ENHANCING THERMAL COMFORT USING VERTICAL GREENERY SYSTEMS (VGS) IN THE DESIGN OF A SUSTAINABLE MID- RISE ESTATE IN THE HOT DRY CLIMATE OF KANO, NIGERIA

By

AISHA DHULQARNAIN

DEPARTMENT OF ARCHITECTURE

FACULTY OF ENVIRONMENTAL DESIGN,

AHMADU BELLO UNIVERSITY, ZARIA

FEBRUARY, 2020

ENHANCING THERMAL COMFORT USING VERTICAL GREENERY SYSTEMS (VGS) IN THE DESIGN OF A SUSTAINABLE MID- RISE ESTATE IN THE HOT DRY CLIMATE OF KANO, NIGERIA

BY

Aisha DHULQARNAIN BSc (ABU) 2016

P16EVAT8049

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

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF

A

MASTER OF SCIENCE DEGREE IN ARCHITECTURE.

DEPARTMENT OF ARCHITECTURE

FACULTY OF ENVIRONMENTAL DESIGN,

AHMADU BELLO UNIVERSITY, ZARIA

FEBRUARY, 2020

DECLARATION

I declare that the work in this Thesis entitled 'ENHANCING THERMAL COMFORT USING VERTICAL GREENERY SYSTEMS (VGS) IN THE DESIGN OF A SUSTAINABLE MID- RISE ESTATE IN THE HOT DRY CLIMATE OF KANO, NIGERIA has been carried out by me in the Department of Architecture under the supervision of Prof. S. N. Oluigbo and Dr. R.B. Tukur. The information derived from the literature has been duly 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.

AISHA DHULQARNAIN		February, 2020
Name of Student	Signature	Date

CERTIFICATION

This Thesis entitled ‘‘ENHANCING THERMAL COMFORT USING VERTICAL GREENERY SYSTEMS (VGS) IN THE DESIGN OF A SUSTAINABLE MID- RISE ESTATE IN THE HOT DRY CLIMATE OF KANO, NIGERIA by Aisha DHULQARNAIN meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. S. N. Oluigbo		
Chairman, Supervisory Committee	Signature	Date
Dr. R. B. Tukur		
Member, Supervisory Committee	Signature	Date
Dr. A.S Salisu		
Head of Department	Signature	Date
Prof. S.A. Abdullahi		
Dean, School of Postgraduate Studies	Signature	Date

DEDICATION

I dedicate this Dissertation to Allah (SWT) the Almighty in whose Hands is my soul. Alhamdulillah.

ACKNOWLEDGEMENT

All praise is due to Allah, who has always guided me and given me the strength and wisdom to face all the challenges during the cause of writing this research thesis.

My profound appreciation goes to my dearest father Engr. Ibrahim Sulu who has sacrificed a lot and has always been there for me. May Allah reward you here and in the hereafter, Aameen. To my sweetest mama and sestra, I miss you so much and pray for a happy reunion, love you loads. My step mother and my siblings, I appreciate everything may Allah grants us success here and in Akhira. To my Aunt, Mrs Yusuf and her family, thanks for all the love and support. My sweetest uncle Abdullah and his family, JazakAllahuKhairan. Also, Maman Safiyya and her family, thanks for everything.

A special thanks to my supervisor Prof. Stephen N. Oluigbo who guided and left no stone unturned in ensuring that quality work is produced. My appreciation also goes to Dr. R.B. Tukur for guiding me during the cause of this research. In addition, my gratitude goes to all my lecturers especially Arc Salihu Murtala who have given their time to go through my work and for their valued contributions in form of constructive criticism that made the research work better.

This acknowledgement would be incomplete without the mention of my friends Hussaina Dansarai, Maryam Bappa, Maryam Ali, Aisha Lami, and my roommates who have helped me through this research. My special thanks to my student mentors mallam Abdulbasit, mallam Yusuf Shinks, Arc Tayyib, Arc Tosin and Arc Ahmad.Thanks for everything, to friends and colleagues, space is a limiting factor in mentioning you all but I appreciate you all and hope we keep the relationship to make our profession a great one.

ABSTRACT

In battling some of the most alarming situations the world is facing right now which are the climate change and global warming, architects are saddled with the responsibility of designing buildings that are energy efficient as buildings account for about 40% of the total energy use. About 40-60% is utilized in cooling the institutional building while in residential buildings, cooling accounts for 30% of the total energy use. In order to reduce carbon emissions and decrease urban heat islands, ecofriendly methods must be employed when designing buildings. This research therefore seeks to enhance thermal comfort using Vertical Greenery Systems (VGS) as an architectural strategy in residential buildings in the hot dry climate of Kano that is known to have very high temperatures.

The study entails the use of visual survey and computer simulation. Case studies on VGS application were carried out in Kaduna and Kano and simulation was carried out using Design Builder® and EnergyPlus® as the simulation engine as this is one of the most common, free and validated simulation software. At the end of the simulation analysis to determine the effect of VGS on thermal comfort, it is found that living walls have the highest impact on temperature reduction attaining a maximum of 7°C using 100% coverage ratio on all orientations. A reduction of 5.35°C was attained using indirect green facades. All the temperatures obtained after the VGS was applied fell in the range of ASHRAE standard 55 (22.2°C-26.7°C) which is the benchmark for thermal comfort in hot dry climates A residential estate was then proposed using the findings from the research. The results of the research implied that living walls are suitable for west and east orientations and green facades for the north and south orientations. The research recommends that simulation softwares should integrate green wall modules to enhance research process and further studies should be carried out on other plants and types of VGS such as the direct green facades.

TABLE OF CONTENTS

Cover Page .....

Fly Leaf 1

Title Page 2

Declaration i

Certification ii

Dedication iii

Acknowledgement iv

Abstract v

List of Figures xi

List of Tables xii

List of Plates xiii

List of Appendices xv

Abbreviations and Definition of Terms xvii

1.0 INTRODUCTION 1

1.1 Background to the Study 1

1.2 Problem Statement 3

1.3 Justification 3

1.4 Aim and Objectives 4

1.5 Research Questions 4

1.6 Scope 4

2.0 LITERATURE REVIEW 6

2.1 Introduction 6

2.2 The concept of Vertical Greenery Systems (VGS) 6

2.2.1 Benefits of VGS in Buildings 6

2.2.2 Classification of VGS 8

2.3 Effects of VGS on thermal comfort 14

2.3.1 Mechanisms through which VGS acts as a passive technique. 14

2.4 Parameters to be considered for the application of VGS 23

2.4.1 Plant species selection 23

2.4.2 Orientation of the façade 27

2.5 Computer Simulation 28

2.5.1 Simulation softwares 28

2.5.2 Validation and Reliability 29

2.5.3 Simulating VGS 29

2.6 Mid-rise Housing Design 30

2.7 Estate Design 30

2.7.1 Guidelines in Midrise estate design 31

2.8 Summary 32

3.0 RESEARCH METHODOLOGY 35

3.1 Introduction 35

3.2 Research Design 35

3.2.1 Case Study Research Design 35

3.3 Research Variables 36

3.4 Sampling Method 36

3.4 Methods and Instruments of Data Collection 36

3.5 Procedure for Data Collection 37

3.6 Simulation 37

3.7 Data Analysis 37

4.0 RESULTS AND DISCUSSION 39

4.1 Introduction 39

4.2 Case Study One (Three Bedroom bungalow) 39

4.2.1 Background 39

4.2.2 VGS description 39

4.3 Case Study Two (A-two storey building) 41

4.3.1 Background 41

4.3.2 VGS description 41

4.4 Summary of results from case study 42

4.5 Simulation Results and Discussion 43

4.5.1 Base-case modelling 45

4.5.2 Variables to be examined 45

4.5.3 Constant variables 46

4.5.4 Comfort profile of the base case 46

4.6 VGS models 48

4.6.1 Indirect greening façade Modelling 48

4.6.2 Indirect Green Façade VGS Model Case 49

4.6.3 Modular living wall VGS Model Case 54

4.7 Summary of results from the simulation 59

5.0 DESIGN PRELIMINARIES 61

5.1 Introduction 61

5.2 Study Area 61

5.2.1 Weather and Climate 61

5.2.2 Vegetation 61

5.3 Site Location 62

5.4 Site Selection Criteria 62

5.4.2 Site 2 63

5.4.3 Site 3 64

5.5 Site analysis 65

5.5.1 Site Location 65

5.5.2 Site Climate 66

6.0 DESIGN REPORT 70

6.1 Brief Development 70

6.3 Design Consideration 70

6.3.1 VGS systems 70

6.3.2 Plant selection 71

6.3.3 Orientation 72

6.3.4 Site planning 72

6.3.5 Services 73

6.4 Schedule of accommodation..... 73

7.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS 77

7.1 Introduction..... 77

7.2 Summary..... 77

8.3 Conclusion 78

8.4 Contributions to knowledge..... 79

8.5 Recommendations..... 79

References..... 80

Appendices..... 86

LIST OF FIGURES

Figure 4.1: Base Case Model generated from DesignBuilder. 45

Figure 4.2: Comfort profile of base case from simulation..... 47

Figure 4.3: Indirect greening using building shading object. 49

Figure 4.4: Air temperature using LAI values 1, 3 and 5 50

Figure 4. 5:Comparing the effects of LAI values on air temperature under 50% coverage 50

Figure 4.6: Comparing LAI value 5 of 50% and 100% coverage ratios. 51

Figure 4.7: Operative temperature between basecase and LAI 5 of 50 and 100% coverage 52

Figure 4.8: East surface temperature of Base case and Variant 2 53

Figure 4.9: West surface temperature of Base case and Variant 2. 53

Figure 4.10:South surface temperature of Base case and Variant 3 54

Figure 4.11: Living wall VGS model in DesignBuilder..... 55

Figure 4.12: Living wall VGS model Case..... 56

Figure 4.13: Air and Operative temperature comparison between Base Case and Living 56

Figure 4.14: Difference in humidity between the Base Case and Living wall Variant 1 57

Figure 4.15: East surface temperature Base Case and LW Variant 2 58

Figure 4.16: West Inside surface temperature Base Case and LW Variant 2..... 58

Figure 4.17: South surface temperature Base Case and LW Variant 3 59

LIST OF TABLES

Table2.1a Summary of Studies on VGS applications..... 21

Table2.1b Summary of Studies on VGS applications 21

Table2.2 Plants Specie and their Benefits..... 23

Table2.3 Simulation softwares used in earlier VGS Studies. 28

Table2.4 VGS Types and their characteristics..... 32

Table 4.1 Showing summary of data from the case studies. 43

Table 4.2 Air temperature and Relative humidity for the Base Case..... 47

Table 4.3 Properties of VGS assigned to building shading object..... 48

Table 4.4 Variants of the indirect greening façade model 49

Table 4. 5 Parameters assigned to different layers for the VGS model. 55

Table 4.6 Variants of the living wall (LW) VGS model..... 56

Table 4.7 Summary of results attained from simulation..... 60

Table 5.1a Site Selection Criteria 64

Table 5.1b Site Selection Criteria..... 65

Table 6.1 Schedule accommodation for two-bedroom prototype for low income earners 73

Table 6.2 Schedule accommodation for three-bedroom prototype for low income earners 74

Table 6.3a Schedule accommodation for three-bedroom for middle income earners 74

Table 6.3b Schedule accommodation for three-bedroom for middle income earners... 75

Table6.4a Schedule accommodation for four-bedroom duplex for high income earners 75

Table6.4b Schedule accommodation for four-bedroom duplex for high income earners 76

LIST OF PLATES

Plate I: Application of VGS on building façade.. 8

Plate II: Application of Internal Living Walls.. 8

Plate III: Direct green façade.. 10

Plate IV: Indirect green facade.. 10

Plate VI: Example of Indirect Greening. 10

Plate VII: Example of Indirect Greening combined with planter box.. 11

Plate VIII: Living wall with a panel system 13

Plate IX: Living wall with an active system 13

Plate X: Examples of Living walls 13

Plate XI: Amount of radiation absorbed, reflected and transmitted on single leaf layer.. 25

Plate XII: VGS on the wall facing east 40

Plate XIII: VGS on wall facing north 40

Plate XIV: VGS on the west facade 42

Plate XV: VGS on the north facade 42

Plate XVI: Image showing all three sites on google earth. 62

Plate XVII: Image showing site 1 on google earth. 63

Plate XVIII: Image showing site 2 on google earth. 63

Plate XIX: Image showing site 3 on google earth. 64

Plate XX: Image showing average temperature in Kano 66

Plate XXI: Image showing relative humidity in Kano 67

Plate XXII: Image showing average rainfall in Kano State. 67

Plate XXIII: Images showing roads and electric lines on site. 68

Plate XXIV: Image of vegetation on site 68

Plate XXV: Image showing site section draining towards the stream 69

Plate XXVI: Image showing site section draining towards the south. 69

Plate XXVII: Images showing plants adopted in VGS 72

LIST OF APPENDICES

Appendix I:Site Plan of proposed mid-rise residential estate..... 86

Appendix II: Ground floor plan of 2 bedroom for High Density..... 86

Appendix III: First - Fifth floor plan of 2 bedroom for High Density. 87

Appendix IV: Approach and Rear Elevations of 2 bedroom High Density. 87

Appendix V: West and East Views of 2 bedroom High Density..... 88

Appendix VI: Working Floor Plan of 2 bedroom High Density. 88

Appendix VII: Section X-X of 2 bedroom High Density. 89

Appendix VIII: Ground floor plan of 3 bedroom for High Density..... 89

Appendix IX: First - Fifth floor plan of 3 bedroom for High Density. 90

Appendix X: Approach and Rear Elevations of 3 bedroom High Density..... 90

Appendix XI: West and East Views of 3 bedroom High Density. 91

Appendix XII: Working Floor Plan of 3 bedroom High Density. 91

Appendix XIII: Section X-X of 3 bedroom High Density. 92

Appendix XIV: Ground floor plan of 3 bedroom for Medium Density. 92

Appendix XV: First - Third floor plan of 3 bedroom for Medium Density. 93

Appendix XVI: Approach and Rear Elevations of 3 bedroom Medium Density..... 93

Appendix XVII:West and East Views of 3 bedroom Medium Density. 94

Appendix XVIII: Working Floor Plan of 3 bedroom Medium Density.. 94

Appendix XIX: Section X-X of 3 bedroom Medium Density. 95

Appendix XX: Ground floor plan of 4 bedroom duplex for Low Density. 95

Appendix XXI: First floor plan of 4bedroom duplex for Low Density. 96

Appendix XXII: Approach and Rear Elevations of 4bedroom duplex for Low Density. 96

Appendix XXIII: West and East Views of 4bedroom duplex for Low Density. 97

Appendix XXIV: Working Floor Plan of 4bedroom duplex for Low Density. 97

Appendix XXV: Sections of 4bedroom duplex for Low Density..... 98

Appendix XXVI: Details of Living wall and Direct green facade. 98

Appendix XXVII: Details of Concrete planters and Steel support for climbers..... 99

Appendix XXVIII: Details of planter 99

Appendix XXIX: Checklist for VGS 99

Appendix XXX: Checklist for Residential Building..... 99

ABBREVIATIONS AND DEFINITION OF TERMS

VGS	Vertical Greenery Systems.
LAI	Leaf Area Index
ETTV	Envelope Thermal Transfer Value
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
VGS	These are structures that allow vegetation to spread over a building façade or an interior wall.
THERMAL COMFORT	This is that state of mind which expresses satisfaction with the thermal environment.
LIVING WALL	This is a type of VGS which are also called green walls and vertical gardens are constructed from modular panels containing soil or other artificial growing medium such as foam, felt, perlite and mineral wool.
GREEN FACADE	This is a type of VGS also known as green screen which are formed by climbing plants or cascading groundcover that are usually supported by cables or trellis.
EVAPOTRANSPIRATION	is the process by which water is transferred from the land to the atmosphere through transpiration from plants.
FOLIAGE DENSITY	This refers to the thickness of the plant canopy that is, layers of leaves of plants.
LAI VALUE	This is the Leaf Area Index which is a relation between the leaf area and the square meters of façade.
COVERAGE RATIO	This is the total area covered by the VGS in relation to the area of the façade

1.0 INTRODUCTION

1.1 Background to the Study

Over the years researches has been carried out on how to improve thermal comfort within spaces and buildings with emphasis on bioclimatic design principles (Hussaini, 2016), building materials such as double cavity walls (Musa, 2016) and building envelope design (Arowona, 2017), these studies were conducted on institutional typologies such as office buildings, hotels, recreation centers and so on. Previous studies also show a lot of work carried out on thermal comfort in residential typologies, (Akande and Adebamowo, 2010; Adaji and Watkins, 2015; Abdulkareem, Almaiyah and Cook, 2015). However, only little work had been carried out on Vertical Greenery Systems (VGS) in Nigeria which includes the works of Akinwolemiwa and Gwilliam (2015) and (Akinwolemiwa, Bleil de Souza, De Luca and Gwilliam, 2018) which were carried out in the hot and humid climate of Lagos state. This research therefore is focused on VGS in the hot dry climate of Nigeria to explore and investigate its application in this climate. Furthermore, there is a wide gap in research on the application of Vertical Greenery Systems (VGS) such as green walls to enhance thermal comfort in Nigeria (Akinwolemiwa and Gwilliam, 2015) as most works done are being carried out in Europe, Asia and the United States with climate such as the hot and humid or the temperate region.

The application of plants in buildings has been in existence for years as seen from the hanging gardens of Babylon (Dahanayake and Chow, 2017). As technology progressed, there are more effective and advanced methods of integrating these plants in buildings and thus the concept of Vertical Greenery Systems (VGS) came into being. VGS are structures that allow vegetation to spread over a building façade or an interior wall (Pérez, Cañero, Franco and Egea, 2016). It is mainly categorized into two based on the growing mechanisms which is the carrier and support (Jaafar, Said and Rasidi, 2011) and are also called living walls and green facades (Pérez, *et al*.,2016).

In battling one of the most alarming situations the world is facing right now which is the climate change and global warming, architects are saddled with the responsibility of designing buildings that are energy efficient as buildings account for about 40% of the total energy use (Perini, Ottelé, Haas and Raiteri, 2011;Raji, Tenpierik and Dobbelsteen, 2014). Most of the energy, about 40-60% is utilized in cooling the institutional building while in residential buildings, cooling accounts for 30% of the total energy use (Federal Ministry of Power, 2016). For architects to contributes their own quota in ensuring the sustainable energy goal of 2030, buildings have to be designed to reduce their energy use and still achieve the desired target.

Plants are known to be excellent in providing microclimate in an environment and have a number of advantages, as such their importance can't be over-emphasized (Prihatmanti and Taib, 2017) They are adopted in bioclimatic design as landscaping, which is one of its major principles in enhancing thermal comfort. Plants are known to provide shade against solar radiation, serve as wind breakers and cool the environment through evapo-transpiration (Afshari, 2017). Research has shown that the application of plants on building façade can cool down the ambient temperature of the immediate environment up to 20°C (Mazzali, Scarpa and Peron, 2014). This is due to the evaporation from the plants and substrate material which is known as evapo-transpiration. In addition, when plants are placed on the interior walls, they improve the indoor temperature and air quality as they filtrate the sorrounding air and are such called biofilters (Raji *et al*.,2014).

Greening has become one of the fastest solutions in the world where rapid urbanisation is the order of the day,as plants absorb the carbon around and give out oxygen in exchange (Dahanayake and Chow, 2017). Integrating plants in buildings will not only enhance thermal comfort but will render other benefits such as wind and noise breaking, reducing

energy consumption, acting as food supply (vertical farming), shading and aesthetics (Prihatmanti and Taib, 2018).

1.2 Problem Statement

Research has shown that Vertical Greenery Systems (VGS) are effective in cutting down the energy used for cooling and enhancing thermal comfort in buildings. Hence, VGS have been applied to various kinds of buildings ranging from institutional to residential, low-rise to high-rise. Previous studies in Nigeria show a lot of work carried out on thermal comfort in residential typologies with emphasis on building envelope, building materials and so on. However, only a few of these works had been carried out on Vertical Greenery Systems (VGS) which was carried out in the hot and humid climate of Lagos state. Most of the studies on VGS were conducted in temperate and fully humid climates, humid sub-tropical and Mediterranean climates in the developed countries. Little has been done on tropical and arid regions and the developing countries. Due to VGS peculiarity with plants it is important to know how these plants behave under different climatic conditions and as to what plants are suitable for a particular climate, as such results from one climate is not sufficient enough to be applied to another. This is why this research is set to investigate how VGS can enhance thermal comfort in the hot dry climate of Nigeria.

1.3 Justification

There is need to provide a thermally comfortable and conducive environment for residents which can only be achieved by finding techniques to mitigate the effects of climate change and global warming such as urban heat island and pollution. Plants are known to be very effective in providing a micro climate, reducing and cooling the surrounding temperature and even filtrating the air. They are one of the best solutions in mitigating urban heat island. By integrating VGS in buildings, energy consumption is reduced as plants are proven to cool the environment, serve as insulation and provide a means of shading.

In addition, there are very few studies available on VGS for enhancing thermal comfort in Nigeria, not only in residential buildings but the whole built environment (Koc, Alan and Paul, 2018). This research contributes to the body of knowledge in response to the Sustainable Development Goals (SDG's) and the 2030 agenda for sustainable energy.

1.4 Aim and Objectives

The aim of this study is to enhance thermal comfort using VGS as an architectural strategy through the following objectives:

1. To examine the relationship between VGS and indoor thermal comfort in buildings.
2. To evaluate the application of VGS characteristics in selected visual survey and assessments.
3. To determine the effects of VGS on thermal comfort in residential building design through computer simulation in the hot dry climate of Nigeria
4. To demonstrates the outcome of the study in the design of a midrise housing estate.

1.5 Research Questions

1. What is the relationship between VGS and indoor thermal comfort in buildings?
2. What are the effects of VGS on thermal comfort of residents in residential building design in hot dry climates of Nigeria?
3. How can the result of the study be best demonstrated in the design of a midrise housing estate?

1.6 Scope

For the purpose of this research, the application of VGS is limited to providing thermal comfort through the shading, evapotranspiration and thermal insulation effects only. The

research is limited to kano state which has a hot and dry climate. The issue of maintenance and occupancy behavior is beyond the scope of this study.

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter gives an overview of Vertical Greenery Systems (VGS), its applications, benefits, relationship with thermal comfort and discusses what has been done from relevant literature. It also sheds light on midrise housing design.

2.2 The concept of Vertical Greenery Systems (VGS)

Vertical Greenery Systems (VGS) can be defined as structures that allow vegetation to spread over a building façade or an interior wall. They consist of vertical structures that spread vegetation that may or may not be attached to a building façade or the interior wall (Pérez, *et al*.,2016). VGS are also known as wall gardens or plants on walls. They are also termed as green-wall technologies, vertical gardens or biowalls. Vegetating of building facades has been in existence since ancient times and as such has been identified as a traditional architectural feature. It dates back to 2000 years ago in the Mediterranean region (Perini *et al*.,2011). These vegetated walls were basically built with self-climbing plants. They have been used in the UK, Europe and in North American cities since the seventieth century. Over the past years there have been significant technological advancements in its application making it more efficient and flexible. Modern VGS are capable of fitting into a wide range of building applications, approaching higher elevations and overcoming most of the limitations encountered previously (Dahanayake and Chow, 2017).

2.2.1 Benefits of VGS in Buildings

Application of greeneries in and on buildings has been recognized as a potential approach in the hot and humid climate to mitigate urban heat island and provide a suitable microclimate (Prihatmanti and Taib, 2018). A lot of research has been carried out with emphasis on the benefits of greeneries in building, focusing mainly on energy efficiency,

cooling strategy, and thermal comfort improvement such as (Perini *et al*.,2011; Jaafar *et al*.,2011; Raji *et al*.,2014; Coma *et al*., 2017; Afshari, 2017), VGS as a source of growing food (Despommier, 2009; Abel, 2010). Occupants' comfort, satisfaction and productivity (Taib and Abdullah, 2012). Carbon sequestration of plants (Amir, Yeok and Rahman, 2014; Charoenkit and Yiemwattana, 2017). VGS is found to be very effective and has function as the green roof (Raji *et al*., 2014). The vertical skin of a building is larger than the roof area and as such found to be important especially for tall buildings, researchers have established some of the benefits of VGS in buildings which are as follows:

1. Reduction of energy consumption
2. Improving thermal comfort
3. Reduce thermal sequestration by growing edible plants
4. Act as food supply (vertical farming)
5. Act as noise barrier
6. Wind braking
7. Shading and Aesthetics

Both living wall and green façade have been proven to reduce the outdoor wall surface and air temperature up to 11°C and 4.71°C respectively (Sunakorn and Yimprayoon, 2011). It is also proven that VGS has its maximum performance in the daytime in terms of its shading, evapotranspiration, and photosynthesis (Wong *et al*.,2010). The work of Wang, Er and Abdul-Rahman (2016) stated that VGS is also effective in improving the aesthetic value of the building as it enhances the visual impact and hide unsightly features this is also in line with the work of White and Gatersleben (2011) who assessed the aesthetic impact and the level of perceived restoration that may be achieved by placing green roofs and facades onto homes. The study revealed that houses with building-integrated vegetation were more preferred and considered more beautiful, aesthetically

pleasing, and restorative than those without vegetation. The plates I and II below show some examples of existing living walls used on both interior and exterior walls.



Plate I: Application of VGS on building façade. Source: Prihatmanti and Taib (2017).



Plate II: Application of Internal Living Walls. Source: Prihatmanti and Taib (2017).

2.2.2 Classification of VGS

According to Pérez *et al*., (2016), VGS can be divided into two major groups Green facades and Living walls which are classified based on the growing mechanism; carrier and support (Jaafar *et al*., 2011)

2.2.2.1 Green Facades

Green Facades also known as green screens are formed by climbing plants or cascading groundcover that are usually supported by cables or trellis. (Perini *et al*.,2011) They are usually rooted at the ground in planters. They can also consist of intermediate planters fixed to the wall at certain spacing, or they are seen falling from rooftops as green cascades over the wall (Pérez, e*t al.*, 2016). According to Perini *et al*., (2011), Green

Facades are classified into three; direct greening, indirect greening and indirect greening combined with planter box.

i. Direct greening; plants are grown on building façade from the ground.
ii. Indirect greening: this involves using cables or meshes to support plants for climbing. It is also known as double skin green façade.
iii. Combination of indirect with planter box: this combines cables, meshes and planter box.

The application of different systems and materials can have either positive or negative influence on the environmental burden. Taking into consideration the plants species, materials involved, benefits to be derived is a sustainable option for new constructions and retrofitting. Consequently, the system or method of VGS must be cautiously considered. It has to be effective, economical, feasible, aesthetically pleasing and suits the climatic condition of the location (Prihatmanti and Taib, 2018).

According to Perini *et al*., (2011), the direct greening system has a very small influence on the total environmental burden, for this reason this type of greening, without any additional material involved, is always a sustainable choice for the examined cases.

The indirect greening system which involves the use of support for growth was seen to have high influence on the total environmental burden when using stainless steel supporting system. Materials such as wood, plastic, aluminum and steel can also be used as supporting system which makes the environmental burden of the system about 10 times lower than the stainless-steel mesh (Perini *et al*., 2011). The plates III, IV, and V below illustrates the direct green facade, indirect green facade and indirect with planter box type of green facades.

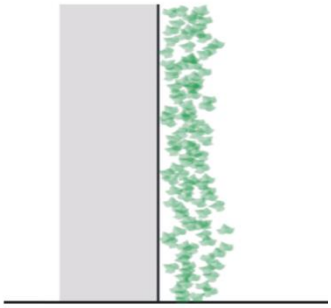
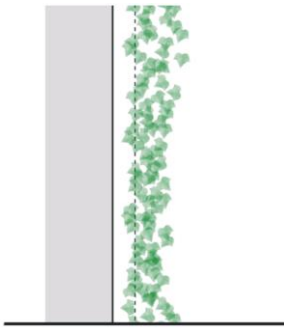


Plate III: Direct green façade. Source: Perini *et al*., (2011).



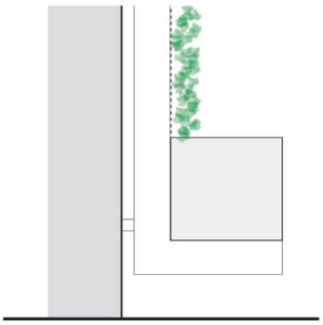


Plate IIV: Indirect green facade. **Plate V**: Indirect combined with planter box. Sources: Perini *et al*., (2011).

The plates VI and VII below show application of the direct and indirect with planter box green facades on exterior walls in existing buildings.



Plate VI: Example of Indirect Greening. Source: Pérez *et al*., (2016).



Plate VII: Example of Indirect Greening combined with planter box. Source: Pérez *et al*., (2016).

2.2.2.2 Living Walls

Living wall systems, which are also called green walls and vertical gardens are constructed from modular panels containing soil or other artificial growing medium such as foam, felt, perlite and mineral wool. The system is based on hydroponic culture that utilizes balanced nutrient solutions to provide the plant's food and water requirements. Living walls require a water proof membrane to prevent dampness and an irrigation system (Pérez *et al*.,2016). Evergreen (as small shrubs) plants are usually used for living walls. The systems have been developed in the last few years, having different characteristics, starting from the growing medium (Perini *et al*.,2011). There are different systems of living walls, which include panel, cloth, pocket system which can be planted in-situ or using pre-vegetated panels. It also consists of a growing media which can be organic or inorganic. Raji *et al*., (2014), mentioned that living walls can be categorized based on their location as External and Internal living walls.

External living walls are placed on the exterior part of the building envelope. They modulate the indoor temperature thereby enhancing the thermal comfort through a combination of 4 mechanisms (Pérez *et al*.,2016): - interception of solar radiation by the vegetation, thermal insulation provided by vegetation and substrate, evaporative cooling and modification of wind pattern in the building environment. According to Mazzali *et*

al., (2014), living walls can reduce the indoor temperature up to about 20°c. The temperature reduction however, depends on lighting and plant species.

Internal living walls are also known as Bio filters (Raji *et al*.,2014). They are placed in the interior of a space and are good alternatives for improving the building's indoor air quality. As biofilters they filtrate the indoor air by purifying the air passively through natural convention or an air conditioning system could be used to facilitate the process. The cooling effect of the indoor living walls results from the combination of evaporation from constant irrigation and transpiration from vegetation. Due to their capacity in oxygen production and biofiltration of volatile compounds (VOCs) and carbon (IV) oxide CO_2 the need for air filtration is reduced (Raji *et al*.,2014). Mostly, indoor living walls are used in transitional spaces such as balconies, foyers, lobbies etcetera (Prihatmanti and Taib, 2017). Indoor living walls has been seen to reduce temperature to about 4-6°C (Pérez *et al*.,2016) and it is enhanced where natural ventilation is optimized.

The Living wall system based on felt layers has a high environmental burden due to the durability aspect and the materials used while those based on planter boxes has not a major footprint due to the materials involved, since the materials affect positively the thermal resistance of the system (Perini *et al*.,2011). The plates VIII and IX below illustrates the different types of living walls indicating their irrigation systems.

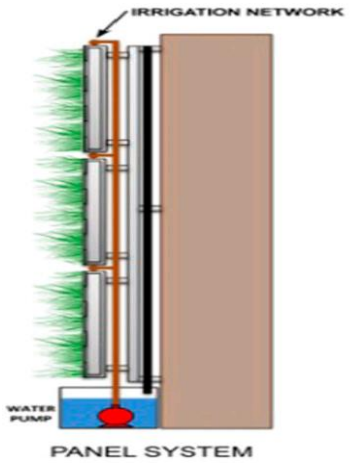


Plate VIII: Living wall with a panel system. Source: Pérez *et al*., (2016).

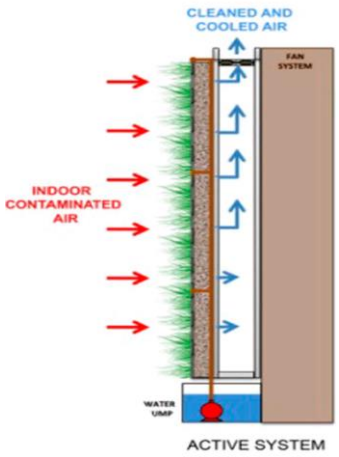


Plate IX: Living wall with an active system. Source: Pérez *et al*., (2016).

Plate X below show existing modular living walls using different types of plants in the popular living wall designed by Patrick Blanc.



Plate X: Examples of Living walls. Source: Pérez *et al*., (2016).

2.3 Effects of VGS on thermal comfort

Different studies have been conducted to investigate the effect of different applications of VGS on energy savings, temperature and thermal comfort in buildings

A study conducted by (Sunakorn and Yimprayoon, 2011) in hot and humid tropical climate the indoor air temperature was measured for 2 west oriented rooms with a room having indirect VGS at 70cm away from the wall and the other one being just a bare wall. To evaluate the impact of wind velocity on thermal performance, natural ventilation and no ventilation scenarios were adopted. The temperature difference between the ventilated and none ventilated were 0.9K and 0.3K. This was also confirmed by (Chen, Li and Liu, 2013) in the study carried out in a lab environment with no ventilation, the temperature reduction was only 0.4°c.

Coma *et al*., (2017) investigated the thermal performance of two different VGS for both cooling and heating periods. The VGS were a double skin green façade made up of deciduous creeping plants and a green wall of evergreen species. The research showed that there is high potential from both VGS to save energy in summer. The green wall showed the highest cooling performance achieving savings of 58.9%, while the green façade showed a reduction of 33.8%. It was also established that there is a direct relation between solar irradiation and energy savings. It indicated that was higher energy savings potential in climates with high solar irradiance. Othman and Sahidin (2016) carried out a study to determine the temperature difference in two office buildings one with VGS and one without in a tropical climate in Indonesia. The results show that the office with the VGS is effective in reducing the indoor temperature by 3.79%. It also indicated that the office with VGS had a decrease in its humidity.

2.3.1 Mechanisms through which VGS acts as a passive technique.

According to Raji *et al*., (2014), and Pérez *et al*., (2016) there are three key parameters which determine the impact of vertical greening systems as a passive technique for energy

saving in a building: the cooling effect of vegetation and substrate through evapotranspiration, the thermal insulation effect through making a microclimate environment between the canopy and building envelope and the shadow effect of the vegetation layer. While in (Coma *et al*.,2017) it was mentioned that four factors influence the operation of VGS as passive system for energy savings in buildings;

The sort of construction system used to place plants on the building facades, the climatic condition, the type of plant species used (deciduous or evergreen, shrubs or climbing plants,) the last key factor is related to the various mechanisms that make these systems act as passive tools for energy savings in buildings such as shadow, insulation, evapotranspiration and wind barrier effects. Earlier studies show that the shadow effect has the highest impact over the reduction of the building wall temperature and, consequently, over the energy consumption (Coma *et al*., 2017). Using deciduous climbers to regulate seasonal variations of shading may be employed especially in winter when energy consumption may increase because of the shadow produced by the vegetation on the building (Pérez *et al*.,2016).

2.3.1.1 Shadow effect of the vegetation layer

Vertical Greenery Systems can protect the building envelope from overheating through shading (Raji *et al*.,2014). The shading effect of a VGS depends mainly on the foliage density and the coverage ratio. The total solar radiation striking a VGS depends on the physical characteristics of the greenery, which is transferred into these three ways: reflected to the atmosphere, or absorbed by the canopy or transmitted through the leaf. A study conducted by (Ip, Lam and Miller, 2010) showed that the solar transmittance through one leaf layer being 45% dropped to 12% when it passes 5 leaf layers. This is also in accordance with the work of (Prihatmanti and Taib, 2018) which indicates the effectiveness of multilayer plant covering in enhancing thermal comfort. Shading by VGS reduces the external surface temperature and the consequent incoming heat flux through

building envelope. A study conducted by (Wong *et al*.,2010) experimented the influence of different VGS on surface temperature of 9 free standing concrete wall in Singapore having the substrate thickness and the foliage height to be different in each vertical system. The maximum reduction was 10.9°c for living walls with modular panels. This might vary according to the climate conditions and experimental conditions. (Chen *et al*.,2013) observed a cooling effect of living walls by a reduction of 20.8°c.

Envelope Thermal Transfer Value (ETTV) is an indicator for the thermal performance of a building envelope. In the work of (Wong *et al*.,2009), in which simulation was done on the effect of vertical greening systems on the ETTV of a 20-storey hypothetical building fully covered by glass. There was a decrease in the building's ETTV by 40% when the plants coverage ratio was 50%, and the solar transmittance value was 4%. When the shading coefficient was increased from 0.5 to 0.98, the ETTV reduced to 21% and 0.6%. Furthermore, they established a linear correlation between shading coefficient and Leaf Area Index (LAI). Which implies that the higher the value of LAI, the lower the solar transmittance, hence greater thermal performance for the building. The effectiveness of VGS is influenced by solar radiation intensity and outdoor conditions. This is evident from the work of (Nori, Olivieri, Grifoni and Bedoya, 2013)that established the highest recorded temperature of 46.7 ºC for a conventional façade, and 22.1ºC for a green façade on a sunny day with a maximum solar radiation of 692 W/m^2K, while on a cloudy day with less solar radiation (MVR: 140.8 W/m^2K), the temperature differences between the two façades was only 3.1 K. Mazzali *et al*., (2014) also showed that the external surface temperature differences of three different Living wall systems had a range between 1 K (a cloudy day) to 20 K (a sunny day) which was affected by the amount of solar radiation. It is established that shadow effect has the highest impact over the reduction of the building wall temperature and, consequently, over the energy consumption.

2.3.1.2 Evaporative cooling of the vegetation and substrate

Evapotranspiration is the process by which water is transferred from the land to the atmosphere through transpiration from plants (Wong *et al*.,2003). VGS can efficiently shield the building from solar radiation compared to conventional solar shading devices (Dahanayake and Chow, 2017). Most of the solar radiation absorbed by the greeneries is used for photosynthesis, metabolism and for evaporating water into the surroundings known as transpiration. The substrate of VGS also evaporates water on absorbing solar radiation. Both processes combined are termed as evapotranspiration which results in a cooling effect of the surroundings (Malys, Musy and Inard, 2014). The evaporation of water is the most inexpensive and effective method to cool a building. A meter cubic consumes 680 kWh of water evaporated. When facades are vegetated, additional evapotranspiration occurs, which has a great potential for reducing temperatures of the surfaces of buildings and improving the environment inside and around the building. The evapotranspiration from plants is the most important environmental benefit of vegetated roofs and facades in urban areas. This is because they reduce the temperature of the surfaces and improves the management of runoff rainwater (Sheweka and Mohamed, 2012). The application of vegetation provides a lot of moisture environmental bonus to dry indoor environment (Miller, Ip, Shaw and Lam, 2007).The water evaporated by trees can increase the absolute humidity up to 1-2 kg of water per m3 of dry air (Papadakis, Tsamis and Kyritsis, 2001).The cooling effect takes place due to the water evapotranspiration process from the plants and substrates. Some studies reviewed by Pérez, Coma, Sol and Cabeza (2017) considered this effect, while some of them did not consider the effect produced by water evapotranspiration. It was noticed that the reduction in surface temperatures of the wall's building façade due to the presence of plants are considered as cooling effect, without differentiating between shading and cooling effect. Regarding the cooling effect, the effect that influences the thermal behavior in Green

Façades is only the transpiration from plants which depends on the plant species, the irrigation regime and the façade orientation. While in the case of Living walls, evaporation from the substrate should be added to the transpiration from plants. The evapotranspiration depends on all the variables of the Green facades and the moisture content of the substrate in its case. Wong *et al*., (2010) studied the influence of various VGS on ambient temperature, it was discovered that the best result was obtained in the vicinity of the living wall with a reduction of 3.3°c and 1.6°c at a distance of 15 and 30 cm from the wall. The VGS no longer affected the ambient temperature at a distance of 60 cm from the living wall. The study also infers that the use of appropriate greeneries improves the microclimate significantly. Perini *et al*., (2011) evaluated the differences in ambient temperature in the vicinity of three VGS (direct, indirect and living wall). It was deduced that at a distance of 10cm to 1 m away from the wall (in all three instances) no remarkable difference was observed. The difference between the two studies is due to the difference of environmental factors on evapotranspiration rate. The second research was carried out in a temperate climate during autumn where the direct solar radiation is low while (Wong *et al*., 2010) was carried out in tropical hot climate in summer. In a study conducted on indoor living walls by (Fernandez-Canero, Urrestara and Salas, 2012) in Mediterranean climate of Spain during the warm period. It was found that the ambient temperature reduced by 4°C, a significant reduction of 7°C was observed at the vicinity of VGS. There was also an increase in indoor humidity to about 15% near the living walls. The study shows that indoor living wall can enhance comfortable condition of a space especially in hot and dry climate.

2.3.1.3 Thermal insulation by VGS

The presence of air cavity between the building façade and VGS results to a microclimate environment which acts as a thermal buffer, reducing the heat flux through the building envelope by regulating the ambient air temperature and wind speed (Raji *et al*., 2014).

VGS usually consist of a number of layers, such as layers of plant, substrate and air. These layers provide additional thermal insulation for the building facade and control the thermal conductance to indoor space. According to Dahanayake and Chow (2016), the thermal conductivity of vegetation is negligible. Hoyano (1988) also established that if a concrete wall is covered with layer of vegetation, heat transfer can be reduced approximately by 0.25 kWhm−2. The insulating capacity of VGS depends on the thickness of the substrate, foliage density and properties of the intermediate air layers. At night, when there is no solar radiation a green façade has higher surface temperature compared to a bare façade (Nori *et al*.,2013). This is due to the thermal buffering ability of intermediate microclimate and its influence on deceleration of the heat loss through the building envelope (Raji *et al*.,2014). The Insulation effect of VGS is related to the insulation capacity of the different layers depending on the different systems composition, such as the thickness and material of the substrate layer, the air in the plant layer, other possible intermediate air layers. A study conducted on a detached green wall, assembled on a steel structure with 80-150 cm distance from northwest, southwest and southeast façade in the dry Mediterranean continental climate by (Pérez, Rincón, Vila, González and Cabeza, 2011)found out that the amount of transmittance through the foliage range from 37% in spring to 3% in summer when the green wall has the highest coverage ratio. The role of microclimate environment in the intermediate layer was also measured and it was discovered that intermediate spaces had lower temperatures (maximum 2 ºC) and higher humidity (maximum 7%) compared to the ambient environment. Chen *et al*., (2013) observed the influence of natural ventilation and the air cavity thickness on the cooling effect of microclimate environment in the intermediate space. The greatest temperature decrease of air cavity was around 9.7 ºC in the Living wall that was placed within 3cm from the wall and sealed in all directions. (Perini, Ottelé, Fraaij, Haas and

Raiteri, 2011) had also investigated the correlation of air cavity thickness with thermal insulation properties provided by green walls. It was found that when the air cavity between the VGS and the wall was little about 4cm which is more effective in providing thermal insulation. They also deduced that a decrease in the air layer thickness of an indirect greening system by around 4-6 cm would improve its thermal insulation impact on building.

2.3.1.4 Wind barrier effect of VGS

Previous studies indicate that VGS has the ability to act as wind barrier and consequently block the effect of wind on building facades (Pérez *et al*.,2011). This effect depends on the density and penetrability of the foliage, façade orientation and the direction and velocity of the wind. McPherson *et al*. (1988) conducted a simulation on vegetation in order to test the effects of irradiance and wind reduction on the energy performance of similar buildings in four US cities representing four different climates. The results indicated that for cold climates, planting should be designed to reduce winter winds and provide solar access to south and east walls. This also is applicable to temperate regions. Nevertheless, when using vegetation as a modifier of the effect of wind on buildings, it must be designed in such a way as to not obstruct the ventilation in summer and not encourage the circulation of air in winter (Sheweka and Mohamed, 2012). For design in hot climates, vegetation should be designed to encourage both shade and wind (Pérez *et al*.,2011). In winter, cold wind plays a crucial role in reducing the temperature inside the buildings. Even in airtight buildings, the wind reduces the effectiveness of regular insulation. Previous studies found out that the energy consumption in winter increases because of the shadow produced on the building, but considerable reductions in energy consumption up to 25 % are finally obtained due to the effect of change in the climate in air cavity between the wall of the building and the green facade and the wind speed reduction (Dinsdale, Pearen and Wilson, 2006).Nevertheless, the ability to reduce the

wind speed and the air cavity between the building wall and the VGS should be taken into consideration as this effect can offset the negative effect of the screens vegetated in winter because of the shadow effect (Bass and Baskaran, 2003). A study conducted by Perini *et al*., (2011), on the effect on air flow and temperature of VGS on the building envelope, it was established that the direct greening system and the living wall system based on planter boxes are the most effective wind barriers, the reduction of the wind velocity affects the thermal resistance of the building envelope and hence its efficiency. Meanwhile, the indirect greening system doesn't affect the thermal resistance due to the thickness of the air cavity; it is likely that the same system with an air cavity of 40-60 mm could work as a stagnant air layer.

Tables2.1a and b show previous studies conducted on VGS, its location, climate, period of study, technique adopted, mechanism reviewed and its impact on thermal comfort.

Table2.1a Summary of Studies on VGS applications

Author	**Location/ Climate**	**Period of Study**	**VGS Technique**	**Plant**	**Mechanism of VGS**	**Impact of VGS**
Hayono (1988)	Japan/ warm temperate; fully humid; hot summer	Summer	Traditional green facade	Parthenocissus Tricuspidata	Shading	10°C temperature reduction on Outdoor surface of green façade
Alexandri and Jones (2008)		Diverse Climates	Double skin green facade		Evapotranspiration Shading	4.5°C decrease in Mediterranean
Wong et.al., (2010)	Singapore/ equatorial; fully humid		Green facade and Living wall	Hemigraphisrepanda, N6: Phyllanthus myrtifolius, Tradescantia spathacea	Shading and evapotranspiration	Reduction of 11.58 °C in exterior surface temperature on green wall and 3.33°C in ambient temperature
Kontoleon and Eumorfopoulou (2010)	Greece/ warm temperate; fully humid; warm	Summer	Direct green facade	Parthenocissus Tricuspidata	Shading and Insulation	5.7°C reduction on external wall surface
Jim and He (2011)	Hong Kong/ Warm temperate; winter dry; hot summer	Summer and Winter	Living wall	Ficus pumila, Campsis Grandiflora	Shading effect	Surface temperature reduction up to 5°C

Table 2.1b Summary of Studies on VGS applications

Author	Location/ Climate	Period of Study	VGS Technique	Plant	Mechanism of VGS	Impact of VGS
(Perez *et. al*.,2011)	Spain/ warm temperate; summer dry; hot summer	Spring and Summer	Double skin green facade	Wisteria sinensis	Shading, Evapotranspiration, Insulation and wind barrier effects	5.5 °C lower exterior surface temperature compared to bare wall
Perini *et.al.*, (2011)	Netherlands	Autumn	Direct green facade, Double skin green facade and a Living wall	Helix Hedera and different evergreen plant species	Wind effect and evapotranspiration	reduction of 1.2°C, 2.7°C, and 5°C in surface temperature for direct, Double and Living wall
Susorova *et.al*., (2013)	Chicago /snow; fully humid; hot summer	Summer	Direct green facade	Parthenocissus tricuspidata	Shading and Insulation	Surface temperature reduction of 0.7°C and 2.1°C reduction adjacent to VGS
Chen *et al.*, (2013	China/ hot and humid	Summer	Modular living wall			Reduction of 20.8°C in exterior surface temperature and 1.1°C in interior space air temperature for living wall
Djedjig *et al.*, *(*2015)	France/Oceanic Athens/ Mediterranean	Summer and Winter	Living wall		Shading, Evapotranspiration and Insulation	heating load reduced by 11.9% in France and by 8.7% in Athens.
(Othman and Sahidin, 2016)	Indonesia/ tropical		Indirect green facade		Shading and evapotranspiration	Reduced indoor temp by 3.79%
Coma *et. al*., (2017)	Spain/ Mediterranean continental climate	Summer and Winter	Living wall and Double skin green facade	Boston Ivy (Rosmarinus officinalis and Helichrysum thianschanicum)	Energy savings	58.9% savings for living wall while the green façade showed a reduction of 33.8%
(Dahanayake and Chow, 2017)	China	Summer	Living walls	Peperomia claviformis	Shading, evapotranspiration, insulation and energy savings	26°C decrease in exterior temperature of facade and 3% decrease in cooling load during summer

2.4 Parameters to be considered for the application of VGS

Earlier studies had established certain parameters to be considered when using VGS as a passive tool for energy savings in buildings especially when using double skin green facades. The following are the most important parameters that researchers used in their analysis: the plant species, the facade orientation, fenestration design, the foliage thickness or density, the substrate thickness for Living walls, and the air gap thickness between the plant layer and the building facade wall (Malys *et al*.,2014; Pérez *et al*.,2014; Pérez *et al*.,2017). When measuring the effects of the wind barrier ability, then the direction and velocity of the wind should be considered (Pérez *et al*.,2011). The above mentioned parameters also depends on some factors such as the climatic condition, the construction technique of the VGS, the amount of solar radiation and the period when the study is taking place such as during the hot or cold period (Perini *et al*.,2011; Prihatmanti and Taib, 2017; Coma et.al., 2017).

2.4.1 Plant species selection

Various significant factors are to be considered before selecting the appropriate plant species. Selecting the appropriate plants for any VGS application is very crucial as the choice of the plant strongly affect its function as well as its visual quality (Prihatmanti and Taib, 2017). Inappropriate selection of plant species can lead to various problems such as excessive growth, plant losses, pest or disease problems, high maintenance, poor public perception, and unattractive structures. This of course will render its application useless. Different weather conditions influence the type of plants to be used. In tropical countries, plants must able to withstand the hot and humid conditions (Prihatmanti and Taib, 2017). Also, to achieve sustainability the plants used should be available from the local market for the ease of maintenance and replacement (Charoenkit and Yiemwattana, 2017). For living walls, small herbaceous species, perennial flowers, low shrubs, ferns and grasses are suitable for living wall application (Prihatmanti and Taib, 2018). The leaf

size also determines the effectiveness of a living wall which is determined by the Leaf Area Index (LAI) value. The diversity of foliage density could modify the microclimate through the different layers as measured by the LAI value. Foliage size and color also improves the thermal comfort as well as enhancing the aesthetic value application (Safikhani, Abdullah, Ossen and Baharvand, 2014; Prihatmanti and Taib, 2018).

Table 2.2 below is showing some plant species adopted in some studies, with their effects on thermal comfort showing the location and authors.

Table2.2 Plants Specie and their Benefits.

Type of Plants Species	Benefits	Author, Location
Ornamental plants - Blue trumpet vine *(Thunbergia grandiflora)* - Ivy gourd (*Coccinia grandis)* ***Edible and medicinal plant*** - Mexican creeper (*Antigonon leptopus)*	Air temperature reduced by maximum 4.71 °C	Sunakorn and Yimprayoon (2011) Location: Bangkok/ tropical climate
Edible and medicinal plants Winged bean (*Psophocarpus tetrogonobulus)*	Average of carbon sequestration 2.35 μmole CO2 m^{-2} s^{-1} was converted to kg CO2 per year per m^2, equal to 9357.83 kg CO2 $year^{-1}$ $hectar^{-1}$	(Amir *et al*., 2014) Location: Malaysia
	Outdoor wall surface temperature reduced by maximum 11 °C	Rahman *et al*., (2011) Location: Malaysia
	Maximum surface temperature drops until 6.4°C	Basher *et al*., (2016) Location: Malaysia
`Ornamental plants - False heather *(Cuphera hyssopifola H.B.K.)* - Princess flowers *(Tibouchina urvilleana)* - Chinese croton *(Excoecaria cochinchinensis)*	has the best performance in temperature reduction Large living wall has better thermal Performance	Charoenkit and Yiemwattana (2017) Location: Thailand/ tropical climate
Ornamental plants - Dragon's breath (*Hemigraphis repanda)* - Ceylon myrtle (*Phyllanthus myrtifolius)* - Oyster plant (*Tradescantia spathacea* 'Compacta')	Wall temperature is reduced by maximum 11.58 ° C	Wong *et al*., (2010) Location: Singapore/ equatorial fully humid
Ornamental plants - King's mantle (*T. electa)* - Mondo grass (*Ophipogan verigated)*	Temperature change occurs consistently on average 1.5 °C at the high-rise building due to the usage of modular system in large quantities	(Jaafar *et al*., 2011) Location: Malaysia / hot and humid climate
Ornamental plant Blue trumpet vine (*T. grandiflora)*	- Indoor temperature is reduced up to 3°C by the living wall and 4°C by the green façade - Wall cavity temperature can be reduced 8°C by the living wall and 6.5°C by the green façade	(Safikhani *et al*., 2014) Location: Malaysia / hot and humid climate

Source: Prihatmanti and Taib (2018).

2.4.1.1 Foliage density

To achieve the optimum performance of VGS in building especially its shading effect, foliage density needs to be considered since shadow effect depends on the foliage density. To generate a high-quality shadow, plants with dense foliage, multiple layers of plant canopy or with dense canopy should be employed (Shahidan and Jones, 2008). In a single layer, a leaf could approximately absorb 50% visible and infrared radiation, 30% would be reflected and only 20% transmitted (Prihatmanti and Taib, 2017). This indicates that more layers of leaves could be more effective at reducing solar radiation. The most common measurement for foliage density is Leaf Area Index (LAI). According to Pérez (2017), LAI is a key parameter to characterize the foliar density as well as the thermal behavior for vertical greeneries due to the shadow effect created by the foliage. Charoenkit and Yiemwattana (2017) defined LAI as the ratio of total-one sided leaf area to the ground surface area. In plants, the large LAI value effectively cools the building and lower the cooling load due to the evaporation effect. The larger the LAI value, the higher the effect of shading quality, magnitude of transpiration process and higher effect of radiation filtration. Plate XI below shows the radiation absorbed, reflected and transmitted through a leaf layer.

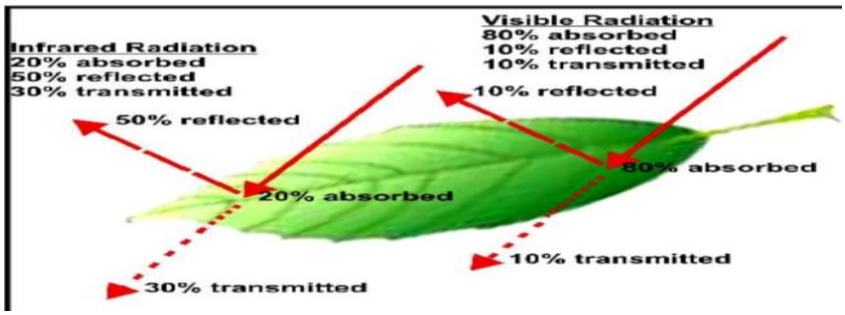


Plate XI: Amount of radiation absorbed, reflected and transmitted on single leaf layer. Source: Prihatmanti and Taib (2018).

2.4.1.2 Leaf Area Index (LAI) value.

LAI is a main parameter in characterizing the foliar density as well as the thermal behavior for VGS due to the shadow effect created by the foliage (Pérez *et al*.,2017). According to Charoenkit and Yiemwattana (2017), LAI is the ratio of total-one sided leaf area to the ground surface area (Ip *et al*.,2010). Leaf area index is a common biological parameter defined by single side leaf area per unit ground area (Safikhani *et al*.,2014) , In the case of vertical greenery, LAI describes a relation between the leaf area and the square meters of façade instead of the relation between the leaf area and the square meters of floor as usual (Jim and He, 2011). Moreover, it is necessary to take into account the fact that in a green facade the LAI value changes with the height (Pérez *et al*.,2017). This implies that a large LAI value could effectively cool the building and lower the cooling load due to the evaporation effect. The larger the LAI value, the higher the effect of shading quality, magnitude of transpiration process, and higher effect of radiation filtration. However, there is lack of study regarding this concept if applied in the form of vertical planting and planted in limited spaces although the presence of greeneries in building is beneficial using LAI to determine the plants influence on several performance variables is what is done in most researches. However, some studies determined plants qualities in different ways in some cases the thickness of plants and substrate (Wong *et al*., 2010) or plants and panel size (Jaafar *et al*.,2013) are measured, and sometimes the density and shadow factors (Pérez *et al*.,2011) are introduced. Sunakorn and Yimprayoon (2011) measured the quality of green facades by the percentage of plants covered on the trellises and the number of leaves layers, while (Perini *et al*.,2011) described the quality of green facades by plants thicknesses. Measuring the quality of plants on VGS is different from one case to another, and depends on different criteria such as kinds of climbers, plants species, trellises, substrate and others.

2.4.2 Orientation of the façade

Orientation of a building is the positioning of a building on site to take advantage of climatic features such as the sun and the air masses (Mcgee, 2013). The best orientation requires that the building should receive maximum solar radiation in winter and minimum in summer (Bano and Kamal, 2016). A long-term research was conducted by (Pérez *et al*., 2017) in the Mediterranean climate of Spain to determine the relationship between Façade orientation and LAI on the shadow effects of the VGS. From the results obtained, it was established that the double-skin facade can provide similar shadow factor values for all orientations, to those provided by the artificial shading devices such as facade setbacks, cantilevers, awnings, slats, and others. In summer 2013, with the green facade only partially developed, the VGS showed high capacity to intercept the direct solar radiation, which had reductions on the external surface wall temperatures up to 10.1 °C on the South orientation, and indoor temperature reductions around 2.5 °C. In summer 2015, when the VGS had a higher foliage development, there was significant reduction on the external surface wall temperature in all orientations (East, South and West). The results also showed savings up to 34% for cooling periods with a LAI of 3.5–4 during the summer periods. It was also confirmed that the energy savings were dependent on the orientation. The green façade on the East orientation was able to intercept the large impact of the solar radiation in the early hours of the day with a reduction of 15 °C on the building surface temperature, going from 36.4 °C to 21.4 °C at noon, and keeping it lower than 23 °C throughout the day. In the South orientation, at 15:45 when the temperature is at its peak, the temperature reduction was up to 16 °C, going from 46.7 °C to 30.7 °C. Lastly, on the West orientation there was a reduction of 16.4 °C, going from 43.9 °C to 27.5 °C at 19:00. The research shows that the shadow effect of green facades on the East and West orientations is significant and should be considered in architectural design strategy with the same importance than South orientation.

2.5 Computer Simulation

Simulation analysis is done to observe the response following a modification in a variable (Batagarawa, 2013). In this research parametric analysis is used to examine the consequence of changing a given independent variable on temperature and thermal comfort using computer simulations. The steps in conducting the simulation analysis in accordance to previous works such as (Larsen, Filippín and Lesino, 2014;Vaezizadeh, Rashidisharifabad and Afhami, 2016; Poddar, Park and Chang, 2017) are as stated below:

1. Define the model, its independent and dependent variables and its comfort profile.
2. Vary the values of each independent variable one at a time, in an incremental manner.
3. Record the corresponding value of the dependent variable
4. Assess and compare the influences of each input/output relationship through statistical methods.

2.5.1 Simulation softwares

Computer software packages are incorporated with numeric building energy calculations that perform numerous functions as created by the developers. Most of the packages are able to calculate cooling and heating loads, simulate atmospheric conditions within the building, costing, feasibility analysis of different retrofits amongst others (Batagarawa, 2013).

Simulation in buildings are majorly divided in two phases; geometric modelling and energy calculation phases. Modelling implies a simplification of the real physical processes in real buildings. These simplifications are made by the designers through the use of assumptions that allow the problem to be solved more easily within practical constraints. Previous studies on VGS used different simulation softwares such as Trnsys®, Ecotect®, EnergyPlus® and DesignBuilder®. Below is Table 2.3 showing some of the simulation softwares adopted in earlier works.

Table 2.3 Simulation softwares used in earlier VGS Studies.

Software	Study
Trnsys®	(Djedjig, Bozonnet and Belarbi, 2015;GrabowieckI, Jaworski, Niewczas and Belleri, 2017)
Energy Plus®	(Larsen *et al.*, 2014; Dahanayake and Chow, 2017;Yuan, 2017)
IESVE®	(Basher, Ahmad and Abdul Rahman , 2017)
DesignBuilder®	(Vaezizadeh, Rashidisharifabad and Afhami, 2016)
Ecotect®	(Yoshimi and Altan, 2011; Jamil, 2016)

2.5.2 Validation and Reliability

Reliability is concerned with the stability of tests measuring dependable variables (Batagarawa, 2013). The dependent variables in this research are temperature and thermal comfort. The software is said to be reliable if re-subjecting the independent variables to the same measuring test will yield the same results for the dependent variables. According to (Dahanayake and Chow, 2017), EnergyPlus is a tool that is highly sophisticated and validated as such it is used to run the simulations in this research.

2.5.3 Simulating VGS

Previous works had discussed methods on how to simulate green walls in different softwares. Most approaches include developing mathematical models of heat transfers of the foliage and integrating it to the simulation software. EnergyPlus or Trnsys were mostly used because it comprises of only the energy calculation tool without the modelling tool where you can draw or create the building case to be simulated. Examples of works that made use of mathematical models for simulations include (Afshari, 2017; Dahanayake and Chow, 2017). Another method is using a building shading object in place of the green façade (Larsen *et al*.,2014). The shading object is assigned the properties of the foliage such as Solar transmittance, Solar reflectance, Visible transmittance, Visible reflectance, Thermal emissivity, Thermal transmittance, Thickness and Conductivity.

2.6 Mid-rise Housing Design

A midrise is defined as any building between four and eleven storeys in height (Burlington, 2019). Midrise housing is a group of households in form of apartments for separate families designed, arranged and piled on top of one another with a vertical means of transportation such as elevators and stair cases for all dwellers to have access to higher floors (Audu, 2013).

In Kano State, where there is rapid urbanization due to the high commercial and industrial activities, availability of adequate housing is a major concern. This has led to various problems such as poor housing condition, substandard buildings, deteriorating housing environment and informal settlement (Muhammad and Bichi, 2014). The government of Kano state tried to solve this growing housing demand by providing a mass housing scheme building the Amana, Kwankwasiyya and Bandirawo estate. There are challenges encountered after the development, though it's beyond the scope of this study which is why it won't be discussed. A major solution to rapid growing population is the implementation of vertical cities, this entails that we build up vertically rather than horizontally. This is more sustainable as there is less pressure on land and site, thereby reducing the ecological footprint.

2.7 Estate Design

Estate design entails the planning and building of mass housing units in the same location, executed within the same project scheme, which could be in form of terraces, tower blocks, semi -detached or detached or both, and or maisonettes (Audu, 2013). It is a tactic used to annihilate the ever-growing housing demand in urban settlement around the world. In estate, social amenities and facilities are usually planned and located where all dwellers will have equal access to them. Auxiliary facilities such as schools, healthcare centers, security, maintenance unit amongst others are usually included and provided. An

estate design should also incorporate recreational and green areas to encourage interaction. Waste disposal, water service and drainage are also put into consideration from the inception of the design. Zoning is also an important factor in designing an estate, the estate should provide areas for the different category of users such low, middle and high -income earners as each housing design is based on the affordability of the users.

2.7.1 Guidelines in Midrise estate design

When designing an estate that has tall structures a lot of factors have to be put into consideration such as the building's orientation, clearance between two structures, entrance design, vehicular and pedestrian routes, building layout and planning, zoning and architectural character.

2.7.1.1 Building orientation

The longer sides of the buildings should be oriented towards the north and south. so as to avoid the direct heating from the west/east radiation and to maximize walls for optimal access to sunlight to habitable rooms. Buildings should be placed to consider existing site conditions so as to retain certain features such as mature trees and topography encouraging sustainability.

2.7.1.2 Clearance between buildings

When designing tall buildings, a minimum separation distance of 15.0 metres should be provided between buildings that face each other. This area should be free of projections such as balconies and cantilevers to allow sunlight to access the lower levels of the building. Depending on the building form wider separation distances may be appropriate, especially if there are residential units at or below the ground floor level (Burlington, 2019).

2.7.1.3 Entrance Design

The main entrance to the buildings should be obviously distinguishable from other entrances through its architectural design and treatment, high visibility, wayfinding and direct pedestrian access.

2.7.1.4 Vehicular and Pedestrian routes

Access points to the site should be situated and designed to complement the street and existing mobility networks beyond the site. Pedestrian access should be designed to prioritize the safety and enjoyment of residents and visitors. The number and width of vehicle access points should be minimal to avoid conflicts between pedestrian and vehicle traffic. Access to parking, servicing and loading should be provided at the rear of the building.

2.7.1.5 Building Layout and Zoning

The estate should be well planned having a defined layout and zoned appropriately. There are a lot of layout patterns available such as the grid, cluster, cul-de-sac and garden-city. Each has a systematic way of laying out roads, placing buildings and locating social amenities and facilities around the site. Zoning is also an important consideration as privacy, noise, views are all factors that are to be considered when allocating spaces for different category of users.

2.8 Summary

This chapter discussed in details the various applications of VGS, the benefits its renders to buildings such as aesthetics, energy savings, shading, wind and noise breaking amongst others, its classifications, the effects it has on thermal comfort, the mechanisms through which it operates such as shading, evapotranspiration, insulation and wind barrier effects. The parameters of VGS to be tested were also deduced from this chapter which includes plant species, LAI value, orientation of the façade, fenestration design, air cavity

thickness, shading coefficient and substrate thickness. Table 2.4 below is showing the available types of VGS, their benefits, limitations and impacts on thermal comfort.

Table 2.4 VGS Types and their characteristics

System	Source	Characteristics	Advantages	Disadvantages	Impacts
Direct green facades	(Perini *et al*., 2011) (Alexandri and Jones, 2008) (Manso and Castro-Gomes, 2015) (Hoyano, 1988)	Grows from planter box or directly from the ground. Grows directly on the building façade. Climbing plants evergreen/deciduous	No materials involved for support. Low environmental burden. Low cost.	Humidity from plants can damage wall surface. Limited plants selection. Slow surface coverage.	Temp decrease in Mediterranean climate 4.5°C. In temperate 2.6°C Temp decrease of 10°C in warm temperate climate
Indirect green façade	(Perini *et al*.,2011) (Manso and Castro-Gomes, 2015) (Coma et.al., 2017)	Uses support system for growth such as cables, meshes or trellises. Climbing plants evergreen/deciduous	Vegetation development guidance. Low water consumption.	Limited plants selection High environmental burden of some materials	Achieved energy savings of 33.8% in Mediterranean climate.
Indirect green façade combined with planter box	(Manso and Castro-Gomes, 2015) (Othman & Sahidin, 2016) (Fernandez-Canero *et al*., 2012)	Uses planter boxes and support structures, situated at certain height on the façade Climbing plants evergreen/deciduous Drip line and holes in planters for irrigation and drainage	Lightweight support Controlled irrigation Easy maintenance Ease of plant replacement.	Limited plants selection High environmental burden of some materials. High installation cost	Temperature reduction of 3.79% in tropical climate 5.5°C Temp decrease in exterior wall temperature in warm climate
Continuous living wall based on cloth/ felt	(Pérez *et al*.,2016) (Manso and Castro-Gomes, 2015) (Safikhani *et al*.,2014)	Growing media placed in the pocket which may be organic or inorganic Requires a water proof membrane. Uses shrubs, grasses and perennials plants Drip line on the top of the wall for irrigation	Flexible and lightweight Uniform growth Support variety of plant species. Uniform water and nutrients distribution Most commonly used attachment methods	Complex implementation High water and nutrients consumption Frequent maintenance	Temperature reduction inside cavity was 8.0 °C, while indoor air temp reduced by 4.0 °C, Increases humidity in hot and humid climates
Modular living wall Panel/ Tray Planter tiles Flexible bags.	(Manso and Castro-Gomes, 2015) (Coma et.al., 2017) (Mazzali *et al*.,2014)	uses modules as a medium to support multiple panels that are of square and rectangular shapes. Growing media placed within panels Pre- vegetated panels or plant in situ could be used. The irrigation for this system is usually placed on top of each module. Lateral and inferior holes for drainage. Uses shrubs, grasses, perennials and succulent plants	Easily disassembled for maintenance Controlled irrigation/drainage Increased variety of plants/aesthetic potential Attractive design of modules Adaptable to sloped surfaces	Limited space for root development High installation cost Complex implementation Surface forms limited to trays/ tile dimensions High environmental burden of some materials Heavier solutions due to growing media/limited to buildings maximum load	Achieved energy savings of 58.9% in Mediterranean climate. Temperature decrease up to 16.5° on south wall in Mediterranean climate. Up to 20°C reduction in surface temperature in temperate region

As shown in Table 2.4 above, the Vertical Greenery Systems have peculiar characteristics and offers different benefits to buildings and also have different limitations. Therefore, when selecting the type of VGS to use, the characteristics have to be considered in order to achieve sustainability. From the table above, two (2) different VGS are going to be tested for the purpose of this research, which are the Indirect green façade combined with planter box and Modular Living wall. The plant species for green facades are mostly climbers and creepers because of their climbing abilities which could be deciduous or evergreen while for living walls they are mostly evergreen shrubs, grasses, flowers, succulents and perennials. The plant species for this research would be chosen based on their adaptability to climate, LAI value, visual quality, maintenance, fire protection and benefits such as thermal comfort and air quality improvement

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This research aims to explore how Vertical Greenery Systems (VGS) can enhance Thermal comfort in midrise housing estate in the hot dry climate of Nigeria. This chapter outlines how the research will be conducted. It discusses the method of data collection, data instruments, analysis and data presentation.

3.2 Research Design

The selection of a research approach is determined by different factors which state its suitability in achieving the objectives of the study. The research is descriptive and quasi-experimental in nature and case study research design was adopted, which was carried out to study the type of VGS adopted, its characteristics and how it was applied.

3.2.1 Case Study Research Design

Case study is defined as a methodology that is used to explore a single phenomenon in a natural setting using a variety of methods to obtain in-depth knowledge (Wyse, 2011).Case studies also involve documentation of the physical features of the subject under study (Oluigbo , 2015), This research design deals with the in-depth study of a particular case in singular unit with the aim of finding comprehensive information about that unit. For the purpose of this research two case studies were conducted and had their features documented.

The features observed included the building materials, construction technique of the VGS, the type of plant used, coverage ratio, foliage density, fenestration design and orientation.

3.2.1.1 Descriptive research

A descriptive research is used for explorative studies with little or no interest in finding out the relationship between identified variables (Batagarawa, 2013). The case study

involved visual assessment which identified the characteristics of VGS and its application. This is further described in Chapter 4 of this research.

3.2.1.2 Quasi- Experimental Research

The assessment of the VGS parameters and its effects on temperature reduction and thermal comfort is based on a quasi-experimental approach. This was achieved by manipulating the variables under controlled conditions in computer simulation. This determines its effects on thermal comfort.

3.3 Research Variables

As deduced from the literature review, the independent variables examined were the VGS parameters: façade orientation, foliage density, Leaf Area Index (LAI), fenestration design (window to wall ratio), air cavity thickness and VGS construction technique. These independent variables were examined and used to test the dependent variable thermal comfort which was determined by the air temperature, mean radiant temperature and humidity level.

3.4 Sampling Method

This research adopted purposive sampling method in selecting case studies that incorporated VGS in them in the hot dry climate region of the country. Purposive sampling is the process of identifying a population of interest. The case studies were selected based on the location and VGS adoption.

3.4 Methods and Instruments of Data Collection

This study employed visual survey and assessment method, computer simulation, physical measurements and documentation to obtain data.

Instruments that were used included camera, checklist, note book, sketch pad and measuring tape. The tape was used to measure the coverage area of the VGS and window

to wall ratios. Photographs were taken to show the existing situation of the cases to be assessed in other to support notes taken.

3.5 Procedure for Data Collection

Letter of introduction from the department addressed to the selected buildings to be studied was collected. During the visits, visual examination of the VGS was carried out which included noting the type of plant used, the height of the VGS, its orientation and the coverage area. The building characteristics were also noted; parameters such as building materials, window to wall ratio and building measurements.

3.6 Simulation

Simulation is based on quasi-experimental research approach and is quantitative in nature. The quasi experimental approach is used to explore the effect of a phenomenon (Batagarawa, 2013). By identifying the key variables, parametric analysis that involves computer simulation was conducted to explore the VGS design and its effect on thermal comfort in residential buildings. EnergyPlus software which is one of the most commonly, open-source and validated simulation tools was used to perform the simulation. A reference building model was developed using information from the case studies and then examined to determine its comfort profile. Along with the reference model, other models were developed with varying VGS parameters that were also simulated.

3.7 Data Analysis

The VGS parameters of the case study models was analyzed through Visual assessment method and measurements. Data was presented in form of descriptions given, photographs, tables and figures. Parametric analysis was used to further analyze the variables. The aim of the parametric analysis is to observe the response following a change in a variable (Batagarawa, 2013).Various VGS applications were simulated in

order to identify their effects on thermal comfort of the building. Graphs, tables and charts were used to represent the data.

4.0 RESULTS AND DISCUSSION

4.1 Introduction

This chapter gives a detailed overview of the visual survey and assessments carried out to examine the type of VGS and its parameters during the field work. It also discusses the parametric analysis conducted that is, the simulation. Lastly, it gives a thorough data analysis and representation.

4.2 Case Study One (Three Bedroom bungalow)

4.2.1 Background

Building one is a bungalow located at Az 47, Mubi close, Maiduguri road, Kaduna state. It comprises of three rooms and a garage built in the 1980's. The walls are made of stone masonry, on the interior it is plastered and painted with milk colour paint. The ceiling is made up of asbestos board. Asbestos cement was also used for the roof which is a hip roof. Casement windows (single glass panel and aluminum frame) measuring 900×1200mm were used. The door is a single panel door made up of aluminum (750×2100). The height of the building is 3900mm.

4.2.2 VGS description

The VGS type employed is the Traditional / direct green façade with planters at the base using the plant Ficus pumila commonly known as "climbing fig". The plant has a LAI value of 2. The VGS is mainly on the North façade and has started to spread to the wall facing east. On the north, the ivy covers about 35% of the wall, while on the east it is only about 10%. The ivy is dense at some part of the wall and scanty in other part mainly due to negligence and lack of maintenance. Due to the stone wall material, the stem of the ivy didn't cause damage to the wall. This shows that rigid surfaces are suitable for direct green facades. According to the previous occupants, no case of pest or rodent's invasion was reported. There are a number of trees surrounding the building, thereby shading it

from direct sun radiation. Plate XII shows the VGS on the east facade of the building which just has about 10% coverage ratio while Plate XIII is showing VGS on the north façade covering about 35%.



Plate XII: VGS on the wall facing east. (Source: Author's fieldwork, 2018)



Plate XIII: VGS on wall facing north. (Source: Author's fieldwork, 2018)

4.3 Case Study Two (A-two storey building)

4.3.1 Background

Building two is a 2-floor single family apartment located at No 24, Borno Avenue, Kano State. It comprises of four rooms, four Living rooms, four washrooms, a kitchen, staircase and a lift. It was built in 2014.The walls are made of sandcrete blocks, plastered and painted with white tyro line paint on the exterior. Some parts of the walls are cladded with stone. The ceiling is made up of Plaster of Paris (POP) while the floors of the living rooms are finished with marble and vitrified ceramic tiles in the rest of the spaces. The windows are of two types, casement windows (1200×1500) and top hung (1200×900) double glazed with aluminum panels. The main door is a double panel security door (1200 ×2100) while the internal doors are wooden flush doors (900×2100). The roof is a flat roof made of concrete.

4.3.2 VGS description

The VGS type employed in this building is also the direct green façade with planters at the base using Ficus pumila. It was planted in 2014 and has attained almost a full coverage on the west façade. The VGS is mainly on the west façade and has started to spread to the wall facing north. On the west, the ivy covers about 75% of the wall, while on the north it is about 30%. The ivy is distributed uniformly in the direction of growth and the growth is guided using ropes attached to the walls. The VGS is in a very good state due to proper and monitored care and maintenance. Also, the ivy didn't cause any damage to the walls mainly due to good workmanship and use of standard materials for construction. During dry season, the VGS is watered twice daily. The house is surrounded by trees, flowers, hedges and grasses. There are also climbers on the fence of the building. Due to the presence of climbers on the walls and surrounding plants the immediate environment is cool and shaded from the sun. The cooling effect of the VGS is noticed by the occupants,

felt inside the house and on the surface temperature of the walls. Plates XIV and XV show the VGS on the west façade with a 75% coverage ratio and on the north façade with a 30% coverage ratio.



Plate XIV: VGS on the west facade. (Source: Author's field work, 2018)



Plate XV: VGS on the north facade. (Source: Author's field work, 2018)

4.4 Summary of results from case study

All the data from the case study which were previously presented are summarized in the table below. The table 4.1 shows the VGS type, orientation, type of plant, LAI value,

window to wall ratio, coverage ratio, challenges and benefits derived for each case study building.

Table 4.1 Showing summary of data from the case studies.

Variables	Case Study One	Case Study Two
Type of VGS	Direct green facade	Direct green façade
Climate	Hot dry	Hot dry
Type of Plant	Ficus pumila	Ficus pumila
Orientation	North and East	West and North
LAI value	2	5
Coverage ratio	35% on north and 10% on east	75% on West and 30% on north
Method of irrigation	VGS is neglected and therefore lacks maintenance.	Watering is done twice daily by the use of water hose.
Window to wall ratio	20%	30%
Reason of Application	Aesthetics	Aesthetics
Current State	VGS currently in a poor state due to negligence.	VGS provides the desired visual impacts and also provides the benefits of cooling and shading.

4.5 Simulation Results and Discussion

As discussed in the literature review, VGS is seen to have many benefits such as temperature reduction, carbon sequestration, air quality improvement and aesthetics amongst others. These benefits come from the mechanisms of the VGS which are shading effects, evapotranspiration, thermal insulation and wind barrier effect. This study seeks to analyze how VGS can help in reducing temperature through quasi-experimental analysis.

The simulation was carried out using DesignBuilder software (Version 4.5.0.148) with EnergyPlus 8.3 as the simulation engine. As at the current scope, VGS is not being integrated into the simulation softwares. A number of works had discussed and

demonstrated methods on how to simulate green walls and facades in different softwares. Most common methods include developing a mathematical model of the heat transfers of the foliage and integrating it to the simulation software. This is done because only the simulation software such as EnergyPlus or Trnsys is being used for the simulation without the design software where you can draw or create the building case to be simulated. Examples of works that made use of mathematical models for simulations include (Djedjig *et al*.,2015; Afshari, 2017; Dahanayake and Chow, 2017). The method adopted in this work is in line with the work of (Larsen *et al*.,2014). This involves using a building shading object in place of the green façade. A building shading device reduces the solar gain and shades the solar radiation from the sky. Therefore, the building shading object is assigned the properties of the foliage. The properties include Solar transmittance, Solar reflectance, Visible transmittance, Visible reflectance, Thermal emissivity, Thermal transmittance, Thickness and Conductivity. Though this method has its limitations, such as not being able to determine its evapotranspiration effect since the building shading object doesn't exhibit this effect.

The following are the steps used in the simulation process

1. Creating new site
2. Creating new building
3. Create component block for shading
4. Assign properties of VGS to shading object
5. Importing data weather files
6. Apply materials for construction
7. Add openings
8. Run simulation

4.5.1 Base-case modelling

The base case model was developed from information derived from primary and secondary data gathered from literature and fieldwork. This information includes building fabric, window to wall ratio, number of occupants and materials. The model is a three storey building measuring 15000mm ×12000mm made up of sandcrete block wall 225×225×450mm plastered on both sides with a U-value of 1.4W/m^2k. The building has 30% window to wall ratio with 3mm clear single glazing. The longest sides are oriented towards east-west. Figure 4.1 below shows the base case from Design Builder.



Figure 4.1:Base Case Model generated from DesignBuilder. Source: DesignBuilder (V4.5)

4.5.2 Variables to be examined

As stated in chapter three, the variables to be studied are the VGS parameters such as the VGS construction technique, LAI value, foliage density, coverage ratio, air cavity thickness and orientation. These would be used to determine the change in air temperature, mean radiant temperature, surface temperature and humidity levels.

1. VGS construction technique: The types of VGS under study are the indirect greening façade which is made up of structural system supporting the vegetation and the modular living wall system which is made up panels, growing media, irrigation system and vegetation.

2. Foliage density and LAI value: The LAI value is measured as the leaf area /m^2 which is dimensionless. The LAI values for the study ranges 1, 3 and 5. These values are derived from previous studies.
3. Coverage ratio: This is determined by the total area covered by the VGS. The coverage ratio also depends on the LAI value. For this study, 50% and 100% coverage ratio would be examined.
4. Air cavity thickness: This is also important as the air gap thickness defines the thermal insulation mechanism of the VGS. From previous studies such as (Perini *et al.,* 2011) the most suitable cavity thickness had been suggested to be between 4cm to 6cm. This enables the air to serve as a stagnant layer enhancing the insulation quality.
5. Orientation: The effects of the VGS would be examined on west east and south facades. The west facade is known to have the highest amount of heat. The application of VGS on the different orientations would determine what amount of shading it can provide.

4.5.3 Constant variables

A number of variables were kept constant throughout the simulation such as the window to wall ratio which was kept at 30%. The fenestration design affects the amount of heat penetrating through the glazing thereby affecting the temperature of the space. Other variables kept constant includes location and climate which is Kano Nigeria, typology, occupancy and building materials.

4.5.4 Comfort profile of the base case

The comfort profile of the base case was derived from simulation analysis. This was done because of the limitations encountered during the visual survey and assessments. The thermal comfort parameters such as air temperature, relative humidity and operative

temperature derived from simulation was in line with previous works on done on thermal comforts in Kano such as (Mukhtar, Muhammad and Enaburekhan, 2015; Gbode, Akinsanola and Ajayi, 2015).

The analysis from the simulation of the base case model is given below which is represented by the air temperature, mean radiant temperature, operative temperature internal and external surface temperature and relative humidity which is analyzed on a monthly time frame. Figure 4.2 below is a bar chart representing the result from the base case.

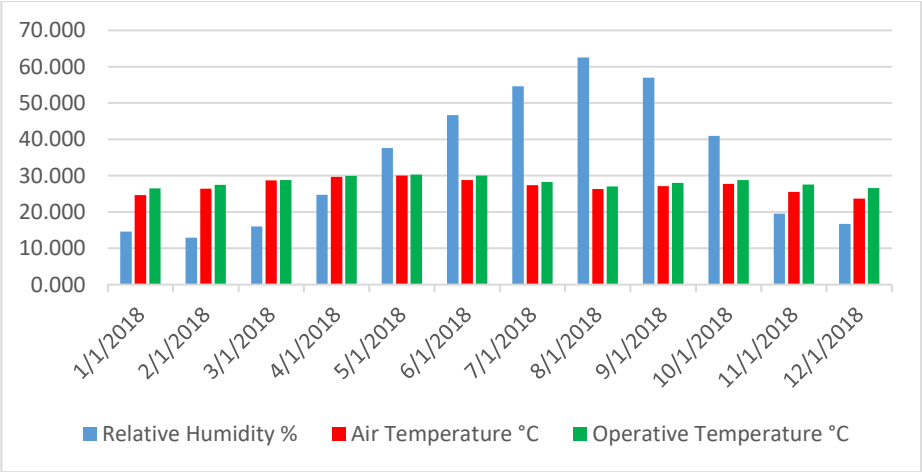


Figure 4.2: Comfort profile of base case from simulation. Source: DesignBuilder (V4.5)

The chart above shows the temperatures from January to December on the ordinary building without the application of VGS. Below is a table showing the average air temperature and relative humidity for each month

Table 4.2 Air temperature and Relative humidity for the Base Case.

Date	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RH	14.57	12.95	16.05	24.75	37.57	46.68	54.60	62.51	57.00	40.80	19.50	16.68
A. T	24.61	26.45	28.67	29.70	30.05	28.83	27.42	26.34	27.16	27.70	25.55	23.65

The above results are going to be compared with the analysis of the base case simulated with the variables of VGS. Simulations were carried out on the following different cases:

4.6 VGS models

The second case is that of VGS. This was made by changing the variables to determine their impact on thermal comfort. The VGS case is broadly divided into two; the indirect greening and the modular living wall system. All the variants under this case were simulated based on 100% and 50% coverage ratios, LAI values of 1, 3 and 5. The orientations had three variations which included all, west/east and south.

4.6.1 Indirect greening façade Modelling

This model was developed in design builder by creating the building shading object parallel to the building façade. This is done by assigning the foliage properties to the building shading object. Table 4.3 below shows the properties assigned to the shading object.

Table 4.3 Properties of VGS assigned to building shading object

Properties	**Value**
Solar transmittance	0.2
Solar reflectance	0.3
Visible reflectance	0.09
Solar absorptance	0.5
Thermal absorptance	0.95
Visible absorptance	0.85
Conductivity ($W/m^{-}K$)	0.59
Density ($Kg/m^{3)}$	1200
Specific heat capacity ($J/Kg^{-}K$)	1000

Source: (Larsen *et al.*,2014)

Figure 4.3 below shows the base case with the indirect green façade model which has been assigned the properties indicated in table 4.3 above.



Figure 4.3:Indirect greening using building shading object. Source: DesignBuilder

The variants examined under this case are summarized in the table below.

4.6.2 Indirect Green Façade VGS Model Case

Table 4.4 Variants of the indirect greening façade model

Variables	Variant 1	Variant 2	Variant 3
Orientation	All	East/West	South
Coverage	100% and 50%	100% and 50%	100% and 50%
LAI	1,3 and5	1,3and5	1,3and5

Table 4.4 above shows the VGS models used for the indirect green façade categorized into three variants, having different parameters which will be tested to determine the variant with the best impact.

4.6.2.1 Impact on air temperature and operative temperature

Taking Variant 1 above, its parameters would be compared using bar chart to determine which has the greatest impact on thermal comfort. The comparison is between the coverage ratios and LAI values. For the first analysis, the LAI values of 1, 3 and 5 would be compared under the 100% coverage ratio. The LAI value is an indication of the foliage density. Figure 4.4 is a bar chart comparing the LAI values 1, 3 and 5 under 100% coverage ratio when the VGS is placed on all facades.

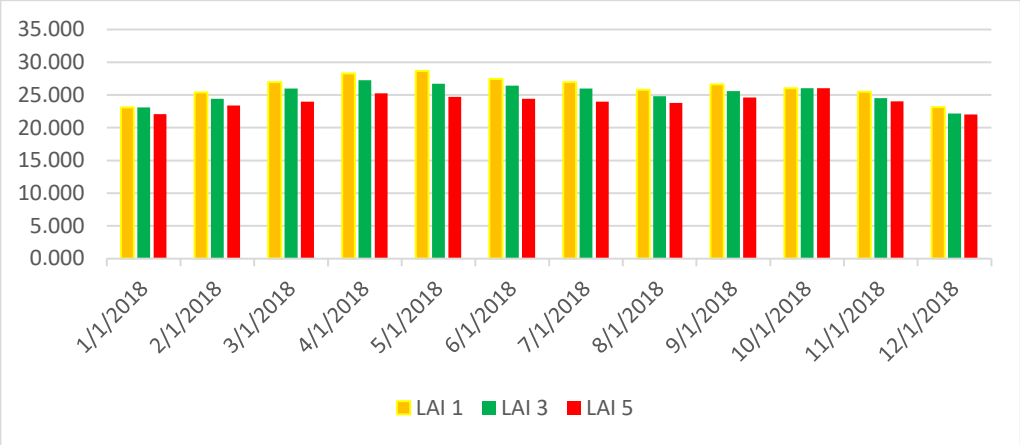


Figure 4.4: Air temperature using LAI values 1, 3 and 5. Source. DesignBuilder (V4.5)

From the graph above, it can be seen that the LAI value of 5 has the highest impact on temperature reduction. This is as a result of the dense foliage and total coverage by the plants. For the month with the highest temperature which is May the temperature reduction exhibited by LAI 1, 3 and 5 is 1.35˚C, 3.35˚C and 5.35˚C respectively. While in the month with the lowest temperature which is December the temperature reductions are 0.51˚C, 1.49˚C and 1.65˚C respectively. For the 50% coverage ratio, the LAI values were analyzed based on the air temperature. Below is a chart in Figure 4.5 comparing the temperature reduction between the LAI values under the 50% coverage ratio.

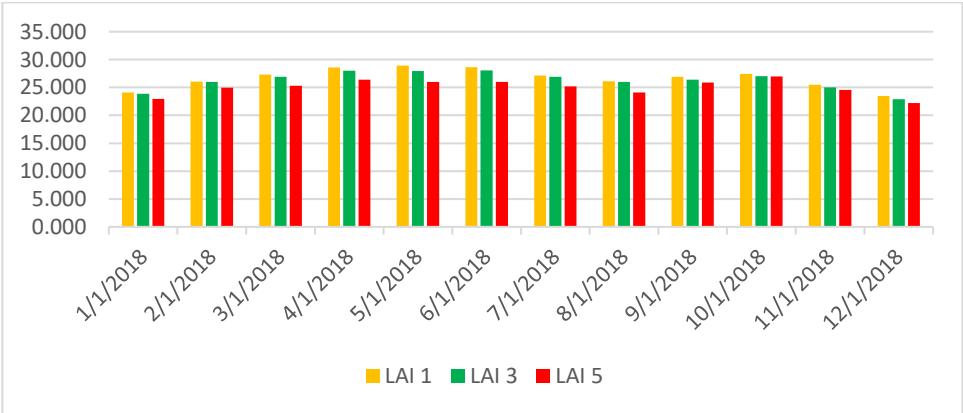


Figure 4. 5: Comparing the effects of LAI values on air temperature under 50% coverage ratio. Source. DesignBuilder (V4.5)

Comparing the difference in temperature with that of the base case in May for LAI values 1, 3 and 5 we have 1.12˚C, 2.08˚C and 4.03 respectively. While in December, the temperature reductions are as follows 0.15˚C, 0.72˚C and 1.4˚C respectively. From the

analysis above, it shows that in both cases (100% and 50% coverage ratios) the LAI value 5 has the highest impact on temperature reduction. It also shows that the higher the coverage ratio the better the temperature reduction especially in month with high temperatures. Below is Figure 4.6 showing a chart comparing the LAI values 5 of the 100% and 50% coverage ratios.

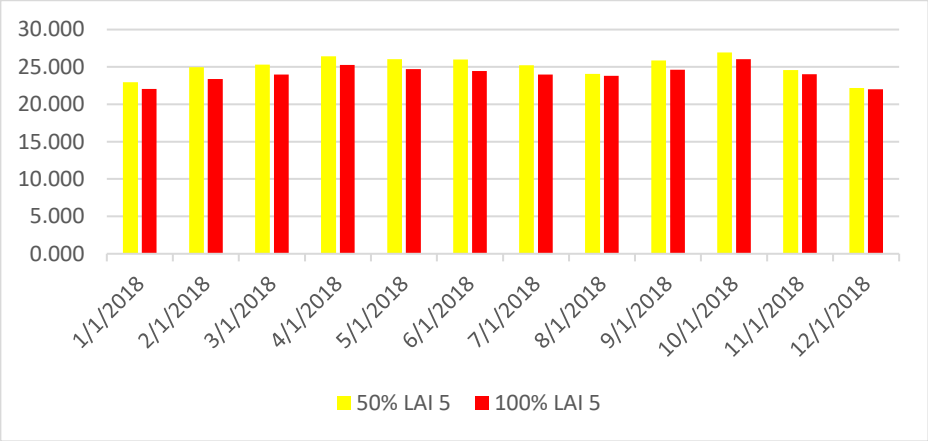


Figure 4.6: Comparing LAI value 5 of 50% and 100% coverage ratios. Source: DesignBuilder

The chart above indicates that 100% coverage ratio and LAI value 5 has higher potential in reducing temperature than 50% coverage ratio especially during the hottest months, whereas in the colder months the VGS could maintain a lower coverage ratio which can be achieved by using plants that partly shed their leaves during the dry season. Below is a graph in Figure 4.7 comparing the operative temperature from the base case, and variant 1 using the LAI value of 5 from both 50% and 100% coverage ratio. Operative temperature is a simplified measure of human thermal comfort which is the average of the air temperature, mean radiant temperature and air speed.

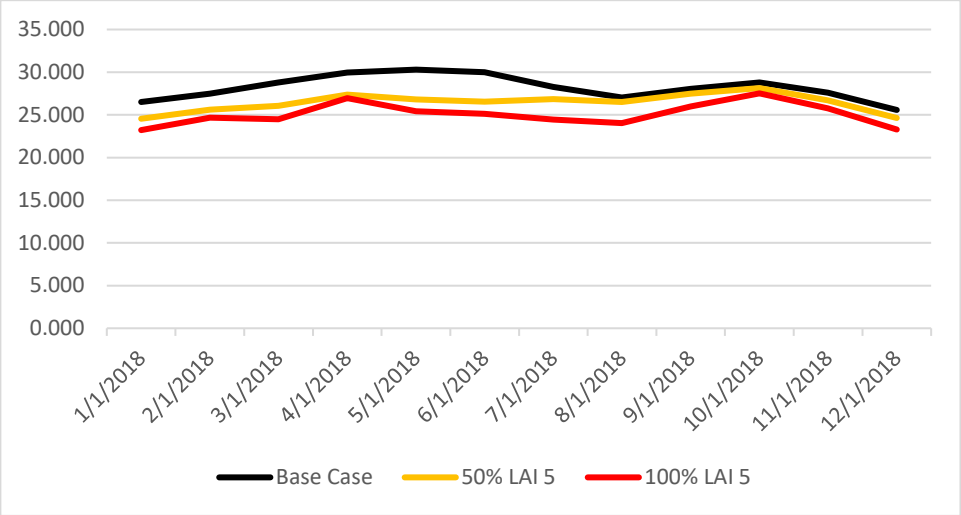


Figure 4.7:Operative temperature between basecase and LAI 5 of 50 and 100% coverage. Source: DesignBuilder (V4.5)

From the graph above it can be seen that the VGS case with 100% coverage ratio of LAI value 5 has the highest impact on operative temperature.

4.6.2.2 Impact on surface temperatures

Variant 2 of the VGS case which is oriented towards the east west was simulated to determine the shading effect of VGS on the facades. From the model it can be seen that the longer sides of the building are oriented towards the east west because of the high amount of radiation generated from these sides especially the west. From the Variant 1above it could be deduced that the higher LAI values give more room for decrease in temperature, that is higher shading effect. For the purpose of variant 2 only the LAI value of 5 is going to be tested on the east/ west orientation for both coverage ratios of 50% and 100%. Figure 4.8 and 4.9 below are charts showing the effect of the VGS on surface temperatures for the east/west orientation compared to the base case temperature of the same façade.

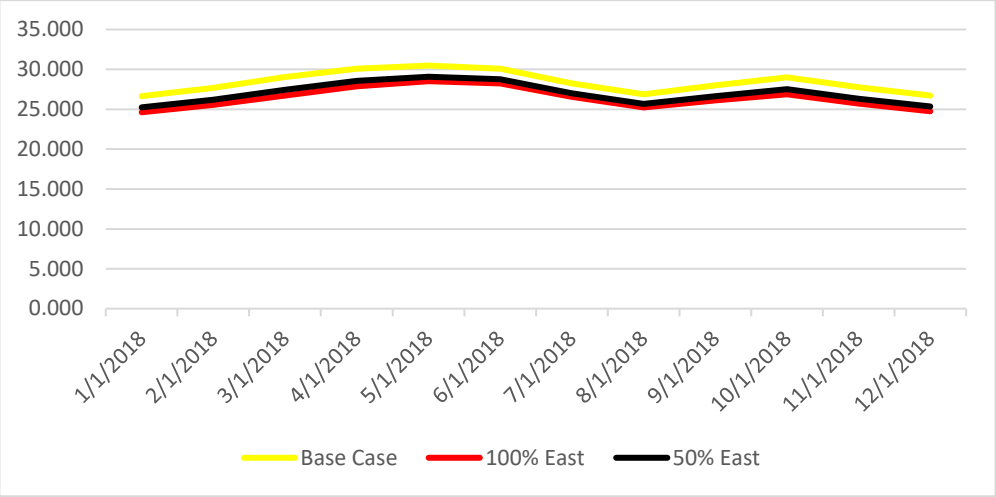


Figure 4.8: East surface temperature of Base case and Variant 2. Source: DesignBuilder

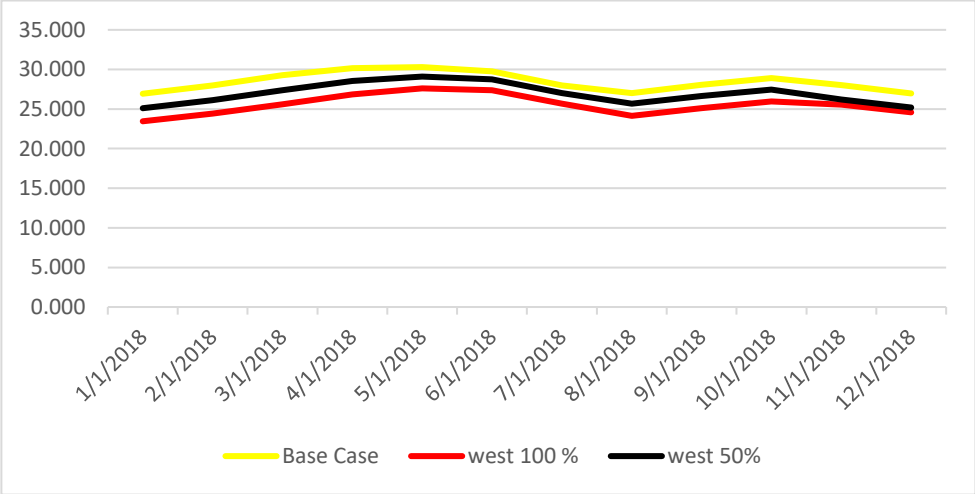


Figure 4.9: West surface temperature of Base case and Variant 2. Source: DesignBuilder

From the analysis above, the VGS shows a considerable reduction on surface temperatures. for the East façade, the internal surface temperature reduction in the month of May is using the 100% coverage is 2.0˚C while in December, there is a decrease of 1.95˚C. For the west façade, the surface temperature decrease in May is 2.7˚C and 2.4˚C in December. Examining the internal surface temperatures on the south façade, variant 3 was simulated using the 100% and 50% coverage ratio with the LAI value of 5. The Figure 4.10 below compares the variation of inside surface temperature between the base case and the VGS variant.

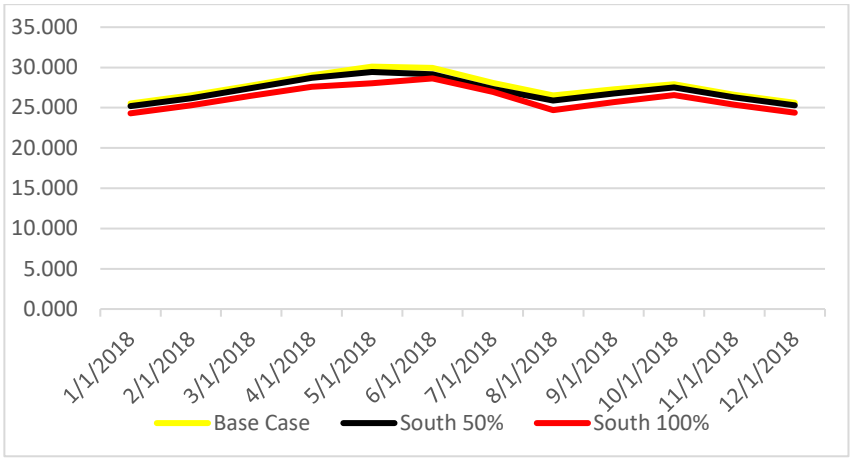
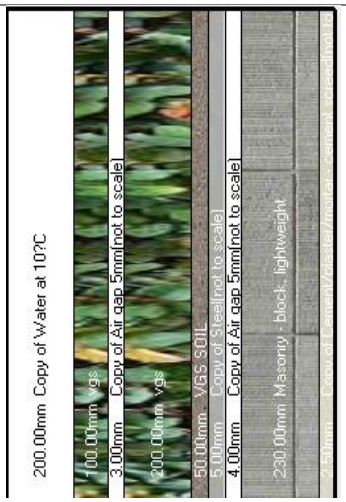


Figure 4.10: South surface temperature of Base case and Variant 3. Source: DesignBuilder

The diagram above shows that there is no much difference between the temperatures of the base case and 50% coverage of VGS with only 0.67˚C drop in May and 0.32˚C in December, while the 100% coverage shows a variance of 2.06˚C in May and 1.2˚C in December.

4.6.3 Modular living wall VGS Model Case

The living wall system makes use of different species of plants such as flowers, shrubs, succulents unlike the green facades which only makes use of climbing plants. Due to this feature it is considered to render more benefits in terms of shading and aesthetics than the green facades. In this research the living wall system was modelled in DesignBuilder® making use of the different layers as present in the living wall system to represent each layer of the wall. This was done because VGS module is not yet integrated into the simulation software. This method adopted is in line with some of the recent works carried out in this field such as (Jamil, 2016; Vaezizadeh *et al*.,2016; Poddar *et al*.,2017;). The VGS living wall model is illustrated in the Figure 4.11 below, showing layers of plaster, air gap, steel base plate, soil, water and plant.



Sandcrete Block wall	230mm
Plaster	25mm
Air gap	40mm
Steel base panel	6mm
Cultivated soil	50mm
Water	20mm
Plant	100mm

Figure 4.11: Living wall VGS model in DesignBuilder. Source: DesignBuilder (V4.5)

Table 4.5 below shows the parameters assigned to each of these materials before simulation.

Table 4. 5 Parameters assigned to different layers for the VGS model.

Parameters	**Air gap**	**Soil**	**Water**	**Plant**
Specific heat capacity J/KgK	1004	1200	1966	100
Density Kg/m^3	1.3	1100	0.6	1201
Conductivity W/mK	5.56	0.35	5.56	0.05
Thermal absorptance		0.9		0.78
Solar absorptance		0.7		0.7
Emissivity				0.95

Source: (Larsen *et al*.,2014; Poddar *et al*.,2017)

Based on the parameters above in Table 4.5, the cases were simulated. For this case, 3 Variants were also produced using only 100% coverage ratio and LAI value of 5 under the same orientations as in the case of the indirect green façade (All, East/ West and South). Figure 4.12 below shows the living wall VGS model case.



Figure 4.12: Living wall VGS model Case. Source: DesignBuilder (V4.5)

Below is Table 4.6 showing the different variants simulated for the living wall VGS case.

Table 4.6 Variants of the living wall (LW) VGS model

Variables	LW Variant 1	LW Variant 2	LW Variant 3
Orientation	All	East/West	South
Coverage	100%	100%	100%
LAI	5	5	5

These variants used in Table 4.6 were compared against the base case model analyzing the air temperatures, operative temperatures, relative humidity and surface temperatures.

4.6.3.1 Impact on air and operative temperature

Figure 4.13 below is a graph comparing the air and operative temperatures of the base case and Living Wall Variant 1.

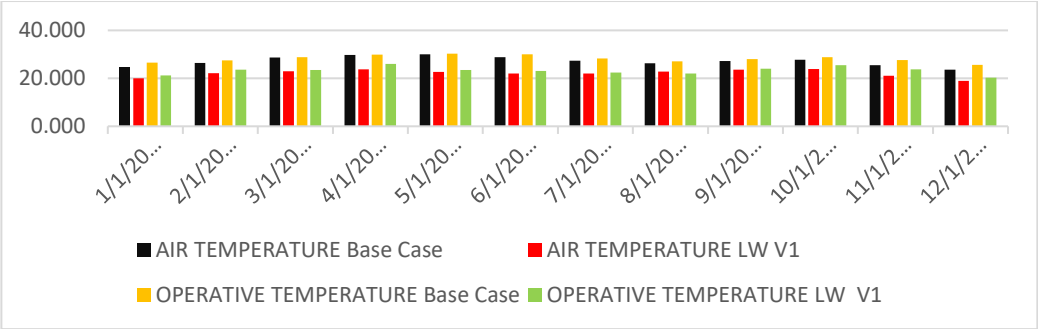


Figure 4.13: Air and Operative temperature comparison between Base Case and Living wall. Source: DesignBuilder (V4.5)

The living wall is seen to have a high impact on temperature reduction for both the air and operative temperatures. For the month of May, the air temperature reduction is 7.351˚C and 4.64˚C in December. While for the operative temperature, the decrease is 6.86˚C in May and 5.33˚C in December.

4.6.3.2 Impact on relative humidity

For this system, the simulation takes cognizance of the water present in the soil and the foliage which infers that there would be an impact on the relative humidity. The chart in Figure 4.14 below shows the variation in relative humidity between the base case and living wall Variant 1.

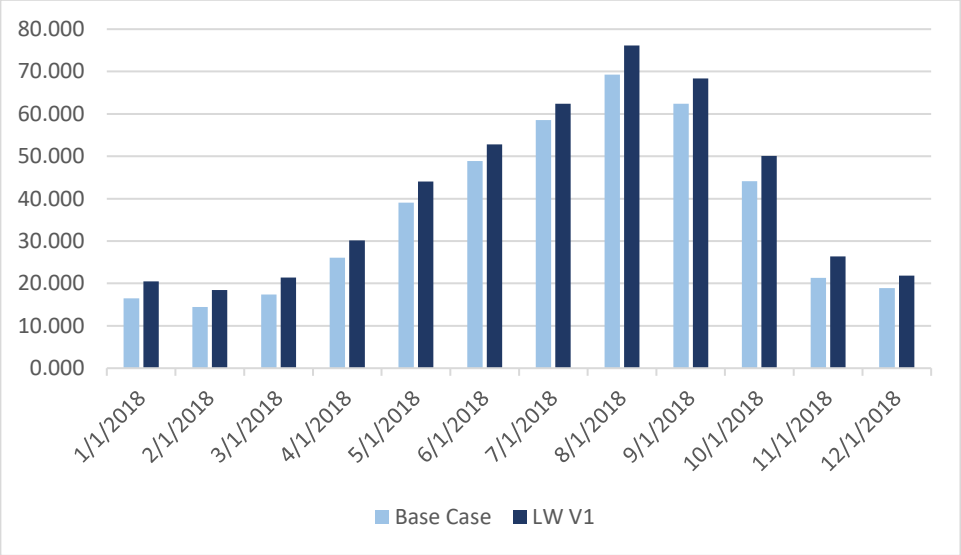


Figure 4.14: Difference in humidity between the Base Case and Living wall Variant 1. Source: DesignBuilder (V4.5)

The above analysis shows that the presence of VGS gives rise to an increase in humidity levels. For the month of February which has the lowest humidity level, there is an increase of 4% and for the month of August which has the highest humidity level, the VGS contributes 6%.

4.6.3.3 Impact on inside surface temperatures

Using the LW variants 2 and 3, the case is simulated to determine the inside surface temperatures on the east and west facades for variant 2 and for the south façade for variant 3. Figure 4.15 below compares the inside surface temperatures for the base case and variant 2 for the East façade.

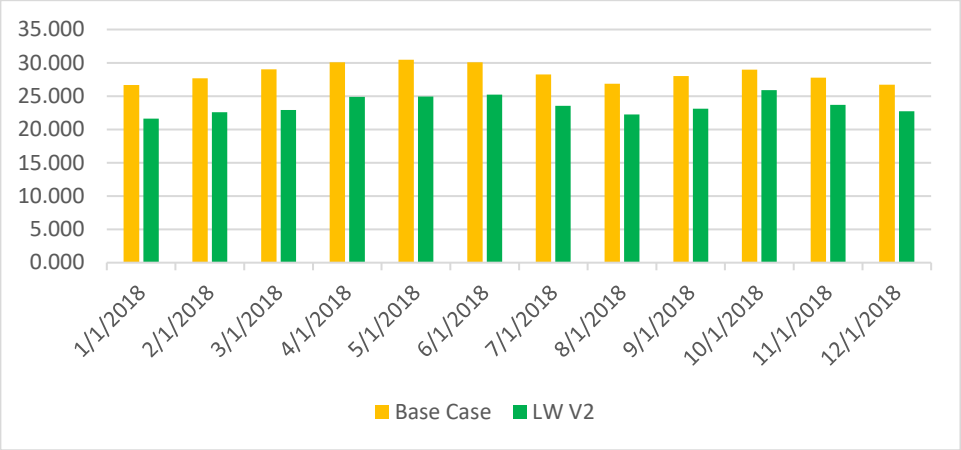


Figure 4.15: East surface temperature Base Case and LW Variant 2. Source: DesignBuilder.

From the simulation, the living wall shows a temperature reduction of 5.6˚C in May and 4.0˚C in December. For the west façade the chart in Figure 4.16 below demonstrates the temperature variations between the VGS case and the base case

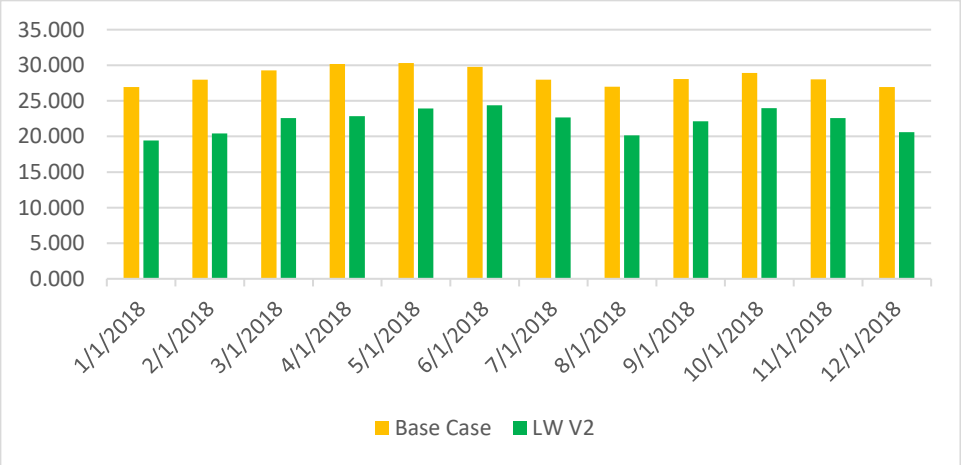


Figure 4.16: West Inside surface temperature Base Case and LW Variant 2. Source: DesignBuilder

The inside surface temperatures for the month of May has a reduction of 6.39˚C and 5.4˚C in December.

Simulating for the South façade, variant 3 was used which has a coverage ratio of 100 and LAI value of 5. Figure 4.17 below is a chart showing the inside surface temperatures for the base case and variant 3.

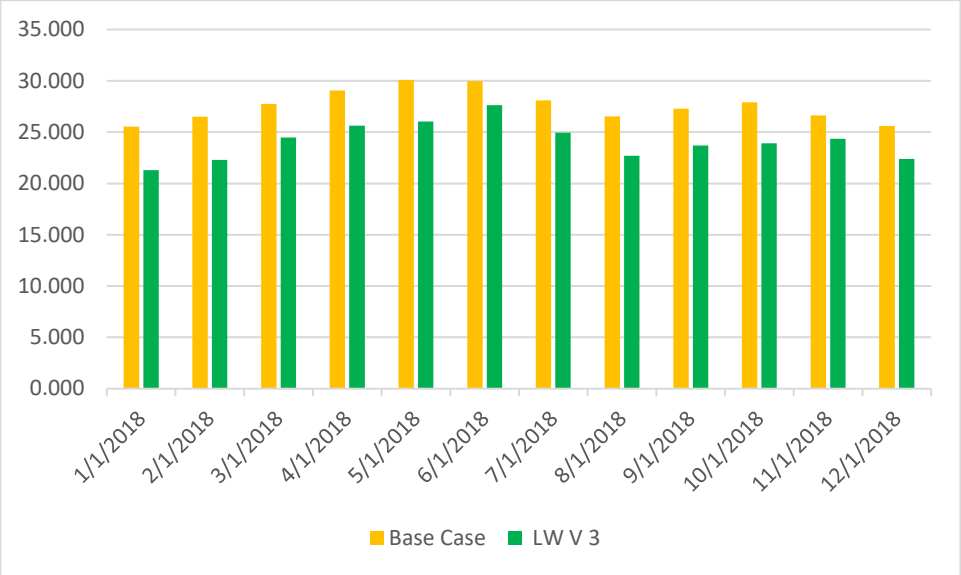


Figure 4.17: South surface temperature Base Case and LW Variant 3. Source: DesignBuilder (4.5).

The analysis above shows a decrease in surface temperatures with the application of the VGS. The temperature reduction for May is 4.06˚C and 3.2˚C for December.

4.7 Summary of results from the simulation

From the simulation performed to determine the effect that VGS has on thermal comfort, it was derived that VGS actually lowers the temperatures and increase humidity levels. Based on the analysis it can be seen that the higher LAI value which was 5 for this research result to better shading effect of the VGS and in turn reduced temperatures considerably. A decrease of 7˚C was derived with the application of the Living wall. It is also deduced that due to the evapotranspiration effects of plant there is tendency to increase humidity levels through VGS application. There was an increase of 4% in humidity levels in the month of February and 6% in August. The table 4.7 below shows the summary of the results gotten from the simulation, indicating the decrease in temperatures when using the VGS variants for both the living wall and indirect greening systems of 100% coverage and LAI value 5.

Table 4.7 Summary of results attained from simulation

	Base Case		Variant 1 decrease		LW Variant 1 decrease	
	May	Dec	May	Dec	May	Dec
Air Temperature	30.05	23.65	5.35	1.65	7.35	4.64
Operative Temp.	30.30	25.52	4.86	2.23	6.86	5.33

Inside surface Temp.	Base Case		Variant 2		LW variant 2	
	May	Dec.	May	Dec.	May	Dec.
West	31.00	26.95	2.70	2.40	6.39	5.40
East	30.48	26.70	2.00	1.95	5.60	4.00

Inside surface Temp.	Base Case		Variant 3		LW variant 3	
	May	Dec.	May	Dec.	May	Dec.
South	30.11	25.60	2.06	1.20	4.06	3.20

	Base Case		LW Variant 1	
	February	August	February	August
Relative Humidity	14.45	69.29	18.45	76.18

5.0 DESIGN PRELIMINARIES

5.1 Introduction

This chapter gives a detailed overview of the design research undertaken. It entails discussions and information on the study area such as its location, weather and climate, the site selection criteria, its location and analysis.

5.2 Study Area

The mid-rise residential estate shall be located in Kano state, Nigeria which is located in the north-west part of the country characterized by the hot and dry climate. It is located between latitudes 11.5° N and 8.5° E. The total area of Kano is 20,131 square kilometers and has an elevation of 488m above sea level with a density of 5700/km^2. It is bounded by Katsina State on the north-west, Jigawa State on the north-east, Bauchi State to the south-East and Kaduna State to the south-west.

5.2.1 Weather and Climate

Kano has a tropical hot and dry climate with the hottest temperature in May, when average daytime temperatures is about 33°C, while January is the coldest month with an average temperature of 21°C. It has little amount of rainfall throughout the year with the highest amount in the month of August reaching 250 mm averagely, and the driest month in February.

5.2.2 Vegetation

Kano state is located within the semi-arid Sudan savannah zone. The vegetation is characterized by sparse drought resistant trees with moderately wide canopies and mostly less than 20m in height. The natural vegetation is rich in flora and fauna resources but it has been modified due to extensive human activities.

5.3 Site Location

A site for residential buildings within Kano would be suitable if the location is in proximity to facilities such as commercial, educational and recreational to enhance and facilitate the ease at which occupant access these areas. The site is located in Kumbotso Local Government and has space for future expansion

5.4 Site Selection Criteria

Some factors were considered based on specific criteria for the selection of site for the mid-rise residential estate. They include:

1. Proximity of site to basic facilities
2. Land-use compliance
3. Size of site, possibility for expansion, suitability and availability.
4. Soil should have a good load bearing capacity.
5. Topography and site vegetation
6. Site should have drainage and waste disposal possibilities.
7. Presence of water body.

Plate XVI below is showing the three sites under consideration for this design



Plate XVI: Image showing all three sites on google earth.

Site one is located at Kwankwasiyya City in Kumbotso Local Government Area at 11°54’4.48°N and 8°31’55.80°E. It has a perimeter of 1,741 metres and a total area of 179,478m^2. The plate XVII below shows site 1 in Kwankwasiyya City on google earth.



Plate XVII: Image showing site 1 on google earth.

5.4.2 Site 2

Site two is located along ring road (bypass) in Kumbotso local government area. It is geographically located at latitude 11°54’49.15"N and Longitude 8°32’03.93"E. It has a total perimeter area of 1, 940 metres mile and an area of 232,752m^2. The site is shown in the plate XVIII below.



Plate XVIII: Image showing site 2 on google earth.

5.4.3 Site 3

Site three is located at Amana City along Zaria road, Kumbotso local government area Kano at 11°52'22.76"N and 8°33'5.06"E. It has a total perimeter of 3,766 metres and an area of 812,856m^2. Plate XIX below shows site 3 at Amana City.



Plate XIX: Image showing site 3 on google earth.

The criteria for the selection are ranked and each site is assessed and scored based on the given ranking below:

Excellent = 5, Very Good = 4, Good = 3, Poor = 2, Very Poor = 1

The site is them chosen based on the highest numeric ranking. Tables 5.1a and 5.1b below are showing the site selection criteria and ranking

Table 5.1a Site Selection Criteria

CRITERIA	**SITE 1** Kwankwasiyya City	**SITE 2** Along Ring Road by-pass	**SITE 3** Amana City	**REMARKS**
Location	5	4	5	Both site 1 and 3 are suitable for a residential development because they are located within residential estates and are easily accessible from the major roads
Land-use compliance	5	5	5	All sites are meant for residential purpose
Proximity to basic amenities	5	4	3	Site 1and 3 have proximity to amenities because they are located within existing estates
Expansion possibility/ size of site	3	5	3	Site 1 and 3 are existing developments and have limited site for expansion while site 3 has enough because it's not developed

Table 5.1b Site Selection Criteria

CRITERIA	SITE 1 Kwankwasiyya City	SITE 2 Along Ring Road by-pass	SITE 3 Amana City	REMARKS
Soil type/ topography/ vegetation of the site	3	4	3	Site 1and 3 have relatively flat slope compared to site 2. Though site 2 has good soil and support vegetation as shrubs and trees are found within and close to the site.
Drainage and waste disposal potential	4	5	4	Site 1 and 2 have better drainage as they slope towards the stream at the eastern part of the site. Site 1 and 3 have already existing waste disposal system
Presence of water body	5	5	0	Site 1 and 2 have a flowing stream running at the eastern side of the sites
TOTAL	30	32	23	Site 2 is chosen as it meets the selection criteria most

From the Tables 5.1a and b above, site 2 has been selected based on the fact that it has more advantage and fulfils the selection criteria, thereby more suitable for the proposed design

5.5 Site analysis

A site analysis is a study of the site, it takes into consideration natural and man-made components present above and beneath the site, as well as climatic conditions present in and around the site. For a comprehensive site study; a macro and micro site analysis is carried out, which the former takes into consideration environmental factors affecting a larger area than the site, such as a region, state or zone. For this study, the entire Kano State is considered for the macro analysis whereas the later analyses the environmental factors affecting the specific site or area

5.5.1 Site Location

The proposed site is located in Kumbotso Local Government Area, along Ring road by-pass, bounded by Kwankwasiyya estate by the south. The longer sides of the site are oriented towards the north and south directions. This makes it easy to orient the buildings

in the same way. The site also has a flowing stream running on the eastern part of the site, which will be utilized in the design as it has to deal with greenery systems.

5.5.2 Site Climate

The climatic conditions of the site are similar to that of the whole Kano city but differs in a slight manner as there is presence of a water body flowing through the site, which gives rise to vegetation on and around the site which affect its micro climate positively. The presence of farmlands around the site also contribute to its distinct micro climate.

5.5.2.1 Temperature

The micro temperature of the site is affected by the presence of the water body and vegetation around the site. Another main factor is the presence of a large estate development Kwankwasiyya estate bounding the site by the south. The average highest temperature occurs in May at about 33^{o}C, while the lowest temperature occurs in January with an average of 19^{o}C as shown by the figure below. VGS would be designed to reduce temperatures in the highest month so as to achieve thermal comfort. Below is plate XX showing the average temperatures in Kano.

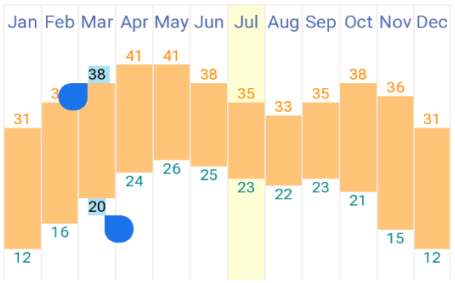


Plate XX: Image showing average temperature in Kano

5.5.2.2 Relative Humidity

The month with the highest average humidity is august with an average of about 80% while February has the lowest with an average of 23%. VGS would be designed to maintain the immediate climate condition during the driest month by making use of plants that require minimal water and still evapo-transpirate during dry seasons. The plate XXI below is a graph showing the relative humidity in Kano.

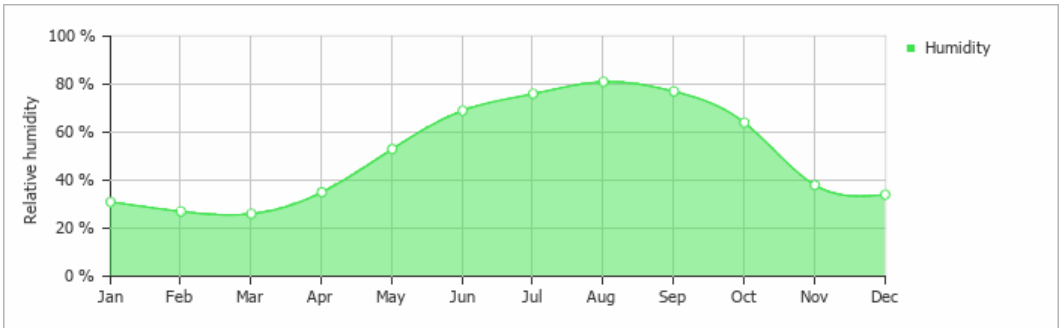


Plate XXI: Image showing relative humidity in Kano

5.5.2.3 Rainfall

Kano experiences minimal rainfall throughout the year with the highest rainfall amount in August averaging 257mm and the driest months range from December to march. VGS is to take advantage of the rainy season and store water for watering during the dry period, also plants selection would be considered to withstand drought. Plate XXII shows the average rainfall in Kano.

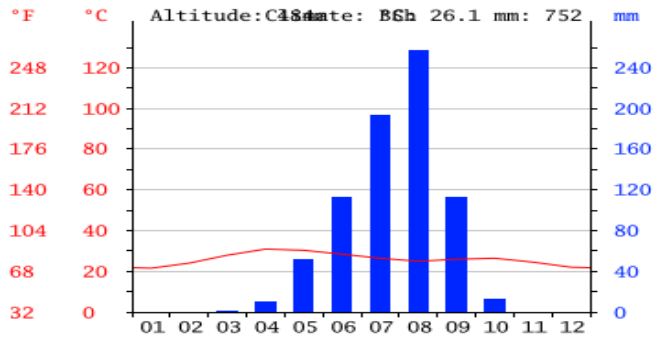


Plate XXII: Image showing average rainfall in Kano State.

5.5.2.4 Sunlight and daylight hours

The presence of trees and shrubs on the site is an advantage as they provide thermal insulation, shading, and evapo-transpire which improve the micro-climate. The month with the highest sunshine is November with an average of 8.8h while the month with the least sunshine is August with an average of 7.1h. The west and east orientations are exposed to direct sunlight as such Living wall VGS systems would be placed here as they are more capable of absorbing more heat and in turn provide more cooling.

Accessibility and Infrastructure

The site is located along an access road which is the Ring road bypass which gives easy access to the site, also the presence of an already existing estate Kwankwasiyya makes it easy to access basic amenities around. The site being located in a virgin land near farmlands and other upcoming developments makes the density to be lower than the metropolis. There is also access to electricity as power lines are located along the road for existing development. below is plate XXIII showing the road and electricity lines around the site.





Plate XXIII: Images showing roads and electric lines on site. Source; Author.

5.5.2.5 Vegetation and Topography

The proposed site is characterized by trees and shrubs this is as a result of the stream flowing through the site. The site slopes eastwards towards the stream but has a relatively flat slope on the western part. The plate XXIV below shows the vegetation on the site and the topography of the site.



Plate XXIV: Image of vegetation on site. Source: Author

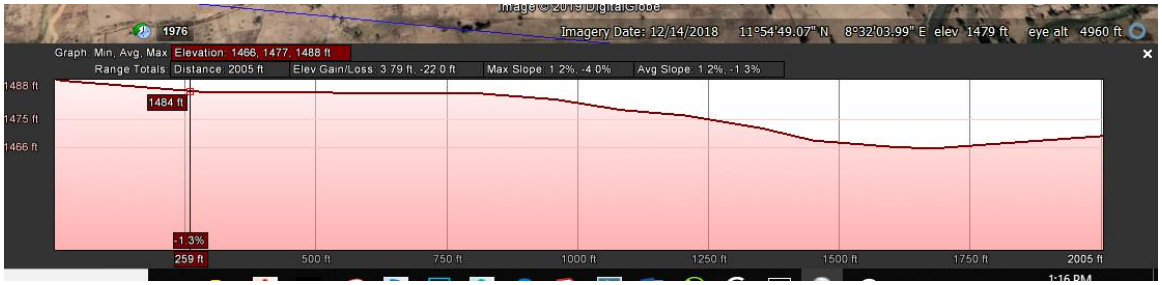


Plate XXV: Image showing site section draining towards the stream

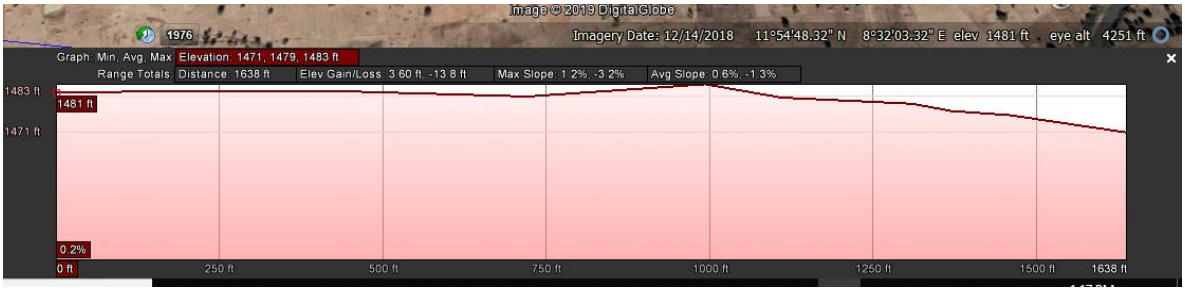


Plate XXVI: Image showing site section draining towards the south.

6.0 DESIGN REPORT

This chapter entails the architectural design process implemented to arrive at the proposed midrise residential estate. The proposed design will aim to reduce high temperatures and enhance thermal comfort through the use of VGS.

6.1 Brief Development

The main consideration for the proposed design is the achievement of thermal comfort through the application of VGS. This will form a bench mark for analysis and subsequent design in the field of architecture. Kano state which has relatively high temperatures during the hot season need to adopt a sustainable means to effectively reduce temperatures and make users comfortable within their spaces as such the client which is the Kano Government plans to employ VGS to cut down on cooling loads in residential buildings thereby contributing their own quota in achieving the SDG's and ensuring the users are thermally comfortable. The design consists of 4 prototypes, 2 for low income earners which consists of 2 and 3 bedrooms totaling 86 apartments. 1 for middle income earners totaling 80 apartments and 1 for high income earners totaling 20 apartments. The whole estate, houses 186 apartments.

6.3 Design Consideration

The variables of the research were the major considerations of this design which includes the VGS systems mainly the indirect green facades and modular living walls, the type of plants, coverage area and foliage density. Other considerations include orientation and functionality

6.3.1 VGS systems

The VGS techniques adopted for this design is the direct and indirect green facades and the modular living walls. The direct and indirect green facades were mainly implemented on the south and north facades as the sun radiation tends to be less on these sides compared

to east-west. They were designed to have a coverage ratio of 100 % and a LAI value of 5 as seen from research that this gives the best temperature reduction on the walls of bed rooms. While on the walls of living areas and balconies they had a coverage ratio of 50% and a LAI value of 5. The indirect green facades were mixed with planter boxes on each floor, which was designed to have drain and irrigation pipes connected down to the ground level. The living walls were used on the bedrooms facing east and west orientations enabling to reduce large amount of heat and providing adequate thermal insulation.

6.3.2 Plant selection

All the plants selected for the design are well adapted to the local climate of Kano and are very good in thermal insulation and as meets the purpose of the research. The plants are locally available and have fast growth and easy planting techniques. The direct green façade made use of the pink bougainvillea climbers which is an evergreen plant, planted in loamy soil from the ground. They often shed their flowers during the dry season, though easily grows them back if watered adequately. They possess hardy stems and can cause damage to walls, to tackle this, a natural stone veneer was used to clad the walls on which the grow.

For the indirect green facades combined with planter box system, the climber known as Ficus pumila (climbing fig) was adopted. It is also an evergreen vine and known to grow very fast and wild if not adequately cared for. It is also known for its considerable transpiration rate and as such is a good enhancer of micro-climate. In this research it is used as shader for the living areas, dining and balconies. Rose climbers which are also cultivated locally were used mainly for their aesthetics function on terraces, and beside service ducts, though they also add to the thermal performance of the building.

For the modular living walls, variety of plants were chosen to enhance the thermal properties of the wall, it was designed using a hydroponic growing media of rockwool making it lighter than using soil. The plants consisted of marigold flowers, English boxwood and Ixora shrubs. These plants are locally cultivated in the north and are often used in landscaping as hedges and shrubs. There are evergreen and are also known to have great impact of thermal comfort. Plate XXVII below show the images of the plants used in the research.



Plate XXVII: Images showing plants adopted in VGS

6.3.3 Orientation

The longer sides of the buildings were orientated towards the north and south, thereby informing the type of VGS to be used on each orientation. The green facades were used on the north and south and living walls on east and west. The windows were also minimized to reduce heat gains and glaring.

6.3.4 Site planning

The site was zoned according to noise and privacy considerations. The lower density which is for the high- income earners also have the advantage of viewing the water body from their spaces. The area surrounding the stream was designed as a recreational facility to enhance interaction and relaxation. The site was also designed to have enough vegetation to create a good micro climate. The auxiliary facilities were planned in the core of the site to enhance equal accessibility from each density.

6.3.5 Services

6.3.5.1 Water recycling

An on-site water recycling system is integrated on the site to recycle grey water and in turn use it for watering the VGS.

6.3.5.2 Sewage

A biogas plant was also incorporated to produce biogas from organic waste which could help in waste management there by reducing greenhouse gases emission and supplying some amount of gas for the estate.

6.3.5.3 Irrigation and drainage of VGS

Underground pumps and pipes were provided to cater for irrigation of VGS. The living walls make use of drip irrigation with pipes on every 2 floors. Both the green facades and living walls have drain pipes connected below the ground

6.4 Schedule of accommodation

The tables below show the space requirements and accommodation schedule for the different prototypes in the design. Table 6.1 shows the spaces in the 2-bedroom for low-income earners with their floor area.

Table 6.1 Schedule accommodation for two-bedroom prototype for low income earners

Rooms Required	Minimum Floor Area	Unit	Furniture Parameters	
Living/ dining	25 m² area	1	Sitting area with center table, decorative shelves miscellaneous items (decorative), Circulation for wheel chair inclusive	
Kitchen	7.3 m² area 3.60 m width	1	Built in cupboards 250 ltr Freezer Clearance between opposite facing fittings Built in shelves and cooker	1500x 600 800x 750 1500 2200x600
Bedrooms	16m² area 4.00 m width	2	Queen sized bed Clearance for dressing Bed side tables (2) Dressing table Large sized wardrobe	2000x1800 1500 750x600 1200x 600 2400x600
bathroom/ WC/ Storage	3.24 m² area 1.80 m width	4	WC Shower tray	700x450 900x900
Entrance	7.20m² area 3.60 m width	1	Provide step less entry. The porch may be part of a verandah. Total area in the range of 80.00m² including all walls.	

The Table 6.2 below shows the spaces required and their area requirements for the three-bedroom prototype for low-income earners.

Table 6.2 Schedule accommodation for three-bedroom prototype for low income earners

Rooms Required	Minimum Floor Area	Unit	Furniture Parameters	
Living/ dining	30m² area	1	Sitting area with center table, decorative shelves miscellaneous items (decorative), Circulation for wheel chair inclusive	
Kitchen	7.3 m² area 3.60 m width	1	Built in cupboards 250 ltr Freezer Clearance between opposite facing fittings Built in shelves and cooker	1500x 600 800x 750 1500 2200x600
Bedrooms	17.0m² area 4.50 m width	3	Queen sized bed Clearance for dressing Bed side tables (2) Dressing table Large sized wardrobe	2000x1800 1500 750x600 1200x 600 2400x600
bathroom/ WC	3.04m² area 1.90 m width	3	WC Shower tray	700x450 900x900
bathroom/ WC	4.60m² area 2.0 m width	1	WC Shower tray	700x450 900x900
storage	3.60m² area 2.0 m width			
Entrance	7.20m² area 3.60 m width	1	Required area for table and chairs for relaxation for 4-6 users Clearance for planting	9m² 2m²
Balcony	6.75m² area 1.50 m width	1	Provide step less entry. The porch may be part of a verandah. Total area in the range of 120.00m² including all walls.	

Tables 6.3a and b below indicate the spaces for the middle -income earners and their minimum floor area, it also shows the furniture parameters which guided the allocation of spaces within the building.

Table 6.3a Schedule accommodation for three-bedroom prototype for middle income earners

Rooms Required	Minimum Floor Area	Unit	Furniture Parameters	
Living	32m² area	1	Sitting area with center table, decorative shelves miscellaneous items (decorative), Circulation for wheel chair inclusive	
Dining	13m² area		Min. requirement for dining table for 6 people Side tables	5100m² 1200x 600

Table 6.4b Schedule accommodation for three-bedroom prototype for middle income earners

Rooms Required	Minimum Floor Area	Unit	Furniture Parameters	
Kitchen	11.0 m² area 3.60 m width	1	Built in cupboards 250ltr Freezer Clearance between opposite facing fittings Built in shelves and cooker	1500 x 600 800x 750 1500 2200x600
Bedrooms	20.0m² area 4.50 m width	3	Queen sized bed Clearance for dressing Bed side tables (2) Dressing table Large sized wardrobe	2000x1800 1500 750x600 1200x600 2400x600
bathroom/ WC	4.50m² area 1.80 m width	4	WC Shower tray	700x450 900x900
storage	3.60m² area 2.0 m width			
Entrance	7.20m² area 3.60 m width	1	Required area for table and chairs for relaxation for 4-6 users Clearance for planting	9m² 2m²
Balcony	8.00m² area 2.00 m width	1	Provide step less entry. The porch may be part of a verandah. Total area in the range of 150.00m² including all walls.	

Tables 6.4a and b below indicate the spaces for a four-bedroom duplex for the high - income earners and their minimum floor area, it also shows the furniture parameters which guided the allocation of spaces within the building.

Table6.5a Schedule accommodation for four-bedroom duplex for high income earners

Rooms Required	Minimum Floor Area	Unit	Furniture Parameters	
Living	33m² area	1	Sitting area with center table, decorative shelves miscellaneous items (decorative), Circulation for wheel chair inclusive	
Family living	18m² area		Sitting area with center table, decorative shelves	
Dining	18m² area		Min. requirement for dining table for 6 people Side tables	5100m² 1200x 600
Kitchen	19.0 m² area 4.20 m width	1	Built in cupboards 250 ltr Freezer Clearance between opposite facing fittings Built in shelves and cooker	1500x 600 800x 750 1500 2200x600

Table6.6b Schedule accommodation for four-bedroom duplex for high income earners

Bedrooms	18.0m² area 4.50 m width	4	Queen sized bed Clearance for dressing Bed side tables (2) Dressing table Large sized wardrobe	2000x1800 1500 750x600 1200x 600 2400x600
bathroom/ WC	5.0m² area 1.80 m width	5	WC Shower tray	700x450 900x900
storage	3.60m² area 2.0 m width			
Entrance	4.90m² area 1.90 m width	1	Required area for table and chairs for relaxation for 4-6 users Clearance for planting	9m² 2m²
Balcony	8.00m² area 2.00 m width	1	Provide step less entry. The porch may be part of a verandah. Total area in the range of 200.00m² including all walls.	

7.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This chapter discusses the summary, conclusion, contributions to knowledge and recommendations of this research. This chapter outlines how the objectives were achieved, limitations and recommendations areas for further research

7.2 Summary

The first chapter introduces the concept of thermal comfort and ways that have been used to achieve it in residential spaces. It also identified the need to look for more sustainable means of achieving thermal comfort especially in hot dry climates of Nigeria. The chapter introduced the concept of Vertical greenery systems and also indicated that only few research works had been carried out in Nigeria on VGS.

Chapter two discussed in details what Vertical Greenery systems are; how they evolved and developed over time, the different types available, and how they had been used in other parts of the world. The chapter also outlined the key works and researches done under this field and mentioned the thermal benefits and other importance of VGS. It summarised the recent works, and the thermal achievement derived.

Chapter three presented the methodology used to carry out the research which included visual survey and computer simulation. The visual survey was conducted on two residential houses that incorporated VGS in their designs, located in Kaduna and kano. Instrument that were used to collect data during the visual survey included camera. Measuring tape and sketch pad. Simulation was carried out using DesignBuilder V4.5.

The next chapter discussed the visual survey and simulation results derived from the analysis. A base case was designed and simulated, after which VGS was added and simulated to obtain the difference. A maximum of decrease of 7°C was derived from

living walls while a decrease of 5.35°c was gotten from indirect green façade with 100% coverage ratio.

Chapter five discussed in detail the site selected for the proposed design, outlined some criteria for the selection which included location, accessibility, proximity to amenities, topography and presence of water body. The chapter also presented the site features such as climate, topography and services and how the features would influence the design.

Chapter six entailed the design process, discussing the brief development and design considerations. It mainly pointed out the VGS techniques adopted which is the direct and indirect green facades and the modular living wall. It also stated out the plants used for the research and how they enhance thermal comfort. In conclusion, it discussed the implementation of the research outcome in the design.

8.3 Conclusion

The aim of this study is to enhance thermal comfort by the application of VGS in midrise residential estates through the following objectives:

1. To examine the relationship between VGS and indoor thermal comfort in buildings.
2. To evaluates the application of VGS characteristics in selected visual survey and assessments.
3. To determine the effects of VGS on thermal comfort in residential building design through computer simulation in the hot dry climates of Nigeria
4. To demonstrates the outcome of the study in the design of a midrise estate.

This was achieved by making thorough research of previous works and studying how VGS have been incorporated in buildings. Two case studies were carried out in Kaduna and Kano each but had limitation as they only integrated the direct green façade only.

From the information derived from the visual survey and literature, a base case was modelled and simulated to obtain the comfort profile. Two different VGS was applied on the walls of the base case, that's the indirect green façade and living wall and then simulated, varying factors such as the coverage ratio, foliage density and orientation to obtain the best results. The research showed that Living walls have the best ability in reducing temperatures as such they are most suitable to be used on east and west orientations. Indirect green facades also exhibited good results and can be used on north and south orientations. In the hot and dry climate of Kano, Indirect green facades can be used as a good option as it has a considerably good effects on thermal comfort and is less expensive than the living walls.

8.4 Contributions to knowledge

1. With the integration of living walls using ixora, marigold and English boxwood shrubs, a maximum reduction of 7°c was achieved.
2. A reduction of 5.35°c for green facades using Ficus pumila and bougainvillea climbers at 100% coverage ratios was obtained at 30% window to wall ratio.

8.5 Recommendations

1. Research on other types of VGS such as the direct green facades should be carried out to know their benefits on thermal comfort in hot dry climates
2. Different plants should be explored as to determine which one has higher impact on thermal comfort.

REFERENCES

Abdulkareem, M., Almaiyah, S., & Cook, M. (2015). *Occupant comfort in mid-rise residential buildings in Abuja, Nigeria:the trade-off between thermal and visual performance.* Technical Symposium, CIBSE, United Kingdom.

Abodunrin, J. (2014). *Simulating the effects of walling materials on thermal comfort in residential buildings of "area a".* Ahmadu Bello University. Zaria: Unpublished Thesis.

Adaji, M., & Watkins, R. (2015). An Investigation into Thermal Comfort in Residential Buildings in the Hot-Humid Climate of sub-Saharan Africa: A Field Study in Abuja-Nigeria. *Passive and Low Energy Architecture (PLEA).* Kent: ResearchGate.

Afshari, A. (2017). A new model of urban cooling demand andheat island − Application to Vertical Greenery Systems (VGS). *Energy and Buildings*.

Akande, O. K., & Adebamowo, M. A. (2010). Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate of Nigeria. *Adapting to Change: New Thinking on Comfort.* United Kingdom: ResearchGate.

Akinwolemiwa, O. H., Bleil de Souza, C., De Luca, L. M., & Gwilliam, J. (2018). Building community-driven vertical greening systems for people living on less than £1 a day: A case study in Nigeria . *Building and Environment*, 277-287.

Akinwolemiwa, O., & Gwilliam, J. (2015). Evaluating the impact of Vertical Greening Systems on Thermal Comfort in Low Income residences in Lagos, Nigeria. (E. Ltd, Ed.) *Procedia Engineering*, 420-433.

Allen, J., MacNaughton, P., Laurent, J., Flanigan, S., Eitland, E., & Spengler, J. (2015). Green buildings and health. *Environ*, 250-258.

Amir, A. F., Yeok, F. S., & Rahman, A. M. (2014). Estimation of Annual Carbon Sequestration in Psophocarpus tetragonobulus used as Biofacade in Tropical Environment. *International Conference on Architecture and Civil Engineering*, 31-37.

Arowona, T. (2017). *Architectural envelope design in warm humid zones to optimize indoor thermal comfort for a proposed lekki free trade zone resort, Lagos.* Unpublished Msc. Thesis, Ahmadu Bello University , Department of Architecture.

ASHRAE. (2009, July 3rd). *ASHRAE Handbook-Fundamentals.* Retrieved June 30th, 2015, from ASHRAE home page: www.ashrae.org

Audu, H. I. (2013). *Design Proposal for Luxury Homes Dawaki Kano State, Nigeria. with Emphasis on Cosmetic Customization.* Federal University of Technology, Minna, Nigeria., D. Minna: Federal University of Technology, Minna, Nigeria.

Bano, F., & Kamal, M. A. (2016, June 5). Examining the Role of Building Envelope for Energy Efficiency in Office Buildings in India. *Architecture Research*, pp. 107-115.

Basher, H. S., Ahmad , S. S., & Abdul Rahman , A. (2017). Simulation of Vertical Greenery System in Reducing Energy Cooling Loads for High Rise Residential Building. *Journal of Mechanical Engineering, 2*(1), 85-196.

Bass, B., & Baskaran, B. (2003). *Evaluating rooftop and vertical gardens as an adaptation strategy for urban areas.* Institute for Research and Construction. Ottawa, Canada: National Research Council.

Batagarawa, A. (2013). *Assessing the Thermal performance of Phase change materials in composite Hot Humid/Hot Dry Climates: An Examination of office buildings in Abuja, Nigeria.* phD Thesis, Newcastle University, School of Architecture, planning and landscape.

Bello, A., & Egresi, I. (2017). Housing Conditions in Kano, Nigeria: A Qualitative Assessment of Adequacy. *Analele Universitatii din Oradea, Seria Geografie*, 205 -299.

Burlington. (2019). *Design Guidelines for Mixed-Use and Residential Mid-Rise Buildings* . Burlington: Burlington.ca.

Charoenkit, S., & Yiemwattana, S. (2017). Role of specific plant characteristics on thermal and carbon sequestration properties of living walls in tropical climate. *Build. Environ, 115*, 67-79.

Chen, Q., Li, B., & Liu, X. (2013). An experimental evaluation of the living wall system in hot and humid climate. *Energy and Buildings.*, 298-307.

Coma, J., Perez, G., Alvaro, G. d., Bures, S., Urrestarazu, M., & Cabeza, L. F. (2017). Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. *Building and Environment, 111*, 228-237.

Dahanayake, K. C., & Chow, C. L. (2017). Studying the Potential of Energy Saving through Vertical GreeneSystems: Using EnergyPlus Simulation Program. *Energy and Buildings, 138*, 47-59.

Dinsdale, S., Pearen, B., & Wilson, C. (2006). *Feasibility study for green roof application on Queen's University campus.* Queen's Physical Plant Services.

Djedjig, R., Bozonnet, E., & Belarbi, R. (2015). Analysis of Thermal Effects of Vegetated Envelopes: Integration of a validated model in a building energy simulation program. *Energy and Buildings*, 93-103.

Elaiab, F. (2014). *Thermal comfort investigation of multi-storey residential buildings in mediterranean climate with reference to darnah, libya.* Department of architecture and built environment. Nottingham: the University of Nottingham.

Fanger, P. O. (1970). *Thermal Comfort: analysis and applications in environmental engineering.* . Copenhagen : Danish Technical Press.

Federal Ministry of Power, W. a. (2016). *Building Energy Efficiency Guideline for Nigeria.* Abuja: Federal Ministry of Power, Works and Housing.

Fernandez-Canero, R., Urrestara, L., & Salas, A. (2012). Assessment of the cooling potentia lof an indoor living wall using different substrates in a warm climate. *Indoor Built Environ*, 642–650.

Gbode, I. E., Akinsanola, A. A., & Ajayi, V. O. (2015). Recent Changes of some Observed Climate Extreme Events in Kano. (T. Reichler, Ed.) *International Journal of Atmospheric Sciences*. doi:10.1155/2015/298046

GrabowieckI, K., Jaworski, A., Niewczas, T., & Belleri, A. (2017). Green Solutions-climbing vegetation impact on building- energy balance element. *Energy Procedia,111*, 377 – 386. Retrieved from http://creativecommons.org/licenses/by-nc-nd/4.0/

Guan, L. (2012, Sept.). Energy use, indoor temperature and possible adaptation strategies for air-conditioned office buildings in face of global warming. *Building and Environment, 55*, 8-19.

Hashe, V. T. (2017). Solar Heating and Cooling in Buildings- How Sustainable? *International Conference on Sustainable Materials Processing and Manufacturing, SMPM* (pp. 92-97). Kruger, National Park: Elsevier Ltd.

Hoyano, A. (1988). Climatological uses of plants for solar control and the effects on the thermal environment of a building. *Energy Build, 11*, 181-199.

Hussaini, I. (2016). *Application of Bioclimatic Archiecture in the Design of Engineering Complex, Bauchi State University*. Unpublished Msc Thesis, Ahmadu Bello University, Department of Architecture, Zaria.

Ip, K., Lam, M., & Miller, A. (2010). Shading performance of a vertical deciduous climbing plant canopy. *Build. Environ., 45*, 81-88.

Jaafar, B., Said, I., & Rasidi, H. M. (2011). Evaluating the Impact of Vertical Greenery System on Cooling Effect on High Rise Buildings and Surroundings: A Review. *SENVAR.* Indonesia: © 2011 12th SENVAR.

Jamil, A. H. (2016). *Effects of Vegetation on Building Environment: Daylighting and Thermal Simulation Study of Green Climber*. Universiti Teknologi Malaysia, Department of Architecture. Malaysia: Universiti Teknologi Malaysia.

Jim, C., & He, H. (2011). Estimating heat flux transmission of vertical greenery ecosystem. *Ecological Engineering, 37*, 1112–1122.

Koc, C. B., Alan, P. H., & Paul, O. (2018, May). Evaluating the cooling effects ofgreen infrastructure: A systematic review of methods, indicators and data sources. *Solar Energy*. doi:10.1016/j.solener.2018.03.008

Larsen, S. F., Filippín, C., & Lesino, G. (2014). Thermal simulation of a double skin façade with plants. *Energy Procedia, 57,* 1763 – 1772 . doi:doi: 10.1016/j.egypro.2014.10.165

Malys, L., Musy, M., & Inard, C. (2014). A hydrothermal model to assess the impact of green walls on urban microclimate and building energy consumption. *Build Environ, 73*, 187–197.

Manso, M., & Castro-Gomes, J. (2015). Green wall systems:A review of their characteristics. *Renewable and Sustainable Energy Reviews, 41*, 863–871.

Mazzali, U., Scarpa, M., & Peron, F. (2014). Modeling the Energy Performance of Living Walls: Validation Against Field Measurements in Temperate Climate. *Energy and Buildings*, 155-163.

Mcgee, C. (2013, June 25). *Passive Design.* Retrieved March 24, 2018, from Your Home: http//www.yourhome.gov.au/passive-design

McQuiston, F., Parker, J., & Spliter, J. (2005). *Heating, Ventilation and Air Conditioning Analysis and Design.* New York: John Wiley and Sons.

Miller, A., Ip, K., Shaw, K., & Lam, M. (2007). *Vegetation on Building Facade " Bioshader".* CaseStudy Report, University of Brighton, London.

Muhammad, M., & Bichi, M. A. (2014, June). Constraints and Challenges on Housing Provision in Kano City, Nigeria. *International Journal of Advancements in Research & Technology*, *3*(6), 4-23.

Mukhtar, I., Muhammad, M. N., & Enaburekhan, J. (2015, November). An Assessment of Thermal Comfort in Hot and Dry Season (A Case Study of 4 Theaters at Bayero University Kano). *International Journal of Multidisciplinary and Current Research*, 1117-1121. Retrieved from http://ijmcr.com

Musa, A. (2016). *Assessment of Ventilated Cavity Wall for Passive Cooling in the Design of 4 Star Hotel, Birnin Kebbi.* Unpublished Msc Thesis, Ahmadu Bello University, Department of Architecture, Zaria.

Nori, C., Olivieri, F., Grifoni, R., & Bedoya, C. (2013). Testing the performance of a green wall system on an experimental building in the summer. *Sustainable Architecture for a Renewable Future.* Munich, Germany: PLEA2013 - 29th Conference.

Othman, A. R., & Sahidin, N. (2016). Vertical Greening Façade as Passive Approach in Sustainable Design. *Procedia - Social and Behavioral Sciences. 222*, pp. 845-854. Jakarta: Elsevier Ltd.

Papadakis, G., Tsamis, P., & Kyritsis, S. (2001). An experimental investigation of the effect of shading with plants for solar control of buildings. *Energy and Buildings*, 831-836.

Pérez,G.,Coma,J., Martorell, I., & Cabeza, L. (2014). Vertical GreenerySystems(VGS)for energy saving in buildings:Areview. *Renewable and Sustainable Energy Reviews, 39*, 139-165.

Pérez, G., Coma, J., Sol, S., & Cabeza, L. F. (2017). Green facade for energy savings in buildings: The influence of leaf area and facade orientation on the shadow effect. *Applied Energy, 187*, 424-437.

Pérez, G., Rincón, L., Vila, A., González, J., & Cabeza, L. (2011). Behaviour of green facades in Mediterranean Continental climate. *Energy Conversion and Management*, 1861-7.

Pérez, L. U., Cañero, R. F., Franco, A. S., & Egea, G. (2016). Vertical Greening Systems and Sustainable Cities. *Journal of Urban Technology*.

Perini, K., Ottelé, M., Fraaij, A., Haas, E., & Raiteri, R. (2011). Vertical greening systems and the effect on air flow and temperature and the effect on air flow and temperature. *Building and Environment, 46*, 2287-2294.

Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2011). Greening the building envelope, façade greening and living wall systems. *Open Journal of Ecology, 1*(1), 1-8.

Poddar, S., Park, D. Y., & Chang, S. (2017). Simulation Based Analysis on the Energy Conservation Effect of Green Wall Installation for Different Building Types in a Campus . *Energy Procedia* , 226 – 234 .

Prabhat, P., & Meenu, M. P. (2015). *Reseaach Methodology: Tools and techniques.* Romania : Bridge Center .

Prihatmanti, R., & Taib, N. (2017). Improving Thermal Comfort through Vertical Greeneries in Transitional Spaces for theTropical Climate: A Review. *Journal of Engineering Technology (JET), 4*(3), 116-123.

Prihatmanti, R., & Taib, N. (2018). Multi-layer planting as a strategy of greening the transitional space in high-rise buildings: A review. *Earth and Environmental Science, 126.* Medan.

Raji, B., Tenpierik, M. J., & Dobbelsteen, A. v. (2014). *The impact of Greening Systems on building energy performance: A Literature Review.* Delft University of Technology,, Faculty of Architecture, The Netherlands.

Saberi, O., Saneei, P., & Javanbakht, A. (n.d.). *Thermal Comfort in Architecture.* Tehran .

Safikhani, T., Abdullah, A. M., Ossen, D. R., & Baharvand, M. (2014). Thermal Impacts of Vertical Greenery Systems. *Environmental and Climate Technologies*, 5-11.

Shahidan, M. F., & Jones, P. (2008). Plant canopy design in modifying urban thermal environment: Theory and guidelines,". *25th Conf. Passiv. Low Energy Archit*, (pp. 1-9).

Sheweka, S. M., & Mohamed, N. M. (2012). Green Facades as a New Sustainable Approach Towards Climate Change. *Energy Procedia, 18*, 507-520.

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

Vaezizadeh, F., Rashidisharifabad, S., & Afhami, R. (2016). Investigating the Cooling Effect of Living Walls in the Sunken Courtyards of Traditional Houses in Yazd . *European Journal of Sustainable Development* , 27-40.

Wang, C., Er, S.-S., & Abdul-Rahman, ,. H. (2016). Indoor vertical greenery system in urban tropics. *Indoor Built Environ, 25*(2), 1420326X14550508.

Wong, N. H., Kwang Tan, A. Y., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., . . . Wong, N. C. (2010). Thermal evaluation of vertical greenery systems for building walls. *Build Environ*.

Wyse, S. E. (2011, September 16). *Snap Surveys.* Retrieved from Sanp Surveys: http://www.snapsurveys.com/blog/2011/09/16/

Yin, R. K. (2003). *Case Study Research and Methods.*

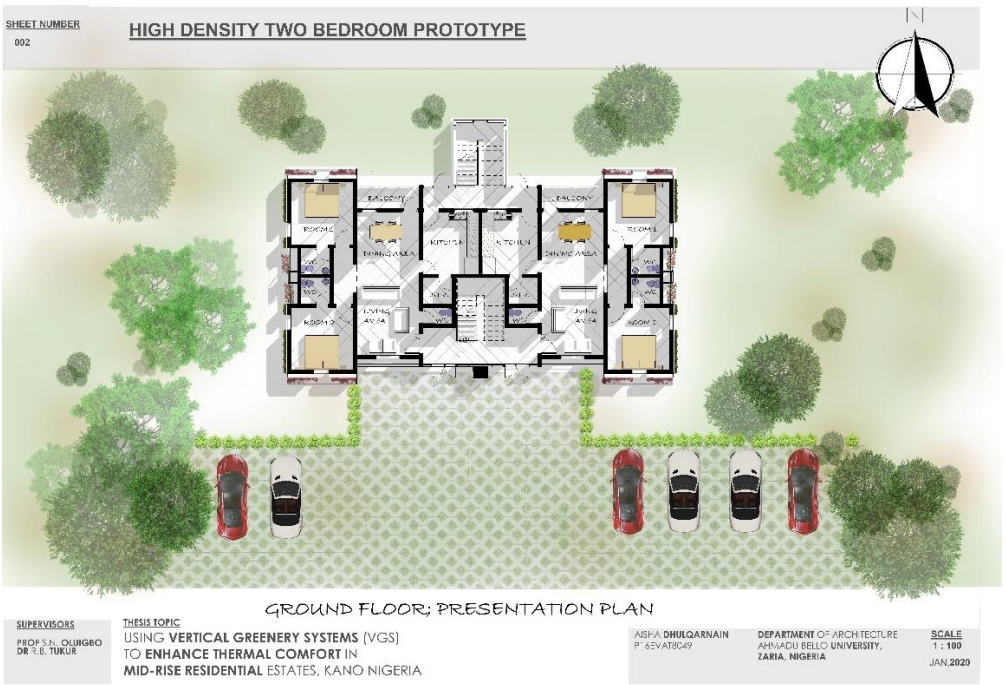
Yoshimi, J., & Altan, H. (2011). Thermal Simulations on the Effects of Vegetated Walls on Indoor Building Environments. *12th Conference of International Building Performance Simulation Association* (pp. 1438-1443). Sydney: Proceedings of Building Simulation.

Yuan, S. (2017). *Cooling Energy Saving Performance of Exterior Greenery System on Department of Energy Reference Buildings.* The Pennsylvania State University, Architectural Engineering. Pennsylvania: The Pennsylvania State University.

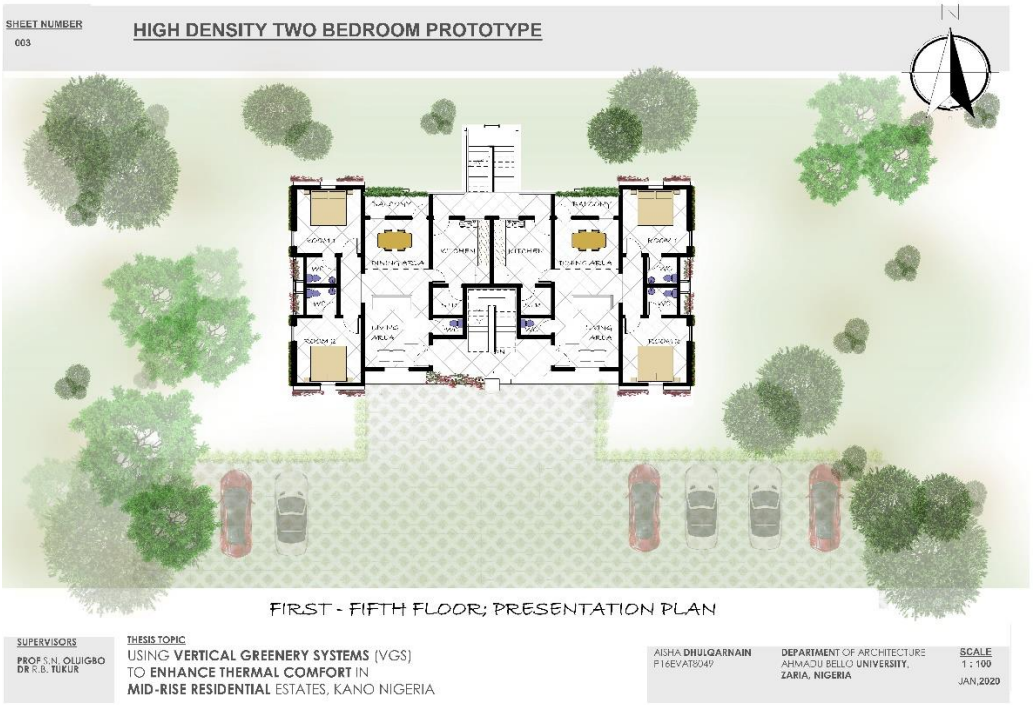
APPENDICES



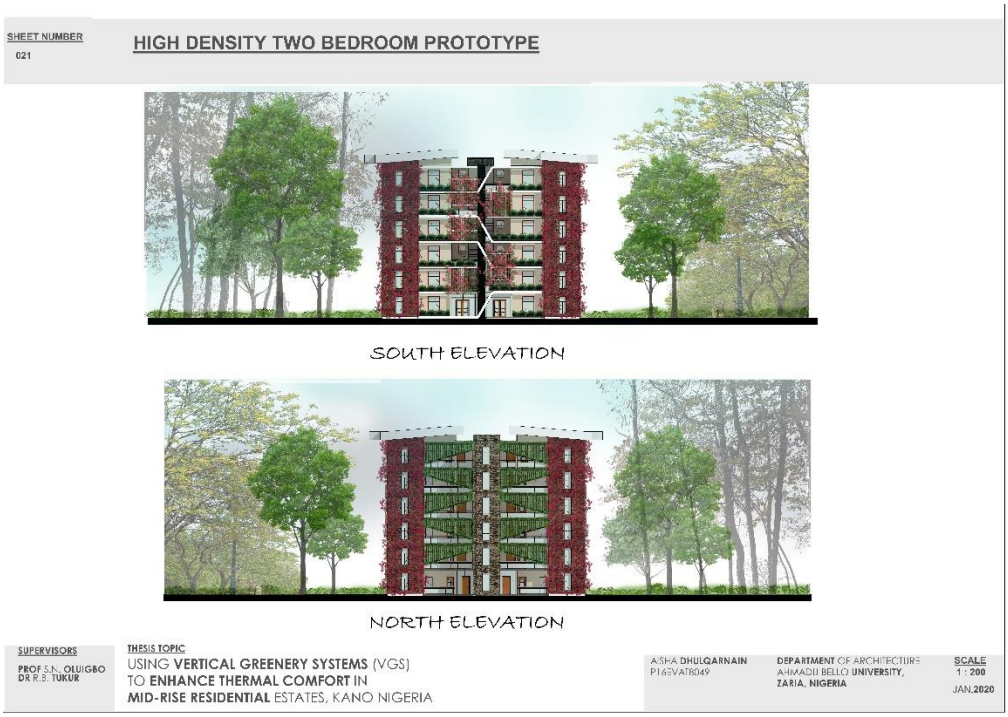
Appendix I:Site Plan of proposed mid-rise residential estate.



Appendix II: Ground floor plan of 2 bedroom for High Density.



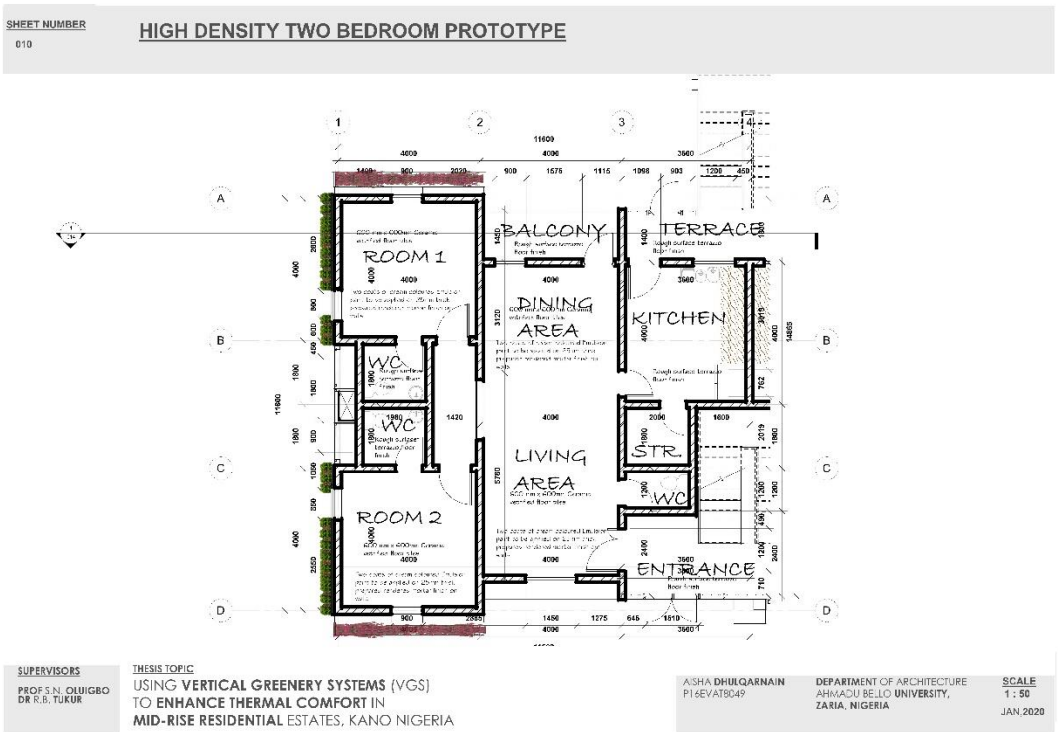
Appendix III: First - Fifth floor plan of 2 bedroom for High Density.



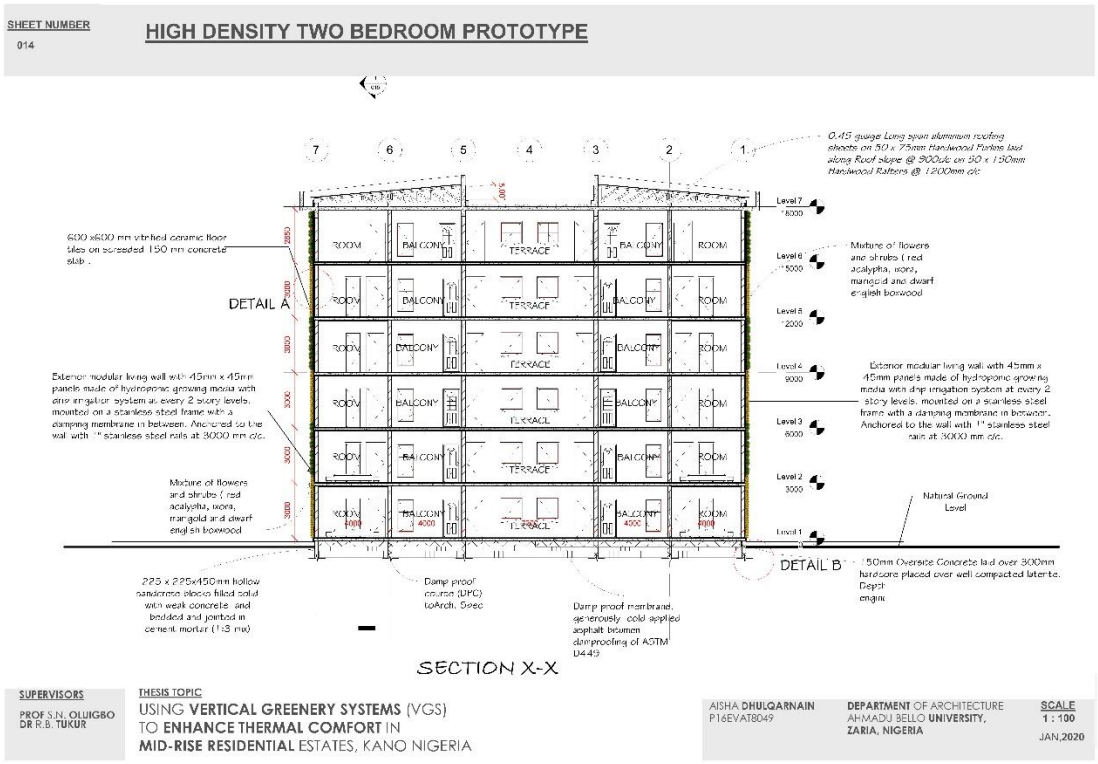
Appendix IV: Approach and Rear Elevations of 2 bedroom High Density.



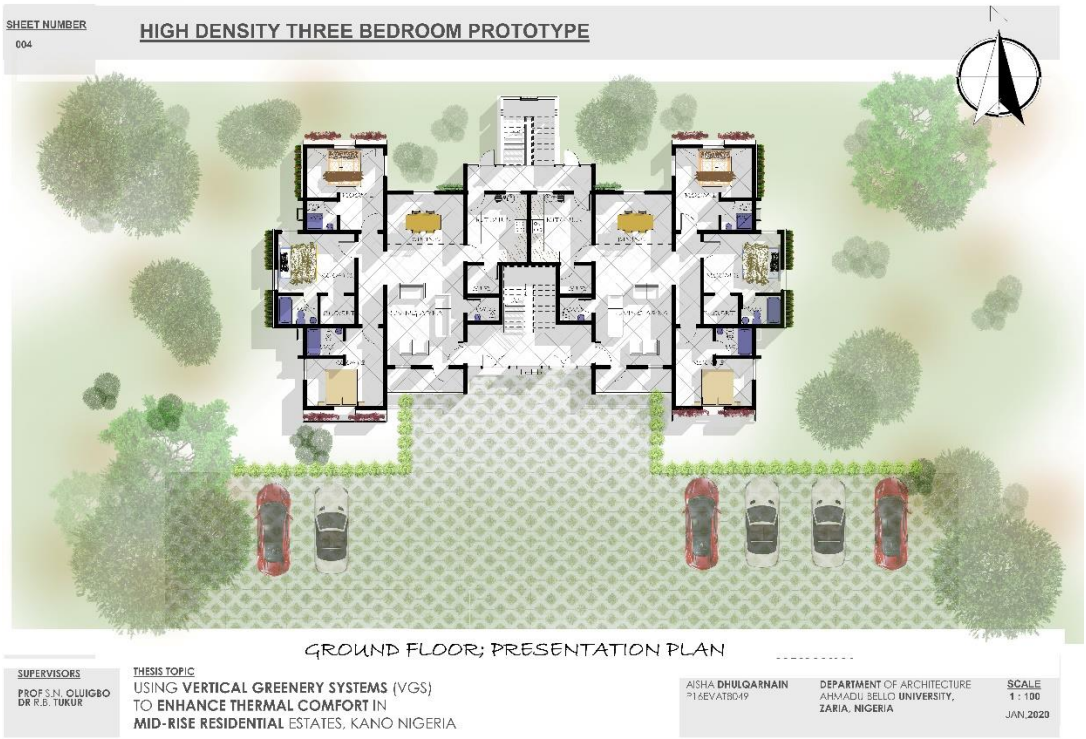
Appendix V: West and East Views of 2 bedroom High Density.



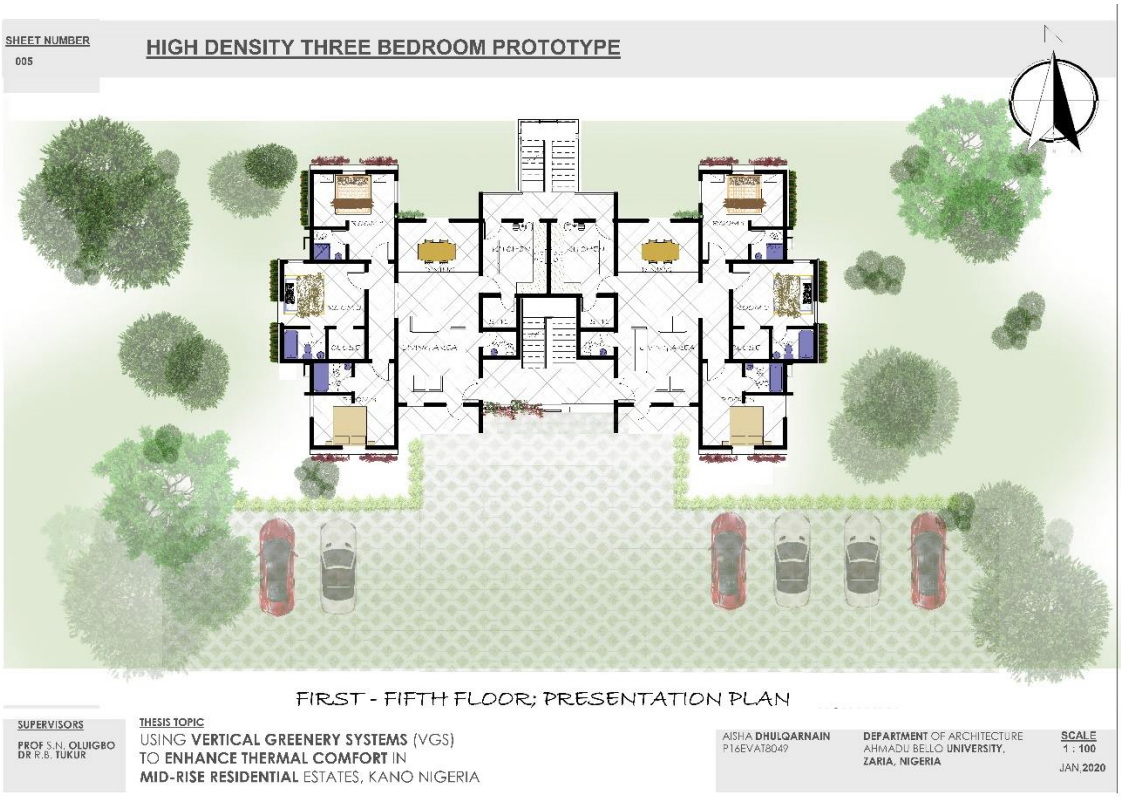
Appendix VI: Working Floor Plan of 2 bedroom High Density.



Appendix VII: Section X-X of 2 bedroom High Density.



Appendix VIII: Ground floor plan of 3 bedroom for High Density.



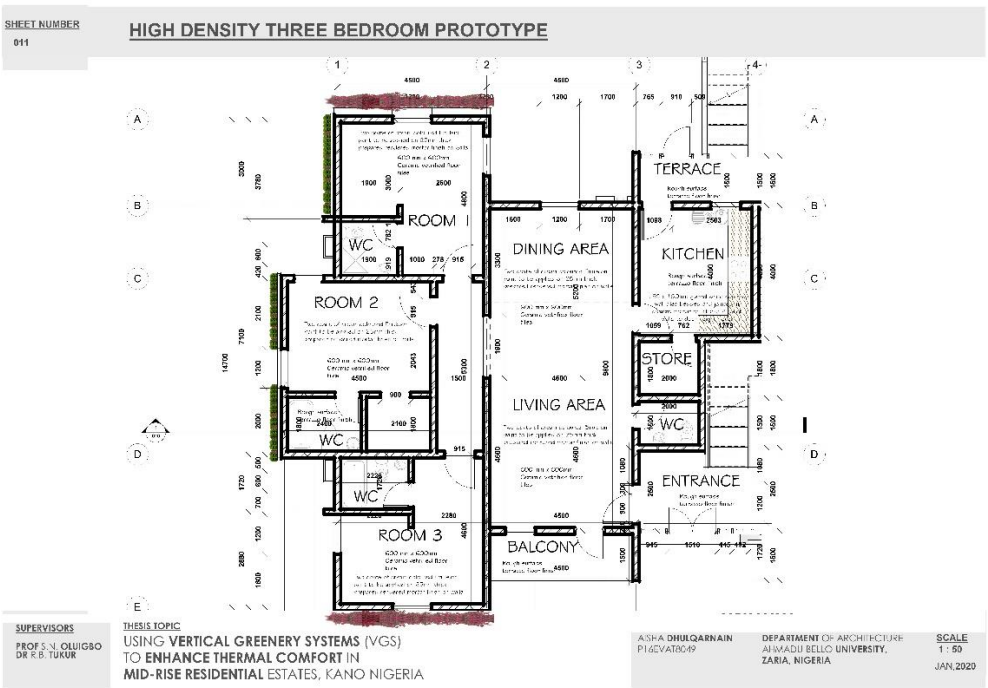
Appendix IX: First - Fifth floor plan of 3 bedroom for High Density.



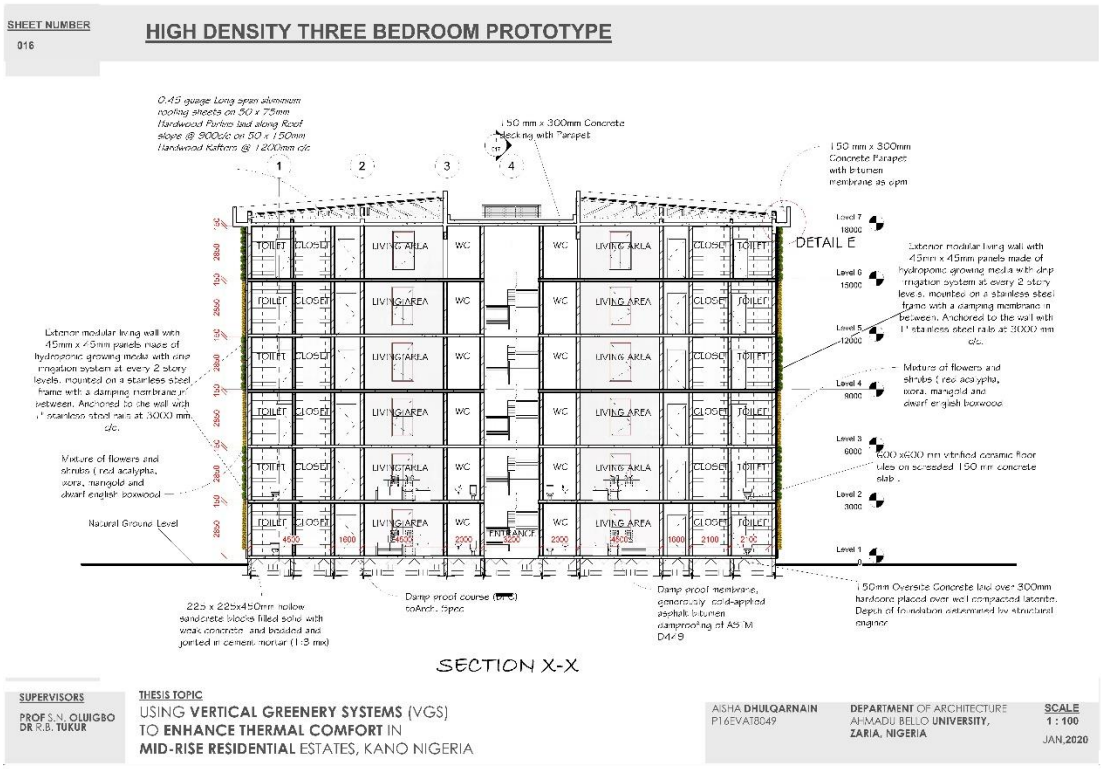
Appendix X: Approach and Rear Elevations of 3 bedroom High Density.



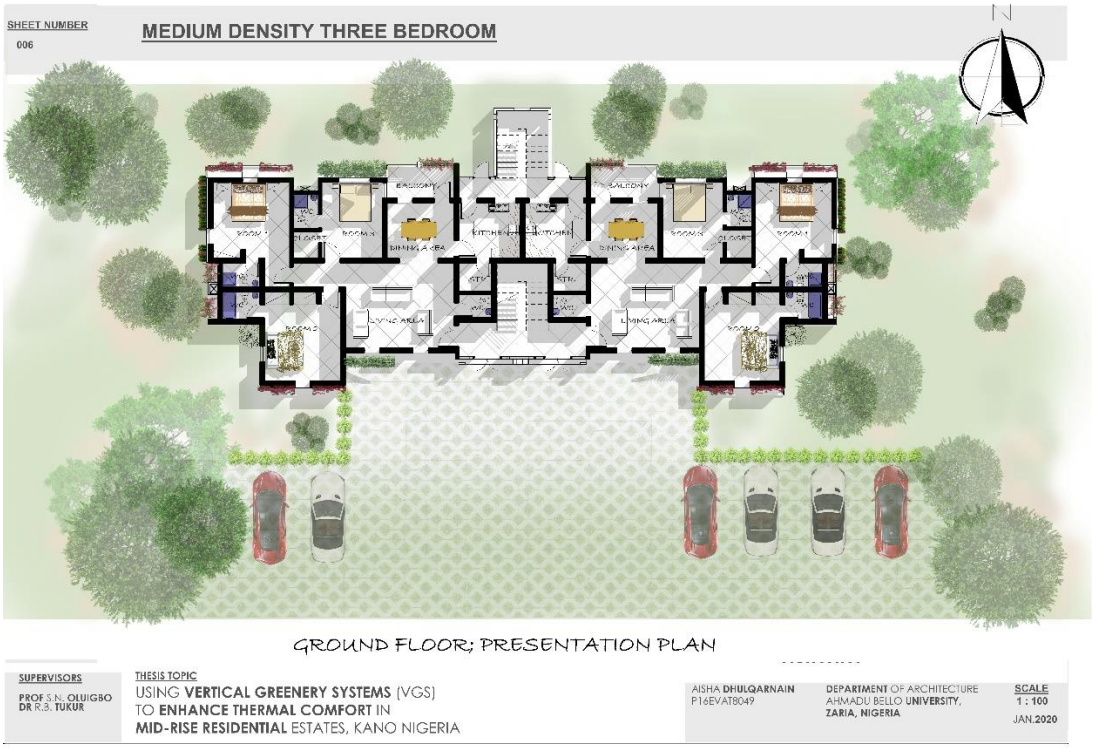
Appendix XI: West and East Views of 3 bedroom High Density.



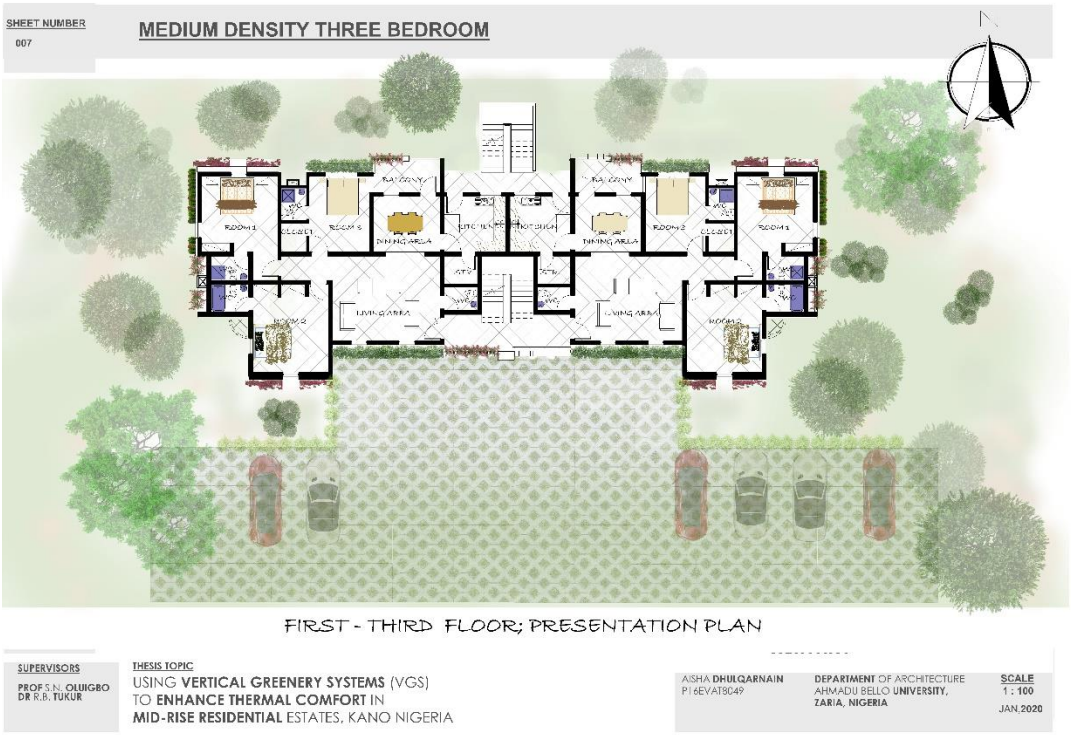
Appendix XII: Working Floor Plan of 3 bedroom High Density.



Appendix XIII: Section X-X of 3 bedroom High Density.



Appendix XIV: Ground floor plan of 3 bedroom for Medium Density.



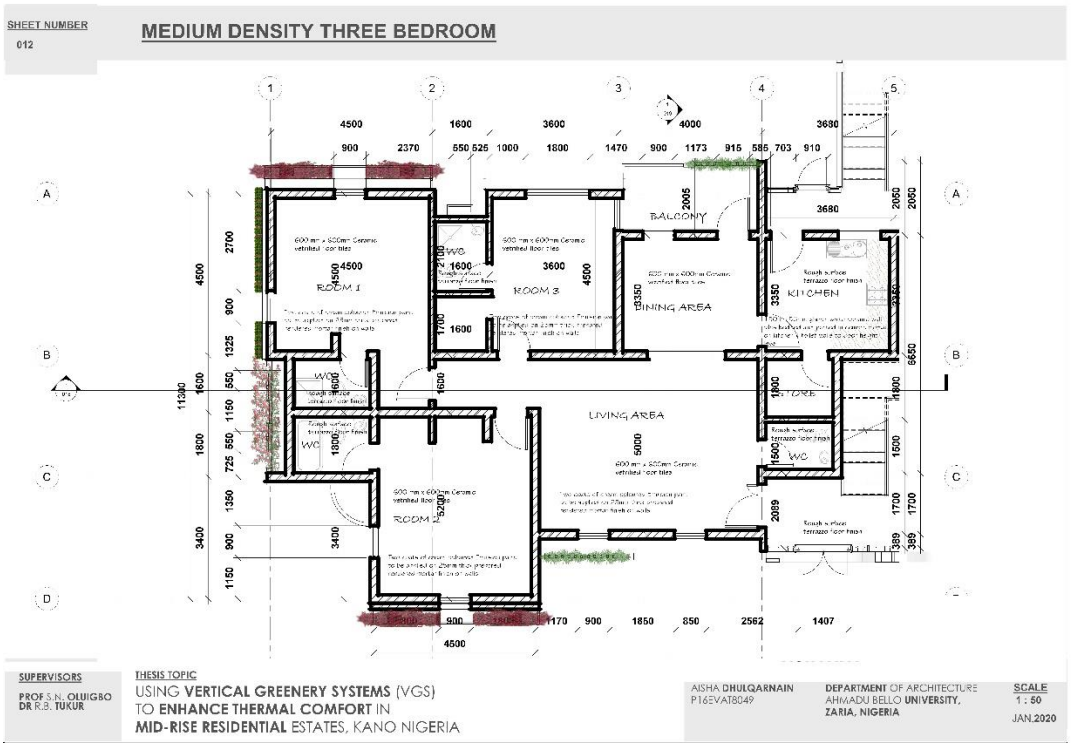
Appendix XV: First - Third floor plan of 3 bedroom for Medium Density.



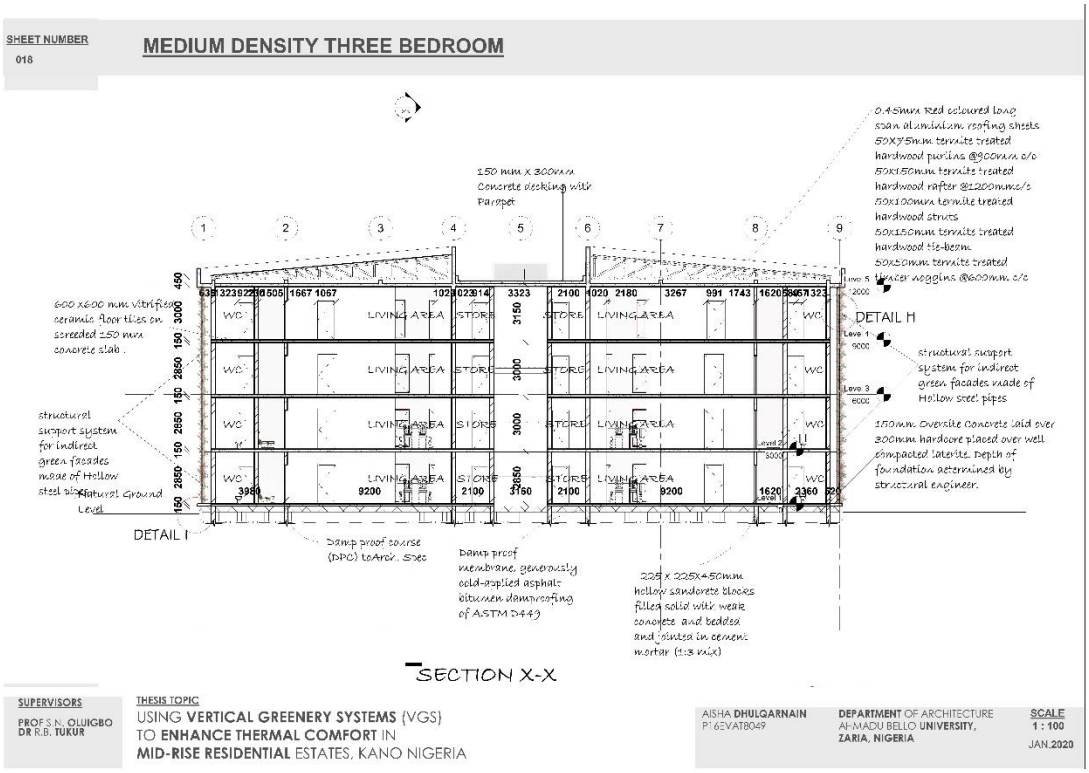
Appendix XVI: Approach and Rear Elevations of 3 bedroom Medium Density.



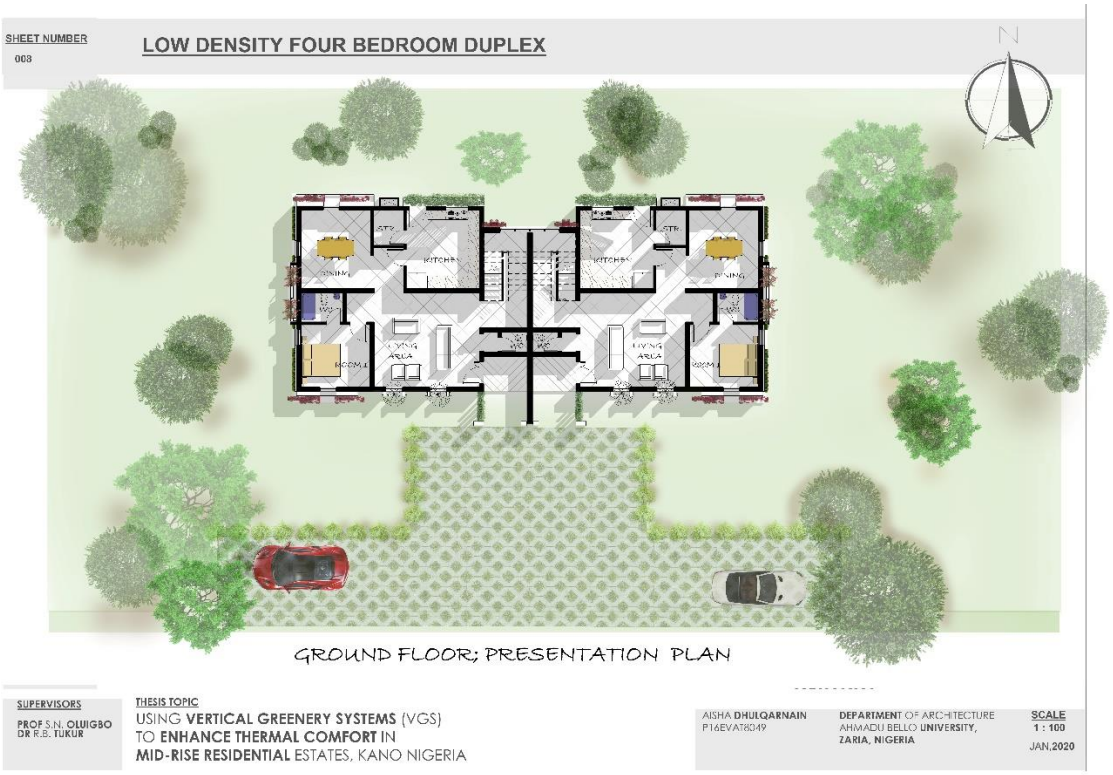
Appendix XVII:West and East Views of 3 bedroom Medium Density.



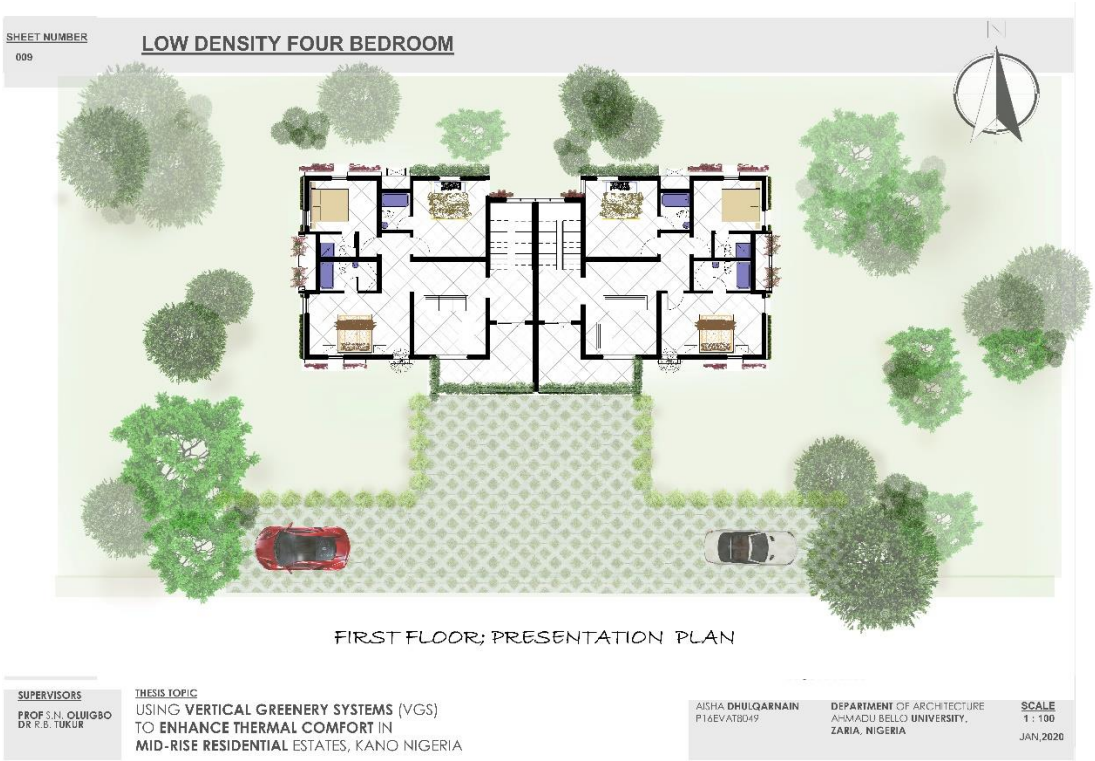
Appendix XVIII: Working Floor Plan of 3 bedroom Medium Density..



Appendix XIX: Section X-X of 3 bedroom Medium Density.



Appendix XX: Ground floor plan of 4 bedroom duplex for Low Density.



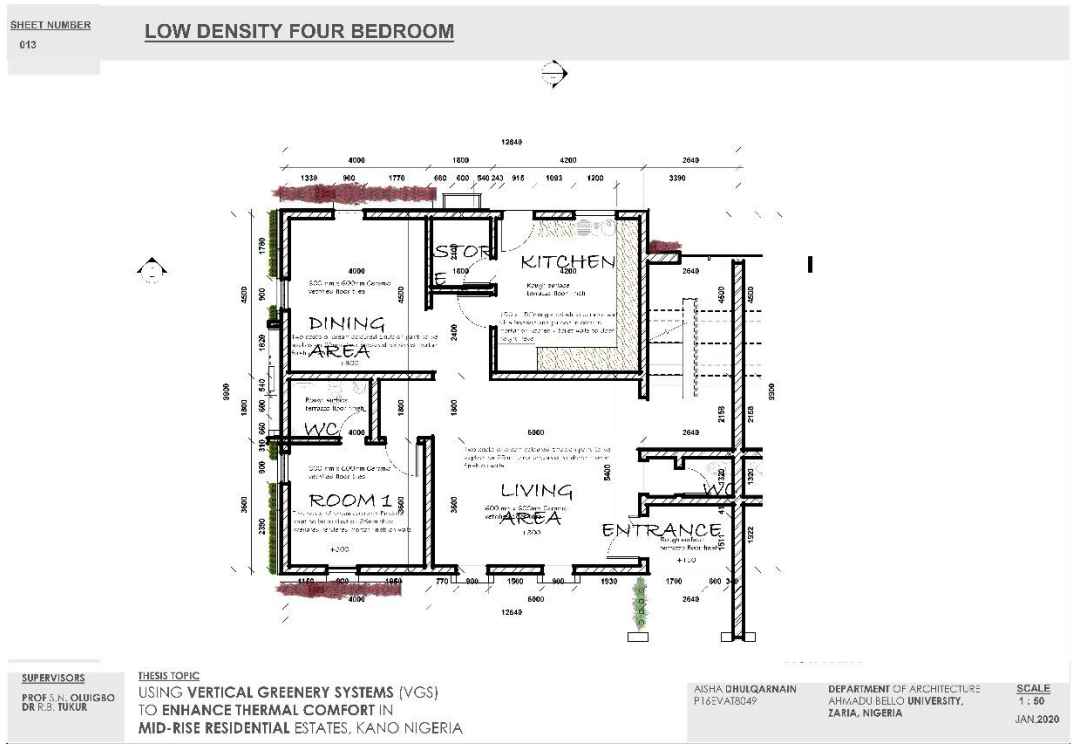
Appendix XXI: First floor plan of 4bedroom duplex for Low Density.



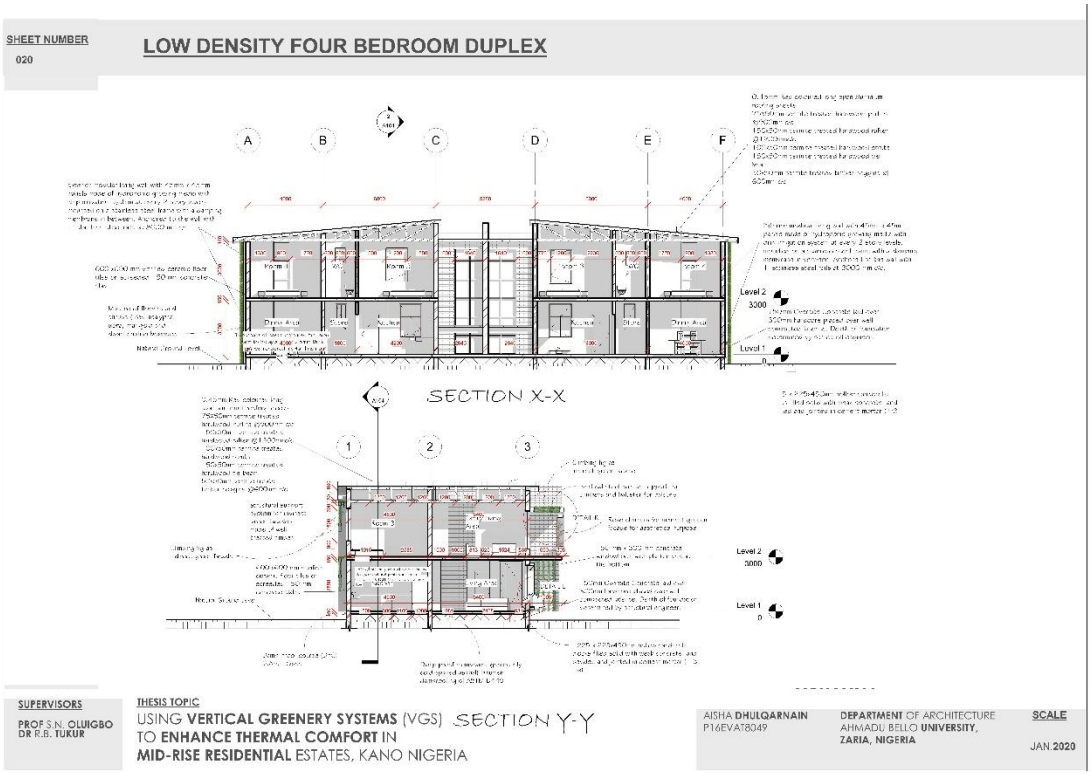
Appendix XXII: Approach and Rear Elevations of 4bedroom duplex for Low Density.



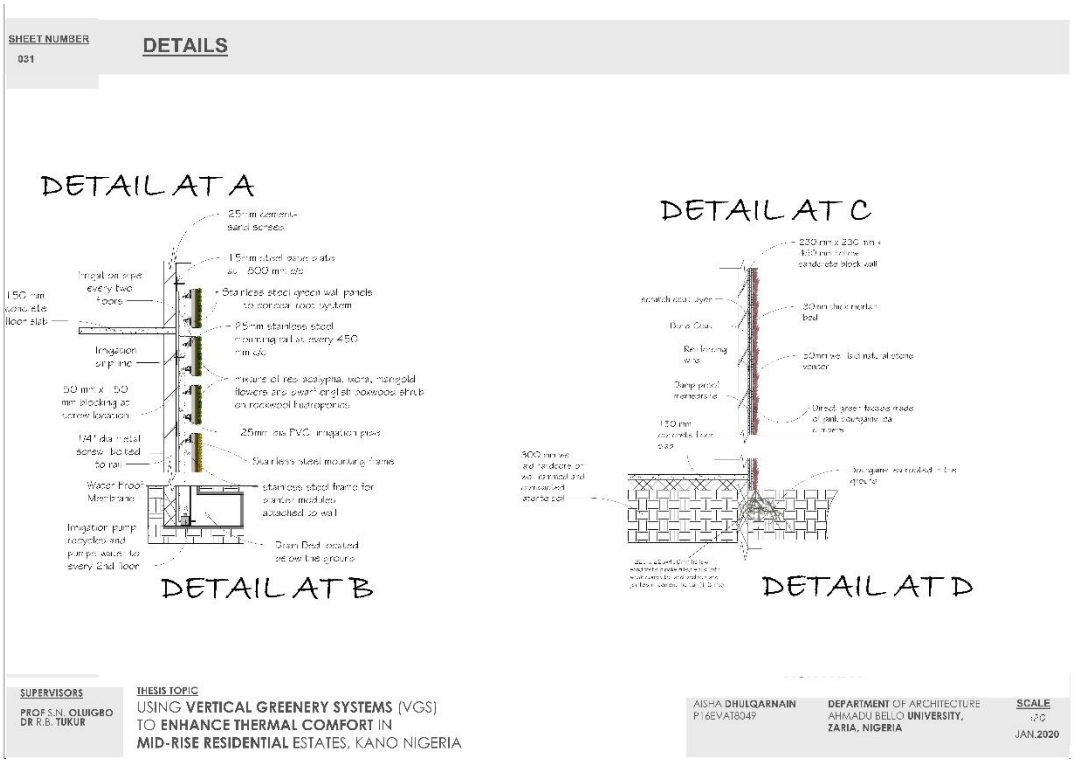
Appendix XXIII: West and East Views of 4bedroom duplex for Low Density.



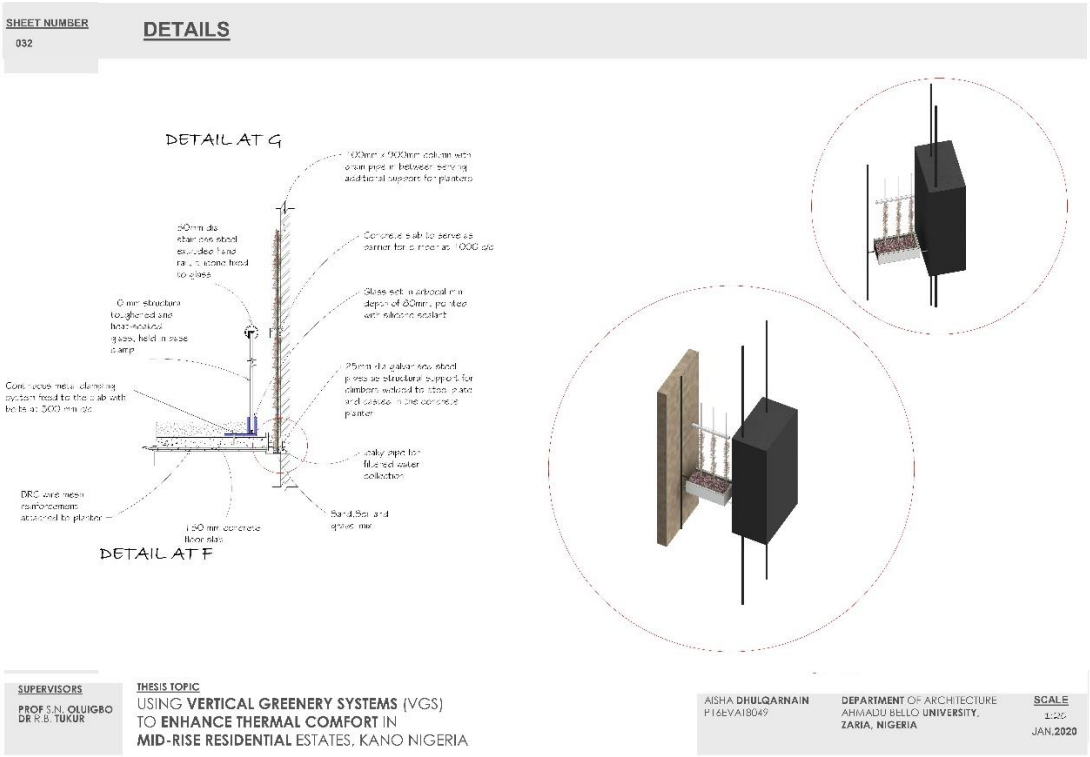
Appendix XXIV: Working Floor Plan of 4bedroom duplex for Low Density.



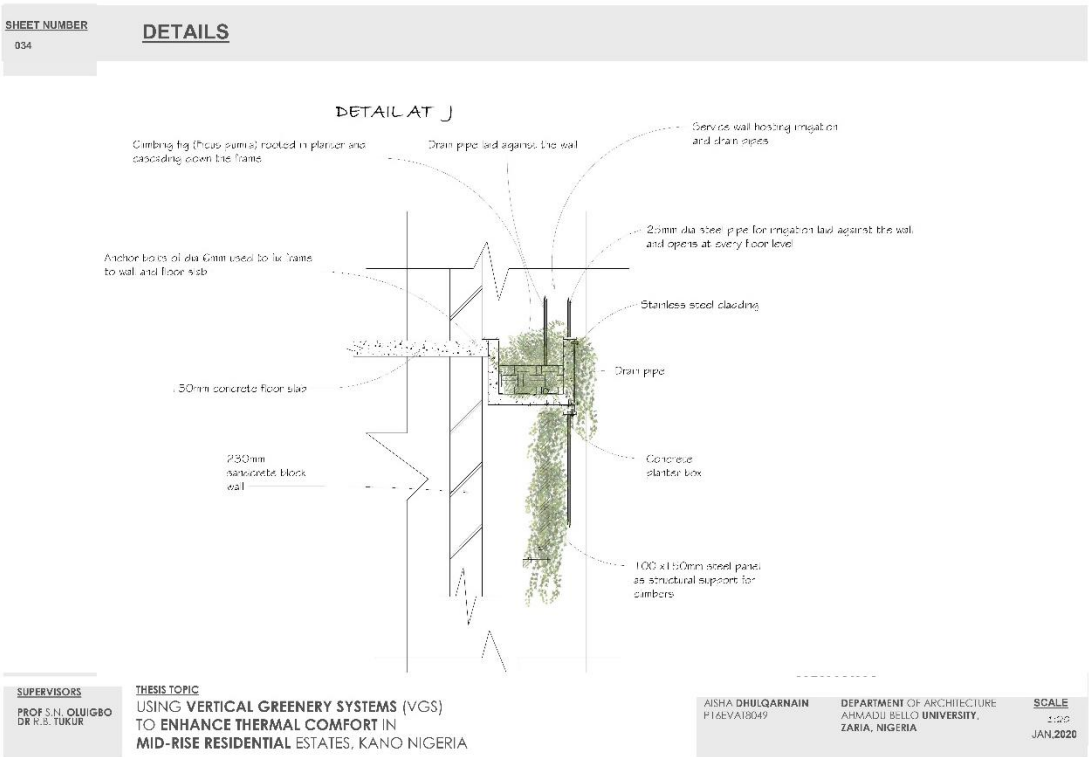
Appendix XXV: Sections of 4bedroom duplex for Low Density.



Appendix XXVI: Details of Living wall and Direct green facade.



Appendix XXVII: Details of Concrete planters and Steel support for climbers



Appendix XXVIII: Details of planter

S/N	Variables	Remarks
1	VGS Construction technique	
2	Coverage Ratio	
3	Foliage Density	
4	LAI Value	
5	Orientation	
6	Type of Plant	
7	Climate	
8	Irrigation Method	
9	Window to Wall Ratio	
10.	Reason for Application	
11.	Current State	

Appendix XXIX: Checklist for VGS

S/N	**Variables**	**Remarks**
1	Type of Building	
2	No of floors	
3	Wall material	
4	Roof material	
5	Year built	
6	Location	
7	Head Room	
8	Area (m^2)	
9	Perimeter	

Appendix XXX: Checklist for Residential Building