Kuwait (Figure 2.6). All buildings are modeled as 20 stories with the same floor area of 12500m^2 (i.e. 625 m^2 per floor). Analysis is carried out with window to wall ratios to vary from 0% to 75%. The overall U-values in each analysis remain constant. After the simulations, it is observed that as the RC increases, the exterior wall area exposed to ambient conditions decreases and consequently the building energy decreases regardless of WWR. However, the trend is found to depend slightly on the building shape, most likely due to variation in solar exposure for different building shapes.

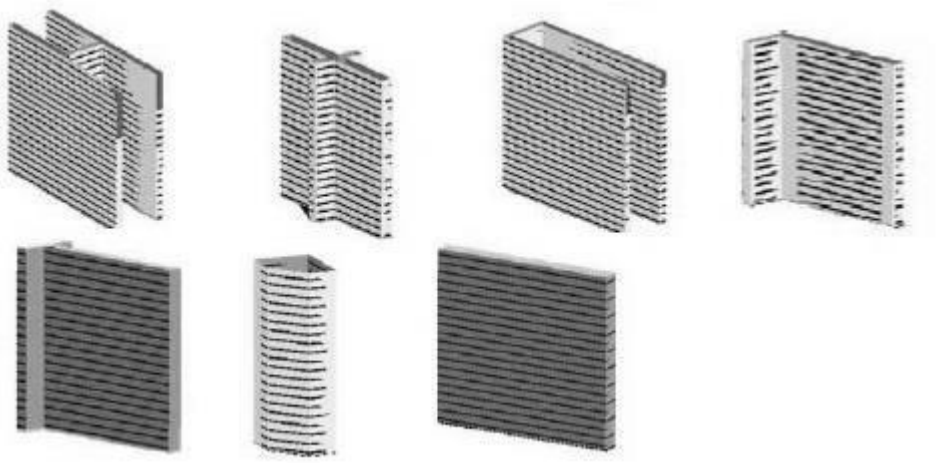


Figure 2.6: L-type, T-type, H-type, cross shape, U-shape, cross shape, and rectangular office buildings.
Source: (AlAnzi, Seo, & Krarti, 2009)

Erdim & Manioglu (2011), also investigated the energy performance of selected residential buildings based on their building form and cardinal points. The research took place in Ankara, Turkey which has a temperate-dry zone. The study focuses on comparing the annual heating and cooling energy consumption of two basic shapes (L and rectangular building form) and also on roof type which is a component of building form and the façade areas oriented in the different directions have an important impact on the annual energy consumption as seen in figure 2.7. The study was carried out by using a building simulation program, eQUEST. The simulation program takes into account the internal heat gain of the occupants, which comes from not only person occupancy, but also the appliances, electronic devices and lighting.

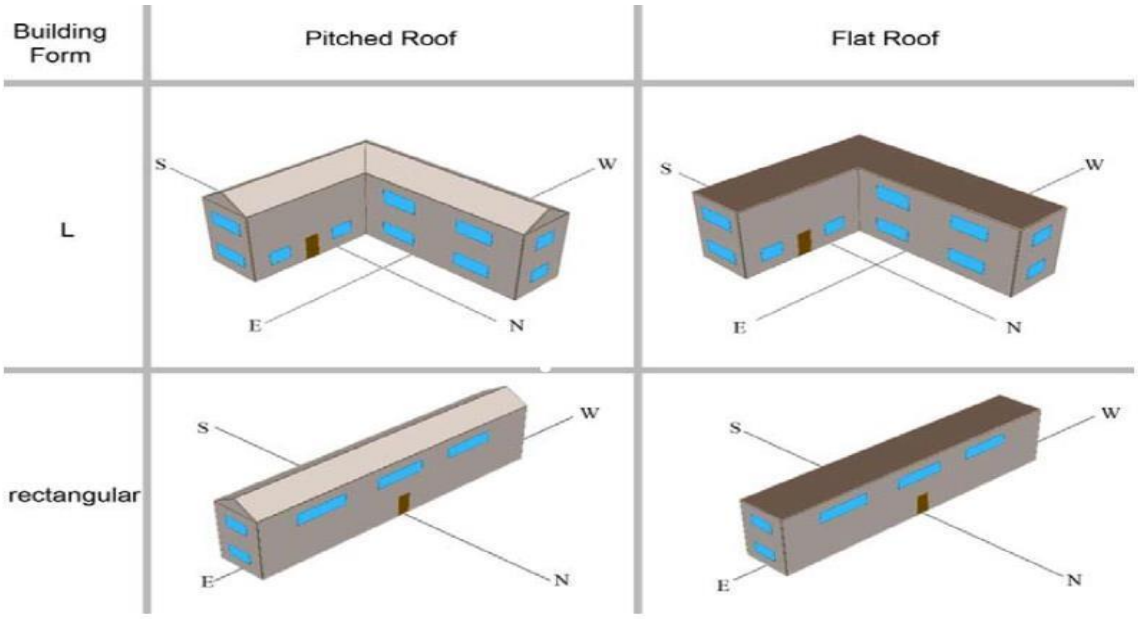


Figure 2.7: 3-D - images of the buildings used in application

Source: (Erdim & Manioglu, 2011)

The result of the simulation process shows that in all calculations, the energy consumption of rectangular shaped building form is 9%-10% less than the energy consumption of L shaped building form. The difference between the annual energy consumptions of L shaped building form and rectangular building forms which have the same floor area, total exterior facade area, volume, roof type and optical and thermo physical properties of building envelope are caused by having the same transparency ratio but different facade areas oriented in the same direction.

2.3.5 Effect of Self – Shading of Building Forms

Muhaisen & Abed (2013) investigated the effect of geometric forms on energy consumption with emphasis to study the potentials of self-shading of the forms. The first

case introduced a study of 14 different geometries with different (S/V) ratio in order to examine the relation

between (S/V) ratio and heating, cooling and total loads. The 14 geometric shapes are circular, square, rectangular, trapezoid, pentagon, hexagon, heptagon, octagon, L shape, T shape, cross shape, H shape, U shape and court shape. The area (A) for these shapes was assumed to be 150 m2 as it represents the average of residential units' areas in Gaza. The height was assumed to be 6 m (2 storeys) and thus the volume equals to 900 m^3. The rectangular shape was assumed to have a width to length ratio of 0.618 as it represents a golden section (golden ratio). The golden ratio is applied also in the rectangular parts of convex shapes such as L, T, cross, H, U and court shape. The ratio of the width of the shading façade to that of shaded façade is termed depth ratio (a/b) was taken to be 1 . All forms were considered as stand-alone building without overshadow from any adjacent buildings. The example shaded façade is as shown in figure (2.8).

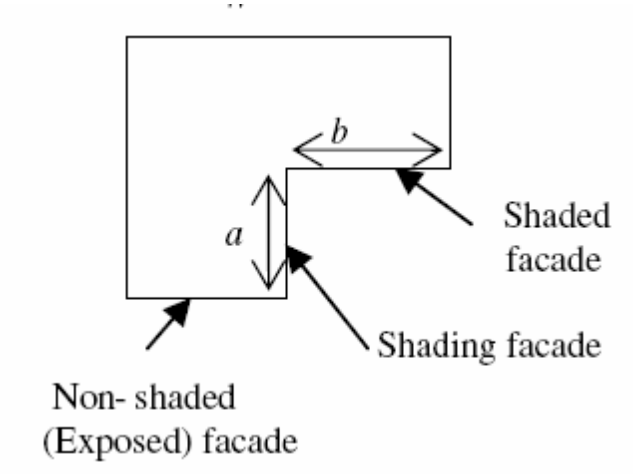
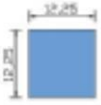
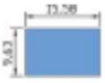
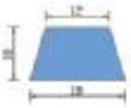


Figure 2.8: Depth ratio (a/b) in the self shading geometries (convex shapes)

Source: (Hachem, Atheinitis, & Fazio, 2011)

Table 2.2: Shape design parameters . Source: (Muhaisen & Abed, 2013).

Perspective							
Plan							
(S/V) Ratio	0.4561	0.4932	0.503	0.506	0.478	0.47	0.466
Perspective							

The investigation was carried out in coastal area in the west-southern part of Palestine which have average daily temperature of 23^0C in summer and 13^0C in winter. The study was carried out using ECOTECT package and the result is validated with IES software. Simulation results were expressed in terms of annual heating loads, annual cooling loads and annual total loads (in MWh). Simulations were carried out during months of January–December. The researchers assumed the HVAC system to be assumed full air conditioning with heating and cooling set point were assumed to be 18.0^0 C and 26.0^0C respectively. Using of buildings (hours of operation) was assumed to be on continuously. As the study focuses on the incident solar radiation as one of the most important variables in the Mediterranean climate affecting heating and cooling energy consumption. However, internal heat gain from occupancy and appliances as well as ventilation heat gain were not

considered in the study, but the U-values, thermal transmittance of the external envelopes were comsidered in the study.

The results of the simulation indicate that the total loads for the simulated shapes are increased by 69% with changing geometric shape from circle to court shape at the East-West orientation (0^0E) in ECOTECT software. From the result obtained, circle shape achieves the lowest energy requirements so it was taken as a reference shape. The percentage of increasing in total loads from the reference shape was evaluated for the other 13 geometric shapes.

From the above results of the investigation on geometric shapes infered that increase in (S/A) ratio leads to corresponding percentage increase in the total load, heating and cooling loads. This means that the (S/V) ratio is the more responsible factor in affecting heating and cooling requirements. Knowing (S/V) ratio for a shape can help to predict the percentage this shape increases in heating and cooling energy from the most compact shape with the same volume. So, the more compact form which contains the same volume with the smallest (S/V) ratio is recommended in the climate of the Gaza Strip according to the researchers‟ results.

2.4 Summary of Findings from Literature Review

The aim of the literature review in this study is to go through extensively the studies that have been carried out as related to this research. It examined different building forms on energy performance of office buildings carried out by various researchers, all along the way to establish a gap which would be filled by this work. The summary of the findings from literature are highlighted below (specifically on building forms):

Table 2.3a : Summary of findings from literature review.

RESEARCHER	FINDINGS	LOCATION
Chia *et al.*, (2007)	Circular shape is best suited as it minimizes solar insolation most, and that W/L ratio (aspect ratio) and orientation are main factors for building shapes and solar insolation.	Hot-humid region in Malaysia
Daluku (2015)	Cylindrical shape requires less energy on cooling and that the factor is due to the best self- shading it has over the other simulated shape.	Hot – humid region of Nigeria
Gelekta & Sedlakova (2012)	Energy use decreases as relative compactness increases. Also, as the relative compactness increases. In this case the compactness of a form (V/S) area is the main factor that reduces energy load	Slovakia
AlAnzi *et al.*, (2009)	Their results finally gathered that, as the relative compactness increases, exterior wall area exposed to ambient conditions decreases.	Kuwait
Behsh (2002)	Other important parameters should be checked other than the V/S ratio such as the relation between the south oriented surfaces and west oriented surfaces ($S/W_{surfaces}$), the relation between the roof area and wall (Roof/wall) ratio for energy savings.	Mediterranean Climate

Table 2.3b : Summary of findings from literature review.

RESEARCHER	FINDINGS	LOCATION
Ross (2009)	The study concludes that, regardless of the effect of fenestration amount, a building‟s energy performance is always determined by the proportions of its surface	Toronto Climate, Canada
Ferdous (2012)	The main factors that determine the energy performance of a form are the wall to window ratio (WWR), the V/S (compactness) of the form, and orientation to the west-east direction.	Toronto Climate, Canada
Erdim & Manioglu (2011)	Concluded that the rectangular form has the least annual energy consumption. And it is due to different façade area oriented in the same plane of both forms.	Ankara, Turkey

From the extensive study of the relevant literature review conducted, it is concluded that the cylindrical and the cubic forms are better in terms of thermal performance, which was due to the high V/S ratio they have over the other forms. I n the next chapter, explantions will be given on how the adopted forms (cylindrical and cubic) could further be optimized based on the aspect ratio ranges studied from the literature.

3.0 METHODOLOGY

This chapter discusses the criteria used for selection of the building forms and also assessing minimum energy consumption of the building forms based on reliable findings of extensive study from literature. It also explains the procedure which this ongoing research seeks to experimentally optimize the selected building forms based on the literature review. The study adopted a quantitative type o research during the course of data collection and analysis.

3.1 Research Design/Approach

The research design adopted in this study is experimental in approach. Because a detailed analysis of different aspect ratios of the forms are subjected to computer simulation in order to obtain different behaviors of the forms‟ aspect ratios with regard to solar radiation.

3.1.1 Experimental/Case study Design

Experiments are characterized by random assignment of subjects to experimental conditions and the use of experimental controls. Computer simulations are the only practical and experimental way to predict the dynamic energy performance for a large number of design solutions (Los Alamos National Laboratory (LANL), 2002). To really influence a building‟s design at early stages simplified versions of energy modeling are needed to be developed (Settlemeyre, 2009).

Through experimental control of the environment, a detailed load analysis through computer simulation was used to identify the energy saving opportunities early in the design process of the selected building forms.

Based on the findings, modifications are made on the form, orientation, and also varying different width to length ratio (Aspect ratio) of the building. A more detailed explanation of the process is provided in the next chapter.

The objective of the case study is solely to assess the buildings‟ geometric properties. The case study was carried out in buildings that have workspaces similar to the scope of this research. The studied buildings are, NCC headquarters, Abuja, and NITEL headquarters,

3.2 Instruments of Data Collection

The tools or instruments of data collection used are:

i. ECOTECT Version 11 (primary data)
ii. Autodesk Revit
iii. Visual survey (primary data)
iv. Sketches/photographs

3.2.1 ECOTECT (ECOTECT Version 11)

Is a software package with a unique approach to conceptualize building design. It couples an intuitive 3-D design interface with a comprehensive set of performance analysis functions and interactive information display. It calculates heating and cooling loads for models and analyze effects of occupancy, internal gains, infiltration, and equipment. Also, it visualize 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 (Autodesk Ecotect Analysis, 2010).

3.3 Criteria for Selecting Simulated Building Forms

Each of the building form is studied based on the main factors that led to the minimum energy consumption. However, aspect ratio of building forms is the main variable in all simulated cases as it is the main extension to this research work, other variables are discussed in the experimental process.

Each of the forms are simulated based on the framework below figure (3.1), as studied from literature review

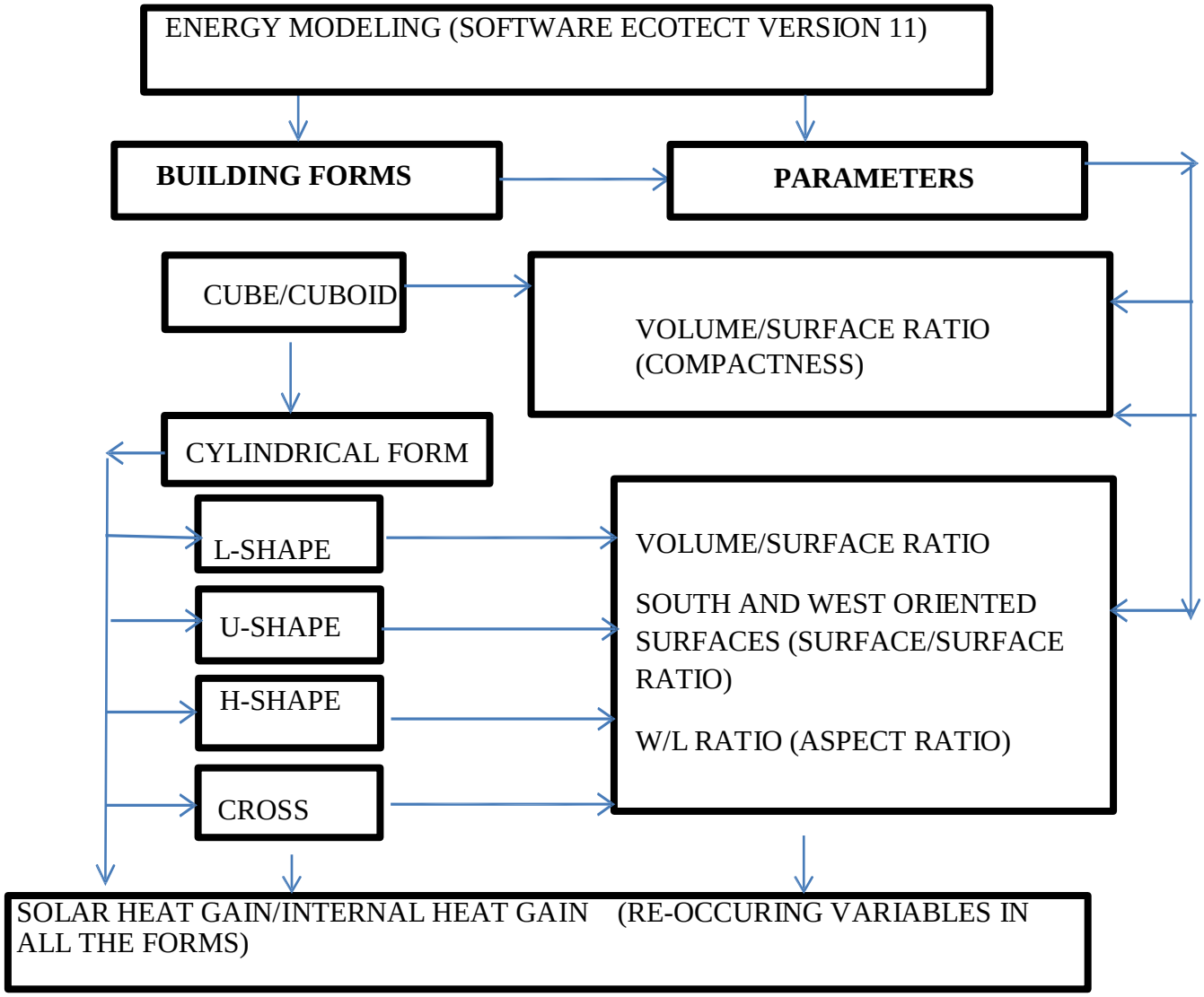


Figure 3.1 : Parametric framework. Source: Findings from Literature Review

3.4 Dependent and Independent Variables

The dependent variables involved are the cooling load on thermal comfort and incident solar insolation. The cooling load on thermal comfort is measured in kwh whereas incident solar insolation is measured in w/m^2. Both dependent variables are adjusted by the independent variables which are the comfort conditions (air temperature, relative humidity, air velocity, activity level, clothing insulation and radiant heat gain), building forms' aspect ratios. This is as shown below in figure (3.2).

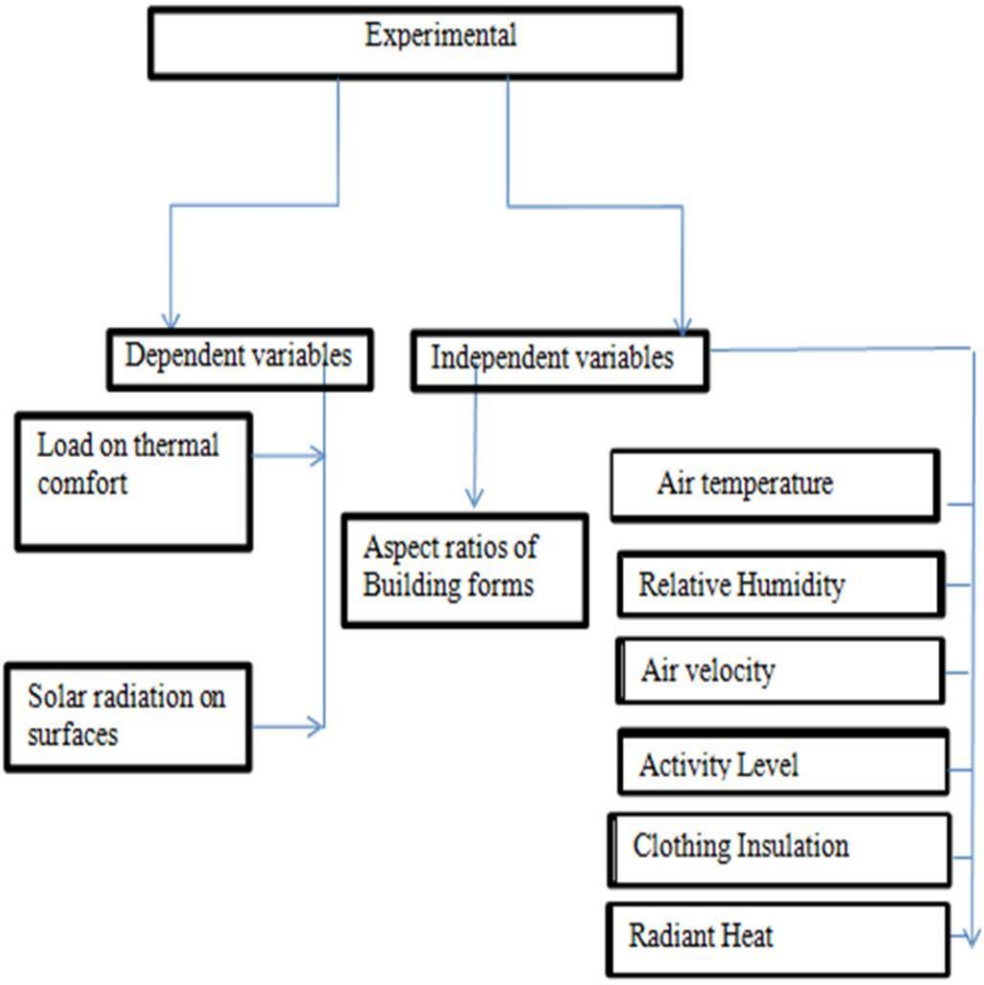


Figure 3.2: Dependent and independent variables . Source : Author's work (2017).

3.5 Procedure for Data Collection (Parametric Analysis)

In the first phase of developing simulation models, 3D massing of each selected form are created using „autodesk revit. Revit is also used to create bounded „rooms‟ (zones) to be identified by the ECOTECT. The mass models are then exported to ECOTECT analysis as „gbxml‟ file.

The gross floor area (GFA) is kept constant as 6500 m^2 for all forms for minimum standard size of telecommunication office facilities. 1200 m^2 was assumed to be the size per floor. To ensure that the building volume remains constant, the total height is kept the same (as 20 m) for all building configurations as discussed further in the next chapter. The building forms are modeled as actual office buildings with telecommunication rooms and equipment rooms with six consecutive stories. A multi- floor model would provide more accurate understanding of energy use as it contains a ground contact floor, several intermediate floors, and a roof top. Because, the heat transfer mechanism with exterior varies at different floor levels (for instance, ground floor and roof will response to the exterior differently than intermediate floor; (Straube, 2012 and Behsh, 2002).

Cylindrical/cubic forms in the framework above (figure 3.1) are simulated with the aid of ECOTECT which was used to analyze data for air temperature, air velocity, humidity and solar radiation on each of the form for daily, monthly and annual basis for the hot-dry climate. The simulation process displayed the graphical distribution pattern of the above named parameters over the surface of the entire building. The research was conducted by varying the different forms over a given set of parameter.

Modification on form, orientation, varying width to length ratio (aspect ratio) for both the cuboidal and cylindrical forms was done.

Finally, Autodesk ECOTECT was used to simulate data for cumulative incident solar radiation on the vertical surfaces of the cuboidal and cylindrical forms on monthly basis. The simulation displays the graphical distribution patterns and availability of solar insolation over the surfaces of the entire building for both hot and cold periods. All simulations are calculated based on the available hourly direct and diffuse horizontal solar irradiance data from ECOTECT Weather Tool for Maiduguri, Nigeria (11^0N, 13^0E).

3.6 Simulation inputs and assumptions

To complete an energy model it is necessary to provide it with several data inputs. When performing the building analysis it is important to provide the simulation tool with location and weather data, construction sets, use profiles, and heat gain characteristics. These will be representative of how the office would be used in reality. (Ferdous, 2012). The assumptions used in the experimental process are given below.

3.6.1 Analysis of Internal Heat Gain

Internal gains are considered from people, lighting, and equipment. At first, occupancy density for the office space is determined according to the default values listed in Standard 62.1- 2007 (ASHRAE, 2007) as 20person/m2. No occupancy is chosen for auxiliary spaces.

i) Heat gain from people

For 24 ºC room dry bulb temperature, an adult will produce 75 W sensible heat and 55W latent heat performing moderately active office works (ASHRAE, 2009). Following this guideline, sensible heat gain and latent heat gain are set as 75W/person and 55W/person respectively.

ii) Heat gain from equipment

Heat gained from equipment are set as obtained from ASHRAE thermal guidelines for telecommunication facilities, 2009. And for the assumed office spaces in the experimental procedure, In a medium to heavy load density office the recommended load factor for equipment is 16.1W/m2. Here equipment refers to computers, monitors, laser printer, and fax machines (ASHRAE, 2009).Therefore, equipment gains are set as 16.1 W/m2 for open plan offices in current project.

3.7 Characteristics of Tropical Hot-dry Climate

(Agboola, 2011) asserts that the hot savannah zone of the middle belt and the northern Nigeria region has a climate that is portrayed by a long dry season (and subsequently a brief rainy season) accompanied with cold and dry harmattan wind, high temperature range (due to hot afternoons and cold nights) and intense sunlight. This region covers the savannah region (grassland), highland region (plateau) and semi-desert region. It comprises of towns like Abuja, Minna, Zaria, Yola, Maiduguri, Kano, Sokoto, Yelwa, Kaduna, Katsina, Nguru and other mountainous regions along the Cameroonian border. The areas are accompanied with cold nights and hot days alternate for six to ten months of the year, and characterized by moderate or low amount of rainfall. Hot and humid conditions are experienced during one or two months.

3.8 Method of Data Analysis

The instruments and methods for data analysis will be computer simulation, statistical charts, graphs and tables.

4.0 DATA ANALYSIS AND PRESENTATION

This chapter seeks to give the detailed analysis of the results obtained from the simulation carried out using ECOTECT thermal analysis. It first illustrates the data as obtained from reliable standards in literature and case studies carried out. These data were used as input information regarding internal heat gain from telecom equipment for each of the respective building form under consideration. It further explains extensively, with statistical charts and tables the energy each of these building forms consumed for thermal comfort based on how they interact with the external environment (solar heat gain and loss).

4.1 Case Study

Two office buildings with similar workspace as the telecommunications buildings have been purposively selected, workspaces are prominent facility which have high demand for occupants comfort in a telecom building in the context of this ongoing research. The case study informations are discussed below.

4.1.1 Case Study I : National Communication Commission (NCC).

Description: The NCC is located of the central area in Abuja on plot 423, Aguiyi Ironsi street, Maitama Abuja . The building is suited for the purpose of this study because it functions and operation is similar to that of a telecommunications building. The main objective of the case study to assess the building form as it is, and to develop an

experimental approach through computer simulation to determine its energy consumption and solar access on it surfaces. The form is cylindrical with total approximate gross floor area of 2827m^2 with 9 floors. The description is shown below:

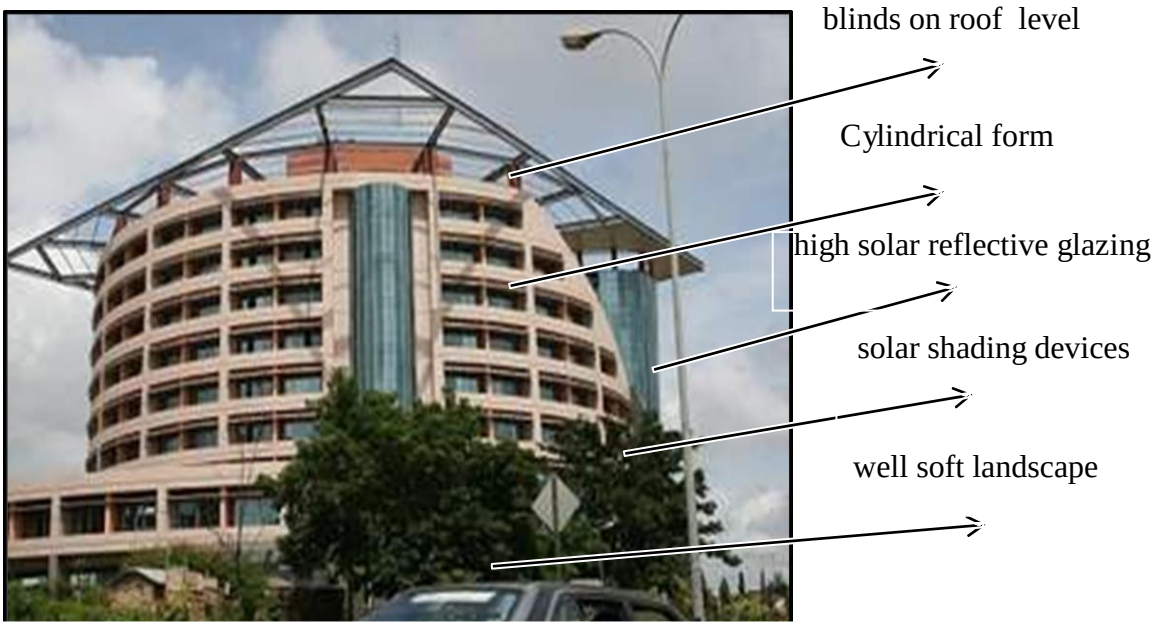


Plate I: Description of variables studied in the case study
Source: Researcher"s work (2016)

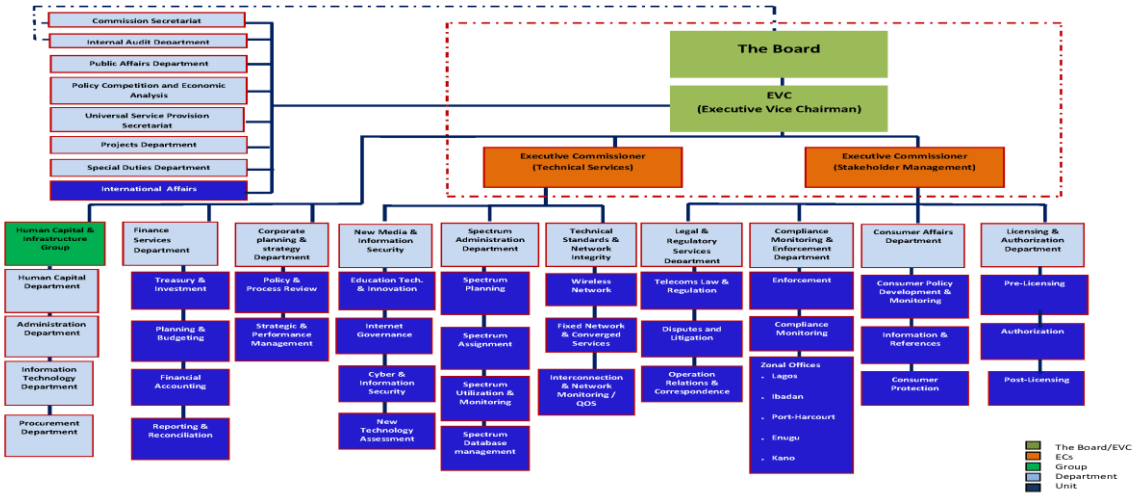


Figure 4.1: NCC Organogram
Source: National Communication commission.



Plate II :Approach view of the building
Source: Researcher‟s work



Plate III:Side view of the building
Source: Researcher‟s work

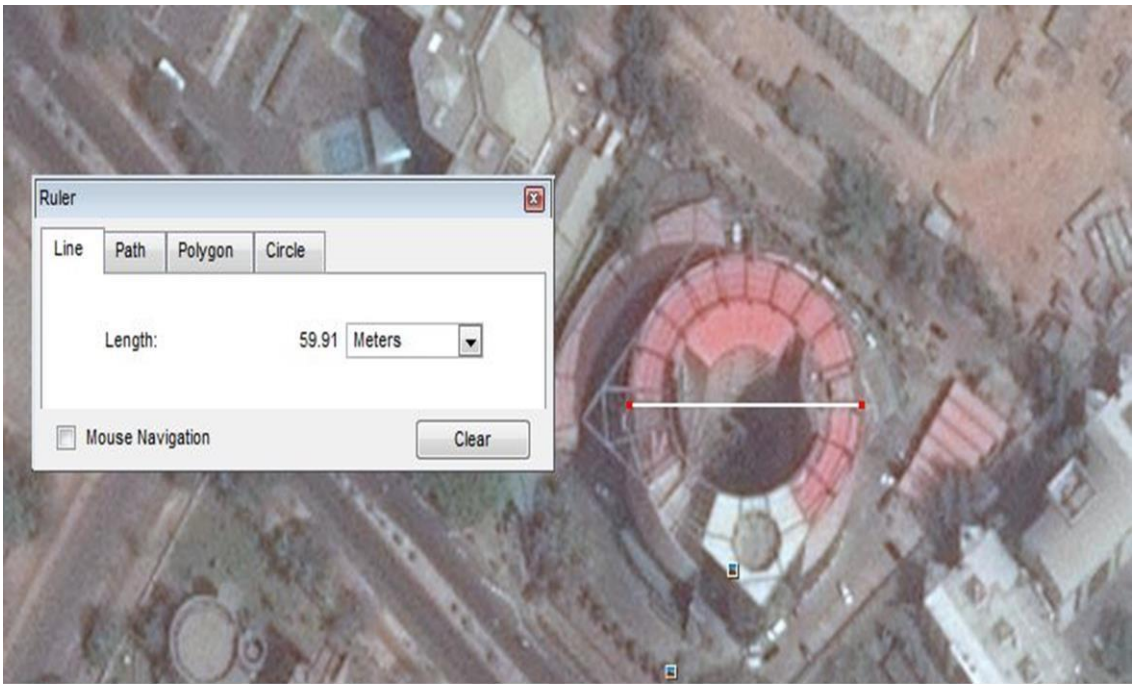


Plate IV: Satellite image showing approximate diameter of the building
Source: Google earth, 2015

4.1.2 Case Study II: NITEL Headquarters, Abuja

Description: The building is also located in Abuja on plot 251 off Herbert Macaulay Way central area , Abuja. The building serves as the principal telecommunications company in Nigeria, and was owned by the government of Nigeria until it was sold to Mtel. The building serves as mobile telecommunications arms of Nitel which is responsible for all wired telecommunications in Nigeria. The building has nature of rectangular form which is of interest to this study. The form of the building is assessed based on solar access and its orientation. The description and general visual survey of the building is being summarized below:



Plate V: Approach view of case study showing visual characteristics of the form
Source: researcher's work (2016)



Plate VI: side view of case study building
Source: Resarcher‟s work (2016)

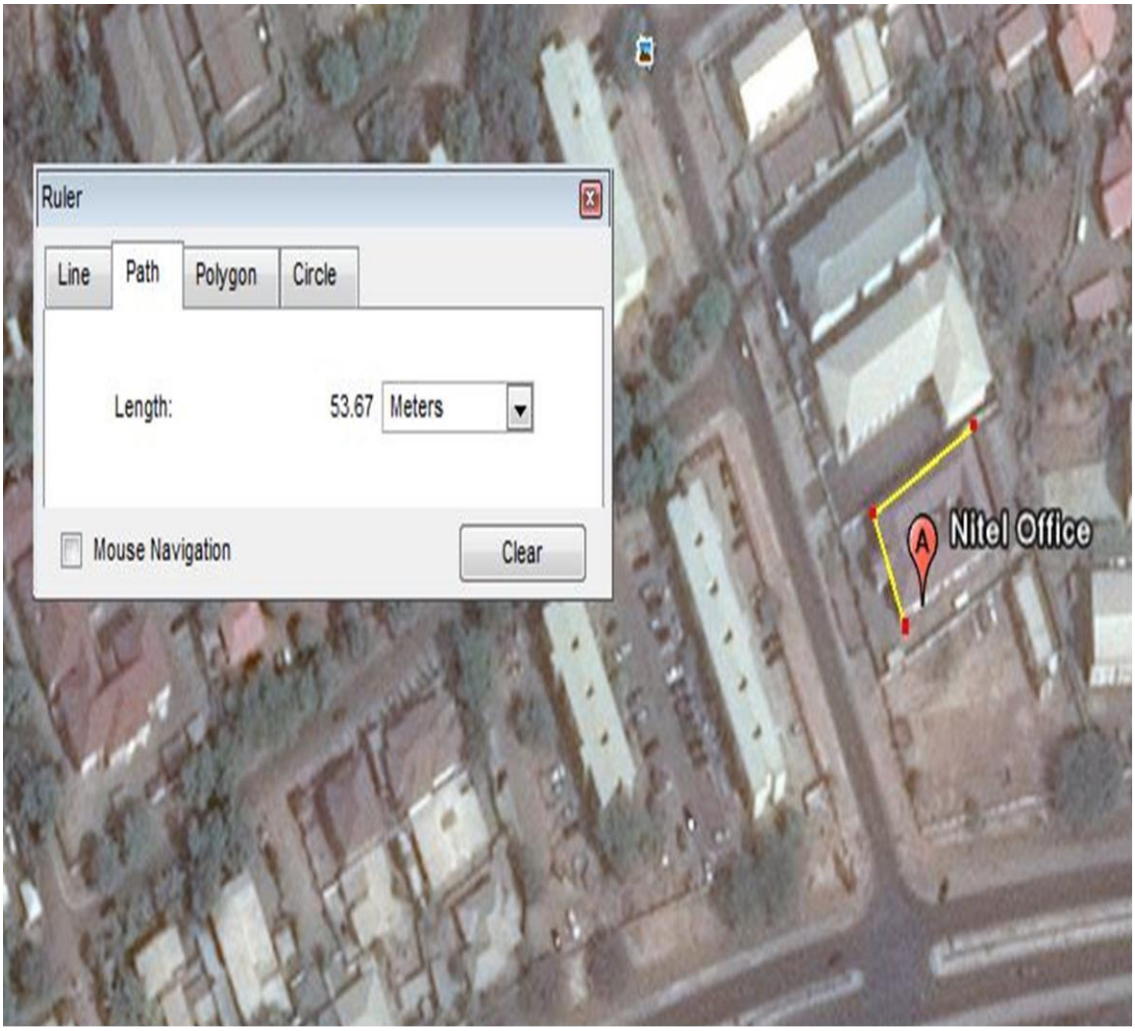


Plate VII: satellite image showing geometric properties
Source: Resarcher‟s work

4.1.3 Simulation Input Information

In order to fulfill the simulation analysis to an average level of accuracy, it is important to highlight the parameters which are inputted in the process based on data from case study interview and standards obtained from literature review as shown in the table below.

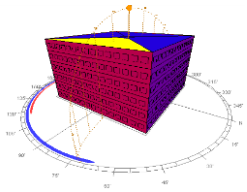
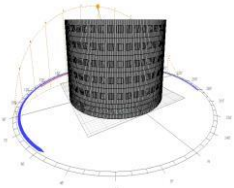
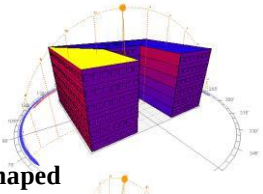
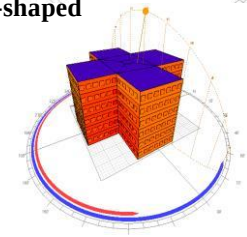
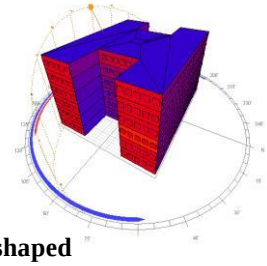
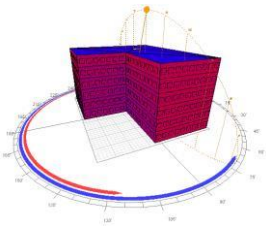
Table 4.1: Illustration of primary parameters for the simulation
Source: ASHRAE (2009)

Heat dissipation in workspace	2.3kw power consumption (ASHRAE, 2009)					
	744w/m^2 heat dissipation (ASHRAE, 2009)					
Functions Assumed	Comfort temperatures (^{0}C)		Equipment Sensible Heat gain (w/m^2)	Heat dissipated from lighting appliances (w/m^2)	Occupants latent heat gain (w/m^2)	Air change rate (/hr.)
	Heating set point	Cooling set point	Heat dissipated per rack=744 Racks per office = 5			
Workspaces area	18.3	32.2	3720.0	22.0 (Data center white paper,2004)	55.0 (ASHRAE, 2009).	15.0 -20.0 (Engineering Tool box,)
Open office	18.0	26.0	16.0 (ASHRAE, 2009)	12.0 (ASHRAE, 2009)	55.0 (ASHRAE, 2009)	3.0 (Engineering toolbox,)

4.2 Thermal comfort conditions and comfort zone parameters for the simulation

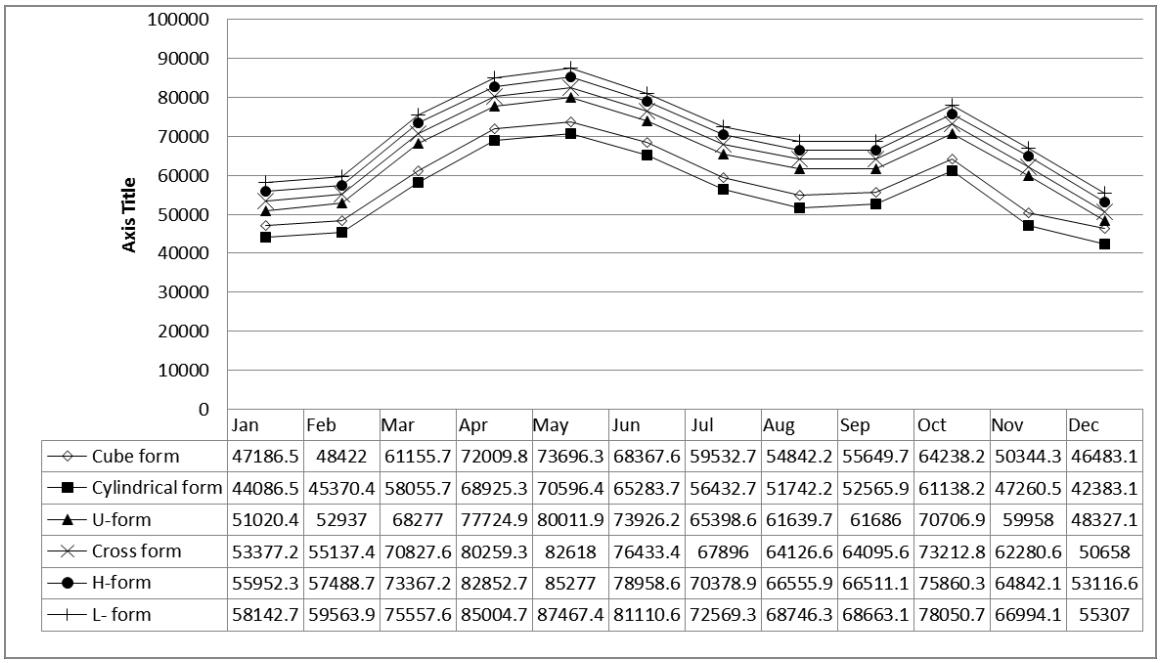
In the other to achieve the building form that provides the least minimum energy required to maintain thermal comfort for a workspace building as such, it is important to set the parameters for comfort as a basis for evaluating the building forms, which are: the air temperature, relative humidity, occupants activity level, occupants clothing insulation, air velocity and air change rate.

Table 4.2: Description of forms that were simulated

Building Forms	Volume	Volume /surface area Ratio (V/S)	Total floor area	Total Surface area	Exposed surface area
 **Cuboid**	29326.4m^3	1.56	7350.0m^2	18828.0m^2	4784.6m^2
 **Cylindrical**	29326.4m^3	1.57	7350.0m^2	18810.0m^2	4582.3m^2
 **U-shaped**	29326.4m^3	1.54	7350.0m^2	19098.3m^2	5010.3m^2
 **Cross -shaped**	29326.4m^3	1.54	7350.0m^2	19082.0m^2	5413.4m^2
 **H-shaped**	29326.4m^3	1.51	7350.0m^2	19406.6m^2	5821.6m^2
 **L-shaped**	29326.4m^3	1.45	7350.0m^2	20180.5m^2	5989.3m^2

4.3 Analysis of Energy Consumption of the Building Forms.

Each building form is analyzed with 20% window to wall ratio to depict an office building. The analyses were also performed by orienting each of the buildings in an east-west direction. About 12 simulation are performed corresponding to simulation of 6 different varieties of form which gave clear preference of each of the forms in terms of energy required for thermal comfort and HVAC load consumption. And thereafter, another simulation for 6 varying aspect ratios of the cube and cuboid form was performed to check the amount of solar insolation on west and south surfaces. Below in figure (4.2) are results of the simulations based on the internal heat gain input information of the case studies interview conduct.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cube form	47186.5	48422	61155.7	72009.8	73696.3	68367.6	59532.7	54842.2	55649.7	64238.2	50344.3	46483.1
Cylindrical form	44086.5	45370.4	58055.7	68925.3	70596.4	65283.7	56432.7	51742.2	52565.9	61138.2	47260.5	42383.1
U-form	51020.4	52937	68277	77724.9	80011.9	73926.2	65398.6	61639.7	61686	70706.9	59958	48327.1
Cross form	53377.2	55137.4	70827.6	80259.3	82618	76433.4	67896	64126.6	64095.6	73212.8	62280.6	50658
H-form	55952.3	57488.7	73367.2	82852.7	85277	78958.6	70378.9	66555.9	66511.1	75860.3	64842.1	53116.6
L- form	58142.7	59563.9	75557.6	85004.7	87467.4	81110.6	72569.3	68746.3	68663.1	78050.7	66994.1	55307

Figure 4.2: Graphical comparison of monthly cooling loads of all the forms

Source: Authors‟ work (2016)

From the analysis performed using Autodesk Ecotect, both the cuboidal and cylindrical forms showed lowest exposed surfaces over other rectilinear forms which are the, L-shape, U-shape, and H-shape.

Daluku (2015) in his study reported less energy consumption from the cylindrical form. Although, it has a continuous uniform surface with no pronounced edge or boundaries, it still possesses high surface / volume ratio.

The above charts and table illustrate the monthly energy consumption on thermal comfort for each of the building forms. From the analysis performed, the cubic form and the cylindrical form showed minimum energy required for cooling annually. Although the cylindrical form shows slight reduction than the cubic form as it dropped by 38087KWh representing 5.4 % less energy consumed. This was because of the slight increase of volume / surface the former has over the latter.(Gratia & De Herde, 2002). However, the cube depicts the definition of compactness of a form in terms of highest value of volume/surface ratio (V/S) over the other rectilinear forms which are the, L-shape, U-shape, and H-shape.(Gratia & De Herde, 2002). The cube form dropped by 69686kwh representing 9% as compared to the U- form. The U- form dropped by 29308 kwh representing 3.7% as compared to the cross-shape. The cross-shape dropped by 30238kWh representing 3.6% as compared to the H-shape. And the H-shape dropped by 26016kwh representing 3% as compared to the L-shape. The significant high reduction in energy consumption from cube and cylindrical-shape compared to the seemingly high energy consumption of L-shape is caused by the fact that the L-shape has the least V/S in terms of compactness as shown in table 4.2 above. The L-shaped form has the least V/S compared to the other forms which translates to its high increase in energy consumption as shown in table 4.2 and graph above. The percentage drop in energy consumption from the

cube forms to the L-form suited is 155250kwh which represents 18% reduction and the cylindrical form to the L-form is 193336kwh representing 22% reduction.

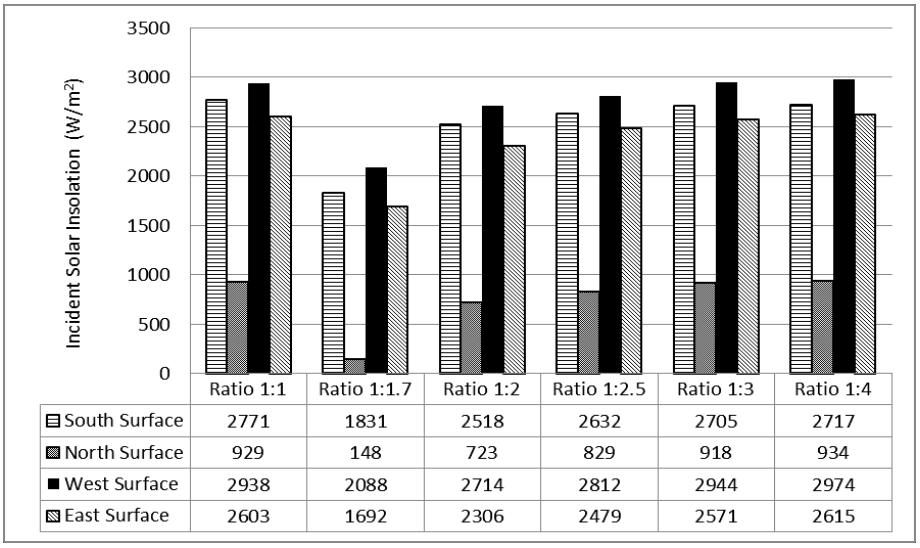
The L-shaped form also has the least V/S compared to the other forms which translates to its high increase in energy consumption AlAnzi et.al (2009).

4.4 Analysis of incident solar insolation on varying surfaces of cube and cylindrical forms with varying aspect ratios

From result above, it is evident that the cylindrical and the cubic form are the most compact forms and have the minimum energy consumptions due to their low exposed areas (Behsh, 2002).

In his study, Behsh (2002) reported that the volume – surface ratio is not a precise indicator of thermal response of forms but other factors such as surfaces and orientation should also be considered.

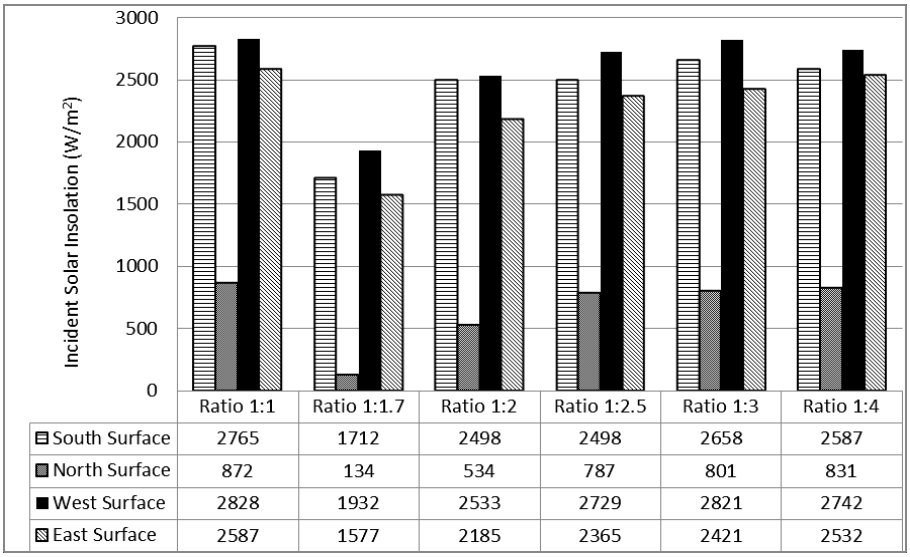
In order to ascertain the surfaces that are most prone to higher incident solar radiation in hotter periods, simulations were conducted to analyze the incident radiation on south, north, west and east surfaces for both the cube and cylinder.



	Ratio 1:1	Ratio 1:1.7	Ratio 1:2	Ratio 1:2.5	Ratio 1:3	Ratio 1:4
South Surface	2771	1831	2518	2632	2705	2717
North Surface	929	148	723	829	918	934
West Surface	2938	2088	2714	2812	2944	2974
East Surface	2603	1692	2306	2479	2571	2615

Figure 4.3: Average solar insolation on North, South, East, & West surfaces for different aspect ratios of cube

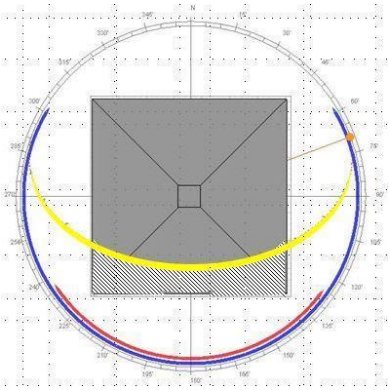
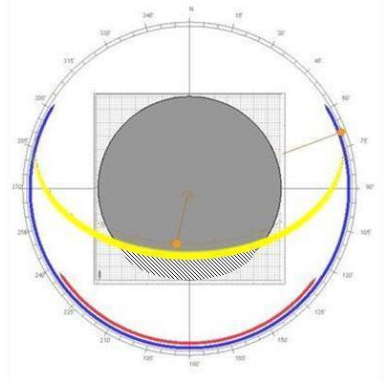
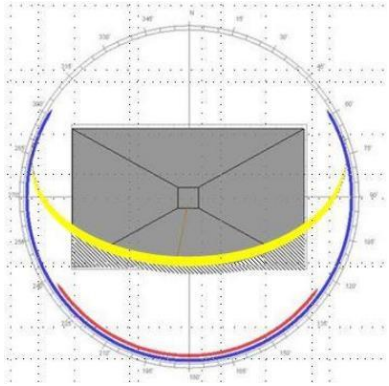
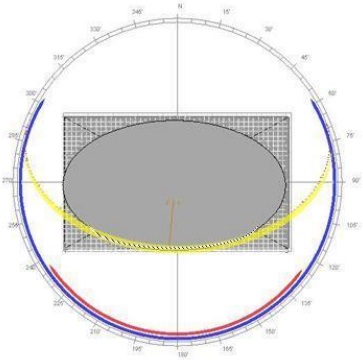
From fig. 4.3 and fig. 4.4 it can be seen that regardless of the amount of incident insolation on the surfaces, the south and west surfaces have the highest incident solar radiation. The north portrays less heat, and incident light. The east surface also has a higher incident radiation but unlike the south and west surfaces, the solar radiation is more of light than solar heat gain.

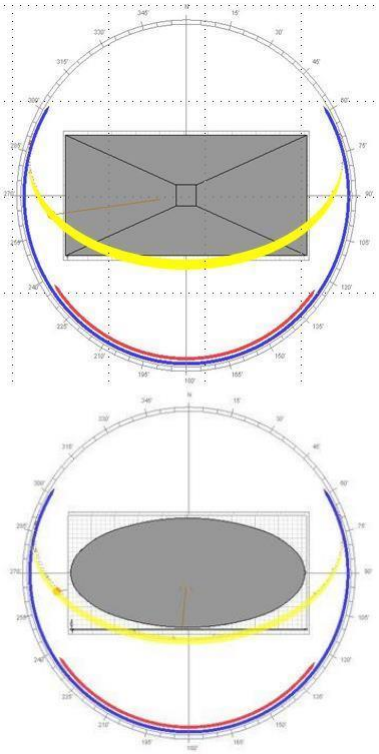
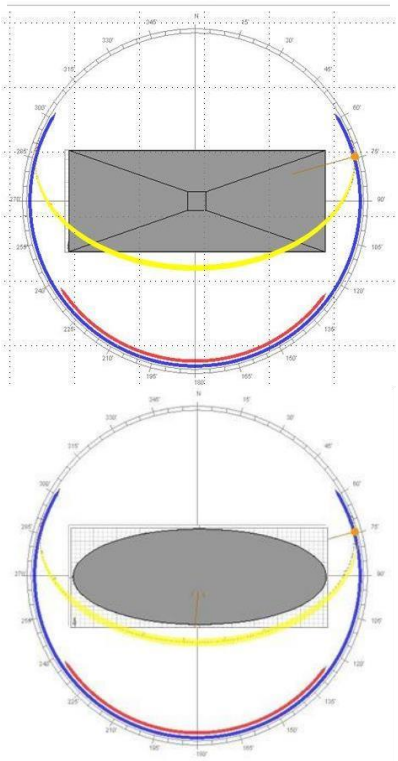


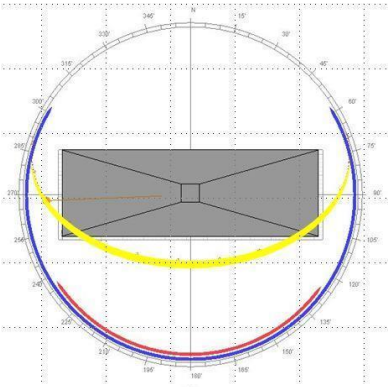
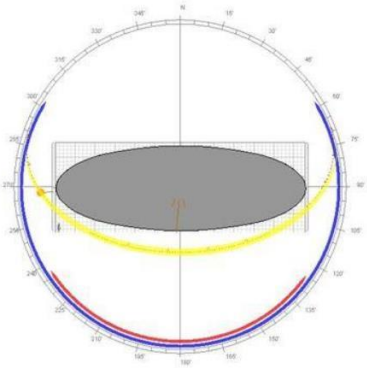
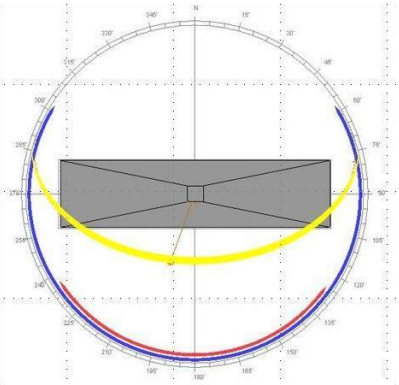
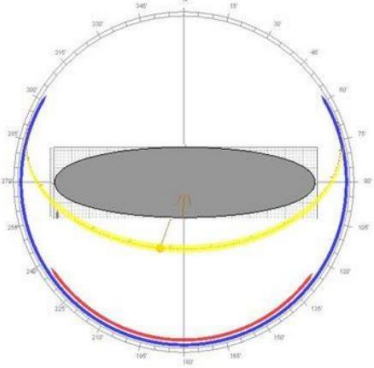
	Ratio 1:1	Ratio 1:1.7	Ratio 1:2	Ratio 1:2.5	Ratio 1:3	Ratio 1:4
South Surface	2765	1712	2498	2498	2658	2587
North Surface	872	134	534	787	801	831
West Surface	2828	1932	2533	2729	2821	2742
East Surface	2587	1577	2185	2365	2421	2532

Figure 4.4: Average solar radiation on North, South, East, & West surfaces for different aspect ratios of cylinder

Table 4.3: High solar radiation on west and south surfaces for different aspect ratios of cube and cylinder

Aspect Ratios (X:Y)	Total Floor Area (m^2)	West Exposed Area(m^2)	South Exposed Area (m^2)	Orientations of Cuboid & Cylindrical Forms With Varying Aspect Ratios
1:1 Breadth x Length = 34.8m x 34.8m	1200	5.6m (exposed) (16%) 29.2 m (shaded) (84%)	0 m (exposed) (0%) 34.8 m (shaded) (100%)	 
1:1.7 B X L = 26.6m x 45.2m	1200	2.1m (exposed) (8%) 24.5m (shaded) (92%)	0 m (exposed) (0%) 45.2 m (shaded) =100%	 

Aspect Ratios (X:Y)	Total Floor Area (m^2)	West Exposed Area(m^2)	South Exposed Area (m^2)	Orientations of Cuboid & Cylindrical Forms With Varying Aspect Ratios
1:2 B X L = 24m x 50m	1200	6.6m (exposed) (28%) 17.4m (shaded) (72%)	50 m (exposed) (100%) 0 m (shaded) (0%)	
1:2.5 B X L = 22m x 55.2m	1200	7 m (exposed) (29%) 15 m (shaded) (71%)	55.2 m (exposed) (100%) 0 m (shaded) (0%)	

Aspect Ratios (X:Y)	Total Floor Area (m^2)	West Exposed Area(m^2)	South Exposed Area (m^2)	Orientations of Cuboid & Cylindrical Forms With Varying Aspect Ratios
1:3 B X L = 20m x 60m	1200	5 m (exposed) (25%)	60 m (exposed) (100%)	
		15m (shaded) 75%	0 m (shaded) (0%)	
1:4 B X L = 17.2m x 70m	1200	5.4 m (exposed) (32%)	70 m (exposed) (100%)	
		11. 8m (shaded) 68%	0 m (shaded) (0%)	

From table 4.3, results show that incident solar radiation on the west decreases from aspect ratio 1:1.7 indicating 92% shading, 1:1 indicating 84% shading, 1: 3 indicating 75%

shading, 1:2 indicating 72% shading, 1: 2.5 indicating 71% shading and 1: 4 indicating 68% shading. Aspect ratio 1: 1.7 showed the highest percentage of shading with minimum percentage of exposure, and aspect ratio 1:4 showed the lowest percentage of shading with a high percentage of exposure. Also, incident solar radiation on the south reduces for both aspect ratio 1: 1.7 and 1:1 indicating 100% shading with 0% exposure whilst aspect ratio 1:2, 1:2.5, 1:3, and 1:4 showed 0% shading with 100% exposure. From these observations, it could be said that aspect ratio 1:1.7 is the most ideal for tropical hot dry climates. This complies with reports from studies of Olgyay (1963) and Yeang (1994) which suggested that a range of 1:1 – 1:3 should be optimum aspect ratios for buildings in tropical climate.

4.5 Total Incident Solar Insolation on the Combined Exposed Surfaces for Overall Orientations

This section describes the incident solar insolation that falls on all the surfaces concurrently. The total average values for the month of May which is considered having the highest solar radiation / wm^2 was calculated for each respective aspect ratio as shown in figure (4.5) below.

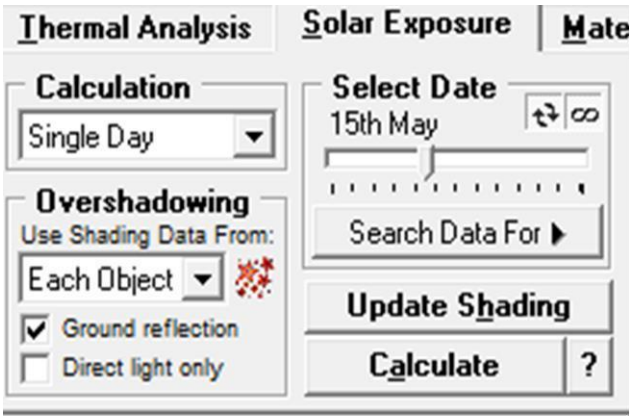


Figure 4.5:Chart representing Month with available highest solar radiation
Source: ECOTECT, 2011

i

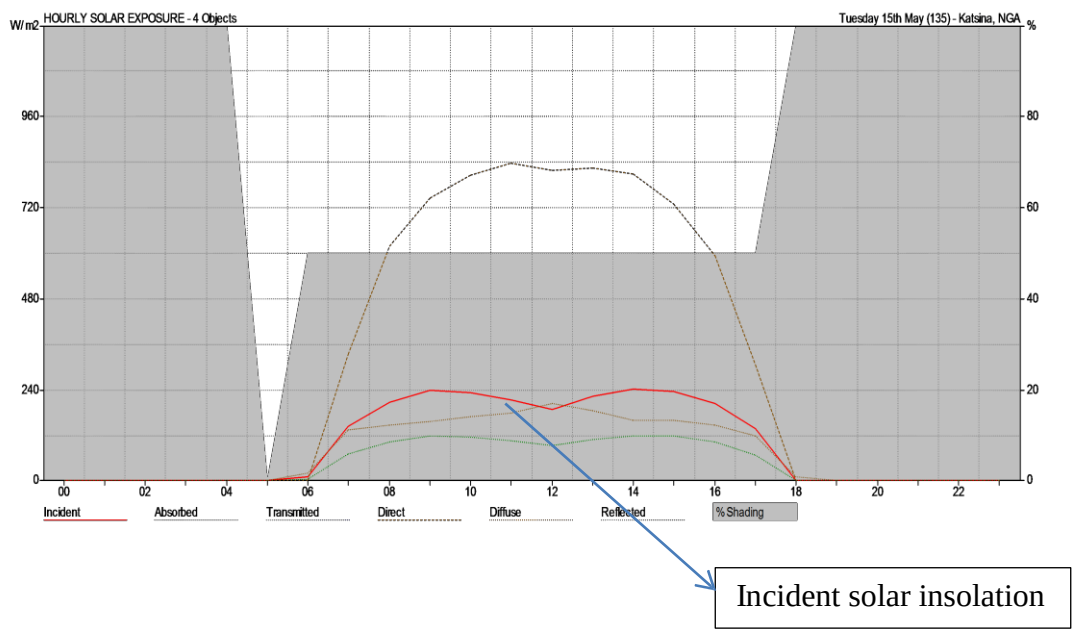


Figure 4.6: Graph for total absorbed and incident solar insolation for aspect ratio 1:1

Source: Researcher"s work

From figure 4.6 above, as indicated by the arrow, it is shown that the incident solar for aspect ratio 1:1 is 240 W/m^2 for hourly solar exposure.

ii

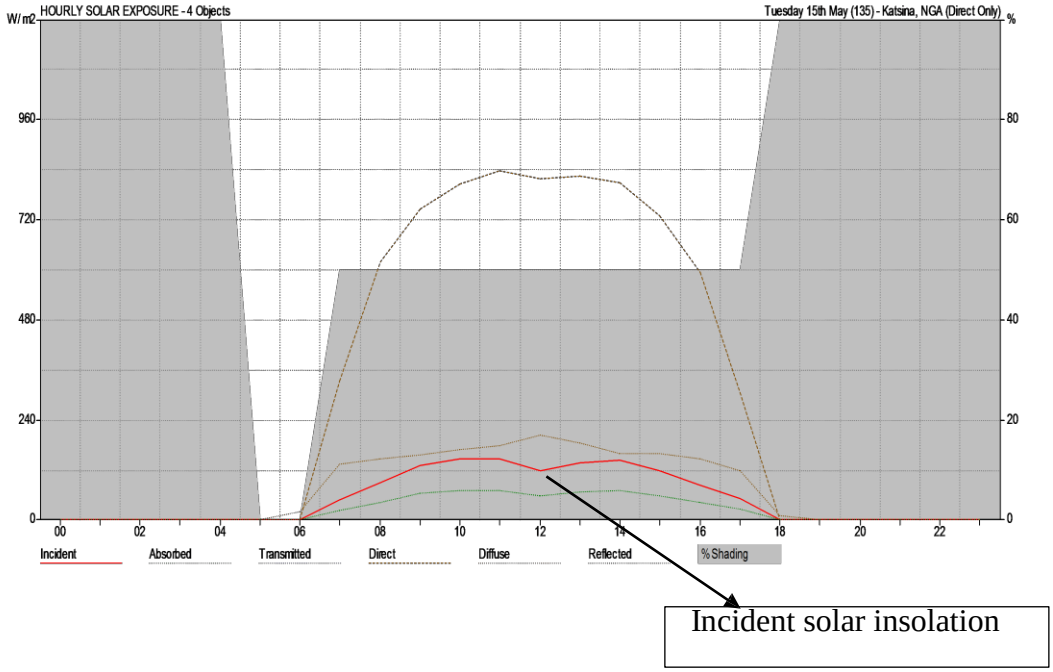
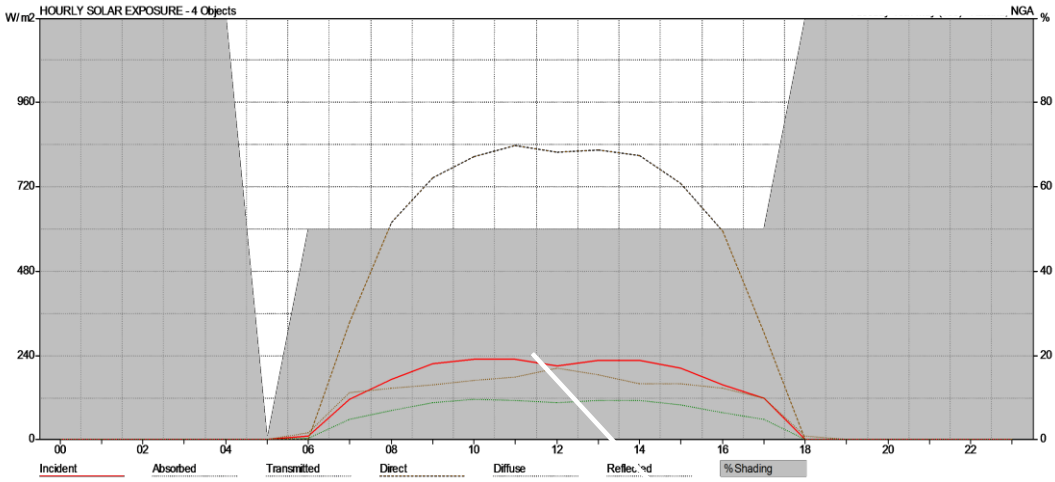


Figure 4.7: Graph for total absorbed and incident solar insolation for aspect ratio 1:1.7

Source: Researcher"s work

Likewise, it is clearly seen in figure 4.7 that the incident solar radiation falling on the cumulative surfaces for the forms with aspect ratio 1.17 is less beyond the hourly solar exposure as compared to ratio 1.1. The hourly solar exposure for aspect ratio 1:1.7 is approximately 125W/m^2 as indicated by the arrow

iii



Incident solar insolation

Figure 4.8: Graph for total absorbed and incident solar insolation for aspect ratio 1:2

Source: Researcher‟ work

Again figure 4.8 shows a slight drop of incident solar insolation in terms of the hourly solar exposure as seen on the chart above for aspect ratio 1:2 as against aspect ratio 1:1.

The incident solar ratio insolation on the surfaces for aspect ratio 1:2 as read from the graph is approximately 237W/m^2.

iv

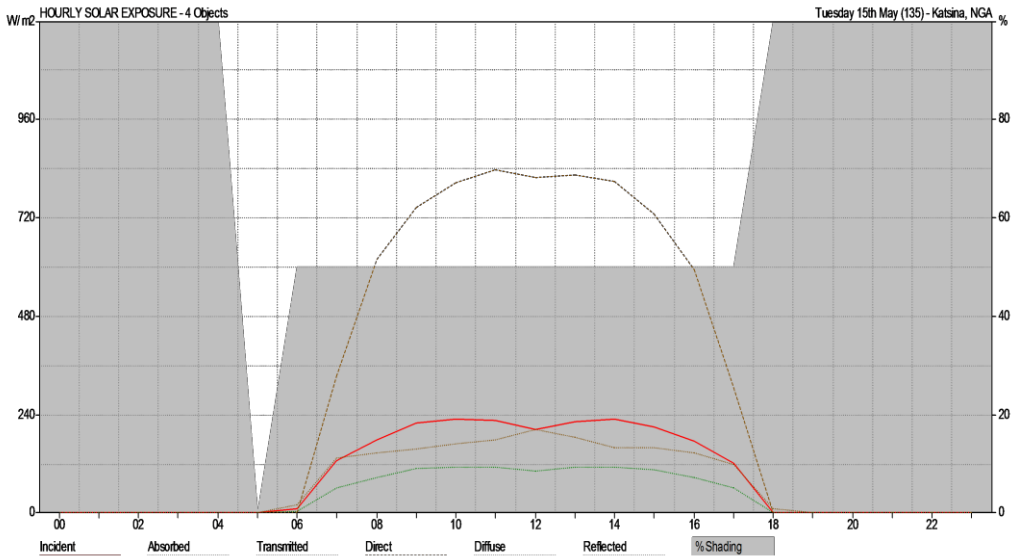


Figure 4.9: Graph for total absorbed and incident solar insolation for aspect ratio 1:2.5
Source: Researcher's work

Similarly, much difference was not noticed between the result shown for aspect ratio 1:2.5 and 1:2 compared with aspect ratio 1:1. . The incident solar insolation in this case is approximately 237- 238W/m^2

v

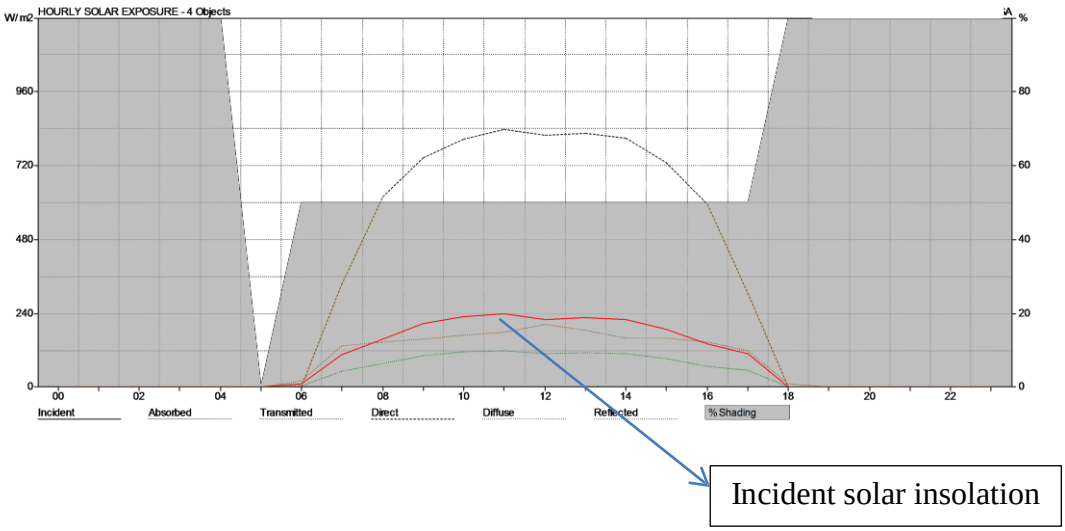


Figure 4.10: Graph for total absorbed and incident solar insolation for aspect ratio 1:3
Source: Researcher‟ work

Incident solar insolation for aspect ratio 1:3 from figure 4.10 above is 236W/w^2 as indicated above.

vi



Figure 4.11: Graph for total absorbed and incident solar insolation for aspect ratio 1:4
Source: Researcher" work (2016).

Incident solar insolation for aspect ratio 1:4 from figure 4.11 above is 233W/m^2

From the graphs above, results also show that when incident and absorbed solar insolation falling on all the surfaces collectively, the optimum aspect ratio is found with the forms with aspectratio1:1.7.

4.6 DISCUSSION OF FINDINGS

In other to justify energy savings of the forms simulated, all the forms were assigned the same floor area, volume, WWR (window to wall ratio), orientation and the building envelopes are kept constant without modification under the same exposed solar radiation in a hot-dry region. Below are the summary of the findings:

i. From the analysis performed, the L – Form showed the highest energy consumption on cooling, while the cylindrical showed the minimum energy required for cooling annually. The cylindrical form shows an annual 22% reduction than the L –Form, the cuboid showed an 18% reduction than the L – Form. Though both the cylindrical and cuboidal forms had lower energy consumptions, the 3% difference between the cylindrical and the cuboidal forms can be related to the slight increase of volume / surface the former has over the latter.

   Consequently, the U – Form showed a 10% reduction from the L – Form, the Cross – Form showed a 6% reduction from the L – Form, and the H – Form showed a 3% reduction from the L – Form respectively.

ii. There is a noticeable progressive reduction in solar radiation on surfaces from aspect ratio 1:1 to aspect ratio 1:1.7, which defines a turning point. After which solar radiation begins to show increase on surfaces rather than continuity in reduction from aspect ratio 1:3 to aspect 1:4.

iii. Influence of optimizing cylindrical and cuboid form with different aspect ratios (1:1,

1:1.7, 1:2, 1:2.5, 1:3, and 1:4) shows further saving of 33% solar radiation on the south surfaces and 28% on west surfaces, when aspect ratio 1:1.7, which resulted as optimum ratio is compared to aspect ratio 1:1.

iv. Due to the high solar angle experienced during hot periods, aspect ratio of 1:1.7 requires less energy to cool down buildings in hot dry regions of Nigeria during hotter periods.

The summary of the findings could be concluded that not only the form of a building is responsible for energy savings, however, an investigated ratio obtained by optimizing the south and west surfaces could lead to much better energy savings. Since an optimum ratio is chosen which determines the minimum allowable surface that is exposed to the west.

5.0 DESIGN PRELIMINARIES

This chapter will focus on the preliminary design proposal and considerations required to give the design a solution to the problems of significant use of energy required to attain occupants‟ thermal comfort for an office building that has large workspaces . This will form the basic guideline for the design proper. The design solution to the proposed "Telecommunications Office Building" will be based on the character of the building form with respect to the ambient solar radiation, building orientation, architectural character for an office building, access control and site design. The character of the form for office buildings with large number of occupants need to be improved in order to shield critical surfaces and orientations against ambient solar radiation especially in regions such as the study area of Maiduguri with high solar radiation.

5.1 General Climate Characteristics

The highest temperature range of 40.0 – 47.0°C was recorded over the northeast and northwest zones of the country. The hottest areas included Maiduguri with the highest record temperature was 47 °C (117 °F) on 28 May 1983, while the lowest record temperature was 5 °C (41 °F) on 26 December 1979. The extreme coastal areas, and Jos and its environs recorded the lowest temperatures in the range of 30.0 – 32.0°C, while other areas recorded 35.0 – 40.0°C maximum temperature in the season. Köppen-Geiger

climate classification system classifies its climate as hot semi-arid. Summary of the climatic data is as shown below:

Climate data for Maiduguri [hide]													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	40 (104)	42 (108)	44 (111)	46 (115)	47 (117)	42 (108)	43 (109)	36 (97)	38 (100)	39 (102)	39 (102)	38 (100)	47 (117)
Average high °C (°F)	31.9 (89.4)	34.6 (94.3)	37.8 (100)	40.1 (104.2)	39.4 (102.9)	36.4 (97.5)	33.2 (91.8)	32.0 (89.6)	33.7 (92.7)	36.4 (97.5)	34.2 (93.6)	32.3 (90.1)	35.2 (95.4)
Daily mean °C (°F)	21.8 (71.2)	24.8 (76.6)	29.3 (84.7)	32.6 (90.7)	32.5 (90.5)	30.2 (86.4)	27.5 (81.5)	26.6 (79.9)	27.2 (81)	27.9 (82.2)	24.9 (76.8)	23.2 (73.8)	27.4 (81.3)
Average low °C (°F)	12.6 (54.7)	15.3 (59.5)	19.7 (67.5)	21.9 (71.4)	25.5 (77.9)	24.5 (76.1)	22.9 (73.2)	22.3 (72.1)	22.4 (72.3)	20.7 (69.3)	16.0 (60.8)	13.1 (55.6)	19.9 (67.8)
Record low °C (°F)	8 (46)	10 (50)	15 (59)	12 (54)	18 (64)	19 (66)	20 (68)	19 (66)	20 (68)	15 (59)	10 (50)	5 (41)	5 (41)
Average precipitation mm (inches)	0.0 (0)	0.0 (0)	0.3 (0.012)	13.0 (0.512)	30.5 (1.201)	73.8 (2.906)	147.1 (5.791)	193.2 (7.606)	83.0 (3.268)	11.1 (0.437)	0.0 (0)	0.1 (0.004)	552.1 (21.736)
Average precipitation days (≥ 1.0 mm)	0.0	0.0	0.5	1.6	4.0	7.0	10.7	10.7	6.8	1.4	0.0	0.0	42.7
Average relative humidity (%) (at 15:00 LST)	15.4	11.2	12.0	17.5	28.4	38.4	55.5	63.4	54.8	30.2	19.0	19.6	30.2
Mean monthly sunshine hours	266.6	249.2	257.3	237.0	263.5	249.0	217.0	204.6	225.0	285.2	282.0	275.9	3,012.3
Mean daily sunshine hours	8.6	8.9	8.3	7.9	8.5	8.3	7.0	6.6	7.5	9.2	9.4	8.9	8.26
Source #1: NOAA,[5] *Climate Charts* (latitude: 11°51'N; longitude: 013°05'E; elevation: 354m, 1161')[6]													
Source #2: *Voodoo Skies* for record temperatures[4]													

Figure 5.1: Climate data for Maiduguri
Source: National Oceanic and Atmospheric Administration (NOAA), 2016

5.1.1 Temperature

The temperature of the area is high throughout the year. The average maximum temperature rises gradually from January 32^0C and shows the highest in May with about 40 ^{0}C before rainfall starts and its lowest in August with about 32^oC as shown in Figure 5.2.

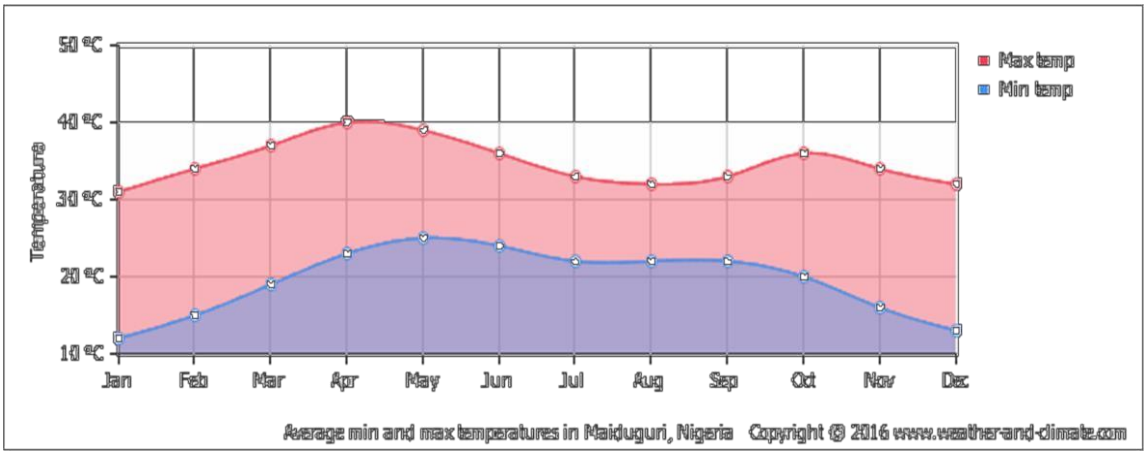


Figure 5.2: Maximum and minimum temperature for Maiduguri
Source: http://www.worldweatheronline.com

5.1.2 Relative humidity

The maximum mean monthly relative humidity occurs in August with about 80% and minimum in January which falls back to 39% as shown in figure 5.3 below.

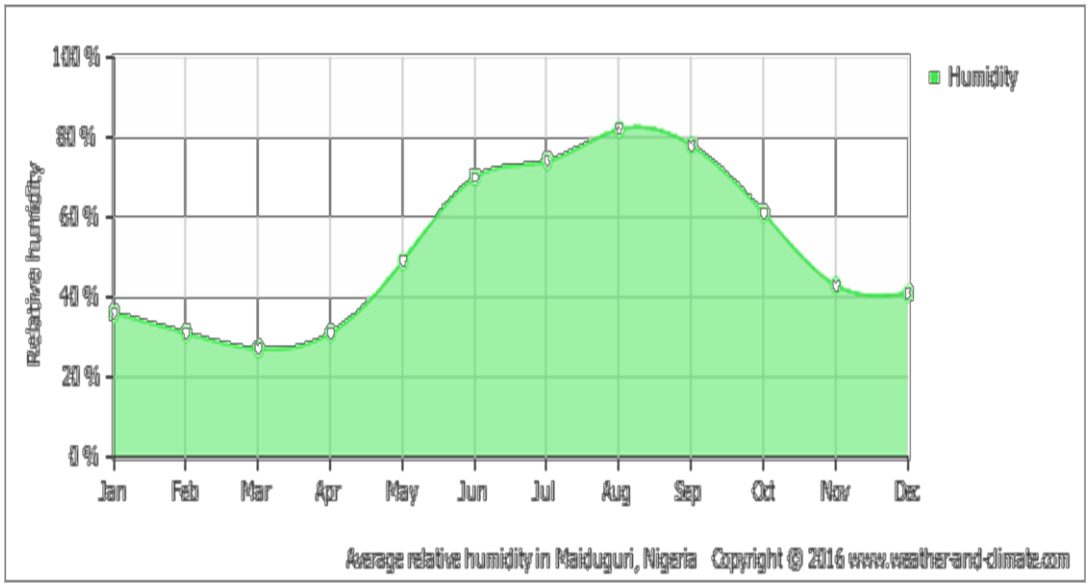


Figure 5.3: Average relative humidity for Maiduguri
Source: http://www.worldweatheronline.com

5.1.3 Sunshine

October sunshine hours vary from 8.9 to 9 hours per day. January sunshine hours are quite high, 8.7 to 9.5 hours. Minimum sunshine hours per day occur in August with as low as 5.1 hours per day as shown in Figure 5.4.

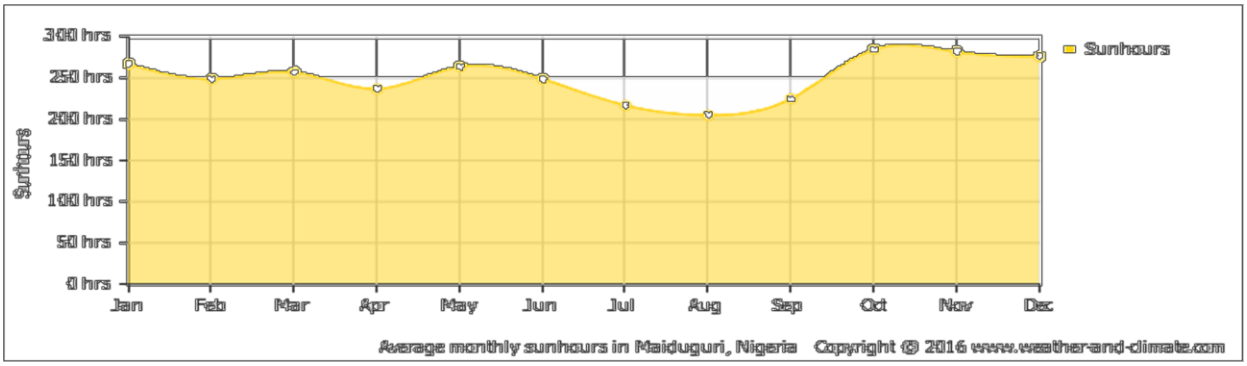


Figure 5.4: Average monthly sunshine in Maiduguri
Source: http://www.worldweatheronline.com

5.1.4 Rainfall

The annual total rainfall occurs between1100 mm to 1600 mm in Maidugri. However, a common feature of the rainfall in Maiduguri is its corrective nature and the occurrence of the associated thunderstorm usually with late afternoon maximum and with September seasonal maximum.

There is usually a dry season that is practically rainless. Rainfall starts in May and increases from 63mm in May to 550mm in August which is the maximum for the years as shown in Figure 5.5.

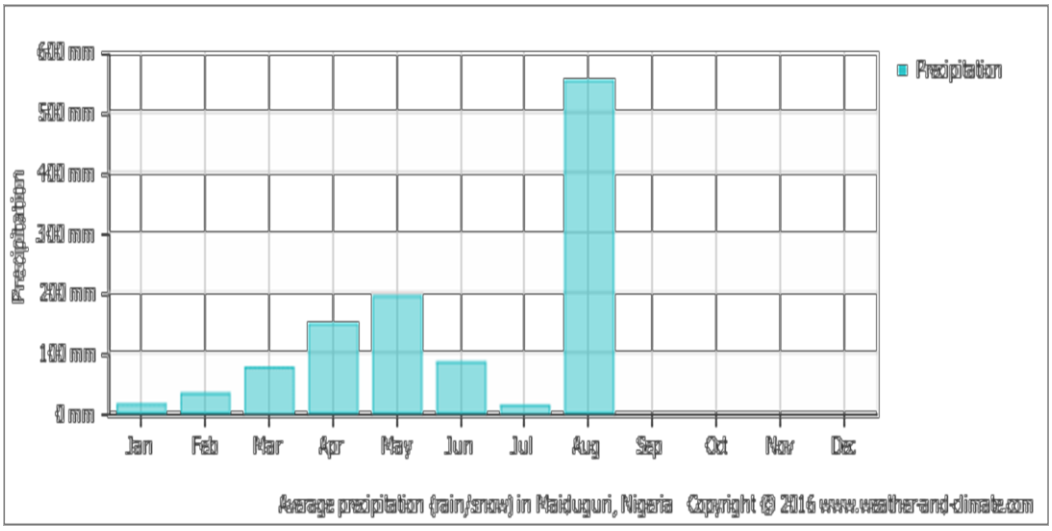


Figure 5.5: Average precipitation in Maiduguri
Source: http://www.worldweatheronline.com

5.2 Site Selection Criteria

Site selection is the first step in the design process. The intention of the site was for it to be compatible with the purpose of the proposed development and be suitable for building .

The proposed project will be located in Maiduguri. The selection of an appropriate/suitable site is paramount to the successful planning and operation of any office building design. The challenge is thus to find a suitable site that does not fall out of the city„s design as well does not disturb its neighborhood.

The following under listed criterias shall be used to weigh the suitability of each of the site and thus the most appropriate site shall be selected. They are:

a) Location/Accessibility

The site proposed for the telecommunications office building should be accessible from the road. The sole reason is because motor vehicles are the primary means of transporting staffs, professionals and affiliate research agenies.

b) Land use compliance

The proposed site should be in compliance with the land-use policies of the area. The facility should be able to meet all the zoning and building code requirements of the area.

c) Security considerations

The Site should be located within close proximity from the law enforcement agency.

d) Size of site

The size of the Site is important. Unlike other public institutions which tend to be very well integrated into the fabric of the local community. Telecommunication buildings are often best located on larger tracts of land away and not too far from nearby residential neighbourhoods.

e) Nearness to existing infrastructures

Access to available electrical services is critical to the operation of a Telecommunication building. On-site backup generators are required to ensure minimum safe operation in the event of an interruption in the electrical service. As well as the availability of network and other communication services are essential to the operations of the telecommunications office building.

f) Vicinity of a research district.

g) Proximity to suppliers

h) Location away from loud noise

i) Availability of social amenities

Site selection

Three sites which all satisfy the land use requirements have been selected. The first is located adjacent to University of Maiduguri as shown in Plate VIII, The second site in Borno state secretariat which is along Rahmat polytechnic as shown in Plate IX, and the third site is located in Mafoni as shown in Plate X.



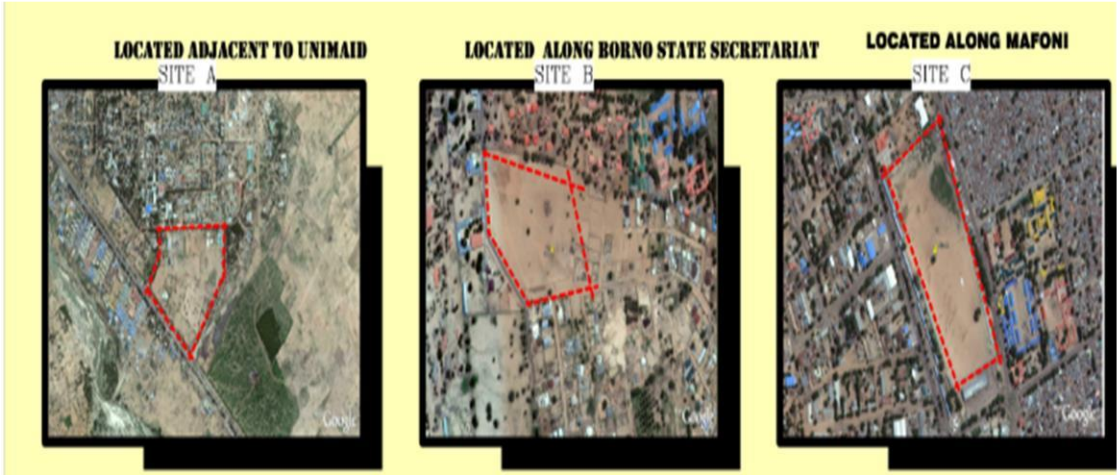
Plate VIII: Google earth image showing Site A. (Source: Google Earth, 2015)



Plate IX : Google earth image showing Site B. (Source: Google Earth, 2015)



Plate X: Google earth image showing Site C. (Source: Google Earth, 2015)



	SITE A	SITE B	SITE C
1.SITE LOCATION/ACCESSIBITY	3	5	3
2.VICINITY OF A RESEARCH DISTRCT	5	5	3
3.LAND USE COMPLIANCE	4	3	3
4.POSSIBILTY FOR EXPANSION, SUITABILITY AND AVAILABILITY	3	4	2
5.SIZE AND TERRAIN OF SITE	3	5	4
6.LOCATION AWAY FROM LOUD NOISE	2	5	2
7.AVAILABILITY OF SERVICES	4	4	4
8.AVAILABITY OF SOCIAL AMENITIES	4	4	4
9.PROXIMITY TO EXISTING SETTLEMENT	3	5	3
10.PROXIMITY TO SUPPLIERS	4	4	4
	35	44	32

Plate XI: Google earth image showing Site Comparison (Source: Google Earth, 2015)

Weighing scale: Excellent 5, Very good 4, Good 3, Fair 2, Poor 1, Very poor 0. Based on the above analysis as shown in plate XI, site B was chosen in preference to site A and B.

5.2.1 The proposed site

The proposed site is located in Borno state secretariat along Rahmat polytechnic in Maiduguri. The site is has a major road positioned transversely along its western axis. To the east part of the site are government facilities and to the north is another major road that linked to Rahmat Polytechnic. To the south is another site densely populated by trees as shown in Plate.



Plate XII: Selected Site for Proposed Design. Source: Google Earth, 2015

5.3 Site Analysis

The physical, climatic, and general features of the site were analysed in order to identify the possible opportunities that will be utilised for a better design and also to take note of the threats and to take possible measures that will reduce their effect to the building. The following are features that were noted during analysis of the site..

5.3.1 Topography

The topography of the site relatively flat and has a Low lying strip of land with 0.5% gradient sloping towards the west-east end of the site. Site drainage would take this direction in order to use the concept of natural gravity. While the water supply should come from north-western direction in order to also use the principle of natural gravity (sloping in the direction of the lower slope).

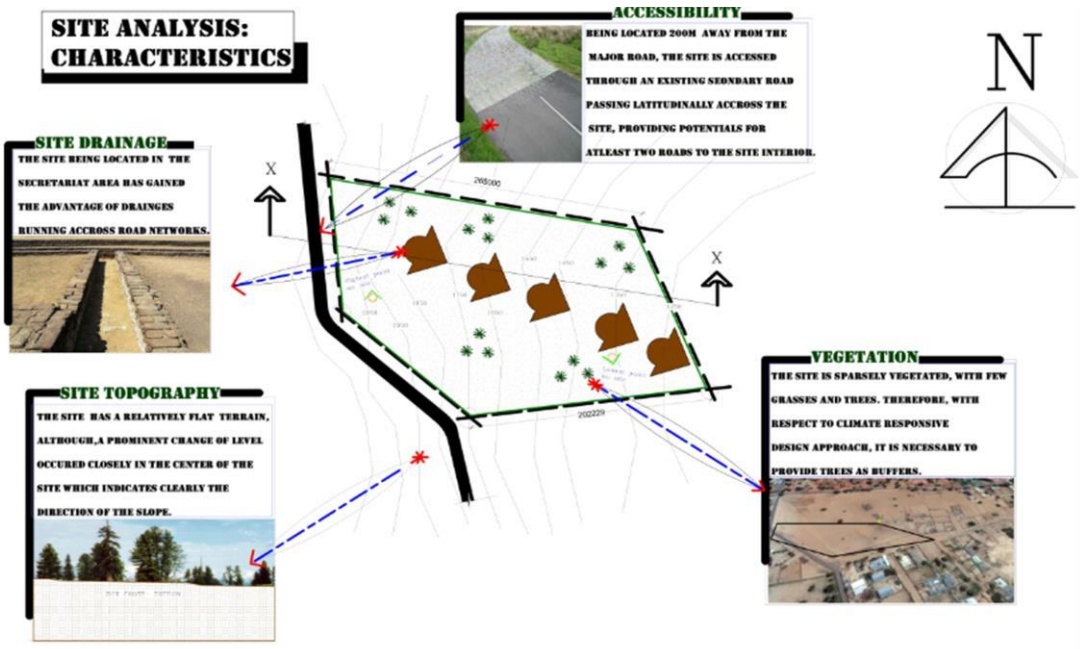


Figure 5.6: Topographical analysis of the site

5.3.2 Vegetation

Vegetation of the site is typically that of the Sudan Savannah, characterized by isolated neem and locust bean trees and shrubs. However, the original vegetation has been greatly altered by human activities such as clearance for cultivation and firewood. More than half of the land is bared with little or no grasses during the dry season but dominated with grasses during the rainy season. However, the western, western part of the site is densely populated with mango trees. Outdoor garden will be best located toward this side.

5.3.3 Services / Infrastructure

Services like electricity power lines, water supply lines, telephone services, well-constructed tarred roads and pedestrian paths, well designed drainages are all available on site .The site is accessed from the main a road along tapped from major road from Rahmat Polytechnic. Also, high tension electrical cables can also be sited from the site.

5.3.4 Climate

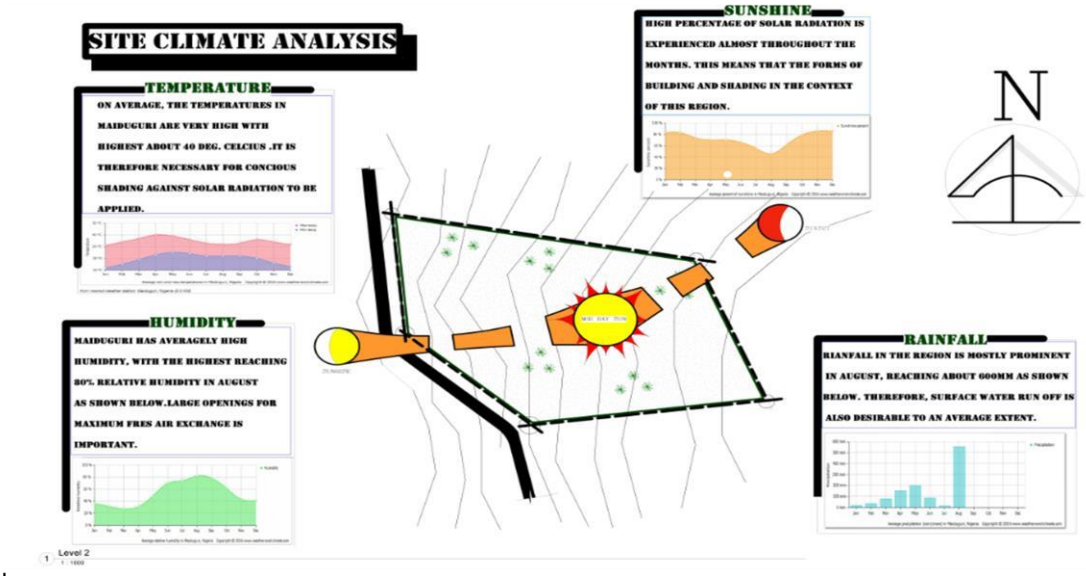


Figure :5.7 Climatic data analysis

5.4 Summary of Site and Surrounding Analysis

The following observations are made from the analysis:

i. The site slopes gently eastwards.

ii. Water supply pipes and power lines are located at the western part of the site.

iii. The site has a negligible vegetation, therefore trees and shrubs will be planted to provide a very conducive micro-climate.

iv. The soil laterite condition is favourable for the development.

v. Current and future land use plan favours the proposed development.

vi. Access to the site through the high way.

vii. The site is near institutional facilities as demanded by the site selection criteria.

5.5 Design Inferences from the Site Analysis

From the site analysis conducted, the following considerations shall be used in the design proposal:

i. Access into the site shall be through the primary road bordering the eastern part of the site.

ii. The orientation of the building will be done as based on the results of the findings from research conducted to minimize heat gain. Solar shading will be applied on openings.

iii. There would be a modification of the temperature on the site by providing extensive green areas which will cool the external environment and reduce solar heat gain caused by reflected solar radiation which causes glare and excessive solar heat gain .

iv. Landscaping will be extensive applied to the site in order to counter the effect of strong harmattan winds and dust arising from the windy weather

6.0 DESIGN REPORT

This chapter encompasses the report of the architectural design of the proposal for telecommunications office buildings. In this chapter key design requirements and how the research findings are been incorporated into the design are discussed. The chapter is arranged under the following headings: The design framework; Site development concepts; Design Philosophy; The Telecommunications office building

6.1 Design brief

Due to the persistent attack of government facilities in the north-eastern part of the country, the World bank in Switzerland has, according to the report from the International Center for Investigative reporting (ICIR), (2015) promised to partner with countries affected by Boko Haram insurgency in reconstructing ravaged areas and displaced persons. Among the facilities to be reconstructed as noted by the government are telecommunication and government security facilities which have been completely destroyed and require reconstruction and replacements. Therefore the design should take into cognizance the principles that will enable occupants‟ thermal comfort in the region. Some of the basic requirement of the brief involved are; Technical staff area, Administrative area, computer and equipment area and ancilliary facilities area.

6.2 Functional flow chart

The design framework in figure (6.1) tries to put together and connect all the functional area in the proposed building, however, definition of relevant spaces are being discussed, thereafter the framework is then developed.

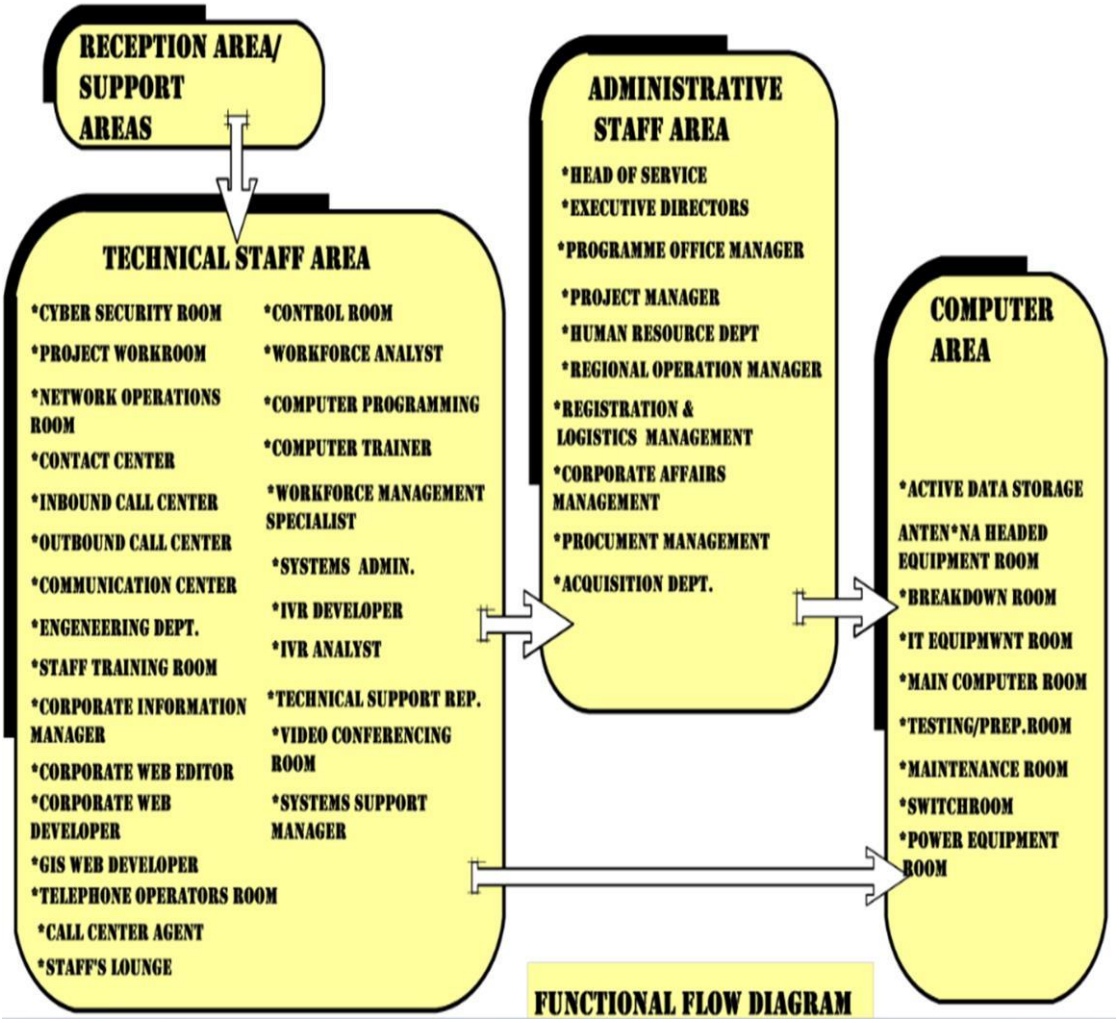


Figure 6.1: Preliminary functional flow chart

6.3 Spaces of the technical staff area

6.3.1 Network operations room:

In telecommunication environments, network operations room are responsible for monitoring power failures, communication line alarms (such as bit errors, framing errors, line coding errors, and circuits down) and other performance issues that may affect the network, and in telecom sector have to track details about the call flow.

6.3.2 Call center department:

A call center is a centralized office in a telecommunications building used for receiving or transmitting a large volume of requests by telephone. An inbound call center is operated by an organization to administer incoming product support or information enquiries from agencies. Outbound call centers are operated for telemarketing, solicitation of charitable or political donations, debt collection and market research. Both inbound and outbound call center have an open workspace for call center agents, with work stations that include a computer for each agent, a telephone set/headset connected to a telecom switch, and one or more supervisor stations. It can be independently operated or networked with additional centers, often linked to a corporate computer network, including mainframes, and microcomputers.

6.3.3 Contact center department:

A contact center is a space in telecommunications building for a coordinated system of people, processes, technologies and strategies that provides access to information, resources, and expertise, through appropriate channels of communication, enabling interactions that create value for the customer and organization.

6.3.4 Communications center department:

In telecommunication, the term communications center is a department charged with the responsibility for handling and controlling communications traffic. The center normally includes a message center, and transmitting and receiving facilities. It also serves as a node for a communications network, equipped for technical control and maintenance of the circuits originating, transiting, or terminating at the node, and may contain message-center facilities, and may also serve as a gateway.

6.3.5 Information security operation department:

Consists of the policies and practices adopted to prevent and monitor unauthorized access, misuse, modification, or denial of a computer network and network-accessible resources. Network security involves the authorization of access to data in a network, which is controlled by the network administrator. It also monitors applications to identify a possible cyber-attack or intrusion (event) and determines if it is a real, malicious threat (incident), and if it could have a business impact.

6.3.6 Geographical Information System (GIS) room:

A geographic information system (GIS) room is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographical data and information.

6.3.7 Interactive Voice response (IVR) room:

In telecommunications, interactive voice response (IVR) is a unit that allows customers to interact with a company's host system via a telephone keypad or by speech recognition, after which services can be inquired about through the IVR dialogue. IVR systems can respond with prerecorded or dynamically generated audio to further direct users on how to proceed.

6.3.8 Transmissions room

In telecommunications, transmission room is where sending and propagating an analogue or digital information signal over a physical point-to-point or point-to-multipoint transmission medium, either wired, optical fiber or wireless is being undertaken

6.4 Bulk schedule and space grouping

The table below shows the overall spaces adopted based on the case studies and review of international and local practices of functional spaces appropriate to a telecommunications.

Table 6.1a Grouping of telecommunications office spaces

S/NO	GROUP	SPACE
1.	Reception area	Entrance
		Retail/snacks facilities
		Exhibition space
		Organization‟s record Office
		Security Room
2.	Technical staff area	Information security operation room
		Network operations room
	Technical specialists staff room	Project work room
		Monitoring room
		Inbound call department
		Outbound call department
		Contact department
		Control room
		Communications department
		Engineering department
		Staffs‟ lounge room
		Staff training room
		Corporate information manager
		Corporate web developer

Table 6.1 b Grouping of telecommunications office spaces

S/N	GROUP	SPACE
		Corporate web editor
		GIS web developer
		IVR analyst
		IVR developer
		Workforce management
		Specialist
		Tehnical support representative
		Workforce analyst
		Systems administrator
		Computer trainer
		Computer programmer
		Call center agent
		System support manager
		Telephone operator's room
	Administrative staff area	Head of service room
		Secretary to head of service
		Executive director‟s room 1
		Executive director‟s room
		Program office manager
		Project manager
		Finance manger
		Human resource department

Table 6.1c Grouping of telecommunications office spaces

S/N	GROUP	SPACE
		Regional operation department
		Registrations and logistics
		Corporate affairs management
		Procurement management
		Acquisition department
		Conference room
	Computer and equipment area	Active data storage room
		Backup computer room
		Antenna headed equipment room
		IT equipment room Main computer room Testing/ preparation room
		Maintenance room
		Switch room
		Transmission room
		Power equipment room
		Server room

6.5 Schedule of Accommodation

Based on the above grouping, the following tables below provide the space required for each of the unit thus:

Table 6.2a: Schedule of Accommodation of Reception/Technical staff area

RECEPTION/TECHNICAL STAFF AREA

S/n	Functional Space	Unit	Parameter	Area (m^2)	Net Area (m^2)
1.	Entrance hall/reception	1		90	90
2.	Mini clinic	1		9	9
3.	Exhibition space	1		45	45
4.	Record Office	1		45	45
5.	Security room	1		9	9
6.	Information security operation room	1	60 workstations	135	135
7.	Network operations room	1	28 workstations	80	135
8.	Project work room (Configurations repair)	1	20 workstations	48	48
9.	Monitoring room	1	17 workstations	45	45
10.	Inbound call dept.		35 workstations	80	80
11.	Outbound call dept.	1	60 workstations	135	135

Table 6.2b: Schedule of Accommodation of Reception/Technical staff area

RECEPTION/TECHNICAL STAFF AREA			72	72
S/n	**Functional Space**	**Unit**	**Parameter**	**Area (m^2)** **Net Area (m^2)**
				135 135
12.	Staff training room	2	20 workstations	
13.	Contact department	1	60 workstations	
14.	Communications center	1	40 workstations	85 85
15.	Engineering dept.	1		45 45
16.	Staffs‟ lounge	2	4 no. sofas	50 100
17.	Staffs‟ W.C	48		1.5 72
18.	copy room	2		20 40

Table 6.3a**:** Schedule of Accommodation of Technical specialists staff rooms

TECHNICAL SPECIALISTS STAFF ROOMS					
S/n	**Functional Space**	**Unit**	**Parameter**	**Area (m^2)**	**Net Area (m^2)**
1.	Corporate information manager	1		45	45
2.	Corporate web developer	1		30	30
3.	Corporate web editor	1		24	24
4.	GIS web developer	1		24	24
5.	IVR analyst	1		24	24

Table 6.3b**:** Schedule of Accommodation of Technical specialists staff rooms

S/n	Functional Space	Unit	Parameter	Area (m^2)	Net Area (m^2)
6.	IVR developer	1		24	24
7.	Workforce management specialist	1		40	40
9.	Technical support representative	1		24	24
10.	Telephone operator's room	1		24	24
11.	Workforce analyst	1		33	33
12.	Systems administrator	1		24	24
13.	Computer trainer	3		24	48
14.	Computer programmer	2		24	48
15.	Call Centre agent	1		45	45

Table 6.4a: Schedule of Accommodation of Administrative staff area

ADMINISTRATIVE STAFF AREA

S/n	Functional Space	Unit	Parameter	Area (m^2)	Net Area (m^2)
1.	Head of service room	1		45	45
2.	Secretary to head of service	1		24	24

Table 6.4b: Schedule of Accommodation of Administrative staff area

S/n	Functional Space	Unit	Parameter	Area (m^2)	Net Area (m^2)
3.	Executive director's room	1		40	40
4.	Program office manager	1		50	50
5.	Project manager	1		50	50
6.	Finance manger	1		48	48
7.	Conference room	1		135	135
8.	Human resource department	1		48	48
9.	Regional operation department	1		48	48
10.	Registrations and logistics	1		33	33
11.	Corporate affairs management	1		33	33
12.	Procurement management	1		24	24
13.	Boardroom	1		24	24
14.	Acquisition department	1		24	24

Table 6.5: Schedule of Accommodation of Computer and equipment area

COMPUTER AND EQUIPMENT AREA					
S/n	**Functional Space**	**Unit**	**Parameter**	**Area (m^2)**	**Net Area (m^2)**
1.	Active data storage room	1		65	65
2.	Backup computer room	1		65	60
3.	IT equipment room	1		21	21
4.	Antenna headed equip-ment room	1		20	20
5.	Main computer room	1		60	60
6.	Maintenance room	2		48	96
7.	Switch room	1		76	76
8.	Transmission room	1		135	135
9.	Server room	1		18	18

6.6 Design Philosophy

The concept of the design was developed using basic rectangular geometric shape developed from the result of the simulation carried out. A cylindrical form with aspect ratio 1:1.7 which formed the baseline of an integrated sustainable office building that

exposes less surfaces to solar radiation. The building incorporated thermal comfort strategies with open ventilated central courtyard that diffuses hot air out from the building as seen below:

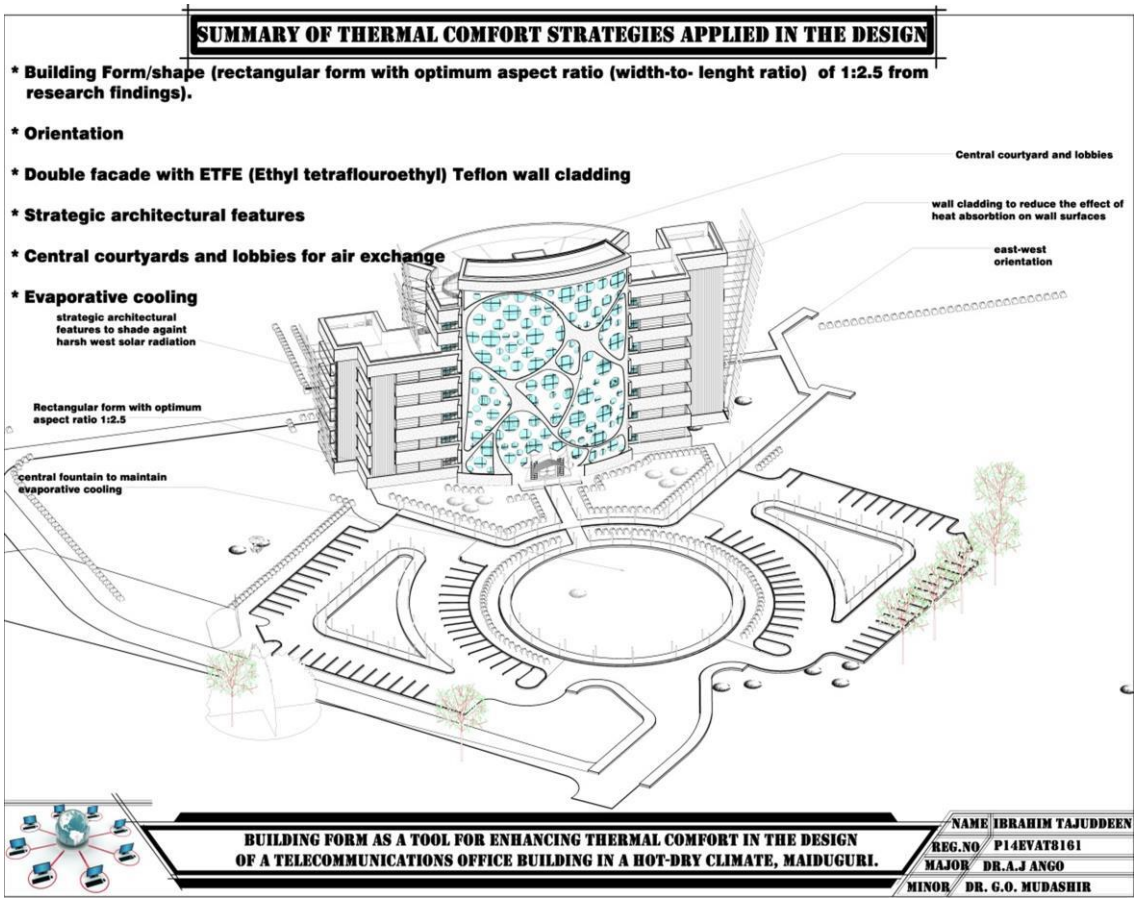


Figure 6.2: Design strategy for thermal comfort

Source: Researcher‟s work (2017)

6.7 Main Buildings in the Centre

6.7.1 The telecommunication office

The telecommunication building consist basically seven floors, with the ground floor comprising of the main entrance, the security post, mini clinical facilities, the inbound call center which is a workspace and few other offices. The first floor comprises of yet other workspaces which are the outbound call center, the staff training room, project work room, monitoring and few offices. The second floor also houses two workspaces which are the contact center, the communication center, a computer training room, engineering department and staff break lounge. On the third floor, there are other two workspaces – the network operations room, and the cyber information security room and offices for agent staffs. The fourth, fifth and sixth floor comprises of the mainly individual staff offices, directors offices, chief of service's office and managers" offices while the seventh floor comprises of the computer, server and power equipment.

6.7. The vocational/technical training unit/restaurant

The vocational training unit and the restaurant are located on the ground floor linked from the main building with covered walkways. The vocational unit comprises of the computer training laboratories/workshop and lecture rooms.

7.0 SUMMARY, CONCLUSION AND RECOMMENDATION

The research identified thermal comfort as a problem in office buildings specifically those with large workspaces such as telecommunications building which was justified to be located in a hot-dry region, Maiduguri. Building form which is one of the architectural parameter that could be properly planned at the design stage was reviewed from relevant literature.

The thermal comfort of the proposed Telecommunication Centre was informed based on the experimental analysis carried out on several building forms of selected case studies similar to the Centre. The results showed corresponding energy saving by considering only optimizing of the length/breadth ratio (aspect ratio) of the forms.

It is therefore expected that office buildings especially those with workspaces, when proper consideration is given to their west surface against solar radiation, will reduce significantly the need for excessive energy to provide thermal comfort, thus ensuring employees‟ comfort and productivity.

7.1 Conclusion

The aim of the study was to investigate various aspect ratios of building forms and their effect on thermal comfort in hot dry climate. A simulation analysis was used to establish ideal office building forms, ideal surfaces of the office building forms, and ideal aspect ratios for the office building forms suitable for achieving thermal comfort in hot – dry climatic region of Nigeria.

From summary of the findings, and in order to answer the research questions in this study,

it could be concluded that not only the form of a building is responsible for energy savings, but, an investigated aspect ratio 1:1.7 of a cylindrical/cuboidal form obtained by optimizing the south and west surfaces could lead to much better energy savings.

7.2 Recommendation

From the conclusion drawn, the following recommendations are necessary in order to proffer a befitting building whereby less concern is needed in providing thermal comfort mechanically:

i. Conceptual design of office buildings in tropical regions should go beyond east-west orientation of selected rectangular shape, however, effort to develop different alternatives for aspect ratio through experimental analysis should be considered as well.

ii. There is need for architects to imbibe different professional skills toward manipulating how large buildings are shielded from intense solar radiation on the south and west at the design stage for reducing energy on thermal comfort.

iii. Factors such as single banking planning, natural ventilation, natural lighting, natural heat dissipation techniques, among others, should all be put into cognizance in a tropical region as doing so have proven less effort to provide thermal comfort.

7.3 Contribution to Knowledge

This study of the influence of building form on energy savings in office building is not the first of its kind, however, previous studies have equally explored different forms and their effect on energy reduction on cooling. This study has specifically targeted the following contributions to knowledge below:-

i. The study has reinvestigated the possibility of increasing the level at which about 22% energy could be saved in one of the existing case studies of similar building, by replacing an east-west elongated form with the same square area as the cylindrical form of the case study typology where aspect ratio was not considered.

ii. The study has experimentally analyzed different aspect ratios of east-west elongated forms, thereby providing an optimum ratio (1:1.7) which represents a turning point at which 33% and 28% energy required for thermal comfort is saved on west and south surfaces respectively.

iii. Aspect ratio of 1:1.7 showed a 33% reduction of incident solar radiation on both west and south surfaces compared to the conventional 1:1 aspect ratio, in attaining thermal comfort for a telecommunication office building in Maiduguri.

REFERENCES

African Business Central. (2014). *NATCOM acquires Nigeria's NITEL and MTEL for $252.5M.* Abuja: African Business Central.

Agboola, O. P. (2011). Importance of climate to architectural designs in Nigeria. *Journal of environmental issues and agriculture in developing countries, 3*(1), 15-28.

AlAnzi, A., Seo, D., & Krarti, M. (2009). Impact of Building Shape on Thermal Performance of Office Buildings i Kuwait. *Energy Conversion and Management 50*, 822-828.

ASHRAE. (2007). ANSI/ASHRAE/IESNA Standard 90.1-2007. In B. E. Criteria.

ASHRAE. (2009). nonresidential cooling heating load calculation. In *ASHRAE Handbook Fundermentals* (SI Edition ed.).

Athanassios, T., Andreas, K. A., & Panagiota, K. (2007). Simulation of Facade and Envelope Design Option for New Institutional Buiding.Sl. In S. Energy.

Australian Government. (2013, December). Better Practice Guide: Datacenter Coolimg. *Australian Government Dat Centre Strategy 2010-2025*, p. 1.

Behsh, B. (2002). Building Form AS an Option for Enhancing the Indoor Thermal Conditions. *Building Physics 2003-6th Normadic Symposium*.

Cheung, C. K., Fuller, R. J., & Luther, M. B. (n.d.). Energy Efficient-Efficient Envelope Design for High Rise Apartments. In *Energy and Buildings* (Vol. 37(1), pp. 37-38).

Chia, S. L., Hamdan, O., Ahmad, M., & Dilshan , R. (2007). The effect of Geometric Shapes and Building Orientation on Minimising Solar Insulation on High-Rise Buildings in Hot Humid climates. *Journal of construction in Developing Countries*, 27-38.

Choi, J., Kim, Y., & Jeon, J. (2007). Cooling Performance of a Hybrib Refrigeration System Design for Telecommunication Equipment Room. In A. T. 27.

Creamer Media Reporter. (2015). *Cooling ICT environments: where to next?* Johannesburg: Creamer Media Publisher.

Daluku, S. K. (2015). *Evaluating the Effects of Building Forms on Thermal Comfort in Office Buildings in Hot-humid Areas.* Ahmadu Bello University, Zaria, Department of Architecture, Zaria.

Dan, M., & Matti, K. (2000). Application of CFD Techniques in Thermal Design of Telecommunication Base Station. *9th International Flotherm User Conference.* Orlando, USA.

Erdim, B., & Manioglu, G. (2011). Impacts of Building Form on Energy Efficient Heat Pump Application. *Proceedings of the Eleventh International Conference Enhanced Building Operations*, (pp. 1-2). New York City.

Feng, Y. (2004). Thermal Design Standards for Energy Efficiency Residential Buildings in Hot Summer/Cold Winter Zones. In *Energy and Buildings* (Vol. 36(12), pp. 1309-1312).

Ferdous, T. (2012). *Determining The Effect Of Building Geometry on Energy Use Patterns of Office Developments.* Retrieved 4 2016, from http://digitalcommons.ryerson.ca/dissertations.

Gelekta, V., & Sedlakova, A. (2012). Shapes of buildings and Energy Conservation. *Research and Development Operational Program*, (pp. 126-129). Slovakia.

Gratia, E., & De Herde, A. (2002). Design of Low Energy Office Buildings. *Energy and Buildings*, 35, 473-479.

Greaves, P. (2015). Where to next for cooling ICT critical environments? *The Future of HVAC 2015 Conference.* Melbourne: Aurecon.

Hachem, C., Atheinitis, A., & Fazio, P. (2011). Parametric investigation of geometric form effects on solar potential of housing units. In *Solar Energy* (Vol. 25, p. 1864).

Hayama, H., & Nakao, M. (1989). Air Flow Systems for Telecommunication Equipmemt Rooms. *Proceedings of the 11th International Telecommunications Energy Conference ,* (pp. 1-7). Florence, Italy.

International Center for Ivestigative Report. (2015). *Switzerland To Spend US$8 Million On Boko Haram Affected Countries.* Adamawa: International Center for Ivestigative Report.

Iordache, V., Virgone, J., & Catalina, T. (2011). Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney. *Study of the Impact of the Building Form on Energy,* (p. 1726). Bucharest, Romania.

Ismail, R. A., Jusoh, N., & Makhtar, N. K. (2010). Assessment of Thermal Comfort: A Study at Closed and Ventilated Call Centre. *American Journal of Applied Science, 7*(3),402-407.

Ling , C. S. (n.d.). The Effect of Geometric Shape and Building Orientation on Minimising Solar Insolation on High-rise Building in Hot-Humid Climate. *Journal of Construction in Developing Countries*.

Los Alamos National Laboratory (LANL). (2002). *LANL Sustainable Design Guide.* Retrieved 4 2016, from http://www.doeal.gov/SWEIS/LANLDocuments/184%20LA-UR-02-6914.pdf.

Maeda, Y., Seshimo, Y., & Okazaki, T. (2005). Study of cooling System for a Telecommunication Base Site. In *Ashrae Transactions* (Vol. 111, pp. 746-755).

Marks, M. (1997). Multi-Criteria Optimization of Shapes of Energy Saving Buildings. *Built Environ Journal*, 331.

Muhaisen, S. A., & Abed, M. H. (2013). Investigation of the Thermal Performance of Building Form in the Mediterranean Climate of the Gaza Strip. *IUG Journal of Natural and Engineering Studies, 21*(1), 101-122.

Nakao, M., Hayama, H., & Uekusa, T. (1988). An Efficient Cooling System for Telecomunication Equipment Rooms. *10th International Telecommunications Energy Conference*, (pp. 344-349). San Diego, Canada.

Nigeria Business Information. (2005, June). Retrieved 2005, from Privatization in Nigeria: http://www.nathaneme.com/resource/ reports/privatization.

Olgyay, V. (1963). Design with Climate. *Bioclimatic Approach to Architectural Regionalism.* New Jersey: Priceton University, press.

Olusoji, O. (2000). The Performance of Privatized Firms in Nigeria. In *Privatization and Poverty Reduction in Nigeria* (pp. 23-33).

Oonuki, T., Ono, Y., Onuora, O., & Kashirajima, Y. (2013). Energy Saving Solution for Data Centers. *Hitachi Review*, 258.

Ross, M. (2009). *Design with Energy in Mind.* Retrieved 4 15, 2016, from http://uwspace.uwaterloo.ca/bitstream/10012/5076/1/Ross_Barbara.pdf.

Schmidt, R. R., & Shaukatullah, H. (2003). Computer and Telecommunication Equipment Room Cooling. In *IEEE Transactions on Components and Packaging Technologies* (Vol. 26(1), pp. 89-98).

Settlemeyre, K. (2009). *BIM and Performance Analysis: Integrated Environmental Solutions.* Retrieved 4 2016, from http://www.iesve.com/corporate/media- center/white-papers/iq-series/iq3.pdf.

Straube, J. (2012). *The Function of Form: Building Shape and Energy.* Retrieved August 16, 2012, rom Building Science Insights.: http://www.buildingscience.com/documents/insights/bsi-061-function- form building-

Taylor, P., Fuller, R. J., & Luther, M. B. (2008). Energy use and thermal comfort in a rammed earth office building. *Energy Build 40*, 793-800.

Udagawa, Y. (2016). Energy-saving Technology of Air conditioning Systems for Data centres. *NTT Technical Review*.

Udagawa, Y., & Matsuo, H. (2013). Power Supply Technology and Air Conditioning Technology for ICT. *NTT Technical Review*.

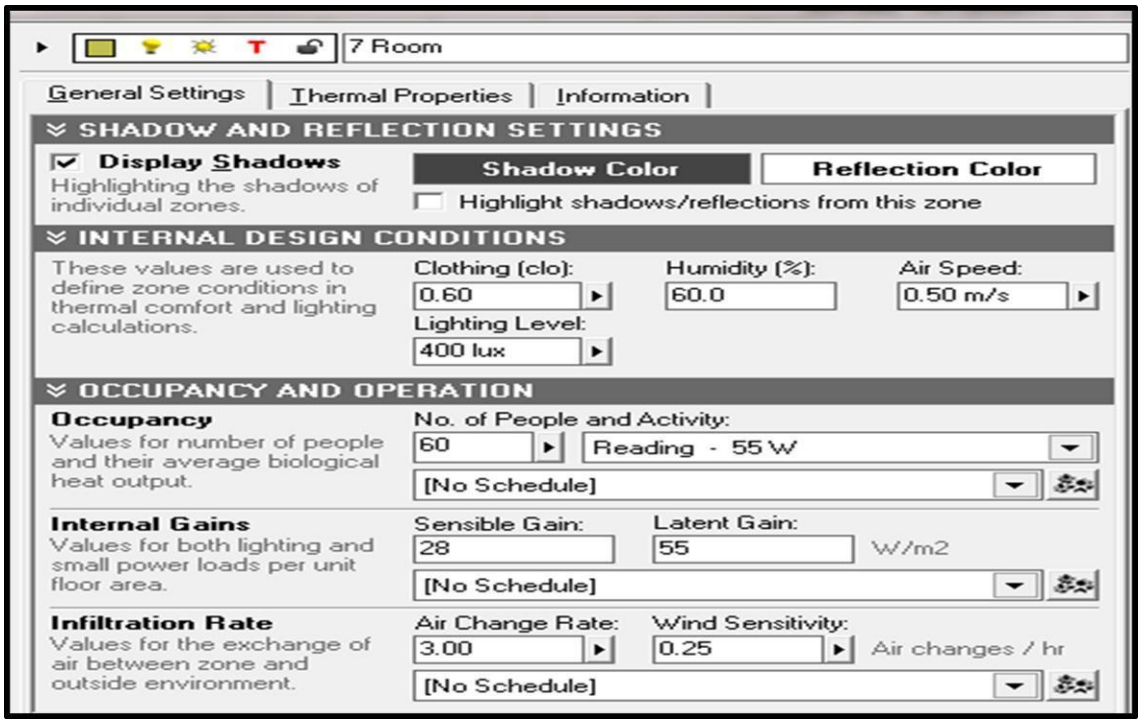
Yeang, K. (1994). Bioclimatic Skyscrapers. London, UK: Artemis London Limited.

Yosuke, U. (2014). Energy-saving Technology of Air-conditioning systems for Datacentres. *NTT Technical Review*, 1.

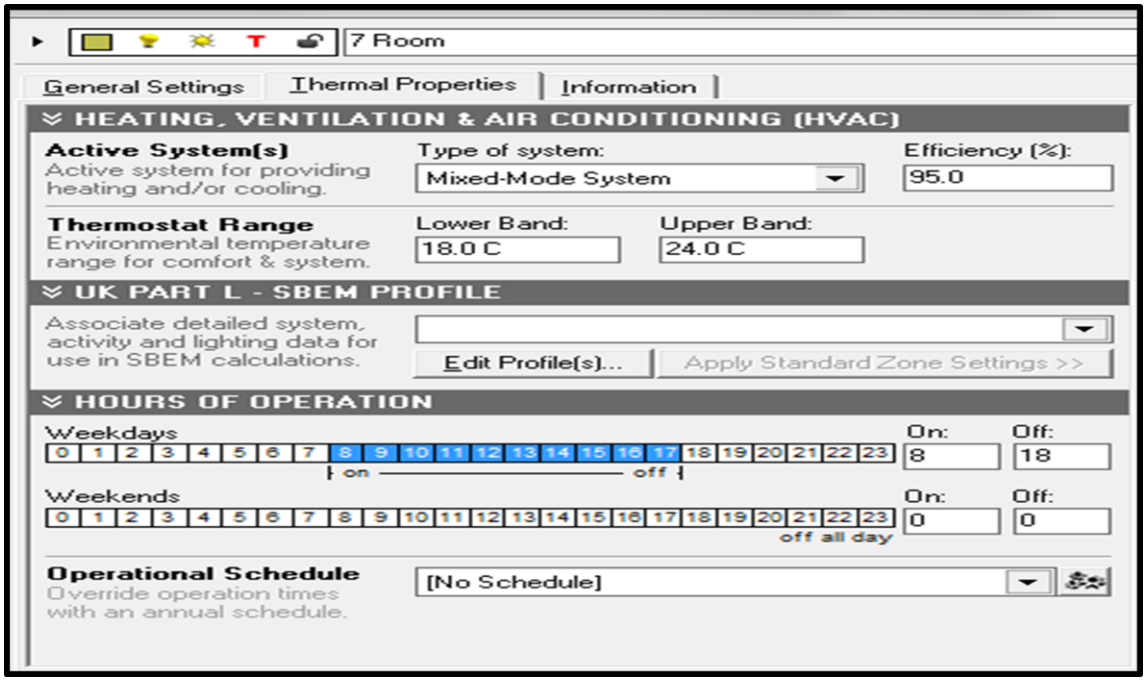
Zhang, Y., Chen, Y., Wu, J., & Meng, Q. (2008). Study on Energy Efficient Envelope Design for Telecommunication Base Station in Guangzhou. *Energy and Buildings*

APPENDICES

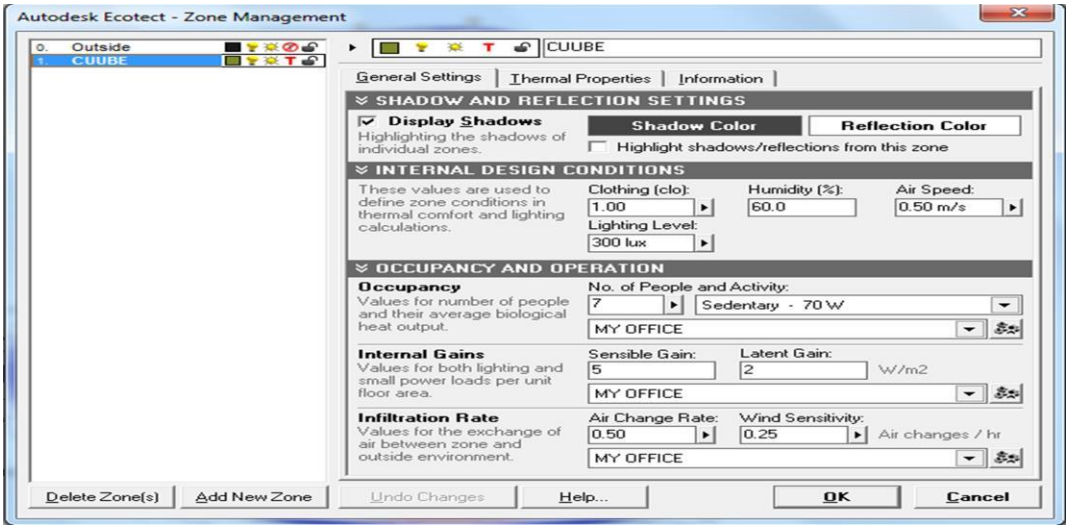
Appendix I: Thermal comfort conditions and comfort zone settings



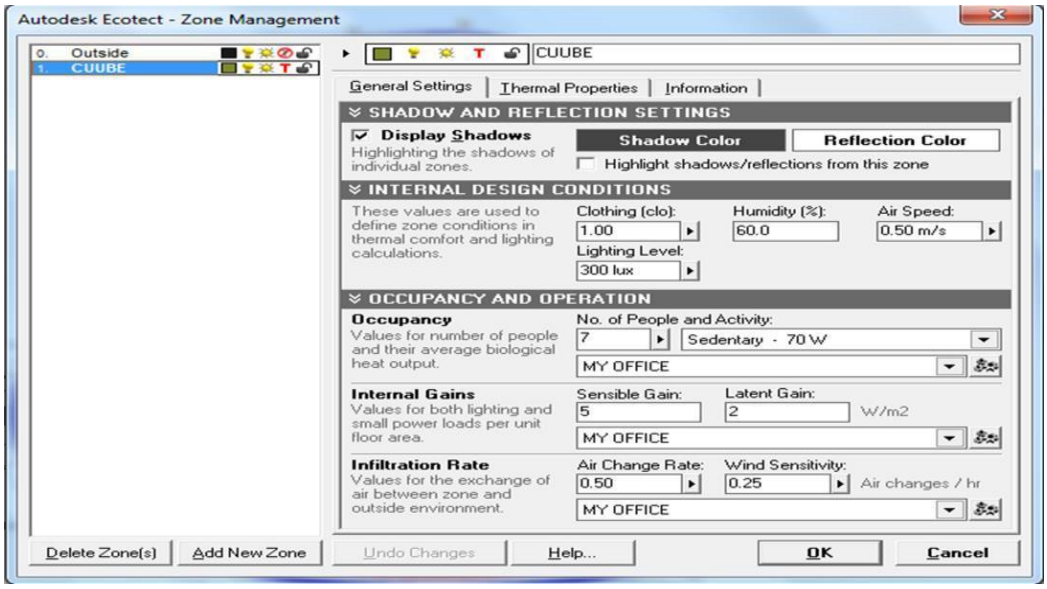
Appendix II: Thermal comfort conditions and comfort zone settings



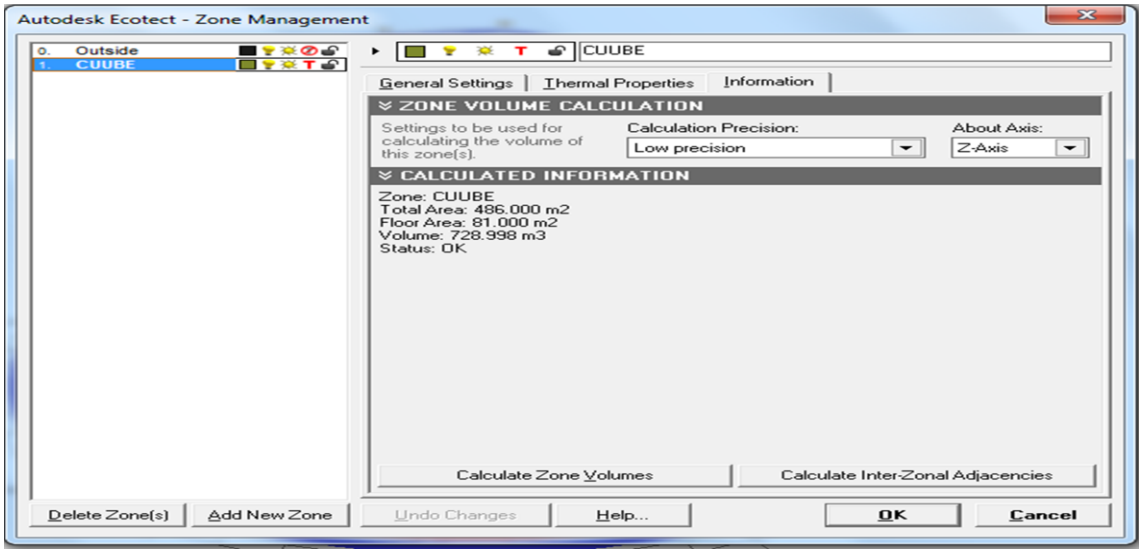
AppendixIII: Thermal and schedule settings in ECOTECT 2011



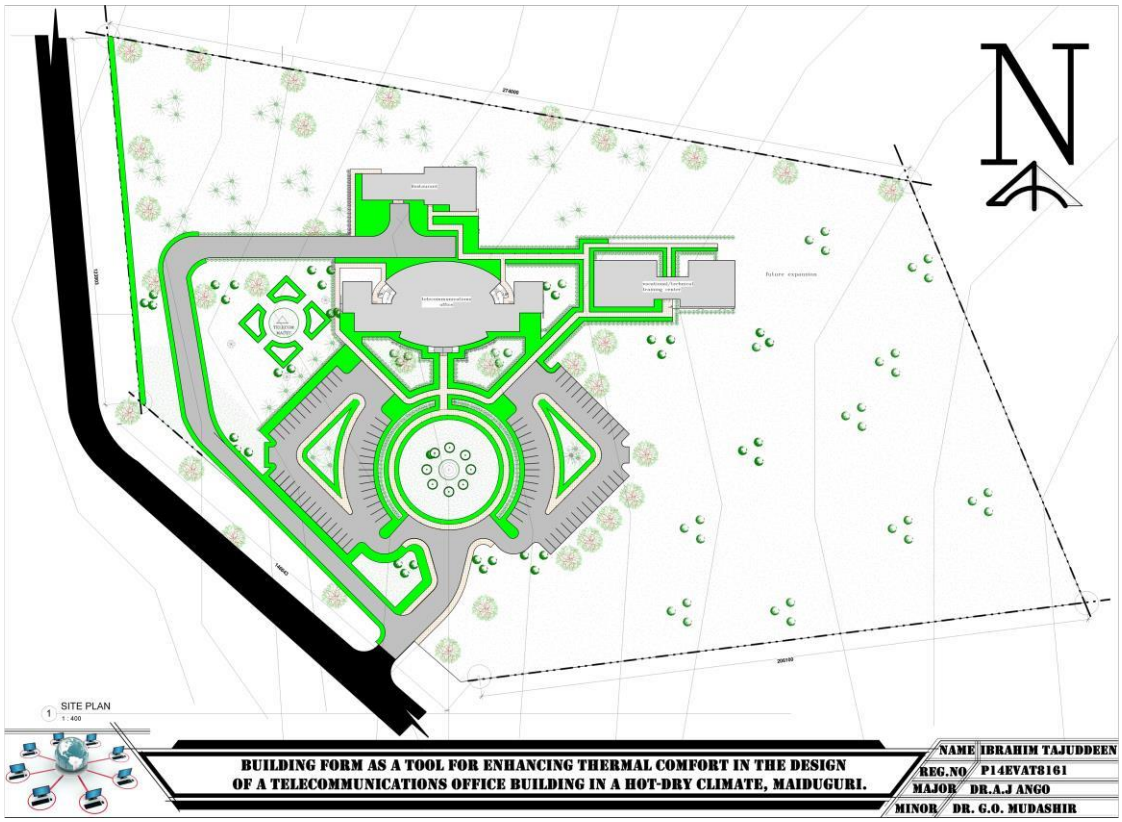
Appendix IV: Zone management general settings in ECOTECT 2011



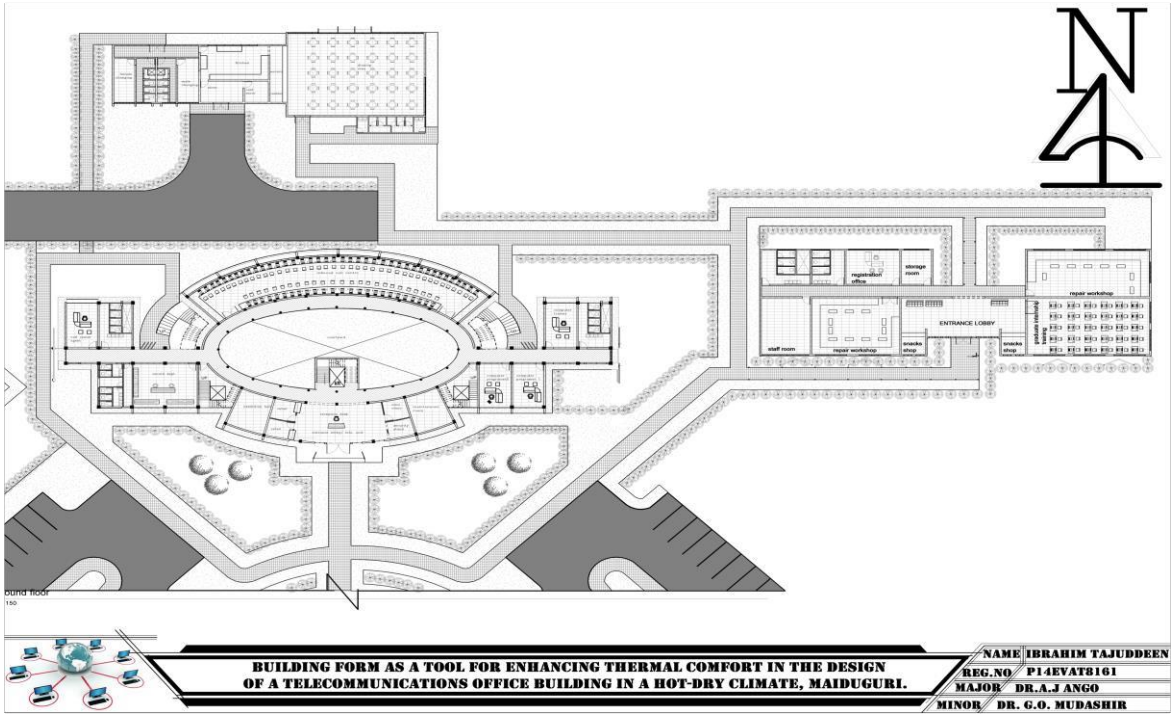
Appendix V: Zone information in ECOTECT 2011



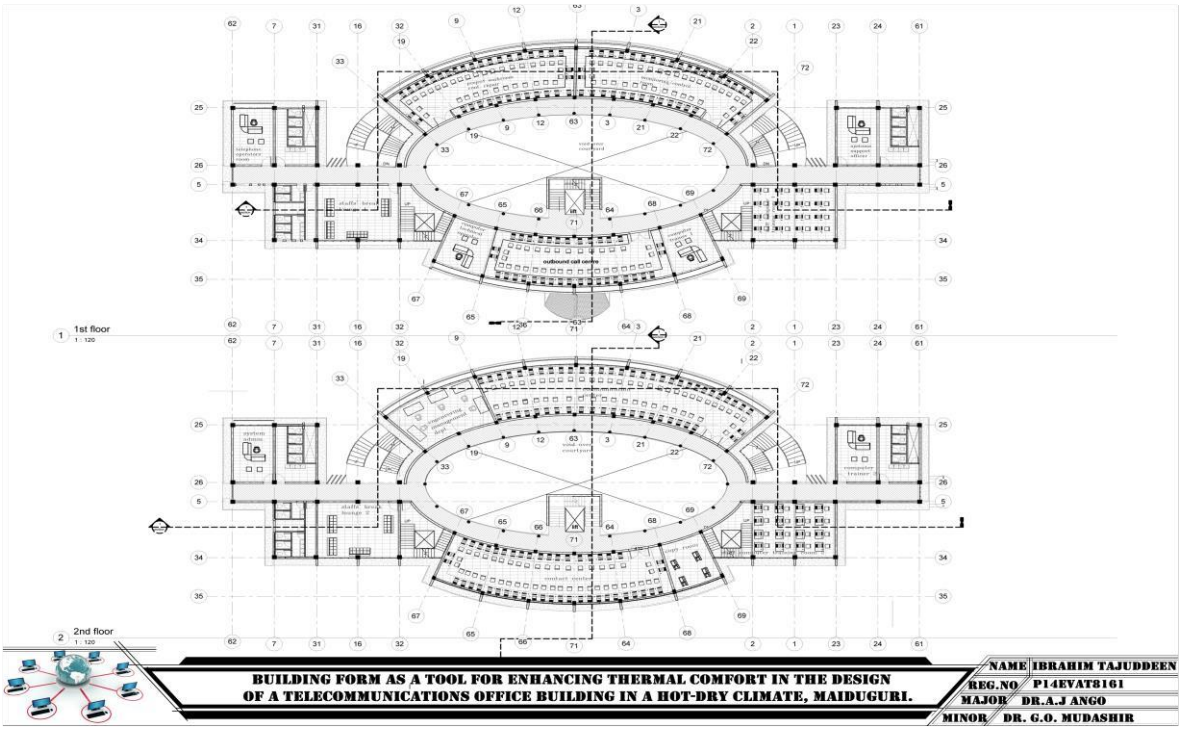
Appendix VI: Site plan of the proposed office building.



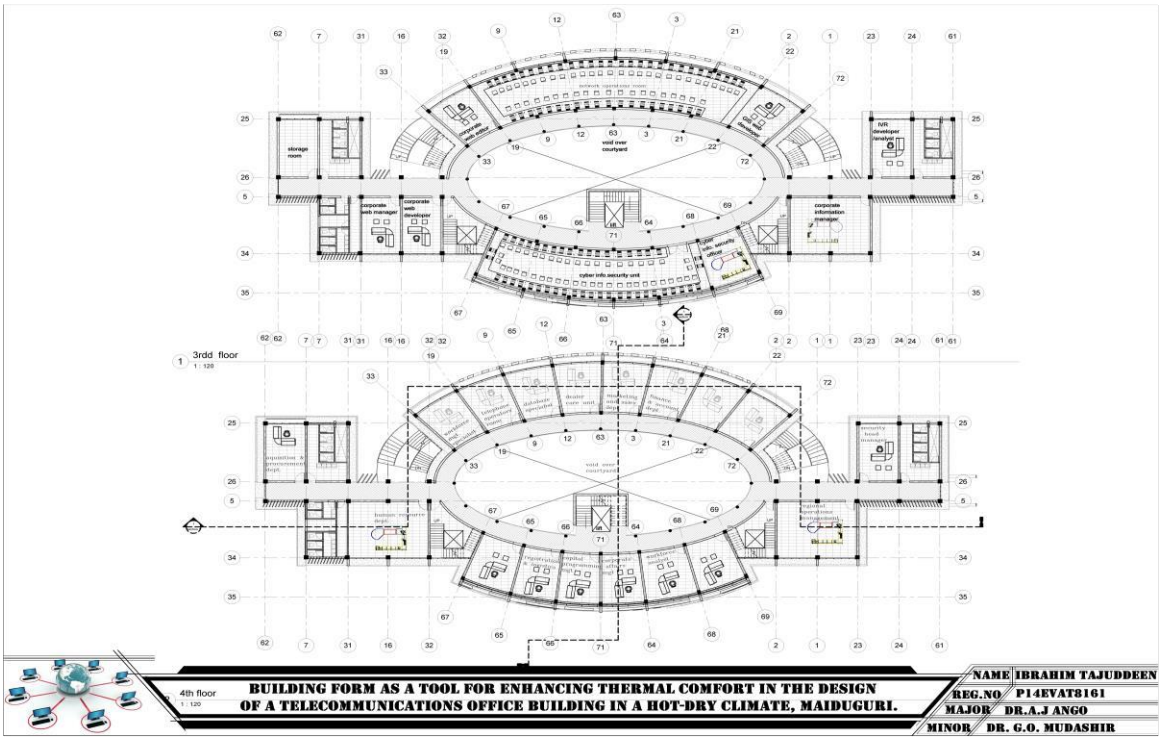
Appendix VII: Ground floor plan of the proposed office building



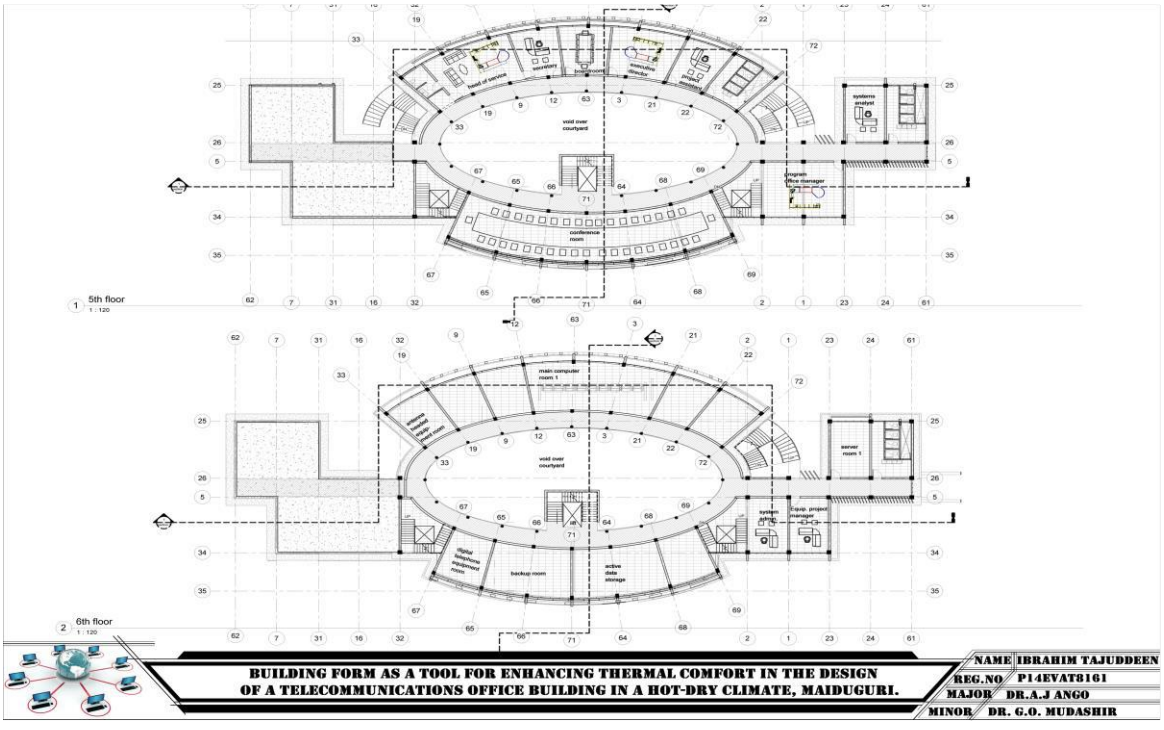
Appendix VIII : first and second floor plan of the proposed office building



Appendix IX: Third and fourth floor plan of the proposed office building



Appendix X: Fifth and sixth floor plan of the proposed office building



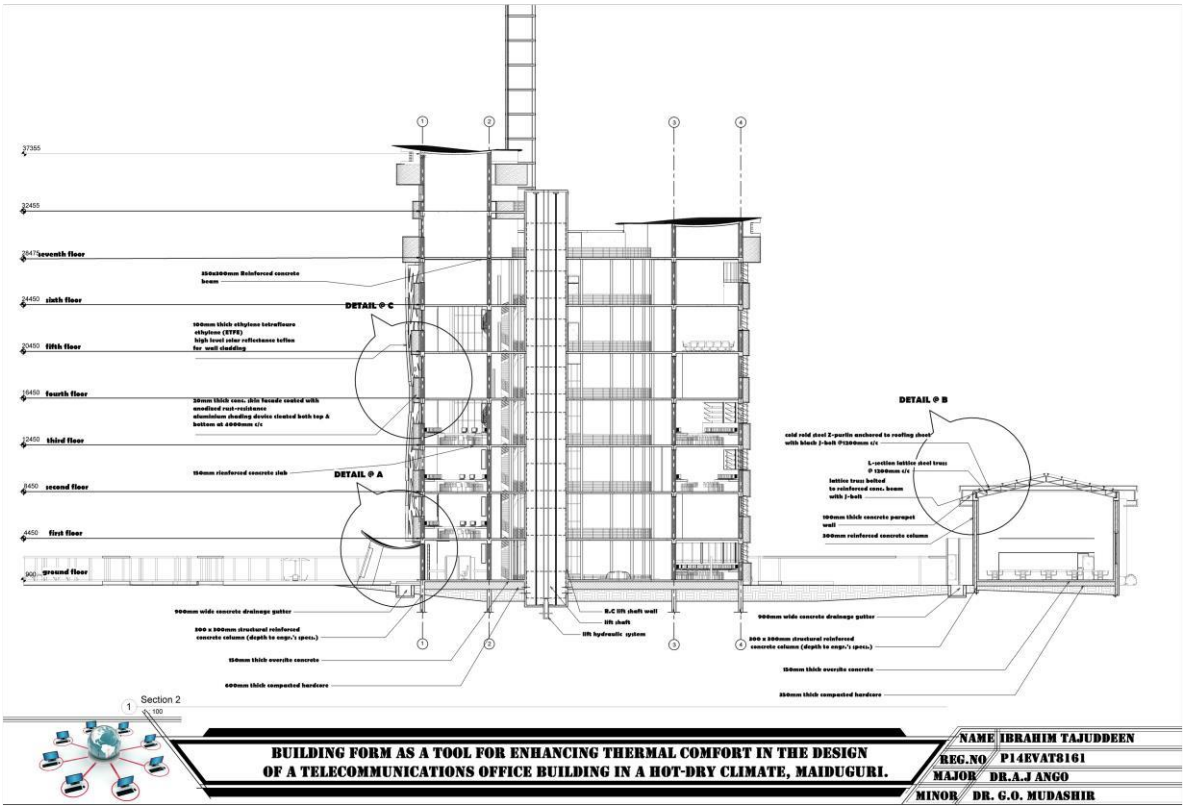
Appendix XI: South and west elevations of the proposed office building



Appendix XII: North and east elevation of the proposed office building



Appendix XIII: Section of the proposed office building



Appendix XIV: 3-D I of the proposed office building



Appendix XV: 3-D II of the proposed office building



Appendix XVI: 3-D III of the proposed office building

