Vertical Greening and its Implementation in the Semi-Arid Region of Northern Nigeria

By

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List of Abbreviations

ABCD	Asset-Based Community Development
CO2	Carbon Dioxide
FSC	Forest Stewardship Council
GtCO2	Gigaton of Carbon Dioxide
GMST	Global Mean Surface Temperature
GF	Green Façade
HVAC	Heating, Venting, and Air Conditioning
HDPE	High-Density Polyethylene
HES	Human-Environment Systems
IPCC	Intergovernmental Panel on Climate Change
LAI	Leaf Area Index
LWS	Living Wall Systems
MFO	Maschinenfabrik Oerlikon
NIMET	Nigeria Meteorological agency
UV	Ultraviolet
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UN SDG	United Nations Sustainable Development Goals
UNWCED	United Nations World Commission on Environment and Development
UHI	Urban Heat Island
VBN	Value Belief Norm
VGS	Vertical Greenery System

Defination of terms.

Microclimate in this study refers to thetemperature, relative humidity and wind speed around the buildings.

Streetscape refers to all natural elements including the microclimate around the buildings.

List of Publications

1. International Postgraduate Research Conference- Poster Presentation.

Perception of Building Professionals on the Implementation of Living walls in Nigeria.

2. Salford Postgraduate Annual Research Conference- Poster Presentation.

Living Walls System and its Implementation in the Semi-arid Region.

3. The University of Huddersfield conference- Paper Presentation.

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Abstract

Climate change continues to be a global concern, necessitating sustainable environmental approaches to mitigate its impact. The United Nations' Sustainable Development Goals (SDGs) aim to address these challenges by 2030, by reducing greenhouse gas emissions. Greening the built environment is a crucial part of climate change mitigation, enhancing the microclimate of the streetscape and urban environments with social, environmental, and economic benefits. Vertical greening (VG), a significant component of green systems, incorporates ecosystems into building designs through vegetated wall surfaces, improving microclimates and supporting sustainable urban rehabilitation and building retrofits. However unlike in Europe, VG has not been extensively explored as a climate mitigation technique in sub-Saharan Africa, particularly Nigeria. Furthermore, limited research exists on VG adoption in Northern Nigeria's semi-arid regions, highlighting the need for more empirical data to enhance its application and mitigate climate change impacts.

This study investigates the potential of VG to mitigate climate change effects and impact the microclimate of streetscapes in Northern Nigeria, offering insights for other semi-arid regions. Using mixed methods—qualitative and quantitative analysis through semi-structured interviews and microclimate simulations—the study evaluates the impact of VG on urban ecological and visual appeal. However, the qualitative analysis shows VG enhances urban ecological and aesthetic appeal, fosters biodiversity, and creates habitats for various species. It identifies resilient plant types suitable for VG in adverse climates but also highlights barriers such as limited funding, water access, and community awareness.

Furthermore, quantitative findings from ENVI-Met simulations reveal VG reduces temperature, enhances cooling, and improves thermal comfort, consistent with qualitative data. VG mitigates severe weather, increases biodiversity, and offers a distinct environmental identity, attracting tourists. During dry seasons, VG reduces temperature, slightly decreases wind speed, and increases relative humidity, with no significant changes during rainy seasons. The study provides valuable data for policymakers, urban planners, and architects on

implementing VG in Northern Nigeria and similar semi-arid regions, promoting nature-based solutions for climate change mitigation.

CHAPTER 1: INTRODUCTION

1.1 Background

Climate change has been a main subject of debate worldwide owing to its potentially devastating effects on man and the environment (IPCC, 2018). In the last 2 decades, the negative impact of climate change has led to extreme weather conditions as well as global warming with consequential effects (UNFCCC, 2021). While evaluating the long-term global warming trends since pre-industrial times, it was observed that the Global Mean Surface Temperature (GMST) between 2005 and 2016 was about 0.87^{o}C (IPCC, 2018). This temperature is above the global average of the pre-industrial period according to the Intergovernmental Panel on Climate Change (IPCC, 2018), with carbon dioxide (CO_2) levels and other greenhouse gases in the atmosphere increasing to new records in 2019. The year 2019 was the second warmest year on record and the end of the warmest decade (2010-2019) ever recorded. The warmest decade on record is 2010-2020, and was characterized by catastrophic wildfires, hurricanes, droughts, floods, and other climatic calamities sweeping the globe (United Nations, 2020). Most countries are affected by the impact of global warming because of climate change. The situation has a significant effect on economic prosperity, with a negative impact on people's lives and livelihood (Christidis et al., 2003) Similarly, some continuous effects of climate change are manifesting with changes in weather conditions, sea levels are rising, and extreme weather events are becoming more common, affecting more than 39 million people (about twice the population of New York) worldwide in 2018(IPCC, 2018). As part of measures to monitor and address the challenges of climate change, the Intergovernmental Panel on Climate Change (IPCC) was established to offer policy makers regular scientific assessments of climate change, its implications, and potential dangers, as well as to propose adaptation and mitigation strategies (IPCC, 2007). These efforts underscore the need for a concerted effort by countries to address the challenges of climate change to prevent the continual rise in global average temperatures with negative environmental impact affecting the natural ecosystem. To combat climate change, global efforts must be significantly boosted. This necessitated the United Nations Framework Convention on Climate Change (UNFCCC) to adopt the Paris Agreement for global safety. The Paris Agreement is a legally binding international treaty on climate change signed by 196 parties and commenced implementation in 2016. The Agreement has the objective of maintaining global warming considerably under 2 degrees Celsius, ideally 1.5, relative to pre-industrial levels (UNFCCC, 2021). The Agreement also intends to improve countries' abilities to deal with the effects of climate change. Similarly, the UN SDGs are a set of 17 goals aimed at achieving a better and more sustainable future for all nations by 2030 (Abashidze et al., 2016). Accordingly, most UN member states and parties to the Paris Agreement are committed to full implementation of the SDGs and the Agreement respectively (UNCCC, 2021). This is considering the critical nature of achieving the set goals and the need to develop the requisite resilience with more sustainable solutions to reduce greenhouse gas emissions as well as other challenges associated with climate change. Technology is crucial for driving climate action and limiting global temperature rise to 1.5°C (UN, 2024). According to UN, 2024. There is significant progress in climate technology under the UNFCCC and Paris Agreement, setting the stage for increased ambition in 2024. At COP28 in Dubai, UNFCCC Executive Secretary Simon Stiell emphasized collaboration and technology in combating climate change. The UNFCCC's Technology Mechanism launched #AI4ClimateAction to explore AI's role in advancing climate action, focusing on developing countries. Emphasising that financing for climate technology is critical, with a new implementation programme supporting developing countries (UN, 2024).

It is important to mention that while countries develop and continue to execute policies to facilitate the implementation of the SDGs to reduce the negative impact of climate change, there are still concerns of increased human activities and other parameters inimical to their success (UNCCC, 2020). Some of these challenges include population increase, deforestation, and rural-urban migration amongst others (UNCCC, 2020). Some of these challenges also affect climate types including the tropical, dry, temperate, continental, and polar climates. For instance, the semi-arid climate, also known as the steppe, is the next driest climate after the desert climate due to climate effects. It occurs in regions with little precipitation and usually borders desert climates (Huebner, 2020). It has slightly more rainfall than the desert climate making it prone to desertification and subdivided into hot and cold seasons. They typically border the sub-tropical desert climate or the tropical savannah climate. It was further noted that semi-arid climates are characterised by warm and dry summers and cold winters because of several factors (Britannica, 2020). The cold semi-arid climate is more common near higher altitudes and away from significant water sources while the hot semi-arid climate is characterised by hot summers, cool winters, and low precipitation. Hot semi-arid climates are prevalent in Africa, South Asia, and Australia and especially prominent in some parts of Europe, particularly Spain, portions of North America (Mexico and the Southwest United States), and parts of South America (Britannica, 2020). The semi-arid region is home to a large number of people who rely on agriculture and pastoralism. Some of the challenges faced by the region are worsened by climate change which results in more frequent and severe droughts, floods, and other extreme weather events, as well as rising temperatures and unpredictable rainfall patterns (R, Mcsweeney 2019). These are consequences of energy-related activities from anthropogenic sources including combustion of fossil fuels for energy use, industrial processes, and deforestation amongst others.

Anthropogenic greenhouse gas concentrations in the atmosphere have increased dramatically since 1750, and currently significantly exceed pre-industrial values found from ice cores dating back thousands of years (IPCC, 2007). More people continue to migrate from the countryside to the city with a corresponding increase in the size and complexity of urban dwellings (Madlener & Sunak, 2011). This also increases demands on resources in the urban environment, thereby exerting pressure on the available resources. The situation is further exacerbated by the rapid increase in the world population, which currently stands at eight billion people (United Nations, 2022). The UN predicts that 66% of this population will be living in urban areas in 2050. Furthermore, in World Population Prospects 2019, the UN further affirms an expected increase of 2 billion persons by 2050, taking the number to 9.7 billion from 7.7 billion (UN, 2019). Consequently, for urban areas to function properly, cities require a large amount of energy (Gago et al., 2013). Hence, this increase in population, human activities, and energy demand are crucial to current concerns of the environmental impact of climate change. To mitigate these challenges, nations have devised various measures to expedite the attainment of a sustainable environment, clean energy, good health, sustainable cities, and climate action (UNCC, 2020). Some of these measures include afforestation, implementing sustainable buildings, renewable energy, and urban green systems (Chen et al., 2022). The growing adaptation of some of these measures especially the urban green systems could facilitate the attainment of SDG targets for nations and other likely environmental benefits (Riba 2030, environmental challenge.

1.2 Urban Green Systems

Green systems like green roofs and green walls are concepts employed to improve building performance and the urban environment with social, environmental, and economic benefits (Manso & Castro-Gomes, 2016). As part of this approach, green roofs are popular techniques used for the retrofitting of buildings to improve the environmental quality of densely populated urban cities to mitigate certain environmental and social challenges. This technique is aimed at mitigating the inherent challenges associated with urbanization and climate change (Meulen, 2019). Furthermore, it was noted that when green roofs are integrated into building architecture, they improve environmental friendliness, appearance, and aesthetics thereby supporting eco-friendly buildings (Sutton, 2014). In addition to the aesthetics of buildings, green roofs were shown to increase the quality of life of buildings' occupants with health benefits (Burhan & Karac, 2013). On the environmental impact, green roofs reduce the urban heat island levels (Amaral et al., 2013), surface temperature and improve the quality of runoff water (Meulen, 2019). This highlights the significance of green roofs as an inherent part of Urban Green Systems in the current policy drive of nations on sustainable environment and climate change. The type of Urban Green Systems amongst several factors could play vital roles in this regard.

1.2.1 Vertical Greening

On the other hand, vertical greening or living walls offer many services to urban ecosystems by increasing the presence of such ecosystems in building designs (Coma et al., 2017). Living walls are among the nature-based practices of greening the environment (Sattler et al., 2008). According to (Perini et al., 2011), vertical greening is the process of greening the building envelope with various vegetated wall surfaces with plants either rooted in the ground, or in the wall itself in modular panels attached to the facade. 'Living Walls' is a descriptive term that refers to all forms of vegetated wall surfaces (Mir, 2011). They can be characterized as plants/climbers grown either directly against or on supporting structures integrated into external or internal walls of buildings (Cuce, 2017). Furthermore, living walls involve planting on the vertical surfaces of buildings either upright or sloping surfaces. The use of living wall systems on both new and existing buildings is a sustainable approach and can deliver numerous environmental benefits (Perini et al., 2011). Modern systems for greening the envelope of buildings are not just vegetation-covered surfaces, the technology involved is being developed to improve the efficiency and durability of buildings. It optimizes the functional benefits of plants and makes part of a sustainable strategy of urban rehabilitation and building retrofitting (Manso & Castro-gomes, 2014). It is important to note that living walls have the capacity to be used as climate change mitigation tools to improve thermal comfort, reduce energy consumption from buildings and sequester carbon (Charoenkit & Yiemwattana, 2017). In addition, it has the ability to modify negative environmental issues appears to be greater with vertical greening systems than with green roofs, since the potential area for vertical greening is significantly higher than the available horizontal surface area (Emilsson & Ode Sang, 2017). With living walls, vegetation is easily intertwined with buildings in the built-up areas. Walls covered with plants contribute to the thermal performance and sustainability of the built environment (Eumorfopoulou & Kontoleon, 2009). The viability and impact of vertical greening/ living walls depend on several factors. These factors include the type of vegetation, plant characteristics, building climatic conditions, and local climatic conditions (Manso & Castro-Gomes, 2015). The work of Dahanayake and associates (Dahanayake et al., 2017) also highlighted the crucial role of selecting plant type, outlined the principles, and exploited the various factors in the choice of plants to enhance the benefits of Vertical Green Systems (VGS). The numerous benefits and positive environmental impacts discussed above underscore the need for more empirical data on living walls to enhance the application of Urban Green Systems techniques to mitigate the impact of climate change.

1.3 Statement of Problem

Nigeria is a developing nation located on the western coast of Africa and its climate ranges from arid to humid equatorial (Kirk-Greene, 2024). Due to urbanisation and climate change, the semi-arid region of Northern Nigeria faces significant challenges. Urbanization leads to increased construction and infrastructure development, which often involves the removal of natural vegetation and the expansion of impervious surfaces like roads and buildings. This process contributes to the urban heat island effect, where urban areas become significantly warmer than their rural surroundings (Ullah, et al., 2023). The lack of vegetation also reduces the natural cooling effect provided by plants and exacerbates the heat.

Human activities have resulted in an unprecedented rate of global warming since the middle of the nineteenth century, thereby intensifying already severe climatic conditions (IPCC, 2007). The Industrial Revolution marked a significant turning point, as the widespread use of fossil fuels like coal, oil, and natural gas led to a dramatic increase in greenhouse gas emissions (Nunes, 2023). These emissions, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), trap heat in the Earth's atmosphere, leading to a warming effect known as the greenhouse effect. This has caused global temperatures to rise at an accelerated rate, contributing to climate change(US-EPA, 2024). According to Diamond and Hodge (2007), human activities in the built environment are a primary source of pollutants. Urban areas, with dense concentrations of buildings, vehicles, and industrial activities, generate significant amounts of air pollutants such as particulate matter (PM), nitrogen oxides (NO_x), and volatile organic compounds (VOCs). These pollutants not only degrade air quality but also contribute to the formation of ground-level ozone and smog, which are harmful to human health and the environment(US-EPA, 2024).

The built environment also contributes to increased heat through the urban heat island effect, where surfaces like asphalt and concrete absorb and retain heat, leading to higher temperatures in urban areas compared to their rural surroundings (US-EPA, 2024). This exacerbates heat discomfort and can lead to higher energy consumption as residents rely more on air conditioning to cool their homes and workplaces. Additionally, the energy used for heating, cooling, lighting, and powering appliances in buildings contributes substantially to overall emissions. The environmental effects of these activities are far-reaching. Increased temperatures can lead to more frequent and severe heatwaves, which pose health risks, particularly to vulnerable populations such as the elderly and those with preexisting health conditions. Changes in precipitation patterns can result in droughts and water shortages, affecting agriculture and water supply(US-EPA, 2024).. Furthermore, the loss of biodiversity and natural habitats due to urban expansion and pollution can disrupt ecosystems and reduce their ability to provide essential services, such as clean air and water.

Consequently, there is an urgent need for sustainable solutions to mitigate the effects of climate change, improve the microclimate of urban environments, and reduce greenhouse gas emissions.

As part of measures to address the impact of climate change and other environmental challenges, the integration of urban greenery constitutes a promising technique. To drive the initiative of urban greenery, a few concepts and techniques have been developed such as Nature-Based Solutions, or Eco-system-based (Kabisch et al., 2016). The work of Emilsson & Sang (2017) affirm that a nature-based solution could be adopted to mitigate the effect of climate change. Utilizing natural resources and techniques to address social issues like climate change is known as "Nature-Based Solutions." The technique acknowledges the significance of ecosystems and aims to capitalize on their positive characteristics for the benefit of man and the environment. Nature-Based Solutions can be implemented in urban contexts through a variety of techniques, including Urban Ecosystem Services and Urban Green Systems or Green Infrastructure. The positive effects that urban ecosystems offer humans include temperature regulation, enhanced air quality, managing stormwater, and the establishment of spaces for recreation. Accordingly, cities may create more resilient and sustainable environments by utilizing and incorporating these services into urban planning and design. Furthermore, the strategic planning and execution of green spaces, such as parks, gardens, street trees, and green roofs and walls, within urban areas is known as urban green systems or green infrastructure (Jones et al., 2022). The reduction in temperature, carbon sequestration, stormwater retention, and biodiversity preservation are a few advantages offered by Urban Green Systems. Additionally, they improve the quality of life and aesthetic appeal of cities, enhancing citizens' quality of life and overall well-being. Moreso, urban greenery promotes a sense of community, increases real estate values, and creates recreational places, all of which have beneficial impacts on society and the economy.

Another technique is vertical greening, a sustainable urban greening strategy involving the integration of vegetation on vertical surfaces. It occupies the vertical surfaces in the urban environment and has been shown to provide numerous benefits. It is a novel technique in urban greening that provides several environmental, social, and economic benefits such as temperature regulation, improved air quality, increased aesthetics, and a better community. There are countless benefits associated with the implementation of vertical greening in the urban environment. This is due to its advantages as vegetation affects the atmospheric heat island through evaporative cooling and reduction of conductive heat flux from cooler surfaces. At the ground surface, it reduces daytime maximum temperature (Duarte et al., 2014). It was also noted that plants act as a solar barrier by absorbing solar radiation for their biological function and growth (Eumorfopoulou & Kontoleon, 2009). The research of Perini et al., (2011) asserted that the presence of vegetation significantly reduces the amount of heat re-radiated by hard surfaces. Furthermore, vegetation also softens the climate extremes by controlling solar radiation, humidity, and temperature, making the environment more comfortable (Sattler et al., 2008). Additionally, the presence of vegetation has numerous benefits ranging from environmental, to social, and economic benefits. Natural resources conservation, pollution reduction and prevention of environmental degradation are some of its environmental benefits (Ragheb et al., 2016). Economically, it leads to improvement in occupant's health and productivity, and reduction in the buildings running cost. Socially, plants are aesthetically pleasing to the eye and negligibly affect the local infrastructure (Ragheb et al., 2016). In warm climates during the hot season, plants provide cooling potential on the surface of buildings (Eumorfopoulou & Kontoleon, 2009) and drop in air temperature at the building level consequently results to a drop in interior temperature (Perini et al., 2011). This underscores the importance of vertical greening to enhance the functionality of buildings for Eco-friendliness, comfort, and sustainability.

According to Pérez et al., (2014), green roofs and green walls are the two ways that vegetation is integrated into the building. It was further observed that in most countries across the globe, the most widely established practice is the use of green roofs, while the use of vertical greening is still in the infancy stage (Coma et al., 2014). However, as part of extensive vertical greening program in the (UK EFB, 2019), "Urban Green" developed a guide for the development of vertical greening. In the guide, it was noted that one of the key drivers in selecting plants for vertical greening is location influenced by temperature, light levels, and other parameters for the survivability of the plant and efficient performance of the system (Jim, 2013). This guide, research efforts, and programs are amongst several efforts by Governments, NGOs, and private organizations in Europe as well as other developed nations to facilitate the implementation of vertical greening systems. While Vertical Greening Systems or Green Walls are an integral part of strategies to mitigate the environmental impact of climate change in Europe, the technique is uncommon in sub-Saharan Africa, especially Nigeria. It was also noted that there is limited research conducted in Nigeria and other semi-arid regions of Africa on vertical greening (Tsoka et al., 2018).

Consequently, the viability of vertical greening in the semi-arid region of Northern Nigeria is still unclear, and there are several barriers to their implementation. This is also considering the current concerns on climate change and reduction in carbon dioxide emission, as well as the SDGs set up by the United Nations. There is therefore the urgent need to develop and implement a framework to allow easy integration of vegetation into buildings in the semi-arid region through the various sustainable building practices within the construction industry including the use of vertical greening. To boost the efficacy and sustainability of vertical greening implementation, it is necessary to use innovative strategies and choose drought-tolerant plant species. Hence, adopting natural alternatives and adding urban greenery into cities in Nigeria can significantly improve the chances of enhancing the microclimate and reducing the consequences of climate change. It is against this backdrop that this research considers vital the implementation of vertical greening in Nigeria and other semi-arid regions as part of the strategies to achieve SDGs and mitigate impact of climate change.

1.4 Aim and Objectives

This research aims to investigate the potential of vertical greening as a sustainable strategy to mitigate the effects of climate change and impact the microclimate of the streetscape in Northern Nigeria and other semi-arid regions.

It will be achieved through the following objectives.

1. Evaluate the impact of vertical greening in enhancing the ecological and visual appeal of the urban environment in Northern Nigeria and other semi-arid regions.
2. Identify suitable plant species for vertical greening in the semi-arid region of Northern Nigeria.
3. Evaluate the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria.
4. Investigate the impact of vertical greening on the urban microclimate such as temperature, humidity, and air quality, and its ability in climate change mitigation.
5. Provide guidance on how to successfully implement vertical greening in Northern Nigeria and other semi-arid regions for policy makers, urban planners, and architects.

1.5 Research Questions

How can vertical greening be effectively implemented as a sustainable strategy to mitigate the effects of climate change and improve the microclimate of streetscapes in Northern Nigeria and other semi-arid regions?

1. What are the potential benefits of incorporating vertical greening into urban environments in the semi-arid region of Northern Nigeria?
2. What plant types thrive and are suitable for vertical greening in Northern Nigeria and other semi-arid regions?
3. What factors impact the integration of vertical greening in the semi-arid region of Northern Nigeria?
4. How does vertical greening influence the urban microclimate in the semi-arid region of Northern Nigeria?
5. What are the most essential factors for policymakers, urban planners, and architects to consider when implementing vertical greening in northern Nigeria and other semi-arid regions?

Table 1.1 Research question with corresponding guiding research objectives.

S/NO	Research Questions	Research Objectives
1.	What are the potential benefits of incorporating vertical greening into urban environments in the semi-arid region of Northern Nigeria?	Evaluate the impact of vertical greening in mitigating the impact of climate change and enhancing visual appeal of the urban environment in Northern Nigeria and other semi-arid regions.
2.	What plant types would thrive or vertical greening in Northern Nigeria and other semi-arid regions?	Identify suitable plant species for vertical greening in the semi-arid region of Northern Nigeria.

3.	What factors impact the integration of vertical greening in the semi-arid region of Northern Nigeria?	Evaluate the factors that impact the integration of vertical greening in the semi-arid region Northern Nigeria.
4.	How does vertical greening influence climate change and the urban microclimate of the semi-arid region of Northern Nigeria?	Investigate the impact of vertical greening on factors such as temperature, humidity, and air quality (microclimate), and its influence on climate change.
5.	What are the most essential factors for policy makers, urban planners, and architects to consider when integrating vertical greening into buildings in northern Nigeria and other semi-arid regions?	Provide guidance on how to successfully implement vertical greening in Nigeria and other semi-arid regions for policy makers, urban planners, and architects.

1.6 Scope and Significance of the Study

This study aims to investigate the possibilities of using vertical greening as a sustainable approach in influencing the microclimate to reduce the impact of climate change in the semi-arid region of Northern Nigeria. The concept of vertical greening refers to vertical gardens that may be installed on the exterior or interior of a building, employing a range of plants and growing media (Manso & Castro-Gomes, 2018). There are considerable social and environmental benefits associated with vertical greening. Vertical greening is widely acknowledged as effective means for boosting biodiversity, lowering the urban heat island effect, improving air quality, and enhancing the aesthetic appeal in urban environments (Hefnawy, 2022). Additionally, they can contribute to the creation of resilient, sustainable urban ecosystems, which are crucial for mitigating the negative effects of climate change and improving the standard of living for urban residents. The study identified suitable plant species and the viability of vertical greening and its impact on the microclimate particularly in the semi-arid region of Northern Nigeria. It also uncovered the factors encouraging and limiting the viability of vertical greening as a means of enhancing the microclimate and lowering greenhouse gas emissions in urban environments. The use of vertical greening will allow easy integration of vegetation into buildings and also assist in achieving the current policy drive on climate change mitigation and the zero carbon targets under the 2015 Paris Agreement (UNFCCC, 2015) The findings of this study would contribute to a better understanding of the impact of vertical greening and the drivers and barriers to its implementation in Nigeria. It outlined the economic, environmental, and social benefits of vertical greening, existing types of vertical greening systems, and focused on enhancing the micro-climate in abating the effect of climate change. The findings will potentially bring forth guidance for policymakers, urban planners, architects, and designers on the best practices for the effective integration of vertical greening into the urban environment in the semi-arid region of Northern Nigeria.

However, the implementation of vertical greening in the semi-arid region of Northern Nigeria may face some challenges. The region is characterized by low rainfall, high temperatures, and frequent droughts, which make it difficult to grow plants. Furthermore, there is a lack of knowledge and awareness about the potential of vertical greening as a sustainable solution to the environmental challenges in the region, which hinders its widespread adoption. The study can contribute significantly to the fields of sustainability, environmental management, and urban planning in the form of the development of sustainable urban design and planning practices that incorporate vertical greening as innovative and effective solutions for urban greening and biodiversity conservation. Additionally, the study can provide guidance on the selection of suitable vertical greening, plant species and growing media for vertical greening in the region, which can inform the development of local horticultural industries and provide economic benefits to local communities. The study can provide valuable insights and inform the development of effective strategies and policies for sustainable urban development in the region.

1.7 Research Methodology

A literature review was conducted to examine the impact of vertical greening in enhancing the ecological and visual appeal of the urban environment and to identify suitable plant species for vertical greening in the semi-arid region of Northern Nigeria. The study was conducted using a mixed-method approach termed the exploratory sequential method.

In the exploratory sequential method, two significant phases of investigations; the qualitative and quantitative were conducted to develop an in-depth knowledge of the vertical greening implementation. It presents an elaborate research approach utilizing the strength of both qualitative and quantitative to aid an in-depth comprehension of the phenomena. To evaluate the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria, a semi-structured interview was conducted with building professionals, horticulturists, and stakeholders to obtain their opinions, experiences, and insights regarding vertical greening implementation. The qualitative data generated from the interview were analysed to explore and develop an understanding of vertical greening implementation. The qualitative data was analysed using thematic analysis and the findings generated insight into the second phase of the investigation. It involved investigating the impact of vertical greening on the urban microclimate such as temperature, humidity, and air quality using a microclimate simulation tool ENVI-met(Tsoka et al., 2018). ENVI-met was chosen for its advanced capabilities in simulating microclimate dynamics and urban environmental processes, integrating various aspects into a comprehensive model. This high-resolution tool accurately depicts interactions between urban surfaces, vegetation, and atmospheric conditions, making it ideal for assessing vertical greening systems (VGS) on urban heat islands (UHI) and climate mitigation. Validation was supported by reviewing results from previous studies, including Liu et al. (2021), who analyzed 79 peer-reviewed studies that used ENVI-met for modeling, validation, and scenario simulation of Green Blue Infrastructure (GBI).

A model of the real phenomenon was created in Envi met with input of the local meteorological data to simulate different scenarios and provide insight into the different conditions and the outcome analysed. The findings were analysed within the microclimate simulation tool Envi met using Leonardo (ENVI-met, 2024). Both phases of investigation provided a comprehensive understanding of vertical greening implementation and its impact on the microclimate towards mitigating the effect of climate change.

1.8 Thesis Structure

The overview of the report comprises seven chapters outlined below:

The first chapter- Introduction is the introductory chapter that outlines the background which provides essential information and justification of the research, as well as the aims and objectives and research questions. As a prelude to the entire research work, this chapter provides a context and an understanding of the significance of the research.

The second chapter- Literature Review provides a comprehensive overview of the literature and situates the study in the context of broader academic research. The chapter further discusses the climatic characteristics of the semi-arid region with regards to sustainable strategies for mitigating the effects of climate change with particular reference to vertical greening. The literature review supports the research objectives thereby laying a solid foundation for future chapters.

The third chapter- Theoretical Framework discusses the theoretical framework and a review of pertinent theories for the research. With the aid of theories from the fields of sustainability, ecology, horticulture, and social/behavioural sciences, the chapter addresses the integration of living walls with the concept of environmental sustainability.

The fourth chapter- Research Methodology focuses on the selected research methodology. The chapter covers the philosophical considerations that inspire the research, explains the justification for the selected approaches and methods, and how the thesis objectives were achieved.

The fifth chapter- Qualitative Study highlights the empirical data collected from the interview which is the initial step of data collection and evaluates the result with reference to the current literature.

The sixth chapter- Microclimate Simulation discusses the microclimate simulation conducted with the aid of Envi-met software, the analysis of findings discussed in the context of the aim and objectives of the research and evaluates the result with reference to the current literature.

The seventh chapter- Conclusuion and Recommendation is the conclusion of the report which highlights the primary features of the study and reveals the major findings with respect to the aims, objectives, and research questions. Additionally, the chapter discussed the limitations, recommendations, and direction for future research.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

This chapter examines the characteristics of semi-arid regions, the impact of climate change, and the potential benefits and challenges of urban green systems. Moreover, it investigates the implementation of vertical greening in semi-arid regions, its contribution to urban sustainability, including its environmental, aesthetic and social performance. It was necessary to first assess existing knowledge about semi-arid regions, climate change, and urban green systems, and their possible environmental and social consequences. The chapter starts by establishing an understanding of the characteristics of semi-arid regions, which is important when determining suitable plants for greening initiatives. It then considers climate change and its consequences in the semi-arid regions. Next, the sustainability of vertical greening is considered, which represents a critical step in the promotion of vertical greening to enhance the microclimate. The range of Urban Green Systems are then reviewed with emphasis on vertical greening, which also considers their design, the selection of plant species, maintenance levels, watering and nutrition schedules. The chapter then evaluates current academic research on the potential environmental and social performances of vertical greening, specifically in the areas of thermal performance, air quality, human wellbeing, urban agriculture, biodiversity, hydrology, noise reduction, and façade protection. In addressing these areas, this chapter achieves objectives three and four, namely “Evaluate the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria”. And “Investigate the impact of vertical greening on the urban microclimate such as temperature, humidity, and air quality, and its ability in climate change mitigation”.

2.1 Characteristics of Semi-arid Regions

The semi-arid climate, also known as the steppe, occurs in regions with little precipitation and is the next driest climate after the desert, which it usually borders (Huebner, 2020). Receiving between 10 and 20 inches annually, the semi-arid climate sees slightly more rainfall than the desert and is often considered an intermediate between the desert and humid climates with considerable temperature changes (e.g. >20°C?) between the day and night (Walton, 1969). One reason for the extreme temperature changes is the clear skies, and dry air.

Semi-arid regions have experienced a substantial growth in surface temperatures and territorial expansion over the past century (Jaber & Abu-Allaban, 2020). Moreover, developing countries' arid and semi-dry regions are projected to witness increased dryness, rising temperatures, soil deterioration, and desertification as a result of climate change. Hydrology and ecology have obvious ties in the semi-arid region where vegetation is more strongly influenced by the spatial and temporal variation of precipitation than anywhere else (Yao et al., 2020). A crucial measure of vegetation tolerance and drought resistance is evapotranspiration, which is the evaporation from plant and soil surfaces and is key to a plant's drought tolerance (Hadebe et. al., 2017). The semi-arid climate has slightly more rainfall than the desert, with temperature fluctuations widening within the region which are anticipated to intensify due to climate change.

2.2 Semi-Arid Climates

The semi-arid climate is further categorised into hot and cold semi-arid, while the tropics and subtropics, which are located at 20s and 30s latitude respectively, have hot semi-arid climates and are often located near the tropical savannah climate or on the fringe of sub-tropical desert. The hot semi-desert climate is mainly found in Africa, South Asia, and Australia and is known for hot summers and cool winters with relatively low precipitation. This climate is also found in some parts of Europe (particularly Spain), parts of North America (Mexico and Southwestern US), and parts of South America (Yang, 2010). Both hot and cold semi-arid climates experience hot summers and cold winters with little rainfall.

2.2.1 Vegetation and Animals

As the rainfall in a semi-arid environment is minimal, it maintains vast vegetation or forests, and small plants, such as shrubs and grasses, characterise these regions. Some semi-arid plants may have a high level of adaptation - like the desert plants - to enable them minimise water loss due to the high temperatures. Some of these plants have thorny branches or waxy cuticles which help them reduce water loss (Misachi, 2017). Similar to desert plants, semi-arid plants have adaptable features that enable them to thrive in the region. Consequently, for vertical greening to thrive, such plant types have to be used to withstand the nature of the environment and provide the best benefits. Figure 2-1 shows the different climates around the world, including Nigeria.

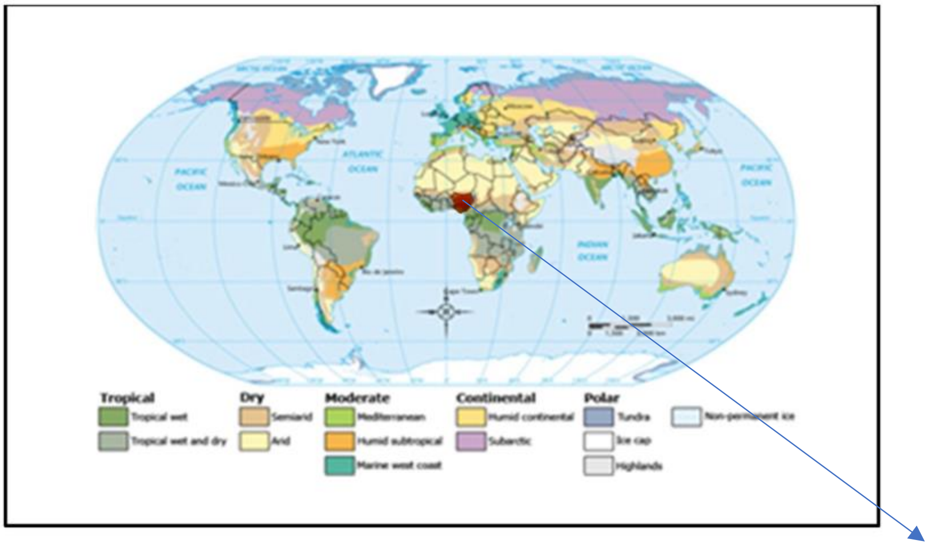


Figure 2-1: Map of the World Showing the Different Climates (Source: Thornthwaite, 2023)

2.2.2 Characteristics of the Study Area Kano State

Kano State is a state located in North-Western Nigeria with its capital named the same as the province. Created on May 27, 1967, from part of the Northern Region, Kano state borders Katsina State to the North-west, Jigawa State to the North-East, and Bauchi and Kaduna states to the South (Britannica, 2010). Kano State is a commercial, agricultural, manufacturing, and transportation hub which connects the region with southern countries of the continent (latlong.net, 2021). Moreover, it is an important commercial and industrial hub connecting the north and south of Nigeria. Thus, it is the largest commercial and industrial center in Northern Nigeria with textile, tanning, footwear, cosmetics, plastics, enamelware, pharmaceuticals, ceramics, furniture, and other industries. Other notable sectors in the area include agricultural implements, soft drinks, food and beverages, dairy products, vegetable oil, and animal feeds.

Kano State's capital city is situated close to the Sahara Desert where the local climate falls between the wet and dry climates of Northern Nigeria. The region is based in the hot semi-arid region which is characterized by five months of harmattan season (This is a cool, dry wind that blows across the Western Sahara from the northeast or east bringing along dust.) from November to mid of March, and four months of rainy season from May to March receiving around 500mm per annum and high temperatures for the rest of the year. It is described as hot and dry with high maximum temperatures and low minimum temperatures meaning there is a significant temperature difference (>=20ºC) between its hot days and cold nights. As Kano State falls within the savannah, its climate is suitable for agriculture, but it has relatively low precipitation to support vast vegetation. Moreover, its naturally growing plants tend to have thorny branches and waxy cuticles to minimize water loss (Britannica, 2012). Figure 2-2 shows the location of Kano State within Nigeria.

Figure 2-2: Map of Nigeria Showing Kano State. (Source: Premium Times, 2019)

2.2.3 Geography

Kano State’s latitude and longitude coordinates are 12°north and 8.51°east (Britannica, 2010)**, and i**ts total land area is 20,760sq kilometers (about the area of New Jersey in the USA) with a population of 9,383,682 (about half the population of New York, USA) (Latlog.net, 2021). It is located within the semi-arid Sudan savannah zone of West Africa and about 840 kilometers (about twice the length of New York State) from the edge of the Sahara Desert. Kano has a mean height of about 472.45 metres above sea level.

2.2.4 Climate of Kano State, Nigeria

The temperature of Kano State usually ranges between a maximum of 38.6°C and a minimum of 29.4°C although sometimes during the harmattan[1] it falls to as low as 10°C (Britannica, 2012). Kano State has two seasonal periods, which consist of four to five months of wet season and a long dry season lasting from October to April. The movement of the southwest maritime air masses, which originate from the Atlantic Ocean, influences the wet season which starts in May and ends in September. The commencement and length of the wet season varies between the Northern and Southern parts of Kano State; the length of the season in Riruwai in the Southern part of Kano state is six months from early May to late September while in northern parts it runs from June to early September (Britannica, 2012).

The average rainfall varies from dry season to wet season eg 63.3mm - 48.2mm in May, and 133.4mm - 59mm in August (Kankara, 2019). The movement of the tropical maritime air masses from the southwest to the north determines the weather of Kano State during the wet season. This air mass carries a lot of moisture from the Atlantic Ocean which condenses when it is forced to rise by convection or over a barrier of highlands or air mass after which it then falls as rain. The wet season occurs when the sun passes over West Africa between March and June, while the dry season starts in October and lasts until about April of the following year. Temperatures are low during this period for two reasons: firstly, the sun is in the Southern Hemisphere and secondly, the movement of the desiccating continental air mass, which originates from the Sahara area and blows from the Northeast carrying along with it the harmattan dust. This period is also the harvesting season (Britannica, 2010). Figure 2-3 shows the minimum and maximum temperatures in Kano State, Nigeria, while Figure 2-4 shows the average monthly sunshine hours for the state over the course of a year. Moreover Figure 2-5 shows the average annual precipitation for the state, and 2-6 illustrates its relative humidity over the year.

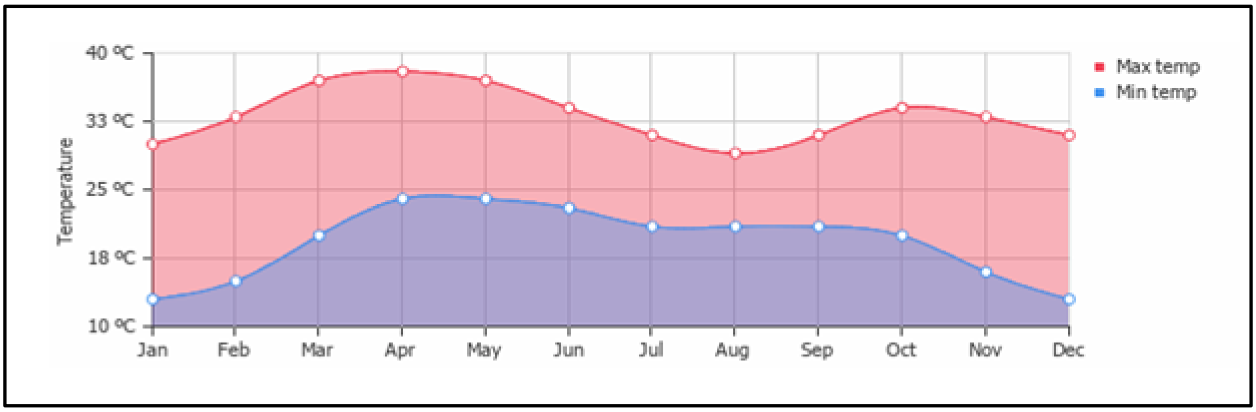


Figure 2-3: Average Minimum and Maximum Temperatures in Kano State, Nigeria (Source: Climate and weather.com 2021)

Figure 2-4: Average Monthly Sun Hours in Kano State, Nigeria (Source: Climate and weather.com, 2021)

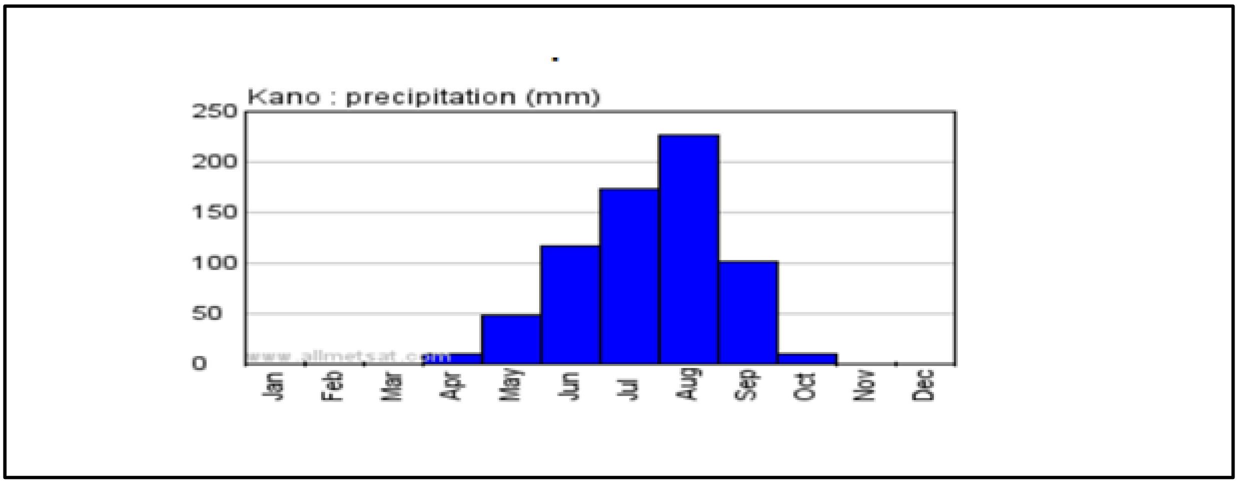


Figure 2-5: Average Precipitation (Rainfall) in Kano State, Nigeria (Source: Climate and weather.com, 2021)

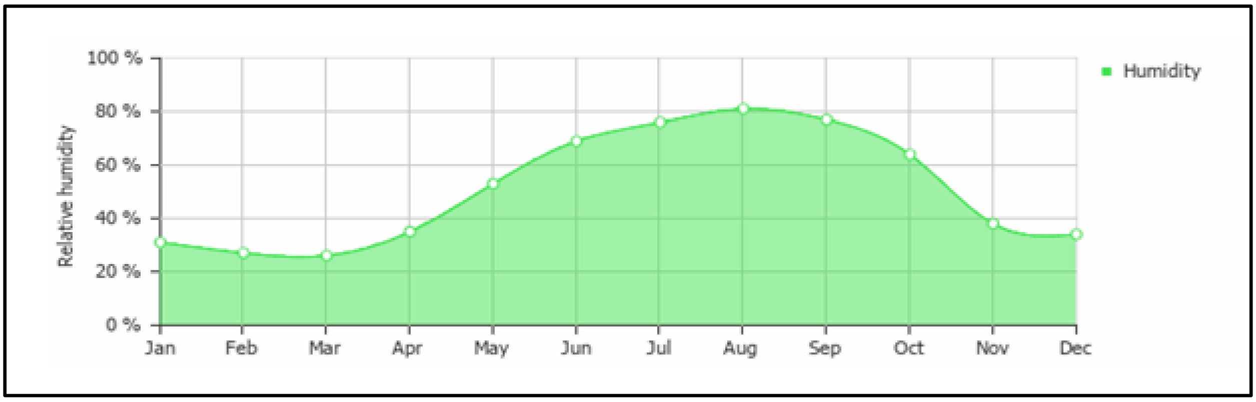


Figure 2-6: Average Relative Humidity in Kano State, Nigeria (Source: Climate and weather.com, 2021)

2.2.5 Vegetation

The vegetation of Kano State is classed as Sudan Savannah, which is surrounded by the Sahel Savannah in the North and the Guinea Savannah in the South. The savannah has been described as the zone that provides opportunity for optimal human attainment because it is rich in faunal and floral resources, suitable for both cereal agriculture and livestock rearing, and offer relatively easy conditions for movement of natural resources and manufactured goods (Connah, 1987). The tree canopies are wide and most of them are less than 20m tall and the species commonly found are resistant to drought.

Moreover, domesticated crops include sorghum, millet and African rice, several indigenous yams, African groundnuts, cowpeas and black benniseed. These products have been available for two to three thousand years as part of the vegetable resources in the West African savannah (Stalker et al., 2021). However, the natural vegetation of Kano State has been modified as a result of several centuries of human activity such as bush clearing and burning for cultivation and hunting, and animal grazing (Nigeria Galleria, 2021).

2.2.6 Climate Change Impact

The most daunting challenge the planet currently experiences is climate change (Betsill & Harriet, 2002), which since 1750 has seen increases in the global atmospheric concentration of carbon dioxide, methane, and nitrous oxide which now exceed the pre-industrial values determined from the ice core (Wong, 2015). The burning of fossil fuel majorly accounts for the increased concentration of these gases in the atmosphere, and the energy balance of the climate system is altered by changes in the built environment (Wong, 2015). Changes in the energy balance (input, output, and absorbed energy) of the planet have altered the earth's climate over millions of years, from the ice age to warmer inter-glacial conditions and back to the icy state. The warming of the climate is seen as a global trend (IPCC, 2011), and has been noted in the raised air and ocean temperatures, melting of glaciers, and rising sea level. Indeed, over the last 50 years, the rate of linear warming has almost doubled that of the past 100 years (Wong, 2015). A significant part of climate change is caused by human activities which alter the energy balance of the planet by continuously multiplying the effect.

Local climate is influenced by alterations to the earth's surface, such as the replacement of vegetated surfaces with paved surfaces which result in the build-up of heat known as the heat island effect. It is evident that the temperatures and air qualities of cities and rural areas vary greatly but these have been exacerbated due to increases in the anthropogenic heat release which result from human activities in urban areas (Vujovic et al., 2021). These affect heat absorption, release and dissemination. IPCC has a goal of limiting human induced warming to less than 2°C which will require cumulative CO_2 emissions from all anthropogenic sources to remain below about 2900 GtCO2 (Satterthwaite, 2008). Nigeria's Climate Change Act aims to achieve low greenhouse gas emissions, as well as green and sustainable growth, by establishing a net zero GHG target for 2050 to 2070 which will be reviewed every five years (Addo, 2021). According to Nigeria's National Determined Contribution (NDC) update, the goal is to achieve net zero emissions as soon as possible in the second part of the century through an Energy Transition Plan. (Federal Republic of Nigeria, 2022; Lo, 2021). This is particularly challenging as, about 1900 GtCO2 had already been emitted by 2011 (Pfister, et al., 2016). Thus, decisive measures are required to check greenhouse gas emissions.

2.2.6.1 The Impact of Climate Change on the Environment

Climate change, which is driven by global temperature increase, has a wide range of negative consequences for the world (Wigley et al., 1981). These impacts interact with one another and amplify their effects, placing the Earth's inhabitants, including humans, at risk. Temperature rises around the globe have an impact on physical, biological, and human systems. Initially, alterations in the planet's biological phenomena can be seen in the melting of the poles, which causes glacial regression, snow melting, warming, the thawing of permafrost, flooding in rivers and lakes, droughts in rivers and lakes, coastal erosion, sea level rises, and extreme natural occurrences (Abouelfadl, 2012). Moreover, plant and fauna death occur in terrestrial and marine ecosystems, while wildfires mean flora and fauna displacement in pursuit of better living conditions. Climate change significantly affects Nigeria, threatening its economy, diverse livelihoods, agriculture, and commodities. Rising sea levels increase flooding and waterborne diseases, while drought and higher temperatures reduce agricultural productivity and fishing, impacting food security and health. Nigeria also faces the highest global deforestation rate, losing 3.7% of its forest annually, including mangrove forests. These issues are exacerbated by substantial greenhouse gas emissions from the energy sector, deforestation, and land-use changes.

Nigeria's climate is marked by rising temperatures, variable rainfall, sea level rise, flooding, drought, desertification, land degradation, extreme weather, freshwater scarcity, and biodiversity loss. Rainfall intensity and variability are increasing, leading to more flooding in southern regions, while droughts persist in the north. Lakes, such as Lake Chad, are drying up, and temperature projections indicate continued increases across all ecological zones.

A review of climate change impacts in Nigeria highlights significant effects on agriculture and farming communities, with limited implementation of mitigation and adaptation measures

Climate change damages and destroys crops which impacts food production, causes disease and mortality, ruins, economic livelihoods, and forces climate refugees to migrate (Acciona, 2019). The changes that affect different systems are related, as detrimental effects reinforce and exacerbate one another. Figure 2-7 illustrates the impact of climate change on physical, biological and human systems.

Droughts and shifting global rainfall patterns are causing crop failure and rising food costs, resulting in food insecurity and nutritional deprivation for the poor, which can have long-term consequences (Wang et al., 2009). Extreme weather events, such as cyclones and heatwaves, are becoming more common and violent, endangering people’s lives and destroying the infrastructure vital to human well-being (Bunyavanich et al., 2003). For example, floods wreak overwhelm water and sanitation systems, which frequently results in diseases like cholera and are especially dangerous to children.

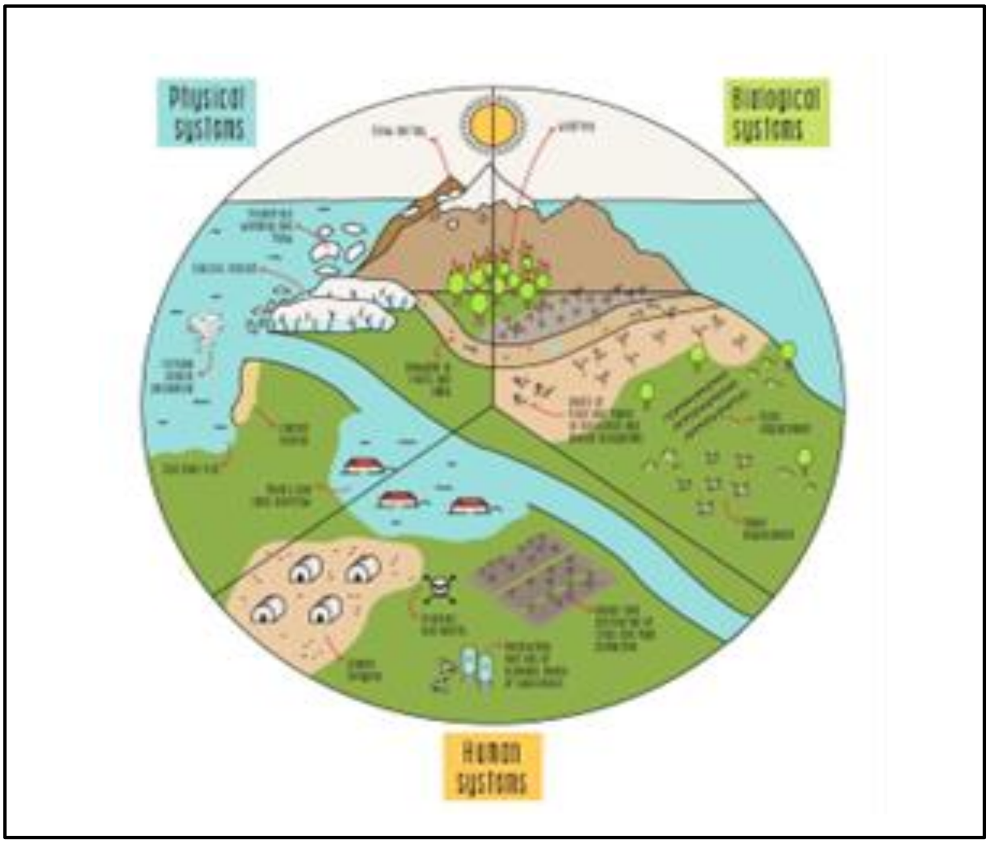


Figure 2-7: Impact of Climate Change (Global Increases in Temperature) on the Earth's Physical, Biological, and Human Systems *Source: (www.activesustainability.com, year)*

A warming atmosphere accelerates the melting of the planet's snowpack, glaciers, sea, and freshwater ice (Dianati et al., 2021). Melting glaciers and polar ice sheets contribute to unprecedented sea level rises. Melting sea ice exposes darker ocean waters, which absorb more sunlight than ice, further heating the ocean and hastening a continuous cycle of melting and heating. The rises in temperature due to global warming aids pollution. In polluted areas, a warmer atmosphere promotes the production of ground-level ozone, often known as smog. Smog affects the lungs and triggers asthma attacks amongst susceptible humans, while smoke from wildfires degrades the air even more. In addition, the oceans are becoming more acidic as they warm up, meaning they have become hotter as a result of absorbing 90% of the excess heat in the environment (Dianati et al., 2021). Approximately one-third of carbon dioxide emissions end up in the oceans, causing a chemical change that makes the water more acidic and erodes sea creatures' shells. Indeed, the ocean is over 40% more acidic than it was previously (Hoegh-Guldberg & Bruno, 2010).

Furthermore, climate change poses a significant threat to agriculture, and therefore to human life and prosperity. Where, how, and when we grow food is inextricably linked to the natural patterns of our climate. Farmers all over the world are having to keep up with changing weather patterns and increasingly volatile water sources, (Wang et al., 2009), while weeds, diseases, and pests are becoming more prevalent which reduce productivity thereby damaging farms. Crop yields are also threatened by extreme events, such as flooding or a lack of water availability (Kumar et al., 2022). In addition, land and water habitats are shifting, causing some species to struggle to survive in their existing environments, while others often migrate in and take over. Some ecosystems are facing the danger of disappearing (IUCN, 2007). According to the European Commission (2012), forests are more vulnerable to lethal infestations. Tree-killing insects thrive in milder winters and longer summers. Furthermore, trees that have been harmed by protracted drought have reduced defense mechanisms. The catastrophic die-off of 70,000 square miles (about twice the area of South Carolina) of Rocky Mountain conifers was most likely caused by a cycle of warmer weather, weak trees, and thriving insects (Environmental Defense Fund, 2019). Therefore, numerous and extensive effects of climate change have been recorded which need to be urgently tackled to mitigate its negative impacts on man and the environment.

2.3 Urban Green Infrastructure

According to the Cambridge dictionary, infrastructure is defined as the fundamental structures and amenities essential for the successful functioning of a certain geographical location. Meanwhile, 'green infrastructure' is described as the network of many forms of green area that together enable the delivery of benefits as commodities and services (Bentsen et al., 2010). Green spaces are also described as any vegetated regions of land or water within or adjacent to an urban area (Taylor & Hochuli, 2017). Climate change adaptation/mitigation, health, well-being, and social cohesion, economic development and investment, wildlife and habitats, and stronger communities are just a few of the primary benefits of incorporating high-quality green infrastructure into the urban environment (Taylor & Hochuli, 2016). The evidence that nature has a positive impact on man and the environment has sparked a surge of interest in greenspace research.

Nevertheless, the disparity between urban areas and rural vegetated landscapes has become more pronounced due to rapid increases in urbanization and population (Yael, 2017). Nature is being encroached upon and replaced with built structures and paved surfaces (Wheeler, 2010). However, the interconnectivity matrices of green spaces found in and around an urban and urban-fringe land scape - called green infrastructure (Mell, 2008) - varies in complexity and morphology. For example, it includes parks, green roofs and walls, green corridors, urban forest, public green spaces, and street trees (Cameron & Green, 2016), although the most commonly known and more conventional approaches to establishing greenery include public parks, backyard gardening, and street landscaping (Taylor & Hochuli, 2016).

According to recent studies, urban green infrastructure can have a positive role in ecosystem services (Elie et al., 2023). It supports the ecosystem in several ways, buffers solar radiation, lowers wind speeds, and uses evapotranspiration processes to regulate the climate. The implementation and conservation of urban greenery is advocated in sustainable approaches to urban design which emphasize the value of plants and planted spaces (Li et al., 2005). Greenery has an impact on air quality by eliminating pollutants from the atmosphere and reducing noise (Wang et al., 2014). In summer, the surface temperature during the day is reduced by trees which provide shade to buildings while at night they prevent heat flow from nearby buildings (Akbari, 2002). Transpiration and evaporation from vegetation and the surrounding soil lowers the ambient temperature. Trees buffer hot summer winds and cold winter winds by shielding properties which helps to maintain comfortable building temperatures (Akhbari, 2002). The indoor environment is directly influenced by urban green infrastructure in terms of temperature, air quality, acoustics, and aesthetics.

Additionally, greenery has a variety of indirect consequences on human health and the economy. Green infrastructure's ability to regulate the climate results in reduced energy costs due to the modification of indoor temperatures (Wang, 2014). Moreover, building-integrated vegetation, often called Biophilic Architecture or Biophilic Design, are less typical approaches that place emphasis on the beneficial impact of vegetation on architecture (Köhler et al., 2003). This includes living walls, as well as more established strategies such as green corridors, urban parks, and green roofs, introduce greenery into modern cities from an environmental perspective. (Loh & Stav, 2008). Thus, when building sustainable and resilient cities, the significance and benefits of green infrastructure cannot be overemphasized.

2.4 Living Wall Systems as a Component of Urban Green System

Living wall is understood as garden design and construction on a vertical plane (Perini et al., 2011). It is a component of green infrastructure which is potentially advantageous in densely populated areas. It is argued that green infrastructure should weave its way through and around the built environment by connecting the city to its larger rural areas, as it can encompass existing and new green spaces (Cameron & Blanuša, 2016). Moreover, it should be sustainable and capable of supporting ecological services and a good quality of life.

As describes, green walls are systems in which plants grow on a vertical surface and are attached to the building exterior using various technologies (Golasz-Szolomicka & Szolomicki, 2019), and historically, vertical greening has been recognised since the Babylonian Hanging Gardens, which were built about 500 BC (Manso & Castro-Gomes, 2019). The benefits of green infrastructure have been researched by several authors which include health benefits for people (Mell, 2007), the promotion of environmental education (Zaremba & Smoleński, 2000), and the establishment of connections between social and environmental history (Mosley, 2012). However, due to pressure from population growth, the rapid expansion of cities, and the economics of tree maintenance, securing land space for greenery has been difficult. Nevertheless, vertical growing areas are estimated to double the amount of ground surface in European inner cities (Kohler, 2006), and vegetation can be introduced through the use of living walls which does not sacrifice expensive urban space or compromise urban density (Yael, 2017). The growing importance of living walls cannot be over-emphasized considering global urbanization trends and the search for better models for a more sustainable urban environment (Williams et al., 2013). Furthermore, the possible area for vertical greening is substantially bigger than the surface area available horizontally; thus, vertical greening systems (VGSs) appear to offer a better capacity to address negative environmental issues (Mårtensson et al., 2014). As the rate of urbanization increases, living walls enable the integration of vegetation into urban areas, thereby providing opportunities for a sustainable, eco-friendly urban environment.

2.5 Urban Sustainability and Living Walls

Researchers have emphasised the negative impacts of high urban temperatures on humans and the environment, including their causes, and outlined suitable mitigation strategies (Gago et al., 2013; Santamouris, 2014). One of the major research strategies noted in the field of urban climatology is the urban heat island, which denotes the high ambient temperature in cities compared to rural areas (Taha, 1997). Changes in urban morphology (due to urbanization) such as increased urban density, increased paved surfaces, and the thermal properties of the construction materials permits the high absorption of solar radiation and re-radiation within the city (Santamouris, 2014). This results in poor ventilation and the entrapment of radiation (Ulpiani, 2021).

As urbanization increases, cities continue to witness decreases in vegetation (Du et al., 2019; Guan et al., 2019; Yao et al., 2017), although research places emphasis on the benefits of vegetation in urban spaces (IPCC, 2007; Marshall et al., 2020; Virtudes & Manso, 2016). Awareness of the environment evolves as cities grow denser which makes traditional approaches to establishing greenery challenging (Stav, 2016). As such, less traditional approaches such as 'building integrated vegetation' or 'biophilic design' which concentrate on the positive impact of vegetation on architecture are becoming more notable as strategies to increase the presence of vegetation in cities (Hidalgo, 2014). Cities have abundant vertical surfaces which are only occupied by adverts and are readily available for the incorporation of vegetation into the built environment (Manso & Castro-Gomes, 2016). When vegetation is introduced to a building on a broad urban scale, it enhances the urban environment by contributing to urban biodiversity (Francis & Lorimer, 2011). The introduction of living walls is a convenient approach to integrating greenery in built up urban areas, especially in modern cities where the environment is dominated by high rise buildings which provide a multitude of vertical surfaces in which to introduce greenery.

2.6 Green Envelope

In this research, the 'green envelope' refers to the surface of a building covered with vegetation, which comprises the roof and wall surfaces (as in green roofs and vertical greening systems). Green envelopes are perceived as a sustainable building practice that reduces the building's impact on the environment (Rosasco & Perini, 2018).

2.6.1 Vertical Greening Systems (VGS)

Green-wall technologies, vertical gardens, and bio walls are terms used to describe Vertical Greening Systems (VGS) (Pérez-Urrestarazu et al., 2015), and denote planting on either the upright or sloping vertical surfaces of buildings. According to Perini & Rosasco (2016), VGS includes the practise of greening the building envelope with all forms of plant, either rooted in the ground, in the wall itself, or modular panels attached to the façade. Applying vertical greening systems on new and existing buildings can offer multiple environmental benefits (Perini, 2016). Over the centuries, simple methods of covering building surfaces with plants, especially self-climbing species, have been used in many countries (Yoshimi, 2016), particularly in Europe although minimal presence has been found in Africa, especially sub-Saharan Africa.

2.6.2 History of Vertical Greening

Examples of vertical greening in architectural history date back to the Babylonians and their famous Hanging Gardens of Babylon, which is considered one of the seven ancient wonders of the world (Shaikh et al., 2015), as shown in Figure 2-8.

Figure 2-8: Hanging Garden of Babylon (Source:Sodai, 2018)

Later, throughout the Mediterranean, Romans trained grape vines (Vitis species) on garden trellises and villa walls from around third century BCE to 17th Century AD (Sudhakar & Swarnalath, 2017). The integration of house and garden through features such as pergolas, trellis structures and self-clinging climbing plants was also promoted by the British and North American Garden City Movement in the 1920s (Gatarić et al., 2019). In 1988, stainless-steel cable systems were introduced for green façades, while in the early 1990s cable and wire-rope net systems and modular trellis panel systems were introduced to the North American marketplace (Radić et al., 2019). The first major application of a trellis panel system was implemented in 1993 at Universal City Walk in California, while by 1994 indoor living walls with bio-filtration systems were installed in the Canada Life Building in Toronto, Canada (Sudhakar & Swarnalath, 2017). Furthermore, in 2002, the MFO Park, a multi-tiered 300' long and 50' high park structure opened in Zurich, Switzerland where the project featured over 1,300 climbing plants (Sudhakar & Swarnalath, 2017).

In 2005, the Japanese Federal Government sponsored a massive Bio-Lung exhibit, which was the centerpiece of Expo 2005 in Aichi, Japan. The wall comprised 30 different modular green wall systems available in Japan, although Patrick Blanc, a French botanist, is widely noted as the first to design the 'modern' pattern of green walls, with a full hydroponic system, an inert medium, and numerous exotic species. His first green wall is at the Museum of Science and Industry in Paris (Papadopoulou, 2013). This history highlights the evolution and the wide, rapid spread of vertical greening in different parts of the world. Figures 2-9 to 2-12 show examples of the use of living walls.

Figure 2-9: Grape Vines Used to Shade Patio Switzerland

(Source: Snow, 2022)

Figure 2-10: Cable Façade at MFO Park in Spain. Source: (Rakhshandehroo et al., 2015)

Figure 2-11: Living Wall Installation, New York (Source: Rakhshandehroo, 2015)

Figure 2-12: Modular Living Walls (Source : Serra et al., 2017)

2.7 Green Walls

The term 'green wall' refers to any method that allows a vertical surface (e.g., façades, walls, blind walls, partition walls, etc.) to be planted with a variety of species, including plants that grow up or within a building's wall. However, current technologies for greening a building's envelope are considered to be more than just vegetation-covered surfaces, as VGS technology is designed to improve a building's performance and longevity (Manso & Castro-Gomes, 2015). It maximizes the benefits of plants to enable building efficiency and forms part of a long-term strategy for urban rehabilitation and building retrofits (Cameron et al., 2014; Charoenkit & Yiemwattana, 2017; Manso & Castro-Gomes, 2015). Urban streets with uninteresting façades and extensive vertical surfaces in cities provide opportunities for building envelopes to be visually altered by adopting natural design features and offering aesthetic enhancement.

The key component of living walls is vegetation which aids in temperature reduction and carbon sequestration (Charoenkit & Yiemwattana, 2017), although most contemporary living walls feature materials and technology that sustain a greater range of plants while maintaining a uniform growth pattern across the surface (Manso, 2014). The practical benefits of maintaining suitable vegetation include the control of heat gain and loss in buildings, which enhance the microclimate in summer and act as a supplementary insulation layer in winter (Tan et al., 2015). Moreover, when diverse vegetation is introduced to building envelopes, it can significantly improve the urban environment by promoting biodiversity. (Francis & Lorimer, 2011). Recent research has shown that green wall systems can control heat gains and losses, and hence improve interior thermal comfort while lowering energy needs for heating and cooling (Yenneti et al., 2020). It can also improve air quality (Rawski, 2019), and mitigate the heat island effect (Gago et al., 2013) meaning it brings benefits both on an individual and a neighborhood scale.

Green walls can also provide social and economic benefits (Rakhshandehroo, 2015) because façade greening in urban areas can double the ground footprint of buildings, while green walls have a greater potential than green roofs (Köhler, 2008). Green wall systems can be utilized as a passive design solution on a building scale (Perez et al., 2011) while plant evapotranspiration can further diminish the influence of solar radiation, resulting in higher humidity levels and lower surface temperatures than hard surfaces (Eumorfopoulou & Kontoleon, 2009). Furthermore, green wall systems are available in a variety of configurations (Virtudes & Manso, 2016); woody climbers were often used as aesthetic parts of the building envelope in European and North American towns in the nineteenth century (Köhler, 2008), while green façades have been popular as contributions to city ecological enhancement since the 1980s. The end of the nineteenth century saw the Garden City Movement which incorporated greening into city planning, while from the early twentieth century, the German Jugendstil (Art Nouveau) movement promoted the integration of the house and garden (Kohler, 2008). Thus, the integration of plants into buildings has historically been recognized for its benefits by improving the microclimate and providing urban ecosystem services.

2.8. Classification of Green Wall Systems

There are varieties of green wall based on the construction method and definitions, and as a result, researchers have devised classification systems, many of which overlap in terms of their characteristics (Manso & Castro-Gomes, 2015). Based on the type of vegetation utilized in the system, green walls are divided into two categories: green façades and living walls

(Köhler, 2008; Dunnett & Kingsbury, 2008). Ottelé (2011) categorised them as direct and indirect green walls based on the presence of an air-filled space between the system and the wall. Some proposed classification systems based on the construction characteristics (Manso & Castro-Gomes, 2015) although Francis & Lorimer (2011) defined the concept 'bio walls' which denotes the use of green walls in indoor places to improve the environment. The terms interior living walls and exterior living walls are commonly used depending on whether they are on the inside or outside a building. This study focuses on exterior living walls and their potential impact on the urban microclimate. Figure 2-13 lists the classification of green walls according to their construction characteristics,

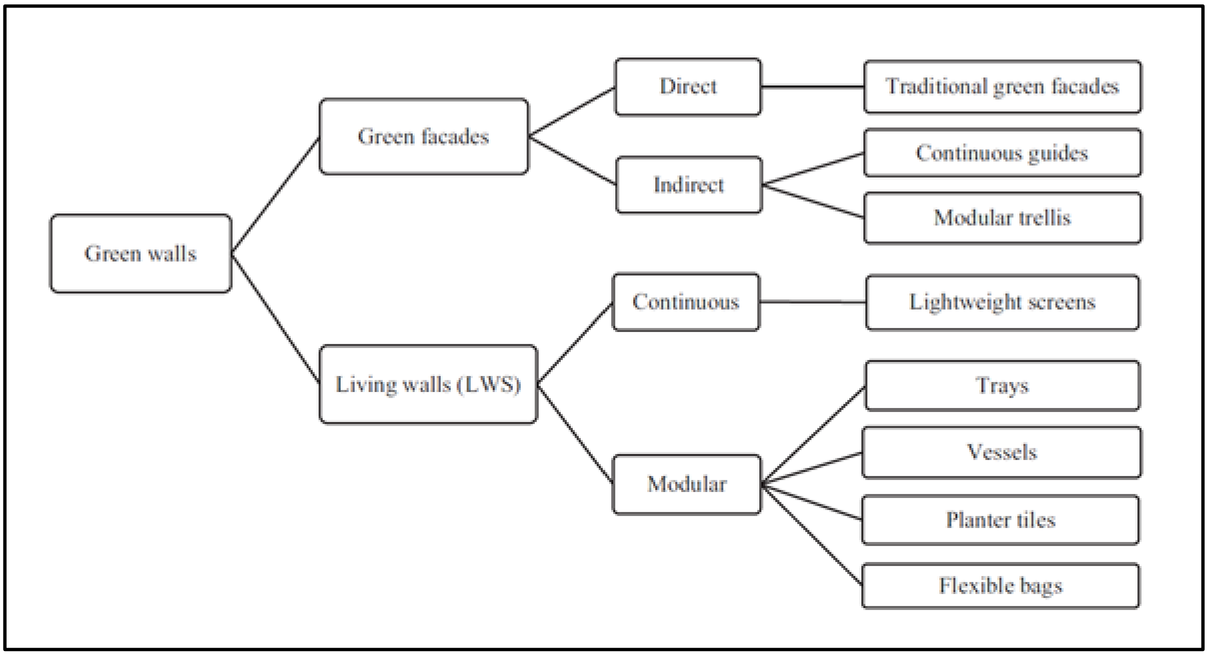


Figure 2:13: Classification of Green Walls According to their Construction Characteristics.   Source: (Manso & Castro-Gomes, 2017)

2.9 Green Façades

Green façades that are directly attached to a wall are known as direct green façades while those with a supporting framework for vegetation are regarded as indirect green façades (Manso & Castro-Gomes, 2015). Both types may mainly incorporate hanging plants at a specific height which grow downwards on a vertical surface (Dunnet & Kingsbury, 2008), or climbers affixed directly to the building surface (as in traditional design), or supported by cables or trellis (Perini et al., 2013).

Traditionally, green façades are a direct greening system that uses self-clinging climbers that are rooted directly in the ground. Indirect greening façades are a new strategy in green façade technology, which have vertical support structures for climbing plants (Manso & Castro-Gomes, 2015). Plants that grow on the ground or in planters and are guided by support structures are classified as continuous and modular indirect greening façades. Continuous guides are based on a single support structure that directs plant growth across the entire surface. In comparison, indirect green façades with modular trellises are similar but are made up of multiple modular parts installed along the surface (Zaid et al., 2018a). Modular trellises differ in that they feature vessels for plant roots and an individual support structure to lead plant growth. This highlights that green façades could hang downwards in pots from a height or climb upwards from the ground. Thus, the major sub-classification in green façades are those with support only or support and planter boxes for the plant, and those without support. Figures 2-14 to 2-19 show a range of different green façades.

Figure 2-14: Indirect Green Façade (Source:Manso & Castro-Gomes, 2015).

Figure 2-15: Direct Green Façade on a Private House in Golegã, Portugal (Source:Manso & Castro-Gomes 2015).

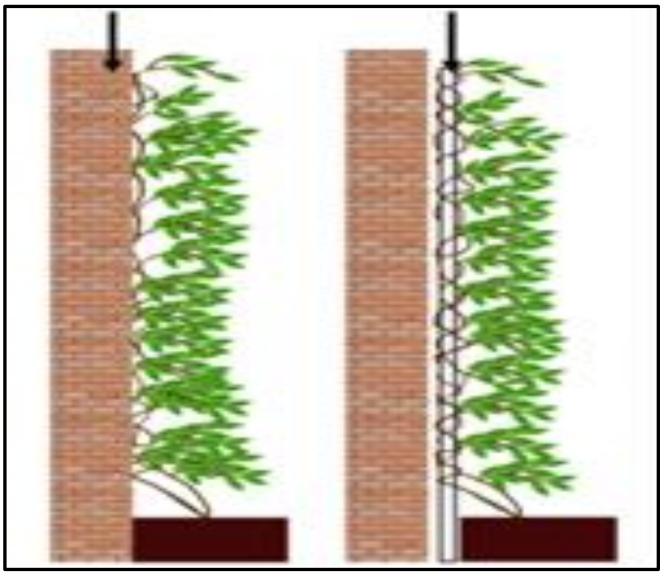


Figure 2-16: Direct and Indirect Green Façades (Source: Bustami et al., 2018)

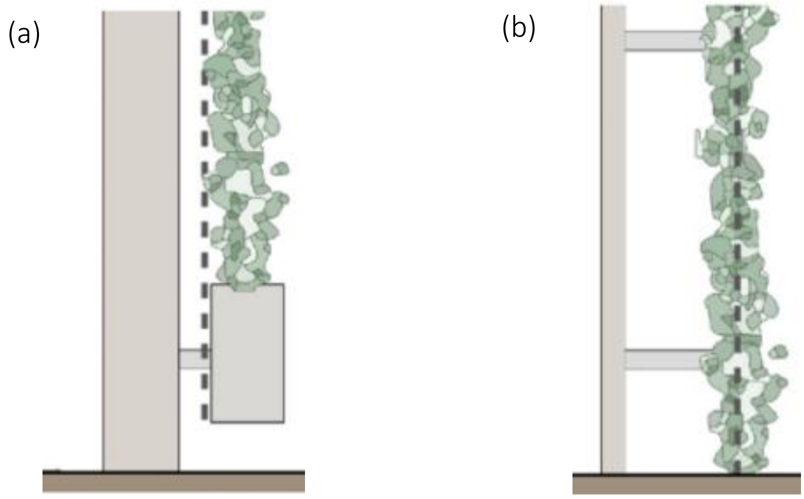


Figure 2-17: (a) Indirect Green Façade with Planter-Box (Source: Gunawardena, 2019). (b) Indirect Green Façade as Double Skin (Source: Sukulje,2014)

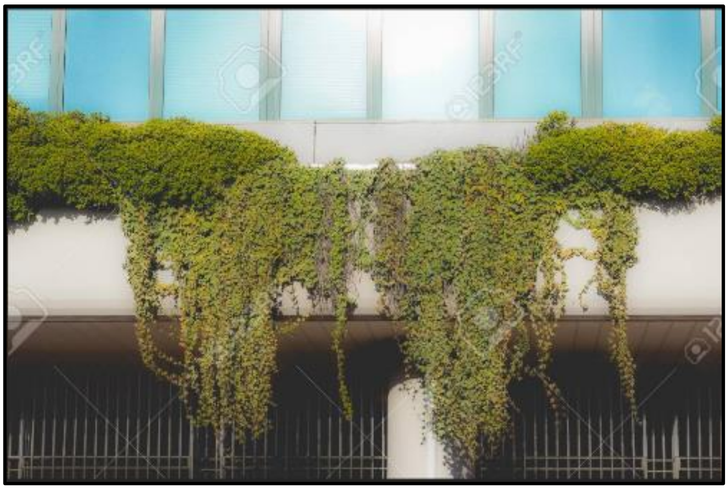


Figure 2-19: Hanging Down Green Façade (Source: 123RF, 2021)

2.10 Living Walls

In the field of wall cladding, living walls are a recent area of innovation comprising plants that are grown in artificial substrates (Serra et al., 2017; Golasz-Szolomicka & Szolomicki, 2019); in the context of this study, they are considered to be vertical structures with different types of plants attached, often planted in a growth medium. Irrigation and nutrient dispersal are accomplished via hydroponic technology, which is a technique for growing plants in nutrient solutions with or without the aid of a mechanical support medium (Charoenkit et al., 2016). According to Manso (2015), uniform and wide surface coverage is easily achieved in living walls. Living walls originated to allow the incorporation of a wide variety of plants into high buildings to enhance its aesthetic appeal. Living walls differ from green façades, which are plants climbing outside the building but rooted in the ground. According to Pe´rez-Urrestarazu (2016), living walls are generally a more complex green infrastructure, and involve a supporting structure with different attachment methods. According to the application technique, living wall systems (LWS) can be categorized as continuous or modular; continuous LWS comprise individual plants within lightweight, permeable screens, while modular LWS includes elements with distinct dimensions, which include the growing media in which plants can thrive (Manso & Castro-Gomes, 2015). Living walls apply more advanced complex technology than that used in green façades but offer greater aesthetic appeal and biodiversity. Figures 2-20 to 2-23 show examples of different living wall systems.

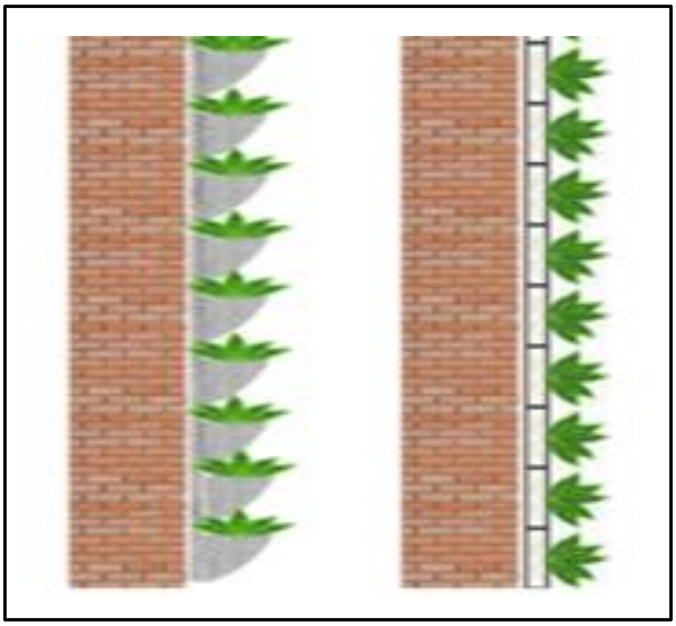


Figure 2-20: Felt System and Horizontal Felt System (Source: Manso & Castro-Gomes, 2015)

Figure 2-21: Continuous Living Wall System at Caixa Forum, Madrid (Source: (Manso & Castro-Gomes, 2015)

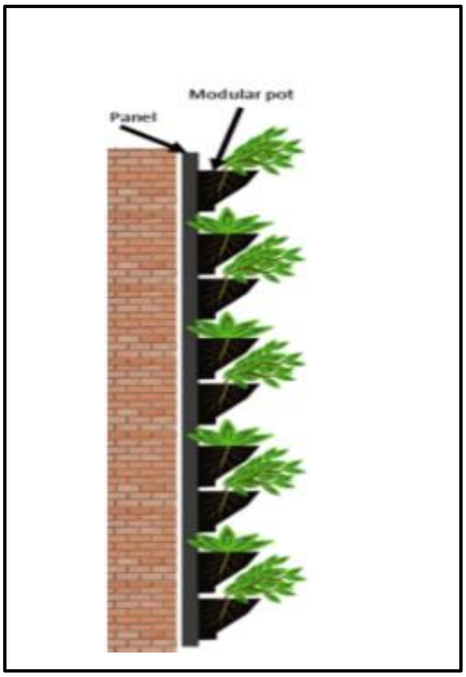


Figure 2-22: Modular Tray Source: (Medl et al., 2017)

Figure 2-23: Modular Living Walls System (Source:Bustami et al., 2018)

In 1994, Patrick Blanc coined in the term Living Wall Systems (LWS) in his publication *Vertical Garden* and popularized the use of this style of LWS across the world (Manso & Castro-Gomes, 2015). Living walls are undeniably attractive but in comparison to green façades, they have shorter lifespans and are more costly because they require more maintenance (Manso & Castro-Gomes, 2015). They enable faster and more consistent coverage of vast areas along a vertical surface reaching higher areas and adapting to all kinds of buildings (Nugroho, 2020). In addition, they also allow for the integration of a greater range of plant species. Figures 2-24 and 2-25 show applications of living walls.

Figure 2-24*:*

Figure 2-25: Quai Branly Museum in Paris (Source: Wilkinson, 2017)

2.11 Types of Living Wall Design

2.11.1 Continuous Living Walls Systems

Continuous living wall systems use lightweight absorbent screens or flexible bags where plants are inserted into cloth (or felt) (Manso & Castro-Gomes, 2015). Flexible bags can take various shapes and have curvy or inclined surfaces comprising medium and lightweight growing materials that support greenery. Continuous LWS involves the installation of a stainless-steel frame attached to the wall which forms a void space between the system and the surface. The frame holds the base panel and protects the wall from humidity, while the base panel supports the next layers. It is covered with layers of permeable, flexible and root proof screens which are stapled to the base. The external layer of the screen is then cut to form pockets for the introduction of individual plants (Manso & Castro-Gomes, 2015). Figures 2-26 and 2-27 show examples of continuous living walls.

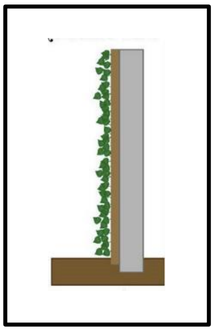


Figure 2-26: Continuous Living Wall (Source: Medl et al., 2017)

Figure 2-27: Vertical Garden GrowBag (Source: Whatwears Manufacturers, 2021)

2.11.2 Modular Living Walls Systems

The composition, weight, and construction of modular LWS differ widely; according to Manso & Castro-Gomes (2015), a modular LWS can take several forms, each requiring a different structure. A modular LWS consists of trays, vessels, planter tiles made of lightweight materials like plastics with interlocking parts and back hooks for hanging (Elgizawy, 2016), and allows for the inclusion of a variety of plants in each row. According to Manso and Castro-Gomes (2015), modular trays are usually composed of several interlocked parts made of lightweight materials as plastic (e.g., polypropylene or polyethylene) or metal sheets (e.g., aluminium, galvanized steel, or stainless steel) while the back surfaces have hooks or mounting brackets for their suspension in the frame profiles connected to the vertical surface. Trays are usually sturdy containers that can hold the plants and substrate weight and are attachable to one another. Vessels are a variation of the most common plant support, with the added benefit of being able to attach to a vertical structure or to each other. Planter tiles highlight the shape of the modular element as elements of design for the building's exterior or interior cladding. Each element can be held in place by a complementary structure or is fastened directly to the vertical surface (Manso & Castro-Gomes, 2015). Modular vessels allow for the installation of several plants in each element along the same row creating a significant visual impact on the building surface (Serra et al., 2017). A modular LWS consists of plastic, tiles or metal modules for the growing medium and plant and can therefore be slightly heavier than a continuous LWS owing to the weight of the modules. The method of attaching the modules is flexible and easy, involving hooks and interlocking parts. Figures 2-28 and 2-29 show examples of modular living wall systems.

Figure 2-28: Front View of a Modular Living Wall (Source: Manso & Castro-Gomes, 2015)

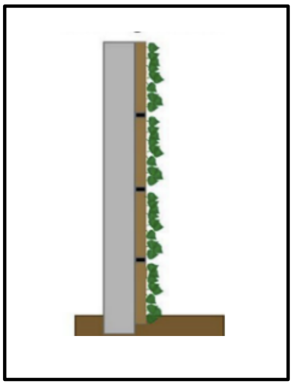


Figure 2-29: Side View of a Modular Living Wall (Source : Medl et al., 2017)

Table 2.1 below shows the summary of a comprehensive comparison of available vertical greening.

S/No		Green façade		Living walls	
1.		Direct greening on the façades, usually a single type of plant.		Indirect greening façades offer greater aesthetic appeal with different types of plants attached.	
2.		Self-clinging climbers that are rooted directly in the ground. A very simple form of greening with no supporting structure. Vegetation coverage is usually slow.		Have vertical structures often planted in a growth medium with different attachment methods That allow for the integration of a greater range of plant species. more complex green infrastructure, and involve a supporting structure They enable faster and more consistent coverage of vast areas along a vertical surface reaching higher areas and adapting to all kinds of buildings	
				Continuous indirect greening façades.	Modular indirect greening façades.

				Continuous guides are based on a single support structure that directs plant growth across the entire surface.	made up of multiple modular parts installed along the surface
				Includes individual plants within lightweight, permeable screens use lightweight absorbent screens or flexible bags where plants are inserted into cloth.	Includes elements with distinct dimensions, which include the growing media in which plants can thrive Have vessels for plant roots and an individual support structure to lead plant growth.
		Irrigation is done directly to the ground		Irrigation and nutrient dispersal are accomplished via hydroponic technology.	

		where the plant is on in flower pots.		
		Plants climbing outside the building but rooted in the ground.		It include a wide variety of plants introduced into high buildings to enhance its aesthetic appeal. It can be inside or outside the building

2.11.3 Green Wall System Requirements

In green wall constructions, the focus is placed on the system design to maximise efficiency in its installation, maintenance, and replacement, and ensure a sustainable construction. Components of the system include supporting elements, growing media, vegetation, irrigation, and drainage systems. Areas of concern include its adaptability to a range of building types (commercial spaces, high-rise buildings), construction methods (new or existing building walls) and types of surfaces (e.g., sloping surfaces, interior partition walls, and free-standing structures) (Manso & Castro-Gomes, 2015).

2.11.4 Supporting Elements

According to Manso and Castro-Gomes (2015), traditional or direct green façades depend on the climbing plants' ability to attach themselves to vertical walls without the use of any support system. However, these can become overly heavy with an increased risk of falling when it reaches full coverage. A support structure is typically used to prevent vegetation from falling from an indirect green façade which creates an air gap that enables it to function as a double skin façade (Ghaffarian et al., 2016). The indirect green façade system, which can be modular or continuous, secures and maintains the weight of the vegetation. Through the support, the system's resistance to environmental impacts (e.g., wind, rain, snow) is increased. The support structures contain continuous or modular guides, such as galvanized or stainless-steel cables, wires, or trellis (Radić et al., 2019). Moreover, steel constructions and tensile cables can be utilized to hold and support climbing plants with denser foliage. To support slow growing plants, grids, and wire net with reduced spacing between can be utilized (Lundholm, n.d.). Modular trellises, particularly in the indirect green façade system, include pots filled with substrate and separate support structures, allowing the elements to be suspended at varying heights along the wall, while a curving grid adds rhythm and three-dimensionality to the façade of new modular trellises (Shaikh et al., 2015). A frame to hold the elements and a plant support are frequently included in living walls, and the base panel is held in place as part of the installation, which protects the wall from humidity and in turn supports the next layer. Layers of permeable, flexible, and root-resistant screens are stapled to the base, and the external layer is split into pockets for the introduction of individual plants (Elgizawy, 2016). Continuous LWS can be directly attached to the wall or wall mounted installations with air gaps between the system and surface.

Modular LWS are applied in a variety of shapes and sizes, each requiring a unique structure (e.g., trays, jars, and planter tiles). Each module usually contains an interlocking system on its sides to connect to each other and ensure system continuity. Trays and vessels are attached to the vertical and horizontal surfaces, while the rear surface may have hooks or mounting brackets to enable suspension in the frame profiles attached to the vertical surface (Koumoudis, 2011). Multiple plants can be installed in each element along the same row in modular vessels. As a result of their form, they have a strong visual influence on the building surface and are made of polymeric material. Planter tiles are linked to each other by juxtaposition, and each has a flat back that is fastened to the building surface with an area where the plants are individually introduced. It can be made with lightweight or porous materials like plastic or ceramics (Taber, 2011), and tiles can be fixed with mechanical fasteners or glued to the vertical surface depending on the type of system (Deutsch-Aboulmahassine, 2009). Alternatively, a modular LWS can take the shape of elongated bags filled with growing media and constructed of flexible polymeric materials with cuts for plant insertion (Bilck et al., 2014). A modular LWS consists of lightweight parts that are easily assembled and attached to the vertical surface for the plant and growth media to be inserted.

2.11.5 Growing Media

According to Manso and Castro-Gomes (2015), only modular systems require growing media on green façades, which must be lightweight because each part will be suspended, and suitable for the selected plant species and environmental conditions. In comparison, a continuous LWS does not have a substrate; therefore, owing to the unavailability of substrate, a continuous LWS is primarily based on a hydroponic technique which necessitates a steady supply of water and nutrients. In these systems, plants are put into pockets on lightweight absorbent screens, and are grown without soil in hydroponic systems which use screens that are kept moist by an irrigation system. The lack of soil is compensated for by irrigation water, which provides the required nutrients for the plant's development (Manso & Castro-Gomes, 2015). A modular LWS contains growth media and can be used when weight is not an issue in the building, while a continuous LWS can be used when the building can support a reasonable amount of weight.

Furthermore, a modular LWS is typically filled with a growing media comprised of organic and inorganic growth media where roots can develop, or with an inorganic substrate, which is usually foam for weight reduction (Boby et al., 2020). To ensure a good capacity for water retention, most modular LWSs include a growth media based on a blend of light substrates with a granular substance that may be expandable or porous (e.g., mineral granules with medium to fine particles, coconut fibers, or recycled fabric) (Koumoudis, 2011). Plant development can be aided by adding nutrients to the substrate (e.g., mixture of organic and inorganic fertilizers, minerals, nutrients and hormones for plants or other additives) (Amaral et al., 2013). To prevent the detachment of growing media, some recommend the use of geotextile bags (Koumoudis, 2011). These bags can either fill the entire module and allow multiple plants to be inserted or used to cover the growing media of each individual plant. To prevent the growth material from falling, each plant can have its own front cover (Cheng et al., 2010). Geotextile bags are fitted into the modular LWS which is filled with either organic or inorganic growth media which allows excellent plant growth.

2.11.6 Vegetation

The choice of plants for vertical greening depends on the climate and purpose; however, plants within vertical greening must be sustainable (Francis et al., 2014). The selection of plants has a significant impact on the maintenance of a vertical greening (Stav, 2017), the climate, the building's characteristics, and the surrounding environment (Manso & Castro-Gomes, 2014). Resilient and durable species that can withstand the temperature, winds, and precipitation of the area are preferable for successful living walls. The selection of plants for vertical greening is also positively linked to growing substrates (Fernández-Cañero et al., 2018). The depth of the substrate determines the overall weight and cost of the vertical greening, and to some extent, it determines the water requirements and size of the plant. Although this can be achieved via a hydroponic method, species that typically grow in soil can be grown without a substrate. These are referred to as hydrophytes (plants that grow in water), epiphytes (plants that grow on other plants), and lithophytes (plants that grow on rocks) (Fernández-Cañero et al., 2018). In plant selection, the following considerations are important (Johnston et al., 2004):

1. Species that can do well in challenging situations;
2. Species not prone to pest infestation;
3. Species that are not prone to nutrient deficiency or toxicity;
4. Species with no weed potential.;
5. Species with minimum maintenance requirement**;**
6. Species must be aesthetically pleasing.

Selection not only ensures that the plants can thrive in the unique conditions provided by a living wall, but it also determines the wall's maintenance level and aesthetics (Stav, 2016). Vertical greening with climbing plants is seen as a low-cost option. The foliage of these plant species can either be evergreen or deciduous; plants that are evergreen keep their leaves all year and deciduous shed their leaves in the autumn, creating a dramatic visual contrast throughout the year. Root climbers and adhesive-suckers are examples of self-supporting climbing plants, while twining vines, leaf–stem climbers, leaf climbers, and scrambling plants are examples of climbing plants that require support (Sulaiman et al., 2018). Traditionally, vines were utilized to cover the exterior walls of small buildings in Germany and France, and in hot summer climates vines were also used to shade the building envelope on pergolas (Dunnet & Kingbury, 2008). However, there is a certain amount of growth restriction associated with climbing plants. Some species grow up to five to six meters in height, while others grow up to ten meters, and still others grow to be 25 meters tall; it takes three to five years to achieve full coverage (Gianoli, 2015).

Researchers in the Mediterranean Continental Climate examined the foliage density of numerous climbing plants, both perennials (Hereda Helix, Lonicera Japonica) and deciduous (Parthenocissus Quinquefolia, Clematissp) after one year of development (Perez et al., 2011). Parthenocissus Quinquefolia, often known as Virginia Creeper, had the densest foliage, although none of the species attained full coverage after a year. Difficulty adapting to climatic conditions, such as high temperatures and limited rainfall all year round, was observed among some species like clematis (Perez et al., 2011). The aesthetic concept of green walls is achievable with living walls, which allow the use of diverse species, pattern, colour, texture, and foliage density. For example, shrubs, grasses, and diverse perennials can be integrated provided their irrigation and nutrient needs are considered feasible. According to Wilkinson (2017) and Blanc (2021), the cultivation of a greater range of plants, including plants in various stages of development, cuttings, and seeds, is feasible with a hydroponic system. However, the desired aesthetic effect determines the selection of the vegetation (Koumoudis, 2011).

Plant development, colour, bloom, leaves, and overall plant composition in relation to the artistic aims of a particular structure should be critically examined. Vegetation must be adapted to the local exposure conditions (e.g., sun, semi-shade, or shade) and weather conditions to meet sustainability goals (Lundholm, 2006). Succulent carpets instead of perennials and shrubs have been the recent choice for modular LWS in green walls. Succulent species that are drought tolerant lessen the demand for irrigation and maintenance by reducing the overall weight of the system (Lundholm, 2006). Succulent carpets work well in compact spaces, giving the impression of a flat vegetated surface. Due to the range of colours and textures that perennials and shrubs can offer, they can be used to create more ornate landscapes on wider surfaces.

Specific shrubs can be employed on sloping surfaces, as demonstrated in a Japanese technique, which included Juniperus Chinensis, Juniperus Conferta, Euonymus Fortunei, Cotoneaster, Cotoneaster Horizontal, and Vitexrotundifolia (Luttenberg et al., 1993). The incorporation of vegetables and aromatic herbs in a continuous or modular LWS is a new concept, particularly in planters or vessels, which improves the system's functional potential for building users (Aucla, 2019). Green walls are perceived to offer potential for urban agriculture which would thereby reduce the environmental impact of food production and distribution, especially in cities with scarce ground space for cultivation. Succulent species which are drought tolerant and demand less irrigation are suitable for semi-arid regions which experience low annual rainfall and relatively high temperatures.

2.11.7 Drainage

Gravity is used to remove excess liquids from green walls (Ascione et al., 2020), and geotextiles are used in both continuous and modular LWS to facilitate drainage along the permeable membrane while inhibiting root proliferation. Modular trays take advantage of module and material overlap to optimize drainage and water reuse for the modules below. The bottom of a modular system can be concave, sloped, perforated, or composed of a porous or absorbent substance for better drainage (Musy et al., 2017). Other examples of vessels include the use of filter materials (e.g., inoculated sand or other techniques to purify rainwater, remove toxins and heavy metals) or a granular inert filler (e.g., expanded clay, expanded slate, gravel) which encourage drainage and root development (Blanco et al., 2018). For better aeration and the removal of excess moisture within the substrate, several modular systems include the insertion of grooves or holes on the sides and back of the modules (Radi´c et al., 2019).

2.11.8 Irrigation

To sustain healthy plant growth, irrigation is crucial and the use of minimal water. The amount is determined in part by the quality of the water deployed and the soil's retention ability (Manso & Castro-Gomes, 2019). Over-irrigation can lead some species to rot at the root level, resulting in the plant's death (Lee, 20, cited in Binabid, 2017). The type of system and climatic condition determines the irrigation requirements. There are various irrigation systems but the most suitable for the semi-arid region is the drip irrigation system. Drip irrigation complements other irrigation methods and is ideal for areas with marginal water quality, steep or poor-quality land, high water or labor costs, or high-value crops needing frequent watering. It is easily automated, making it useful where labor is scarce or costly. Drip irrigation allows frequent water application, creating favorable crop growth conditions. Unlike surface and sprinkler irrigation, drip systems wet only part of the soil root zone, typically around 30%. The wetting pattern depends on discharge and soil type. Drip irrigation does not reduce the water needs of crops but saves water by minimizing deep percolation, surface runoff, and soil evaporation. Its effectiveness relies on proper use by the operator.

To provide the necessary water for plant development, modular green façades, and LWS require irrigation systems, meanwhile irrigation water can be enriched with nutrients, fertilizers, minerals, phosphates, amino acids, or hydroponic materials to enhance the development of vegetation. A continuous irrigation tube installed at the top of the building supplies water for a LWS. The permeable screen in a continuous LWS facilitates the homogeneous dispersion of water and nutrients over the surface. The irrigation tube is inserted into a recess on the top façade of some modular LWSs which take the form of trays. Several holesin the recesses of trays allow gravity to wet the growth media, and excess water is able to irrigate the modules beneath the trays through drainage holes at the bottom (Blanusa & Vaz Monteiro, 2018). Irrigation tubes and connectors are available in a variety of materials (e.g., rubber, plastics, piping thermoplastic, silicone, and irrigation hose) and adopt a variety of outputs (e.g., drip, sprinkler, holes, and pipe) with distribution and intensity tailored to the plants' irrigation requirements. To avoid clogging, the irrigation system can also include a filter system, and some vertical greeening suggest measures for reducing the amount of treated water utilized. Some of the options available include rainwater recovery from building roofs, the reuse of fluid collected in drainage systems, and the monitoring of water supply needs through the installation of sensors that control the collecting water tank level, irrigation time, and weather conditions (e.g., quantity of rainfall, humidity, temperature, atmospheric pressure) (Koumoudis, 2011). Modular and continuous LWS allow for the installation of gutters at the base of the system', which collects and stores surplus water for reintroduction to the irrigation system. The use of sensors to measure nutrient requirements in the growth medium is another crucial technique for minimizing nutrient use and matching the needs of the plant (Bribach, 2011). Irrigation is an important part of the

LWS, and the most suitable technique should be employed, which should consider water storage to avoid over- and under-irrigation (Nikalaoua et al, 2020).

2.12 Installation and Maintenance

The maintenance levels of vertical greening are categorised from extensive to intensive, while Ottele et al. (2011), Perini & Rosasco (2013) and Wood et al. (2014) have argued that the expense of installation and maintenance are the focus of some articles in academic and commercial research. Categorisation could be determined by the frequency or complexity of maintaining a vertical greening, which includes its watering frequency, fertilization methods, and plant selection (Stav, 2017). Green façades, which include climbing plants, are less expensive to install but offer a restricted choice of plants (Manso & Castro-Gomes, 2015), and struggle to maintain vegetation continuity in the case of plant replacement. Some climbing plants require direction during their growth to ensure entire surface coverage. It is also worth noting that some climbing plants can damage the surface of a building with their roots and infiltration of voids or gaps (Djedjig et al., 2017).

A comparison of continuous guides on installation and maintenance procedures indicates that modular trellises have advantages; for example, planting at various heights reduces the influence of dispersed climbing plant growth along the surface and allows for the replacement of failing plants (Santi et al., 2019). To reduce issues with installation, maintenance, and replacement, a growing number of modular LWS are appearing on the market. Some modular systems allow for individual module disassembly or feature a movable front cover for wall maintenance or vegetation replacement (Lee & Jim, 2017). In addition, some modular pieces can be nested into each other to make transportation and application operations easier (Serra et al., 2017).

Compared to modular LWS, a continuous LWS allows for the production of lighter vegetated surfaces with a greater diversity of plant species and a density of around 30 plants per square meter (Manso & Castro-Gomes, 2015). However, hydroponic systems are designed to have a continuous supply of water and nutrients, which pose challenges to sustainability and incur increased maintenance costs due to their irrigation requirements. Based on their aesthetic potential, cost, and maintenance requirements each green wall system has its distinct characteristics with benefits and drawbacks (Sattler et al., 2008). It is vital to understand their differences in composition and their main characteristics because the most appropriate system is determined by the building's attributes (e.g., orientation, accessibility, and height) as well as the climatic conditions (e.g., sun, shade and wind exposure, rainfall). When considering plant type and maintenance requirements, the installation and maintenance of green walls can range from extensive to intensive although green façades incur the lowest cost.

2.13 Environmental Performance and Costs

Researchers have conducted various studies to analyze the environmental performance of different green wall systems during their whole lifecycle to better understand if they are sustainable solutions (Perini, 2011). Direct green façades offer a more environmentally friendly and cost-effective approach since there are no materials involved and thus require minimal maintenance, meaning these systems have a low environmental impact (Davis et al., 2016). However, sustainability may be a challenge when analyzing the lifecycle of some LWS (Sheweka & Mohamed, 2012). The kind of materials utilized, their durability, recycling potential, vegetation durability, and water consumption can all have a significant environmental impact (Perini et al., 2012). A lower impact is envisaged by using recycled materials, for example High-Density Polyethylene (HDPE), hardwood with a Forest Stewardship Council (FSC) certificate, or coated steel rather than stainless steel support systems (Ottelé et al., 2011).

Material durability is a crucial issue as some materials require replacement multiple times in the lifecycle of a building (Serra et al., 2017). Although green wall systems often use materials that have a high environmental impact, this can be reduced by adding to the wall's thermal resistance, resulting in lower energy consumption for heating and cooling (Ottelé et al., 2011). The price of green wall systems is another factor to consider when planning (Perini et al., 2012). Green façades, both direct and indirect, are less expensive than LWS, and the cost of modular green façades varies depending on the materials used. The HDPE system is much cheaper than galvanized steel; furthermore, the prices of vertical greening are also heavily influenced by the system's complexity and the materials utilized. This includes the application technique in terms of the surface dimension and accessibility and the maintenance requirements such as irrigation, nutrients, and plant replacement (Ottelé, 2011). Improving the performance of modern green wall systems can lead to an increase in their application in buildings and, as a result, reduce costs. The environmental impact of its components, such as the energy or water used and material recyclability, alongside the associated costs over its entire lifecycle, and the construction, and climatic constraints, should determine the most suitable green wall system for a project (Manso & Castro-Gomes, 2015).

2.14 Benefits of Vertical Greening

In the twenty first century, the use of vertical greening is becoming popular due to their impact on buildings' interior and exterior temperatures (Perini et al., 2011). Many studies have acknowledged a substantial rise in urban greening due to its importance (Anguluri & Narayanan, 2017; Castiglia Feitosa & Wilkinson, 2018; Charoenkit & Yiemwattana, 2016; Loh & Stav, 2008). Living walls offer a creative and exciting way to improve green infrastructure in cities where green areas are scarce and open ground space is minimal (Anguluri & Narayanan, 2017). Indeed, current literature refers to the aesthetic, ecological, social, and economic advantges of vertical greeningsystems (Zaid et al., 2018; Virtudes & Manso, 2016).

The advantages of vertical greening cover a wide range of disciplines and act on different scales (Sheweka & Magdy, 2011). The benefits of vegetation are only appreciated at the neighborhood level if a considerable area of the same region is also covered with vegetation. However, other benefits are appreciated at the building scale (Rakhshandehroo et al., 2015); such benefits are determined by factors such as foliage thickness, water content, and probable air cavities among the layers. (Perini et al., 2013). The potential benefits of vertical greening are numerous, and include reduced building energy use, air filtration, aesthetically beautifying the urban landscape, raising property prices, and extending the wall surface life. Sound reduction and potential carbon dioxide absorption are also recognized environmental benefits (Perini, 2011), while benefits of green roofs that may also be applicable to living walls including storm water reduction, improved runoff quality, food production, fire prevention, and enhanced biodiversity (Stav, 2016). The depth of the growth media, overall coverage, and materials used as structures and components of the vertical greening are three aspects that determine the potential for noise reduction (Chau et al., 2010). The most important goal of living wall design is to improve aesthetics. Urban streets with dull façades, enormous parking structures, public park walls, university buildings, retail buildings, and transit shelters offer opportunities to visually vary the building envelope by incorporating living walls (Sutton, 2014). Moreover, cooling buildings in hot climates by offering shade, increasing the quantity of exterior wall insulation, evaporating moisture from the growing substrate, and transpiring moisture from leaf surfaces are additional benefits of vertical greening systems (Chen et al., 2013).

2.15 Environmental Benefits

The presence of plants on vertical walls offer shading to buildings which is determined by the density of plant in the vertical greening system (Djedjig et al., 2015; Raji et al., 2015), meaning the temperature is often lower both in shaded buildings and in the surrounding area. Decreases in temperature have an impact on the building and the urban environment (Raji et al., 2015), although the shading and evaporative cooling provided by plants has been lost in cities due to the replacement of green surfaces with paved impermeable surfaces. As a result, heat is reflected from such surfaces and accumulated as urban heat island (UHI) (Koyama et al., 2013). Therefore, Anguluri & Narayanan (2017) acknowledged that vertical greening has a role in temperature reduction in cities, meaning that it offers a positive strategy to neutralise the effect of UHI.

According to Stec et al. (2005), the first simulation-based study for vertical gardens was a model with a double-skin façade that included plants that utilized the characteristics of real plants in a test facility; a 19% reduction on cooling energy use was observed due to the shading it provided. A simulation of energy transfer and UHI reduction by vertical vegetation in a tropical climate revealed that the full coverage of a building with vertical vegetation can significantly reduce the thermal transfer value of the building envelope and that the efficiency of the related thermal transfer reduction is heavily dependent on the vegetation's Leaf Area Index (LAI) (Wong et al., 2009). The widely recognised environmental advantage of plants has been observed through their ability to enhance air quality by filtering airborne particles and pollutants in their leaves and branches, and absorbing gaseous pollutants through photosynthesis (Loh, 2008). In addition, biodiversity enhances the ecological quality of an area, offering humans additional social, physical, intellectual, and emotional benefits (Johnston et al., 2004). Plants add oxygen to the atmosphere through photosynthesis which takes in carbon dioxide, while impurities in ground water are filtered by plants roots prior to draining into the aquifer. The quantity of impurities in the soil is minimized when plants take up nitrogen and phosphorus for plant growth (Johnston et al., 2004). Plants can serve as buffer in the city shielding varying noises thereby reducing noise pollution (Yenneti et al., 2020), which Perini et al. (2017) stated is adaptable to vertical greening systems. In green walls, sound frequencies are absorbed by plants (Dunnet & Kingsbury, 2008), while Charoenkit and Yiemwattana (2017) acknowledged the ability of living walls to sequester carbon by converting it into carbon, hydrates and oxygen. Thus, living walls can help improve the environment and establish urban ecosystems which offer a variety of ecosystem benefits.

2.16 Thermal Benefits of Vertical Greening

According to Walikewitz et al. (2015), there is a significant environmental risk to human health from heat stress which is mostly due to UHI. Vertical greening have a high potential to minimise UHI problems by reducing wall temperatures due to shading and evapotranspiration (Victorero et al., 2015). In a Singapore study, the thermal impact of eight different vertical greening systems discovered that vertical gardens reduced the surface temperature of building façades in a tropical climate by up to 11.58 °C (Wong et al., 2010). Additionally, Cheng et al. (2010) stated that by delaying the transfer of solar heat, vertical gardens were found to reduce interior temperatures by up to 14.5 °C in subtropical Hong Kong. Similarly, in a Malaysian study of green façades and living walls, temperature reduction was also observed, (Jaafar et al., 2013). Furthermore, a model for evaluating the heat flux transmission of vertical greening systems developed and tested in Hong Kong revealed that vertical greening absorb a considerable amount of heat flux due to evapotranspiration (Jim & He, 2011). Such studies indicate the ability of vertical greening to improve human thermal comfort.

Green façades, on the other hand, have been demonstrated to produce a microclimate between the wall and vegetation, with somewhat lower temperatures and higher humidity (Perez et al., 2011). Numerous studies from the Mediterranean climate indicated a reduction in temperature when comparing bare walls and those covered with green façades (Eumorfopoulou & Kontoleon, 2009) suggesting that the internal surface of the wall has a cooling effect of 0.9 °C on average during the summer. Additionally, Mazzali et al. (2013) found that on hot summer days in a temperate Mediterranean region, living walls can reduce external wall surface temperatures by up to 20 degrees Celsius, while another study researched the impact of orientation and the percentage coverage of vertical greening in a Mediterranean region, establishing that adequately vegetation-covered walls, particularly on east and west facing walls, improve building energy efficiency (Kontoleon & Eumorfopoulou, 2010).

According to research that evaluated different living wall systems, green façades cool less effectively than living walls with a substrate layer (Perini et al., 2011; Wong et al., 2010). Green roofs and other forms of urban vegetation have been shown to be effective in reducing UHI on a wider scale. (Köhler et al., 2003). Conclusively, living walls have been demonstrated to significantly lower building energy consumption and moderate the urban heat island effect. Moreover, numerous studies have considered the impact of varying parameters of living wall designs (such as wall aspect, wall coverage, plant species selection, growth substrate material and geometry, water availability, etc.) on thermal impact.

2.17 Using Vertical Greening to Improve Air Quality

Toxic gases and microscopic particles can be absorbed into the leaves by vegetation via the stomata, and particulate matter can be deposited on the exterior layers of leaves, trunks and twigs (Beecham et al., 2018). The accumulation of particulate matter is enhanced by certain plant species (e.g., those with hair and wax coating) (Appuhamillage, 2018). For example, an exterior green façade has been the subject of research in Berlin, which included a 10-year trial that showed considerable improvements in the interior air quality (Köhler et al., 1993). Recent research that focused on fine dust particles revealed that vertical vegetation generates sinks that trap "large quantities of health-damaging particles from the atmosphere" notably particulate matter (Ottele et al., 2010). Studying air quality at the street level found that living walls can reduce particulate matter (PM_{10}) concentrations by up to 60% and Nitrogen Dioxide (NO_2) concentrations by up to 40% (Pugh et al., 2012). PM_{10} is a common air pollutant and is defined as very small particles found in dust and smoke, with a diameter of 10 micrometers (0.01 mm) or smaller. Nitrogen dioxide (NO_2) is one of a group of gases that largely appear as a result of diesel cars. Nitrogen dioxide also reacts with hydrocarbons in the presence of sunlight to create ozone and contributes to the formation of particles (Chaparro-Suarez et al., 2011). The presence and impact on such particulate matter indicates that with the inclusion of living walls in urban areas can reduce air pollution.

Social Benefits

Visual and physical contact with plants has been proven to have beneficial effects (Williams et al., 2019). Plants can serve a variety of purposes including the provision of avenues for sports and relaxation, opportunities for social interaction, and an escape from city life (Sadeghian, 2016). Moreover, plants can offer health benefits that relieve stress, improve patient recovery rates, and increase resistance to illness. The benefits of vertical greening also include noise reduction, the filtering of airborne dust and pollutants (Ottele et al., 2010) and temperature reductions around the vicinity (Wong et al., 2010), thereby making the environment more conducive for social interaction.

The most obvious goal of vertical greening design is aesthetic improvement. Urban streets with monotonous façades and extensive vertical surfaces in cities offer opportunities to enhance the building envelope by incorporating natural design principles (Rakhshandehroo, 2016). Thus, including vertical greening into buildings helps to introduce landscape aesthetics (Hunter et al., 2014), as vertical greening can offer a variety of pleasant natural views. They offer opportunities to address stress-related symptoms and can support a faster recovery by exposure to natural, pleasant visual scenery (Ulrich et al., 1991). In addition, while highly reflective surfaces pose a health risk, since high prolonged glare harm the eyesight (Mediastika & Binarti, 2004), vegetation helps to reduce glare by blocking sunlight and thereby the controlling light intensity (Medl et al., 2017), which implies that natural scenery can positively affect human well-being.

2.18 Contribution to a Better Quality of Life

The therapeutic effects of greenery and nature have been studied since the 1980s. It has been shown that hospitalized patients were able to recover faster, and that improvements to psychological and psycho-physiological health were possible through the lowering of blood pressure and increased happy feelings (Yenneti et al., 2020). Recent studies have suggested that people generally prefer a view of a natural settings than a congested or cluttered built environment (Veitch & Canada, 2014). A glimpse of gardens and green vegetation is also said to restore calm and relieve tension (Velarde et al., 2007), and access to nature in the workplace promotes worker contentment, excitement, and attention, and minimizes frustration. The presence of living walls creates a reconnection between workers and biophysical vegetation, which can enhance productivity and reduce sick days (Hopkins &

Goodwin, 2011). The findings of urban study initiatives support the premise that people's exposure to natural elements improves their ability to focus, cope with stress, develop creative ideas, and reduce volatility (Banting et al., 2005). Several studies has shown that landscaping has a favourable impact on both commercial and residential property rental rates, while between 3.5% and 4.5% increases in property prices was associated with the presence of trees. Specifically, Sander et al. (2010) found that trees were found to relate to a 2 to 35% rise in property sales prices in the United States. In addition, an extensive review of the perceived relationship between green infrastructure and ecosystem health on human health and wellbeing found that green space contributes to increased longevity, better self-reported health, improved attention-demanding cognitive performance, increased positive emotions, increased recovery from stress, and decreased mentalism (Tzoulas et al., 2007). According to a perceptive study, buildings with green roofs and walls (and green façades in particular) are often preferred to buildings without greenery, as residences with green roofs and/or vertical greening were seen as more attractive and therapeutic (Ninla et al., 2014). Moreover, green views and the presence of vegetation are proven to provide positive benefits, while vertical greening have the potential to provide a plethora of impacts that are beneficial to human health and well-being. However, there is little research that directly establishes these advantages of vertical greening.

2.19 Vertical Greening and Increased Biodiversity

Some research focuses on urban green roofs that provide habitats for various plant, bird, and insect populations (Fernández-Cañero et al., 2018). According to recent findings, green roofs and living walls may function as reconciliation ecology in which the anthropogenic environment may be transformed to support nonhuman use and biodiversity preservation without jeopardizing societal utilization (Francis & Lorimer, 2011). A growing number of studies have considered living walls as a potential habitat and an initiative to promote urban biodiversity. It has been suggested that applying ecological engineering principles to vertical greening systems may enhance their capacity to function as habitats and that they may also be utilized to integrate urban ecosystems with green roofs (Francis & Lorimer, 2011).

One of the most essential design decisions when establishing a vertical greening is the choice of plants. Selecting plants that can thrive and spread on the substrate, usually a shallow layer of substrate, is the first step to creating a vertical greening (Mårtensson et al., 2014). The diversification of plant species is another way to effectively utilize available resources (Lundholm, 2006), while according to recent research in the UK, green façades may offer a variety of resources for birds in urban settings without incurring costly land acquisitions (Sheweka & Mohamed, 2012). This highlights the growing evidence that vertical greening can improve urban ecology and biodiversity by providing habitats for plants and animals.

2.20 Vertical Greenings' Hydrological Benefits

Thuring et al. (2010) found that green roofs can postpone peak stormwater flow and retain a considerable portion of the runoff (19% to 98%) and stated that this is influenced greatly by the thickness of the green roof substrate layer. According to hydrological modeling research, urban green roofs can replicate the water cycle's interception and evapotranspiration in less disturbed ecosystems (Lamera et al., 2014). Some green roofs have been observed to retain practically all rainfall during light and medium rain events and delay peak flow during severe rain events. A study on the moderation of stormwater runoff through the use of green retaining walls has shown that they can significantly reduce runoff (Ostendorf et al., 2011). Green retaining walls may reduce stormwater runoff in a similar way to other green technologies, such as green roofs, bioswales or pervious pavement. It encourages interception, infiltration, and evapotranspiration while also cooling and shading the adjacent urban microclimate (Ostendorf et al., 2011). It also emphasizes the significance of plant selection and, more crucially, the growing medium. Verical greening projects identified the use of grey water for irrigation, allowing the vertical greening to play a positive and active role in sensitive water management in urban environments (Loh & Stav, 2008). Conclusively, it can be said that green walls, like green roofs, have positive effect on urban hydrology but due to the vertical orientation and thickness of the substrate layer they are projected to have a different impact on urban hydrology compared to green roofs.

2.21 Attenuation of Noise by Vertical Greenin

Living vegetation and substrate materials can act as a sound-absorbing layer due to their acoustic properties; for example, Wong et al. (2010) indicated that the substrate of living wall systems plays a vital role, even though vegetation cover enhances sound absorption. Vegetation is good for high frequency absorption whilst the substrate performs well for low frequency absorption (Rakhshandehroo et al., 2015). Coma et al. (2014) and Wong et al. (2010) verified the boost to noise reduction by plants through sound absorption, diffraction and reflection, which further supports their sound insulation abilities. Thus, it may be concluded that a thicker layer of substrate improves the noise reduction of living walls.

2.21 Vertical Greeening Protection of Building Façades

A vertical greening system can extend the life of a building's exterior by protecting it from severe rain and hail, as well as UV radiation (Ottele et al., 2011). The mechanical characteristics of coatings, paints, and claddings are harmed by ultraviolet light (Hare, 1992). However, a green façade has been shown to block approximately 80% of solar radiation from reaching the wall's surface (Blanco et al., 2018). Thus, in addition to reducing the risk of damage to the building envelope, vertical greening extend the building envelope's lifespan and lower its maintenance expenses (Susorova et al., 2013). Vertical greening act as an extra external layer that protects the façade from a variety of physical environmental effects. Its usage extends a building's life, reduces climatic stress on the building's façades, and reduces costs associated with painting (Radić et al., 2019). Wong (2006) explained that a building's life expectancy is extended by slowing down the rate of wear and tear and reducing the need to repair façade parts by controlling the diurnal fluctuations in wall surface temperatures. Haggag (2010) added that if waterproof panels are employed and separated by a layer of air, vertical greening can indeed extend the life of existing façades by protecting them from wind, solar radiation, and rain, allowing moisture to escape, and contributing to the decrease of expansion and contraction of building materials.

2.22 Aesthetics of Vertical Greening

Vertical greening have immense potential as public art; according to Perini and Rosasco (2016), they offer more creative potential by enhancing the façades' aesthetical appeal. The visual impact is primarily determined by the plant density of the wall coverage (Fernández-Cañero et al., 2018). Typically, vertical greening attain a high percentage coverage with a variety of plants that enhance their aesthetic appeal. When the primary material is felt, vertical greening can be designed in a variety of shapes (Fernández-Cañero et al., 2018). Recently, new varieties of vertical greening with additional design options have been introduced to the market (Tamási & Dobszay, 2016). According to Meral et al. (2018), vertical greening are positively rated by people for their visual perceptions, which are based on criteria such as plant diversity, naturalness, colorfulness, complexity, and color vibrancy. According to White & Gatersleben (2011), buildings with greenery are considered more desirable, beautiful, restorative, and have a higher positive affective quality than those without. Indeed, a recent assessment of passersby's perceptions of vertical greening found that most viewed them as aesthetically pleasing (Radi´c, et al., 2019). In summary, vertical greening offer a great degree of coverage with a diverse variety of species which enables them to be vibrant and take on various shapes and forms, offering natural beauty which is considered pleasing.

2.23 Educational Impact of Vertical Greening

The visual impact of vertical greening can create a lasting impression on viewers while also raising awareness about the importance of ecology (Galagoda et al., 2018). Vertical greening can be utilized as tools for ecological observation, producing plants and vegetables, and protecting a building (Mayrand et al., 2018). Students in biology or art programs in schools or nature education institutions might consider the development of vertical greening. Barcelona School’s vertical garden project is among the various examples of VGSs erected around the world, particularly in schools (Radi´c et al., 2019). According to Sheweka & Magdy (2011), green roofs and walls offer] ideal tools for teaching students about the environment. Brkovĭ c (2013) added that using green roofs and vertical greening in school architecture can make the building more sustainable and serve as 3D sustainability textbooks, for example Sottevilleles Rouen High School in France and the School of Art, Design, and Media at Nanyang University in Singapore are models of good practice in this respect (Stav, 2016). However, very little research has been conducted to directly establish these advantages of vertical greening. It is also suggested that exposure to natural environments encourages involuntary attention, as such initiatives offer opportunities for short breaks from the learning environment which enable a reset and redirected attention (Kaplan, 1995). According to McCullough et al. (2018), incorporating internal living walls in classrooms through a combination of project-based learning methodologies and environmental education could stimulate critical thinking. Nevertheless, data is not widely available on the impact of vertical greening on education although living walls suggest a promising impact.

2.24 Economic Benefits

The environmental impact of the vertical greening is strongly connected to economic benefits (Yenneti et al., 2020). Plants installed around buildings can improve overall structural integrity by minimizing weather impacts (Sadeghian, 2016). Vertical greening can minimize climatic stress on building façades, prolong the building's lifecycle, and save costs on painting materials (Johnston & Newton, 1996). Studies have also indicated a reduction in heating costs in winter and a reduction in cooling costs in summer (Huang et al., 2019), thus greenery in cities contributes significantly to energy savings, which is a considerable economic benefit. The economic sustainability of vertical greening was evaluated by Perini and Rosasco, (2016) through a cost-benefit analysis. The cost saving items considered included: air quality improvements, carbon reduction, energy demand reduction (for heating and cooling), increased lifespan of the building envelope, and an increase in property value (Huang et al., 2019).

Furthermore, Wong et al. (2010) asserted that vertical greening prolong the lifespan of building façades and slow down wear and tear. They also enable cost savings in the maintenance and replacement of façade parts due to their capacity to limit the temperature fluctuations of wall surfaces. Furthermore, Bentsen et al. (2010) and Radić et al. (2019) affirmed that vertical greening increase real estate value by 6-15%. A variety of vertical greening systems were compared for their economic sustainability by Perini and Rosasco (2016) and a variety of living walls and green façades were compared, as follows:

a. Two-layer geotextile;
b. Mat based green wall system with an aggregate mix, a variety of vertical greening systems comprising:

i. A direct green façade,
ii. An indirect green façade supported by high-density polyethylene HDPE (plastic mesh),
iii. An indirect green façade supported by a steel mesh,
iv. An indirect green façade integrated with HDPE planter boxes, and
v. An indirect green façade combined with steel planter boxes.

Direct green façade is the only vertical greening system that is economically sustainable due to its economy in all the assumed scenarios. Minimal installation, maintenance, and disposal costs incurred compared to the high installation and maintenance costs due to other supporting systems, particularly steel mesh (Perini & Rosasco, 2016). Thus, a living wall design is costly but offers ample benefits. However, with research into the field of vertical greening more affordable options can be identified.

2.25 Vertical Greening for Urban Agriculture

Urban agriculture is the production of agricultural products in urban and peri-urban areas (Lee-Smith et al., 2019). As a form of urban agriculture, living walls have another obvious benefit, as their vertical aspect can be used to cultivate a variety of crops in areas where land is scarce (Utami et al., 2012). The focus in this context would be horticulture, namely the cultivation of vegetables, fruits, medicinal, and ornamental plants. According to research on urban agriculture's influence on the environment, the growth of urban agriculture could greatly help to minimize the urban ecological footprint (Dubbeling et al., 2009). The benefits of urban agriculture and its potential contribution to sustainability, as well as the consequences of incorporating urban agriculture into urban planning and land-use policies, have recently been considered by developed nations (Specht et al., 2013). The benefits of urban agriculture encompass improved food security, enhanced food quality, recreational opportunities, strengthened community values, improved urban soil, water and waste management, and a reduction in food miles (Artmann & Sartison, 2018). Some instances of the use of existing green roofs for urban agriculture include the roof garden at the Fairmont Hotel in Vancouver, Canada, and Earth Pledge's green roof in New York City (Stav, 2017). Only anecdotal references to food-producing living wall projects exist despite the multiplicity of benefits derived from urban agriculture and the growing trend to use green roofs for agricultural purposes (Wood et al., 2014). However, the benefits of vertical greening constructed for urban agriculture include boosting access to fresh food, minimizing the environmental impact of the traditional food system, and enhancing community connections.

2.26 Importance of Living Walls in Achieving Net Zero Energy Building

Vertical greening plays a crucial role in the semi-arid region of Nigeria when it comes to sustainable building practices, particularly in achieving Net Zero Energy Buildings (NZEBs). The UK Green Building Council (UKGBC) defines NZEB as a building that, over its entire life cycle, including disposal, produces zero or negative greenhouse gas (GHG) emissions from both operational and embodied footprints (UKGBC, 2019; Twinn et al., 2019). The UKGBC is currently reviewing this comprehensive approach, which involves a tiered strategy that prioritises eliminating embodied emissions before achieving net-zero carbon for operational energy. The primary objective is to achieve a state where the building's total carbon emissions over its lifespan are reduced to zero (Tirelli & Besana, 2023). Vertical greening, the practice of incorporating vegetation on the exteriors of buildings, is especially advantageous in semi-arid areas such as Nigeria. It improves the energy efficiency of buildings by offering natural insulation, thereby decreasing the requirement for artificial cooling and heating. Shirinbakhsh and Harvey (2021) define NZEBs as buildings producing and exporting emission-free renewable energy to compensate for their yearly operational emissions. Vertical gardens can mitigate the urban heat island effect by lowering ambient temperatures and improving air quality. As a result, the energy consumption needed for cooling can be reduced. Feng et al. (2019) propose that attaining NZEB (Net Zero Energy Building) status is more attainable in regions with low-carbon energy networks. By incorporating vertical greening into Nigeria's energy infrastructure, the country can decrease its reliance on external energy sources by utilising natural mechanisms for regulating temperature and purifying air. In addition, Cohen et al. (2021) contend that buildings located in countries with well-developed carbon capture, utilisation, and storage (CCUS) infrastructure can effectively attain a state of "net zero" energy consumption. While Nigeria currently lacks a comprehensive CCUS infrastructure, implementing vertical greening can be an immediate and practical approach to reduce greenhouse gas emissions and improve the sustainability of buildings. Studies have shown that NZEBs, or Net Zero Energy Buildings, can meet their own water and energy needs and are built using environmentally friendly materials (Jaysawal et al., 2022; Hossaini et al., 2018). Vertical greening in semi-arid regions can enhance water efficiency by integrating rainwater harvesting systems and minimising stormwater runoff. In addition, Satola et al. (2021) propose a classification system that takes into account energy consumption, greenhouse gas (GHG) emissions, and carbon dioxide (CO2) emissions, emphasising the significance of sustainable practices. Kilkis (2022) highlights that the existing interpretations of NZEB (Net Zero Energy Buildings) may not be sufficient to achieve long-term decarbonisation goals unless the impact of energy wastage is recognised as a significant source of emissions. Vertical greening in this context can significantly contribute to reducing energy waste by providing natural cooling and shading, thereby decreasing the building's overall carbon footprint. The study demonstrates a noteworthy decrease in carbon emissions by deliberately substituting specific components, emphasising the necessity for inventive strategies such as vertical greening to attain genuine carbon neutrality. To summarise, vertical greening is essential for promoting Net Zero Energy Buildings (NZEBs) in semi-arid areas such as Nigeria. It offers inherent thermal insulation, decreases energy usage, and improves sustainability by utilising natural processes. Introducing vertical greening can make a substantial impact in attaining net-zero carbon emissions and enhancing the overall environmental quality in these areas.

2.26 Chapter Summary

This chapter has described the semi-arid region and the alteration of natural surfaces which has resulted in increased urban heat and contributed to the warming of the climate. This change has resulted in environmental degradation, meaning that the natural resources, ecological structure, and regenerative processes that humans depend on need to be sustained. Nevertheless, a balance must be attained between environmental conservation and human development. The implementation of sustainability strategies can reduce this environmental degradation, and one of these strategies is the Urban Green System which introduces nature to the urban environment. Green walls are one technique within this strategy which allows for the integration of vegetation into dense urban areas.

The chapter has outlined the benefits of vertical greening, although the findings are not particularly balanced as limited research has been conducted and only concentrates on certain areas. Integrating vegetation into architecture is recognized for its environmental benefits, particularly in mitigating the effect of climate change such as Urban Heat Island (UHI). Effective mitigation strategies include green infrastructure and reflective materials on surfaces. Green infrastructure enhance these strategies, with VGS addressing limitations of green spaces. Accurate life cycle assessments (LCA) are needed to optimize VGS's environmental impact, considering the aforementioned benefits. Although further research is required to determined its impact compared to other sustainable green infrastructure measures in combating the effect of climate change such as UHI.

The amount of information available on the thermal benefits of vertical greening is significant but information on the mitigation of urban heat islands at the city level seems scarce compared to that at the building level. Furthermore, there is substantial research regarding the ability of vertical greening to improve indoor air quality while other vertical greening benefits are relatively unknown and mostly based on research linked to green roofs and types of plants. In addition, the contribution of vertical greeening to human well-being, including psychological and health advantages, is predicted to be comparable to those of other green spaces in the city. It is uncertain, however, if the vertical orientation of vertical greening can enhance these benefits. Nevertheless, growing food in cities is a relatively new technique, and the vertical orientation of vertical greening may have an impact on their usability and productivity. If vertical greening can be employed for urban agriculture, the benefits should be similar to those of other urban agricultural applications.

Thus, vertical greening are predicted to have a similar impact on urban ecology and biodiversity as green roofs, since they increase the number of desperately needed green spaces in cities. Vertical greening can cover enormous vertical surfaces in congested cities and establish ecologically essential links between green roofs, ground-level parks and brownfield areas. Despite the limited amount of experimental data on vertical greening, it is plausible to assume that existing knowledge about green roofs may be transferred to vertical greening in terms of noise reduction and façade protection. The current understanding of their hydrological effects is limited, but vertical greening are thought to assist filter stormwater runoff and moderate peak flow, making them an important component of water-sensitive urban design schemes. However, for the optimal performance of vertical greening, their location must be carefully considered.

CHAPTER 3: THEORETICAL FRAMEWORK

3.1 Introduction

The third chapter discusses the theoretical framework and reviews pertinent theories for the research. With reference to theories from the fields of sustainability, ecology, horticulture, and social/behavioral sciences, the chapter addresses the integration of vertical greening within buildings in semi-arid regions, specifically considering the concept of sustainability and the human environmental system.

This chapter offers an insight into theories related to the study and the theoretical framework developed. It discusses the physical, social, and psychological approaches to mitigate climate change and further explains the concepts of sustainability, environmental sustainability, human-environment interaction and their impacts on the microclimate (including the mitigation of climate change). Furthermore, the chapter highlights humans' responsibility for the sustainability of the human-environment system by examining the radical transformation brought about by adaptation and innovation that has led to the concept of sustainable development.

The chapter also discusses: pro-environmental behaviour in the theory of planned behaviour; the concept of environmentally literate citizens, as described in the environmental citizenship model; the impact of human activities on the environment, as highlighted in the model of human interaction; how human value affects environmental behaviour, as captured in Value Belief Norm (VBN) Theory, and how it can affect the integration of sustainable strategies, such as vertical greening. These theories provide information about the causes and impacts of climate change as well as viable strategies to mitigate the effects.

3.2 Theories, Theoretical Frameworks, and Models of Natural and Built Environment Interactions.

Theory is a collection of interconnected ideas (concepts), definitions, and hypotheses that gives a systematic view of phenomena by establishing relationships between variables to explain and predict the phenomena (Kerlinger & Lee, 2000). Applying behavioural models and theories can be a valuable strategy to understand the patterns, connections, and root causes of climate change. According to Swanson & Chermack (2013), theories are the result of repeated observations and tests, and include widely acknowledged facts like predictions, laws, and tested assumptions. Theories comprise concepts and are implemented using models; moreover, they are well-established principles which have been developed to elucidate dimensions of the natural world (Akintunde, 2017). In addition, a theoretical framework provides a platform to present the theory of a research study; thus, it describes a theory that explains why a research problem exists (Swanson & Chermack, 2013). Furthermore, a model is a plan for action that universally describes what happens. Models are used to describe how theories are applied in a specific situation. Thus, theories are well-known facts and proven assumptions while models are a plan of action that universally describe what happens and why (Nilsen, 2015).

3.3 Environmental Sustainability Theory

Throughout history, humans have relied on nature as the environment provides a home for humans and a plethora of other organisms (Inglis, 2008). However, their demands have compelled humans to evolve survival and adaptation strategies which have impacted the surrounding environment. Crucially, the economic and social well-being of humans is intertwined with the well-being of the environment. Thus, Wall (1991, cited in Inglis, 2008) states the emergence of human-environment studies seeks answers to existing environmental concerns, and recognizes that for an environment to be sustainable, anthropogenic activities that negatively affect it must be balanced with those creating a positive impact. Moreover, a range of theories offer ideas on how the implementation of vertical greening can mitigate the impact of climate change in semi-arid regions. Sustainability is a multi-context concept with different meanings which are associated with different practices at different times, in different locations, by different characters (Pfister et al., 2016). Although sustainability is defined as the capacity to maintain a process over time, the concept indicates the reciprocal consequences of environmental degradation caused by human activities and the threats caused by global environmental problems to human systems (Selwyn, 2010). Problems such as the loss of biodiversity and climate change highlight the global scope of influences on humanity and the magnitude of the threat. Climate change and global warming have increasingly dominated the discussion on sustainability since the mid-1980s, while the principle of sustainability has become a global standard that a vast number of individuals and organizations around the world embrace (Pfister et al., 2016). Additionally, the concept has been co-opted within a political agenda by international organizations, and by national, regional, and local governments who have developed strategies and practices for implementation. Indeed, the inclusive scope and prospective vision of the sustainability ideology makes it absorptive and politically popular (Selwyn, 2010). As such, reform across many human systems, including financial, political, manufacturing and education, is required to mitigate the impact and risk of climate change (Selwyn, 2010).

3.4 Sustainable Development

The term 'sustainable developments is an economic planning method that aims to promote economic growth and protect the environment for future generations (Jarvie, 2016). Although it is a well-known term, its meaning is frequently extremely difficult to specify. However, sustainable development as a concept is used to describe desirable societal development. Issued in 1987, the Brundtland Commission's report "*Our Common Future*" contains one of the most common definitions of the concept, namely "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Jarvie, 2016). For example, the implementation of v ertical greening is one of a range of sustainable environmental practices designed to mitigate the effect of climate change.

3.5 Sustainability in the Construction Industry

The construction industry is among the largest contributors to greenhouse gas emissions accounting for 35% of global CO_2 emissions and generating between 45 and 65% of the waste deposited in landfills (Lima et al., 2021). According to the United Kingdom (UK) Parliament Report (2005), the UK is on a path to cut its carbon dioxide emissions on 2000 levels by around 60% by 2050. Thus, the UK government has highlighted that the construction industry is a key sector in which carbon reductions should be made and indicated that innovation will offer the means to such change.

To tackle the issue of sustainability, the global construction industry has taken decisive steps to implement sustainable practices and thereby curb emissions. Developers and builders have been forced to adopt more sustainable attitudes regarding the design and management of building projects (Kinnunen et al., 2022). Sustainability has emerged as a priority amongst project owners and managers, which has increased the importance of environmental and social impacts (Lima et al., 2021). It impacts project management, site selection, land use, design principles, material selection and application, and stakeholder participation. As a result, a multidisciplinary knowledge base for sustainable construction has emerged, encompassing areas such as architectural design, materials science, project management, real estate development, finance, purchasing, technology, and engineering (Butt & Dimitrijevic, 2022).

Notably, the construction industry in some developing nations has undergone significant modifications to meet global economic goals and, more importantly, to comply with emerging global sustainable advancements (Leiserowitz et al., 2006). The implementation of sustainable environmental policies in the construction industry has led to the emergence of eco-friendly and intelligent buildings based on ecological principles and resource efficiency (Yilzam & Bakis, 2015). However, the transition of the industry towards greater sustainability demands a collaborative approach to mitigate environmental impacts and promote an environmentally friendly future. Thus, the perception of sustainability as inclusive and complex places the ecological dependence of organisms, which focuses on biological diversity and the ecological integrity of society, within both economic and political structures (Selwyn, 2010).

3.6 Ecological Model of Sustainability

The ecological model of sustainability prioritises the maintenance of biological diversity and ecological integrity (Selwyn, 2010), while anthropocentric and ecocentric perspectives feature as significant ways to decide what to sustain. The anthropogenic perspective argues that essential natural resources, ecological structures, and regenerative processes that human systems depend on should be sustained, while the ecocentric perspective states that species should be sustained for their inherent value as sources of creatures with intrinsic value as well as for ecological processes (Selwyn, 2010). All entities associated with the Earth's ecosystem are included in ecological sustainability, which encompasses: the stability of climatic systems; the quality of air, land, and water; land use and soil erosion; biodiversity (diversity of both species and habitats); and ecosystem services (e.g., pollination and photosynthesis). Bongaarts (2019) argues that the ecosystem’s carrying capacity must not be jeopardized by the production of goods and services, as nature must be able to restore its depleted resources. Ecological sustainability is principally concerned with the operation of the Earth's biogeochemical system which includes (Aarts, 1999): water (pollutants, groundwater levels, salinity, temperature, and invasive species); air (pollutants, particles, the ozone layer, the climate system, and noise); land (pollutants, erosion, land use, and invasive species).

Furthermore, there should be balance in the Earth's biogeochemical system to ensure a sustainable environment. Thus, the implementation of vertical greening is considered an anthropogenic initiative that prioritizes ecological sustainability through its impact on the quality of the air, biodiversity (diversity of both species and habitats), and ecosystem services (e.g., pollination and photosynthesis).

According to Harley (2017), the term 'environmental sustainability' relates to the effects of human activity on our environment. Human behaviour can be characterized as either sustainable or non-sustainable. It is primarily concerned with the preservation of the Earth's resources for future generations. The degradation of biophysical resources, particularly the Earth's ecosystems, is a primary driver of the human effect on Earth's systems (Harley, 2017). As such, for human action to be sustainable, any negative environmental impacts must be counterbalanced by equally positive environmental impacts. According to Yohe et al. (2006), the term 'environmental sustainability' is a critical component in tackling climate change. The United Nations World Commission on Environment and Development defines environmental sustainability as acting today in a manner that will ensure that future generations have sufficient natural resources to sustain lives that are equal or better than the current generation (Dahl, 2012). Achieving a balance between human consumption and natural resources is one of the most important aspects of the climate-change puzzle. Unregulated biodiversity loss will trigger universal food and energy crises and an increase in global greenhouse gas emissions which will result in a global warming catastrophe. Consequently, to maintain the sustainability of the world and its inhabitants, there must be balance between environmental conservation and human development. This exact balance can be challenging to attain but it is achievable, as many constraints on the use of natural resources are risky to economic and technological progress but beneficial to environmental sustainability. However, vertical greening is a sustainable strategy that has a positive environmental impact and critically helps to mitigate the effect of climate change. It can ensure the sustainability of biodiversity, sequester carbon dioxide and reduce temperatures.

3.7 Concept of Human-Environment Interaction

Human environment interactions can be characterized as exchanges between the human social system and the environment. Although human-environment interactions have always existed, their scope and intensity have changed dramatically since the Industrial Revolution (Brondízio & Moran, 2013). Nevertheless, both are complex adaptive systems (Marten, 2001) as they comprise many aspects and interconnections, and have feedback systems that help their survival in a continuously changing environment. Throughout history, human overdependence on nature has resulted in environmental degradation and the depletion of natural resources (Inglis, 2018), while human impact on the environment increases as populations grow (Weber & Sciubba, 2019). Niragu (1994) argued that throughout history people have proven to be resilient in the face of challenges and adapted strategies to survive. Thus, even as humans exert greater control over the environment, the expanding scope of anthropogenic operations threatens its long-standing natural equilibrium (Galvani et al., 2016). Notably, mining, refining, and fossil fuel consumption pose global climate change concerns in addition to occupational and local threats. In addition, extreme climate occurrences are one of several worsening environmental issues; storms, droughts, and floods not only create physical damage, but also have long-term effects on food security, infectious disease outbreaks, and economic stability (Galvani et al., 2016). People who are typically the most severely affected by such extreme occurrences and their aftermath are also least able to recover. Thus, to solve the interconnected challenges of maintaining the natural environment while also protecting the health of human populations and progress in innovation and adaptation, sustainable and equitable solutions are required. The implementation of vertical greening can therefore help to enhance the quality of this human-environment interaction.

3.8 Human–Environment Systems

Human-Environment Systems (HES) is an interdisciplinary approach within the social sciences that studies the interaction of these two systems. In studying environmental and social concerns, HES aims to bridge the gap between social and natural sciences and integrate knowledge from both into one framework (Scholz & Binder, 1987). According to the field of HES, human and environmental systems are mutually dependent and although there has always been interactions between the two, their scope and intensity have grown dramatically since the Industrial Revolution.

HES is founded on the assumption that humans are not external but rather integral to the human-environment system (Scholz & Binder, 1987) and as such, must share responsibility for its long-term sustainability. Thus, HES combines both human and natural components to examine their complex interactions and feedback. The most internationally accepted framework for the study of such systems is the DPSIR model, representing drivers, pressures, state, impact, and response (Akintunde, 2017). This framework recognizes the human activities which place pressure on the environment and how these pressures modify the current state of the atmosphere, hydrosphere, lithosphere and biosphere (Akintunde, 2017). This leads to impacts on the environment and on social and economic systems. In turn, human society attempts to solve problems to remove, reduce or prevent the drivers and pressures, restore the state of the environment, and mitigate negative impacts. Identifying the drivers and barriers to the implementation of vertical greening in order to enhance the microclimate can be seen as a strategy towards sustainable human-environment systems. Figure 3-1 provides a modified version of this model which can be used to assess the causes and impacts of environmental change and the strategies to manage them.

Additionally, numerous theories and concepts address the interaction of humans and the environment, and some of these (including their relevance to ecological sustainability) are examined below. These theories and concepts explain human interactions with the environment, and include: the Human Adaptation and Innovation Model, Theory of Planned Behaviour, Environmental Citizenship Model, Model of Human Interaction with the Environment, the Value Belief Norm Theory of Environmentalism, and the Biophilic theory.

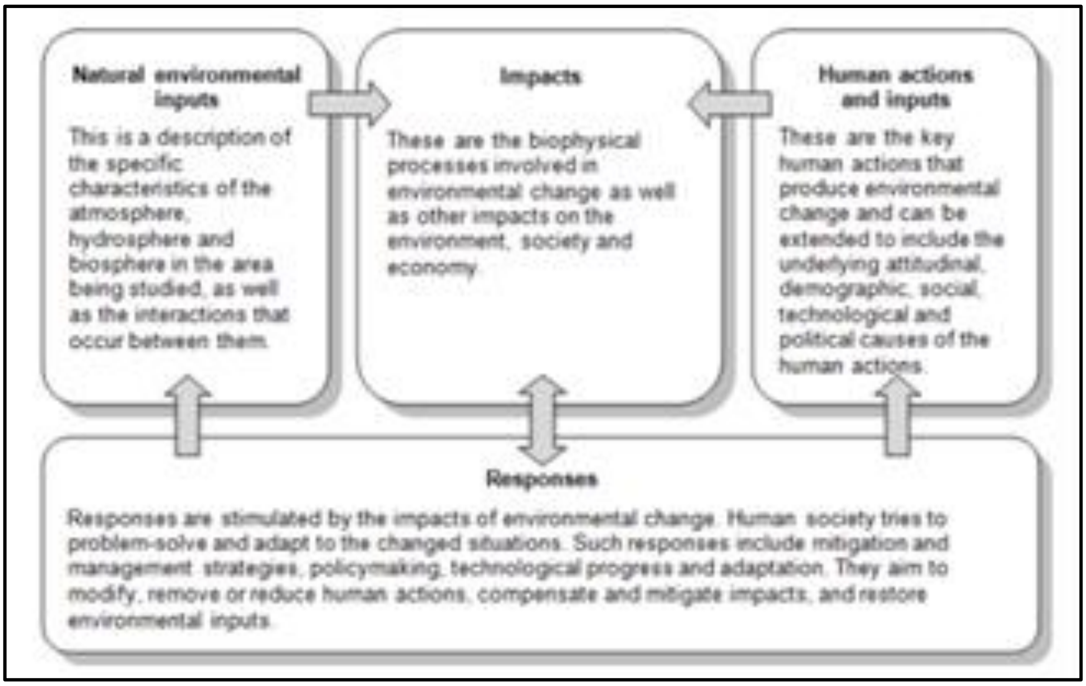


Figure 3.1 Simplified human environment system model (Source: Human Environment System Model Education Service Australia, 2013)

3.9 Human Adaptation, Innovation and Sustainable Development

According to Meadows et al. (1992) throughout human history, environmental changes and population growth have motivated the need for adaptation. Two million years ago hunter-gatherers evolved their lifestyle to include the hunting of large animals, which marked a significant change to human life as hunters were forced to move from their customary hunting grounds when wild supplies became scarce. Moreover, early people relocated to other continents because of nomadic wandering (Mebratu, 1998) while others reacted to the depletion of resources by farming, which allowed them to remain in place. According to Meadows et al. (1992), the domestication revolution which occurred around 7500 BCE, radically transformed communities as they began to cultivate crops and domesticate animals.

Increasing populations in settlements posed the next challenge to human life, which emerged as a concern around 5500 BCE and led to the agricultural revolution in England (Gottlieb, 1996). Consequently, forests were destroyed, the population increased, and the resources essential to human life decreased (Wall, YEAR OF WALL'S WORK, cited in Inglis, 2008). In the 1750s, the Industrial Revolution began enabled by the discovery of coal which replaced forests as a source of energy. According to Mebratu (1998), mining and steam powered industries necessitated a shift in production methods from manual to machine, thus production techniques shifted. In addition, innovation resolved the difficulties threatening human survival, and humans' relationship with the natural world changed radically (Mebratu, 1998). As progress was fueled by economic and individual status, and power, little attention was devoted to the environmental consequences (Akintunde, 2017).

From the 1950s, computers emerged, and the global economy developed which later became known as the Information Revolution; this period has seen a further exacerbation of the disparities between rich and poor, and prompted a further rapid increase in the growth of manufacturing industries in industrialized countries (Brent & Thompson, 1995). The human desire for affluence demonstrably increased as it became possible to ‘move up’ the social ladder. Thus, the depletion of the Earth's resources was exacerbated by science, technology, and globalization which increased the impact of global warming and hastened environmental degradation globally. Thus, as concrete constructions have become commonplace, nature has become increasingly distanced and inaccessible (Scull, 1999). Humans have perceived the Earth's resources as commodities and depleted them faster than they could be replaced.

In the meantime, the concept of sustainable development evolved in the 1970s, and the importance of sustainability as a management tool was acknowledged at the 1972 United Nations Conference. Furthermore, in 1987, the World Commission on Environment and Development (WCED) produced a report titled “Our Common Future”, which articulated a global concept of environmental sustainability that was adopted throughout the developed world (Mebratu, 1998). In the 1960s, before it was recognized as a management tool, DuBose et al. (1995) stated that sustainable development was noted as a useful technology to assist developing countries. Sustainable solutions evolved to mitigate the challenges imposed by the Industrial Revolution.

Although the survival of human society remains dependent on nature, the early 21st century is increasingly recognized as a period of overconsumption and population growth, which are exerting pressure on the Earth's ability to sustain the current level of resource depletion (Pimentel et al., 2013). Some of this latest threat may be mitigated by new sustainable strategies, and by restoring and protecting the Earth’s natural resources (Galvani et al., 2016). Thus, vertical greening systems serve as a sustainable strategy to reduce the impact of man on the environment and in the long term offers a climate change mitigation strategy to improve the micro-climate. Table 3.1 illustrates an example of human adaptability spurred by challenging historical events.

Table 3.1: Human Adaptation and Innovation (Source: Inglis (2008) adopted from US Census Bureau (2005) and Fraizier (2005))

	HUNTER-GATHERERS Basis for spiritual connection with nature (Scull 1999b)	DOMESTICATION REVOLUTION Cause of separation from nature (Shepard 1982)	AGRICULTURAL COMMUNITIES	AGRICULTURAL REVOLUTION (ENGLAND)	INDUSTRIAL REVOLUTION	INFORMATION REVOLUTION	SUSTAINABLE DEVELOPMENT recognised as a management tool
Timeline	2 Million BC	7500 BC	5500 BC	1500's	1750's	1950's	1970's
Approximate Population	100 Thousand	4 Million	4 Million	425 Million	625 Million	2,555 Million	4,086 Million
Crisis Stimulus	Population growth and degradation of plants and animals is a theme throughout history that has lead to scarcity of natural resources, and forced humans to explore innovative ways to survive which in turn has transformed human society structures (Curran & De Sherbinin 2004; Meadows, Meadows & Randers 1992).						
	Scarce wild resources in traditional hunting grounds	Population increase led to scarcity of food supplies in settlements	Agriculture led to increase in population in communities	Advanced agriculture, land ownership and concepts of wealth led to scarcity of land, energy & trees	Increased reliance on machines for production of food and energy sources	Computers led to the development of a global economy hastening natural resource use and strain on the earths systems	Population increase & accelerated resource use resulted in food & water shortages, global warming and damage to the earth systems
Response To Crisis	Migration (nomads moved further) and some began farming, planting crops and domesticating animals	Agriculture discovered	Advanced agricultural techniques developed	Coal and steam replaced trees as an energy source	Computer technology developed	Sustainability adopted as a management tool	Sustainable and renewable green energies. Limits to growth. Restore and protect the earths natural systems by re-establishing the value of nature in the consciousness of societies

3.10 Theory of Planned Behaviour

Ajzen (2002) proposed the Theory of Planned Behaviour, in which the primary determinants of pro-environmental behaviour are the will to act and objective situational factors. The complex interaction between cognitive variables (knowledge of action strategies and issues, action skills) and psychological factors (locus of control, attitudes, and personal responsibility) determines the intention. The Theory of Reasoned Action produced Planned Conduct Theory which proposes that three belief constructs drive human behaviour: Beliefs about consequences, the expectations of others, and items that may support or hinder behaviour. Hammond (1995) explains that one of the theory's key principles is that, at a conceptual level, links connecting influences on behaviour and their consequences are captured by one of the model's components or relationships. The theory details factors which determine human behaviour and the relationships between them. Thus, individuals may be inspired to effectively implement sustainable practices, such as vertical greening, if they understand the consequences of their actions. The model's relevance to this study is its explanation of the relationships between knowledge, attitude, behavioral intention, and actual behaviour as they influence environmental sustainability. While the theory offers useful insights, it has some drawbacks in that it simplifies complex human behaviour and overlooks individual variation. However, it offers an awareness of the motivational factors driving pro-environmental behaviour which can inform strategies for the advancement of environmental sustainability.

3.11 Environmental Citizenship Model

Developed by Hungerford and Volk in 1990, the Environmental Citizenship Model has made a significant contribution to environmental education. It seeks to decipher factors that impact a person's environmental awareness and involvement; establishes approaches which evaluate distinct intellectual and behavioural traits for educational involvement; and shows the evolution from primary awareness to complete empowerment. According to Hungerford and Volk (1990), there are three stages of involvement in education each with distinct knowledge and attitude traits: first, exposure (entrance) then ownership (commitment) and finally true involvement (empowerment). When Hungerford and Volk (1990) created this model, they broke down all the factors that determine whether a person acts into three categories. Entry-level variables, which include general environmental sensitivity and knowledge represent an initial awareness, curiosity, and basic understanding of environmental topics and concepts, and concern for environmental problems. The ownership level includes in-depth knowledge of the subject, personal dedication, and desire, while the knowledge-based commitment and involvement stage includes sustainable practices and a passion to make a positive impact. Finally, empowerment variables such as action skills, the locus of control, and purpose to act denote the enthusiastic stage which includes the appropriate skills and mindset to produce a positive impact. Figure 3.2 shows an illustration of the Environmental Citizenship Model.

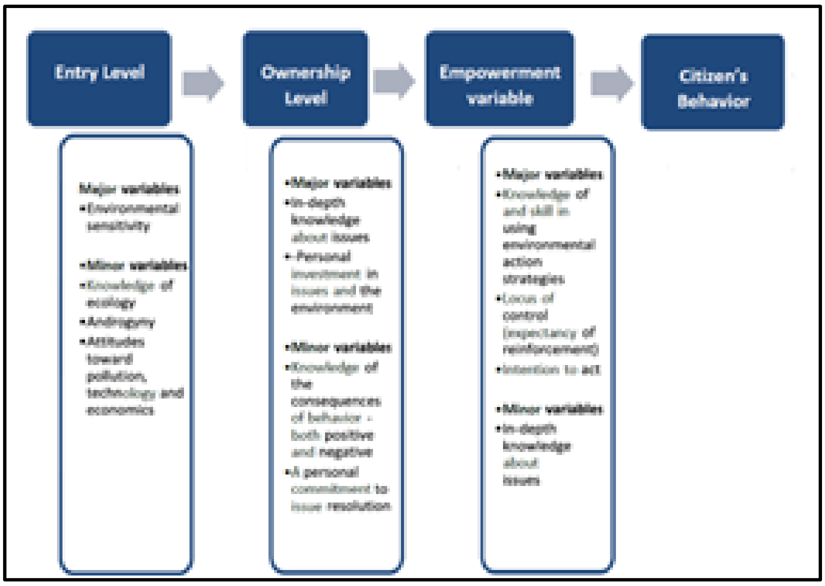


Figure 3.2: Environmental Citizenship Model (Source: Stern (2000)

The Environmental Citizenship Model highlights the most significant variables necessary for the advancement of environmental literacy and involvement. Additionally, the model established a framework to aid the categorization of environmental literacy based on the degree of relevance (namely, a major or minor variable) (Stern, 2000). As an added benefit, the model provides a scale to identify a person's literacy level so that it is possible to determine whether a citizen is at the entrance level, ownership level, empowerment level, or have matured into an ecologically responsible citizen. This theory suggests there is the potential to develop an environmentally sustainable conscious citizen who acts in the best interest of the environment. In the long term, this theory could be used to encourage sustainable approaches to the environment, regardless of the activity. It will encourage the easy adoption of vertical greening as a sustainable strategy to mitigate the effect of climate change through environmental sensitivity and entry level knowledge. However, this model has limitations as it does not consider the individual's cultural background and socio-economic situation, and it simplifies the intricacies of environmental behaviour.

3.12 Model of Human Interaction with the Environment

In 1995, Hammond (1995, cited by Stern, 1999) proposed a model of human interaction with the environment that included four points of interaction: Source: Humans extract natural resources from the environment for economic benefit thereby depleting these resources or deteriorating the biological systems on which their continued production depends. Sink: Industrial activity transforms natural resources into products (such as pesticides) and energy services that are utilized or dispersed before being discarded or dissipated, resulting in pollution and waste that flows back into the environment unless recycled.

1. Life support: Ecosystems provide essential life-support services. Environmental degradation and encroachment by humans can impair the environment's ability to provide important life-support services, such as the breakdown of organic waste, nutrient recycling, oxygen production, and biodiversity maintenance.
2. Impact on human welfare: Contaminated air, water, and food directly impair human health and welfare.

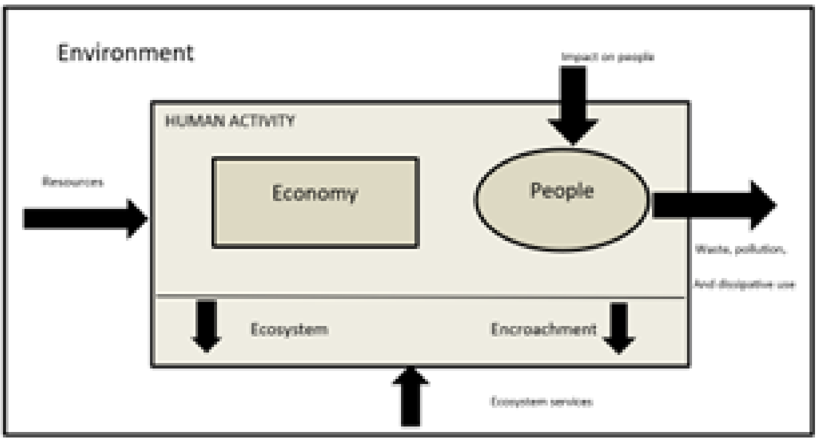


Figure 3.3: Model of Human Interaction with the Environment (Source: Stern (1999)

The model, illustrated in Figure 3.3, shows how all human activities have an impact on the environment. Knowledge of the model's interacting variables enhances an understanding of the possible consequences of diverse behaviours on the environment which offers an insight into ways to mitigate the effects of climate change. For example, introducing green walls (vertical greening) in urban cities can enhance the ecosystem by reducing the impact of environmental degradation. Although the model has some weaknesses it offers a framework to analyse human-environment relations. However, its primary focus is not sustainability but rather economic gain and is presented as a linear resource flow that simplifies intricate relationships.

3.13 Value-Belief-Norm Theory of Environmentalism (Paul Stern 1999)

Stern (1999) proposed Value Belief Norm (VBN) Theory to demonstrate how human values impact behaviour in an environmental context. The theory contends that personal values, environmental perception, and social norms affect the environmental decisions people make. This theory proposes a causal chain of relationships between values, beliefs, norms, and behaviours (Stern, 2000) whereby value is defined as a guiding concept for any behaviour which is based on desired trans-situational objectives that change in perceived significance (Schwartz, 1992).

Environmental perception and behaviour are influenced by personal values, and the theory explains the difference between basic, altruistic, biospheric, egoistic, and ‘openness to change’ values (Schwartz, 1992). Firstly, basic values are … Secondly, altruistic values are social values that drive people to engage in pro-environmental behaviour, and refer to any action that protects the environment. Biospheric and egoistic values are considered the most pertinent to environmentalism (Stern, 2000). Biospheric values are expressions of individuals' concern for the proper functioning of the natural environment whereby priority is given to the protection of nature by people with such values. In contrast, egoistic values focus more on personal gain; individuals with such values neglect environmental behaviors with no direct impact on them. Finally, ‘openness to change values’ refer to stimulation and self-direction and is focused on the motivation of independent thought and action, as opposed to the desire to fulfill the expectations of others (Stern, 2000).

This theory also recognizes that prevalent expectations among a community can substantially influence environmental behaviours to develop a social norm. These social norms are subdivided into:

- Descriptive norms explain an individual's ideas about others' behaviour in a specific scenario where they are inclined to engage in environmentally friendly behaviour if that is what others do;
- Injunctive norms explain individuals' concerns about what people find acceptable or unacceptable which compels them to act in a similar way;

- Personal norms are individuals' intrinsic behaviours which influence their moral values and make them act in favour of the environment without any expectations.

In addition, belief is an individual's assessment of the condition of the environment including the causes of environmental ills and the viability of prospective solutions. Belief has been classified into:

- Worldview beliefs which refer to an individual's perspective of the world and how they fit within it which can be man's control over nature or harmony with nature;
- Cause-effect beliefs which refer to an individual's perceptions of the underlying causes and effects of environmental ills, some of which may be man-induced, such as climate change;
- Problem-solving beliefs refer to an individual's assessment of the efficacy of various strategies to mitigate environmental challenges, which may be through individual or collective effort.
- The sense of obligation to pro-environment behaviour and ecosystem sustainability could encourage the implementation of vertical greening due to their impact on the ecosystem. Thus, the Value-Belief-Norm (VBN) Theory of Environmentalism explores the relationship among values, beliefs, norms, and behaviours and further explains the influence of human values on environmental behaviour by offering a framework to understand pro-environmental behaviour. Nevertheless, the theory neglects the influence of socio-economic and cultural factors on behaviour.

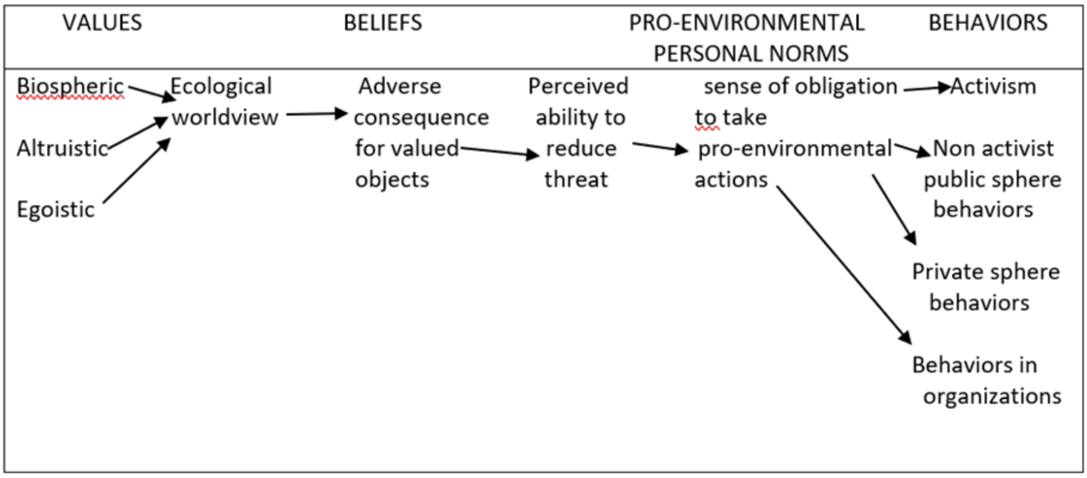


Figure 3.4: Value-Belief-Norm Theory of Environmentalism (Source: Stern (2000)

3.14 Theory Development

The theory developed for this study was based on the connections identified between human engagement with the environment and climate change impact and mitigation. As empirical evidence indicates anthropogenic activities play a significant role in the negative impact of climate change, similar to individual beliefs and norms, and interactions with the environment, which are critical to the successful implementation of a strategy for mitigation. These theories are crucial for the development of the theory as a valuable resource by which to evaluate the data generated. Nevertheless, the theory should possess prognostic capabilities to exceeding its capacity as purely a theoretical resource. The relationship between human interaction with the environment and its mitigation of climate change thus serves as a foundation for the theory's development. To justify the selection of the proposed theory, these features will be discussed further.

The aforementioned theories indicated several interrelated ideas and concepts that may underpin the implementation of vertical greening in the semi-arid region as initiatives to help mitigate the impact of climate change. It recognizes Environmental Sustainability Theory as critical to climate change mitigation and reveals that the implementation of sustainable strategies in the building industry, such as vertical greening, may lower greenhouse gas emissions and enhance biodiversity which corresponds with ideals of environmental sustainability. Additionally, it acknowledged that the concept of sustainable development promotes economic growth while protecting the environment for future generations. Vertical greening can be seen as a sustainable practice within the construction industry. By incorporating such practices within building projects, the construction industry can enhance the environmental and social impacts of construction projects and contribute to the creation of an ecologically sustainable built environment.

Furthermore, emphasis is placed on the significance of human-environment interaction by proposing the integration of vertical greening approaches which would thereby improve the microclimate and create an eco-friendly environment. Such initiatives also have the potential to promote ecological sustainability by limiting human-induced environmental deterioration. The theory acknowledges the significance of collaboration by promoting sustainability and suggests that by understanding the drivers and barriers to implementing vertical greening, stakeholders can interact to explore strategies that enhance the microclimate, mitigate environmental impacts, and encourage sustainability in semi-arid regions. Deduction from the theories suggests that implementing vertical greening strategies along with other initiatives in semi-arid regions can help to mitigate the effects of climate change by boosting the microclimate (that is making the the temperature, relative humidity and wind speed at a comfortable level for human) increasing biodiversity, and fostering a more sustainable and resilient environment.

Therefore, the implementation of vertical greening is offered as a comprehensive approach to reduce the impact of climate change in semi-arid regions. It acknowledges the significance of environmental sustainability, human-environment interactions, the ecological model of sustainability, and the intricacies of human-environment systems and interactions. To implement vertical greening and encourage a broad adoption of sustainable practices, multiple stakeholders, including the construction industry, policy makers, and local communities, must collaborate. However, it is important to note that for vertical greening to be successful as a climate change mitigation strategy, multiple variables must be considered. This includes local climatic conditions, plant selection, irrigation and maintenance practices, and the integration of other sustainable measures. To validate and improve this theory in the context of semi-arid regions, additional studies and empirical evidence are required.

The theory and related propositions are developed around three themes namely:

i. The relationship between the impact of climate change and human activities.
ii. The links between sustainable mitigation strategies (vertical greening) and human-environment system (the ecosystem and human system).
iii. The association between human-environment interactions, and pro-environmental and social norms

The impact of climate change refers particularly to global warming and its consequential effects, while the mitigation strategy involves the implementation of vertical greening. Figure 3.5 shows an illustration of the theoretical framework for understanding climate change and sustainable mitigation strategies.

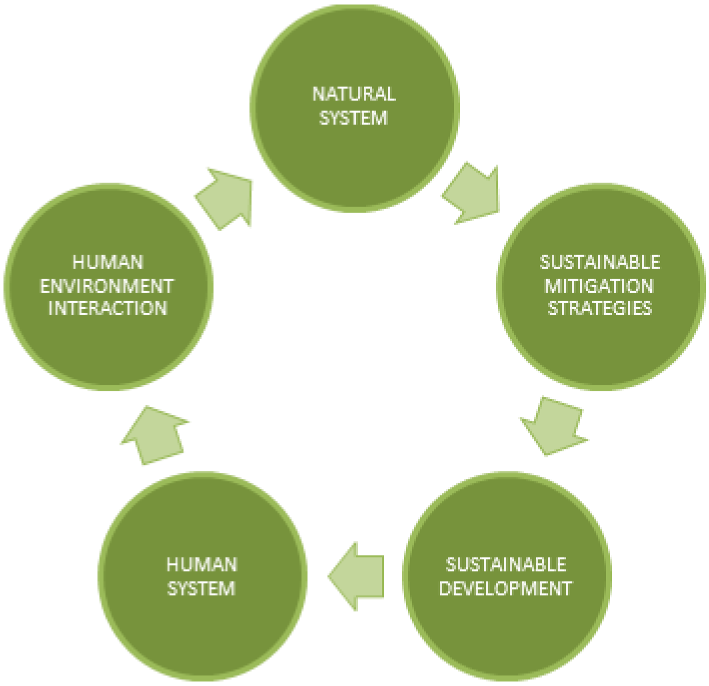


Figure 3.5: Theoretical framework for understanding climate change and sustainable mitigation strategies (Source: Self)

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

This chapter describes the philosophical underpinnings, ontology, epistemology, axiological assumptions, and research methods applied to the study, and offers an understanding of the underpinning assumptions, paradigms, and strategies. The methodology develops from the researcher's philosophical stance on the research and guides the selection of the most suitable data type, collection method and analysis tool (Rehman & Alharthi, 2016). This phase elucidates the limitations and strengths of various approaches, and how they can be addressed within the context of the study. Moreover, it explains the study's philosophical perspective, the research methodology employed, and how the chosen methods will be used.

The chapter explains why the data collection and analysis approaches were selected as the most effective in answering the study objectives identified in chapter one. In addition, the chapter provides an understanding of how vertical greening can impact the microclimate of the streetscape in the semi-arid region of Northern Nigeria. Figure 4.1 provides an overview of the content of this chapter.

Table 4.1: Research process alongside the methods used at each stage

Chapters	**Content**	**Employed Methods**
One	Background, justification, aim, objectives and research questions.	Literature review
Two	Climatic characteristics, semi-arid region, sustainable strategies, climate change mitigation, vertical greening	Literature review
Three	Theoretical framework	Literature review
Four	Research methodology, philosophical considerations and methodological justification.	Literature review

Five	Qualitative data collection and analysis	Semi-structured interviews, thematic analysis using NVIVO
Six	Microclimate simulation and analysis of results.	Envi-met simulation software

4.2 Research Concept

According to Western Sydney University (2020), Research is perceived as the creation of original knowledge or utilization of pre-existing knowledge in an innovative manner to generate new ideas, methodologies, and understandings. *This can include the synthesis and analysis of previous research which* can lead *to new and creative outcomes.* On this premise Vertical greening, also known as green walls or living walls, involves the use of vegetation on vertical surfaces such as building facades, walls, and fences. This concept has potential applications in various climates, including semi-arid regions like Northern Nigeria. This research explored the feasibility, benefits, and challenges of implementing vertical greening systems in the semi-arid region of Northern Nigeria., This was achieved by extensive identifying the specific problems in Northern Nigeria, such as urban heat islands, poor air quality, limited green space, and the need for sustainable agriculture and water management. This was followed by extensive review literature review and plant selection process as well as the selection of appropriate software for simulation. This process is in line with the work of Ghauri and Gronhaug (2002) cited in Saunders et al., 2019), of 'systematic way' of conducting a research in logical relationship. Against this background, the research concept for this study is as follows:

Objectives: It assessed the impact of vertical greening on urban microclimates in Northern Nigeria and identified suitable plant species and irrigation systems for vertical greening in semi-arid conditions. It also evaluated the socio-economic benefits and community acceptance of vertical greening.

Hypothesis: Implementing vertical greening in urban areas of Northern Nigeria was expected to significantly reduce ambient temperatures and improve air quality, while providing economic and social benefits.

Literature Review: The study conducted a systematic analysis of existing studies on vertical greening in arid and semi-arid regions, successful case studies, and advancements in green wall technologies.

Methodology: The methodology involved site selection for pilot projects, Identification of native and drought-resistant plant species. This specifies of pants were included in simulation environment with design and installation of various vertical greening systems. Furthermore, measurement of temperature, humidity, and air quality before and after installation were necessary for each simulation. Surveys and interviews with local residents and critical stakeholders were conducted to gauge perception and acceptance.

Expected Outcomes: The expected outcomes were aimed at the reduction in urban temperatures and improvement in air quality. The Identification of best practices for vertical greening in semi-arid regions was also considered important in the light of this research.

Significance: The research was expected to contribute to sustainable urban development in semi-arid regions, offering practical solutions to environmental and social challenges.

1. The concept of the research was crucial in answering the following research questions: The potential benefits of incorporating vertical greening into urban environments in the semi-arid region of Northern Nigeria;
2. The plant types which thrive and are suitable for vertical greening in Northern Nigeria and other semi-arid regions;
3. The factors which impact the integration of vertical greening in the semi-arid region of Northern Nigeria;
4. The influence of vertical greening on the urban microclimate in the semi-arid region of Northern Nigeria;

5. The most essential factors for policymakers, urban planners, and architects to consider when implementing vertical greening in northern Nigeria and other semi-arid regions.

4.3 Research Design

This section provides an overview of the plan to answer research questions defined in Chapter One and summarized in the previous section. According to Saunders et al. (2019), a research design comprises explicit objectives drawn from the research question(s), which specifies the source(s) from which the data will be acquired, how the data will be collected and analysed, and the ethical considerations and constraints encountered (for example, access to data, time, location, and money). According to Saunders et al. (2019), the choice of research philosophy and approach to theory development influences the answers to the research question.

The research design can take various forms to achieve the research aims and objectives and answer the research questions. Nevertheless, according to Blaikie (2019), it should focus on both the method and approach. Consequently, two models were examined when selecting a viable design for this study, the Nested Model (Kagioglou et al., 2000) and the Research Onion (Saunders et al., 2019).

The Nested Model (see Figure 4.2) was developed by Kagioglou et al. (2000) and consists of three cycles: philosophy, approach, and techniques. Various researchers have adopted the nested approach (Kasim, 2008; Ling, 2003), as it aids reflection on the main components of a systematic study. The model was developed to create a comprehensive methodology that supports the connections between the research theories, strategies, and techniques. In this model, the research philosophy is the foundation for knowledge creation, while the research approach is a process for developing and testing theories (such as a case study, survey, action analysis, and evaluation), while the research techniques are the means by which the data are collected (such as interviews, questionnaires, observation or focus group).

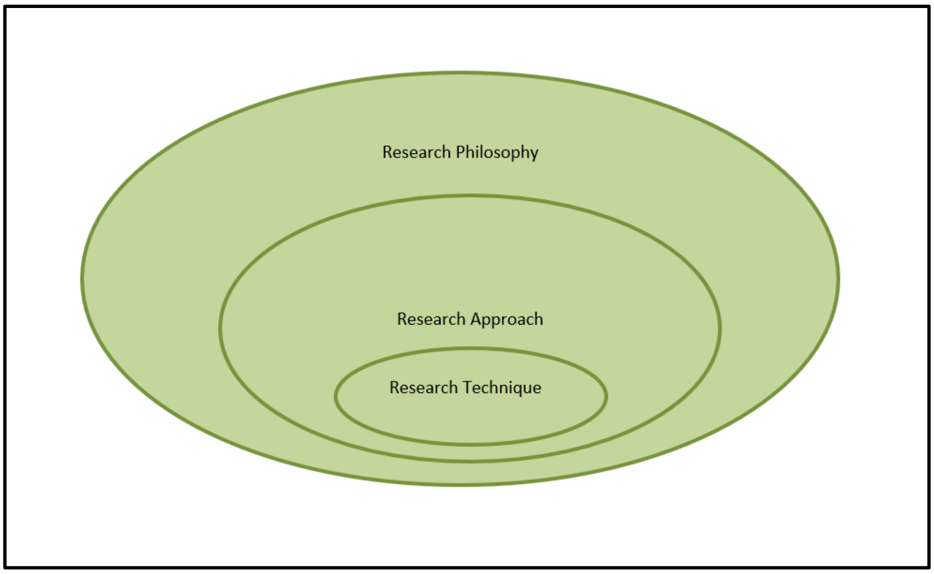


Figure 4.2: Nested Research Methodology (Adapted from: Kagioglou et al., 1998).

The Research Onion (see Figure 4.3) was developed by Saunders et al. (2019) and contains six layers: Research philosophy, research approach, methodological choices, research strategies, time horizons, and procedures. Research philosophy forms the outer layer of the onion and the first consideration within the research design, which then proceeds through the layers to the inner core that details the research techniques (data collection). The characteristics of the two research models are listed in Table 4.2.

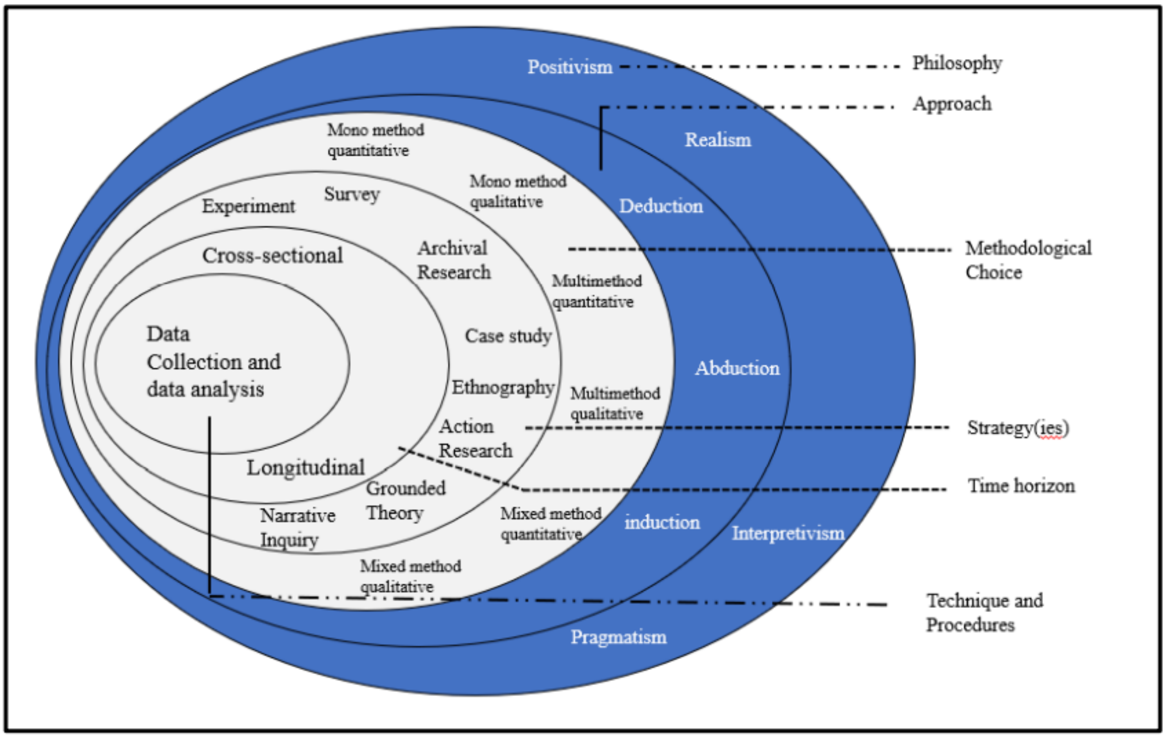


Figure 4.3: The Research Onion Model (Saunders et al., 2019)

Table 4.2: Characteristics of the two research models

Research Onion Model (Saunders et al., 2019)	**Nested Model (Kagioglou et al., 2000)**
Research philosophy	Research philosophy
Research approach	
Methodological choice	Research approach
Strategy	
Time horizon	
Technique and procedure	Research technique

From a comparison of the two models, the Research Onion is considered more comprehensive, offering clearer, more thorough guidance when developing a research design. Through its six layers, the researcher selects the most appropriate strategies and approaches. The methodological structure of the model offers a useful, practical guide to develop research. Additionally, the time horizon layer offers an additional advantage over the Nested Model by incorporating a key boundary for research. Hence, the Research Onion will be adopted for this study, and will be discussed in detail over the next sections.

4.4 Research Paradigm

A research paradigm is the set of fundamental beliefs and a theoretical framework comprising assumptions concerning ontology, epistemology, and methods (Rehman & Alharthi, 2016). It is the philosophical way of thinking, and the way an individual perceives truth about the world. The key components of a research paradigm include ontology, epistemology, axiology, methodology and methods. Ontology and epistemology form the foundation of research, axiology denotes values and ethics, while methods build upon these foundations (Grix, 2010).

4.4.1 Ontology

Ontology relates to the nature of existence by considering what exists, and the nature of reality (Burrell & Morgan, 2019). This belief shapes how the researcher sees the study and how it will be carried out. It is a belief system that reveals the researcher's perspective on what is regarded as true; thus, it concerns the researcher’s belief about reality. Ontology distinguishes between the two major philosophical research traditions - subjective and objective (Guthrie, 2010). Objective reality asserts that the universe and objects exist regardless of external influences or experience, while subjective reality is based on the researcher's experience and perception. In objective research, both physical and social worlds are perceived as visible objects while subjective research concerns human thought about objects, which are unseen constructs (Guthrie, 2010). On a continuum, these traditions are described as polar opposites with various philosophical perspectives located between the two extremes (Holden & Lynch, 2004). The ontological perception of truth/reality in this research falls between objectivity and subjectivity, thus it is founded on the assumption that single or multiple realities can exist which are open to empirical inquiry (McCoy, 2015). On an ontological level, mixed method research allows for the intricate and multifaceted nature of reality and considers that various facets of reality may call for distinct approaches of enquiry to enable a comprehensive understanding of a phenomenon.

This research focuses on vertical greening; plant selection; the impact of vertical greening systems on the streetscape microclimate; the perception of its implementation by stakeholders; and the drivers and barriers to its implementation in Nigeria. Additionally, it is essential to understand both the subjective and objective perspectives of people and their environment in order to successfully implement vertical greening and support the creation of successful and sustainable policies and programmes.

4.4.2 Epistemology

Epistemology is concerned with the study of the theory of knowledge. It is the belief in knowledge, particularly what connotes genuine and acceptable knowledge, and how it is communicated (Burrell & Morgan, 1979). It encompasses everything from the origins to the scope of knowledge (or the boundaries of what is known) and how knowledge is communicated to others. Thus, it is concerned with the foundation of knowledge and how it is comprehended. Moreover, ontological beliefs guide the researcher's epistemological beliefs. For a researcher to adopt a position in a research context, the nature of knowledge and the relationship between the inquirer and the inquiry needs to be clear (Kivunja & Kuyini, 2017). The study of epistemology (knowledge) has resulted in a tremendous deal of misconception concerning what constitutes actual knowledge.

Empiricism, based on experience, and idealism, based on innate understanding, are the two most common approaches in epistemology (Potter, 2016). Multiple epistemologies are used by different researchers in research, which include projects based on archive research, autobiographical accounts narratives, and fictional literature (Saunders et al., 2019). To elicit answers to questions on the nature and justification of knowledge, researchers draw from five diverse sources (Kivunja & Kuyini, 2017): Positivism, critical realism, interpretivism, postmodernism, and pragmatism. Positivism and interpretivism, which focus on innate knowledge, are fundamental epistemological assumptions (Irshaidat, 2019). The epistemological perception of this research is pragmatism, as presented in Figure 4.5. The study focuses on problem solving and informs future practice. It is concerned with the best way to answer the research questions and is based on measurable facts. These facts take the form of geographical location and weather data findings which were used in the Envi-met model to determine various scenarios (percentage of vegetation coverage) in the semi-arid region and the perception of building professionals and other stakeholders on the drivers and barriers to the implementation of vertical greening in Nigeria.

4.4.3 Axiology

- Axiology is considered at each level of the research process, it explores the influence that values and ethics play in research (Saunders et al., 2019). Researchers must consider their own values and those of the research participants, as axiological assumptions are based on opposite extremes of a spectrum, namely either value-free in positivist research or value-laden in interpretivism (Saunders et al., 2019). The axiological inclination of this research is value-driven and lies between the two extremes. The research is initiated and sustained by the researcher's doubts and beliefs, including their reflexivity. Moreover, due to varying assumptions in social science research which are based on philosophical and methodological choice, research philosophies are located along multidimensional continua between two opposing extremes of objectivity and subjectivity (Niglas, 2010, cited in Saunders et al., 2019). These two extremes are further discussed below.

    - Objectivism

    Assumptions within the study of natural sciences are based on objectivism which suggests that the social world is extrinsic to ourselves and others (Saunders et al., 2019). Objectivism assumes that social entities are analogous to physical entities in the natural world as they exist regardless of perceptions of them. Thus, perceptions of social and physical phenomena have no bearing on their reality. Ontologically, objectivism supports realism in its most extreme version, and epistemologically, to uncover 'the truth' about the social world, objectivists utilise facts that can be observed and measured to derive law-like generalisations about a universal social reality. Axiologically, objectivists maintain that research remains free of values because social entities and social actors exist independently of each other.

- Subjectivism

Subjectivism underpins assumptions in the humanities and arts, claiming that the social world is created from actors' perceptions and consequent actions. Ontologically, subjectivism embraces nominalism. In its most extreme form, nominalism holds that the order and patterns of social phenomena (as well as the phenomena themselves) are formed using language, conceptual categories, perceptions, and actions by researchers and other social actors (Saunders et al., 2019). According to Burrell and Morgan (2016), nominalists believe there is no underlying reality besides that which an individual attributes to the social world. Everyone experiences and perceives reality differently; hence it is important to recognise multiple realities. Social phenomena are in a perpetual change because social interactions between actors are a continuous activity (Saunders et al., 2019). A subjectivist researcher is interested in varied perspectives and narratives that help account for the range of social realities experienced by various social actors. Table 4.3 summarises objectivism and subjectivism in relation to the three philosophical assumptions - ontology, epistemology and axiology.

Table 4.3: Philosophical assumptions based on objectivism and subjectivism (Saunders et al., 2019)

Philosophical Assumption	**Questions**	**Objectivism**	**Subjectivism**
Ontology	What is the nature of reality?	Real, external one true reality.	Nominal socially constructed multiple realities.

Epistemology	How can we know what we know? What is considered acceptable knowledge? What constitutes good quality data? What kinds of contribution to knowledge can be made?	Adopts the assumptions of the natural scientist: Facts, numbers, observable phenomena law-like generalizations.	Adopts the assumptions of the arts and humanities: Opinions, written, spoken and visual accounts Meanings are attributed to individuals and contexts, specifics.
Axiology	What is the role of values in research? Should we try to be morally neutral when we do research, or should we let our values shape research? How should we deal with the values of research participants?	Value-free detachment.	Value-bound, integral and reflexive

4.5 Research Philosophy

Research philosophy describes the belief system that informs knowledge creation (Saunders et al., 2019). The study of knowledge, and the nature of reality and existence is defined as philosophy (Manicas, 1991), while “A system of beliefs and assumptions about the development of knowledge” is referred to as research philosophy (Saunders et al., 2019, p.130). Understanding research philosophy involves meticulously questioning beliefs. Philosophical choices enable a researcher to justify methodological choice, including strategies, data collection and analysis techniques (Lincoln & Guba, 2000). At every level of research, a variety of assumptions are made, whether consciously or subconsciously (Burrell & Morgan, 2016). Among these are assumptions about the reality experienced during research (ontological assumptions), assumptions about human knowledge (epistemological assumptions), and assumptions regarding the impact of personal beliefs on the research process (axiological assumptions) (Saunders et al., 2019). A researcher's understanding of their research question, the methodology they employ, and how they interpret their findings is significantly shaped by these assumptions (Walford, 2012). Conscious and consistent assumptions guide methodological choices, research strategy, data collection techniques, and analysis procedures, which forms the foundation of a credible research philosophy. Researchers should be aware of their philosophical commitment through their choice of research strategy which impacts what and how the research is carried out (Johnson & Clark, 2006). Thus, reflexivity is required to explore and understand research philosophy. This involves thoroughly evaluating the researcher's assumptions and preconceptions (Haynes 2012).

The importance of philosophical differences in research cannot be overstated when defining research philosophy and structuring research projects. Many research philosophies and methodologies have emerged due to the different philosophies drawn from various disciplines. However, scholars are divided on whether the diversity of research philosophies, paradigms, and methodologies is beneficial (Saunders et al., 2019). Research philosophy is distinguished by major research paradigms. The following are five research philosophies widely used by researchers and their philosophical foundations: Positivism, interpretivism, pragmatism, critical realism and postmoderism. Understanding these enables the researcher to describe their philosophy and justify it in comparison to available options (Mendy, 2016). This significantly improves the researcher's ability to describe and justify the adopted methodological choice, research strategy, and data collection procedures and analysis techniques. The research process is outlined in the Research Onion model.

4.5.1 Positivism

The perspective was developed as a philosophical idea and movement by Auguste Comte (1798-1857) who suggested that the laws that regulate the social world must be explained, much like the laws that govern the natural world. To comprehend human behaviour, Comte emphasized observation and experimentation. Positivism has numerous definitions, some of which reflect its negative nature, while others emphasize its descriptive potential (Bryman, 2016). From a positivist perspective, which is sometimes called the scientific method or science research, reality is stable and can be described and observed objectively (Creswell, 2014). Positivism deals with observable social realities that present accurate and precise knowledge, while positivist researchers use hypothesis formulation, quantitative data collection, and statistical testing. This philosophy has the following attributes:

a. It studies the world objectively; only the senses can verify existence and knowledge with techniques based on data collection and analysis such as observation, measurements, and calculations.
b. It promotes deductive thinking, arguing that hypothesized theories may be validated or disputed. Data is seen as independent of the observer (Guthrie, 2010) and not affected by human bias.

Kinross and Darzi (2010) assert that social policy makers believe that the most reputable work is unbiased, neutral, and scientific, which suggests a favouring of positivist approaches. Although social science research focuses on human behaviour, it demonstrates that humans cannot be treated as objects or subjected to theories that result in laws as they are impacted by other elements such as feelings and perceptions (Easterby-Smith et al., 2012). Ontologically, positivists view physical and natural objects as real, while epistemologically only observable and measurable entities produce data that are considered relevant and dependable (Crotty, 1998). This study's objective "to investigate the impact of vertical greening on the urban microclimate such as temperature, humidity, and air quality, and its ability in climate change mitigation" aligns with a positivist philosophy. However, positivism in this research would imply that a microclimate simulation is an independent practice and not influenced by social factors. Consequently, a strictly positivist approach would not result in meaningful results in relation to the study's objectives and research questions.

4.5.1 Interpretivism

In the early and mid-twentieth century, interpretivism emerged as a critique of positivism, and the most prominent were hermeneutics, phenomenology, and symbolic interactionism (Crotty 1998). According to interpretivism, humans are distinct from physical things in that they create meaning. As such, human beings and their social environments cannot be researched in the same manner as physical events, which suggests that social science research must be distinct from natural science research. Interpretivists are critical of positivist attempts to discover definite, universal 'laws' that apply to everyone because different people from different cultural backgrounds, under different circumstances and at different times make different meanings, and thus create and experience different social realities (Saunders et al., 2019). Interpretivist research aims to develop new, more nuanced conceptions and interpretations of social environments and situations. They argue that when such intricacy is relegated to a series of law-like generalisations, important insights into humans are lost (Saunders et al., 2019). Interpretivist researchers strive to account for this complexity by gathering information that is meaningful to their study participants. Interpretivism's many branches focus with varying degrees of emphasis on how to achieve this in practice. Interpretivists emphasise the significance of language, culture, and history in influencing our interpretations and experiences of organisational and social environments (Crotty, 1998). Interpretivism is clearly subjectivist in its emphasis on complexity, richness, various interpretations, and meaning making. Axiologically, interpretivists acknowledge that their interpretation of research materials and data, and thus their own values and beliefs, play an essential role in the research process (Saunders et al., 2019). Thus, an interpretivist researcher must take an empathic perspective, which is critical to this philosophy. The interpretivist's challenge is to understand the social environment of their study participants and integrate it within their perspective.

In this study, an interpretivist research philosophy which embraces a socially created reality will encourage building experts and other stakeholders to voice their thoughts regarding the factors that encourage and hinder the implementation of vertical greening. Therefore, situating the research within an interpretivist philosophy aligns with the objective "to evaluate the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria." The adoption of this philosophy prompted the selection of interviews as a research method.

4.5.2 Pragmatism

Philosophers Charles Pierce, William James, and John Dewey developed pragmatism in the United States in the late nineteenth and early twentieth centuries (Atã & Queiroz, 2019). Pragmatists develop research that impacts on practice, and perceive that concepts are only relevant where they facilitate action (Kelemen & Rumens, 2008). Pragmatism aims to balance objectivism with subjectivism, facts and values, accurate and rigorous information and varied contextualized experiences. Rather than examining theories, concepts, ideas, hypotheses, and research findings in a purely abstract way, pragmatists evaluate them in terms of their function as tools for thought and action, and for their practical repercussions in specific circumstances. Therefore, they prioritise the practical impacts of ideas and knowledge due to their ability to enable successful action. Pragmatists seek practical answers to an identified problem to inform current and future practice. Practical outcomes are more important to pragmatists than abstract distinctions, therefore the degree to which their work can be considered objective or subjective can vary widely (Saunders et al., 2019). Pragmatists assume that no single point of view can ever provide the complete picture, meaning they believe there are numerous ways to perceive the world. Thus, pragmatists select the method or procedures that allow for the collection of trustworthy, well-founded, dependable, and relevant evidence that advances their research (Kelemen & Rumens, 2008). The most significant determinant for a pragmatist in research is the research problem and research question, and the emphasis of practical outcomes. Research challenges that do not explicitly suggest one sort of approach are consistent with a pragmatist's viewpoint. In this study pragmatism would help to develop an insight into the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria and investigate the impact of vertical greening on the urban microclimate through temperature, humidity, and air quality. It could also determine its ability to mitigate climate change in Nigeria and other semi-arid regions of the world by using a microclimate simulation tool (Envi-met). This would provide guidance on how to successfully implement vertical greening in Northern Nigeria and other semi-arid regions for policy makers, urban planners, and architects.

4.5.3 Critical Realism

Critical realism is a philosophy that focuses on understanding what we see and feel in terms of the underlying structures that affect observable occurrences. According to Reed (2005), Roy Bhaskar developed critical realism in the latter half of the twentieth century as a response to both positivist direct realism and postmodernist nominalism. Reality is the most important philosophical topic for critical realists (Fleetwood, 2005), which is perceived as external, independent and not accessible through observation and knowledge. Rather, we perceive sensations, which form a manifestation of the real world, rather than objects themselves

(Saunders et al., 2019). Critical realists believe that what we see are sensations that represent the real world but emphasise that our senses often mislead us. Critical realists describe two steps to understand the world; firstly, the sensations and events we experience, and secondly, the mental processing where the researcher reasons backward in a process called retroduction (Reed, 2005). Thus, critical realists tend to look for clearer explanations. Knowledge of the social structures that have given rise to phenomena is essential to support any comprehension of the social world (Fay, 1990). As a result, critical realist research seeks to explain observable, organisational events by investigating the underlying causes and mechanisms by which deep social structures impact everyday organisational life. According to Reed (2005), critical realist research focuses on the in-depth historical analysis of social and organisational structures and their dynamics by embracing epistemological relativism. Thus, such approaches do not adopt quantitative analysis. Axiologically, a critical realist's understanding of reality is a product of social conditioning which cannot be comprehended independently of the social actor. As such, in order to minimize bias and maintain objectivity, a critical realist attempts to be conscious of the ways in which the subject's sociocultural background and experiences could impact a study.

4.5.4 Postmodernism

Postmodernism was pioneered as a critique of positivism in the late twentieth century by the French philosophers Jean-François Lyotard, Jacques Derrida, Michel Foucault, Gilles Deleuze, Félix Guattari, and Jean Baudrillard (Saunders et al., 2019). In their critique of positivism and objectivism, postmodernists went further than interpretivists by emphasising the relevance of language. Postmodernism claims that reality cannot be fully comprehended, and that truth cannot be defined. Extreme postmodernists believe that nothing can be known at all, and that the most researchers can do is allow people to communicate their experiences and sentiments with one another (Saunders et al., 2019). According to postmodernists, impartiality is impossible since everyone has interests and attitudes that impact how topics are chosen, questions are answered, and methods of analysis are adopted. As no two researchers are identical, their opinions are unlikely to be the same (Saunders et al., 2019). Therefore, instead of accepting that there is only one valid position, postmodernists believe that the researcher's perspective is only one of many and has no more legitimacy than the perspectives of those examined. Table 4.4 shows the characteristics of the five research philosophies.**Table 4.4**: Characteristics of the five research philosophies (Saunders et al., 2019)

	Positivism	**Critical Realism**	**Interpretivism**	**Postmodernism**	**Pragmatism**
Ontology	Real, external, One true reality	Stratified/ layered. External, independent, intransient, objective	Complex, rich, socially constructed through culture and language. Multiple meanings, interpretations,	Nominal complex, rich socially constructed through power relations. Some meanings, interpretations, realities are dominated and silenced by others Flux of processes, experiences, practices	Complex, rich, external 'Reality' is the practical consequences of ideas Flux of processes, experiences, and practices

Epistemology	Scientific method Observable and measurable facts Law-like generalisations, numbers, causal explanation and prediction	Knowledge historically situated and transient Facts are social constructions Historical causal explanation as contribution	Theories and concepts too simplistic Focus on narratives, stories, perceptions, and interpretations	What counts as 'truth' and 'knowledge' is decided by dominant ideologies	'True' theories and knowledge are those that enable successful action. Focus on problem solving and informs future practice as a contribution
Axiology	Value-free research, objective researcher who is detached from what is researched	Value-laden research. Researcher acknowledges bias by world views, cultural experience, and upbringing.	Value-bound research. Researchers are part of what is researched, subjective	Value-constituted research. Researcher is radically reflexive	Value-driven research initiated and sustained by researcher's doubts and beliefs. Researcher reflexive

Methodology	Usually deductive, highly structured, large samples, measurement, typically quantitative methods of analysis, but a range of data can be analysed.	Retroductive, in-depth historically situated analysis of pre-existing structures and emerging agency. Range of methods and data types to fit subject matter	Usuallyinductive. Small samples, in-depth investigations, qualitative methods of analysis, but a range of data can be interpreted	Usually deconstructive In-depth investigations of anomalies, silences and absences. Range of data types, typically qualitative methods of analysis	Based on research problem and research question. Range of methods: mixed, multiple, qualitative, quantitative, action research. Emphasis on practical solutions and outcomes

The first layer of the Research Onion is research philosophy; pragmatism was adopted by the researcher in this study. The second layer is the research approach which was developed from the research philosophy; from this layer, abduction was adopted. The third layer is the methodological choice which influences the researcher's decision on the next layer; mixed method was adopted from the third layer. The fourth layer is the research strategy, from which a survey and experiments were adopted. The fifth layer is the time horizon, in which a cross-sectional boundary was adopted, while the sixth and final layer is the data collection and analysis method.

4.6 Theory in Research

A theory is a set of ideas providing an explanation (Collins English Dictionary, 2023). As an explanatory viewpoint, it systematically explains observed facts and laws that relate to a particular aspect of life (Williamson, 2002). Theory serves as the framework in research by offering a background explanation (Bryman, 2016). The development of theory is seen as an important aspect of scientific inquiry (Smyser, 1928), and the three main approaches are inductive, deductive, and abductive. The approach to theory in this study falls between inductive and deductive reasoning (illustrated in Figure 4.4), which is referred to as abductive. Abduction combines deduction and induction by oscillating between theory and data, rather than simply going from theory to data or from data to theory (Makri & Neely, 2021).

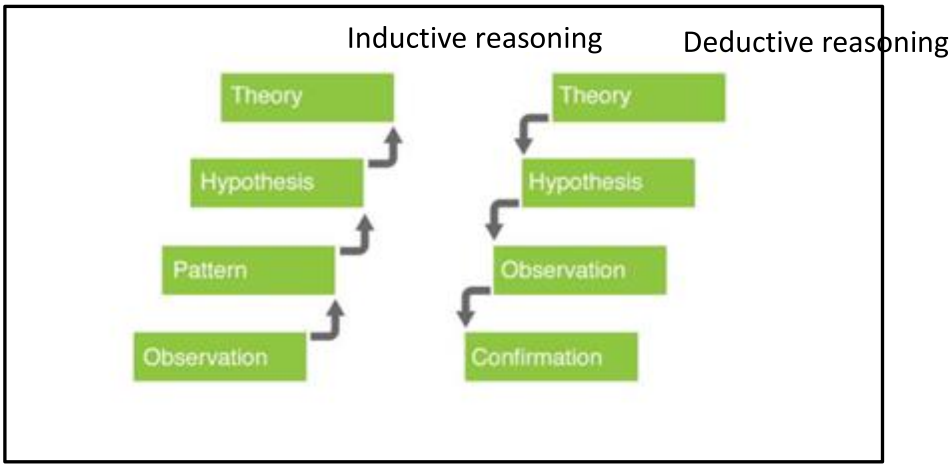


Figure 4.4: Inductive and Deductive Reasoning (i2tutorials, 2019)

4.6.1 Theory Development Approach

The research approach is considered the second layer of the onion and serves as a guide by offering direction for the research design process. After adopting a philosophical perspective researchers must select which method best matches the study (Saunder et al., 2019). The use of theory in research is essential because it gives a context for the research (Bryman, 2016). Theory thus creates the basis for a good perspective on social interaction. As a result, data obtained during research are used to either test or build theories at the end of the study. The three main approaches to inquiry are: deductive, inductive and abductive reasoning (Bryman, 2016).

4.6.1.1 Inductive Reasoning (theory building)

Inductive reasoning helps to create a universal generalisation; it collects data to make generalisations which are then used to explain new observations. An inductive approach implies movement from the specific to the general, or from practice to theory. A small sample can be sufficient to generate theories in an inductive approach. Interpretivism is frequently applied to inductive thinking since it is both open-ended and exploratory in nature.

4.6.1.2 Deductive Reasoning (theory testing)

Deductive reasoning tries to evaluate existing theories, develop a theory, or deduce a hypothesis, which is then tested through comparison with empirical results (Blaikie, 2007). It starts with a general statement and concludes with a specific statement, which is known as a top-down method and is frequently associated with positivism. It is heavily influenced by scientific study, as deductive approach helps to quantitatively evaluate facts and explain linkages (cause-and-effect) between variables. Laws serve as the foundation for explanation, allowing the deductive researcher to anticipate phenomena, and hence govern their occurrence. It is the dominant approach in the natural sciences (Saunders et al., 2019).

4.6.1.3 Abductive Reasoning

Abduction starts with the observation of an 'astonishing reality'; a credible explanation is then devised to explain what happened (Saunders et al., 2019). It combines deduction and induction by going back and forth between the two, rather simply than going from theory to data or data to theory (Suddaby, 2006). Researchers from a variety of research philosophies can employ an abductive approach because of its flexibility (Saunders et al., 2019).

4.7 Methodological Choice

According to Saunders et al. (2019), methodological choice is the theory of how to evaluate research. Research methodology addresses the whole research process, which influences how research is carried out, as to answer a research question/s, a range of methods can be used. It is concerned with the development and nature of epistemology in the field of research. The aim of the study, any epistemological considerations, and previous work in the field influence the methodological choice (Buchanan & Bryman, 2007). Traditionally, qualitative and quantitative research were the only research methods considered (Bell et al. 2018). Quantitative research is centered on an objectivist ontological viewpoint and positivist epistemology with a deductive approach and analyses the scientific assumption in the science field. In comparison, qualitative research adopts a subjectivist ontological viewpoint and adopts an interpretivist epistemology with an inductive approach. It evaluates social occurrences in the field of social science field. The combination of quantitative and qualitative research makes it possible for researchers to understand different viewpoints, positions, and perspectives (Johnson & Onwuegbuzie, 2007). Mixed methods research integrates approaches from quantitative and qualitative practices to answer research questions that cannot be answered by a single method (Tashakkori & Teddlie, 2003). Mixed methods are used in this thesis due to the combination of qualitative and quantitative approaches.

4.7.1 Quantitative Method

The aim of quantitative research is to analyse and evaluate natural phenomena. It typically relates to natural science and the quantification of data and analysis (Bryman, 2016), and tends towards the social science description of a 'scientific method'. Quantitative research is influenced by a deductive approach, positivist epistemology, and an objective ontological perspective (testing of theory). Statistical analysis is conducted on the data collected by using descriptive or other complex statistics such as regression or correlation analysis (Wilkinson, 2015).

The quantitative method examines the relationships between variables which are measured numerically, and the researcher is considered separate from the participants. According to Kumar (2014), quantitative research has the following attributes: Quantification of the extent of variation; the measurement and objectivity of the process; substantiation on the basis of a large sample size; emphasis of validity and reliability; the analytical communication of findings; and the generalisation of conclusions and inferences. A single data collection technique can be employed, referred to as mono method, while two or more data collection techniques is referred to as multi method (Saunders et al., 2019). In summary, a quantitative methodology is commonly employed in natural science research and is typically deductive, objective and encourages the generalisation of findings.

4.7.2 Qualitative Method

Qualitative research is mostly exploratory in nature and commonly found in the humanities and social sciences. It typically relates to a subjective ontological approach with an interpretivist epistemology and inductive approach (Denzin & Lincoln, 2018). Qualitative research generates meaning from words and images concerning social phenomena and the natural environment (Creswell, 2018). Its focus is on the lived experiences and knowledge of participants. A study by Clarke et al. (2019) concluded that outcomes from qualitative research are often skewed toward a specific audience. However, research participants often provide longer narratives about a phenomenon, therefore a lot of data can be generated. Using a small number of participants, qualitative research produces limited but comprehensive data which reveal participants' narratives (Clarke & Braun, 2018). Moreover, the researcher is inseparable from the researched. Interviews, focus groups, and participant observation/ethnography are examples of qualitative data collection approaches (Creswell & Clark, 2017). As well as examining complicated issues, the qualitative approach also describes phenomena in detail based on human experience. According to Kumar (2014), qualitative research: follows an open, flexible, and unstructured approach; explores diversity; emphasises description and the narration of feelings, perceptions and experiences; describes and narrates findings; and places minimal to no emphasis on generalisation. A single data collection technique can be employed, referred to as mono method, while two or more data collection techniques is referred to as multi method (Saunders et al., 2019). In summary, qualitative research is commonly employed by social science and humanities researchers and is based on in-depth descriptions of personal experience from a small number of participants. It is based on human interpretation and cannot be generalised. Table 4.5 lists the distinct characteristics of quantitative and qualitative methods.

Table 4.5: Distinction between quantitative and qualitative research approaches (Saunders et al., 2019)

Inclination	**Quantitative Method**	**Qualitative Method**
Philosophy	Positivism/realism	Interpretivism/idealism
Research Objective	Confirmatory scientific (hypothesis and theory testing)	Exploratory scientific method (hypothesis and theory generation)
Methodology	Experimental/manipulative	Hermeneutical/dialectical
Role of Theory	Deductive approach	Inductive approach
Epistemology	Objectivity and generalizable (one true reality)	Subjective, reality is socially constructed, individual and context specific
Axiology	Value free	Value bound
Types of Result	Generalizable findings based on statistical techniques	Descriptive, narrative, and individual specific
Research Methods	Experiments, measurements, questionnaire, verifiable examination,	Case study, ethnography, filming, focus group, interviews, observation, and narration
Data Analysis	Statistical analysis and diagrams	Identify patterns, themes, and diversity, and utilise descriptive data.

Data Type	Numerical	Non-numerical (observable)
Data Instrument	Variables, structured and validated data collection instrument	Words, images participant observation, field note, audio recordings

4.7.3 Mixed Method

According to Creswell & Clark (2017), mixed methods is characterised as a research technique that integrates qualitative and quantitative strategies across several phases of the research process and is guided by a philosophical perspective and method of enquiry. In a single study or program of inquiry, the investigator collects and analyses data, integrates findings, and develops conclusions utilising both qualitative and quantitative approaches and methods (Tashakkori & Teddlie, 2010). A mixed methods approach offers an opportunity to combine qualitative and quantitative methodologies. It is frequently associated with two philosophical positions, pragmatism and critical realism, and adopts either an inductive, deductive, or abductive research approach to develop theory (Saunders et al., 2019). The theory can give the research greater focus and can help to develop boundaries in terms of scope (Tashakkori & Teddlie, 2010). It affords the researcher flexibility by taking advantage of both qualitative and quantitative research approaches (Creswell & Clark, 2018). The researcher benefits from a hybrid method since it mitigates the drawbacks of separate qualitative and quantitative approaches. This research method is utilised when qualitative or quantitative research methods alone are insufficient to address the research questions (Clark & Creswell, 2018). Different sorts of mixed methods can be applied depending on how and to what extent these techniques are used (Creswell & Clark 2011). Quantitative and qualitative methodologies are integrated in various ways to create complex and sequential approaches. A concurrent mixed method refers to the application of both quantitative and qualitative approaches within a single phase. In comparison to a mono method design, this enables a deeper and more comprehensive response to the research question. In a sequential mixed technique, data collection and analysis take place throughout several phases. Qualitative and quantitative flaws are minimized in mixed method research, allowing the researcher to be flexible and integrative while yet producing generalisable results (Creswell & Clark, 2017). Mixed methods was selected as the best method to answer the research questions in this study. It was therefore adopted due to its methodological eclecticism, which involves the use of techniques that encompass quantitative and qualitative methods. It involves knowledgeably and intuitively selecting the best techniques to answer research questions that may evolve as the study unfolds.

4.8 Choosing a Time Horizon

Depending on the type of research question/s, a study can involve a series of events over a long period of time, which is usually referred to as longitudinal, or the examination of a particular phenomenon at a specific time, referred to as cross-sectional (Saunders et al., 2019). Irrespective of the methods chosen, research questions are highly significant for the researcher to address the amount of time needed. According to Saunders et al. (2019), if the research is conducted at a particular point in time, it is said to adopt a cross-sectional time horizon. However, this approach does not necessarily provide information on why and how circumstances change over a long period of time. This study aimed to investigate the potential for vertical greening as a sustainable strategy to mitigate the effects of climate change and impact the microclimate of the streetscape in Northern Nigeria and other semi-arid regions. However, the time horizon for this study was cross-sectional because this research was conducted at a specific time.

4.9 Research Design

According to Saunders et al. (2019), the choice of research philosophy and approach to theory development influences answers to the research question. However, the next three layers of the Research Onion are influenced by the research philosophy and approach to theory development. These three layers - methodological choice, research strategy or strategies, and the time horizon - focus on the research design process, which shows how research question/s are transformed into a research project. However, the most important consideration is to reflect a full consideration of the components of research design. To achieve coherence, each of these options is likely to call for a different mix of elements (Blaikie, 2007). Likewise, one or more research strategies will need to be used to ensure coherence within the research project. However, to select the most appropriate technique/s, a researcher must focus on the research questions (Patton, 2002; Rossman & Rallis, 2017). The choice of a suitable time horizon will be influenced by methodological choices and the related strategies. Each research design will generate ethical concerns, which must also be considered. A comparison of two of the most popular research design models was conducted and the Research Onion adopted as the most appropriate model to develop the research design.

This research was underpinned by a pragmatist philosophy and applied a mixed method research design that started with a qualitative research method followed by a quantitative research method. It involved semi-structured interviews with members of the building industry and other stakeholders to explore the potential for vertical greening as a sustainable strategy to mitigate the effects of climate change and impact the microclimate of the streetscape in Northern Nigeria and other semi-arid regions. In addition, neighborhoods in Kano metropolis were selected and modelled in a microclimate simulation tool (Envi-met) to explore and explain the impact of vertical greening on the microclimate in the semi-arid region of Nigeria and other semi-arid regions. An experimental method was adopted to explore the modelled building, which also allowed the researcher to manipulate the variables in different scenarios in terms of vegetation type, and percentage coverage to determine its effect on the microclimate.

4.10 Selected Research Method and Justification

The researcher's goal is to obtain the most comprehensive data in order to fully understand and develop better knowledge of the implementation and impact of vertical greening on the microclimate of the streetscape in Nigeria and other semi-arid regions. Utilising a mixture of approaches can help researchers find solutions to challenges (Abowitz & Toole, 2009). Mixed methods research entails the use of both qualitative and quantitative methodologies in a single study (Creswell, 2014). A qualitative approach enables the researcher to establish in-depth knowledge on the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria while a quantitative approach enables the researcher to use a microclimate simulation software to identify the impact of vertical greening in a specific Nigerian climate and particular building type within a number of scenarios. Qualitative research can provide a greater knowledge of events that have occurred in genuine, day-to-day situations, and the meanings and processes that result from human interaction (Daher et al., 2017). While in an experimental design, the quantitative approach explores the relationships between variables, numerical measurement and statistical analysis under a controlled environment to assure the validity of the data (Saunders et al., 2019). In this study, the researcher used mixed methods research as it had the potential to elucidate the factors that impact the integration of vertical greening, as well as the impact of vertical greening on the urban microclimate such as temperature, humidity, and air quality, and its ability to mitigate climate change.

4.11 Philosophical Stance

A philosophical stance is characterised as the direction and belief of the world view and nature of research studied by the researcher (Creswell, 2004). Thus, it explains the philosophical underpinning of the research. Every philosophical stance influences the way researchers undertake a study. These conceptual positions are based on the researcher's discipline, their supervisor's background, and prior research experience (Denzin & Lincoln, 2013). Table 4.6 indicates the ontological, epistemological, and axiological assumptions and methods adopted by the researcher in this study. Figure 4.5 illustrates the philosophical stance adopted by the researcher. It indicates the contrast between social science and pure science research. This research uses both stances to get the most comprehensive answers to the research questions.

Table 4.6: Assumptions and Methods (Saunders et al., 2019)

Ontology (Existence of reality)	**Epistemology (what connotes genuine and acceptable knowledge)**	**Axiology (beliefs on value)**	**Methods**
Pragmatism			
Reality is the practical implication of beliefs,	'True' theories and knowledge are those that enable successful	Value-driven research initiated and sustained by	Mixed method research with emphasis on practical

encounter, and practices.	action and focus on problem solving.	researcher's doubts and beliefs	solutions and outcomes

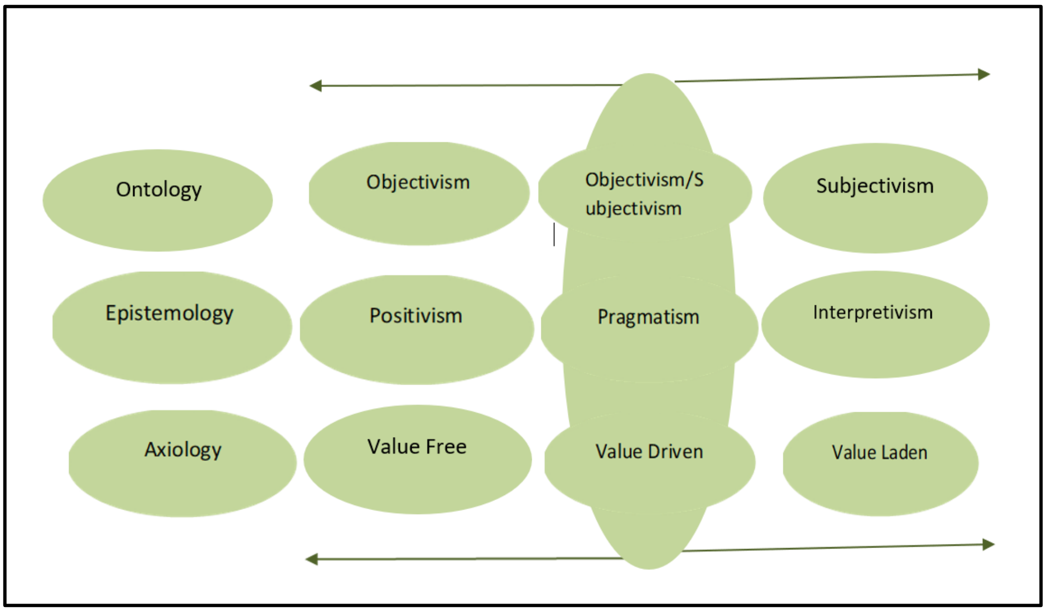


Figure 4.5: Distinction between social science and pure science research and the researcher's stance. (Saunders et al., 2019)

4.12 Ethical Considerations

Ethics can be defined as the moral norms that impact how we behave and interact with others (Cooper & Schindler, 2014; Saunders et al., 2009). Research ethics involves conducting the entire research project in a moral and ethical manner. Ethics is concerned with advising researchers in a specific discipline how to conduct their study in an ethically acceptable manner (Forrester & Sullivan, 2018). According to Saunders et al. (2019), ethics in a research setting denote the appropriateness of behaviour in relation to the rights of those who become participants in the research or are affected by the research; thus, a research design should not subject participants to risk in any form. In social science, 'ethics' is described as the moral deliberation, choice, and accountability of researchers during the study process (Joungtrakul & Allen, 2012). It is also a function of obligation, namely the researcher's social and moral responsibilities (Denzin & Lincoln, 2011). Other ethical responsibilities include those connected to individual researchers, research subjects, professional colleagues, the learning community, and research sponsors (Hitchcock et al., 1995). According to Silverman (2016), qualitative researchers must address the following critical ethical issues:

- Consent: Study participants have the right to know they are being studied, the right to be informed about the nature of the research, and the right to withdraw at any time. The participant should be informed whether their involvement includes any dangers, how their data will be managed, who will have access to their data, and the goals and purpose of the research (Ravitch & Carl, 2019). Consent implies that participants must be informed of their voluntary participation and their free will to withdraw at any time during the study.
- Confidentiality: Built on the principle of autonomy and interpreted to indicate that personal information gathered throughout the study process will not be revealed without authorisation (British Sociological Association, 2017). It implies that the researcher is obligated to protect each participant's identity, place, and location in the study.
- Trust: Focuses on the relationship between the researcher and participants, including the researcher's commitment to conduct the research in a professional manner to allow potential researchers immediate access to subjects (Silverman, 2016). Participants in the study must be able to trust the researcher as this fosters the positive interaction required throughout the study.

It is critical to examine ethical challenges when designing a research project and gaining access to organisations and individuals. However, it is vital to remember that each institution has its own code of ethics and regulations that inform the methods for conducting research. The researcher considered ethical considerations and complied with the University of Salford's research ethics framework (see Appendix 2). Before the data collection phase, the necessary ethical approval forms were completed and submitted, and approved by the University of Salford’s Research Ethics Committee. Participants were also provided with a copy of the ethics code in the form of a consent form (see Appendix 4) to encourage trust and to assure that any information gathered would be kept confidential and anonymous. Participants in the study were also informed they could leave at any moment, with or without giving a reason.

4.13 Selection of the Research Strategy/Strategies

A plan of action to achieve a set goal is called a strategy, while a research strategy is a plan of how a researcher will address the research questions. It is the methodological relationship that exists between philosophy and the data collection and analysis procedures (Denzin & Lincoln 2018). Various research traditions have led the development of a variety of research strategies, primarily associated with quantitative, qualitative, and mixed method research designs (Saunders et al., 2019). A research philosophy and approach to theory development may be linked with specific research strategies. One research strategy is not considered inherently better or worse than another; rather, the ability to answer research questions and maintain coherence throughout the research design are the most significant considerations (Saunders et al., 2019). The extent of current knowledge, available time, resources, access to potential participants and other data sources influence the choice of research strategy. Moreover, different research strategies can be combined as they are not mutually exclusive (Lê & Schmid, 2020). The research strategy is greatly influenced by the researcher's philosophical stance (Saunders et al., 2019) as it outlines the process by which the research is conducted, and the data is collected, analysed, and interpreted (Bryman, 2016). Various research strategies are discussed below.

4.13.1 Case Study Strategy

According to Yin (2014), an in-depth investigation of a topic or phenomenon in its real-world context is termed a case study. The case may refer to different types of subjects such as a person, group, organization, or event (Saunders et al., 2019). The case study strategy is a qualitative approach that gives an in-depth understanding of the research problem using a variety of evidence such as interviews, artefacts, questionnaires, documents, and observations (Yin, 2014). It can yield insights through a rigorous and in-depth investigation into a phenomenon in its real-life context, resulting in rich, empirical descriptions and the creation of theory (Yin, 2014). In a case study strategy, it is important to understand the context. Dubois & Gadde (2002) argue that case studies are the greatest way to develop a deep understanding of the interplay between a phenomenon and its setting. A case study research strategy is distinguished from other strategies because the study takes place within a real-life setting or context (Saunders et al., 2019). It is designed to understand the interactions between the subject of a case and its context. Case studies are ideal for researchers who want to gain a thorough understanding of the research context and processes (Morris and Shore, 1991). In addition, it can be used to identify what is happening and the reason for its occurrence, as well as to comprehend the consequences of the situation and the implications for action (Saunders et al., 2019). Case study research is best at giving in depth knowledge of the interaction of a case within its real-life context.

4.13.2 Survey Strategy

A survey strategy is often applied in exploratory and descriptive research as it is used to address questions such as 'who,' 'what,' 'where,' 'how much' and 'how many'. It is generally associated with the deductive approach to research (Saunders et al., 2019). According to Fellows and Liu (2003), a survey is a cost-effective collection of uniform data. Saunders et al. (2019) explained that within a survey strategy, statistical analyses using inferential and descriptive statistics are possible with the aid of data collection tools like questionnaires, structured interviews, and structured observations. Such analysis can explain why a probable relationship between variables exists and develop models of those correlations. Furthermore, a survey strategy is relatively simple to explain and comprehend. Using a survey technique provides better control over the research process, and the ability to generate conclusions that are statistically representative of the entire community at a lower cost than collecting data for the entire population (Saunders et al., 2019). Survey data is unlikely to be as diverse as data acquired through other research strategies as there is a limit to the number of questions posed to ensure the best possible response rate from the sample (Saunders et al., 2019).

4.13.3 Action Research

Action research is participatory and designed to create solutions to particular organisational problems through collaboration (Saunders et al., 2019). It is an iterative investigative problem-solving approach (Saunders et al., 2019) that involves the process of acting and observing the process and consequences of the transition, reflecting on those mechanisms and consequences and then re-planning, observing, and reflecting (Kemmis & McTaggart, 2000). According to Koshy (2010), action research contributes to the resolution of practical problems in order to bring about change in a particular context. A variety of skills must be developed and utilised by the researchers to achieve the set goals, including careful preparation, good observation, listening, and assessing and analysing objectively. Action research is useful due to its emphasis on change and the engagement of participants in the research process but requires substantial time to allow for preparation, analysis, intervention, and assessment (Saunders et al., 2019).

4.13.4 Experimental Research Strategy

An experimental strategy is a type of natural science research that also plays an important role in psychology and social science (Goodin, 2011). Experiments are commonly employed in exploratory and explanatory research to answer 'what', 'how', and 'why' questions (Saunders et al., 2019). The goal of an experiment is to determine the change in a dependent variable from change in an independent variable; thus, the researcher manipulates one or more variables to observe their effect on another/s (Hedge, 2015). Experimental research is best employed for problems with known or confidently hypothesized variables (Fellows & Liu, 2015). In an experiment, the researcher utilises a hypothetical explanation (hypothesis) to predict whether there is a relationship between the variables. In a standard experiment, two contrasting hypotheses are formulated: the null hypothesis (no relationship between the variables) and the alternative hypothesis (a relationship between the variables). The simplest experiments are concerned with determining if two variables are related, whereas more complex experiments address the magnitude of the change and the relative significance of two or more independent variables (Saunders et al., 2019). Experimental designs (such as classical and quasi-experiments) have varying benefits and drawbacks and can be applied with control and confounding variables.

This research employed two strategies: firstly, an experimental strategy to investigate the impact vertical greening integration in the semi-arid region of Northern Nigeria, and secondly a survey strategy (structured interview) to investigate the impact of vertical greening on the urban microclimate, specifically on temperature, humidity, and air quality, and its ability to mitigate climate change). In the experimental research strategy, the researcher manipulated the plants (independent variable) in terms of type, percentage coverage and proximity to the building to observe the effects on the microclimate (dependent variable).

4.14 Sampling Techniques

In some research, it is possible to collect data for the entire population due to its size. However, sampling occurs when limitations on time and expenditure prohibit the researcher from surveying the whole community, or where surveying the entire population is practically impossible (Saunders et al., 2019). Due to time, money, and often access constraints, it can be impossible for researchers to collect or analyse all the prospective data. This necessitates the selection of data for a subgroup or sample to represent all potential scenarios. By evaluating data from a subgroup, sampling techniques allow the researcher to limit the amount of data needed for collection. Thus, some research questions allow for the generalisation of all cases from which the sample is selected (Kumar, 2014). A range of sampling procedures are available to help the researcher reduce the amount of data needed. According to Saunders et al. (2019), methods are often divided into probability and non-probability sampling, while a combination of the two is known as multi-stage sampling. Multi-stage refers to a sampling technique with two or more sequential steps and can use either probability, non-probability, or both types of sample selection. There are no restrictions on the number of techniques utilised in research.

4.14.1 Probability Sampling Techniques

In probability sampling, the likelihood of selecting each case from the target population is known and usually equal for all cases. This implies the statistical estimation of the target population's attributes from the sample to answer the research questions thereby and achieve the objectives. According to Etikan (2016), probability sampling consists of four stages:

1. Identifying the most appropriate sampling method based on the research questions and an appropriate sample size.
2. Selecting the most appropriate sampling method and sample.
3. Determining the relationship of the sample to the population indicated in the research.
4. Ensuring the survey is a representation of the entire population.

According to Acharya et al. (2013), probability sampling is mostly used in survey-based testing techniques, and target populations are drawn at random from the population. Probability sampling enables the researcher to statistically predict the characteristics of the population based on the survey (Saunders et al., 2019), thereby addressing the research questions. Additionally, Saunders et al. (2019) highlighted four probability sampling techniques, namely simple random, systematic, stratified random, and cluster.

4.14.2 Non-probability Sampling Techniques

Non-probability samples are those in which the likelihood of choosing each case from the target population is unknown. Answering research questions or meeting objectives that require statistical assumptions concerning the population becomes impossible with these techniques. However, it is still possible to generalise the target population from non-probability samples, although not statistically. In addition, the research questions, objectives and strategy employed may direct the researcher to adopt more than one technique. Saunders et al. (2019) highlighted four non-probability sampling techniques: Quota, purposive, haphazard, and volunteer sampling. The different types of sampling techniques are elaborated in Table 4.7.

Table 4.7: Sampling Techniques (Saunders et al., 2019)

Probability Sampling	***Non-probability Sampling***
Simple Random Sampling Involves selecting the sample at random from the sampling frame. Every participant has an equal possibility of being selected.	***Quota sampling*** It is a non-random option to probability sampling for Internet and interviewer-completed questionnaires. Quota sampling is based on the argument that the sample will represent the target population as irregularity in the sample is the same as the target population. It involves participants who are representative of the larger population.
Systematic Sampling Systematic random sampling entails selecting a sample from the sampling frame at regular intervals. It requires a complete population list and every nth is selected.	***Purposive Sampling*** Also known as judgmental sampling, it requires the researcher to exercise discretion in selecting cases that will best answer the research question(s) and fulfil the objectives.
Stratified Radom Sampling The target population is divided into relevant and significant strata based on some attributes and a random sample (simple or systematic) is then drawn from each of the strata.	***Volunteer Sampling*** Also known as snowball sampling, it involves participants that volunteer to be part of a study when it is difficult to find members of the desired population. After two or more contacts, the researcher requests the volunteers suggest additional contacts.
Cluster Sampling The target population is divided into discrete groups called clusters prior to sampling (Barnett, 2002). The sampling frame is the	***Haphazard Sampling*** Cases are selected haphazardly simply because they are readily accessible (or most convenient) for sampling with no regards to

complete list of clusters rather than a complete list of individual cases within the population.	clear organisational principles in relation to the research question.

This research employed purposive sampling which is a type of the non-probability sampling as it gathers responses (from building professionals and other stakeholders) that will best enable the researcher to answer the research question on factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria.

4.15 Envi-Met Simulation Model

Envi-met is a three-dimensional micro-climate prognostic model that simulates on a microscale the interaction between atmosphere, soil, vegetation, and buildings (Huttner, 2012). The Envi-met model was developed by Michael Bruse at Rurh University of Bochum (Bruse & Fleer, 1998) and is now widely used as a micro-climate analysis dynamic simulation tool. Based on various urban climate analyses, it can be concluded that the Envi-met model is reliable provided that the user accounts for all limitations during the interpretation of the simulation (Tsoka et al., 2018). Envi-met was selected for this research as it provides a multitude of tools to simulate and analyse interactions between the vegetation and microclimate. It calculates the following prognostic variables which directly relate to the core analysis of this research (Huttner, 2012):

a. Direction and speed of wind.
b. Temperature of air and soil.
c. Humidity of air and soil.
d. Turbulence.
e. Radiative fluxes.
f. Gas and particle dispersion.

4.15.1 Microclimate Modeling in Envi-Met

Envi-met is a three-dimensional predictive microclimate model that simulates the interplay of surfaces, plants, and air in an urban environment (Bruse & Fleer, 2009) with a typical resolution down to 0.5 metres in space and one to five seconds in time. Envi-met is a prognostic model that is based on the fundamental laws of fluid dynamics and thermodynamics. It is a state-of-the-art, high-resolution, three-dimensional microclimate modelling system. Thus, it can be used in areas such as architecture, landscape architecture, building design, and environmental planning, amongst others. The urban microclimate is an interactive system consisting of dozens of dynamic subsystems that can be simulated with Envi-met, which includes atmospheric dynamics, soil physics, and vegetation response to building indoor and outdoor climate. Mean air flow, turbulence, short-wave, and long-wave radiation fluxes, air temperature, and humidity are calculated using atmospheric dynamics. Moreover, soil physics estimate surface and soil temperatures, as well as soil water fluxes, and are linked to the vegetation model, which calculates evaporation rates, leaf temperature, and heat, evaporation, and transpiration fluxes between the vegetation and environment. Building physics calculates momentum, heat, and vapour fluxes at and inside the building walls and roofs while also considering material qualities. All systems, from soil hydrology to building energy modelling, are estimated in a single large model, such as an urban quarter, which allows them to interact and adapt in the same way as real-world environmental systems. The Envi-met system offers high-resolution data for any of these components, whether a single structure out of 500 or a single tree among 1,500. Additionally, Envi-met simulations of the following are included in the model:

- Impact of vegetation on the local microclimate,
- Bioclimatology,
- Pollutant dispersion.

4.16 Strategies/Methods Adopted in this Research and the Justification

Pragmatism aims to balance objectivism with subjectivism as it seeks views that provide the complete picture. It evaluates theories, concepts, ideas, hypotheses, and research findings in terms of their function as tools for thought and action. Moreover, it assesses their practical repercussions in specific circumstances, and enables the prioritisation of practical impacts of ideas and knowledge due to their ability to enable successful action.

Mixed methods was employed in this study using both qualitative and quantitative approaches with the aim of achieving the most comprehensive answers to the research questions. Interviews were conducted to uncover the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria according to building professionals and other stakeholders. Furthermore, a microclimate simulation was conducted with the exact natural characteristics of the setting while other variables were manipulated to determine effects on the urban microclimate, such as temperature, humidity, and air quality, with no alteration to the natural setting and at minimal time and cost. It incorporated control to ensure the validity of the data (Saunders et al., 2019). Observation has been the traditional means of investigation into the urban microclimate (Tsoka et al., 2020). However, advances in computational resources in the last decade have seen numerical scientific tools gain significant attention in the search for adaptable strategies (Tsoka et al., 2018).

According to Tsoka (2018), from its first release in 1998 through to 2017 the Envi-met model has been used by 1900 users for microclimate research. In March 2018, 280 related papers featured in the Scopus database. The model has been applied in most existing studies, not only for the investigation of current microclimate conditions, but also for a comparative evaluation of the output of different mitigation strategies against the UHI effect.[1] Envi-met studies listed in the Scopus Database were further categorised by their geographic location. The bulk of these studies were conducted in Europe and Asia, rarely in Australia and very few in Africa although those featured were predominantly based in North Africa. A great part of Envi-met research has been conducted in areas characterised by humid subtropical climate with most case studies in South and South-eastern part of China, and in the warm Mediterranean climate predominantly in the south of Europe, such as Italy, Greece, and Portugal. A large number of studies was conducted in the marine/ocean climates found in the eastern and central parts of Europe (Tsoka, 2018). However, no research study has been

[1] The urban heat island (UHI) phenomenon is a prominent environmental concern evident in urbanized areas, marked by a significant rise in air temperature compared to the adjacent suburban regions. Xie et., al 2015.

found on the adoption of the Envi-met model to assess vertical greening in semi-arid regions such as Nigeria.

4.17 Data Collection, and Analysis Technique and Procedure

Data collection and analysis are within the inner layer of the Research Onion (Saunders et al., 2019), and varieties of tools and techniques can be applied (Webb, 1949) The data collecting techniques include experiments, interview, questionnaire survey, and focus groups (Suter, 2014). Both quantitative and qualitative data were generated in this study. Quantitative data were generated through a microclimate simulation with the aid of the Envi-met model, although secondary data in the form of meteorological data were also required for the simulation. The qualitative data generated by this research were obtained from semi-structured interviews with building professionals and other stakeholders and were thematically analysed.

4.17.1 Criteria for study area selection

There are numerous factors that affect the urban heat island effect and temperature rise in urban areas. These include the depletion of greenery, high building densities, the use of reflective materials for building facades, the high use of impervious and heat-retaining materials, and the increased greenhouse gas emissions from vehicles and buildings. Additionally, the emergence of air pollution as a significant issue further exacerbates these factors (Rupasinghe & Halwatura, 2020).Kano metropolis is between longitudes 80 25’ E to 80 40’E and latitudes 110 50’ N and 120 10’ N. The metropolis comprises of eight (8) local government areas (Dala, Fagge, Gwale, Kano Municipal, Nassarawa, and Tarauni) and parts of Kumbotso and Ungoggo (Maigari, 2014). It covers a total built-up area of about 238.42 km2 as of 2018. The metropolis's population is projected to about 4, 008, 306 (population stat.com,2020). The area has undergone rapid growth and transformation, which is accompanied by an increase in the intensities of human activities, land conversion, convergence and dynamics of social and environmental risks and disasters (Barau et al., 2015).

A semi-arid climate characterises the metropolis, with a daily mean temperature of about 30C. Lowest temperatures, i.e. 20C, are, recorded between December and February (Tanko and Momale, 2014). The climate is characterised by two main seasons: the wet rainy season around May- October and the dry season between November and April. The climate is the tropical wet and dry type coded as Aw by Koppen‘s climate classification. The rainfall regime is such that the amount is highest in the south(1200mm/annum) and decreases northward to less than884mm/annum.

Despite the potential benefits, vertical greening in Nigeria is still in its infancy, and there is a limited understanding of these systems. There have been very few studies investigating the impact of vertical greening integration in the semi-arid region of Northern Nigeria and the implications of its implementation. This underscores the need for further research in this area.

4.17 Secondary Data

Secondary data is data obtained for other purposes and used for further analysis to provide additional knowledge and interpretation (Bishop & Kuula-Luumi, 2017). This may include both raw data and published summaries (Saunders et al., 2019). Secondary data helps the researcher respond to the research question, either completely or partially. Over the last decade, the number of secondary data sources has exploded, as has the ease with which they can be accessed (Rabianski, 2003). To support their day-to-day operations, most businesses acquire and store a substantial amount of data. These may include business transactions, photographs of events, official statistics covering social, demographic, and economic topics, historical documents, such as photographs, drawings, among other sources. Some data are peculiar to some organisations and need to be negotiated for access while others are readily available online for download, such as government survey data (most governments make their data open to the public). Secondary data are often the most likely main source for answers to the research question(s) and help to address objectives that require national or worldwide comparisons. This can also be useful when gathering data from a large sample or developing a historical or longitudinal study. This research utilised a combination of secondary and primary data. The secondary data took the form of meteorological data such as temperature, humidity, wind speed and direction which were input into Envi-met.

4.18 Primary Data: Research Interview

The research interview is a structured dialogue involving two or more persons whereby the interviewer asks succinct, explicit questions and listens intently to the interviewee's responses (DiCicco-Bloom & Crabtree, 2006). Successful interviews rely on the interviewer and interviewee developing a bond. An interviewer can investigate areas of interest and elucidate and verify meanings by listening closely to the interviewee. Research interviews can aid in the collection of meaningful and dependable data which are relevant to the research question(s) and objectives. Interviews are broadly classified into objective and subjective approaches. The philosophy, goal, and technique of these two interview approaches differ significantly. The character of any interview should be compatible with the research question(s), objectives, research purpose, and research strategy adopted. The research interview is viewed as a means of collecting data from interviewees who are considered witnesses to a situation that exists independently of them. This method has its origins in research that relies on interviewees to offer answers to questions that are mainly assumed to be true. In this study, the research interview was viewed as an acceptable and effective method of data collection, provided that suitable participants could be identified. The difficulty with this technique is that it focuses solely on finding answers rather than attempting to comprehend interviewees' perspectives and cultures as social actors who interact with, interpret, and construct their social environment and are changed by it. The understanding that perceptions about the social world are socially formed is linked to a subjective approach, which considers that interview data are socially created, produced jointly by the participant's views and interpretations, and the interviewer’s questions and responses to the participant (Denzin, 2001). Thus, an interview acknowledges the interviewer's position in the construction of meaning, as well as their ability to reflect on and analyse the interviewing method.

Furthermore, in order to conduct the interviews, purposive sampling was employed to select and consult building and horticultural experts in public and private sector for the qualitative interviews. The group of professionals consisted of Architect, Urban planners,Landscape architects and horticulturist who are experts in the field and are in active research. Purposive sampling involves selecting individuals who possess the expertise and knowledge to participate in an interview (Etikan et al., 2016). These individuals were selected based on their extensive knowledge and experience in building and agricultural practice. The identified experts were sent a consent letter and several semi-structured interviews were conducted with them. The interviews were organized and planned according to the participants' convenience. The interviews were conducted informally and were conversational in nature in order to further enhance transparency and integrity. It made the interviewees felt more at ease.The study utilized a semi-structured interview approach, where a predetermined interview guide (see appendix 5) was created beforehand.

Different types of research interview depend on the number of participants or the structure of the research interview, which can be structured, semi-structured, or unstructured. In addition, Saunders et al. (2019) explained that interviews can be performed in a variety of ways, including face-to-face, over the phone, and online. Interviews can be conducted entirely through speech or visually. Some examples include group and focus groups, telephone interviews, Internet-mediated (electronic) interviews, and visual interviews.

4.18.1 Structured Interviews

Structured interviews are based on a predetermined set of identical questions and are carried out by disseminating questionnaires which are completed by the researcher. Questions are read out from the questionnaire, and responses recorded on a standardised schedule. They are referred to as quantitative research interviews as they are used to collect quantifiable data.

4.18.2 Semi-structured Interviews

Semi-structured interviews are often referred to as ‘qualitative research interviews’ and are ‘non-standardised’. To guide the conduct of each interview, semi-structured interviews begin with a planned list of themes and key questions relating to these themes are influenced by the philosophical assumptions. When a researcher believes truth is external to the interpretation of the participant, a more structured and consistent approach to the conduct of a semi-structured interview is utilised to explore each theme consistently with each participant. Thus, participants’ responses to each theme can be compared to uncovering the underlying reality.

4.19 Envi-met Simulation

To perform an Envi-met simulation, the input parameters must be provided for the area input file, database, and configuration files. the area input file (.INX) stores data regarding the size and resolution of the domain, as well as the spatial characteristics of the calculation mesh. This is undertaken by using an orthogonal 3D grid (either equidistant or telescoping), in which sizes in x, y and z directions can be defined by the user. Links with the database ensure that descriptive parameters (such as thermal conductivity, albedo, and water content) for soil, vegetation and surface materials can be used to solve equations within this mathematical model. Finally, the configuration file (.SIMX) stores the simulation settings including weather boundary conditions.

4.20 Qualitative Data Collection Tool

According to Saunders et al. (2019), research data is information acquired from primary and secondary sources for the purpose of conducting research. This section provides an overview of the qualitative data collection, namely the interview process employed during the qualitative phase of the study. A semi structured interview was adopted as participant responses influenced the questions.

4.20.1 Semi-Structured Interview

An interview is a carefully planned dialogue between two or more persons in which one participant (the interviewer) asks questions and the other (the interviewee) responds voluntarily. Purposive sampling was used to identify experts in the building industry and other stakeholders. The researcher’s judgement was used to select cases that would best answer the research question(s) and achieve the objectives - also referred to as judgmental sampling (McIntosh & Morse, 2015). This technique is often used when working with very small samples, as in case study research, and for the selection of cases that are particularly informative. The research question(s) and objectives determine the strategy for the sample selection in purposive sampling. In purposive sampling, for the sample to be statistically representative it is important to select information rich samples (Patton, 2015). Individuals with the relevant expertise and required knowledge are invited to take part in the interview. The selected professionals were considered for this study because they demonstrated a generally high level of expertise and experience in the building construction sector. Consent letters were issued to the experts identified, and (on average) 45-minute semi-structured interviews were conducted and recorded electronically with the consent of the participants. Participants were recruited voluntarily after completing the consent form which expressed their comprehension of the study and their willingness to participate. The interviews were scheduled and conducted informally at the convenience of the participants. To foster transparency and integrity, the interviews were conversational in style, enabling the participants to feel more comfortable and relaxed. The interviews were conducted in a semi-structured format; therefore, the interview schedule was developed in advance (see Appendix 5 for the interview schedule).

4.20.1.1 Criteria for interview questions

An interview guide was developed to facilitate the semi-structured interview discussions (see Appendix 5). Oppenheim (2000) recommended using an interview guide to ensure that important topics are covered while allowing for flexibility in the conversation.

The introduction covers the study's context, backgrounds of the respondents, their organizations, and their involvement in vertical greening, buildings and horticulture. The second part focused on green infrastructure strategies, their interactions and involvement within construction and the factors that can influence the of green infrastructure. The third part delved into living walls and its awareness, suitable plant species for living wall in semi-arid region among other aspects. The final part explored the knowledge and involvement in projects that involved the incorporation of living wall and challenges faced in its implementation. (refer to Appendix 5 for the interview questions).

During the qualitative data collection phase, participants engaged in discussions and shared their opinions. Prompts were used to facilitate conversations about energy conservation. Finally, participants were given the opportunity to provide any additional feedback at the conclusion of the interview.

4.20.2 Telephone Interview

Certain situations make telephone interviews more appropriate even though, as Gillham (2005) states, they lack natural interaction as there are no visual clues. On this basis, Rubin and Rubin (2005) affirm that telephone interviews are not well suited to qualitative interviewing. Despite these disadvantages, there are scenarios in which telephone interviews represent the best option, such as: when participants are in various geographical areas; when the research is sensitive; when greater anonymity is required; in places with limited technological capacity; or in places of civil unrest or pandemics. Certain activities need to be undertaken to obtain the best from a telephone interview; for example, a full transcription should be made soon after the interview to minimise misconception and generate accurate empirical data (Easterby-Smith et al., 2008; Saunders et al., 2012). The context of what participants feel and say, as well as the researcher's experiences, are critical for any qualitative data analysis. For this study, semi-structured telephone interviews were selected and held with building industry professionals and other stakeholders to obtain expert perspectives and insights on the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria.

4.20.3 Data Analysis

According to Bogdan and Biklen (2003), qualitative data analysis entails: Organising the data, breaking it into useful units, coding it, synthesising it, and matching patterns. When data is acquired using specific research approaches, interpretation may be required to reveal the patterns, trends, and results (Bryman, 2016). According to Saunders et al. (2009) and Denscombe (2014), there are five common methodologies for interpreting qualitative data: Content analysis, thematic analysis, rooted analysis, argument analysis, and comparative analysis. Thematic analysis was selected for this study. This involves data coding, which is the classification of data to define trends, concepts, and interpretations derived from the results. Similarities and differences in the interviews were categorised, which made it easier for the researcher to identify and compare trends in order understand them. A thematic analysis software package - NVivo - was used to synthesise and handle themes from the large volume of qualitative data by grouping data into useful nodes (themes) (Richards, 1999). The choice of telephone interviews for data collection was primarily influenced by the COVID-19 pandemic. Strict COVID-19 regulations were in effect at the time the data was being collected. In order to stop the virus from spreading, these limitations restricted face-to-face interactions and enforced social distancing measures. As a result, data collection was modified to adhere to these health and safety resrictionss, which required us to use telephone interviews rather than face to face interactions. Secondly, the security situation in Northern Nigeria also played a role in the decision to conduct telephone interviews. Significant instability and conflict in the region at the time of the study, posed serious safety risks for interviewer. To ensure the safety of the researcher, telephone interviews would be the most suitable and secure way to gather data. This approach allowed gathering the required data without exposing the researcher to potential harm in the unstable areas.

4.20.4 Thematic Analysis

Braun and Clarke (2006) characterise thematic analysis as the basic process of qualitative analysis inherent in other qualitative analysis techniques. The primary principle of this technique is to look for recurring themes or patterns in a given set of data, such as a series of interviews, observations, documents, diaries or websites (Saunders et al., 2019). The researcher used thematic analysis to code qualitative data and uncover themes or patterns for subsequent analysis that are relevant to the research question. A thematic analysis technique is both systematic and flexible (Braun & Clarke, 2006), enabling a coherent and logical analysis of the different sizes of qualitative data sets, which leads to extensive descriptions, explanations, and theorizing. It is an independent analytical technique that is not specific to any philosophy or research approach but rather defined by the researcher's philosophical assumptions (Alhojailan & Ibrahim, 2012). In this research, multiple interpretations of the interview response were explored with the aid of theoretically derived themes.

4.20.4 1 Procedure for Thematic Analysis

In practice, thematic analysis entails a set of parameters for conducting the analysis; it does not proceed in a simple linear fashion, but rather in a concurrent and recursive manner, requiring iteration in the data analysis between coding and categorization, and any newly collected data (Saunders et al., 2019). The following steps are included in the procedure: Data familiarisation, data coding, search for themes and identification connections, identifying connections, and searching for themes.

4.20.4.2 Data Familiarisation

The interview transcription process allows the researcher to become more engaged with the data which helps to generate summaries; this is a vital step in data analysis (Saunders et al., 2019). The engagement phase lasts the duration of the study, and uncovers meanings, recurring themes, and patterns in the data.

4.20.4 3 Data Coding

Coding means assigning a code to each unit of data within a data item (such as a transcript or text) that reflects the meaning of that item and aids the categorisation of similar data (Braun & Clarke, 2012). A code is a single word or short phrase that can be abbreviated in use, which makes the data accessible for further analysis. Coding is a vital tool for managing data which means that it may be reorganised and retrieved using relevant codes. Coding entails segregating the original data items and grouping units of data with similar attributes to enable an exploration that references other groups of similar units of data. According to Braun & Clarke (2012), a coded extract of data is a unit, which can be a set of words, a section of a transcript, a phrase, a number of sentences, a complete paragraph, any quantity of textual data, or a visual image that is summarised by a specific code. The meaning of a unit of data determines its actual size, and sometimes units are given multiple codes while some overlap (Saunders et al., 2019). To ensure consistency, a list of codes in use and a suitable definition for each should be maintained throughout the coding process.

4.20.4.4 Identifying Connections and Searching for Themes

The search for themes is considered a separate stage of analysis after coding. From the list of developed codes, the researcher will make sense of and draw meaning from the data. This means examining a lengthy list of codes for correlations in order to develop a shorter list of themes that are relevant to the research issue. The theme is a wide category that includes numerous codes that closely relate to each other and reflect a notion relevant to the research question. A theme can also be a single code that represents a notion with universal significance to the research question. The process of searching for themes is part of the larger strategy to reduce the original data, first by coding it and then by categorising it into analytic categories. Data is organised by coding, while codes are organised by grouping them into themes. Searching for themes entails absorption in the data, which helps the researcher to form judgments. It entails identifying how the developed codes potentially link to enable additional analysis and requires the researcher to question the codes. This means initially deciding on themes for further analysis, followed by defining the themes and their associated relationships, and then evaluating the themes and their interrelationships. These could be primary, secondary, or tertiary themes with a range of linkages (Saunders et al., 2019).

4.20.4.5 Refining Themes and Testing Propositions

A significant aspect of the analysis procedure is the refinement of themes and their interconnections. According to Saunders et al. (2019), to establish a well-structured analytical framework for the analysis, the proposed themes must form part of a coherent group. The coded data extracted under the relevant theme or sub-theme are restructured as the themes evolve. This helps to determine whether these coded data are meaningful to one another within their theme, and whether (and how) themes are meaningful in relation to one another and the data set (Saunders et al., 2019). Re-reading and reorganising data, and evaluating the employed codes, and developed themes are all part of the theme refinement process. Testable propositions are generated when patterns in the data are revealed and the interconnections between themes are identified (Braun & Clarke, 2012). However, to identify a real relationship, apparent relationships or connections between themes first need to be evaluated. It is feasible to create valid/credible and logical findings by thoroughly examining propositions against the data, looking for alternative explanations, and attempting to explain why negative cases occur. Moreover, cases that contradict the findings are referred to as negative (Saunders et al., 2019).

4.21 Summary of Research Methodology

This section provides details of some critical areas of the research methodology with specific justification as integrated within the various sections of the chapter as highlighted below.

4.21.1 Research methodology

This research employed a dual-strategy approach, incorporating both experimental and survey research methods to comprehensively investigate the impact of vertical greening integration in the semi-arid region of Northern Nigeria. The objective of the experimental research strategy was to ensure that detailed investigation into the impact of vertical greening on the microclimate of urban areas in Northern Nigeria. This research strategy considered the type of plants used, the percentage of vertical surface coverage, and the proximity of the vertical greening to buildings as it independent variable, while the microclimate parameters, specifically temperature, humidity, and air quality were dependent in nature. In this regard, the researcher systematically manipulated the types of plants selected for vertical greening and different levels of percentage coverage of vertical surfaces were applied. Furthermore, he proximity of the vertical greening installations to the buildings was varied, the resulting changes in the microclimate, such as variations in temperature, humidity, and air quality, were meticulously observed and recorded. On the other hand, Survey Research Strategy was aimed at investigating the broader impact of vertical greening on the urban microclimate and its potential to mitigate climate change through structured interviews. The interviews were conducted with residents, urban planners, environmental scientists, and other stakeholders. Consequently, a structured interview format was designed to gather qualitative and quantitative data on the perceptions and observed impacts of vertical greening. The questions focused on changes in urban temperature, humidity, air quality, and overall comfort levels due to the introduction of vertical greening. In addition, responses were analysed to identify patterns, correlations, and insights into the effectiveness of vertical greening in improving urban microclimates and contributing to climate change mitigation. By combining experimental manipulation with survey-based insights, this research aimed to provide a comprehensive understanding of how vertical greening can be effectively integrated into urban environments in semi-arid regions to improve microclimatic conditions and combat climate change.

4.21.2 Research Design

This research focuses on vertical greening, plant selection, the impact of vertical greening systems on the streetscape microclimate, stakeholder perceptions of its implementation, and the drivers and barriers to its implementation in Nigeria. Understanding both the subjective and objective perspectives of people and their environment is essential for the successful implementation of vertical greening and for supporting the creation of effective and sustainable policies and programs. For the design, the Research Onion Model by Saunders et al. (2019) was adopted to structure the research, as it provides comprehensive and clear guidance for this study. The first layer of the Research Onion is research philosophy; pragmatism was adopted by the researcher in this study. The second layer is the research approach which was developed from the research philosophy; from this layer, abduction was adopted. The third layer is the methodological choice which influences the researcher's decision on the next layer; mixed method was adopted from the third layer. The fourth layer is the research strategy, from which a survey and experiments were adopted. The fifth layer is the time horizon, in which a cross-sectional boundary was adopted, while the sixth and final layer is the data collection and analysis method. By following this structured approach, the research aims to provide a comprehensive understanding of how vertical greening can be effectively implemented in urban environments in Nigeria, considering the various factors that influence its success.

4.21.3 Sample Population and Sampling Technique

This research employed purposive sampling, a type of non-probability sampling, to gather responses from building professionals and other stakeholders. This approach was chosen because it enables the researcher to select participants who are most likely to provide valuable insights into the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria. Purposive sampling allows the researcher to intentionally select participants who have specific characteristics, experiences, or knowledge relevant to the research question. In this study, the target participants include building professional like architects, urban planners, engineers, and landscape designers who have direct experience with or knowledge of vertical greening systems. It also includes other stakeholders such as residents, environmental scientists, policymakers, and urban developers who are affected by or have an interest in the implementation of vertical greening. The researcher identified key groups of individuals who are directly involved in or affected by vertical greening projects. Furthermore, criteria for selection included professional expertise, experience with vertical greening, and influence on or interest in urban development and environmental sustainability. In addition, Individuals were selected based on their ability to provide detailed and relevant information regarding the integration of vertical greening. Efforts were also made include a diverse range of perspectives to ensure a comprehensive understanding of the factors influencing vertical greening. By employing purposive sampling, this research was able to gather detailed and relevant information from knowledgeable and experienced participants, thereby enhancing the overall quality and applicability of the findings.

CHAPTER 5: QUALITATIVE STUDY

5.1 Introduction

This chapter conducts a comprehensive evaluation of the factors influencing the integration of vertical greening within the semi-arid region of Northern Nigeria, focusing on insights from stakeholders through a semi structured interview. This endeavor seeks to identify, from individuals engaged in the realms of construction and green infrastructure, the reasons behind the limited adoption of vertical greening practices, despite the extensive literature supporting the manifold advantages associated with such practices.

The chapter reports the qualitative data generated through semi-structured interviews with members of the building construction industry and other relevant stakeholders. The chapter discusses the output of the qualitative enquiry by highlighting key points of the research data analysis and the presentation of the results focuses on the themes, aligned to the main objectives of the research. Furthermore, detailed discussions of the various themes are provided, while highlighting the statements and inputs of respondents. Finally, the chapter discusses findings from the study as it relates to key research questions on vertical greening in semi-arid regions towards achieving the research objectives. It has effectively addressed objective three by thoroughly assessing the key factors influencing the implementation of vertical greening in the semi-arid region of Northern Nigeria.

5.2 Towards the implementation of vertical greening in the semi-arid region of Nigeria

Vertical greening is an important issue in modern-day architectural design, and its selection as the focus of this study was influenced by the range of benefits to humanity and the environment, and current global efforts to achieve the net zero objectives. Daemei et al. (2021) outlined the environmental, economic, social and health benefits of vertical greening, while highlighting its importance for the future of architectural design in creating more sustainable buildings. The selection of a semi-arid region in Nigeria was influenced by the lack of data in this area of study, and to this end, semi-structured interviews were considered appropriate. The interview participants were selected from a range of building construction professionals and other stakeholders.

The implementation of vertical greening in semi-arid regions calls for a multidisciplinary approach and participation by many stakeholders, including real estate developers, architects, landscape architects, horticulturists, and the public and private sector. Hence, a multi-stakeholder approach was critical in the selection of respondents for the qualitative data generation. This qualitative data contributes to a mixed method approach for the research and towards understanding the impact of vertical greening in developing appropriate policies for Nigeria. Accordingly, for the analysis of the qualitative data it is important to consider the views of participants on the factors inhibiting the application of vertical greening in Nigeria and the species appropriate for this.

5.3 Research Data Analysis

The research data for this qualitative study was generated from interviews with 26 participants who are relevant stakeholders in either the public and private sector. All interviews were recorded for ease of reference and the initial step was to transcribe the record, which took about three days for a 45-minute interview. The process involved listening to the audio record, and deciphering and evaluating it in detail to elicit meaning for the discussion. This ensured the researcher's familiaraisation with the data, which also forms the first stage of the thematic analysis. This process allowed for a preliminary examination of the data, and to generate summaries which outlined the essential meanings, recurring themes, and patterns (Saunders et al., 2019). Each transcript was examined independently to identify the primary themes, while similarities and differences between the interviews were categorized separately. The next step identified popular themes highlighted by the interviewees.

To ensure detailed analysis of the qualitative data, three processes were carried out simultaneously: data coding, the identification of connections, and the search for themes. The aim of the coding was to firstly, ensure the effective segregation of the original data items and secondly to group units of data with similar attributes. Additionally, the second step enabled an exploration of the similarities between units of data (Saunders et al., 2019), and was carried out with the aid of Microsoft Excel spreadsheets. Some of the responses were difficult to categorise, as they were lengthy and subject to the interviewees' experiences, views, and perceptions. Consequently, there was more focus on the research questions, while considering useful supplementary information from the interviews. The participants were alphabetically labelled to ensure the confidentiality of the results, and an overview is given in Table 5.1.

Table 5.1: Demography of Semi Structured Interview Participants

Participants	Academic / professional qualification	Years of experience in present organization	Workplace description	Workplace schedule	Information on green infrastructure
A.	Architect	6	Private firm	Design, field work and administrative work	Informed
B.	Landscape Architect	15	Research and training	Design, field work and research	Well informed
C.	Landscape Architect	18	Research and training	Design, field work and research	Well informed

D.	Architect	16	Private firm	Design, field work and administrative work	Informed
E.	Architect	13	Research and training	Design, field work, and research	Well informed
F.	Landscape Architect	17	Government Parastatal	Design, field work	Well informed
G.	Architect	10	Private firm	Design, field work and administrative work	Well informed
H.	Agriculturist	10	Research and training	Field work and research work	Informed
I.	Horticulturist	12	Government Parastatal	Field work and administrative work	Informed
J.	Landscape Architect	25	Private firm	Design, field work and administrative work	Well informed
K.	Architect	4	Research and training	Design, field work and research	Well informed
L.	Architect	11	Government Parastatal		Informed
M.	Landscape Architect	8	Private firm		Well informed

N.	Architect	20	Research and training	Design, field work and research	Well informed
O.	Architect	19	Government Parastatal		Informed
P.	Landscape Architect	20	Private firm	Design, field work and administrative work	Well informed
Q.	Architect	22	Research and training	Design, field work and research	Well informed
R.	Horticulturist	10	Government Parastatal	Field work and administrative work	Informed
S.	Architect	15	Private firm	Design, field work and administrative work	Well informed
T.	Urban Planner	18	Research and training	Design, field work, and research	Well informed
U.	Real Estate Agent	10	Private firm	Administrative work and redevelopment.	Well informed
V.	Urban Planner	15	Research and training	Design, field work, and research	Well informed
W.	Real Estate Agent	5	Private firm	Administrative work and redevelopment	Well informed

X.	Urban Planner	12	Research and training	Design, field work, and research	Well informed
Y.	Urban Planner	15	Research and training	Design, field work, and research	Well informed

5.4 Results and Discussion

The researcher used NVivo, Microsoft Excel, amongst other data analysis tools to support the analysis of the qualitative results. These tools were judged to be appropriate for the qualitative data sets as they enable ease of analysis and a better understanding of the data in relation to best practice, which thereby facilitates informed decisions about the research outcomes. From the participants' demographics, it was noted that there is a significant level of understanding about Vertical Greening (VG) amongst the professionals (as indicated in Figure 5.1), which suggests knowledge proficiency regarding green infrastructure. The data is presented in terms of frequencies and percentages and shows that 72% of respondents were 'well informed' about the importance of VG, while only 28% were 'informed'. This indicates a high level of knowledge amongst this group of critical stakeholder and implies that the development of vertical greening is likely to be accepted as a positive implementation amongst professionals.

Furthermore, Table 5.2 provides a comprehensive overview of the socio-demographic characteristics of the study participants. Most participants (84.2%) are from the architectural professions, while a smaller portion (15.8%) are agriculturists, indicating a predominant involvement from the architectural field. Participants exhibit a balanced distribution of years of experience in their profession, as 30.4% have ≤10 years, 57.9% have 11-20 years, and 10.5% possess 21 years or more, which suggests a variety of perspectives on the subject. In addition, workplace diversity is also evident, as the sample spreads across government parastatals (26.3%), private firms (36.8%), and research and training institutions (36.8%), ensuring a wide array of workplace settings from which to draw insights. Furthermore, participants' work schedules encompass different combinations of responsibilities, such as design, fieldwork, administrative tasks, and research, which highlights the multifaceted nature of their roles. Lastly, most participants who are well informed about green infrastructure, indicate greater impetus to develop a framework or initiatives to encourage the implementation of vertical greening in Nigeria.

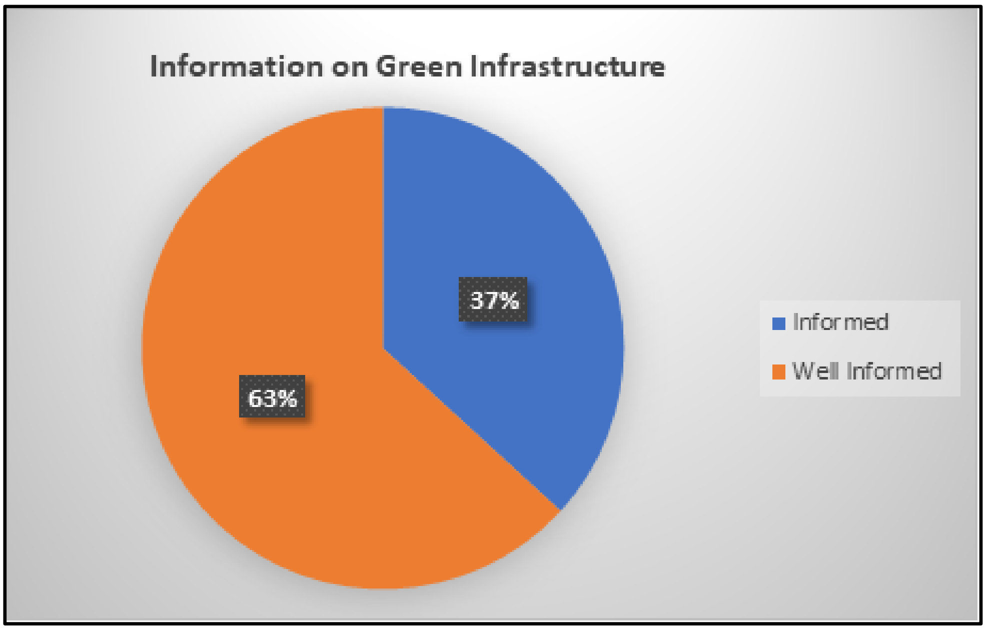


Figure 5.1: Information on Green Infrastructure by Stakeholders

Table 5.2: Participants' Socio-Demographics

Variable	**Categories**	**Frequency**	**Percentage**
(a)	(b)	(c)	(d)
Academic/Professional Qualification	Agriculturist	3	15.8
	Architect	16	84.2
Years of Experience	≤10 years	8	34.8
	11-20 years	15	65.2
	21 years and above	2	10.5
Workplace	Government Parastatal	5	26.3
	Private Firm	7	36.8
	Research and Training	7	36.8

Workplace Schedule	Nil	3	15.8
	Design, Fieldwork	1	5.3
	Design, Fieldwork, Administrative Work	6	31.6
	Design, Fieldwork, Research	6	31.6
	Fieldwork, Administrative Work	2	10.5
	Fieldwork, Research Work	1	5.3
Information on Green Infrastructure	Informed	7	28
	Well Informed	18	72

As part of a more holistic approach to understanding the influence of professional stakeholders (participants), it is useful to further analyse participants' demographic data. Table 5.3 illustrates the relationship between participant characteristics and their knowledge proficiency. The variables examined are academic/professional qualification, years of experience, workplace, and workplace schedule. Each variable is divided into categories, and Table 5.3 provides the number and percentage of participants categorized as 'informed' or 'well informed' within each category. Furthermore, the Table reports statistical measures, including the Pearson Chi-Square statistic, degrees of freedom (df), and p-values to assess the significance of these relationships.

On analyzing the results, several key findings emerged. Firstly, there was a lower proportion of 'well informed' participants with an academic or professional qualification in agriculture compared to architects, and this difference was statistically significant ($p = 0.013$). However, years of experience did not appear to significantly influence knowledge proficiency according to the non-significant p-values for different experience groups ($p = 0.446$). In terms of workplace, there was no strong statistical evidence of a significant association with knowledge proficiency, although government parastatal employees had a slightly lower proportion of 'well informed' participants ($p = 0.057$). The workplace schedule also did not show a statistically significant relationship with knowledge proficiency, though the p-value (0.065) suggests it may warrant further investigation.

The analysis denotes that architects had greater knowledge proficiency in green infrastructure compared to agriculturists which suggests that the design and implementation of vertical greening is dominant in the design and construction of sustainable and environmentally friendly buildings. Furthermore, research and training institutions and the private sector are more conversant with the concept of green infrastructure than government employees. However, further investigation and analysis of the qualitative data is necessary to better understand the potential for green infrastructure growth in Nigeria. Accordingly, subsequent sections will discuss the analysis of the transcribed qualitative data.

Table 5.3: Relationship Between Participant Characteristics and Knowledge Proficiency

Variable	**Categories**	**Informed**	**Well Informed**	**Total**	**Pearson Chi-Square**	**df**	**P-value**
Academic/ Professional Qualification	Agriculturist	3 (15.8%)	0 (0.0%)	3 (15.8%)	6.107	1	0.013
	Architect	4 (21.1%)	12 (63.2%)	16 (84.2%)			
Years of Experience	≤10 years	3 (15.8%)	3 (15.8%)	6 (31.6%)	1.614	2	0.446
	11-20 years	4 (21.1%)	7 (36.8%)	11 (57.9%)			
	21 years and above	0 (0.0%)	2 (10.5%)	2 (10.5%)			
Workplace	Government Parastatal	4 (21.1%)	1 (5.3%)	5 (26.3%)	5.739	2	0.057
	Private Firm	2 (10.5%)	5 (26.3%)	7 (36.8%)			
	Research & Training	1 (5.3%)	6 (31.6%)	7 (36.8%)			
Workplace Schedule	Design, Fieldwork	0 (0.0%)	1 (5.3%)	1 (5.3%)	10.405	5	0.065

	Design, Field work, Administrative Work	2 (10.5%)	4 (21.1%)	6 (31.6%)			
	Design, Field work, Research	0 (0.0%)	6 (31.6%)	6 (31.6%)			
	Field work, Administrative Work	2 (10.5%)	0 (0.0%)	2 (10.5%)			
	Fieldwork, Research Work	1 (5.3%)	0 (0.0%)	1 (5.3%)			
	Nil	2 (10.5%)	1 (5.3%)	3 (15.8%)			

5.4.1 Themes and Sub-Themes in Implementing Vertical Greening in the Semi-Arid Region

The initial analysis of the transcribed data played a pivotal role in this research and led to the identification of codes. These were examined and resulted in the emergence of five primary themes and corresponding sub-themes which related to the research objectives as follows:

- Objective 1: 'To evaluate ecological and visual appeal' contained codes that concerned the assessment of ecological and visual aspects of vertical greening projects.
- Objective 2: 'To identify suitable plant species' included codes that included the selection of plant species suitable for vertical greening in a semi-arid context.
- Objective 3: To determine the 'factors impacting integration' involved codes that identified various factors which influence the successful integration of vertical greening initiatives.
- Objective 4: 'To influence the urban microclimate' consisted of codes which examined the effects of vertical greening on the urban microclimate, including temperature regulation.
- Objective 5: 'Guidance for implementation' constituted codes that provided recommendations for practical implementation.

Each main theme contained associated sub-themes that deepened the understanding of the theme; these sub-themes included: vertical greening knowledge, ecological aesthetics, implementation factors, temperature effects, recommendations, guidelines, and tackling challenges. These themes and sub-themes were organised using Nvivo, as shown in Figures 5.2 to 5.4, ensuring a structured and rigorous analysis of the collected data. The relationship between the participants and their attributes towards the implementation of vertical greening in a semi-arid climate is presented in Figure 5.5. The following sections explore these themes and sub-themes in the context of the primary research focus.

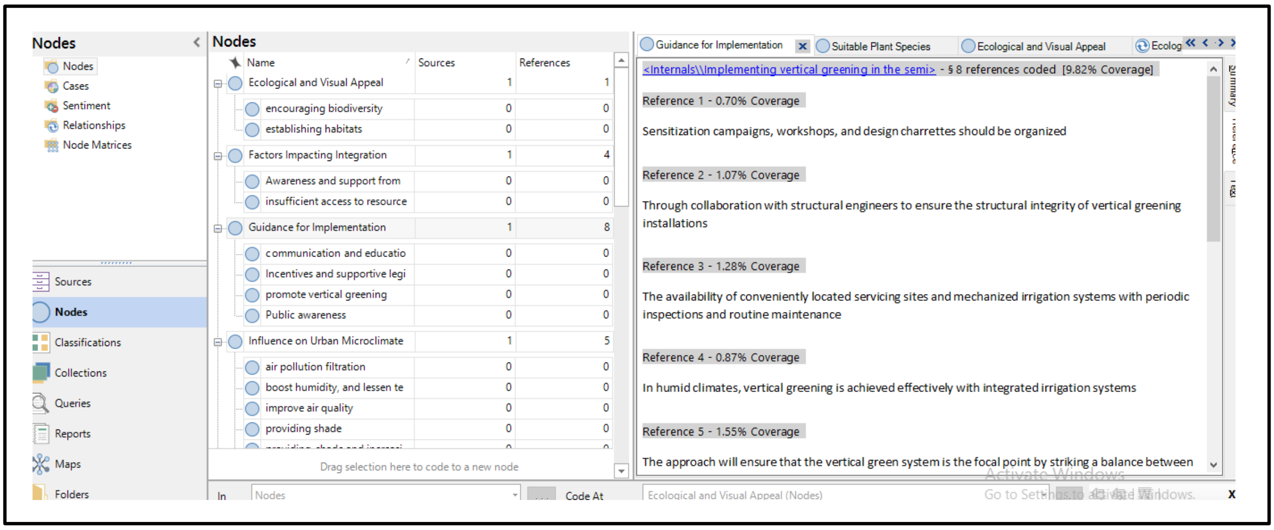


Figure 5.2: The NVivo Screenshot for the Themes and Sub-Themes

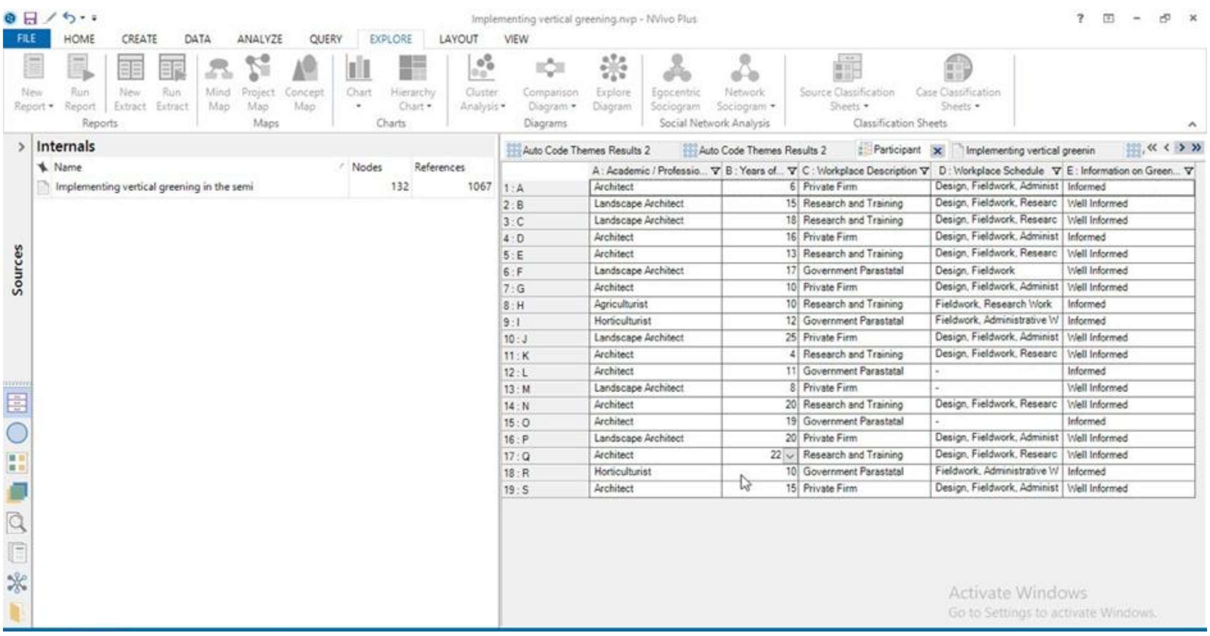


Figure 5.3: NVivo Screenshot for the Themes and Sub-Themes Based on all Participants

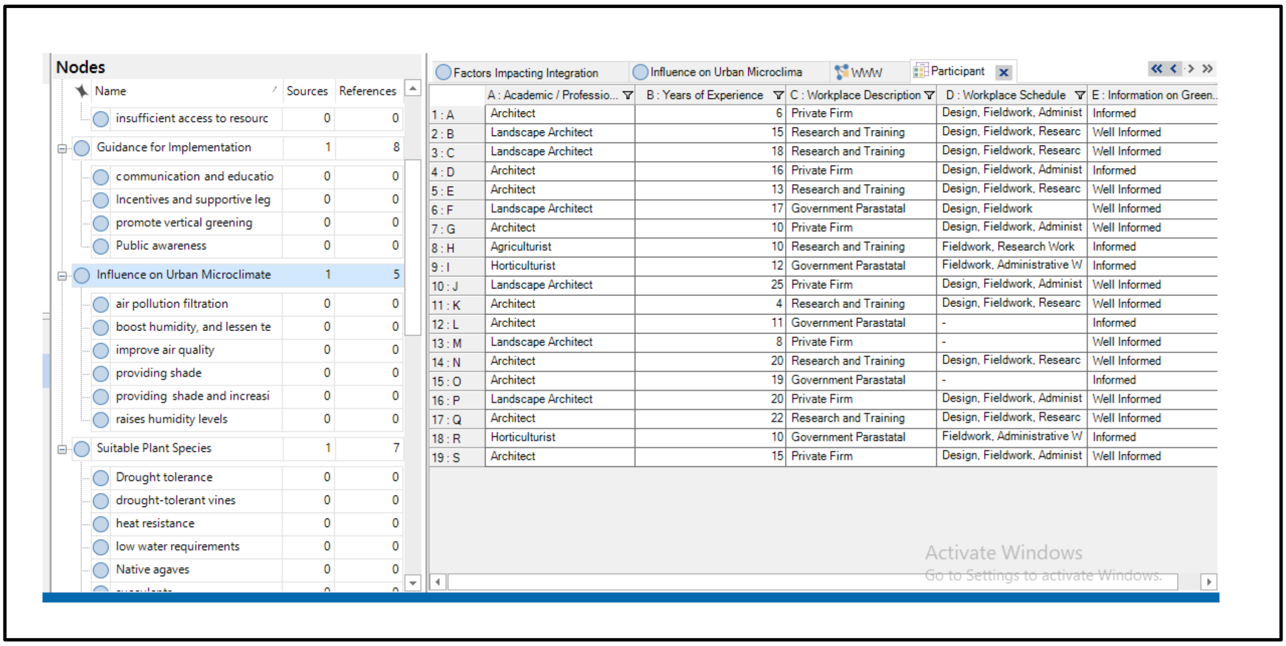


Figure 5.4: NVivo Screenshot for the Themes and Sub-Themes Based on all Participants

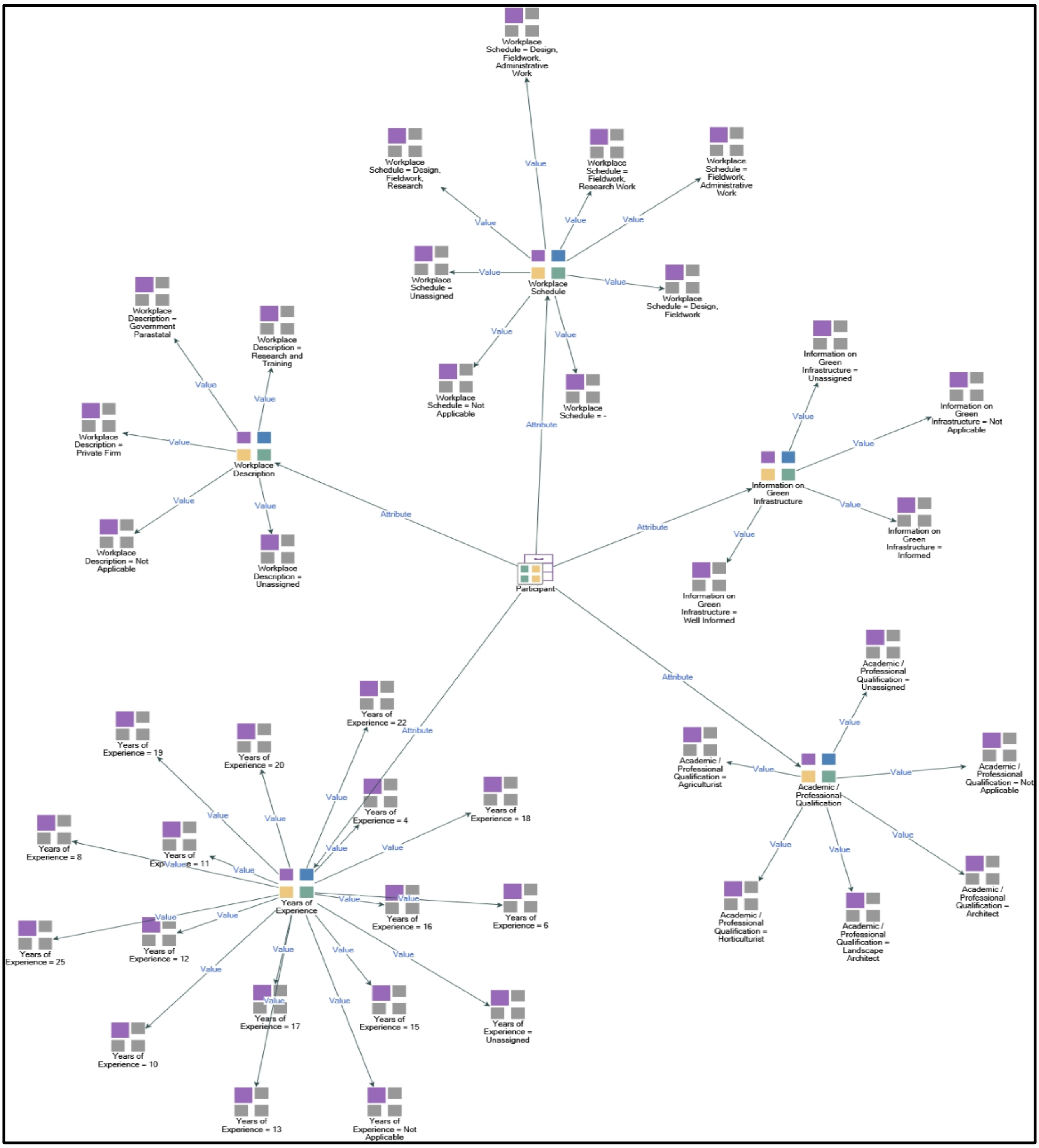


Figure 5.5: NVivo Screenshot for the Themes and Sub-Themes Concerning the Relationship between Participants and Attributes.

Below are enlarged images of the NVivo Screenshot for clear viewing.

Figure 5.5.1: Enlarged NVivo Screenshot for the Workspace Schedule of the stakeholders.

Figure 5.5.2: Enlarged NVivo Screenshot for the Workspace Description of the stakeholders.

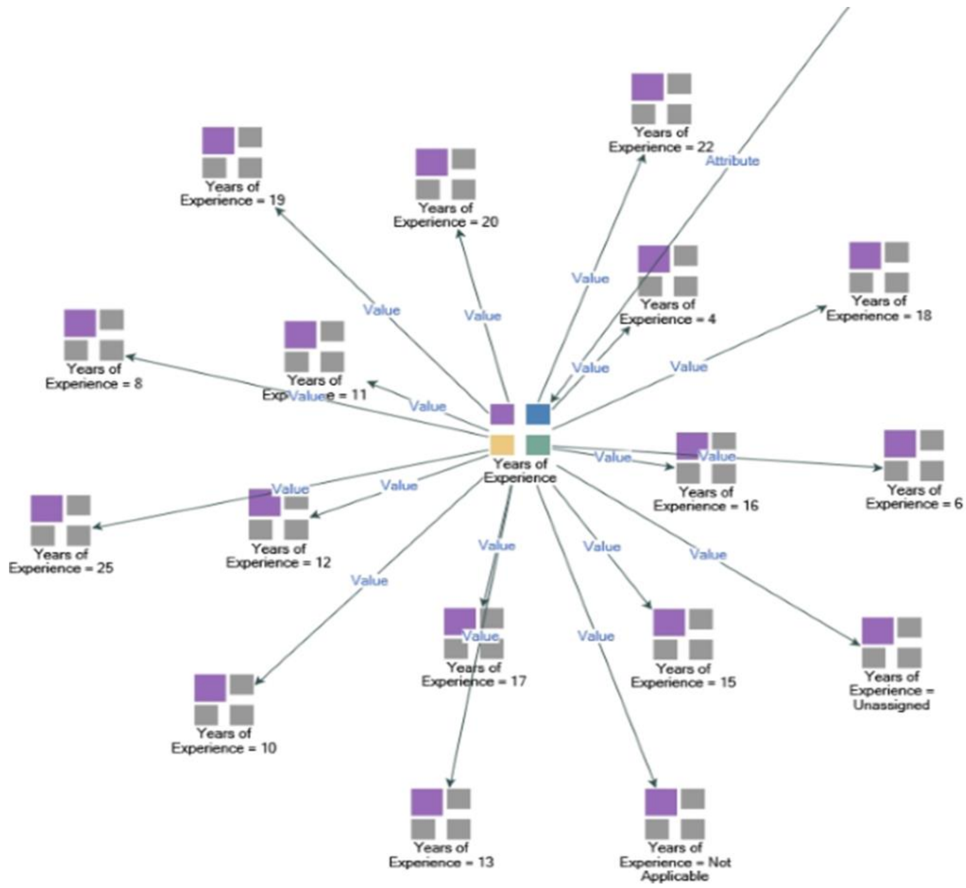


Figure 5.5.3: Enlarged NVivo Screenshot for the Years of Experience of the stakeholders.

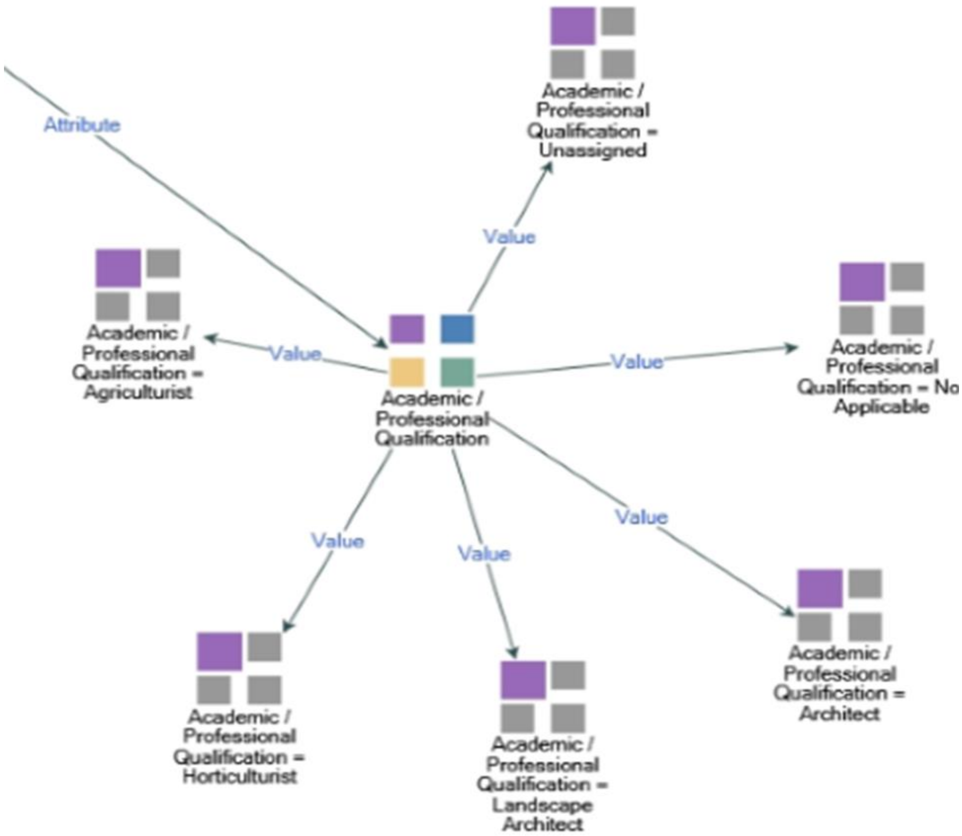


Figure 5.5.4: Enlarged NVivo Screenshot for the Academic /Professional Qualification of the stakeholders.

5.4.1.1 Assessing the Ecological and Visual Aspect of Vertical Greening Projects

Concepts such as green infrastructure, nature-based solutions, and ecosystem services have gained popularity in recent discourse on urban planning. Despite their recognition as innovative concepts, all share a degree of ambiguity. Although fuzziness can be a weakness it can also be an opportunity to shape novel concepts with stakeholders who are likely to implement them in practice.

An evaluation of the ecological and visual appeal of green infrastructure was conducted with the participants. Notably, participants with roles in research and training tend to be well-informed about green infrastructure, as they engage in design, fieldwork, research, and administrative tasks related to ecological and visual appeal. Participants from private firms, government parastatals, and research and training backgrounds are actively involved in designing, fieldwork, and administrative work concerning green infrastructure. Participants' qualifications and experience range widely, with notable expertise among those with 15 years or more experience. The diverse group of professionals provided valuable insights into the ecological and visual aspects of green infrastructure. Their extensive experience in design, fieldwork, and research meant they were able to offer well-informed perspectives.

The participants provided thoughtful responses to questions regarding the impact of vertical greening in semi-arid regions like Northern Nigeria. They generally agreed that vertical greening has the potential to enhance the ecological and aesthetic appeal of urban environments. By fostering biodiversity and creating habitats for different species, vertical greening can significantly improve ecological attractiveness. Additionally, it was noted that adding lush greenery to otherwise concrete urban landscapes enhance their visual appeal, making urban environments more pleasant. In response to a question about effective instances of vertical greening in similar climates, one participant mentioned a project involving green façades with climbing plants. This project was seen as successful in adding a distinctive visual feature that connected with the neighbourhood.

5.4.1.2 Selection of Plant Species Suitable for Vertical Greening in Semi-Arid Regions

To understand the key factors involved in selecting plant species for vertical greening within semi-arid regions like Northern Nigeria, the research sought insights from a diverse group of experts. The study enquired about the factors that participants would consider in their choice of plant species for vertical greening in a semi-arid area like Northern Nigeria. In response, participants emphasized the critical importance of factors such as drought tolerance, heat resistance, and low water requirements. These considerations were seen as paramount when choosing plant species for vertical greening projects in environments characterized by limited water resources and challenging climatic conditions.

Additionally, the inquiry extended to the identification of plant types that exhibit resilience and suitability for vertical greening in adverse climates. Participants highlighted native agaves, succulents, drought-tolerant vines, bougainvillea, desert marigold, and aloes as plant types that have shown potential. They emphasised the significance of choosing species that can thrive in adverse conditions and thus contribute to the success of vertical greening initiatives.

When asked about the factors to consider when choosing plant species for vertical greening in a semi-arid area, participants emphasized the importance of selecting plant species with specific characteristics, such as drought tolerance, heat resistance, and low water requirements. These factors are crucial in a semi-arid climate.

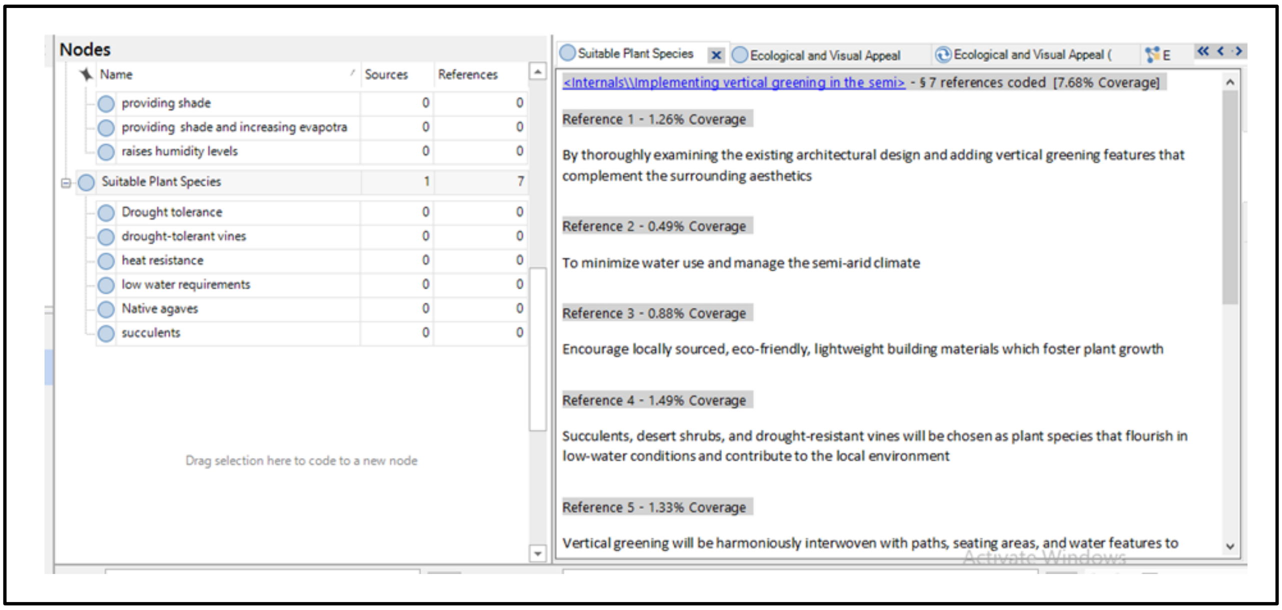


Figure 5.6: Nvivo Analysis and Overall Report on the Selection of Species

The plant types identified demonstrate the potential for vertical greening in challenging environments. The NVivo analysis and reports (as shown in Figure 5.6) detailed the views of participants concerning the choice of appropriate plant species in vertical greening within semi-arid regions. A complete report from the NVivo analysis is also presented in Figure 5.6. Although the selection of plant species is critical, their adaptability to low water levels or minimum water supply is vital. It was further observed that choice of building materials also affects the successful growth of plant species. Despite the views of participants, it is crucial to carry out further testing of the suggested plant species and the associated factors in a simulated environment using appropriate software applications. This will provide a better understanding of the applicability of suggestions to vertical greening initiatives and facilitate informed decisions.

<Internals\\Implementing vertical greening in the semi> - § 7 references coded [7.68% Coverage]

Reference 1 - 1.26% Coverage

By thoroughly examining the existing architectural design and adding vertical greening features that complement the surrounding aesthetics

Reference 2 - 0.49% Coverage

To minimize water, use and manage the semi-arid climate

Reference 3 - 0.88% Coverage

Encourage locally sourced, eco-friendly, lightweight building materials which foster plant growth

Reference 4 - 1.49% Coverage

Succulents, desert shrubs, and drought-resistant vines will be chosen as plant species that flourish in low-water conditions and contribute to the local environment

Reference 5 - 1.33% Coverage

Vertical greening will be harmoniously interwoven with paths, seating areas, and water features to create a unified and appealing landscape design

Reference 6 - 1.15% Coverage

Utilize drip irrigation, moisture sensors, and self-watering techniques to improve water distribution and minimize water waste

Reference 7 - 1.08% Coverage

Little water and pruning are needed when using bougainvillea for vertical greening. Pests or insects never attacked it.

Figure 5.6 NVivo Analysis and Reports

5.4.1.3 Factors Influencing the Successful Integration of Vertical Greening Initiatives

An increase in the use of Vertical Greening System (VGS) in modern building design and construction demonstrates its growing popularity despite the need for more innovative and nature-based solutions to address urban sustainability challenges. Notwithstanding recent progress in VGS, it is critical to identify some inherent challenges impeding its implementation. Accordingly, the primary focus was the identification of obstacles that could hinder the successful implementation of vertical greening in a semi-arid area of Nigeria. Some of the responses from the interviewees revealed that limited access to essential resources such as the availability of funds and water, the maintenance of systems, and planting spaces for the structures are major hindrances to the implementation of VGS. The challenge of sufficient water could be attributed to the dry nature of semi-arid regions, while the maintenance of the system means a dependence on the nature or species of plants used amongst other factors. Furthermore, similar challenges associated with high maintenance costs and limited blank wall/vertical spaces were observed in studies based on the tropical climate of Lagos and Akure in Nigeria, and in Dar es Salaam in Tanzania (Adegun et al., 2022). However, the lack of water was not found to be as significant a challenge in tropical regions as semi-arid regions. It is important to note that Adegun et al. (2022) analysed the post implementation phase of a VGS in the temperate climate regions of sub-Saharan Africa, which differs from the region this study's focus on pre-implementation. Hence, there is a need to conduct further testing on the qualitative data to ensure a better understanding.

Another hindrance to the integration of vertical greening is a lack of awareness of the importance and benefits of the system to communities. For instance, the Environmental Citizenship Model deciphers factors that impact a person's environmental awareness and involvement (Hungerford & Volk 1990). It was noted that initial awareness, curiosity, a basic understanding of environmental topics and concepts, and a concern for environmental problems are critical factors aiding the successful integration of vertical greening systems amongst communities. This challenge could be attributed to the communication gap between the drivers of critical initiatives on sustainable environment and building with a local community from inception. Hence, this emphasizes the urgent need for community engagement and education to foster a supportive environment for vertical greening initiatives. This finding aligns with the power system framework for the implementation of the Asset-Based Community Development (ABCD) which highlights the impact of community engagement and the use of community resources as critical for enhanced development (Mcclure, 2022). Additionally, the engagement of the community to create awareness of the implementation of VGS is also consistent with the critical success factor for project implementation (Israa, 2018). The insights shared by participants derived from their extensive experience and expertise provided valuable guidance to address challenges in the integration of vertical greening projects. These insights are integral to the research's broader objective of providing practical recommendations and guidelines for the implementation of vertical greening in semi-arid regions. The data collected was organized in NVivo and presented in Figure 5.7, which shows a structured and rigorous analysis of these critical aspects.

Reference 1 - 0.15% Coverage

Funds are limited

Reference 2 - 0.63% Coverage

infrastructure is expensive, and obstacles particular to these places

Reference 3 - 1.49% Coverage

Succulents, desert shrubs, and drought-resistant vines will be chosen as plant species that flourish in low-water conditions and contribute to the local environment

Reference 4 - 1.24% Coverage

By using a variety of plant species to enhance biodiversity by luring pollinators and forming microhabitats in the vertical green system

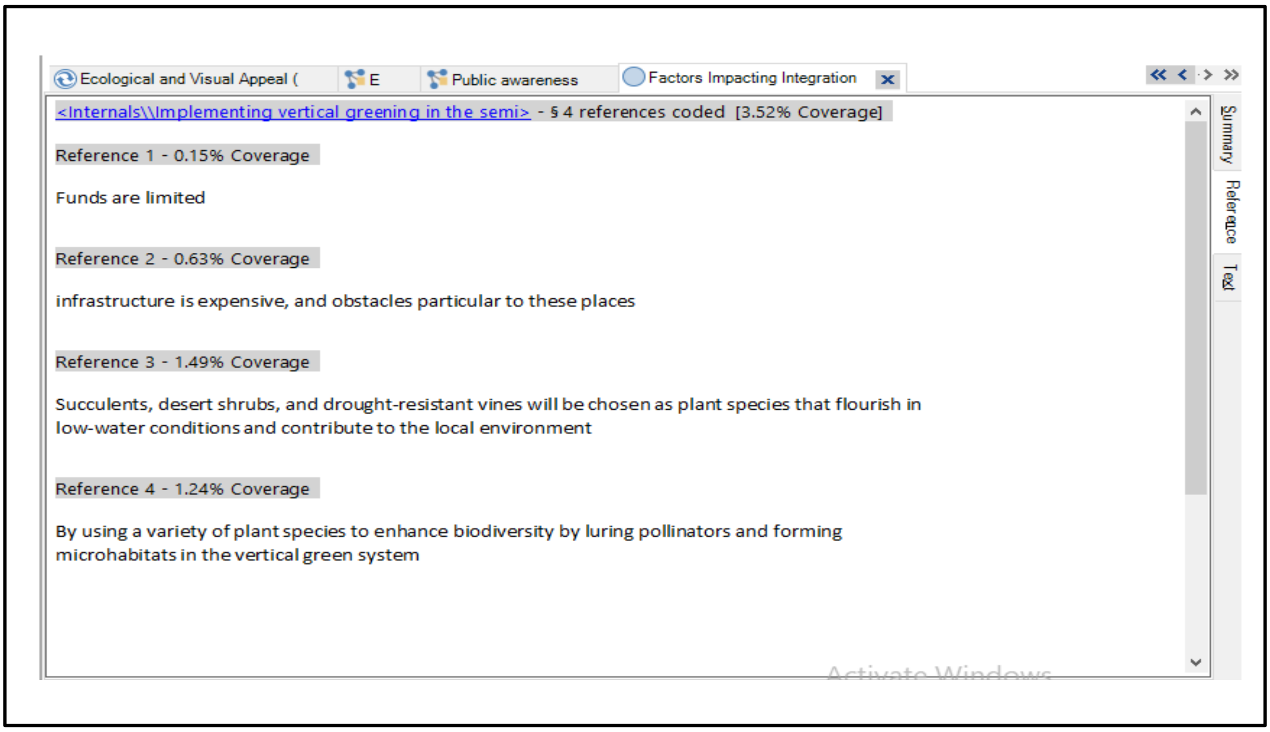


Figure 5.7: NVivo Analysis and Overall Report on the Selection of Species.

5.4.1.4 Effects of Vertical Greening on Urban Microclimates

Rural-urban migration has been increasing due to the need to seek more tenable economic circumstances, and this affects the environment, particularly influencing the urban microclimate. To this end, a better understanding of the impact of VGS on the urban microclimate of semi-arid regions is needed, which aligns with the research objectives. Thus, the research investigated the impact of VGS on temperature, humidity, and air quality in cities, particularly in semi-arid regions. In their responses, respondents revealed that the implementation of VGS lowers temperatures by providing shade and the release of water by plants also cleans the atmosphere of impurities. Based on most participants' experience, it was further noted that temperature swings are better regulated by implementing VGS.

The convergence of different opinions and experiences amongst the participants enhances the understanding of VGS impacts. For instance, Cao et al., 2022 conducted a study on green infrastructures on the microclimate of an urban residential area experiencing hot weather with a subtropical monsoon climate type (Cao et al., 2022). The study revealed that vertical greening had better cooling and humidifying effects before noon but slightly increased temperatures in the afternoon. Overall, it was noted that vertical greening had a significant effect on temperature (lowering temperature), which was similar to the views of participants in this study. This implies that VGS impacts urban microclimates irrespective of their climate type. However, some key challenges could impede the successful implementation of the initiative, as shown in Figure 5.8, suggesting a need to address some of these hindrances to maximize the benefits of the system.

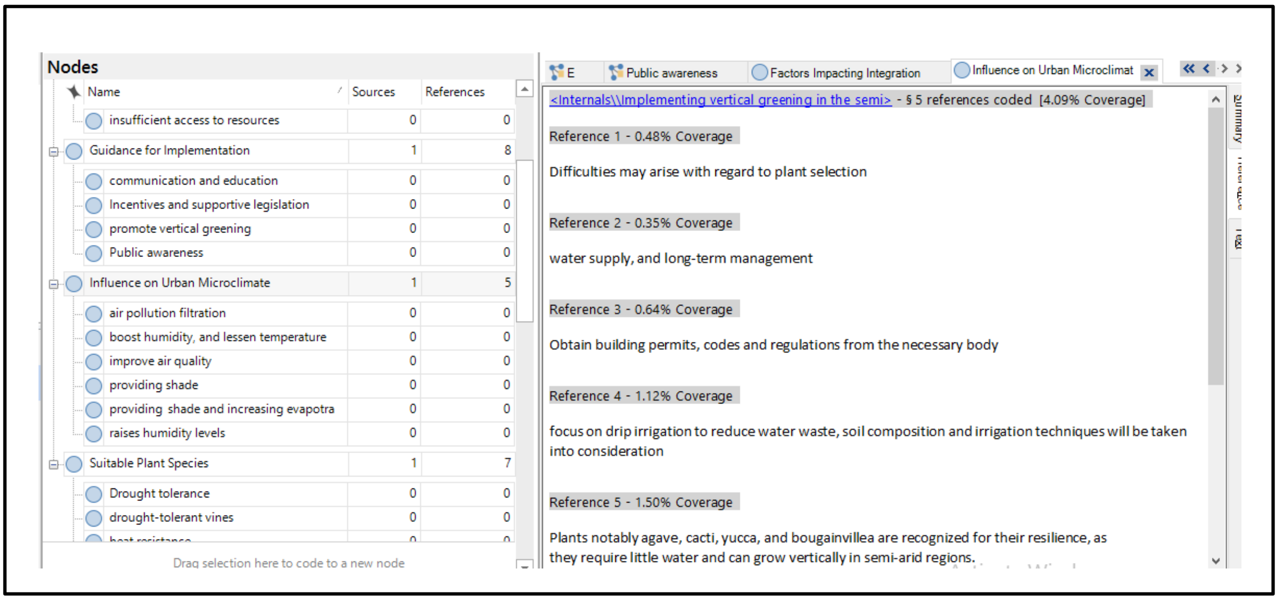


Figure 5.8: Nvivo Screenshot for the Analysis of the Theme

5.4.1.5 Guidance for the Implementation of Vertical Greening

The engagement of diverse professionals elicited discussion on their experiences of implementing VGS as well as workplace roles and schedules. While some of the participants offered valuable inputs which drew from their experiences of VGS, others made suggestions based on empirical data or theoretical knowledge of implementation of VGS in semi-arid regions. The findings revealed that incentives from a regulatory perspective are necessary to support the implementation of vertical greening initiatives. It was further noted that policy makers could support critical initiatives through legislative instruments which promote vertical greening for a more sustainable environment. The support of the government in the implementation of vertical greening was highlighted in the case study of Ljubljana (Gantar et al., 2022). The successful implementation of this vertical greening initiative was due to the involvement of the government which supported the initiative from its inception.

On the other hand, landscape architects with urban planning backgrounds suggested that the integration of vertical greening initiatives should be included in the master plans of cities, while architects opined that it is necessary to design structures which are compatible with vertical greening. These would ensure a more structured and systematic approach that created more sustainable buildings and environments, and to achieve the SDGs as well as other desired goals. It is vital to collaborate with relevant stakeholders as a key success factor in the implementation of VGS. In this regard, the participants emphasized that effective communication and education are vital to increasing public awareness, generating interest and facilitating successful implementations. Furthermore, participants noted that collaboration should persist throughout all stages of VGS implementation from planning, design, implementation, and maintenance. For instance, the importance of communities as critical stakeholders in the design and implementation of vertical greening projects was emphasized as a success factor (Dominici et al., 2022). Considering that vertical greening initiatives may be new to some communities, collaborative efforts with stakeholders to deliver new or innovative initiatives were noted in the work of Ozdemir et al. (2019). Hence, the successful implementation of vertical greening could be enhanced through stakeholder awareness and collaboration which would be supported through a coordinated participatory approach that develops robust and comprehensive solutions.

5.4.2 Stakeholders Views on the Implementation of Vertical Greening

This section discusses the views of the stakeholders in relation to the main objectives of the research for greater critical analysis. The stakeholders considered in this section include real estate developers, cooperate and private sector professionals, architects, landscape architects and horticulturist who offered their views and experience on the implementation of VGS in semi-arid regions of Nigeria.

5.4.2.1 Evaluation of the Ecological and Visual Appeal of Vertical Greening

One of the main objectives of the research is to evaluate the ecology and visual appeal of VGS, therefore this section presents the views of stakeholders. The respondents showed a deep understanding of the principles and practices of vertical greening thereby evidencing knowledge of the ecological intricacies. In this regard, stakeholders indicated that including vertical greening into existing or future architectural design is valuable in complementing and enhancing the surrounding aesthetics. Furthermore, research into the impact of vertical greening on ecological aesthetics revealed that the visual appeal and ecological equilibrium of urban environments are critical to enhancing the implementation of VGS. The importance of visual appeal was noted by Hefnawy (2022) who demonstrated the fundamental effects of visual appeal and its impact on the imageability of urban spaces. The study further noted that current efforts in vertical greening also offer benefits in addressing urban environmental concerns. Similarly, the literature observed that beyond the conventional aesthetic purpose of vertical greening, it also creates a novel ecosystem and helps to facilitate the implementation of sustainable development goals (Irga et al., 2023). Stakeholders also suggested that the local sourcing of eco-friendly, lightweight building materials fosters plant growth and forms the main strategy in enhancing aesthetic appeal and ensuring environmentally friendly VGS. Collaboration with structural engineers to ensure the structural integrity of vertical greening installations is vital for its sustainability and to achieve the desired objectives. Hence, a more robust strategic and regulatory framework is crucial to ensure the benefits of vertical greening are exploited and the SDGs are achieved.

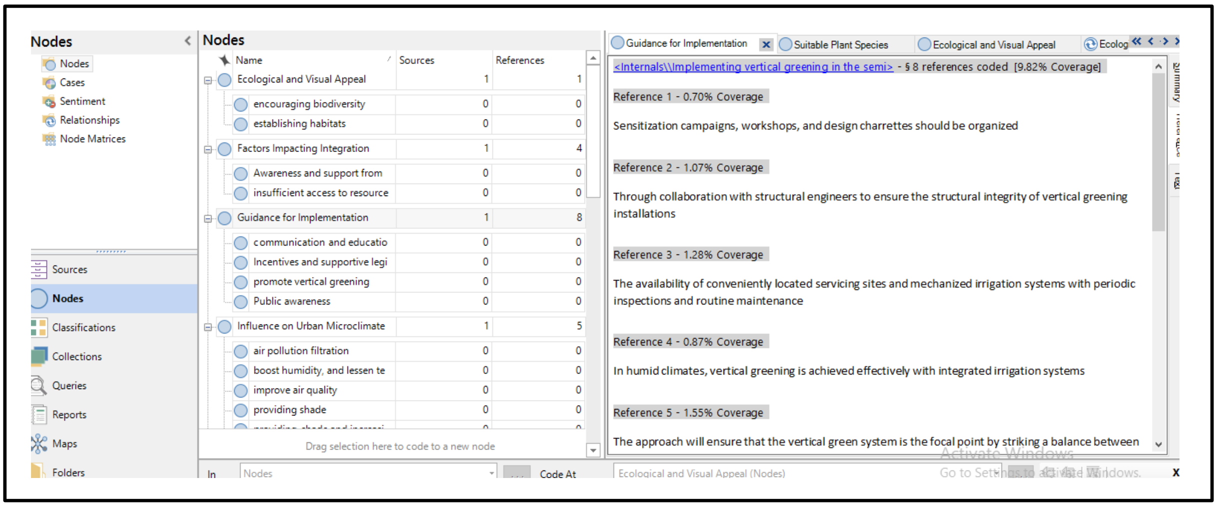


Figure 5.9: Nvivo Screenshot for the Visual Appeal

5.4.2.2 Identification of Suitable Plant Species

In the identification of suitable plant species, stakeholders highlighted some critical factors that determine the choice of plants for vertical greening, including environmental, climatic, and structural considerations. Furthermore, the semi-arid arid region of Nigeria has unique characteristics, such as less annual rainfall, variations in heat during the dry season and flooding during the rainy season, which also influences the survival of plant species. In this regard, some stakeholders suggested that plants - notably agave, cacti, yucca, and bougainvillea - are recognized for their resilience as they require little water and can grow vertically in semi-arid regions. Additionally, other stakeholders believe that succulents, desert shrubs, and drought-resistant vines could be chosen to flourish in such low-water conditions and contribute to the local environment. It was noted while some of the stakeholders consider water deficiency a main criterion for the selection of plant species, others consider water deficiency, aesthetics, ecological long-term maintenance, environmental impact, and the need to mitigate climate change challenges. However, it is apparent that more reliable data is necessary for the further analysis of suitable plant species in semi-arid regions. This could be achieved by varying some of the selection criteria or combining some criteria in a simulated environment before full implementation. This would allow for the correction of errors and the inclusion of conditions which enable better outcomes.

5.4.2.3 Factors Affecting the Integration of Urban Greening

Various factors affecting the integration of vertical greening in urban landscapes were critically evaluated including any regulatory and structural constraints. In this regard, stakeholders identified some of the main factors including the lack of pro-environmental culture, absence of defined design and installation standards and the lack of policy and building regulations on the integration of vertical greening. Others included poor sustainable strategies as well as high installation and maintenance costs. In addition, a lack of sensitization concerning the environmental benefits and positive impact are also challenges contributing to its slow implementation. Hungerford and Volk (1990) explained that within the Environmental Citizenship Model there are three stages of involvement in environmental education. The first is exposure (entrance), which includes sensitization to the general environmental and knowledge on the environment. The second is ownership which involves personal investment in environmental issues, and the final stage is empowerment which means having knowledge of and skills associated with environmental action strategies. The Hungerford Volk Model highlights a range of variables which indicate that a citizen is sufficiently environmentally literate to facilitate pro-environmental initiatives like vertical greening. This emphasises the need for pro-environmental sensitization to create the necessary awareness, especially in semi-arid region of Nigeria which has a low level of literacy.

In addition, it is important to note that vertical greening systems are an advanced technology that requires specialist design and installation. However, there is a lack of guidelines, maintenance procedures and construction technical standards to support the implementation of vertical greening. Furthermore, the lack of standardization is also a significant factor minimizing the development and spread of vertical greening. In this regard, Giordanoa et al. (2016) noted that to prevent environmental degradation and promote urban livability, policies have been adopted around the world to encourage the construction of vertical greening. However, these policy frameworks and regulations are presently lacking in Nigeria, which impedes the implementation and growth of VGS. In addition, vertical greening systems can be expensive to install and maintain due to their unique nature. This challenge was emphasized by Perini and Rasasco (2013) who noted that the maintenance of a VGS has always been a barrier for its wider usage. Hence, the implementation of vertical greening - especially in low socioeconomic areas - will generate less interest due to its high implementation and maintenance costs. Furthermore, a comprehensive awareness is required of the benefits of vertical greening, including the implementation of vertical greening in building regulations, and the development of policies to enhance its implementation in Nigeria. It is also crucial to implement robust incentives, maintenance measures, and design guides to encourage its easier integration by building professionals in Nigeria thereby ensuring greater sustainability.

5.4.2.4 Influence on the Urban Microclimate

The impact of vertical greening on the urban microclimate is another important component of this study. Stakeholders were of the view that vertical greening reduces temperature, enhances cooling effects, and increases thermal comfort. It was further noted that vertical greening helps to lessen the severity of weather conditions, increases biodiversity, and gives the region a distinct identity, potentially attracting tourists. Beyond temperature reduction, vertical greening has a broader impact on the microclimate including improving air quality, enhancing humidity levels, and elevating the overall urban living conditions. For instance, studies have shown that 30-50% of facades in high-density urban cities record a reduction in both day and night air temperature, improve relative humidity, and VG walls emit long-wave fluxes (Morakinyo et al, 2019). Similarly, vertical greening was noted to significantly reduce the amount of incoming solar irradiation and manage high temperatures and relative humidity fluctuations in Ghent, Belgium (De Groeve et al., 2023). It is important to note that while living walls have an impact on the urban microclimate, the degree of influence differs from region to region depending on the climatic conditions or type of plant species. To fully understand the level of influence of vertical greening on semi-arid regions of Northern Nigeria and thereby facilitate implementation, variations in microclimate conditions should be tested to gather more realistic empirical data.

5.4.2.5 Guidance for the Implementation of Vertical Greening

Stakeholders' perceptions were critically analysed to offer practical guidance for the implementation of vertical greening in the semi-arid region of Northern Nigeria, which were tailored for policy makers, urban planners, and architects. When considering an appropriate design to address issues with climatic conditions and water supply, it was necessary to utilise native or local plant species. This ensured their survival and maintenance in the extreme climatic conditions of a semi-arid region. Furthermore, the use of a local irrigation system would reduce the challenges of insufficient water for plant growth at certain periods of the year. It was also noted that a variety of plant species would enhance biodiversity by luring pollinators and forming microhabitats in the vertical green system to encourage ecosystem health and biodiversity. As part of the measures to promote plant health, it is important to ensure the frequent trimming of the plants, their selective fertilization and integrated pest management.

For the successful implementation of vertical greening in semi-arid regions of Northern Nigeria, there is a need for immediate government intervention. The government should make vertical greening mandatory in certain areas as part of a holistic framework to enhance existing efforts or policy frameworks relating to afforestation. This would reduce the impact of climate change and facilitate current governments effort to meet its commitments on climate action and sustainable development goals. To ease the process of implementation, it is also critical for the government to develop comprehensive policies or strategies with detailed action plans containing clear objectives and responsibilities amongst various stakeholders. This framework should also include appropriate steps to ensure a successful implementation and long-term maintenance. The government could provide some financial incentives or tax waivers for stakeholders with vertical greening in their concepts to encourage implementation. This would also consider that the inclusion of vertical greening technology normally increases the overall cost of building. There is also a need for regulations to include a compliance regime for the implementation and maintenance of VGS to ensure sustainability.

In addition, the findings from this study show that the government should ensure all legal, regulatory, or strategic frameworks on VGS are comprehensive and therefore accommodate all relevant stakeholders in the implementation process, especially within the community. The government should consider the engagement of community leaders by ensuring their buy-in to support implementation. In addition, more research by the government and other stakeholders on emerging innovative approaches is crucial for successful implementation and sustainability. Finally, continuous education and awareness amongst communities and end users are also critical success factors for the effective implementation of VGS.

5.4.2.6 The Semi-Arid Region of Northern Nigeria

The climate of Northern Nigeria is a typical Sahelian hot and semi-arid in nature, with an average daylight temperature of 35^{o} C (95^{o}F), less rainfall during the rainy season and a dry sandy harmattan season. This section presents the specific inputs by some critical stakeholders (for example real estate agents and urban planners) on the Northern region of Nigeria due to their critical role in the design and implementation of VGS. It was noted that sustainable practice like vertical greening has the potential to increase the market value and desirability of buildings or properties, particularly in semi-arid regions. It also enhances visual appeal thereby attracting users or occupants who prioritise sustainability and favour natural vegetation amongst environmental, social and other benefits. The prioritisation of ecological aspects such as trees, grasses, hedges, and vertical greening in urban areas leads to the creation of a more pleasant and sustainable living environments and results in increased demand for such initiatives. The provision of healthier and more visually appealing environments can potentially attract a wider range of prospective buyers and renters, and hence increase the demand for properties in these locations. In addition, the aesthetic appeal and ecological advantages, such as increased air quality and reduced temperatures, can enhance the desirability of such properties. As a result, this can give rise to increased pricing, which has the potential to yield improved returns for property owners. The views of stakeholders are consistent with those of Rosasco (2018) who expatiated that vertical greening provides energy savings, the material protection of buildings and increases the building real estate value due to their aesthetic contribution. This underscores the importance of VGS in enhancing the aesthetics of buildings, amongst other associated benefits.

However, while greening has added value to Northern Nigeria, the high cost of its design, execution and maintenance hinders its wider implementation due to low income or difficult economic realities. It was further observed that property developers and owners consider that a lack of understanding of the benefits of vertical greening, its initial installation and maintenance costs are amongst the reasons that discourage its implementation in most buildings. To address these challenges, stakeholders opined that awareness of its numerous benefits would facilitate its implementation and acceptance in semi-arid regions of Northern Nigeria, particularly with the peculiar cultural and religious inclinations of people in the region. Furthermore, education, sensitization, and awareness amongst potential buyers and sellers would promote and increase property sales or rentals. Collaboration with local authorities and environmental organisations offers potential avenues for funds or incentives to address some of the challenges associated with the high cost of VGS installation and maintenance. This should be included within appropriate policy frameworks by governments to support the implementation VG initiatives in Northern Nigeria.

As part of urban planning, there is a need to incorporate vertical greening within the framework of initiatives in the semi-arid region of Northern Nigeria, as discussed with urban planners. The study revealed the requisite capacity to integrate vertical greening within urban plans, to thereby facilitate the mitigation of high temperatures, enhance air quality, and establish urban areas that are both sustainable and visually appealing. Indeed, with a minimum of 10 years in their profession, these urban planners have the requisite experience, as shown in Figure 5.9. For the successful incorporation of vertical greening in projects in Northern Nigeria, there is the need for the meticulous evaluation of several pivotal aspects including the education of inhabitants, collaboration with stakeholders, a comprehensive understanding of the distinct climatic characteristics, irrigation and water management techniques suitable for the plant species, and maintenance and infrastructure compatibility in the regions.

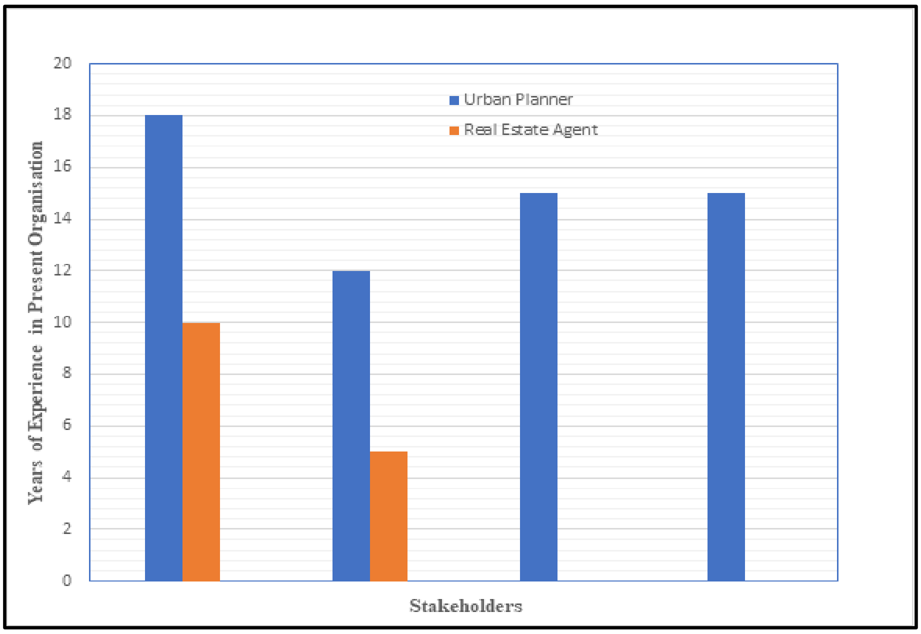


Figure 5.9: Stakeholders According to Number of Years Experience

To fully implement VGS, stakeholders believe that the development and execution of building standards and regulations that explicitly permit and provide incentives for installation are crucial. Also, financial incentives or rebates can serve as effective mechanisms to promote the adoption of vertical greening among property owners. These incentives could potentially encompass tax exemptions or financial assistance in the form of grants specifically aimed at promoting and encouraging the adoption of sustainable building practises. The formulation of guidelines or recommendations on the selection of plant species that are well-suited to the local environment and require minimal maintenance, and the optimisation of a permitting procedure on vertical greening installations has the potential to mitigate bureaucratic impediments and foster the inclination of property owners towards environmentally sustainable initiatives such as VGS. In addition, actively involving and educating the local population about the advantages of vertical greening are vital components of awareness and would facilitate its implementation. This approach has the potential to garner public backing and motivate property owners to integrate such systems. Other important steps to accelerate the implementation include public and private initiatives and programmes, the adoption of vertical greening practises in both public and private domains and collaboration with critical stakeholders such as architects, developers, and landscape designers to integrate vertical greening into building designs and landscape planning.

5.5 Conclusion

This chapter presented the qualitative data of the study as generated from semi-structured interviews with relevant critical stakeholders on the implementation of VGS in the semi-arid region of Nigeria. The data was presented and discussed after detailed analysis of the themes and subthemes and after analyzing the views of relevant stakeholders in relation to the key research objectives. Accordingly, findings from these studies demonstrate how knowledge of the opportunities and challenges associated with vertical greening in a semi-arid region have been enhanced by the insights from a range of stakeholders including architects, landscape architects, and horticulturists. The findings highlighted the significance of ecological and visual appeal, the selection of appropriate plant species, factors that influence successful integration, the effect of the urban microclimate, and appropriate guidance for a successful implementation. The knowledge acquired from these professionals and practitioners serves as a significant resource for policymakers, urban planners, and architects in semi-arid regions like Northern Nigeria who seek to enhance the sustainability and aesthetics of urban spaces in such regions. Furthermore, it underscores the importance of fostering collaboration, engaging the community, and formulating comprehensive policies and strategies to effectively integrate vertical greening initiatives into urban landscapes.

5.6 Summary of findings

The results of this investigation suggest that the implementation of VGS in the semi-arid region of Nigeria presents opportunities as well as challenges. The research examines important criteria including ecological and aesthetic appeal, the choice of appropriate plant species, variables influencing integration, the influence of VGS on the microclimate of urban areas, and recommendations for practical application. The inclusion of stakeholder perspectives, such as those from architects, landscape architects, urban planners, estate agents and horticulturists, enhances the overall comprehension of these aspects. Stakeholders explicitly identify the favourable impact of VGS on the microclimate of urban areas, with a particular emphasis on their ability to regulate temperatures and enhance air quality. Nevertheless, it is acknowledged that the influence on climatic conditions and plant species might vary. The research underscores the pivotal significance of the selection of plant species, with a particular emphasis on traits such as drought tolerance and adaptability to the specific climatic conditions of the region. Adding that critical success factors for VGS include community awareness, water availability, and routine maintenance and the significant obstacles encompass constraints in resources, including financial and water-related limitations, sensitisation in addition to difficulties in maintenance. The creation of unique approaches is vital in light of the arid characteristics of the semi-arid region.

Furthermore, employing microclimate simulation tools would provide researchers with the means to observe and analyze the specific impact of different plant species on the semi-arid climate. This approach promises valuable insights into the extent of coverage and overall adaptability of these plants within such environmental conditions.
In summary, the essential use of microclimate simulation serves as a crucial bridge between theoretical research findings and the practical application of Vertical Greening Systems (VGS). This tool plays a paramount role in fostering well-informed decision-making processes for urban planners, policymakers, and architects. Its overarching goal is to advance the sustainable development of visually appealing and ecologically conscious urban environments, with a specific focus on semi-arid regions like Northern Nigeria.

CHAPTER 6: MICROCLIMATE SIMULATION

6.1 Introduction

Evaluations of the influence of vertical greening on microclimates typically employ two primary methodologies: experimental and numerical analyses (Rajak et al., 2022). These approaches play a crucial role in assessing how vertical greening affects microclimate and thermal performance and serve as essential tools to validate microclimate research

(Brozovsky et al., 2020; Toparlar et al., 2015; Del Rio et al., 2020). Additionally, benchmarking a numerical study against other research offers greater rigour, whilst an exploration of methodologies is helpful in comprehending the research landscape.

The attainment of the fourth objective - focusing on the evaluation of vertical greening's impact on the microclimate of urban areas in the semi-arid region of Northern Nigeria - was successfully realised by implementing a microclimate simulation. This study seeks to delineate the correlation between vertical greening and the microclimate with particular emphasis on its effects on temperature, humidity, and air quality within the study area. Furthermore, it strives to determine the effectiveness of vertical greening in mitigating the impacts of climate change in semi-arid regions.

The outcomes of this study are designed to be relevant to the semi-arid regions of Northern Nigeria and to analogous environments worldwide. Nevertheless, this chapter serves as a comprehensive guide to the microclimate simulation process. It elucidates the methodology, tools, and procedures employed to evaluate the impact of vertical greening in semi-arid regions, emphasising its potential implications for broader global contexts.

6.2 Background to the Simulation Model

6.2.1 ENVI-MET Microclimate Modeling Tool

The selection of an appropriate microclimate modelling tool is critical to ensure precision and reliability in environmental simulations. As a range of microclimate simulation software options are available, the most appropriate depends on the comprehensiveness of the available data. A specialised tool for conducting three-dimensional microclimatic simulations is the ENVI-Met software, developed by Bruse in 2004. This software is widely used (Toparlar et al., 2017) as it incorporates all essential elements relevant to urban environments and produces empirically validated outcomes. It is specifically tailored to replicate intricate interactions among surfaces, vegetation, and the atmosphere within urban settings, and can accommodate a range of vegetation. This capability allows for a more nuanced understanding of the microclimate and contributes to the richness of the simulation results.

ENVI-Met was specifically developed for analysing microscale phenomena and has a standard horizontal resolution ranging from 0.5 to 5 metres. It typically operates over a timeframe of 24 to 48 hours using time steps of a few seconds. This resolution also enables the researcher to scrutinise minute-scale interactions among individual structures, surfaces, and plants (Bruse & Fleer, 1998).

Primarily employed for simulating urban environments, the ENVI-Met model excels at capturing variables such as potential temperature, mean radiant temperature, wind speed, wind direction, and other pertinent factors. Its applicability transcends geographical boundaries, as it has been implemented in various nations characterised by diverse temperature zones (Tsoka et al., 2017). Its versatility has enabled the comparative analysis of thermal performances before and after the implementation of specific configurations or interventions, which has enabled a greater understanding of the impact of urban greenery on microclimates.

6.2.2 Data Collection in Microclimate Simulation

Before embarking on the microclimate simulation, it is imperative to gather relevant data on which to conduct comprehensive analysis. The initial phase of this research acquired an in-depth understanding of the current state of the microclimate of Northern Nigeria. This involved obtaining the records of key variables such as temperature, humidity, wind speed, and direction. The meteorological data utilized for this study was sourced from the Nigeria Meteorological Agency (NIMET) (see Appendix 3).

The primary objective of this data collection was to establish the baseline microclimate parameters before implementing any intervention, such as vertical greening. Baseline temperatures play a crucial role in obtaining a nuanced understanding of the prevailing temperature patterns by including diurnal oscillations, seasonal variations, and localised areas of heightened temperature. Furthermore, to assess the potential impact of vertical greening on humidity, it is essential to be cognizant of current trends in humidity. Similarly, it is vital to determine the existing wind speed and direction when evaluating the effectiveness of vertical greening as a strategy for enhancing air quality. The collected data serves as a foundational benchmark for assessing the influence of vertical greening on temperature, humidity, and overall air quality. This systematic approach ensures a robust foundation for subsequent microclimate simulations and interventions.

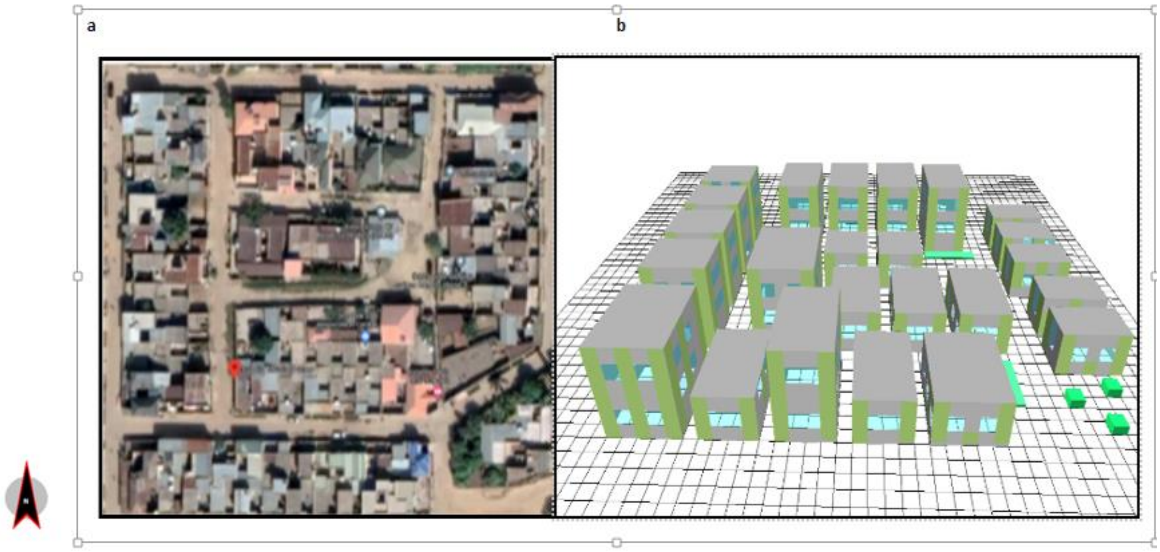
6.2.3a Model Area

The formulation of the model constitutes an integral facet of this research as it provides a nuanced comprehension of a building, its environment, and associated features. The bedrock of a microclimate model lies in the meteorological data gathered, which incorporates diverse variables pertinent to a microclimate simulation, such as building materials, ground surface composition, plant types, and the percentage of vertical surfaces covered. The model for this study serves as a valuable tool for predicting and illustrating prognostic outcomes across various scenarios. Initially, a baseline scenario emerged from the collected meteorological data and these values were employed to execute a comprehensive microclimate simulation, which were then subject to comparative analysis with other simulations.

The simulation protocol required the precise geographic coordinates for Kano State in Nigeria, namely at latitude 11.50° and Longitude 8.51°. Furthermore, two distinct climatic periods were identified, representing the midpoint of the dry season (January 16th) and the midpoint of the wet or rainy season (July 16th), spanning from 6:00 am to 6:00 am, and totaling 24 hours. The focus of the simulation predominantly centred on the urban area of Kano State due to its high population density and its buildings which were characterised by comparable architectural styles. A simulation was conducted of the two specific urban regions by employing a software grid of 5m x 5m x 5m for the X, Y, and Z axes; thus, each grid cell represented a space of five metres.

As part of the study, the architectural attributes of the buildings included flat roofs without protrusion. To ensure precision in the building heights, a telescoping factor of 20% was incorporated, and all buildings were set to heights of 6 and 12 metres. Simulated vegetation, comprising grasses, trees, and hedges, mirrored the characteristics of a typical natural setting. The models were executed with a grid resolution of 50x50x40, and output files were saved at 60-minute intervals. In addition, temperature, relative humidity, wind speed, and direction were the only variables modified in the simulations' two climatic seasons.

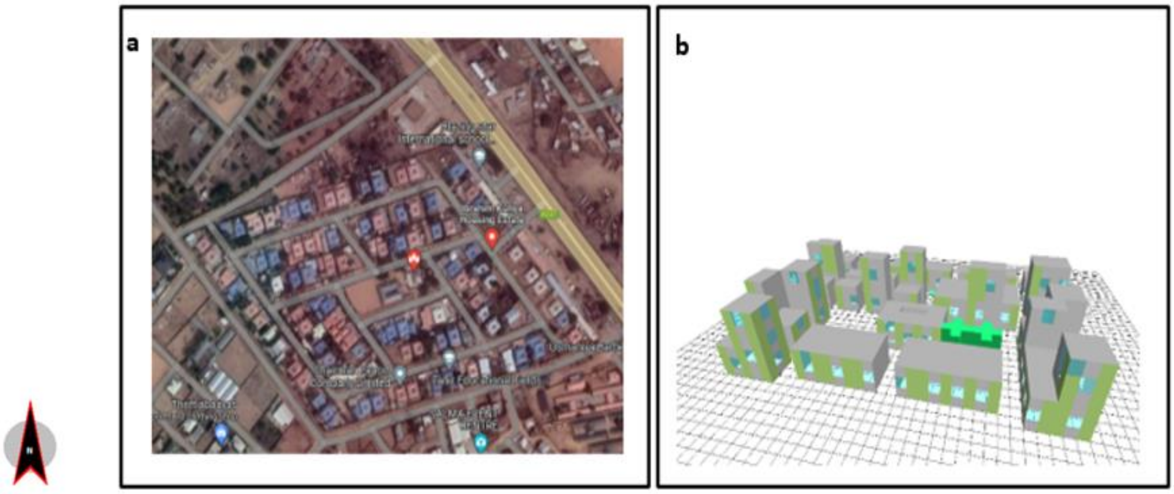
Owing to the relevance of their attributes to the study, two neighborhoods in Kano State, Northern Nigeria - Kundila and Ibrahim Kunya housing estates - were selected. The model area designated for Kundila Housing Estate covers a significant expanse, utilising a grid comprising 50x50x40 cells, each with dimensions of 5x5x5 metres. These two neighbourhoods were strategically chosen as representative microcosms for the study, serving as exemplars of a typical urban environment in the semi-arid region of Northern Nigeria. The consistency in dimension, building height, housing design, and neighborhood characteristics facilitated meaningful and comparable microclimate simulations across both regions. The average height of the buildings in this neighbourhood was approximately 10 metres, while the predominant housing typologies were semi-detached and detached, with more duplexes than bungalows. Notably, the landscape was characterised by the presence of scattered hedges in both front and backyards. The locality was crisscrossed by an interconnected network of unpaved streets which provided access to the houses. Figures 6.1 (a) and (b) respectively show the aerial view of Kundila Housing Estate and the model area of the estate with evident vertical greening with airspace.



c.

Figure 6.1: (a) Kundila Housing Estate (b) Model Area Vert Greening with Airspace

The designated area for Ibrahim Kunya Housing Estate was configured to mirror the spatial dimensions of Kundila Housing Estate. This configuration resulted in a grid comprising 50 columns, 50 rows, and 40 layers, with each cell measuring 5 metres each along the x- y-, and z-axes. Similar to Kundila, the mean building height of Ibrahim Kunya Housing Estate was approximately 9 metres. The architectural styles in this locale predominantly featured semi-detached and detached houses, with a higher prevalence of bungalows than duplexes. Decorative hedges often adorned the front of residences, contributing a botanical element to the immediate environment. Some neighbourhood lanes were paved, while others retained a natural soil composition (illustrated in Figures 6.2 (a) and (b)).



c.

Figure 6.2: (a) Ibrahim Kunya Housing Estate (b) Model Area 50% Coverage (c) Elevation view.

6.2.3b Input Variables in ENVI-met Microclimate Simulation

Reliability and validity of the simulation depend on exact and comprehensive input variables. The primary categories of input variables include:

a. Meteorological data, comprising wind direction and speed, temperature, and relative humidity.
b. Geographical and environmental data such as topography and surface types.
c. Urban geometry and building data including street geometry, building heights and building materials
d. Vegetation data such as plant types and vegetation characteristics.
e. Simulation configuration such as simulation period, time steps and grid resolution.

For ENVI-met to be used in dependable and realistic microclimate simulations, accurate input variables are essential. Researchers and urban planners can efficiently assess and optimise urban environments for better thermal comfort, lesser urban heat islands, and improved sustainability by cautiously altering these variables.

Table 6.1: The input variables in ENVI-met Microclimate Simulation

S/NO	Variable	Type
1.	Meteorological data	Wind direction and speed Temperature Relative humidity
2.	Geographical and environmental data	Topography Surface types

3.	Urban geometry and building data	Street geometry Building heights Building materials
4.	Vegetation and substrate data.	Plant types Vegetation characteristics Soil type
5.	Simulation configuration	Simulation period Time step Grid resolution.

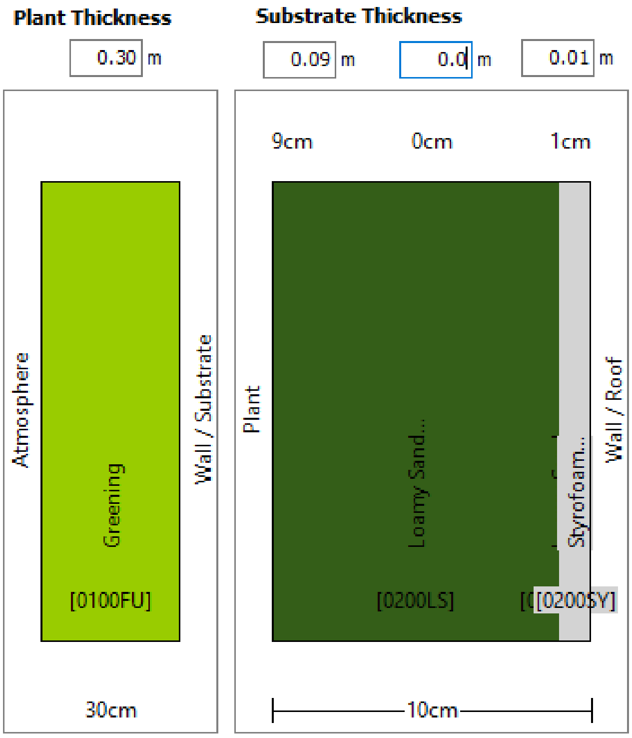


Figure 6.3:Greening input variable.
Source ENVI-met software 2023.

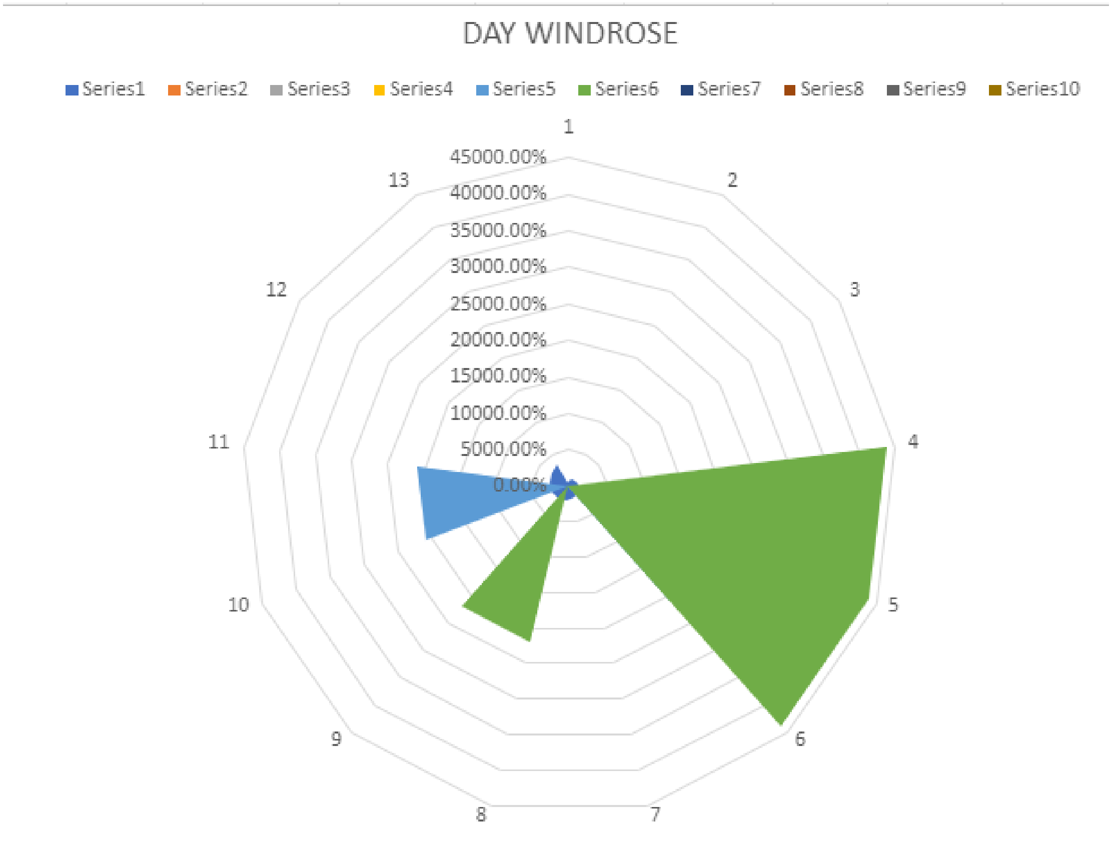


Figure 6.2:DAY WINDROSE
Source Excel, 2024

6.2.4 Microclimate Simulation Scenarios

A series of simulations were conducted to assess the influence of diverse scenarios on microclimate conditions and understand the impact of variations in key environmental factors on model outputs. A sensitivity analysis involves systematically adjusting input parameters within the microclimate model to measure their effects on variables such as temperature, relative humidity, and air quality. These simulations explored proposed climate change mitigation strategies by incorporating vertical greening; a range of scenarios within the model areas were examined to determine its influence on the microclimate. The simulations encompassed a spectrum of scenarios across the dry and wet seasons, and each featured different percentages of vertical greening cover (0%, 25%, and 50%), including greening with airspace. These scenarios used various street surfaces including asphalt and natural soil.

During the wet season simulation, the model replicated environmental conditions consistent with typical weather patterns; it registered a minimum temperature of 21.5°C and a maximum of 38°C. This scenario accurately portrayed a standard rainy day in Northern Nigeria during the wet season, capturing both normal and hotter day conditions. Thus, the boundary conditions derived from typical wet season data exhibited diurnal air temperature profiles consistent with the expected seasonal trends. Similarly, the simulation for the dry season mirrored the effects of a typical dry day. This scenario captured decreased temperatures with a peak of 30.5°C and a low of 11.2°C, which emulates the conditions of extended harmattan periods in Northern Nigeria's dry season.

These simulations were set for the mid-months of each season - January and July - as these months often represent balanced and average conditions. Choosing the same middle months for both wet and dry seasons provides consistency, ensuring that simulations are conducted under comparable conditions and thereby facilitate a meaningful evaluation of the impact of vertical greening. Three different times were selected - early morning at 6:00 am, late afternoon at 4:00 pm and night at 10:00 pm - which captured unique temporal environmental variables. These timings improved the comprehensiveness and usefulness of the microclimate study as each interval represented a distinct day stage, which enabled a comprehensive analysis of the microclimate variables at different periods. Wind conditions were represented by the northeast trade wind from the Sahara Desert, which carried dust with a wind speed of 9 knots on the 16th of January 2021, and the southwest moisture wind from the Atlantic Ocean brought rain with a wind speed of 3 knots on the 16th of July 2021. The initial relative humidity varied among the scenarios producing a mean value of 22.6% for a typical dry season day and a higher mean value of 52.5% for the wet season.

The year 2021 was chosen for the simulation as it is widely and credibly recognised as one of the seven warmest years documented (Zhou et al., 2022; Demirtas, 2023). It ensured the study aligned with current climatic patterns and enabled a comprehensive evaluation of the possible consequences. Overall, these simulations provided an extensive assessment of the potential impacts of vertical greening on the microclimate in the semi-arid region of Northern Nigeria, by understanding its effects in both wet and dry weather conditions.

6.2.5 Proposed Outputs and Results

The data extraction process involved the generation of visual maps from the output files of all simulations using the Leonardo program within ENVI-Met. These maps provided insights into dynamic changes during the simulation periods, which illustrated meteorological outcomes such as air temperature, wind speed or change, specific or relative humidity, dissipation, and pressure perturbation. By gathering and comparing data at regular intervals of 60 minutes every day, this approach facilitated a thorough understanding of environmental changes. A comparative analysis was then conducted to identify differences between the two seasons and the amount of vertical greening coverage for each day, which was compared to the base case scenario. This method contributed significantly to an in-depth analysis and assessment of how different variables influenced the simulated conditions over the study's duration. Following the generation of these results, detailed analysis was conducted using the maps shown in Figures 6.3 to 6.37b, which specifically focus on the designated locations at the predetermined times.

6.3 Evaluation of the Simulation Results

6.3.1 Simulation Results for Kundila Housing Estate in January 2021 at 0% Vertical Coverage

6.3.1.1 *Air Temperature Analysis*

At a height of 3 metres, the simulation outcomes for air temperatures at Kundila Housing Estate during January with no vertical coverage (0%) revealed distinct temperature variations at different times of the day. In the early morning at 6:00 am air temperatures ranged from 12.37°C to 13.62°C. In addition, there was an increase in temperature during the afternoon at 4:00 pm, which fluctuated between 25.92°C and 27.52°C. At night, at 10:00 pm, the recorded temperatures ranged from 17.57°C to 18.54°C, as shown in Figures 63, 63a and 63b. The daily mean temperature for this scenario was deemed comfortable at 19.26°C. However, the afternoon period recorded the highest temperature at 27.52°C mostly around the northeast axis with a lower temperature in between the buildings, and the morning recorded the lowest at 12.37°Cespecially around the northeast axis. At night Similar to the morning hours, the temperature is around the northeast axis. These findings contribute valuable insights into the diurnal temperature variations experienced in Kundila Housing Estate during the day, offering an understanding of local microclimate dynamics.

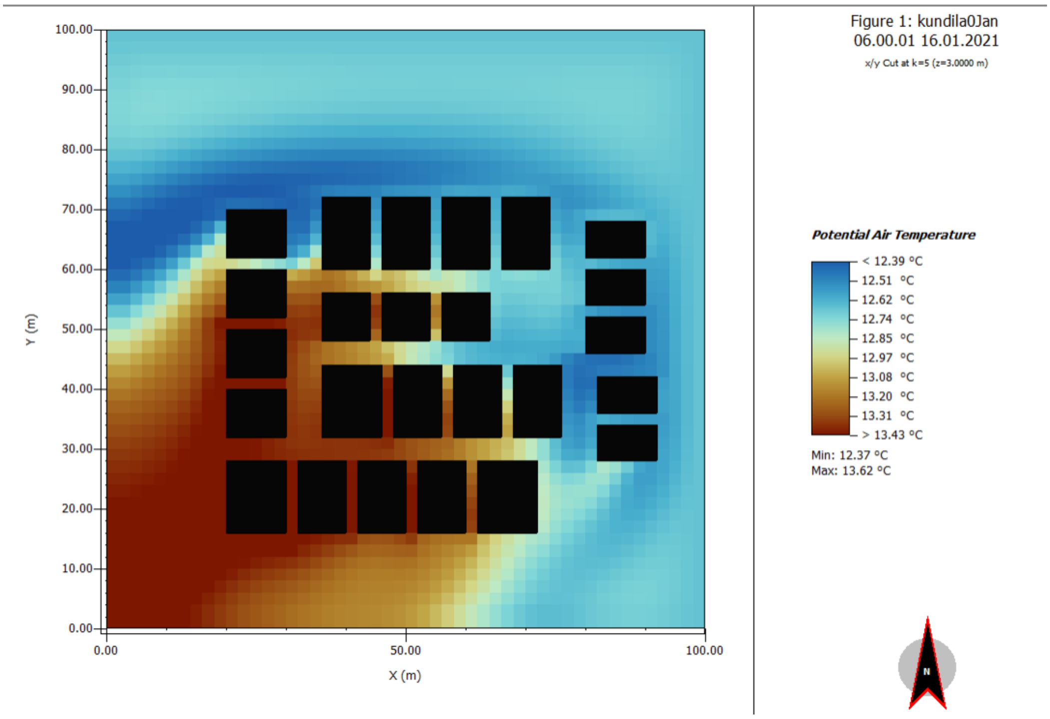


Figure 6.3: Envi Met output from Leonard: Temperature at 6:00 am

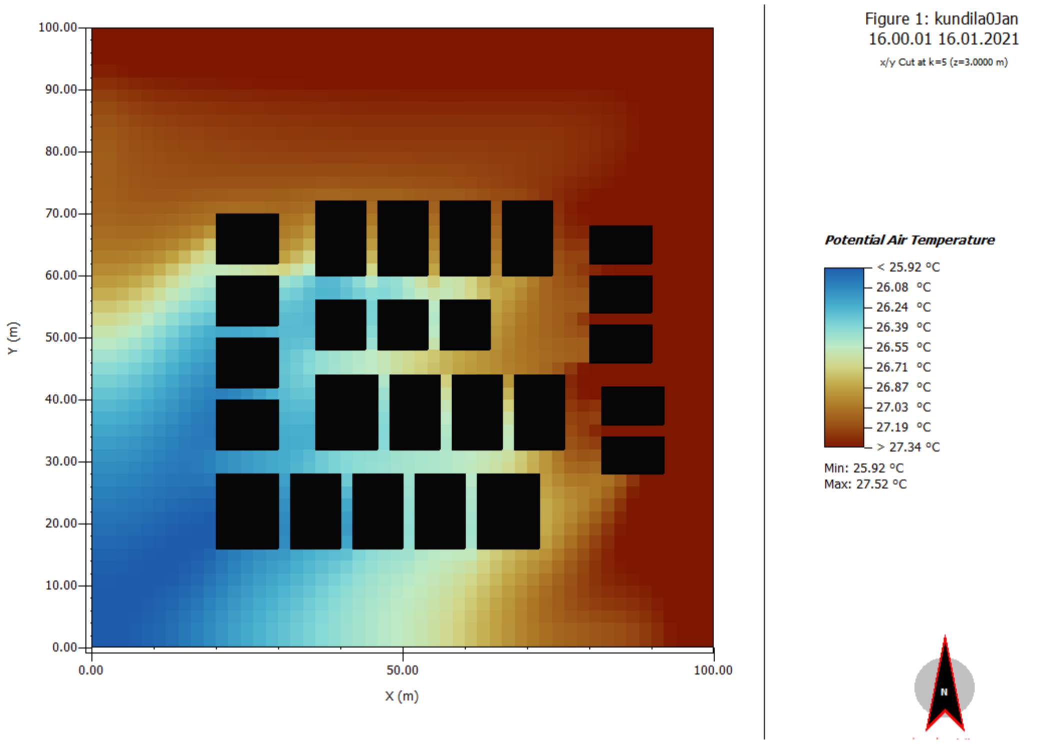


Figure 6.3a: Envi Met output from Leonard: Temperature at 4:00 pm

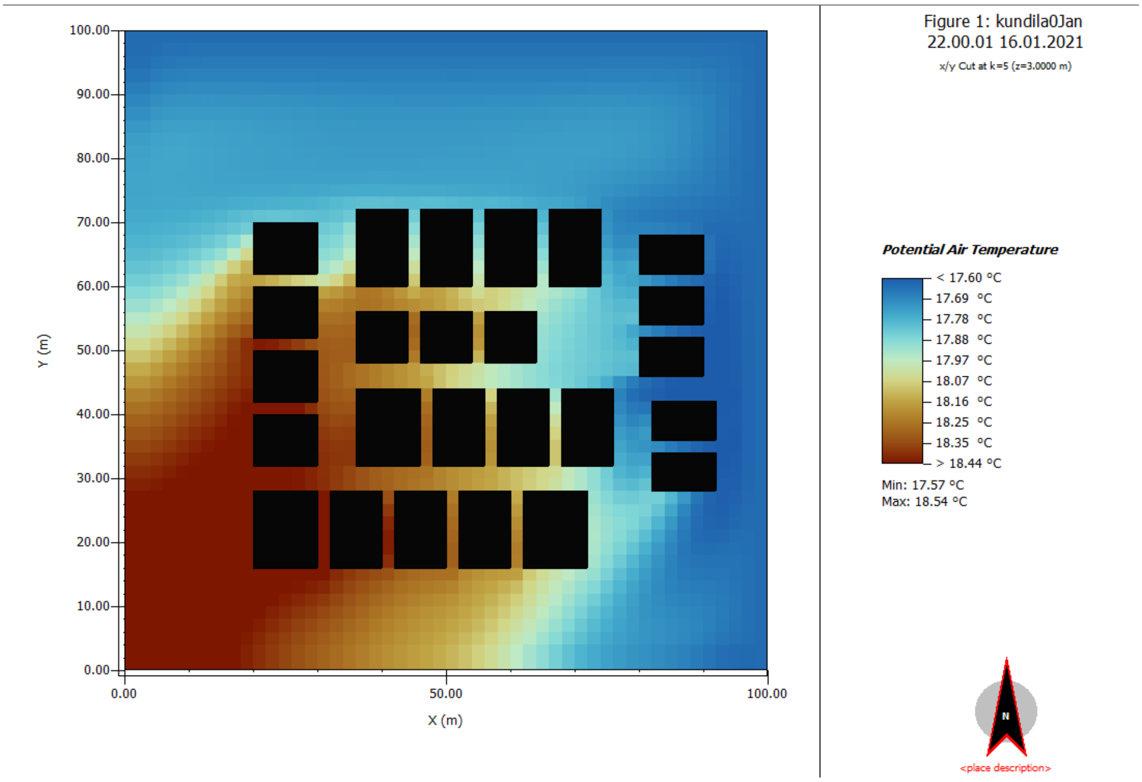


Figure 6.3b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.1.2 Wind Speed Analysis

The simulation results indicate a range of wind speeds at Kundila Housing Estate during the specified times of the day. At 6:00 am, the wind speed fluctuated between 0.17 m/s and 7.96 m/s. A parallel trend was observed in the afternoon at 4:00 pm, with wind speeds varying from 0.05 m/s to 9.48 m/s whilst at 10:00 pm they ranged from 0.11 m/s to 8.93 m/s (illustrated in Figures 64, 64a and 64b respectively). The average wind speed for these scenarios was calculated at 4.45m/s, while the presence of staggered buildings contributed to a considerable reduction in wind speed in between these areas, the wind speed is considerably lower around the vertical greening. This observation highlights the influence of local architectural configurations on wind dynamics, emphasising the importance of building layouts in microclimate analyses and also of vegetation on wind speed. The comprehensive wind speed data offers valuable insights into spatial and temporal variations which contribute to a nuanced understanding of the microclimatic conditions at Kundila Housing Estate.

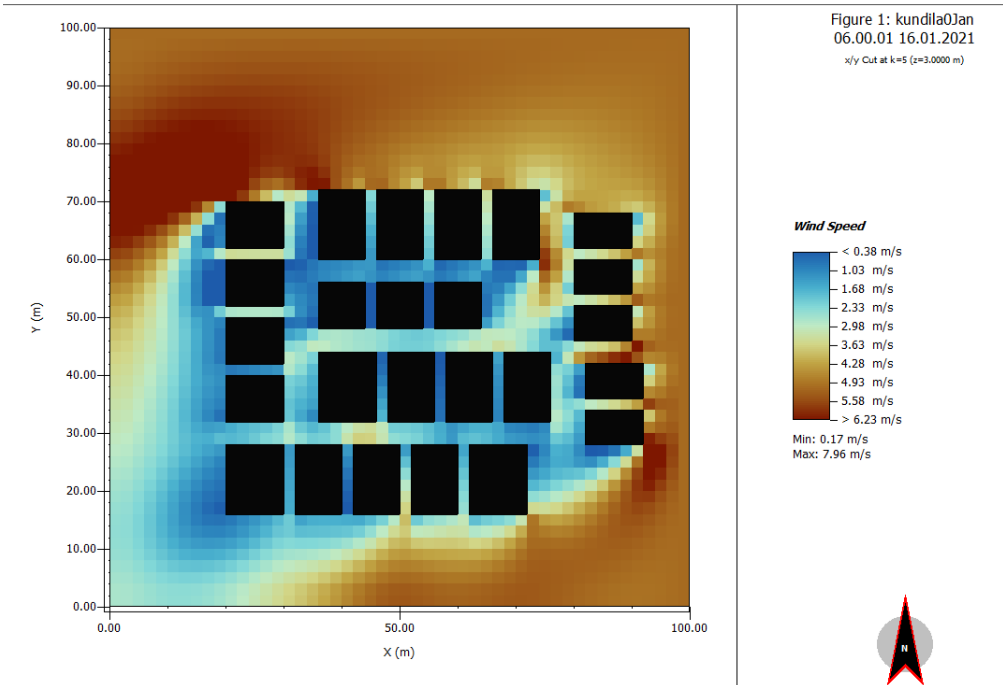


Figure 6.4: Envi Met output from Leonard: Wind speed at 6:00 am

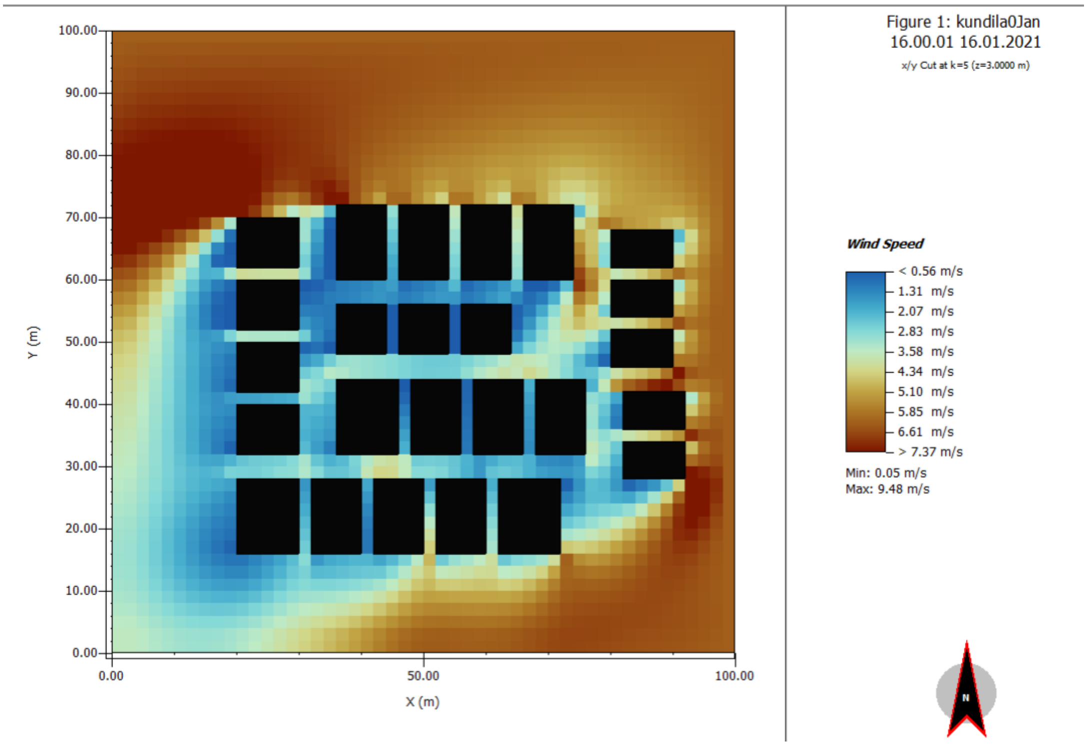


Figure 6.4a: Envi Met output from Leonardo: Wind speed at 4:00 pm

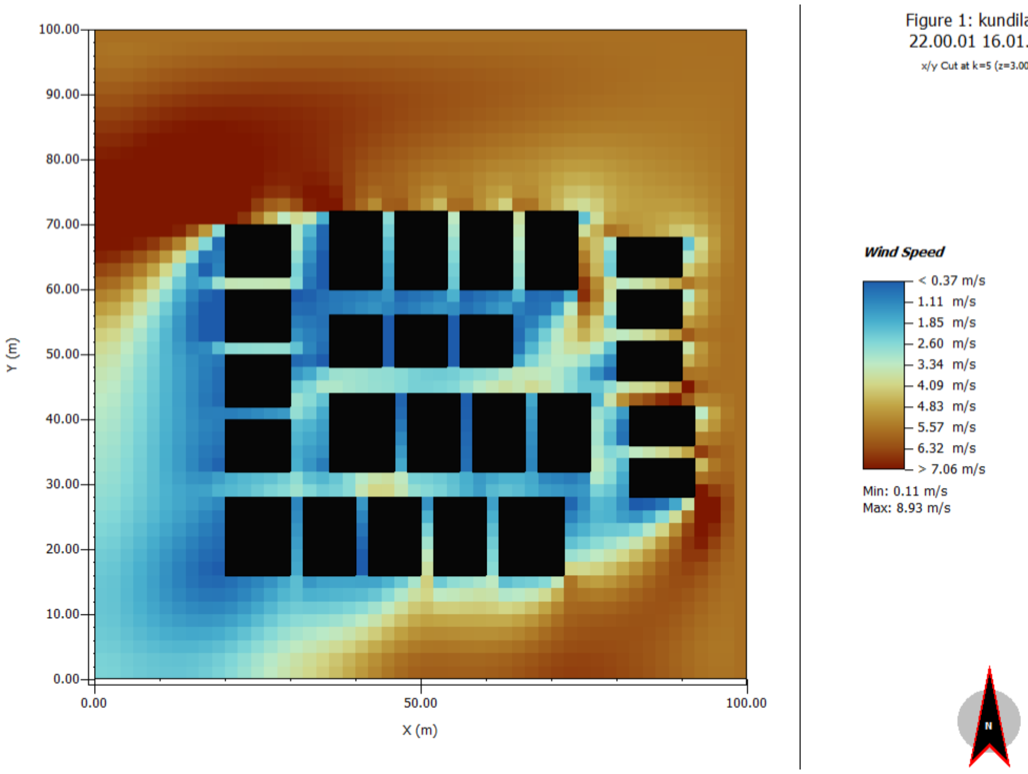


Figure 6.4b: Envi Met output from Leonardo: Wind speed at 10:00 pm

6.3.1.3 Relative Humidity Analysis

The simulation outcomes for relative humidity at Kundila Housing Estate during the specified times of the day provide valuable insights into the moisture content of the air. At 6:00 am, the morning relative humidity was between 67.42% and 74.17%, while at 4:00 pm it fluctuated between 17.56% and 22.34%, and at 10:00 pm, it ranged from 43.91% to 44.90% (Figures 65, 65a and 65b respectively). Moreover, the afternoon experienced the lowest relative humidity at 17.56%, and the morning recorded the highest at 74.17%, while the average across these periods was calculated at 45.05%. These findings contribute to a nuanced understanding of the diurnal variations in humidity, which is vital for comprehending the microclimate dynamics at Kundila Housing Estate.

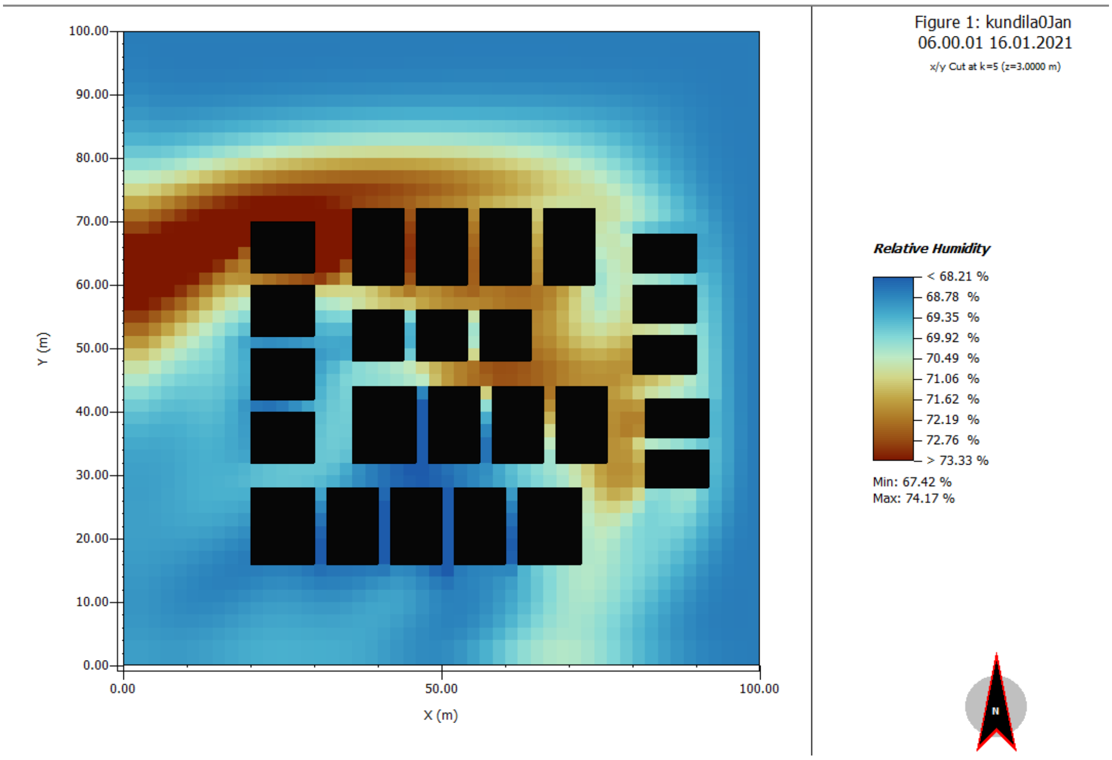


Figure 6.5: Envi Met output from Leonardo: Relative humidity at 6:00 am

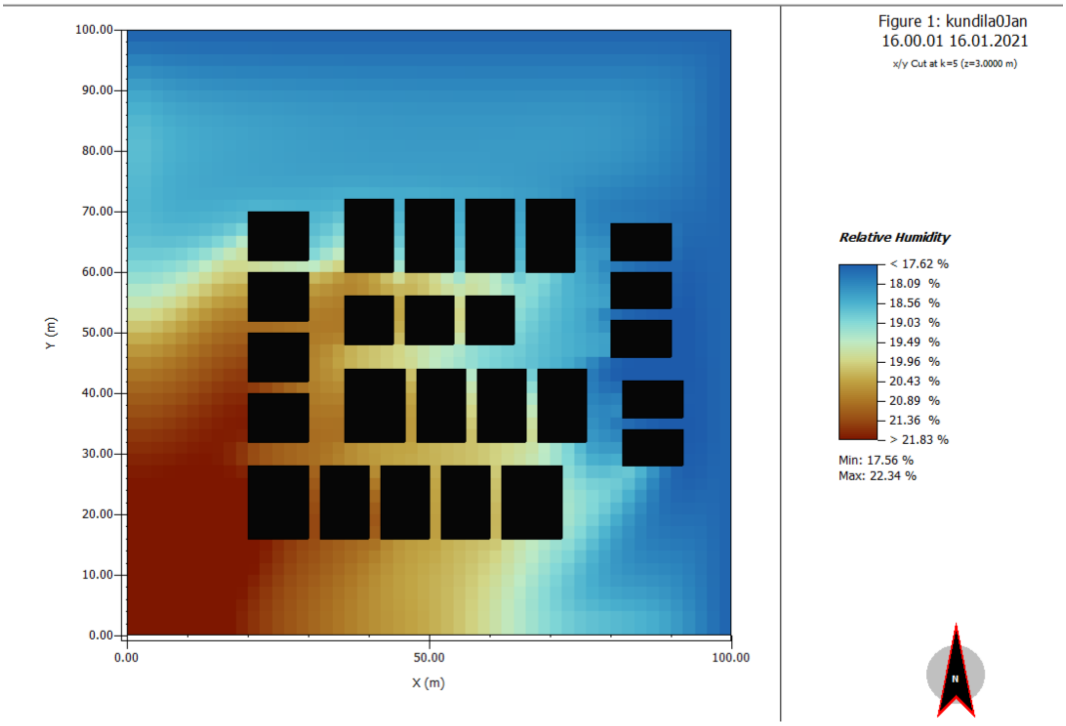


Figure 6.5a: Envi Met output from Leonardo: Relative humidity at 4:00 pm

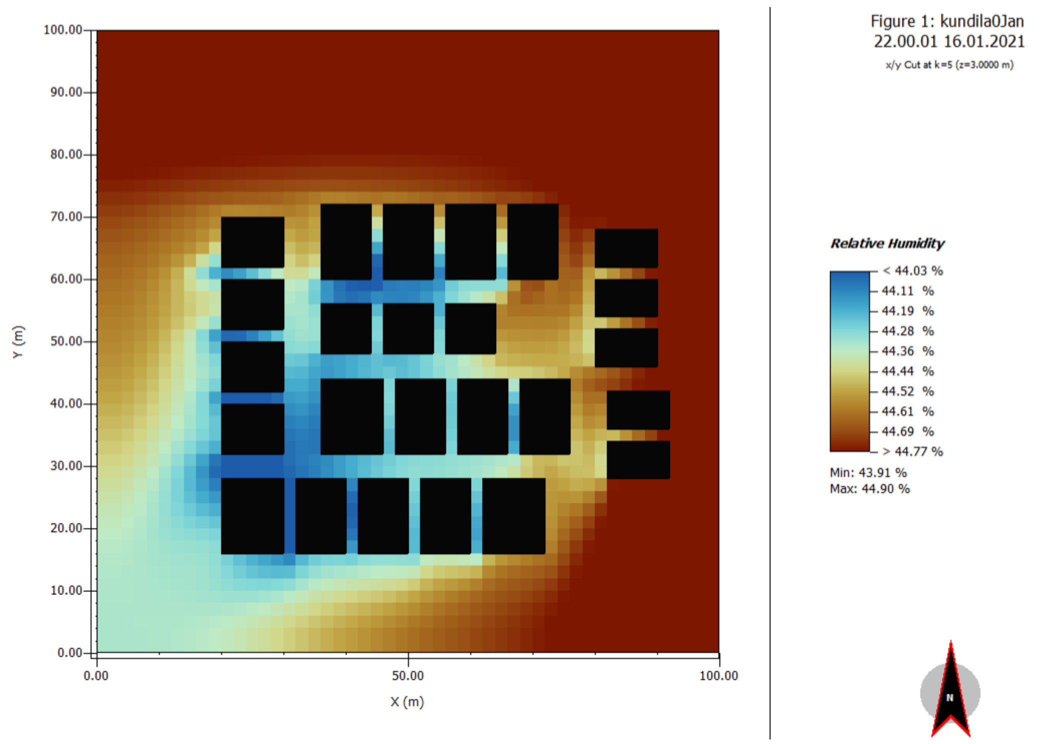


Figure 6.5b: Envi Met output from Leonardo: Relative humidity at 10:00 pm

6.3.2 Simulation Results for Kundila Housing Estate in January 2021 with 25% Vertical Coverage

6.3.2.1 Air Temperature Analysis

At a height of 3 metres, the simulation outcomes for the air temperature at Kundila Housing Estate in January with a vertical coverage of 25% revealed distinct variations at different times of the day. At 6:00 am, the air temperatures ranged from 12.37°C to 13.46°C, while there was an increase at 4:00 pm to between 21.95°C and 25.53°C, and at 10:00 pm they ranged from 15.58°C to 17.21°C (illustrated in Figures 6.6, 6.6a and 6.6b respectively). Although the afternoon recorded the highest temperature at 25.53°C and the morning saw the lowest temperature at 12.37°C, the daily mean for this scenario was deemed as comfortable at 17.68°C.

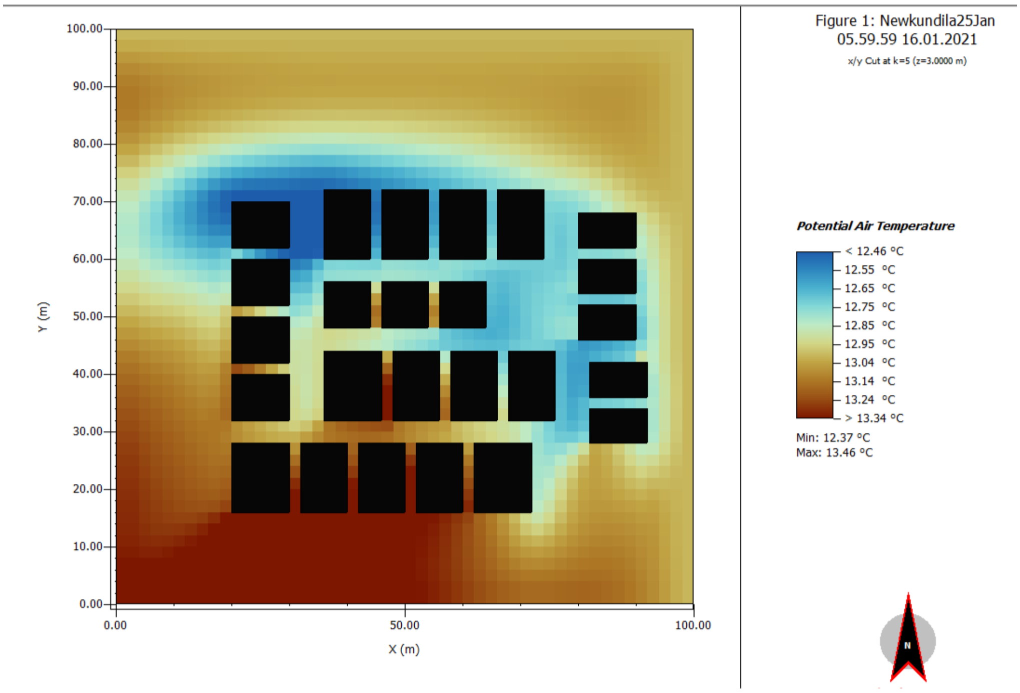


Figure 6.6: Envi Met output from Leonardo: Temperature at 6:00 am

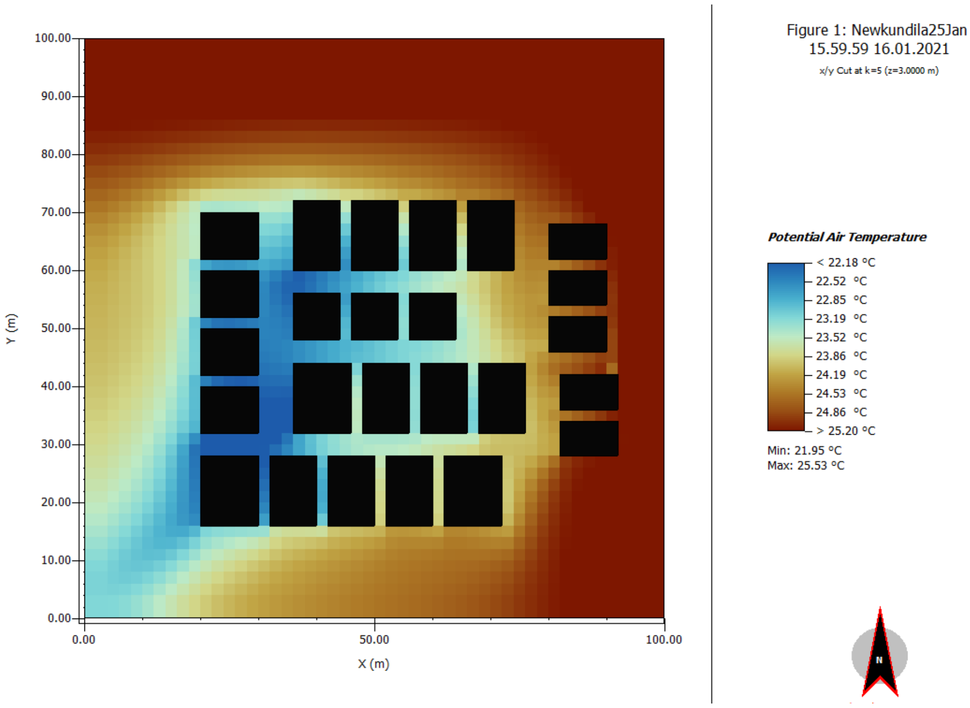


Figure 6.6a: Envi Met output from Leonardo: Temperature at 4:00 pm

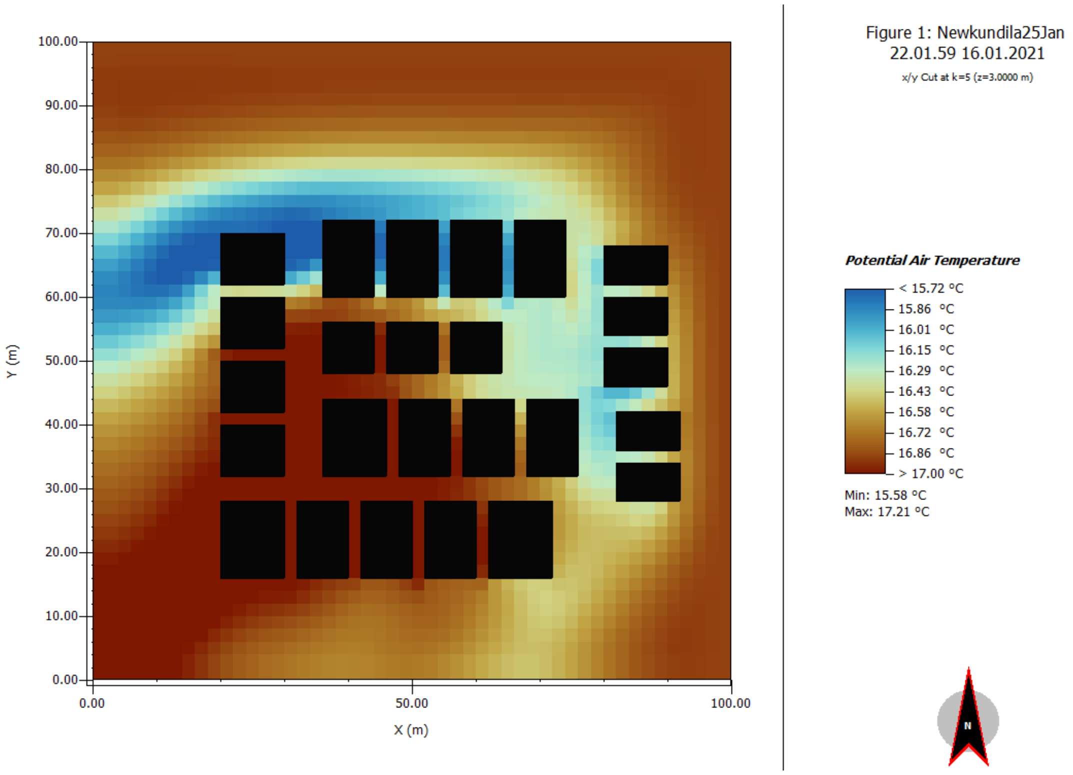


Figure 6.6b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.2 .1 Wind Speed Analysis

The simulation results recorded a range of wind speeds at Kundila Housing Estate at the specified times of day (illustrated in Figures 6.7, 6.7a and 6.7b respectively). At 6:00 am the wind speed fluctuated between 0.39 m/s and 14.51 m/s, and a parallel trend was observed at 4:00 pm with wind speeds varying from 0.39 m/s to 16.16 m/s. At 10:00 pm the speeds ranged between 0.05 m/s and 7.97 m/s, while the calculated average for these scenarios was 6.58m/s.

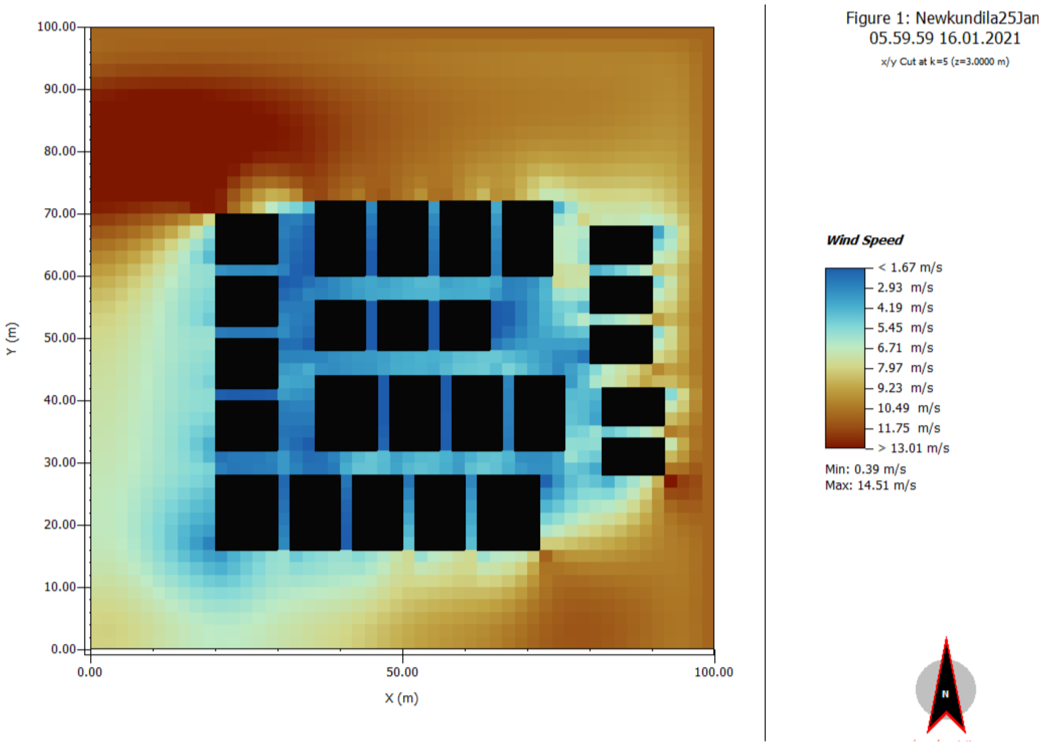


Figure 6.7: Envi Met output from Leonardo: Wind Speed at 6:00 am

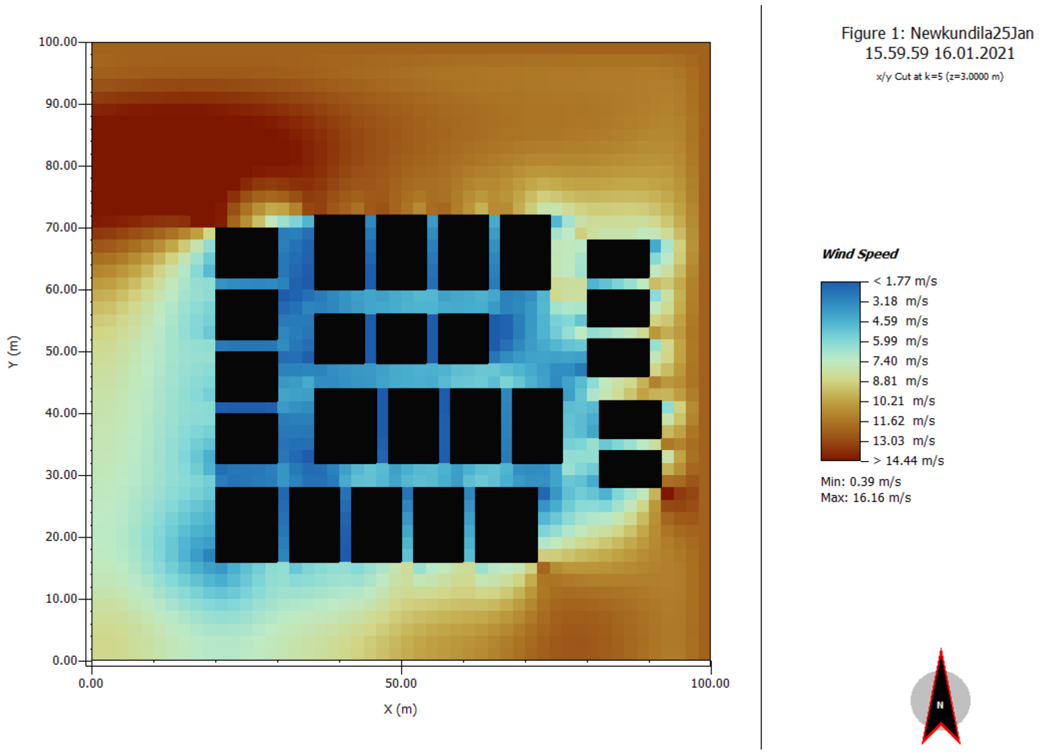


Figure 6.7a: Envi Met output from Leonardo: Wind Speed at 4:00 pm

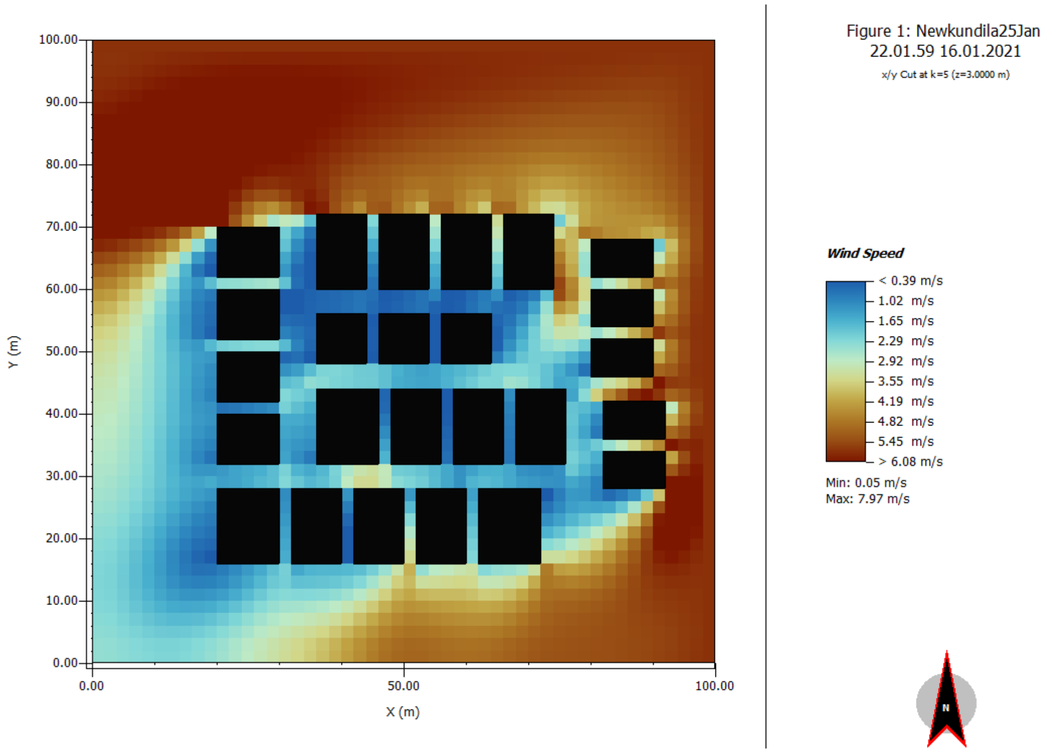


Figure 6.7b: Envi Met output from Leonardo: Wind Speed at 10:00 pm

6.3.2 .1 Relative Humidity Analysis

At 6:00 am, the relative humidity ranged from 71.04% to 78.76%, while at 4:00 pm it fluctuated between 22.81% and 36.81%, and from 48.08% to 59.36% at 10:00 pm (shown in Figures 6.8, 6.8a and 6.8b respectively). Therefore, the afternoon experienced the lowest relative humidity at 22.81%, and the morning recorded the highest at 78.76%, while the average across these periods was 52.81%.

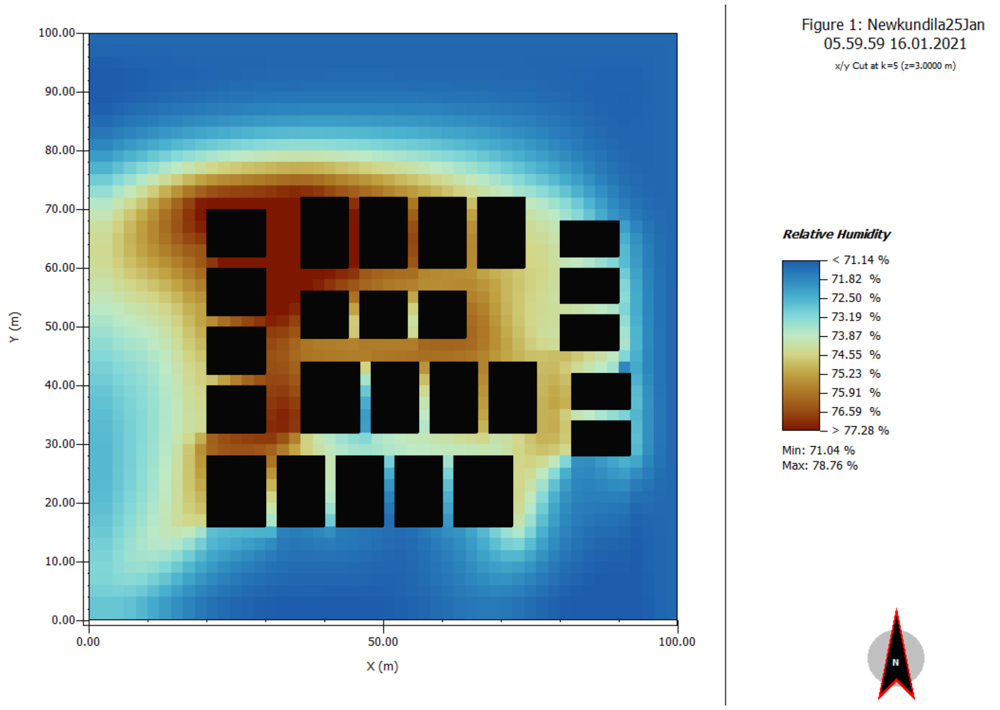


Figure 6.7: Envi Met output from Leonardo: Relative Humidity at 6:00 am

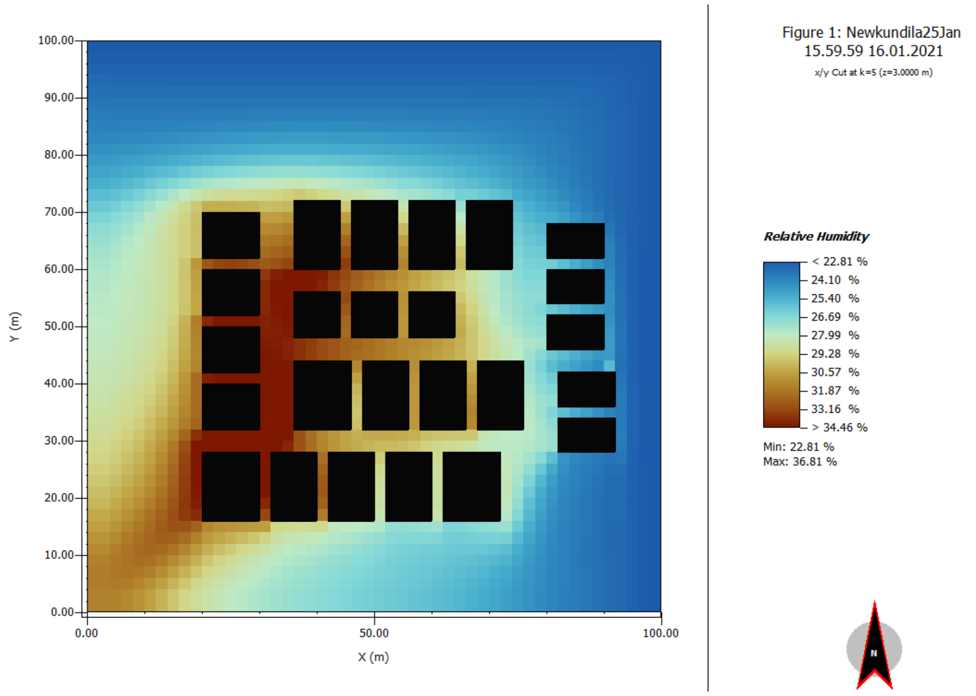


Figure 6.7a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

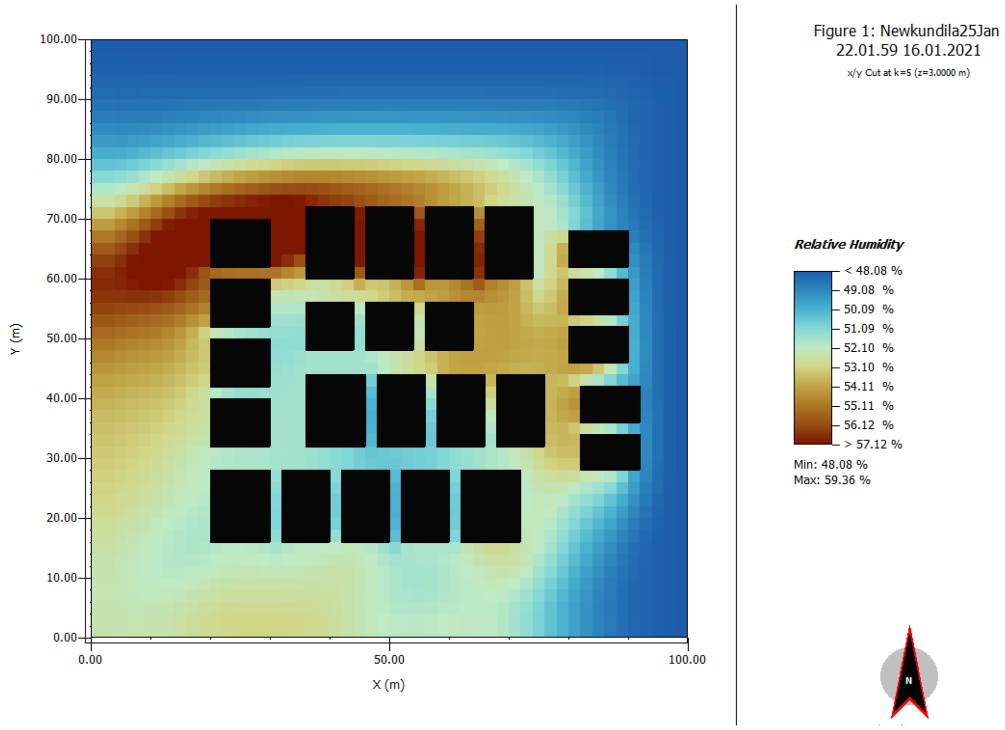


Figure 6.7b: Envi Met output from Leonardo: Relative Humidity at 10:00 pm

6.3.3 Simulation Results for Kundila Estate in January 2021 at 50% Vertical Coverage

At a height of 3 metres, the simulation outcomes for air temperatures at Kundila Housing Estate during January 2021 with a vertical coverage of 50% captured distinct variations across the day. At 6:00 am, the air temperature ranged from 12.29°C to 13.67°C, at 4:00 pm they fluctuated between 22.27°C and 26.57°C, while at 10:00 pm they were between 15.48°C to 17.14°C (shown in Figures 6.8, 6.8a and 6.8b respectively). Although the afternoon recorded the highest temperature at 26.57°C, and the morning recorded the lowest at 12.29°C, the daily mean for this scenario was deemed comfortable at 17.90°C.

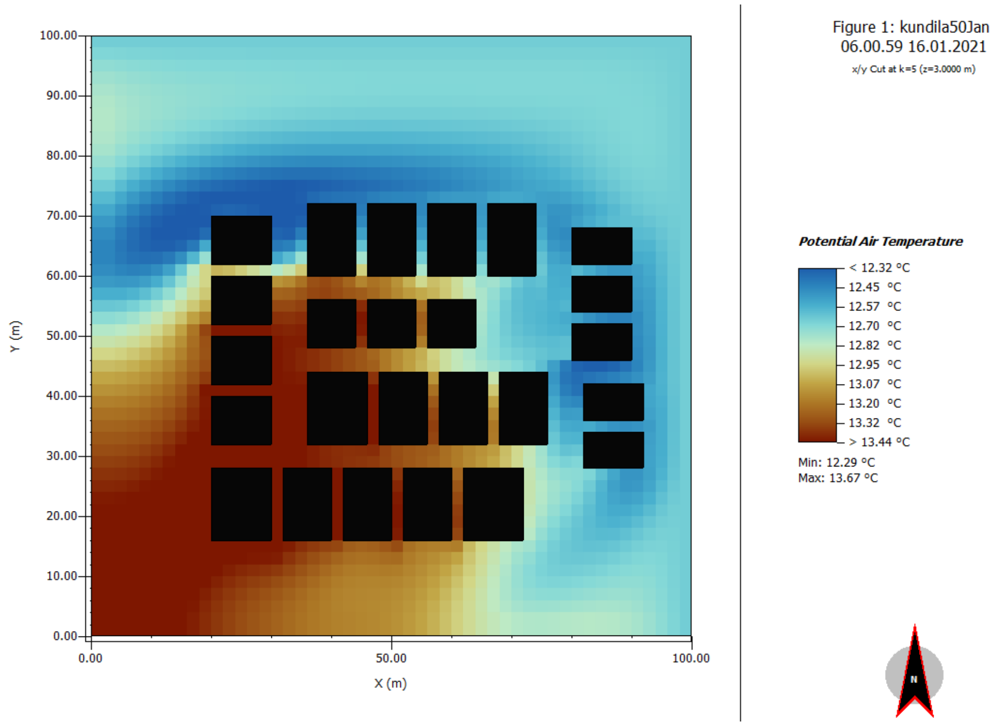


Figure 6.8: Envi Met output from Leonardo: Temperature at 6:00 am

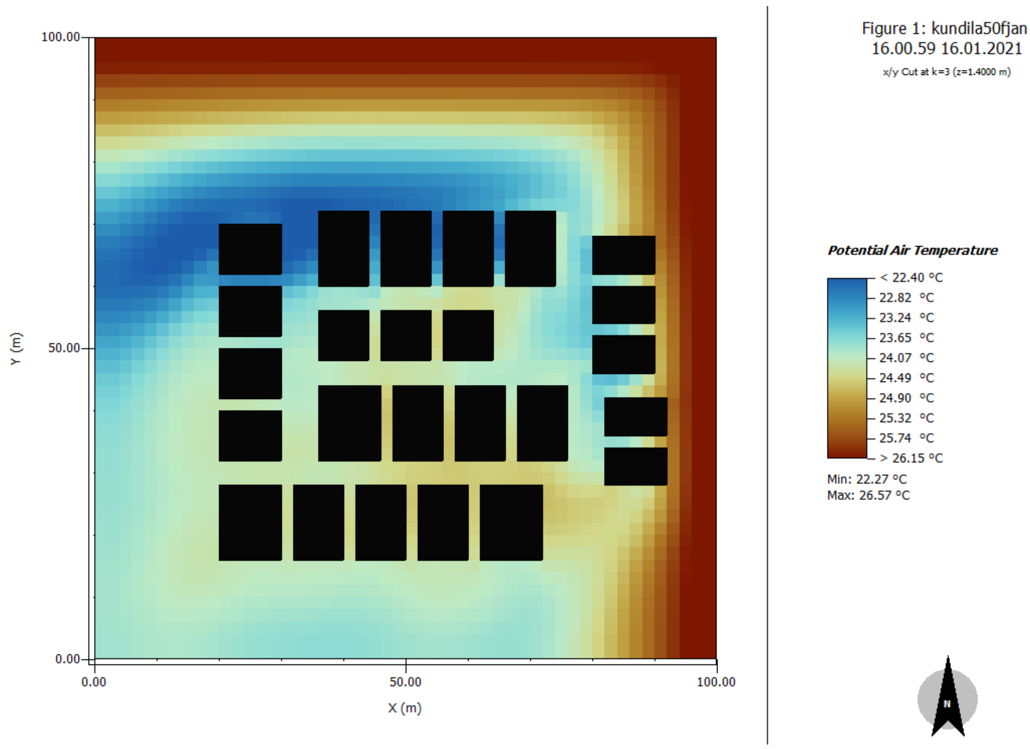


Figure 6.8a: Envi Met output from Leonardo: Temperature at 4:00 pm

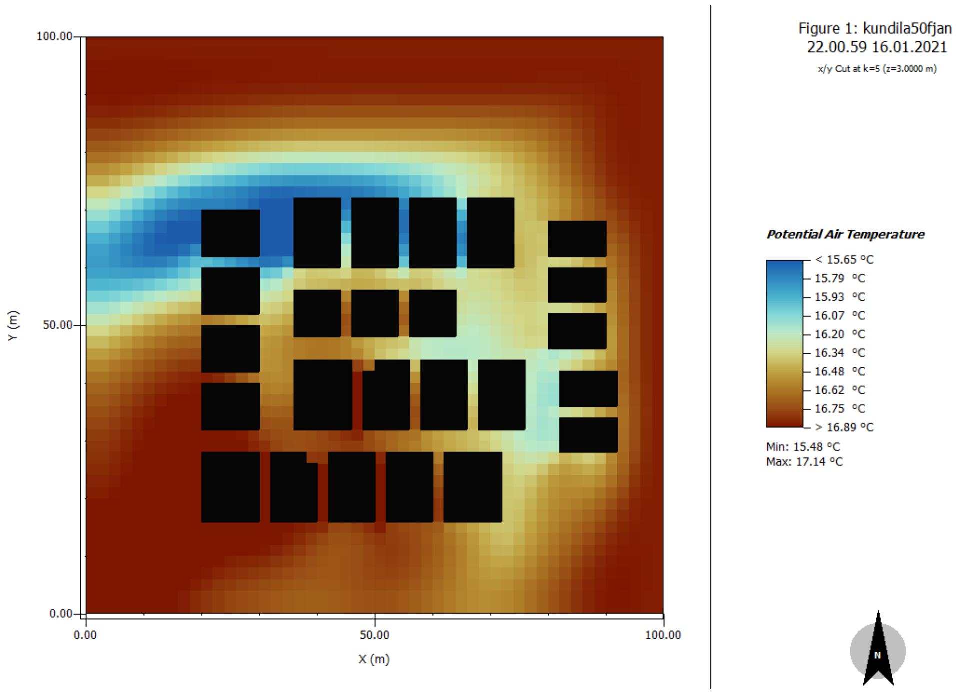


Figure 6.8b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.3.1 Wind Speed Analysis

The simulation results indicated a range of wind speeds at Kundila Housing Estate at the specified times of day (illustrated in Figures 6.9, 6.9a and 6.9b respectively). At 6:00 am, the wind speed fluctuated between 0.11 m/s and 7.43 m/s, and similarly, at 4:00 pm they varied from 0.03 m/s to 7.89 m/s. Moreover, at 10:00 pm the wind speeds ranged between 0.21 m/s and 8.14 m/s. The calculated average wind speed for these scenarios was 3.97 m/s.

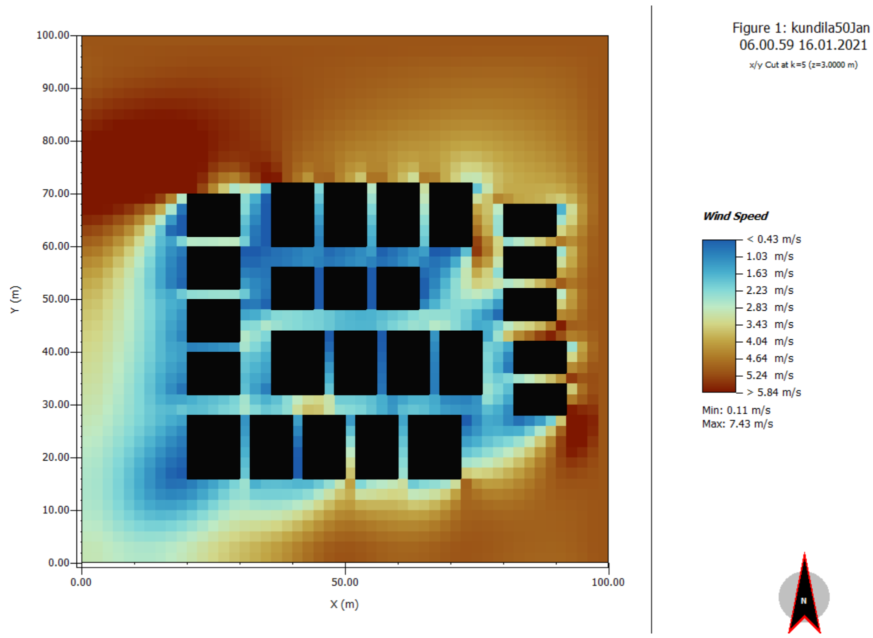


Figure 6.9: Envi Met output from Leonardo: Wind Speed at 6:00 am

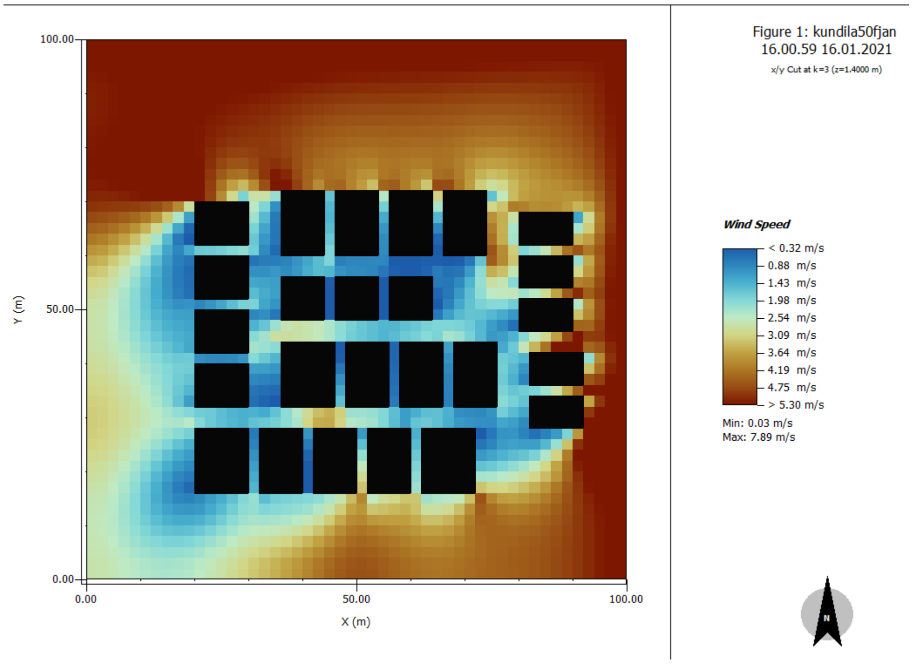


Figure 6.9a: Envi Met output from Leonardo: Wind Speed at 4:00 pm

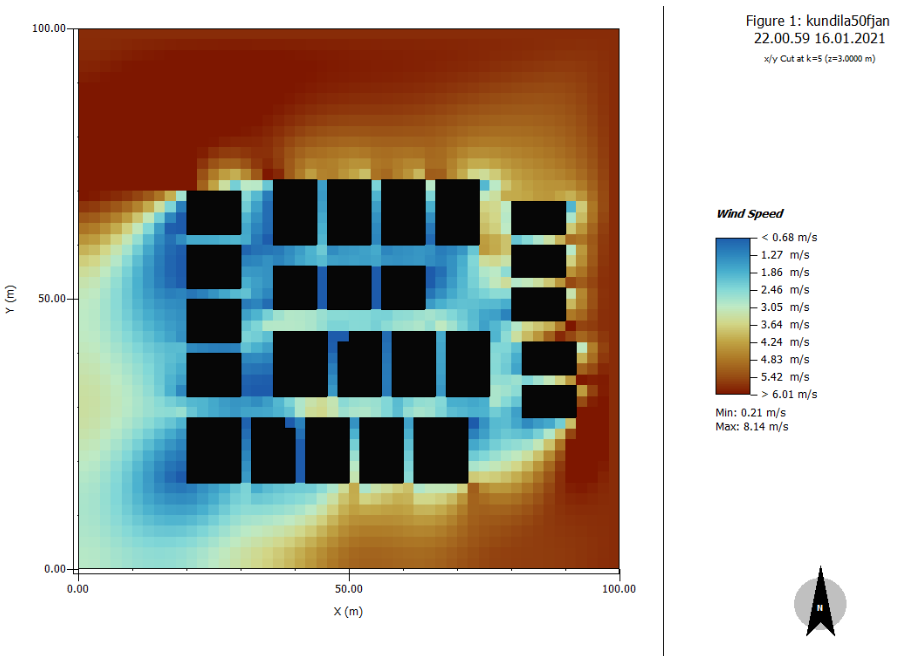


Figure 6.9b: Envi Met output from Leonardo: Wind Speed at 10:00 pm

6.3.3.2 Relative Humidity Analysis

At 6:00 am, the relative humidity was between 67.37% to 75.28%, whereas at 4:00 pm it fluctuated between 20.04% and 36.60%., and at 10:00 pm it ranged from 47.97% to 59.79% (shown in Figures 6.10, 6.10a and 6.10b respectively). The average relative humidity across these periods was calculated as 51.18%, although the afternoon experienced the lowest relative humidity at 20.04%, and the morning recorded the highest at 75.28%.

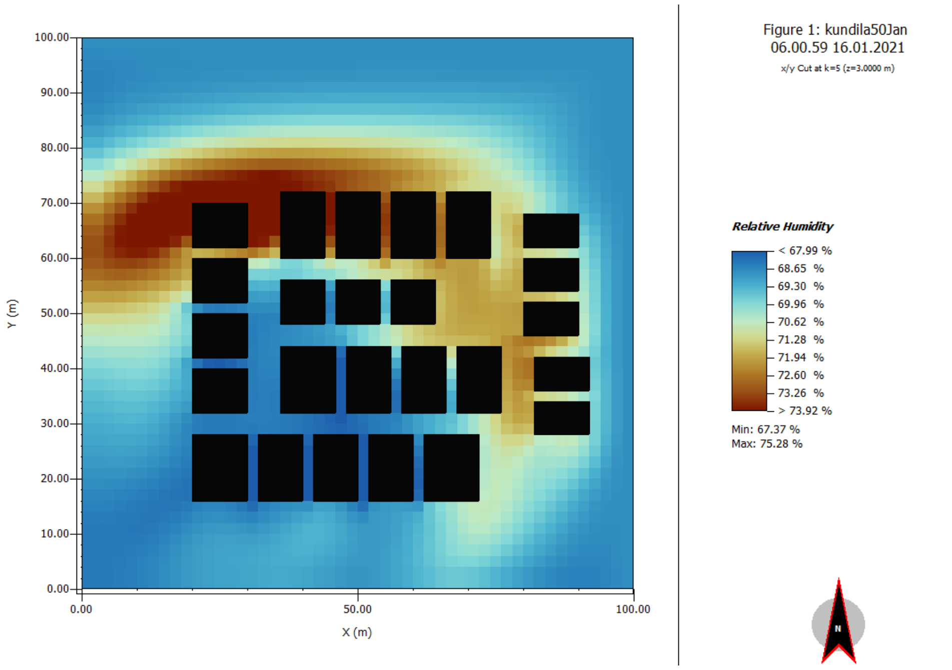


Figure 6.10: Envi Met output from Leonardo: Relative Humidity at 6:00 am

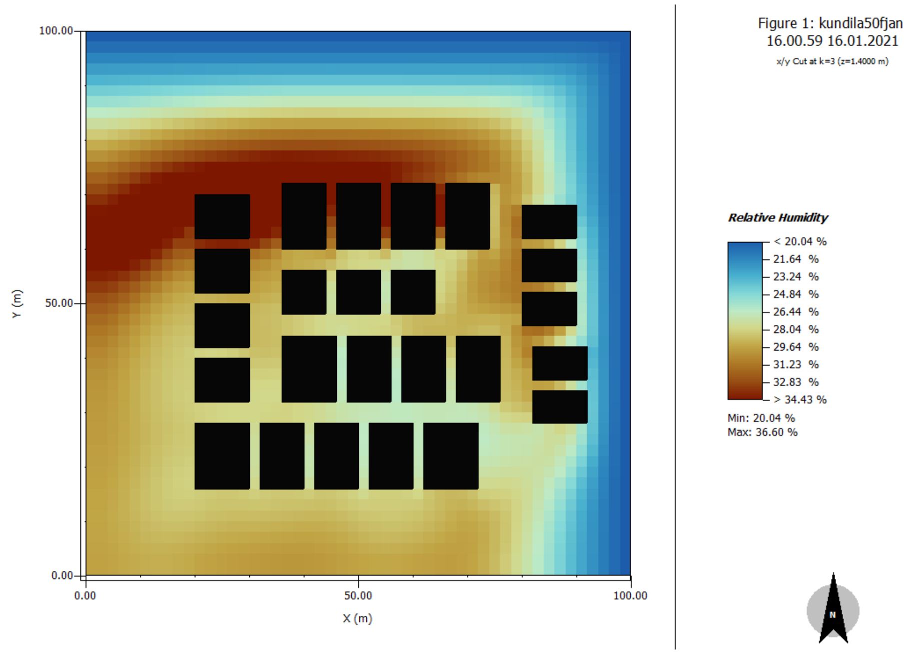


Figure 6.10a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

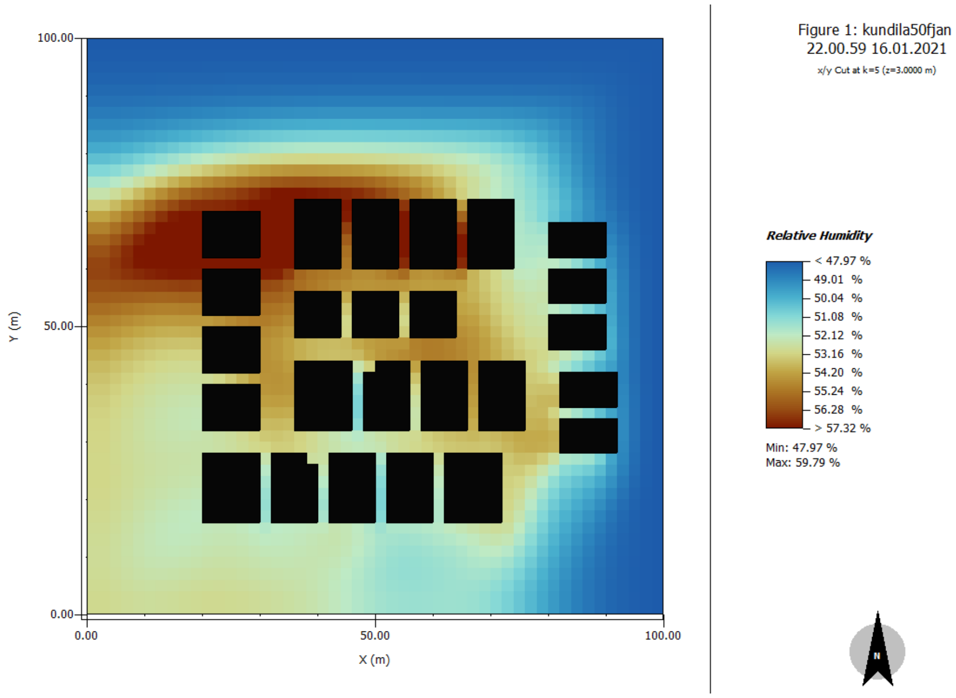


Figure 6.10b: Envi Met output from Leonardo: Relative Humidity at 10:00 pm

During the dry season at Kundila Housing Estate, the minimum temperature observed around the buildings at 4 pm, with no vertical greening (VG) was recorded as 25.92°C. Introducing 25% VG coverage resulted in a decrease to 21.95°C, and with 50% VG coverage, the temperature further dropped to 20.04°C. This data suggests a substantial reduction in minimum temperature—specifically, a 3.97°C decrease with 25% VG coverage and a more significant 5.88°C reduction with 50% VG coverage. It is important to note that these findings pertain to the minimum temperature of the general neighgbourhood. The extent of temperature reduction may vary based on the specific grid or location selected for measurement. These observations underscore the potential impact of vertical greening on temperature moderation in Kundila Housing Estate during the dry season, with implications for urban planning and environmental considerations. Further research and analysis may reveal additional nuances and opportunities for optimizing the benefits of vertical greening in specific regions of the estate.

6.3.4 Simulation Results for Kundila Housing Estate in July 2021 at 0% Vertical Coverage

6.3.4.1 Air Temperature Analysis

At an elevation of 3 metres, discernible variations in air temperatures were recorded across the day (illustrated in Figures 6.11, 6.11a and 6.11b). At 6:00 am temperatures ranged from 24.01°C to 24.65°C, at 4:00 pm the temperature span widened, fluctuating between 29.01°C and 30.54°C, while at 10:00 pm they ranged from 25.84°C to 27.14°C. The calculated daily mean temperature was recorded at a comfortable 26.87°C, although extremes were observed in the afternoon (registering the highest temperature) at 30.54°C, and the morning (recorded the lowest temperature) at 24.01°C.

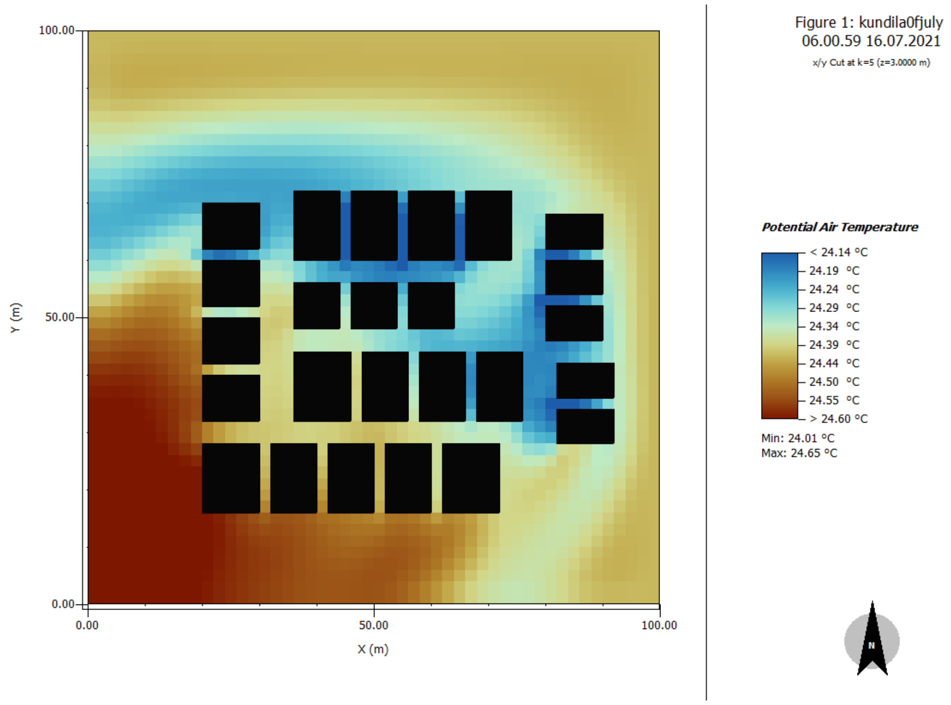


Figure 6.11: Envi Met output from Leonardo: Temperature at 6:00 am

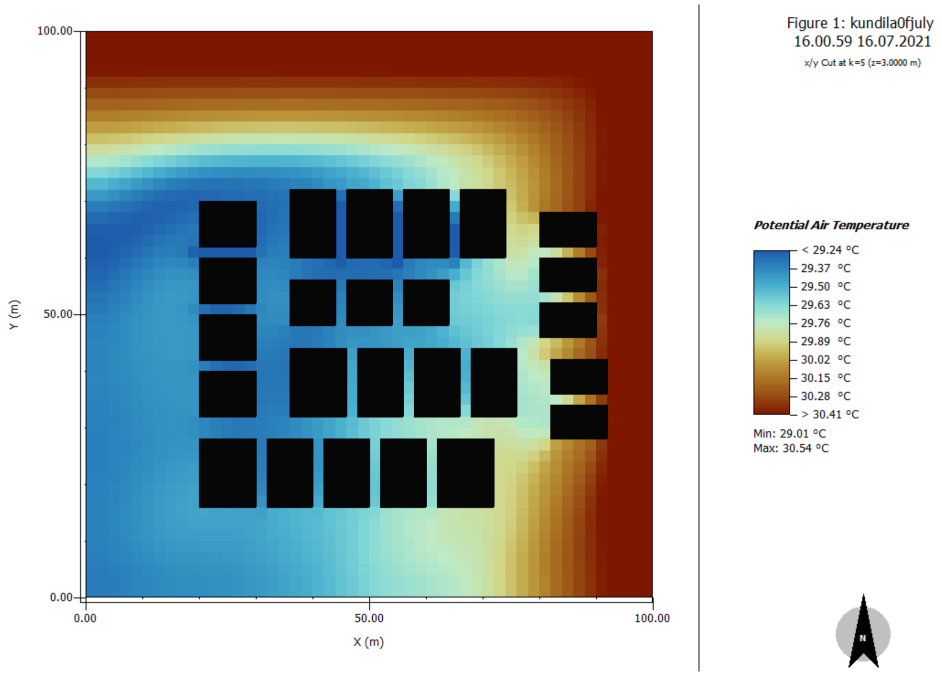


Figure 6.11a: Envi Met output from Leonardo: Temperature at 4:00 pm

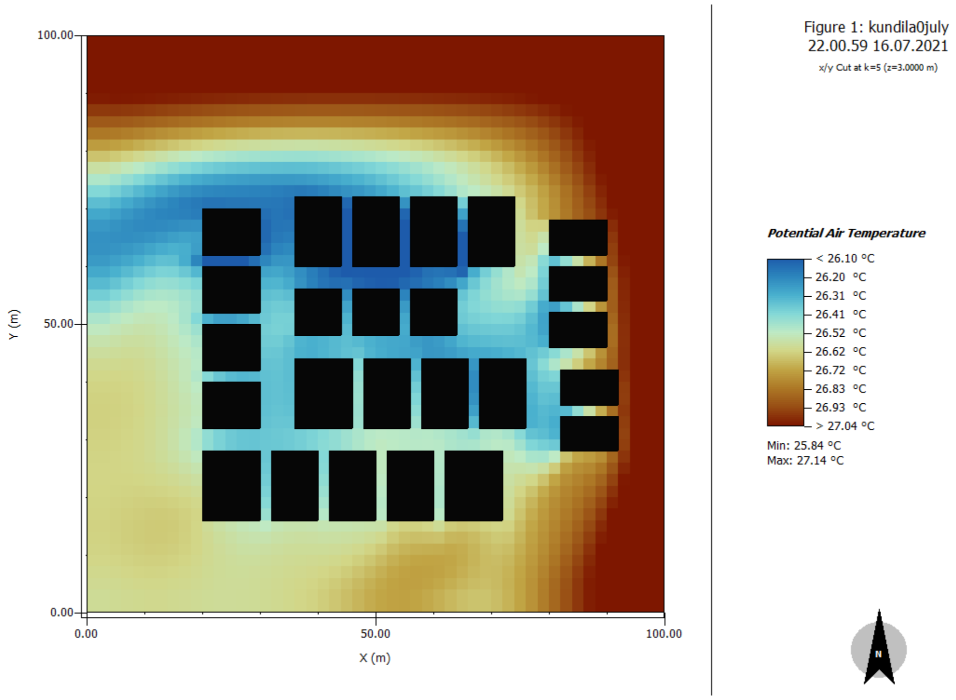


Figure 6.11b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.7.4.1 Wind Speed Analysis

At an altitude of 3 metres, wind speeds fluctuated slightly at different times of the day. Specifically, at 6:00 am the wind speed ranged from 0.03 m/s to 3.00 m/s, at 4:00 pm it varied from 0.01 m/s to 3.63 m/s, and at 10:00 p.m., it spanned 0.04 m/s to 3.35 m/s, (illustrated in Figures 6.12, 6.12a and 6.12b respectively), and the average wind speed calculated over the specified time intervals was 1.68 m/s.

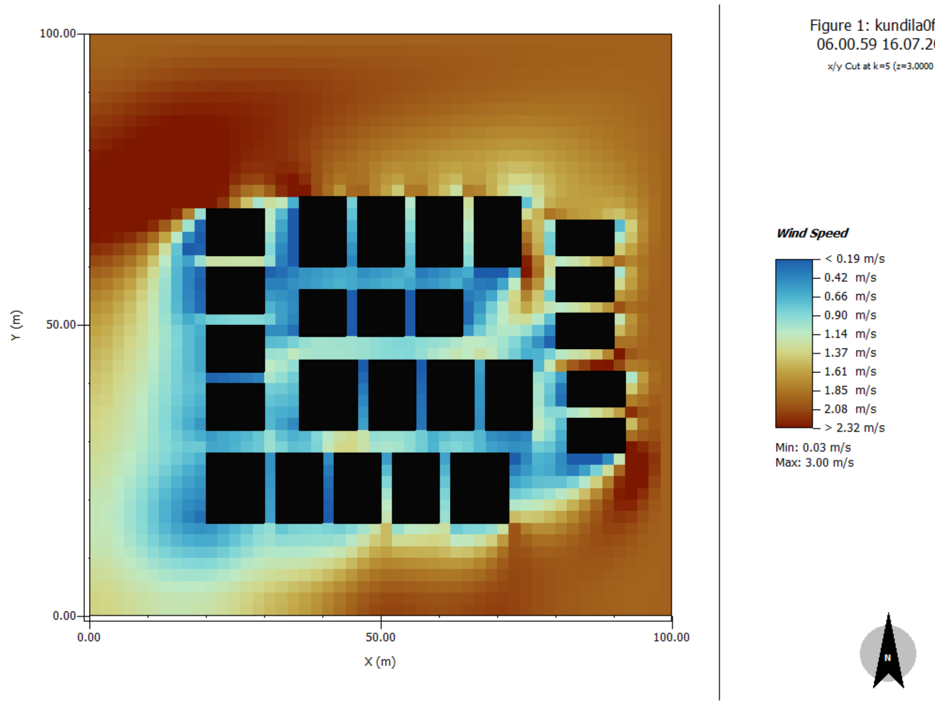


Figure 6.12: Envi Met output from Leonardo: Wind Speed at 6:00 am

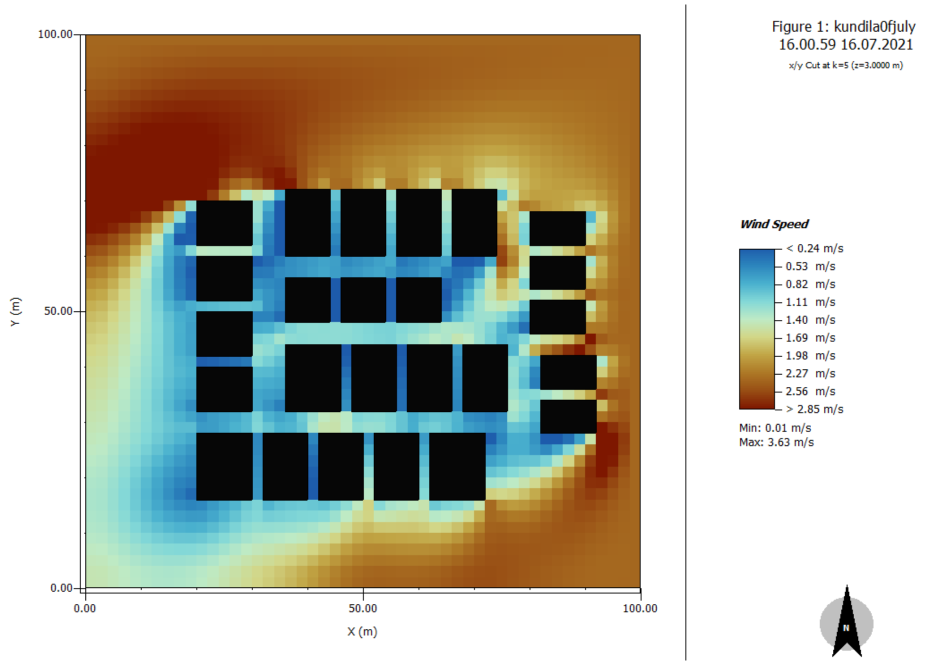


Figure 6.12a: Envi Met output from Leonardo: Wind Speed at 4:00 pm

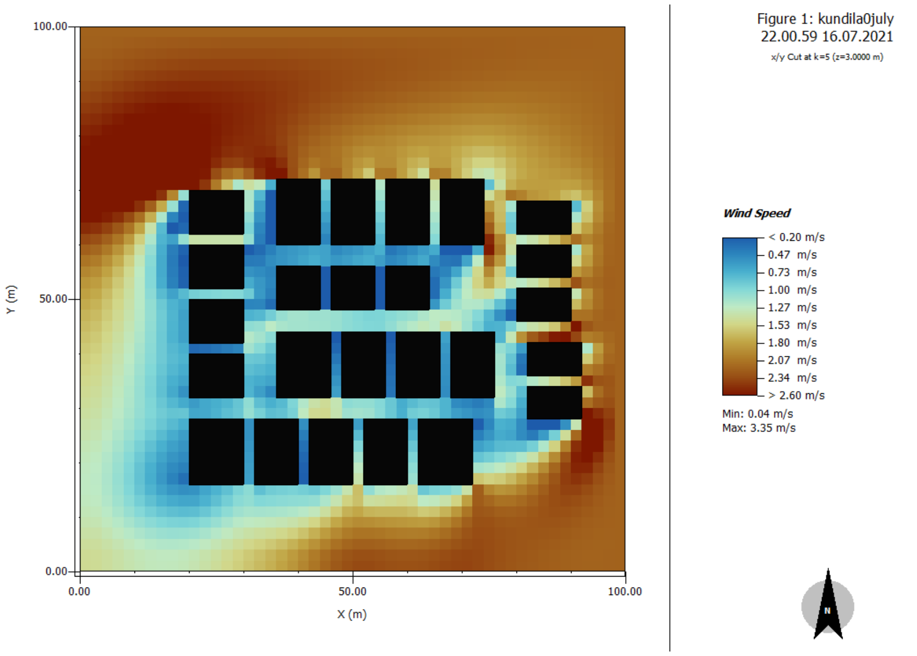


Figure 6.12b: Envi Met output from Leonardo: Wind Speed at 10:00 pm

6.3.4.1 Relative Humidity

At an elevation of 3 metres, variations in relative humidity were perceived across the intervals. At 6:00 am the relative humidity varied from 82.70% to 90.92%, while at 4:00 pm it fluctuated between 54.30% and 62.18%, and at 10:00 pm it ranged from 71.62% to 79.90% (shown in Figures 6.13, 6.13a and 6.13b respectively). The average relative humidity across these time periods was calculated at 73.60%, while the lowest relative humidity was recorded for the afternoon at 54.30%, and the highest in the morning at 90.92%.

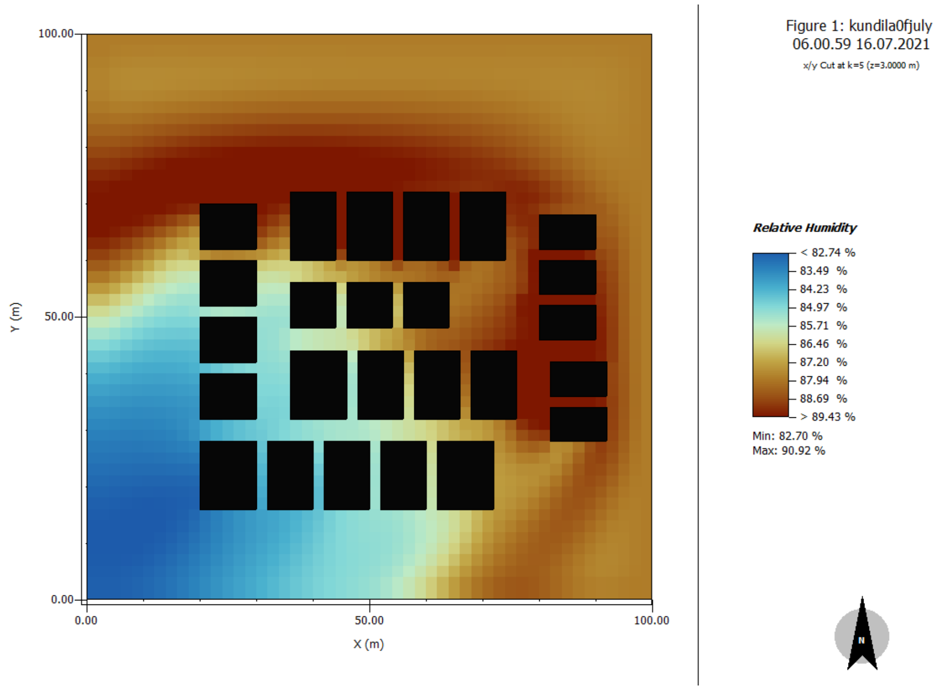


Figure 6.13. Envi Met output from Leonardo: Relative Humidity at 6:00 am

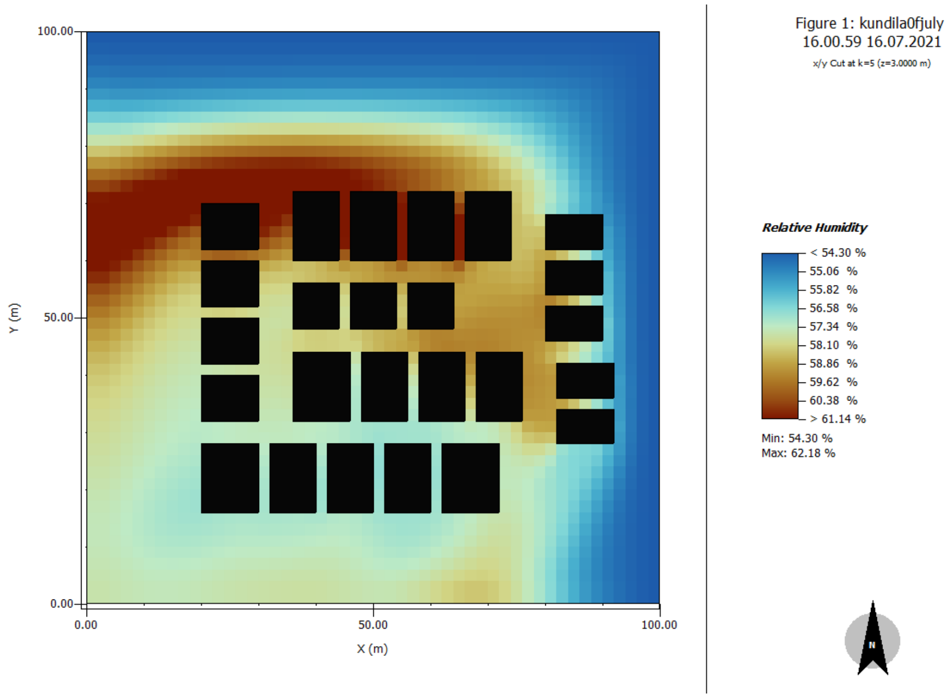


Figure 6.13a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

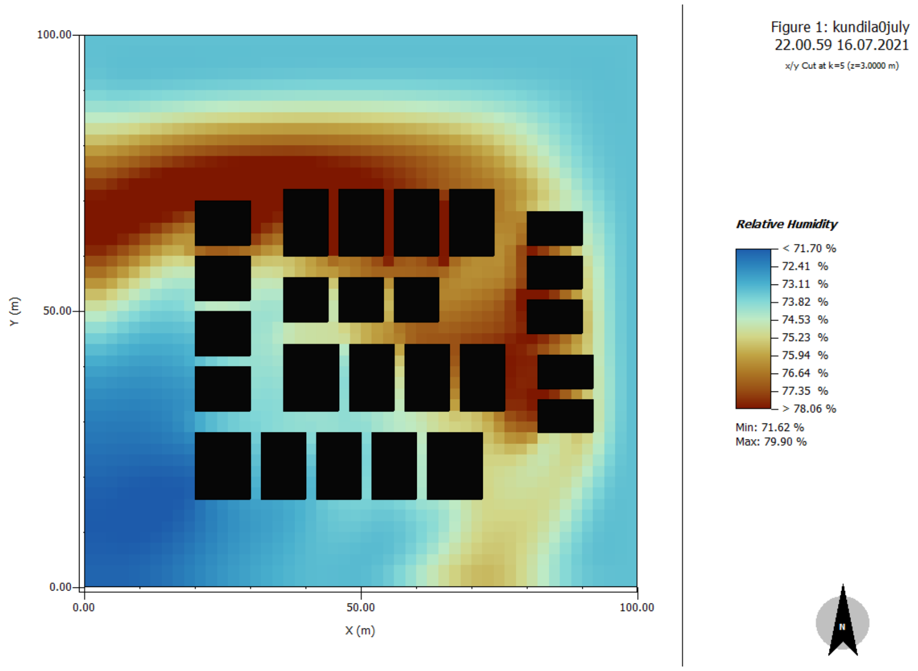


Figure 6.13b: Envi Met output from Leonardo: Relative Humidity at 10:00 pm

6.3.5 Simulation Results for Kundila Housing Estate in July 2021 at 25% Vertical Coverage

6.3.5.1 Air Temperature Analysis

At an elevation of 3 metres, the air temperatures displayed discernible variation across distinct time points. At 6:00 am, temperatures ranged from 24.01°C to 24.65°C, while at 4:00 pm the span widened between 29.01°C and 30.54°C, and at 10:00 pm they varied from 25.84°C to 27.14°C (shown in Figures 6.14, 6.14a and 6.14b respectively). Extremes were observed in the afternoon which registered the highest temperature at 30.54°C, while the morning recorded the lowest temperature at 24.01°C. However, the daily mean temperature was calculated at a comfortable 26.87°C.

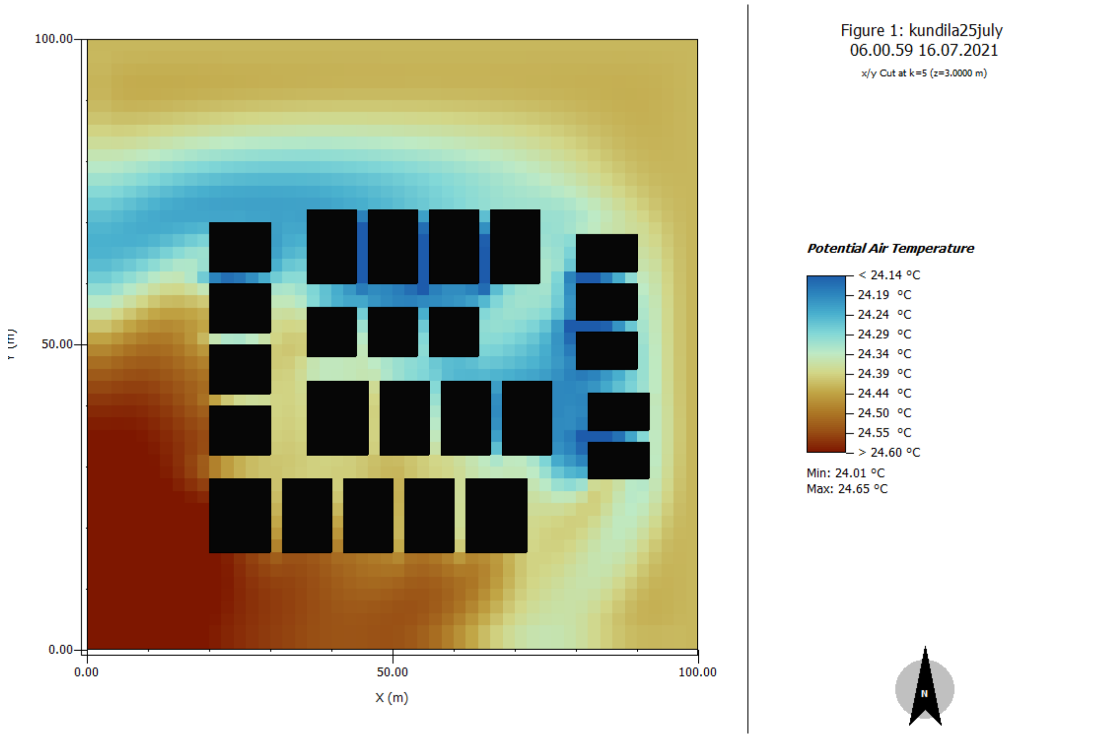


Figure 6.14: Envi Met output from Leonardo: Temperature at 6:00 am

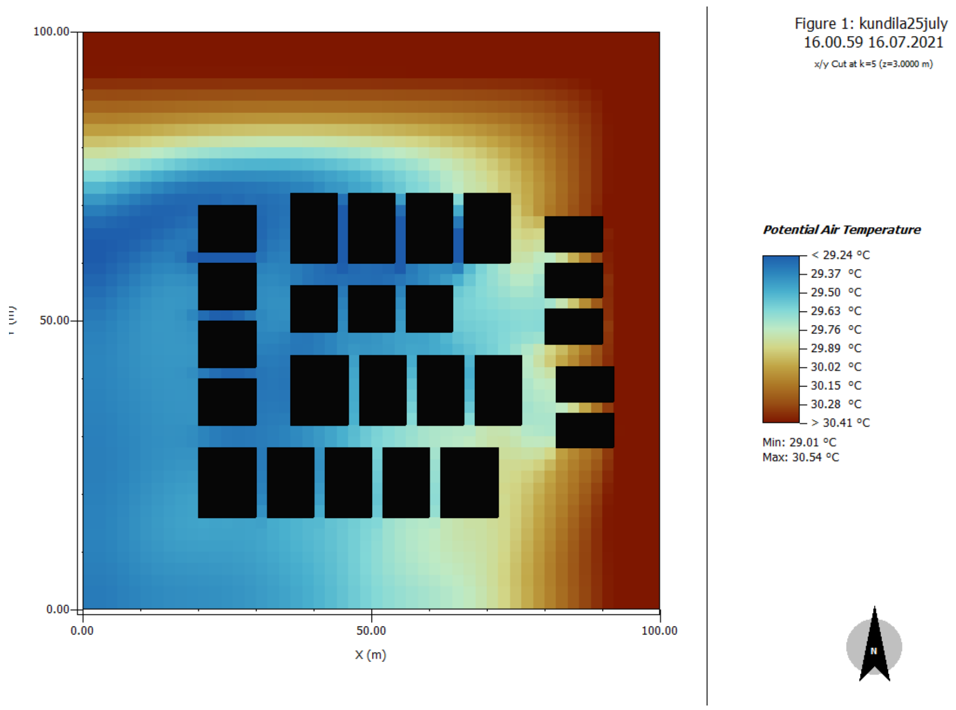


Figure 6.14a: Envi Met output from Leonardo: Temperature at 4:00 pm

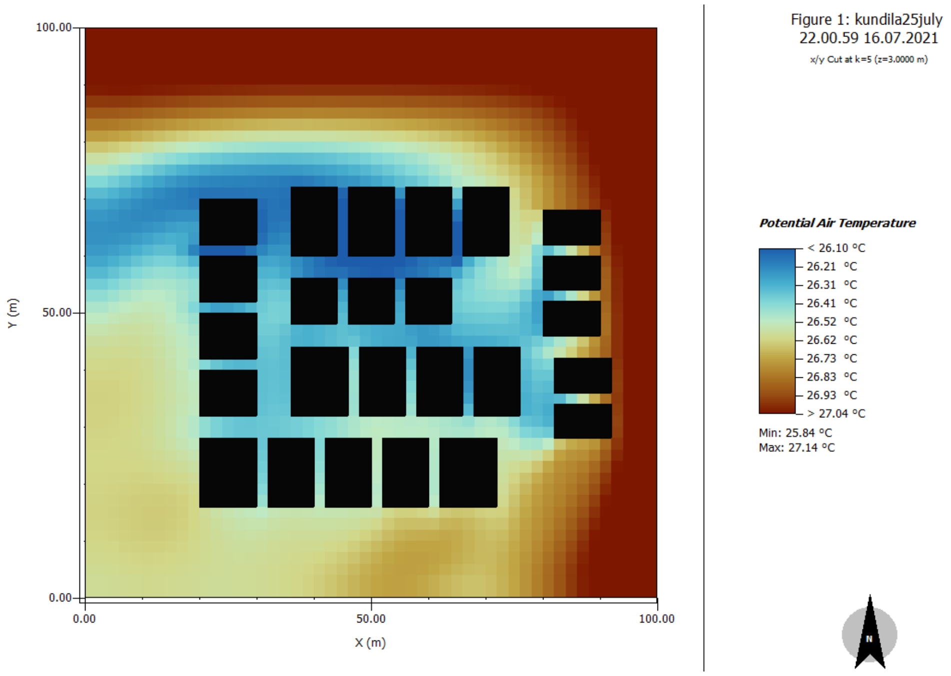


Figure 6.14b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.5.1 Wind Speed

At an altitude of 3 metres, wind speeds fluctuated slightly over the different time periods. At 6:00 am, the wind speed ranged from 0.03 m/s to 3.00 m/s, at 4:00 pm it varied from 0.01 m/s to 3.63 m/s, and at 10:00 pm it differed from 0.04 m/s to 3.35 m/s (illustrated in Figures 6.15, 6.15a and 6.15b respectively). The average wind speed over the specified time intervals was calculated at 1.68 m/s.

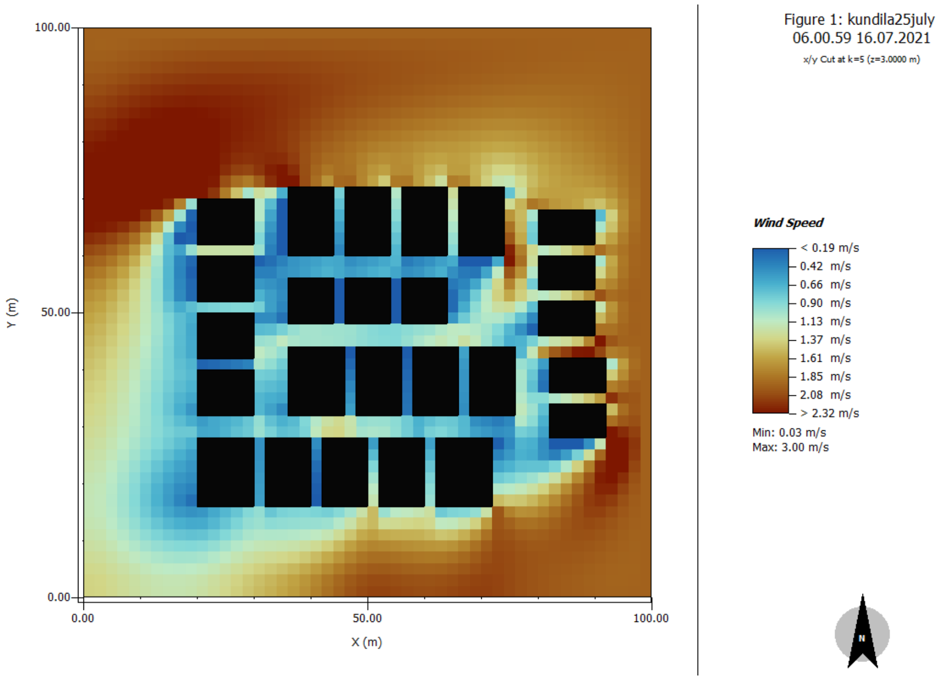


Figure 6.15: Envi Met output from Leonardo: Wind speed at 6:00 am

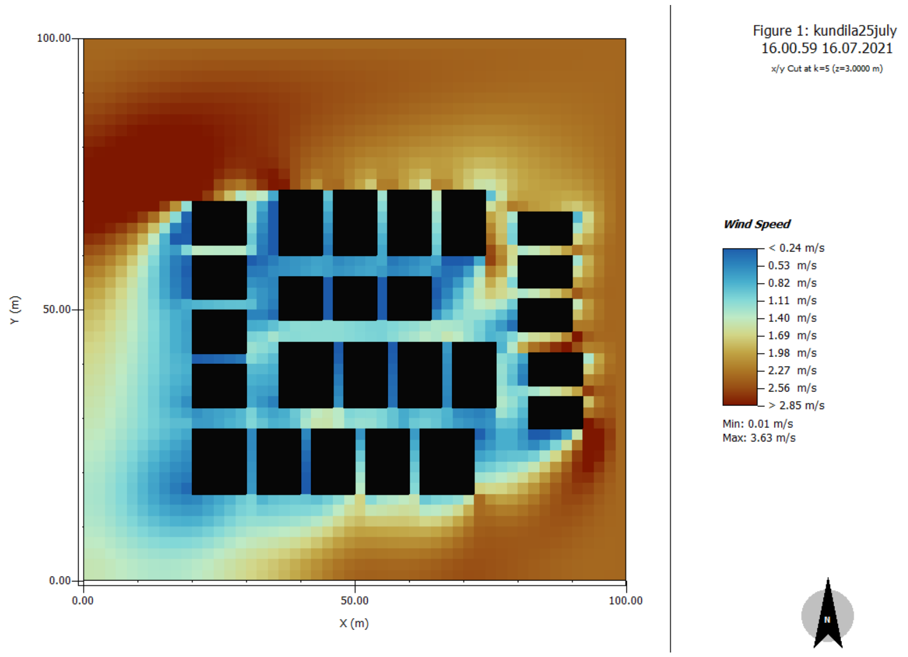


Figure 6.15a: Envi Met output from Leonardo: Wind speed at 4:00 pm

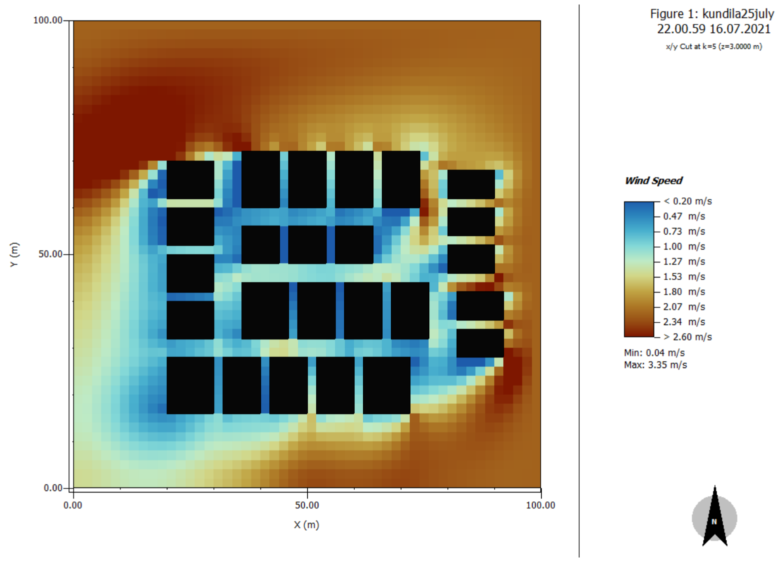


Figure 6.15b: Envi Met output from Leonardo: Wind speed at 10:00 pm

6.3.5.2 Relative Humidity

At an elevation of 3 metres, variations in relative humidity were recorded across the temporal intervals. Specifically, at 6:00 am the relative humidity ranged from 82.70% to 90.92%, whilst at 4:00 pm, it ranged from 54.30% to 62.16%, and by 10:00 pm a minimum of 71.62% and a maximum of 79.89% were recorded (shown in Figures 6.16, 6.16a and 6.16b respectively). Notably, the lowest relative humidity was observed during the afternoon at 54.30%, while the highest was registered for the morning at 90.92%. The average relative humidity across these time periods was calculated as 73.60%.

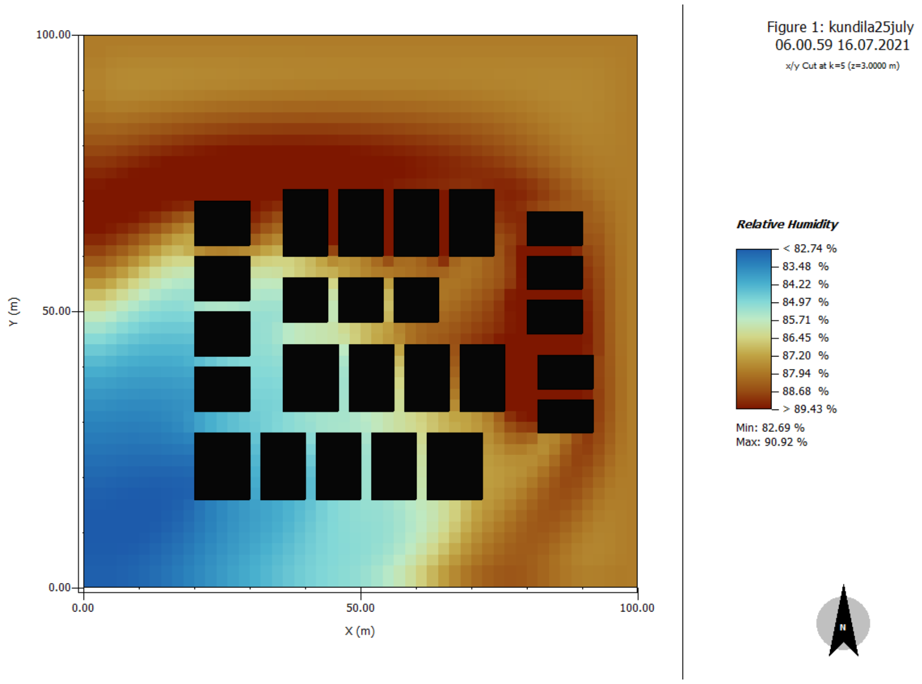


Figure 6.16: Envi Met output from Leonardo: Relative humidity at 6:00 am

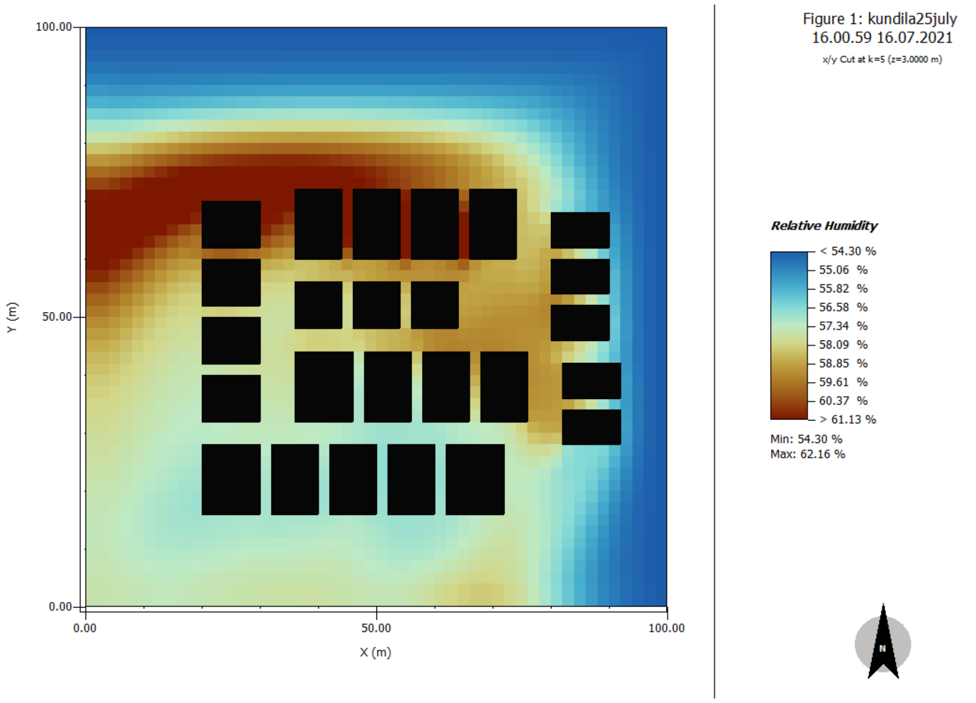


Figure 6.16a: Envi Met output from Leonardo: Relative humidity at 4:00 pm

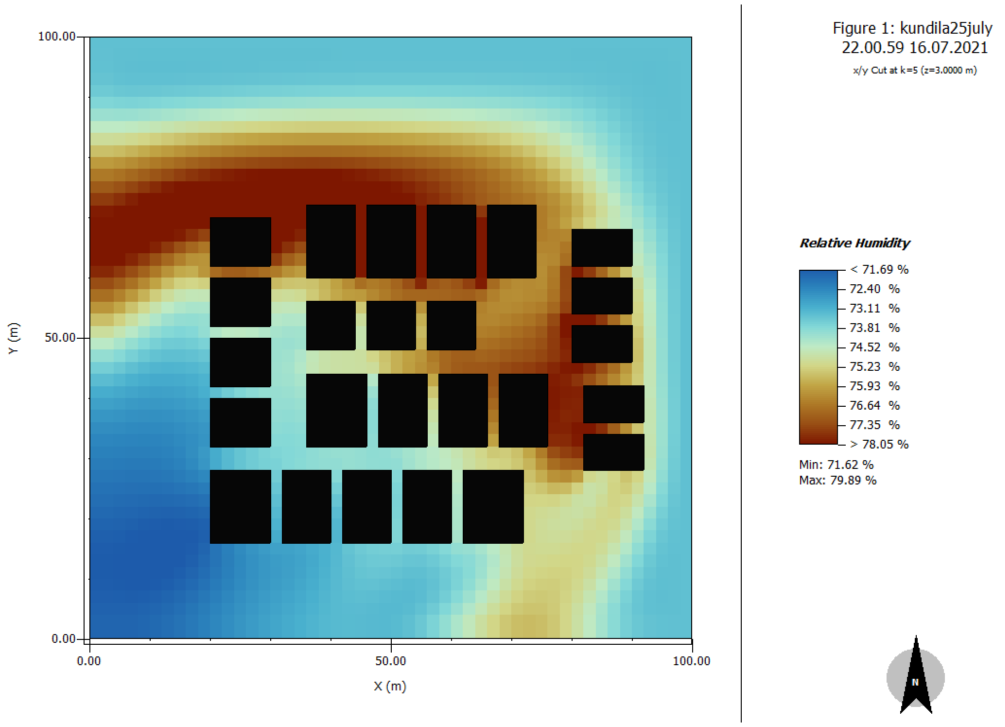


Figure 6.16b: Envi Met output from Leonardo: Relative humidity at 10:00 pm

6.3.6 Simulation Results for Kundila Housing Estate in July 2021 at 50% Vertical Coverage

6.3.6.1 *Air Temperature Analysis*

At an elevation of 3 metres, air temperatures displayed discernible variations across the time periods. At 6:00 am, they ranged from 24.10°C to 24.66°C, whilst at 4:00 pm, the span widened to 29.10°C and 30.55°C, and at 10:00 pm they ranged from 25.97°C to 27.14°C (illustrated in Figures 6.17, 6.17a and 6.17b respectively). The daily mean temperature was calculated at a comfortable 26.92°C although extremes were observed; the afternoon registered the highest temperature at 30.55°C, while the morning recorded the lowest at 24.10°C.

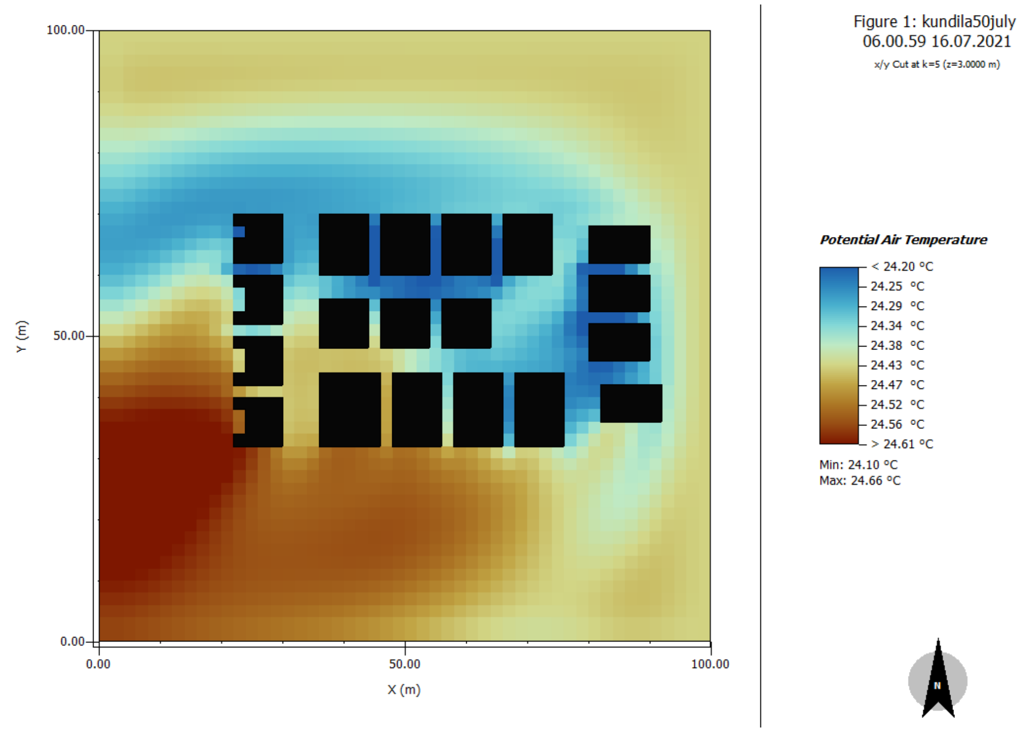


Figure 6.17: Envi Met output from Leonardo: Temperature at 6:00 am

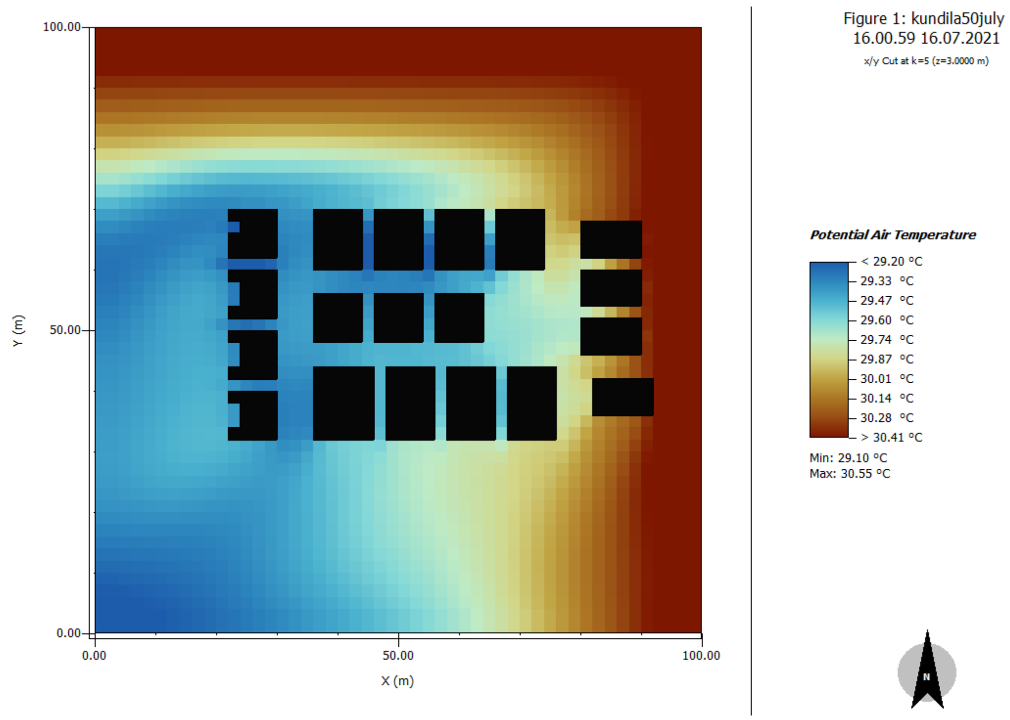
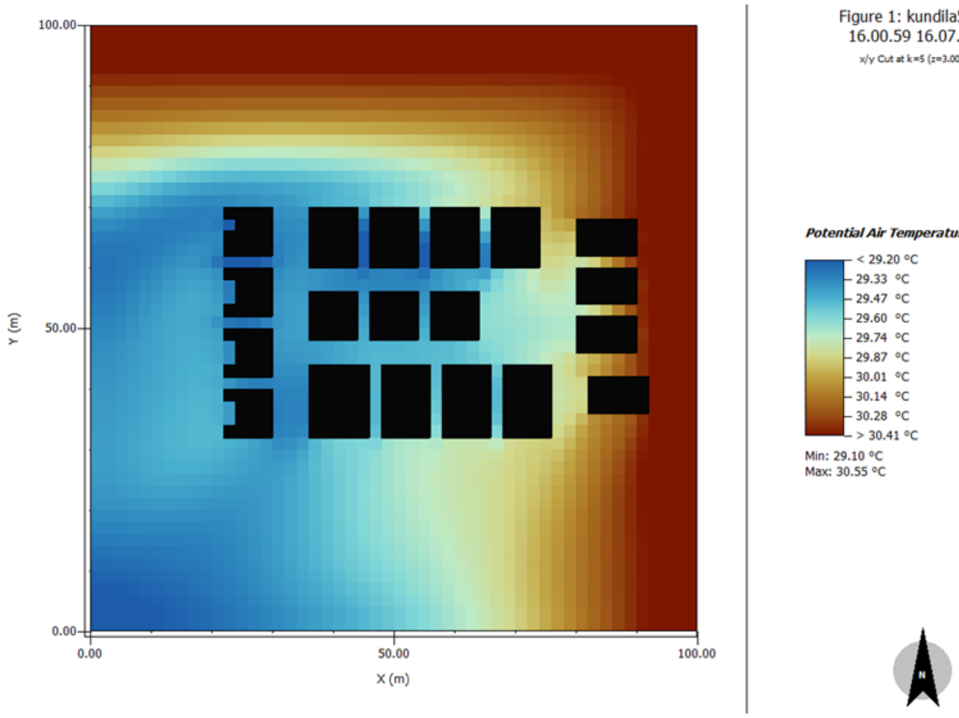


Figure 6.17a: Envi Met output from Leonardo: Temperature at 4:00 pm



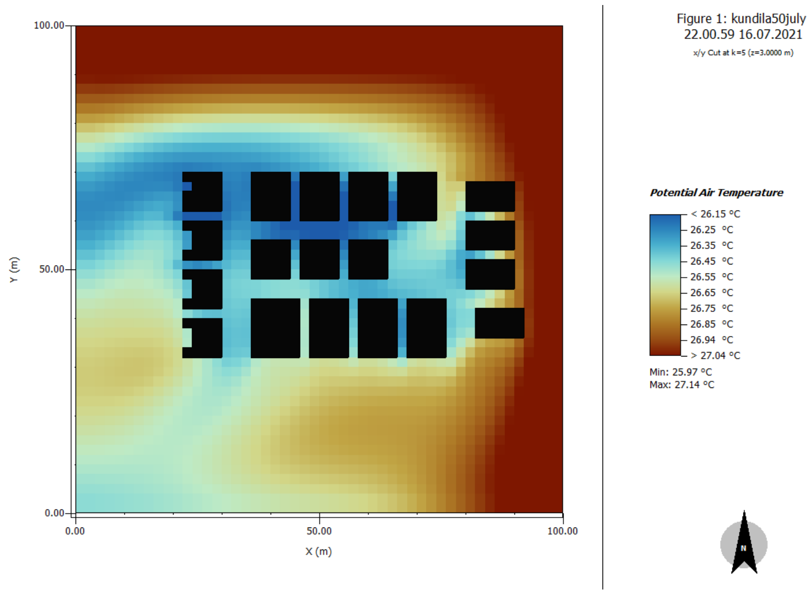


Figure 6.17b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.6.2 Wind Speed Analysis

At an altitude of 3 metres, a range of wind speeds were recorded at different times of the day. At 6:00 am it ranged from 0.00 m/s to 3.10 m/s, and at 4:00 pm it varied from 0.00 m/s to 3.70 m/s, whilst by 10:00 pm they spanned 0.00 m/s to 3.45 m/s (illustrated in Figures 6.18, 6.18a and 6.18b respectively). The calculated average wind speed over all recorded time intervals was 1.71 m/s. Notably, areas characterised by a staggered arrangement of buildings experienced a noteworthy reduction in wind speed.

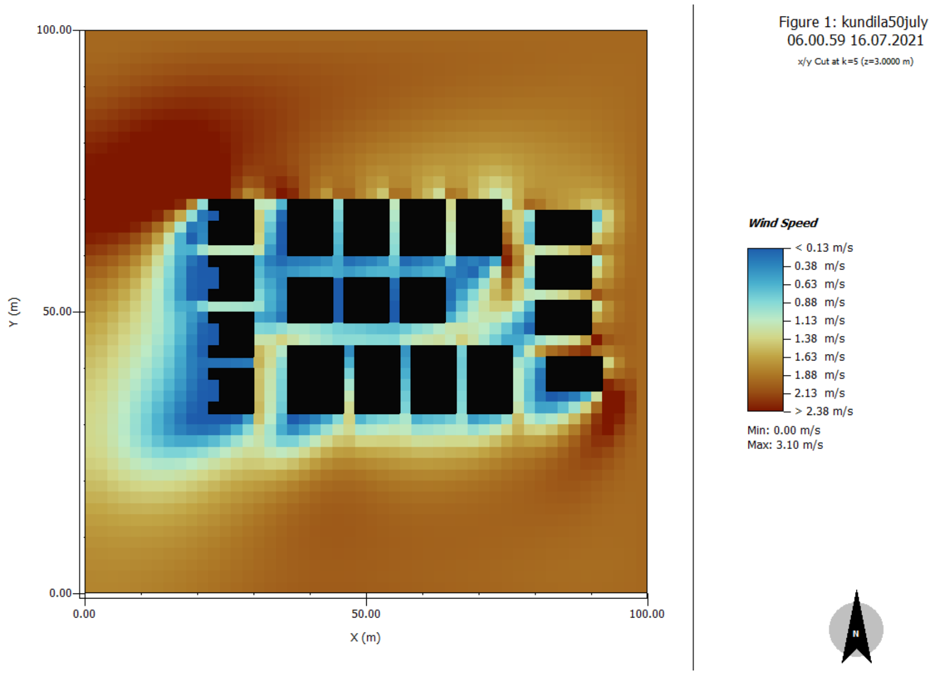


Figure 6.18: Envi Met output from Leonardo: Wind speed at 6:00 am

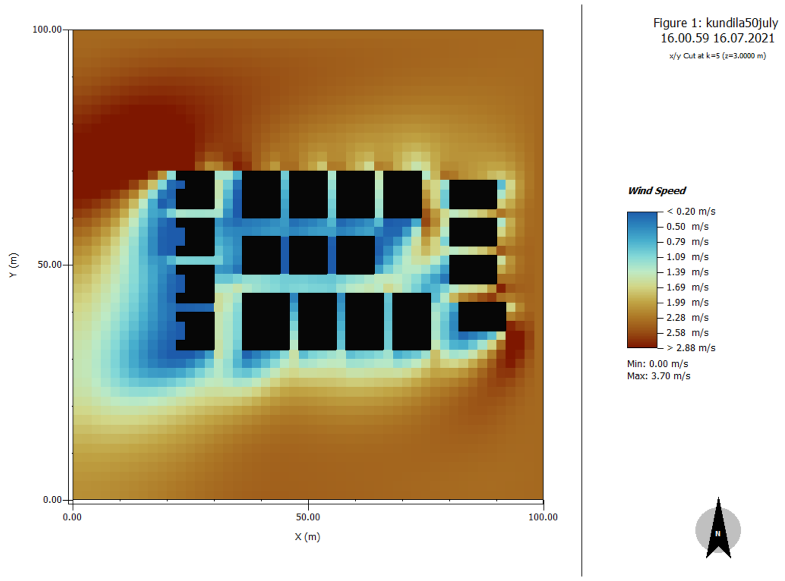


Figure 6.18a: Envi Met output from Leonardo: Wind speed at 4:00 pm

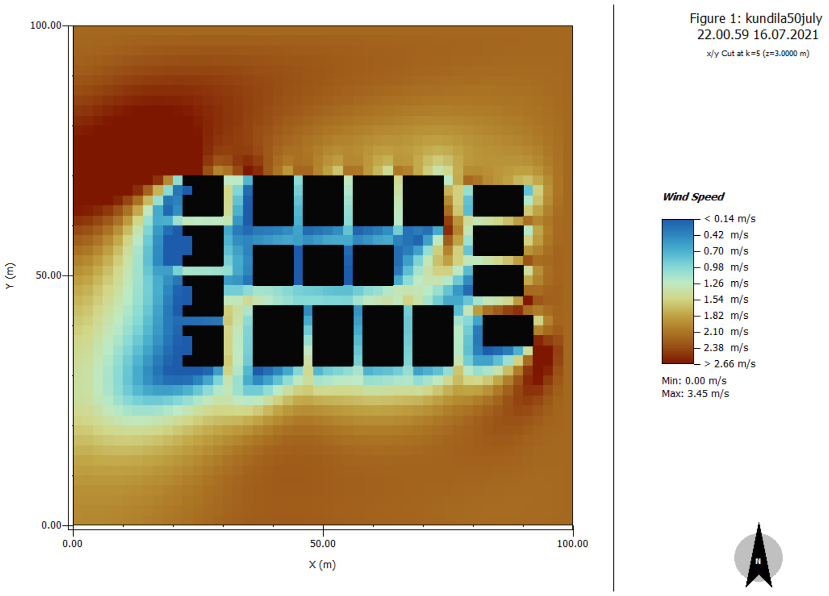


Figure 6.18b: Envi Met output from Leonardo: Wind speed at 10:00 pm

6.3.6.3 Relative Humidity Analysis

At an elevation of 3 metres, variations in relative humidity were perceived across the time intervals. At 6:00 am, the relative humidity ranged from 83.03% to 90.65%, at 4:00 pm it fluctuated between 54.33% and 61.74%, and by 10:00 pm a minimum of 71.87% and a maximum of 78.99% were recorded (shown in Figures 6.19, 6.19a and 6.19b respectively). The average relative humidity across these time periods was calculated at 73.44%. Moreover, the afternoon recorded the lowest relative humidity at 54.33%, while the morning registered the highest at 90.65%.

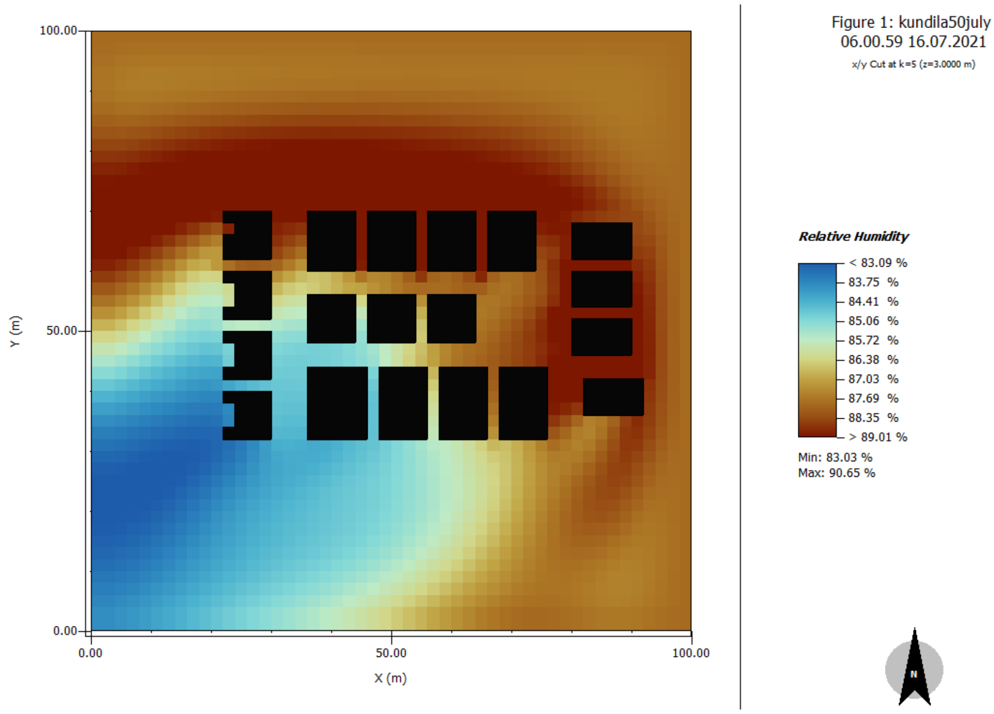


Figure 6.19: Envi Met output from Leonardo: Relative Humidity at 6:00 am

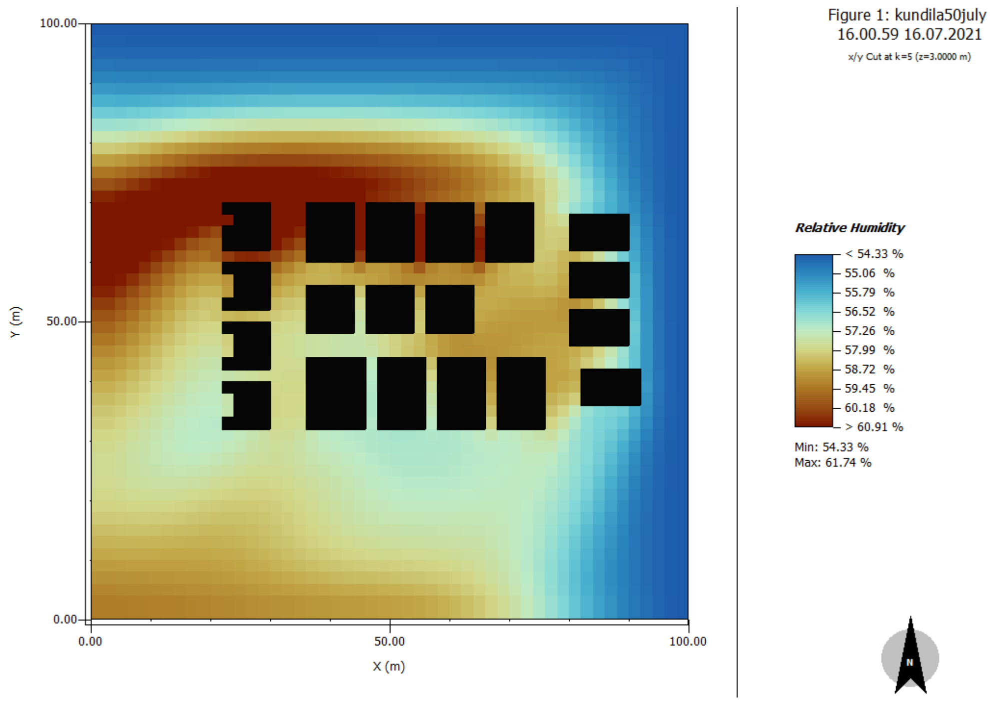


Figure 6.19a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

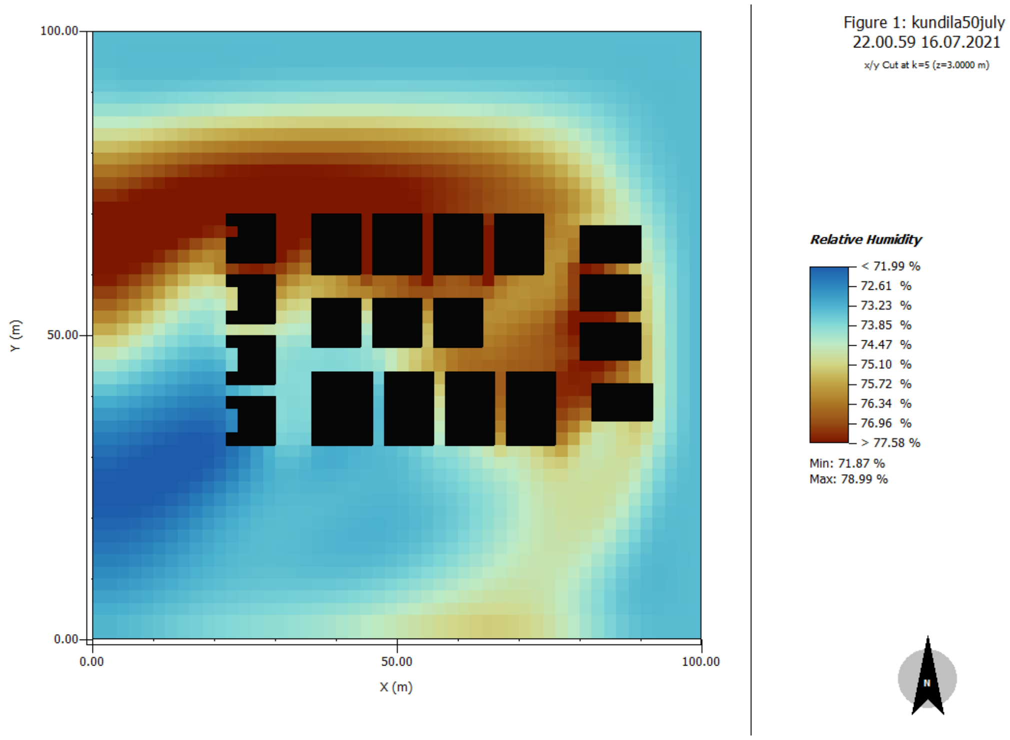


Figure 6.19b: Envi Met output from Leonardo: Relative Humidity at 10:00 pm

During the rainy season, characterized by elevated relative humidity levels, minimal variations were observed in the minimum and maximum temperatures, wind speed, and relative humidity across different percentage coverages. While the readings were recorded under time constraints, it is evident that further investigation is imperative to elucidate the underlying reasons for these consistent results.

The subtle differences in climatic parameters during the rainy season, despite varying degrees of coverage, highlight the need for a more in-depth analysis to uncover the factors influencing these patterns. This inquiry may uncover valuable insights into the unique interplay between vertical greening and climatic conditions during the wet season, informing future considerations for urban planning and environmental management.

6.3.7 Simulation Results for Ibrahim Kunya Housing Estate in January 2021 at 0% Vertical Coverage

6.7.3.1 *Air Temperature Analysis*

The simulation outcomes for Ibrahim Kunya Housing Estate in January 2021 with no vertical coverage (0%) recorded distinct patterns in the air temperature at heights of 3.5 metres. At 6:00 am, air temperatures ranged from 12.02°C to 13.14.30°C, while at 4:00 pm they increased notably, between 26.83°C and 28.84°C, and by 10:00 pm, they ranged from 17.42°C to 19.21°C (illustrated in Figures 6.20, 6.20a and 6.20b respectively). The calculated daily mean temperature for this scenario was deemed comfortable at 19.77°C. In addition, the highest temperature was recorded for the afternoon at 28.84°C, while the lowest was observed in the morning at 12.02°C. These findings contribute valuable insights to the diurnal temperature variations at Ibrahim Kunya Housing Estate in January 2021, which informs a comprehensive understanding of local microclimate dynamics.

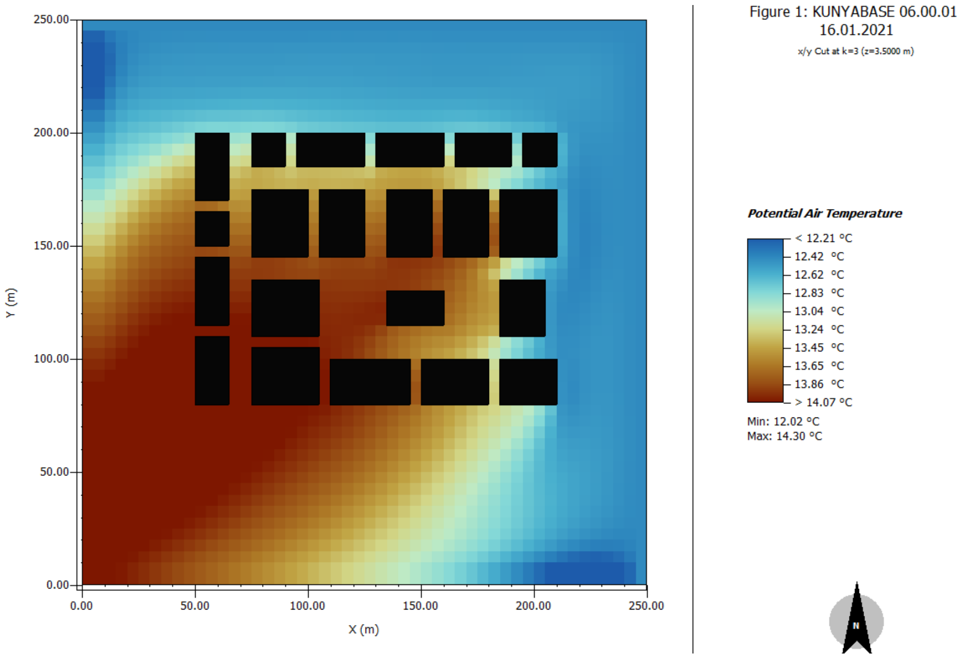


Figure 6.20: Envi Met output from Leonardo: Temperature at 6:00 am

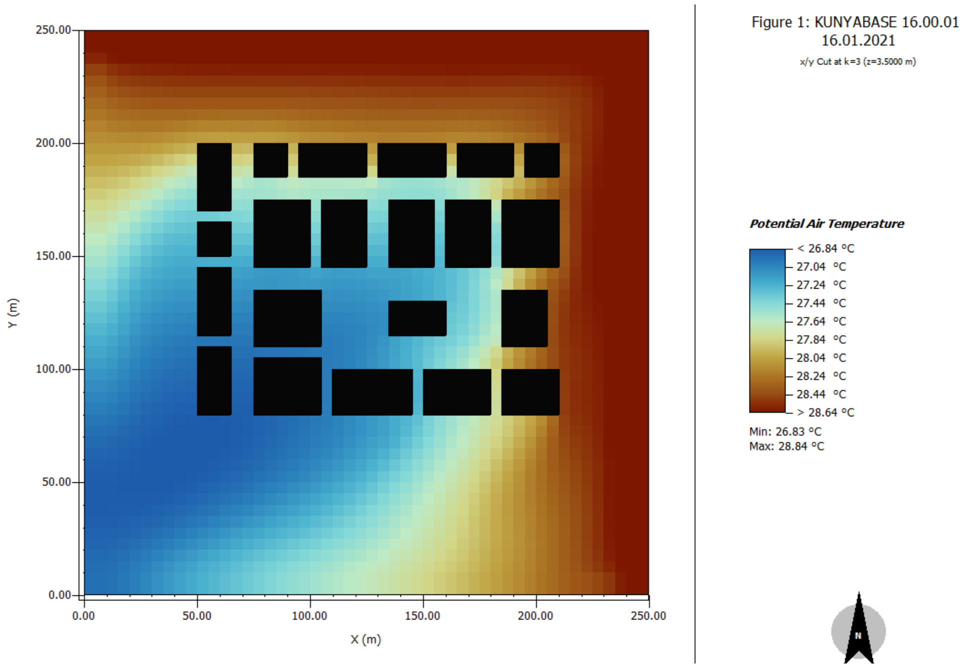


Figure 6.20a: Envi Met output from Leonardo: Temperature at 4:00 pm

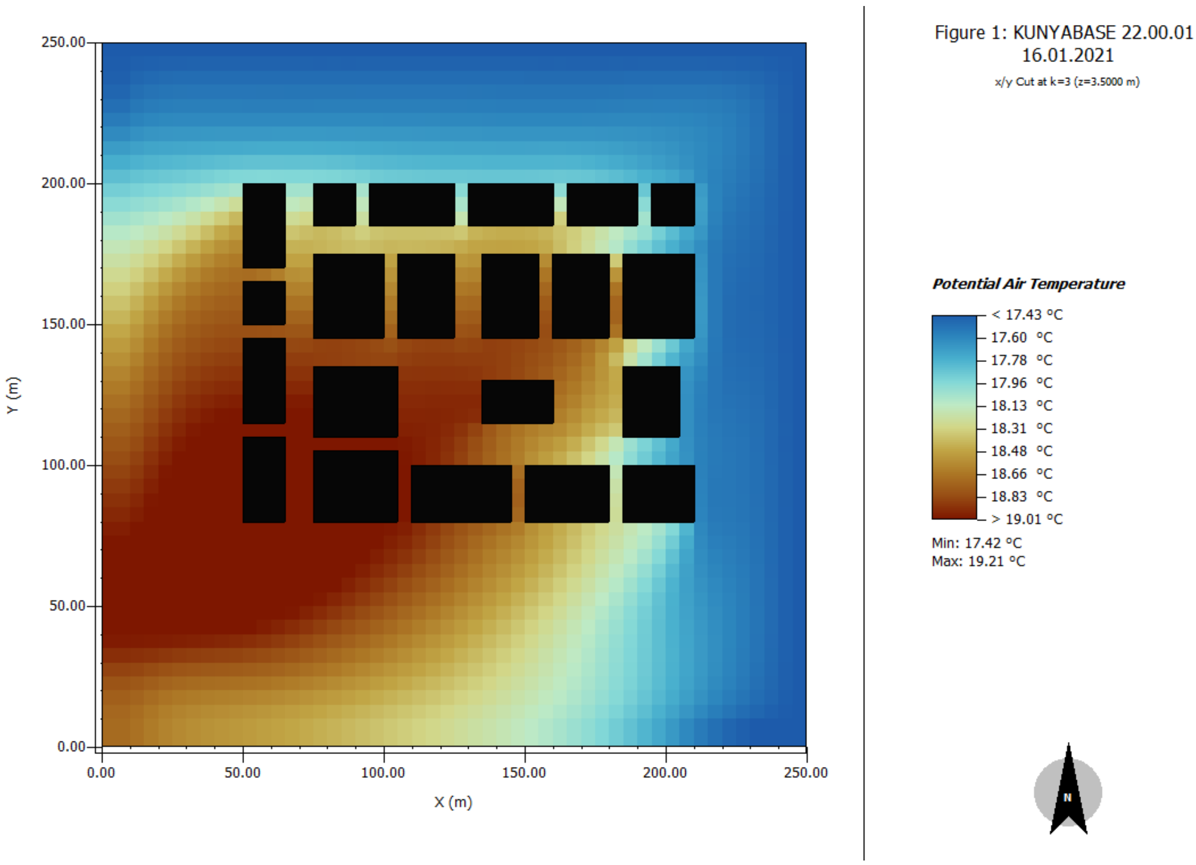


Figure 6.20b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.7.2 Wind Speed Analysis

The simulation outcomes recorded a range of wind speeds for Ibrahim Kunya Housing Estate at the specified time periods. At 6:00 am, the wind speed varied from 0.21 m/s to 2.94 m/s, and it similarly fluctuated at 4:00 pm between 0.17 m/s and 2.94 m/s, while at 10:00 pm, it ranged from 0.07 m/s to 2.54 m/s (illustrated in Figures 6.21, 6.21a and 6.21b). The average wind speed for these scenarios was calculated at 1.56 m/s. A substantial reduction in wind speed was observed in areas characterised by staggered building configurations, which highlights the impact of local architectural layouts on wind dynamics and the significance of building arrangements in microclimate analyses. However, the maximum wind speed recorded is at the outskirts not close to the vertical greening. Comprehensive wind speed data provides valuable insights into spatial and temporal variations and contributes to a nuanced understanding of the microclimatic conditions at Ibrahim Kunya Housing Estate.

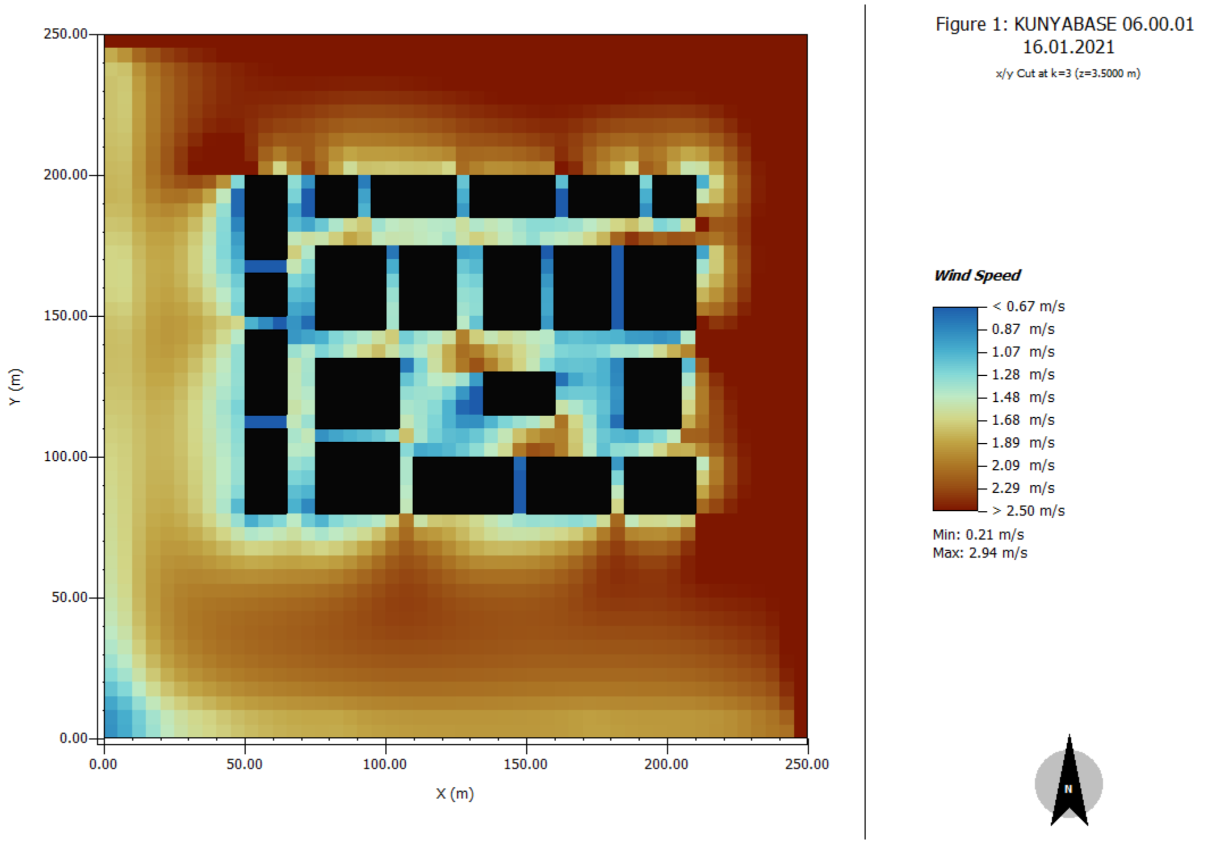


Figure 6.21: Envi Met output from Leonardo: Wind speed at 6:00 am

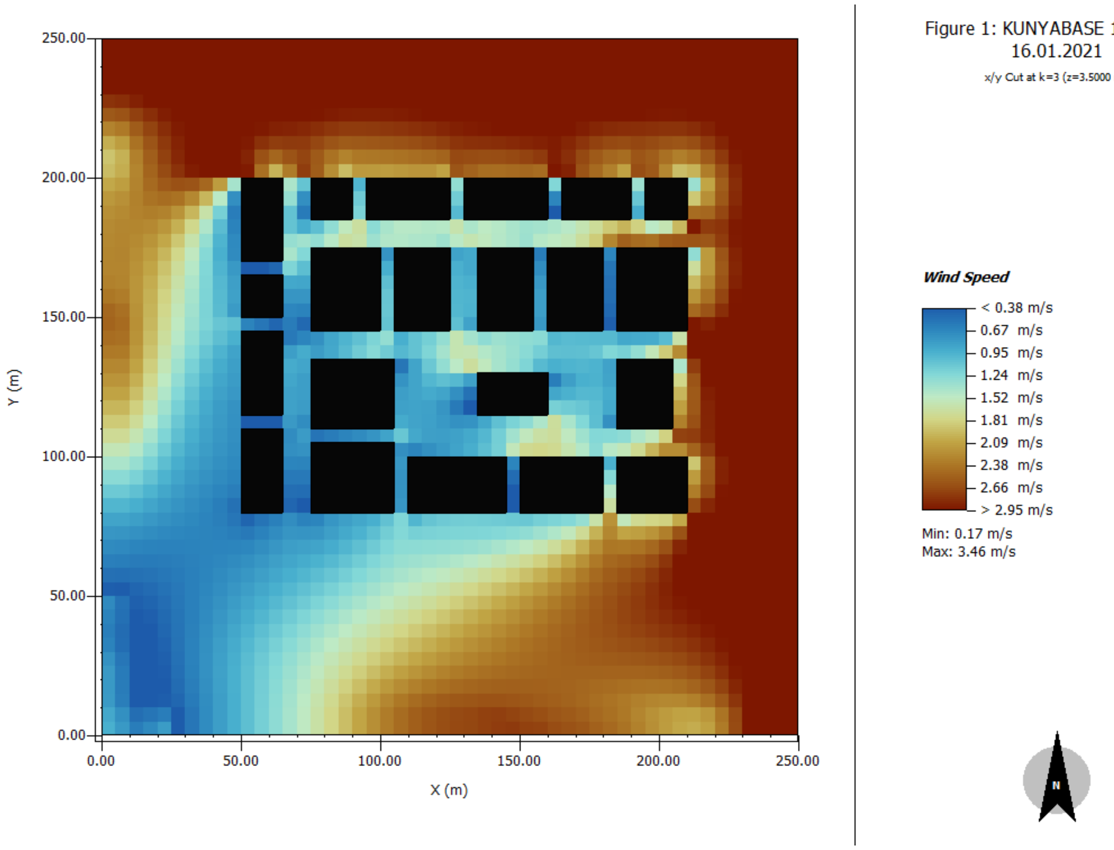


Figure 6.21a: Envi Met output from Leonardo: Wind speed at 4:00 pm

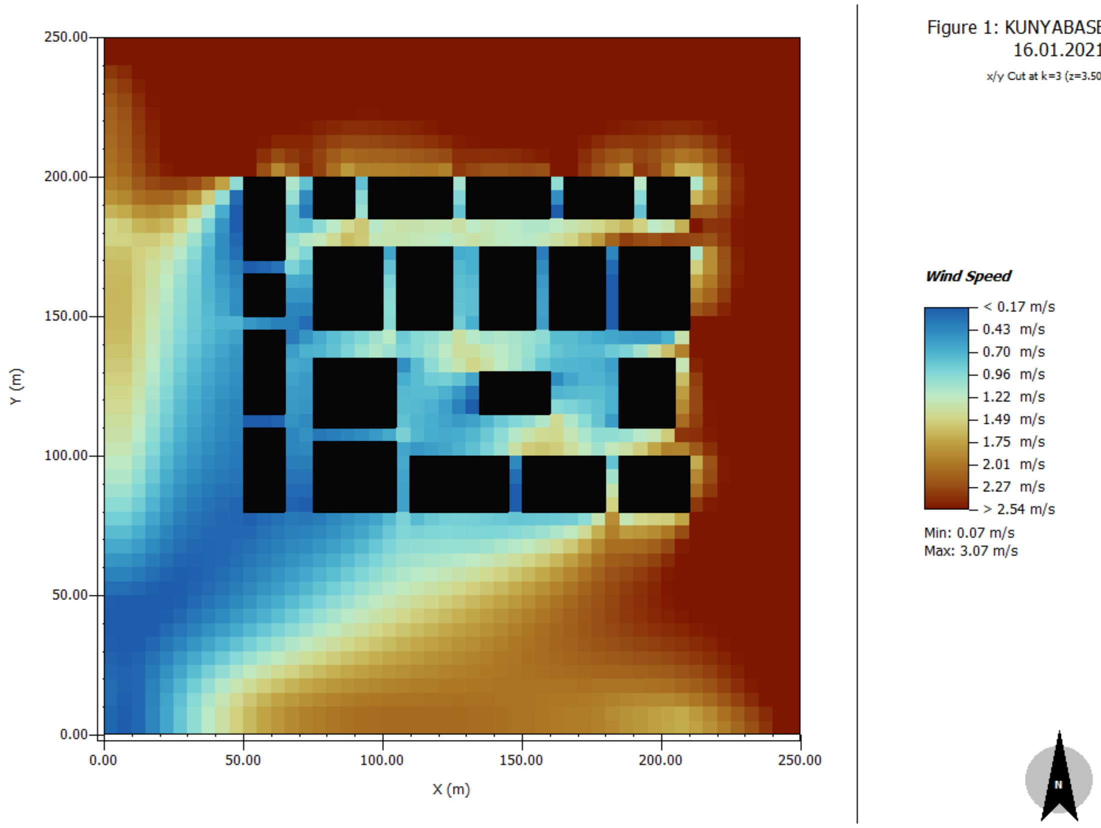


Figure 6.21: Envi Met output from Leonardo: Wind speed at 10:00 pm

6.3.7.3 Relative Humidity Analysis

The simulation results for relative humidity at Ibrahim Kunya Housing Estate offer valuable insights into the moisture content of the air. At 6:00 am, relative humidity was between 55.17% to 65.76%, while at 4:00 pm it varied from 14.00% to 18.38%, and at 10:00 pm, it ranged from 36.09% to 39.71% (refer to Figure 6.22, 6.22a and 6.22b respectively). The average relative humidity across these periods was calculated at 38.19%, although the afternoon recorded the lowest level at 14.00%, while the morning recorded the highest at 65.76%. These findings contribute to a nuanced understanding of the diurnal variations in humidity and provide essential information on the overall microclimate dynamics at Ibrahim Kunya Housing Estate.

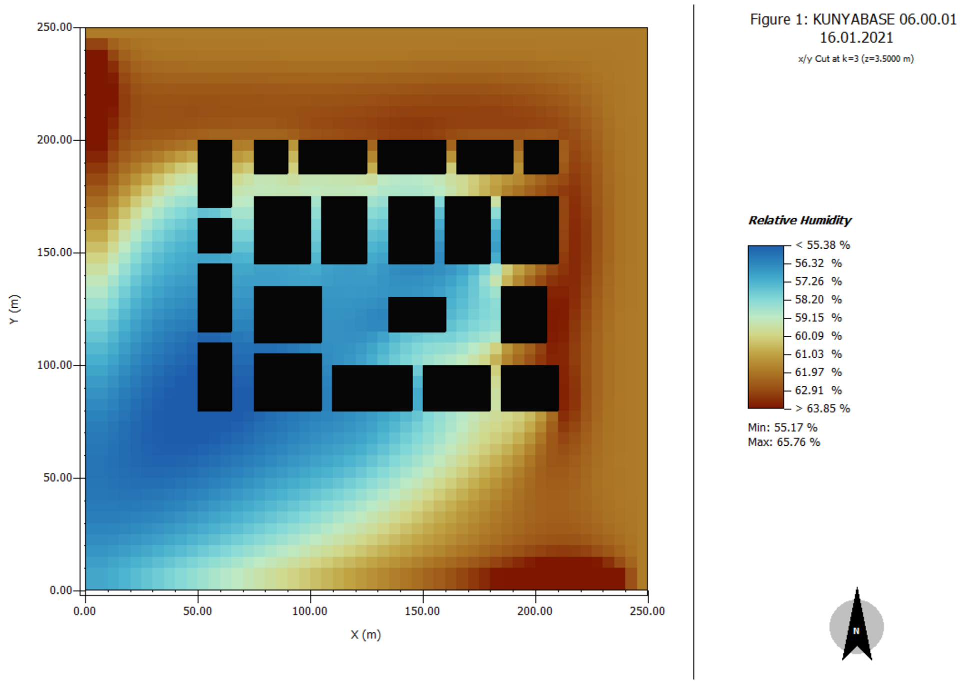


Figure 6.22: Envi Met output from Leonardo: Relative Humidity at 6:00 am

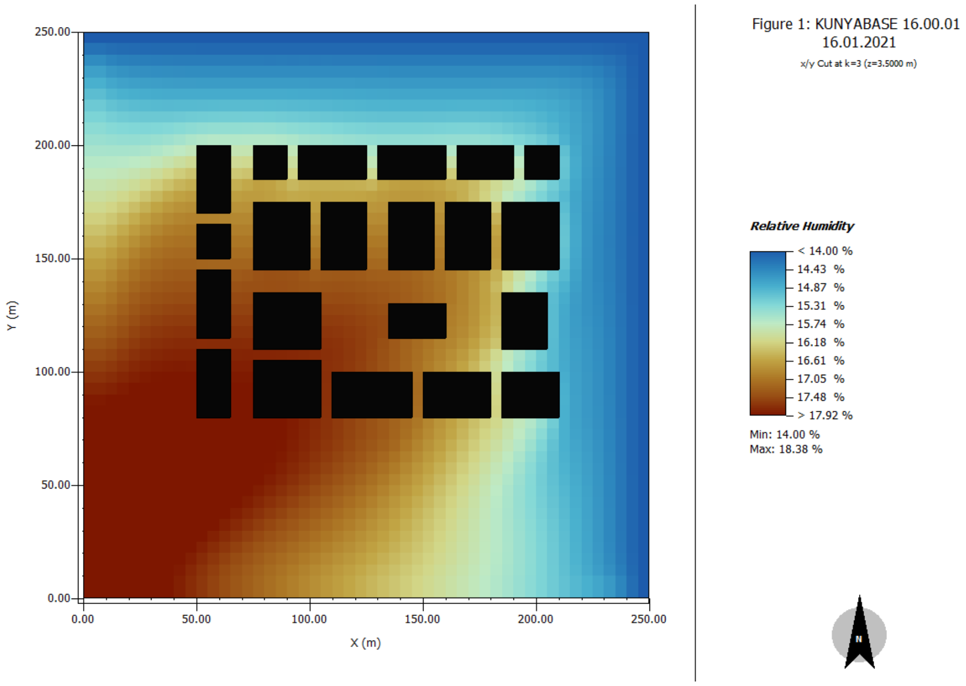


Figure 6.22a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

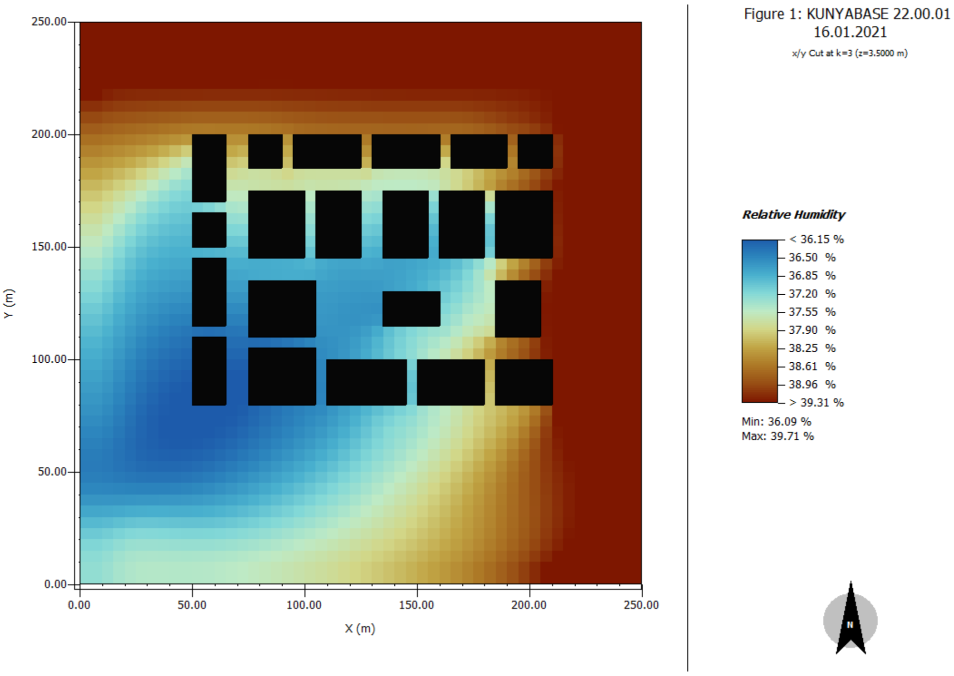


Figure 6.22b: Envi Met output from Leonard: Relative Humidity at 10:00 pm

6.3.8 Simulation Result for Ibrahim Kunya Housing Estate in January at 25% Vertical Coverage

6.3.8.1 Air Temperature Analysis

The simulation outcomes elucidated the variations in air temperature at a height of 3.5 metres for Ibrahim Kunya Housing Estate across the time periods. At 6:00 am air temperatures ranged from 11.98°C to 14.13°C, while at 4:00 pm they were higher ranging from 26.82°C to 28.79°C, and at 10:00 pm, they spanned 17.32°C to 19.06C (refer to Figures 6.23, 6.23a and 6.23b respectively). The computed daily mean temperature for this scenario across all time periods was deemed comfortable at 13.62°C. The afternoon recorded the highest temperature at 28.82°C, while the morning recorded the lowest at 11.98°C. These findings contribute valuable insights to the diurnal temperature fluctuations at Ibrahim Kunya Housing Estate, and offer a greater understanding of local microclimate dynamics.

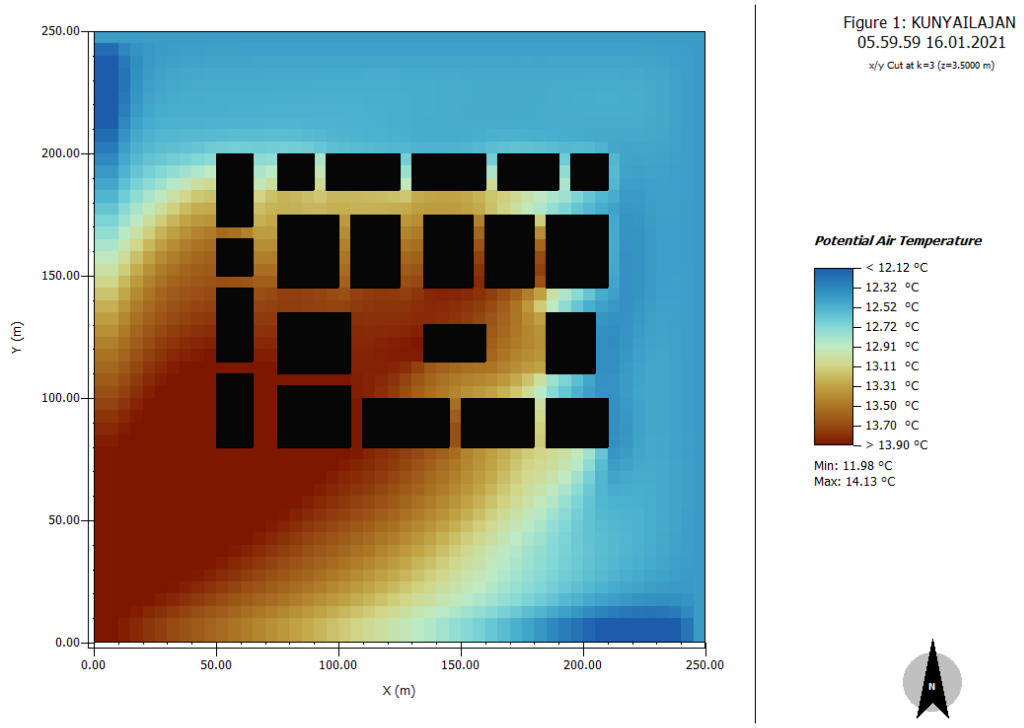


Figure 6.23 Envi Met output from Leonardo: Air Temperature at 6:00 am

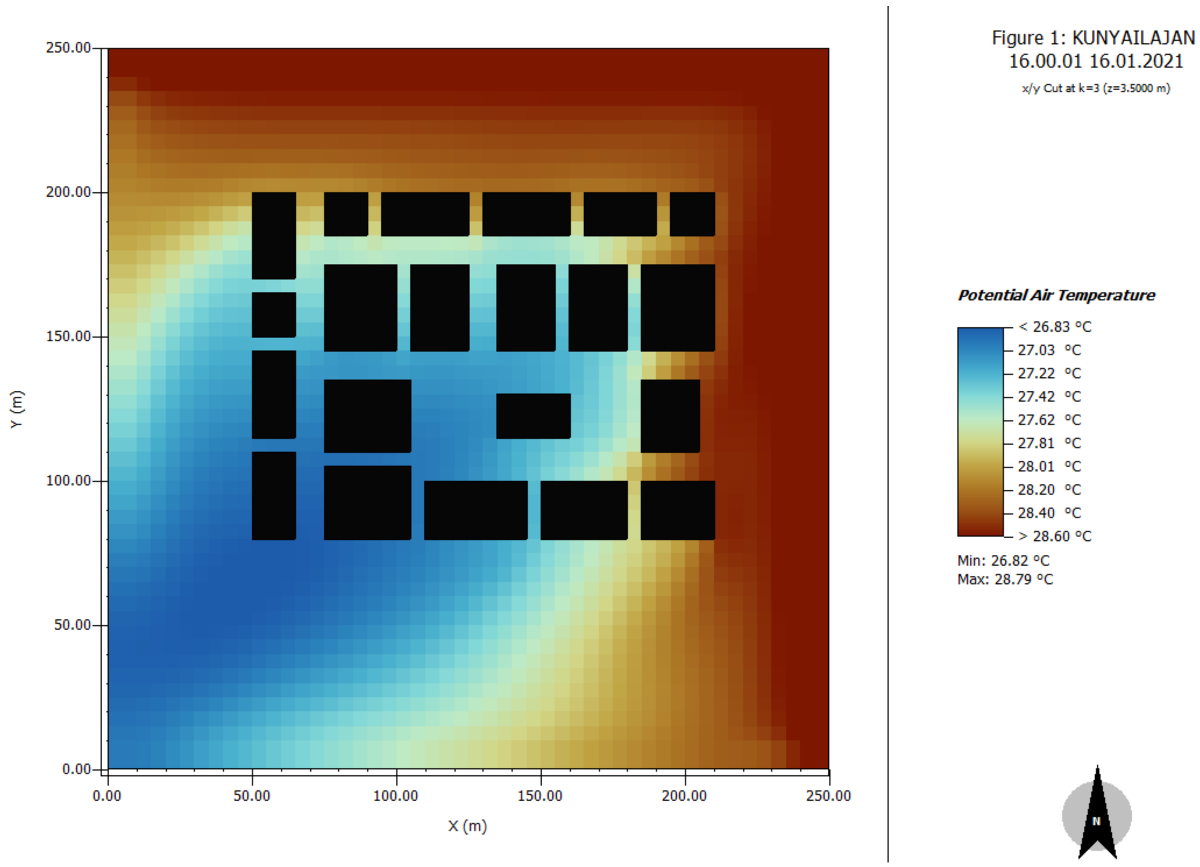


Figure 6.23a Envi Met output from Leonardo: Air Temperature at 4:00 pm

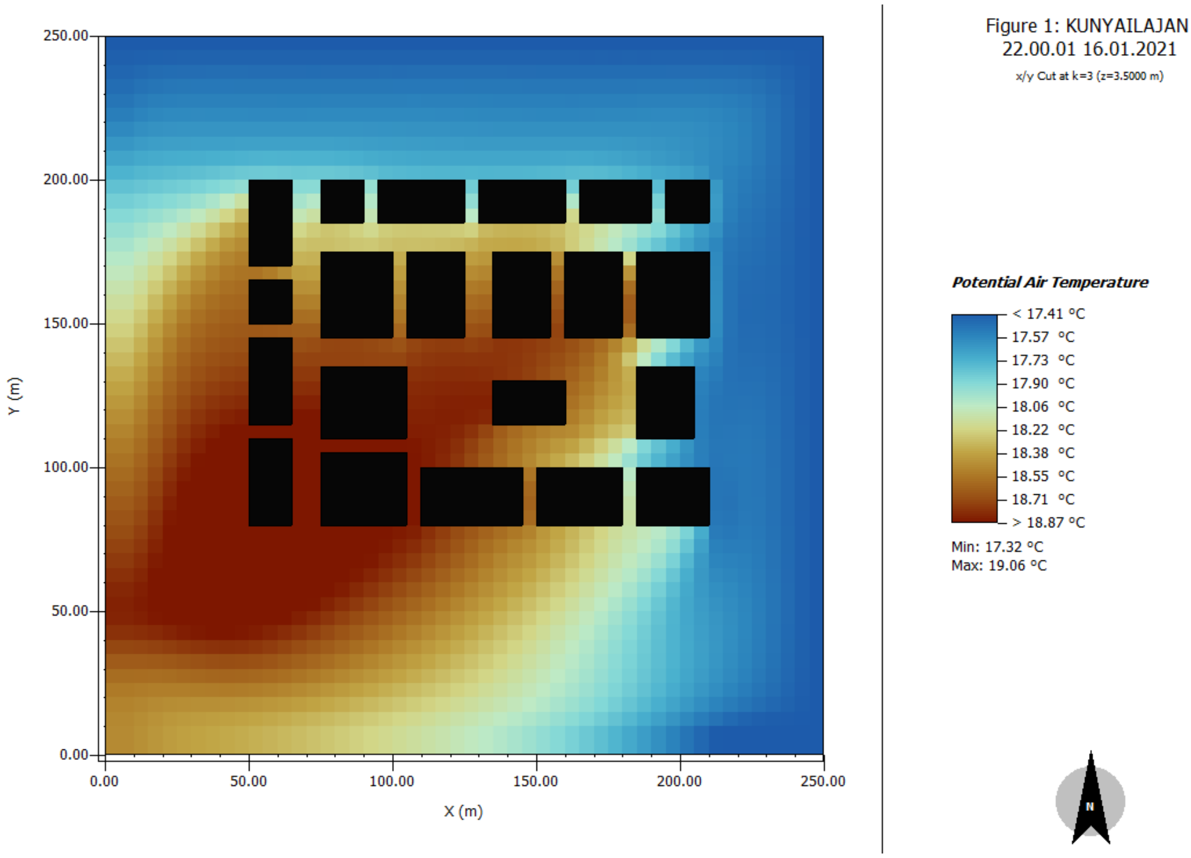


Figure 6.23b: Envi Met output from Leonardo: Air Temperature at 10:00 pm

6.3.8.2 Wind speed Analysis

The recorded wind speeds varied between the time periods. At 6:00 am they ranged from 0.26 m/s to 3.45 m/s, and similarly varied at 4:00 pm from 0.23 m/s to 4.03 m/s.; at 10:00 pm they spanned 0.06 m/s to 3.50 m/s (as illustrated in Figures 6.24, 6.24a and 6.24b respectively). The average wind speed for all time periods was calculated at 1.33 m/s. Notably, areas characterised by staggered building structures experienced a significant reduction in wind speed.

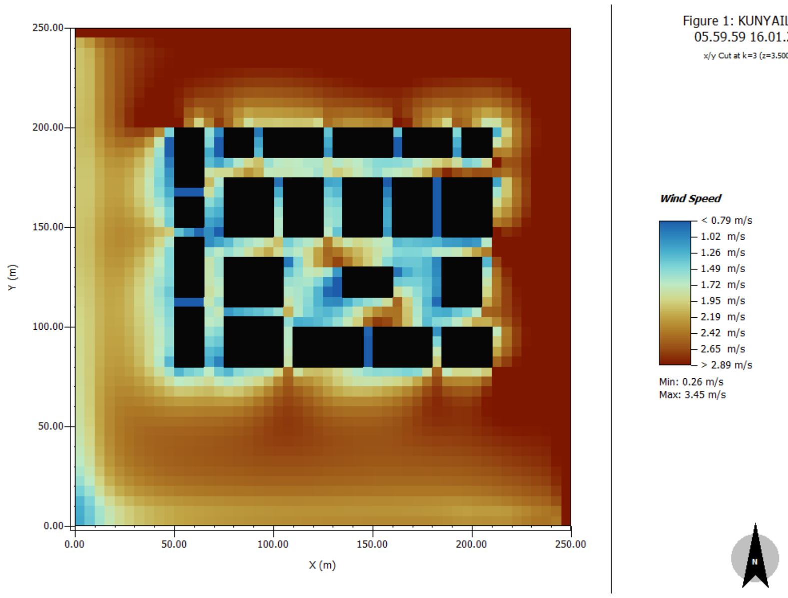


Figure 6.24: Envi Met output from Leonardo: Wind Speed at 6:00 am

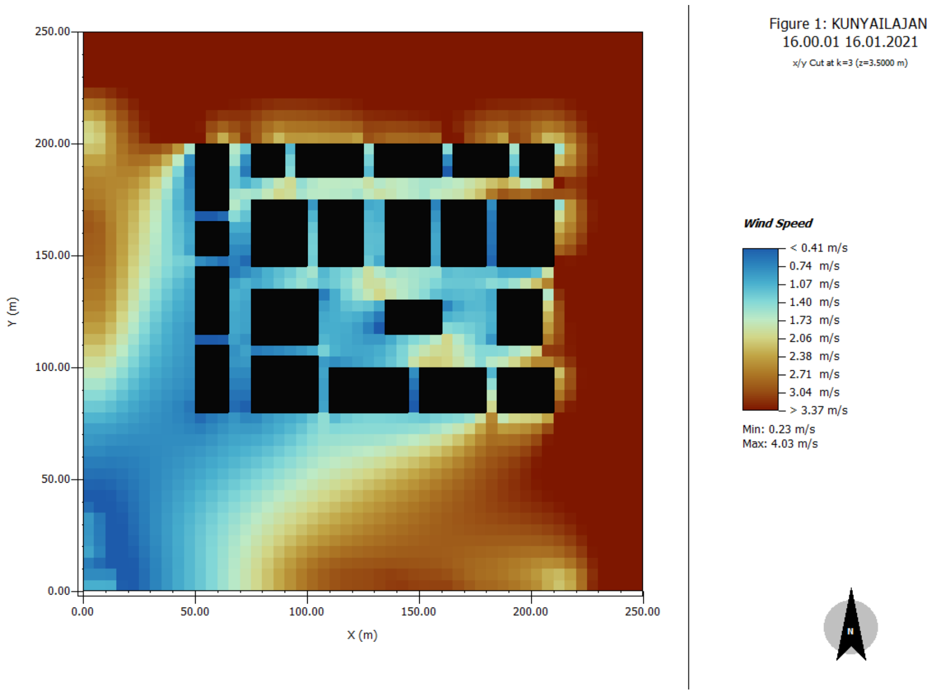


Figure 6.24a: Envi Met output from Leonardo: Wind Speed at 4:00 pm

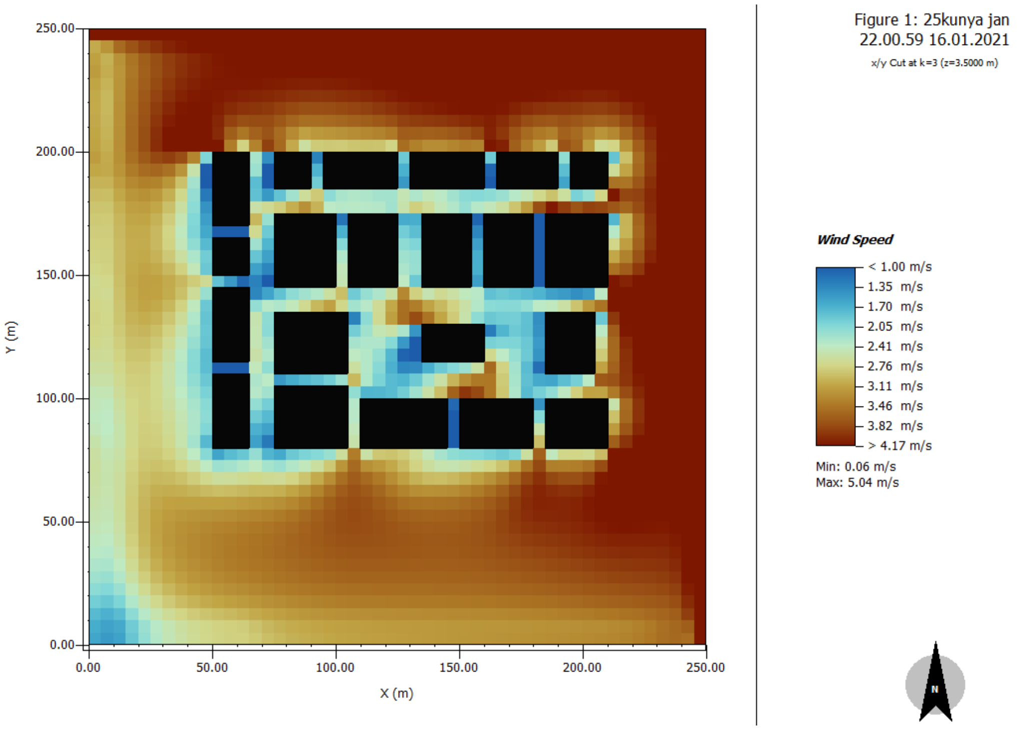


Figure 6.24b: Envi Met output from Leonardo: Wind Speed at 10:00 pm

6.3.8.3 Relative Humidity Analysis

The relative humidity recorded at 6:00 am ranged from 56.04% to 66.11%, at 4:00 pm from 14.02% to 18.13%, and at 10:00 pm between 36.43% and 40.05% (illustrated in Figures 6.25, 6.25a and 6.25b respectively). Moreover, the calculated average relative humidity across all specified time periods was 38.49%. Notably, the relative humidity attained its lowest value of 14.02 during the afternoon, whereas the morning recorded the highest relative humidity at 66.11%.

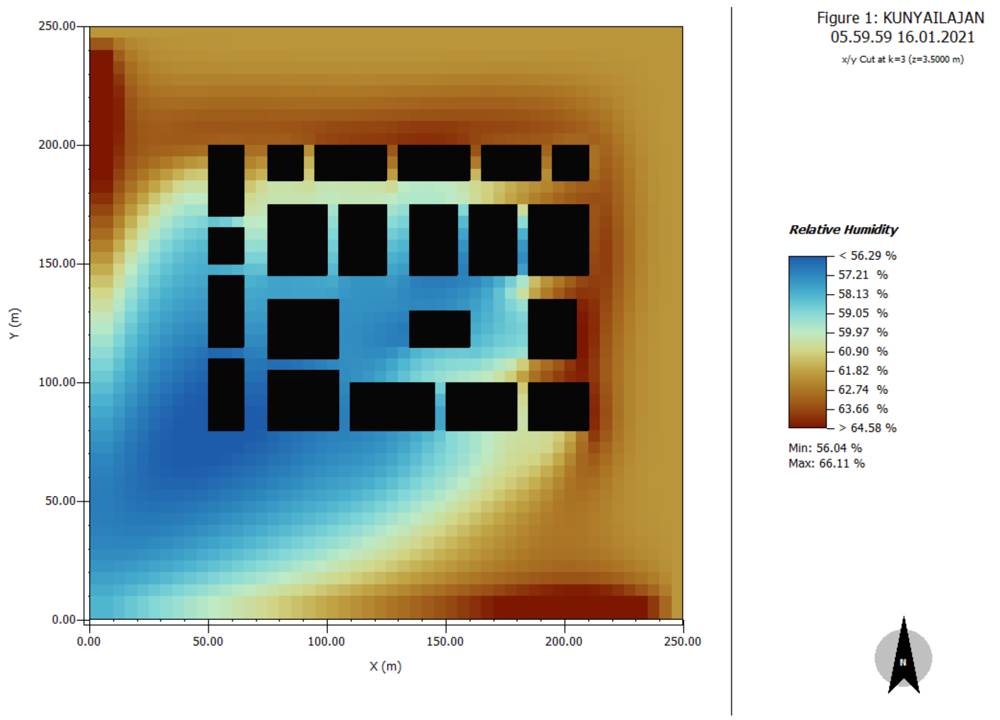


Figure 6.25: Envi Met output from Leonardo: Relative Humidity at 6:00 am

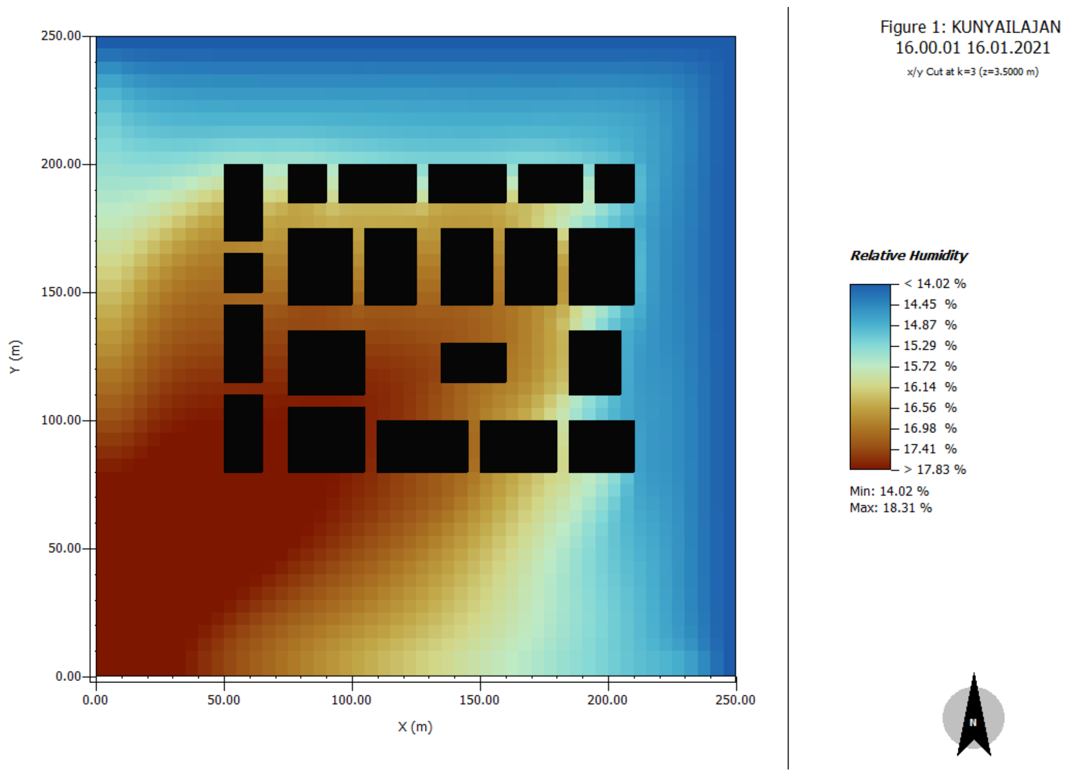


Figure 6.25a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

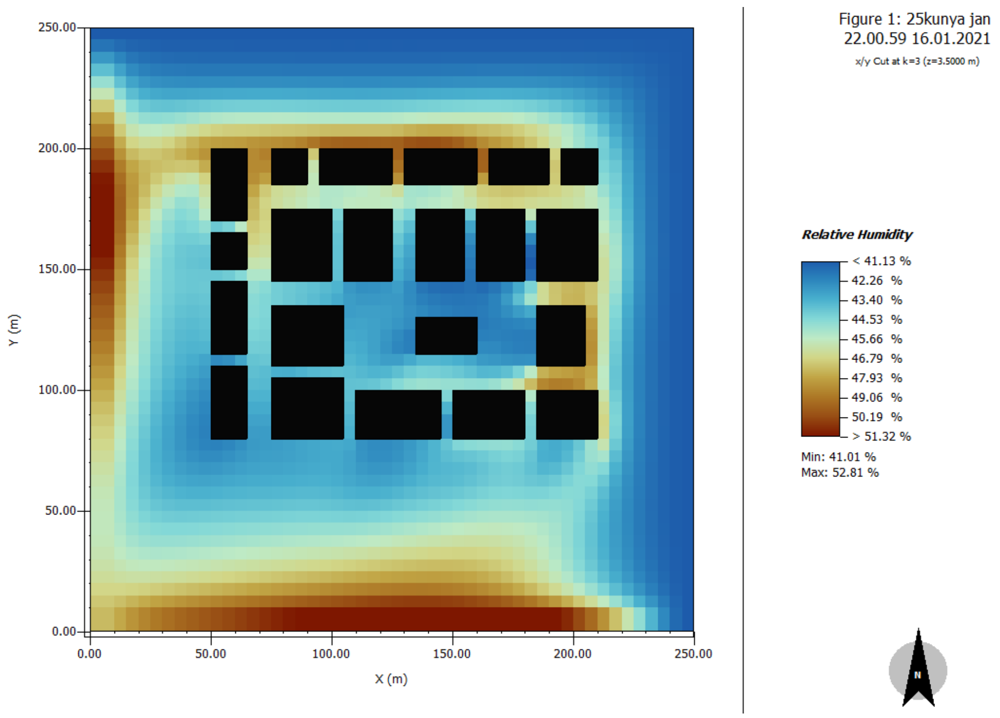


Figure 6.25b: Envi Met output from Leonardo: Relative Humidity at 10:00 pm

6.3.9 Simulation Results for Ibrahim Kunya Housing Estate in January 2021 at 50% Vertical Coverage

6.3.9.1 Air Temperature Analysis

At an elevation of 3.5 metres, air temperatures recorded diurnal variations across the time periods. At 6:00 am temperatures ranged from 11.84°C to 13.86°C., at 4:00 pm, the span widened to 24.40°C and 28.38°C, and at 10:00 pm, they ranged from 15.63°C to 17.78°C (illustrated in Figures 6.26, 6.26a and 6.26b respectively). The calculated daily mean temperature was recorded at a comfortable 18.65°C. Noteworthy extremes were observed, in the afternoon which registered the highest temperature at 28.38°C, and the morning which recorded the lowest at 11.84°C.

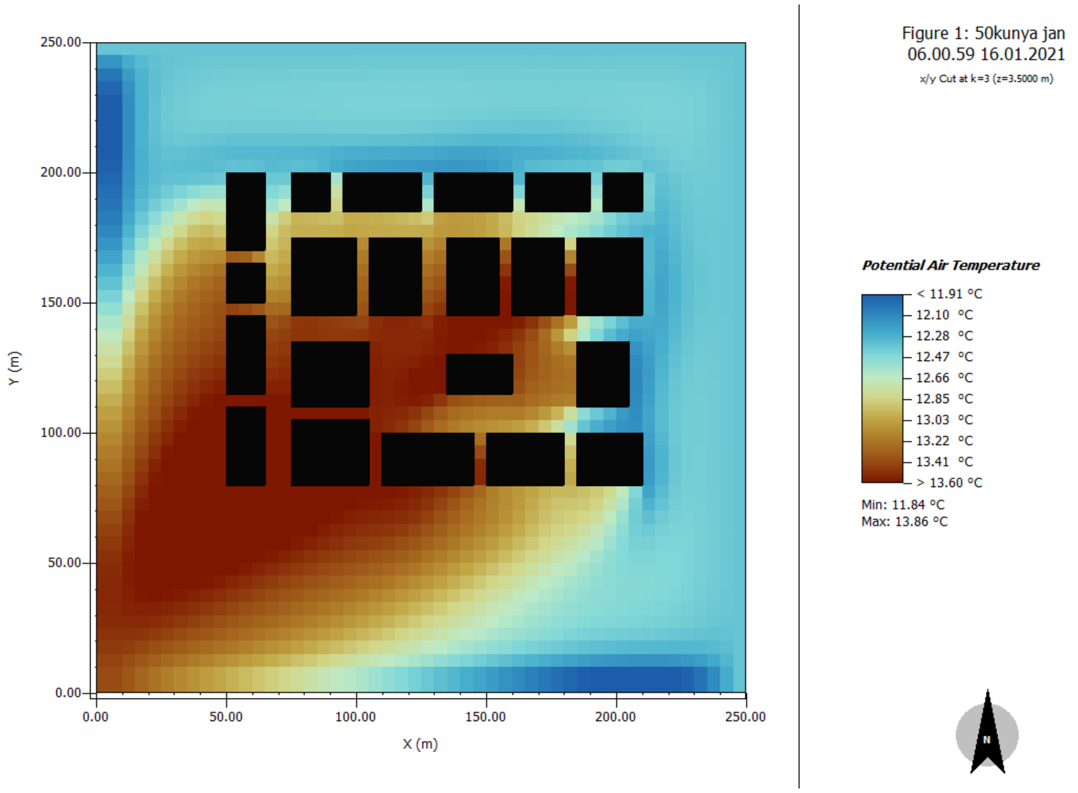


Figure 6.26: Envi Met output from Leonardo: Temperature at 6:00 am

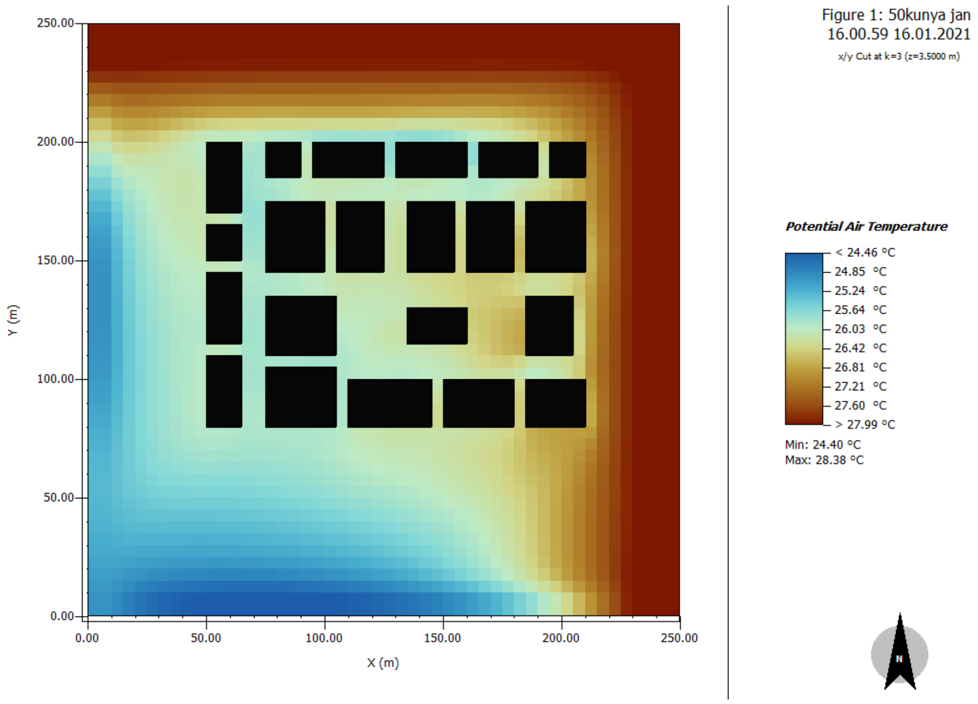


Figure 6.26a: Envi Met output from Leonardo: Temperature at 4:00 pm

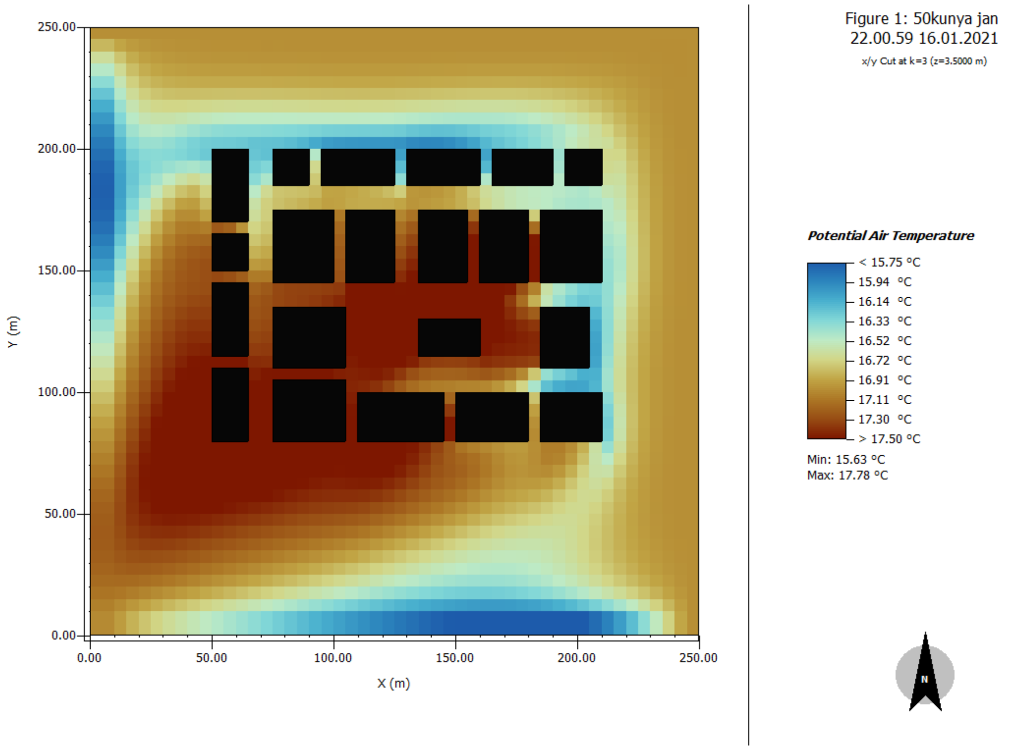


Figure 6.26b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.9.2 Wind Speed Anaysis

Varied wind speeds were recorded throughout the day, with distinct levels captured at the different time periods. At 6:00 am the wind speed ranged from 0.12 m/s to 4.68 m/s, at 4:00 pm it varied from 0.10 m/s to 5.79 m/s, and at 10:00 pm, it ranged from 0.06 m/s to 5.04 m/s (as illustrated in Figures 6.27, 6.27a and 6.27b respectively). The average for specified intervals was calculated at 2.63 m/s, while the areas characterised by a staggered arrangement of buildings experienced a discernible reduction in wind speed.

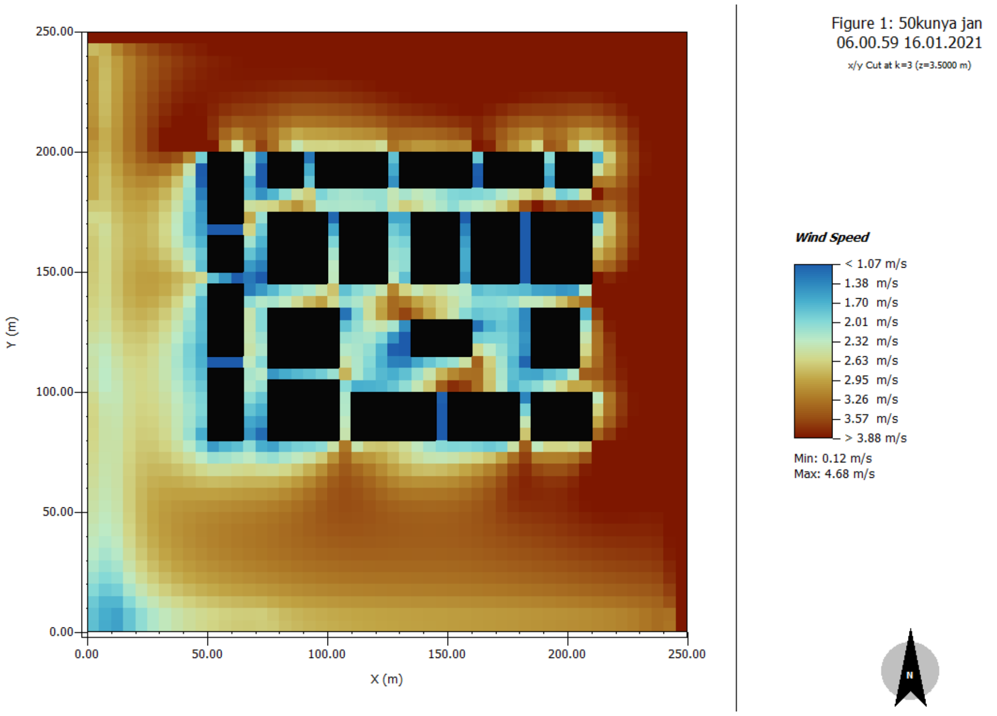


Figure 6.27: Envi Met output from Leonardo: Wind Speed at 6:00 am

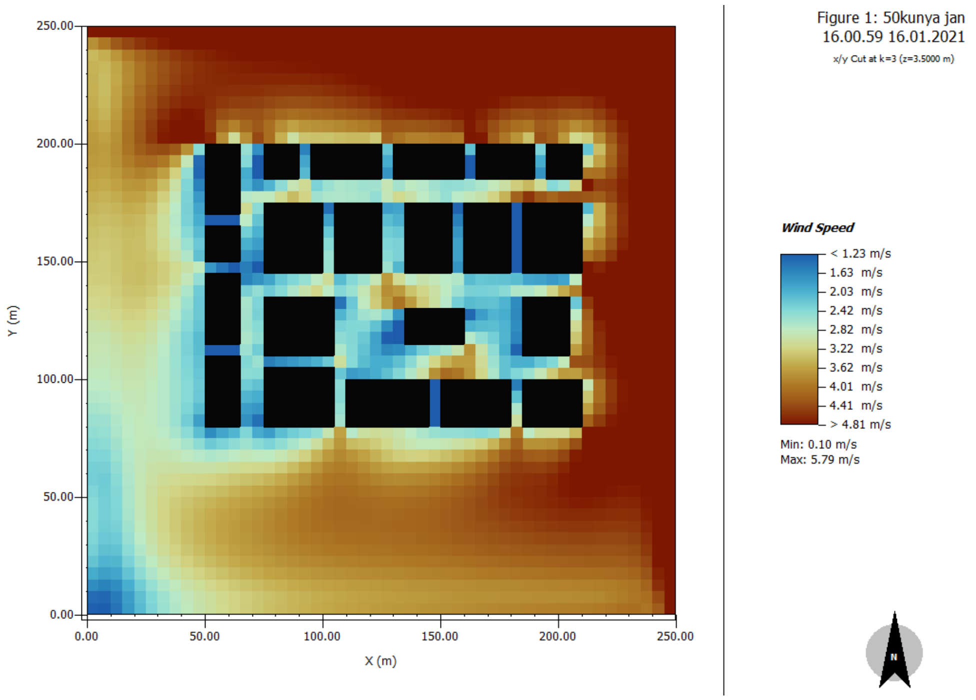


Figure 6.27a: Envi Met output from Leonardo: Wind Speed at 4:00 pm

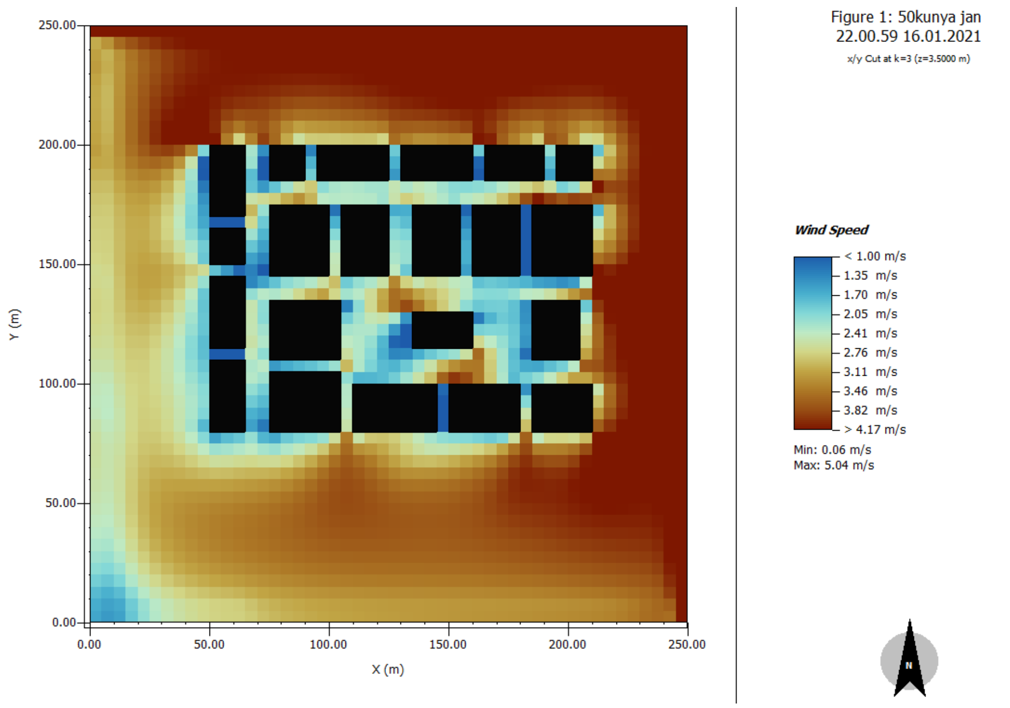


Figure 6.27b: Envi Met output from Leonardo: Wind Speed at 10:00 pm

6.3.9.3 Relative Humidity Analysis

The relative humidity recorded at 6:00 am ranged from 58.87% to 70.34%, while at 4:00 pm, it fluctuated between 14.10% and 27.58%, and at 10:00 pm, it varied from 41.01% to 52.81% (illustrated in Figures 6.28, 6.28a and 6.28b). The calculated average relative humidity across these time periods was documented at 25.7%. Moreover, the lowest relative humidity was observed during the afternoon at 14.10%, while the the highest was registered in the morning at 70.34%.

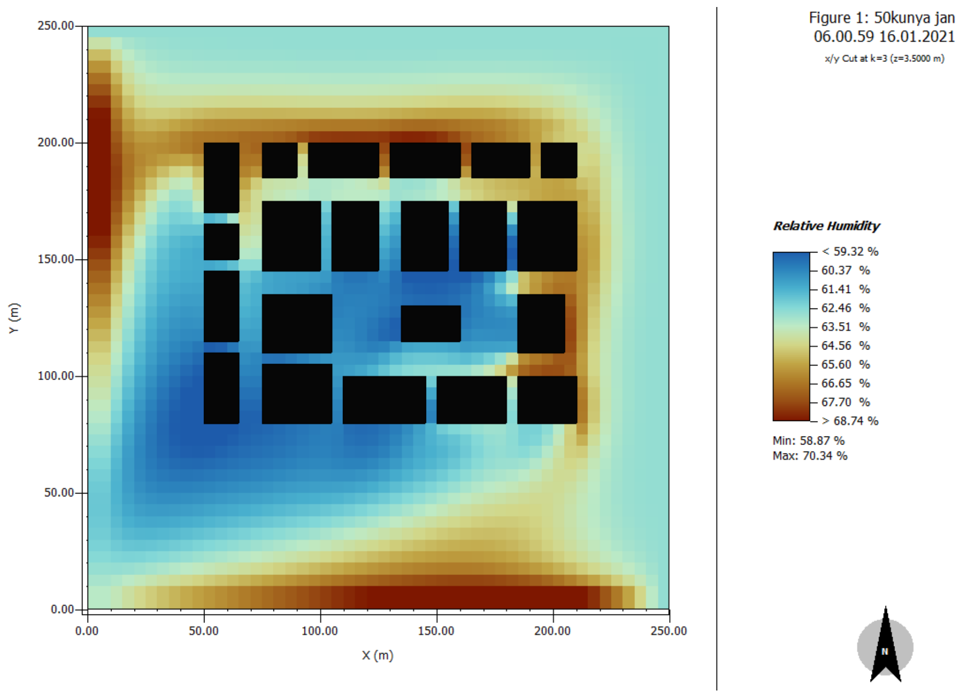


Figure 6.28: Envi Met output from Leonardo: Relative Humidity at 6:00 am

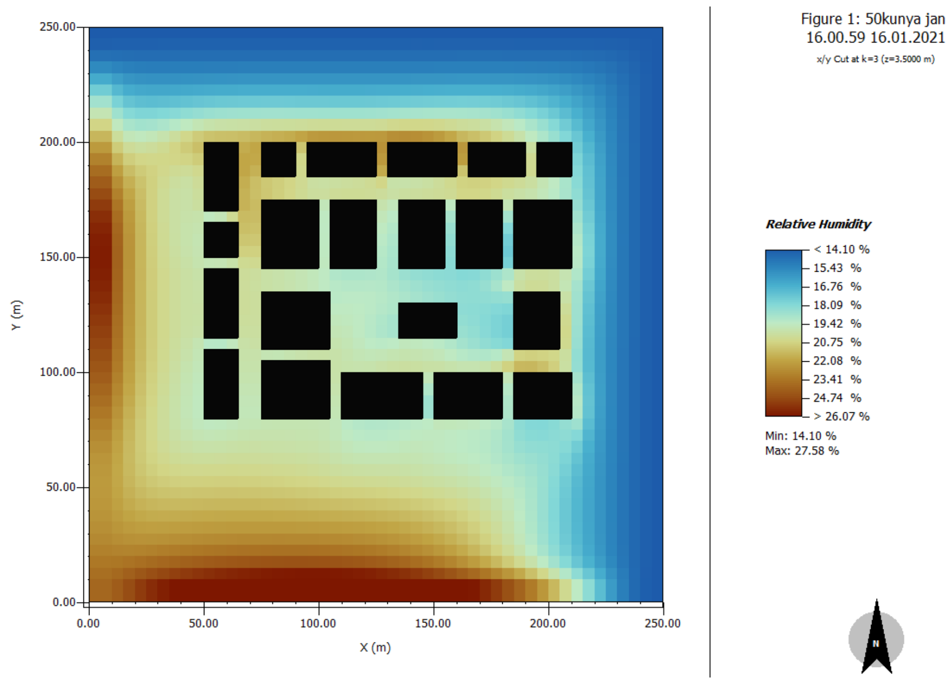


Figure 6.28a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

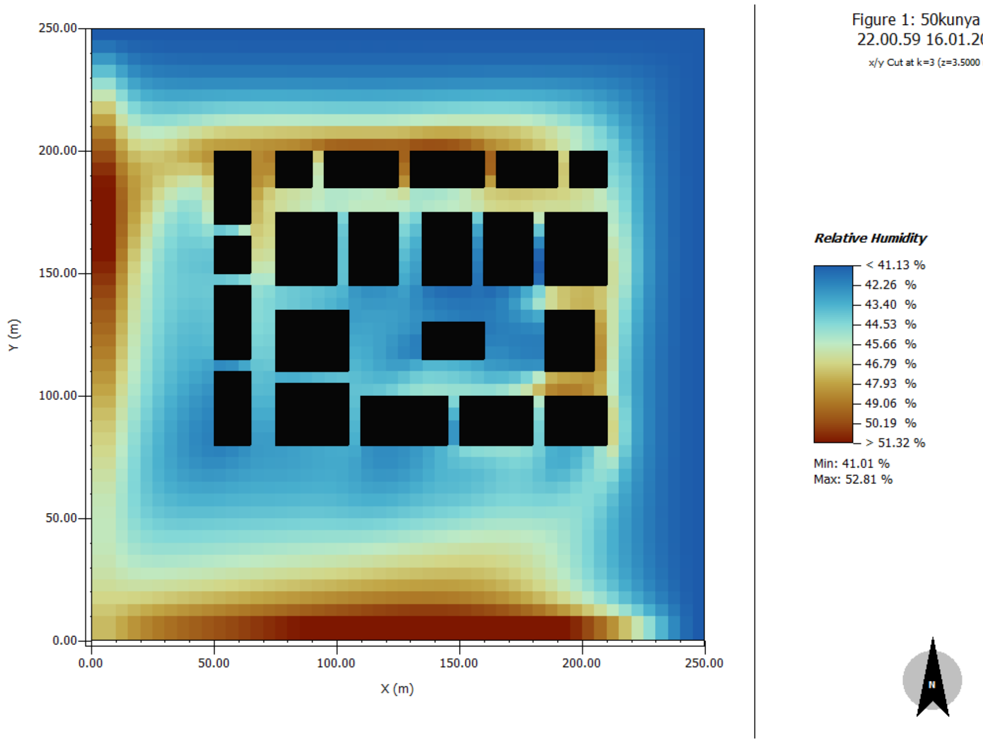


Figure 6.28b: Envi Met output from Leonardo: Relative Humidity at 10:00 pm

At Ibrahim Kunya Housing Estate, the lowest temperature measured at 4 p.m. during the dry season without vertical greening (VG) was 26.83°C. The temperature decreased to 26.82°C when 25% VG coverage was added, then it decreased even further to 24.40°C when 50% VG coverage was added. This data suggests a very negligible reduction in minimum temperature of 0.01°C with 25% VG coverage and a more significant 2.43°C reduction with 50% VG coverage. It is noteworthy that the results are relevant only to the neighborhood's minimum temperature. Depending on the particular grid or measurement point chosen, the degree of temperature drop could vary. These findings highlight how vertical greening may moderate temperatures in Ibrahim Kunya Housing Estate during the dry season, which may have an impact on environmental and urban planning challenges. Additional intricacies and potentials for maximising the benefits of vertical greening in specific region of the may be revealed by further investigation and analysis.

6.3.10 Simulation Results for Ibrahim Kunya Housing Estate in July 2021 at 0% Vertical Coverage

6.3.10.1 Air temperature Analysis

Air temperatures varied significantly across the time periods captured. At 6:00 am temperatures ranged from 24.23°C to 24.83°C, while at 4:00 pm a broader range was recorded from 29.68°C to 31.03°C, and at 10:00 pm temperatures varied from 26.66°C to 27.33°C. (shown in Figures 6.29, 6.29a and 6.29b respectively). The calculated daily mean temperature was recorded at a comfortable 31.38°C, although the afternoon recorded the highest temperature at 31.03°C, while the morning observed the lowest at 24.23°C

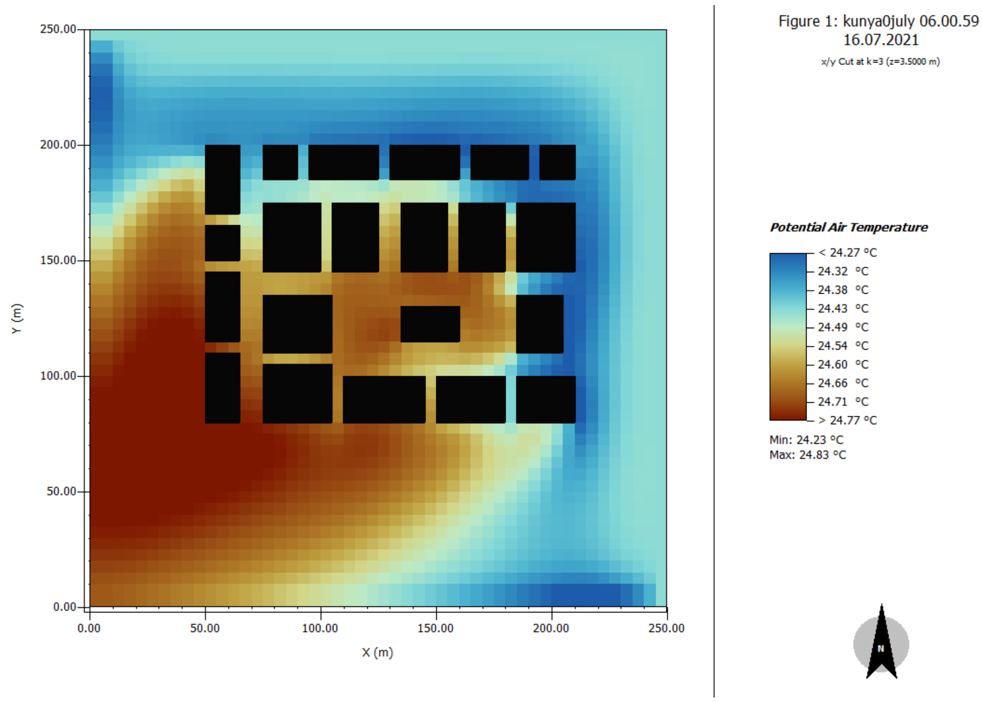


Figure 6.29: Envi Met output from Leonardo: Temperature at 6:00 am

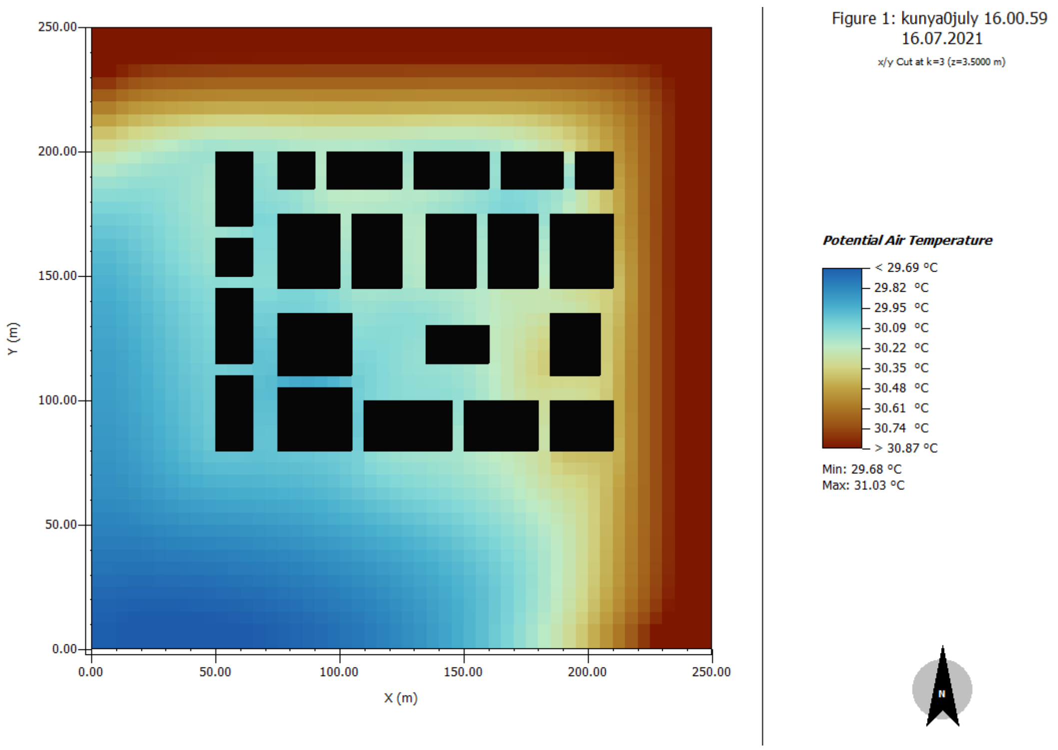


Figure 6.29a: Envi Met output from Leonardo: Temperature at 4:00 pm

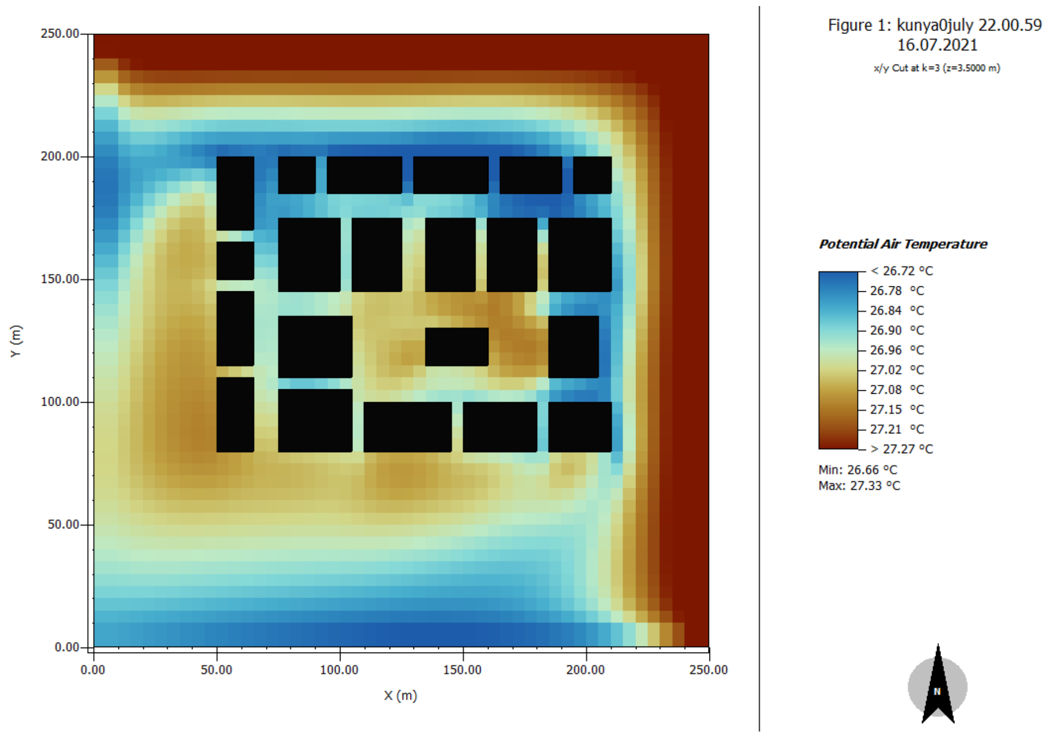


Figure 6.29b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.10.1 Wind speed Analysis

Distinct variations of wind speed were recorded for the time periods. At 6:00 am the wind speed ranged from 0.29 m/s to 2.33 m/s, and at 4:00 pm it oscillated between 0.33 m/s and 2.77 m/s, while at 10:00 pm, it varied from 0.30 m/s to 2.64 m/s (shown in Figures 6.30, 6.30a and 6.30b). Notably, areas characterised by a staggered arrangement of buildings recorded a significant reduction in wind speed.

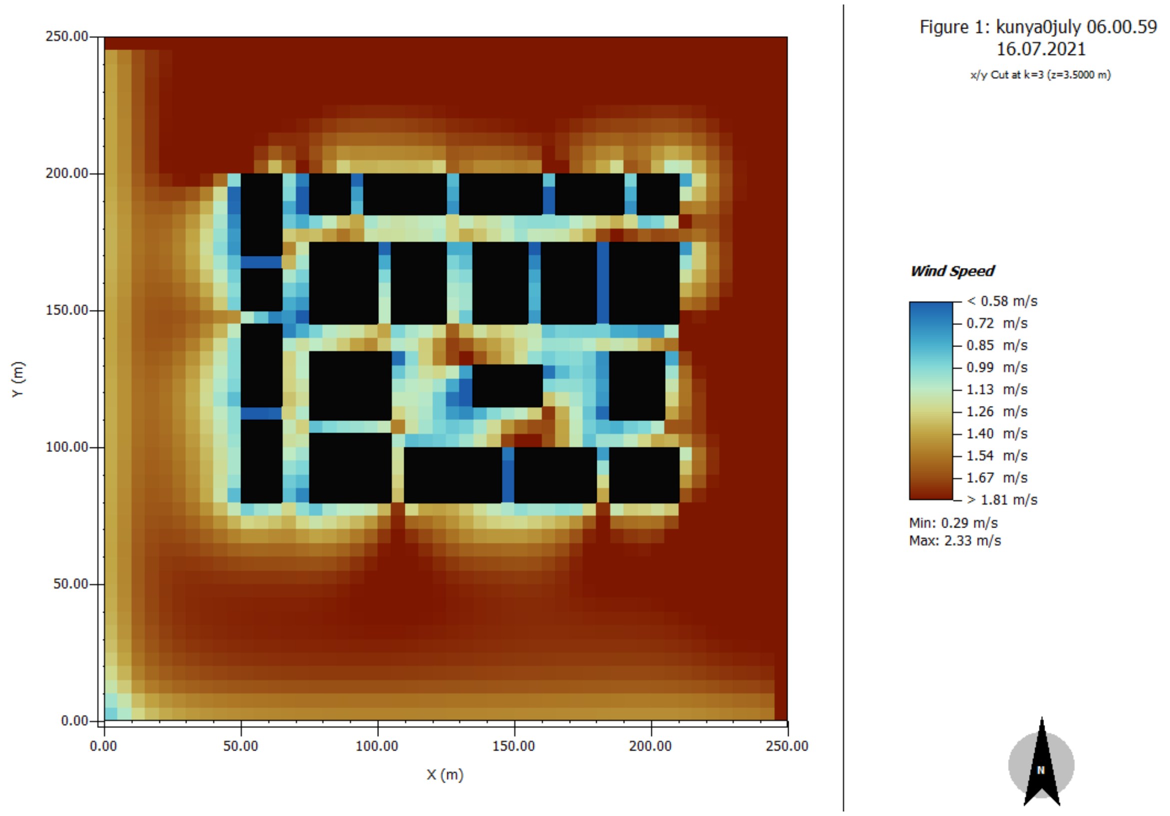


Figure 6.30: Envi Met output from Leonardo: Temperature at 6:00 am

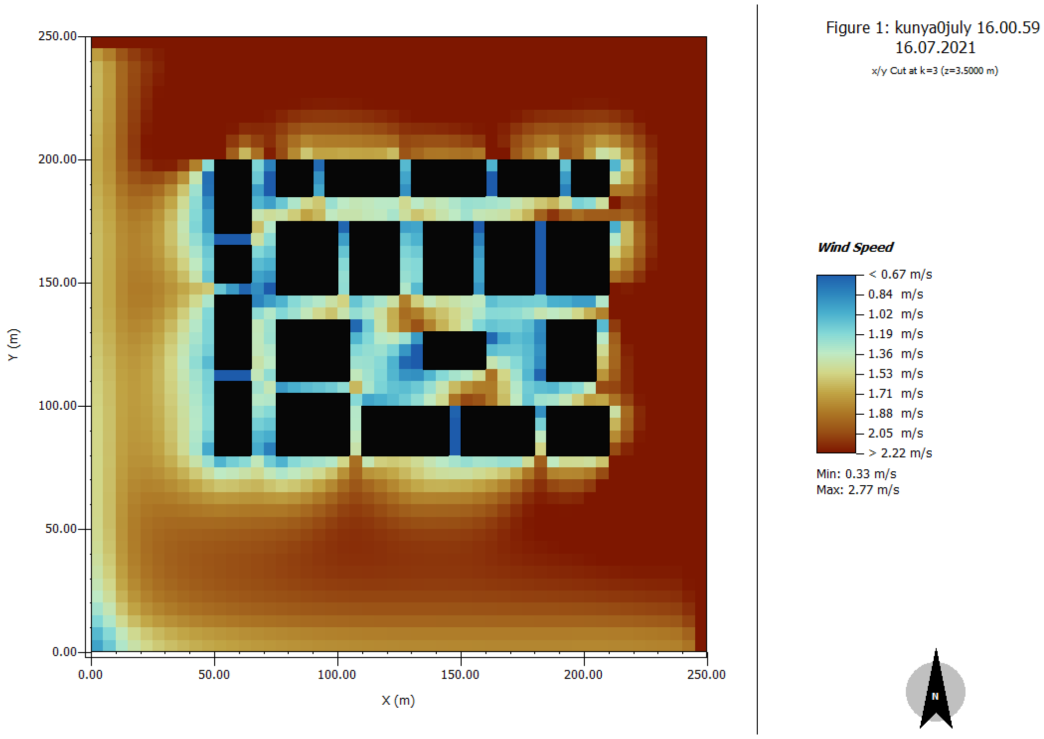


Figure 6.30a: Envi Met output from Leonardo: Wind Speed at 4:00 pm

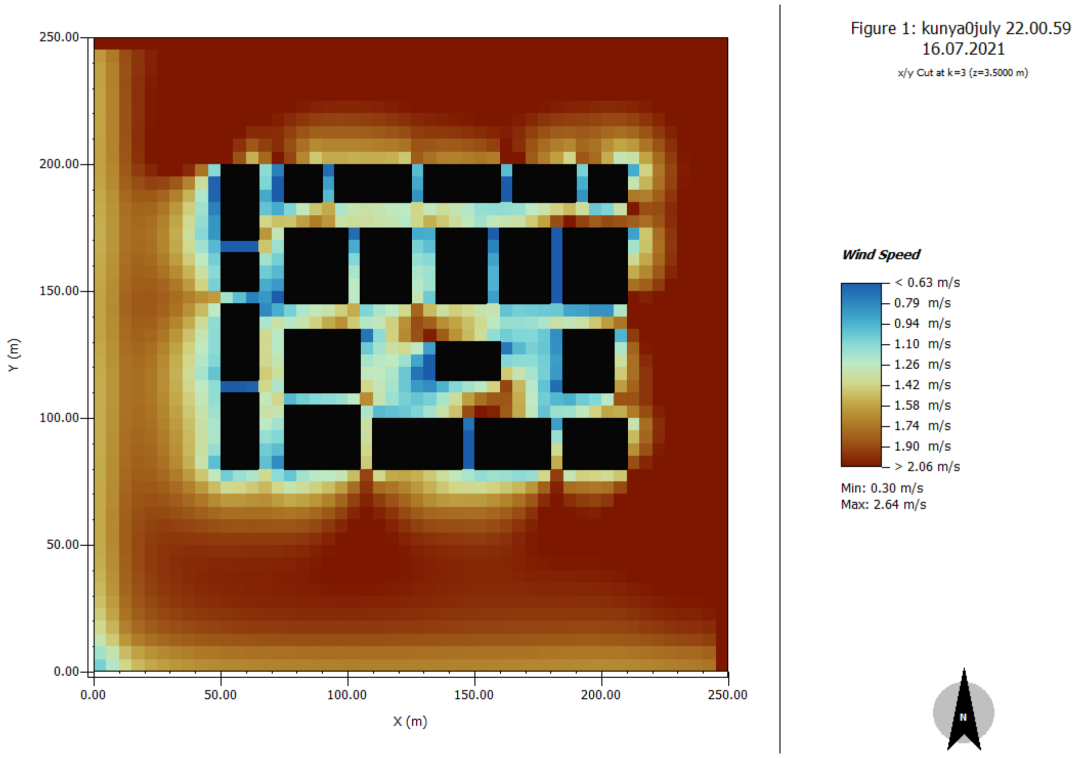


Figure 6.30b: Envi Met output from Leonardo: Wind Speed at 10:00 pm

6.3.10.2 Relative Humidity Analysis

At 6.00 am the relative humidity at Ibrahim Kunya Estate ranged from 88.19% to 92.50%, while at 4:00 pm it fluctuated from 56.96% to 64.92%, and at 10:00 pm from 77.14% to 80.83% (shown in Figures 6.31, 6.31a and 6.31b). The average relative humidity across these time periods was calculated at 76.76%. Moreover, the lowest relative humidity was observed during the afternoon at 56.96%, while the highest was recorded in the morning at 92.50%.

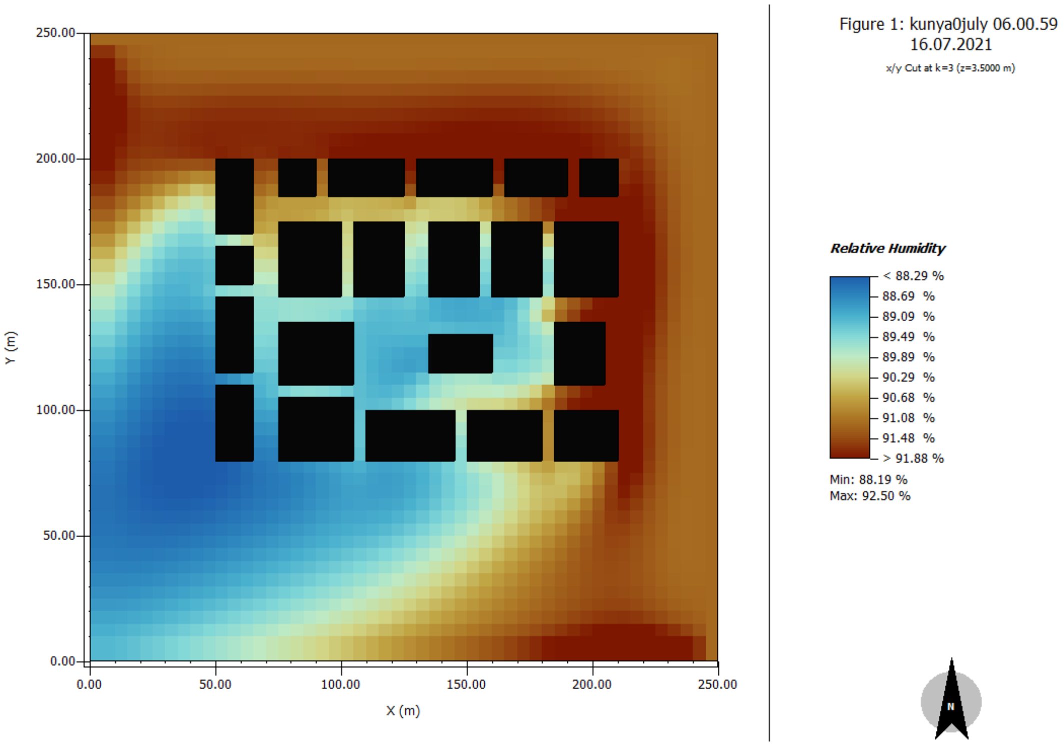


Figure 6.31: Envi Met output from Leonardo: Relative Humidity at 6:00 am

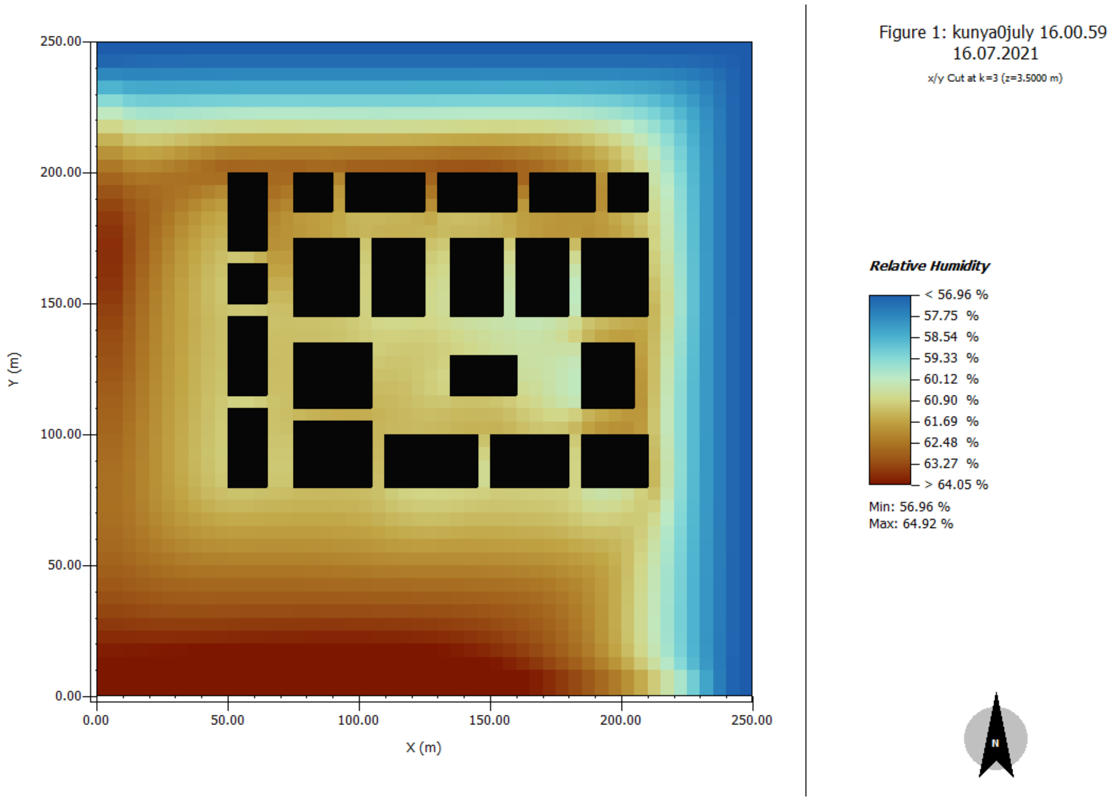


Figure 6.31a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

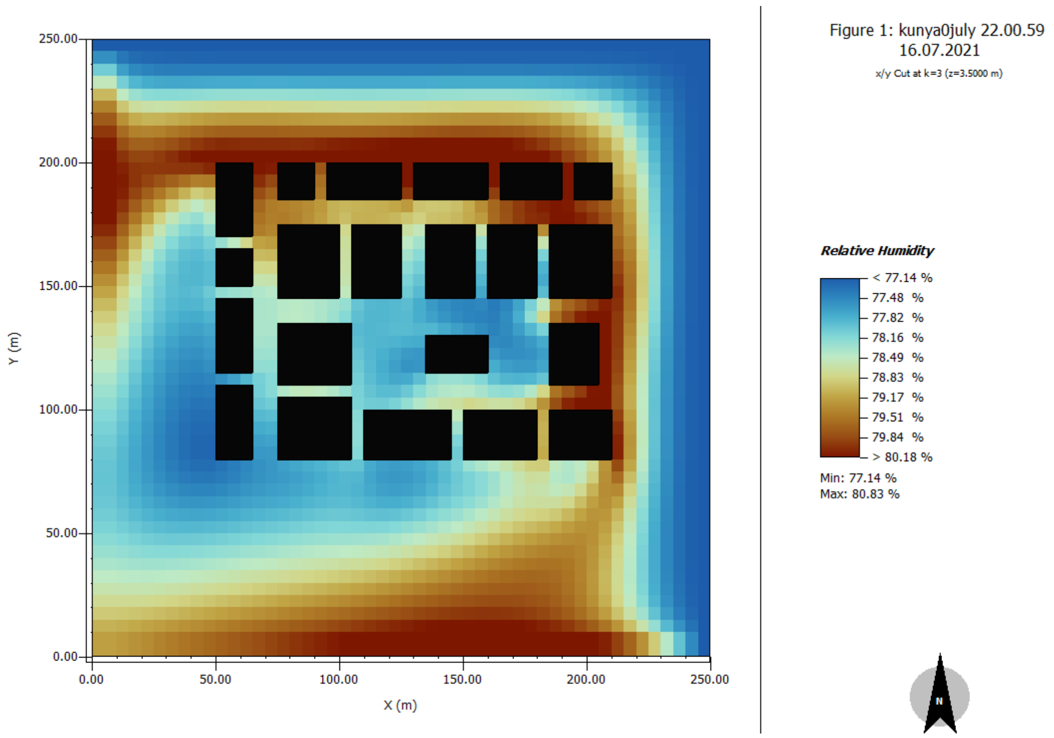


Figure 6.31b: Envi Met output from Leonardo: Relative Humidity at 10:00 pm

6.3.11 The Simulation Outcome of Ibrahim Kunya Estate for 25% Coverage in the Month of July

6.3.11.1 Air Temperature

Air temperatures exhibited discernible variation across the time periods examined. At 6:00 am temperatures ranged from 24.23°C to 24.83°C, although at 4:00 pm the span widened to between 29.68°C and 31.03°C, and at 10:00 pm they varied from 26.66°C to 27.33°C (illustrated in Figures 6.32, 6.32a and 6.32b respectively). The daily mean temperature was calculated at a comfortable 27.39°C while extremes were observed in the afternoon, which registered the highest temperature at 31.03°C, and the evening, which recorded the lowest at 24.23°C.

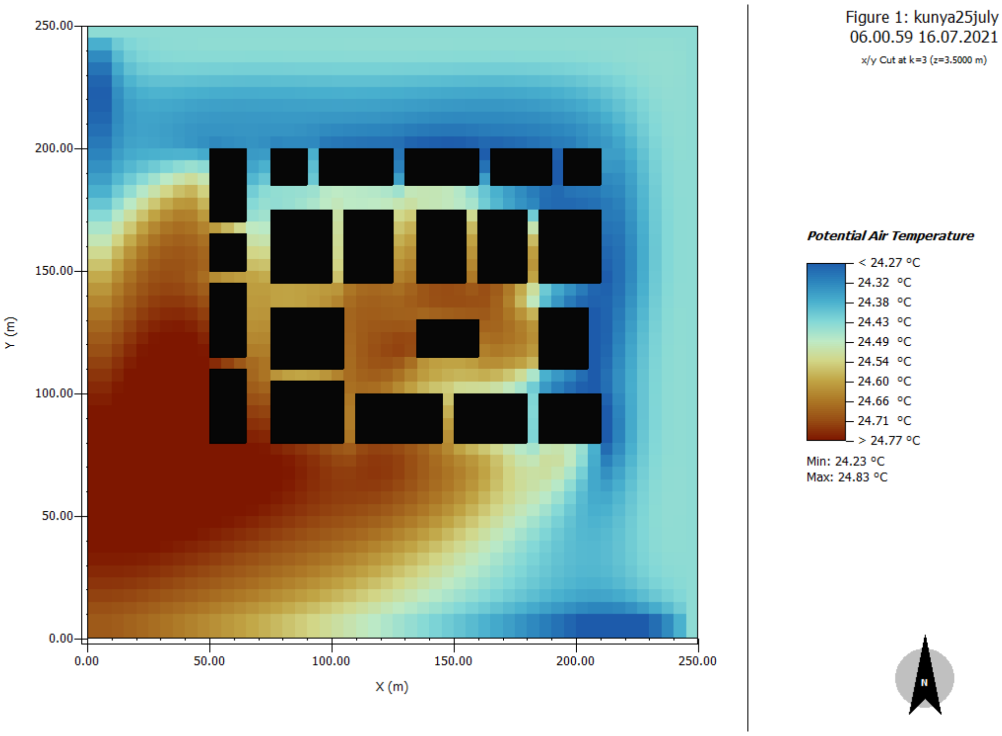


Figure 6.32: ENVI-Met output from Leonardo: Temperature at 6:00 am

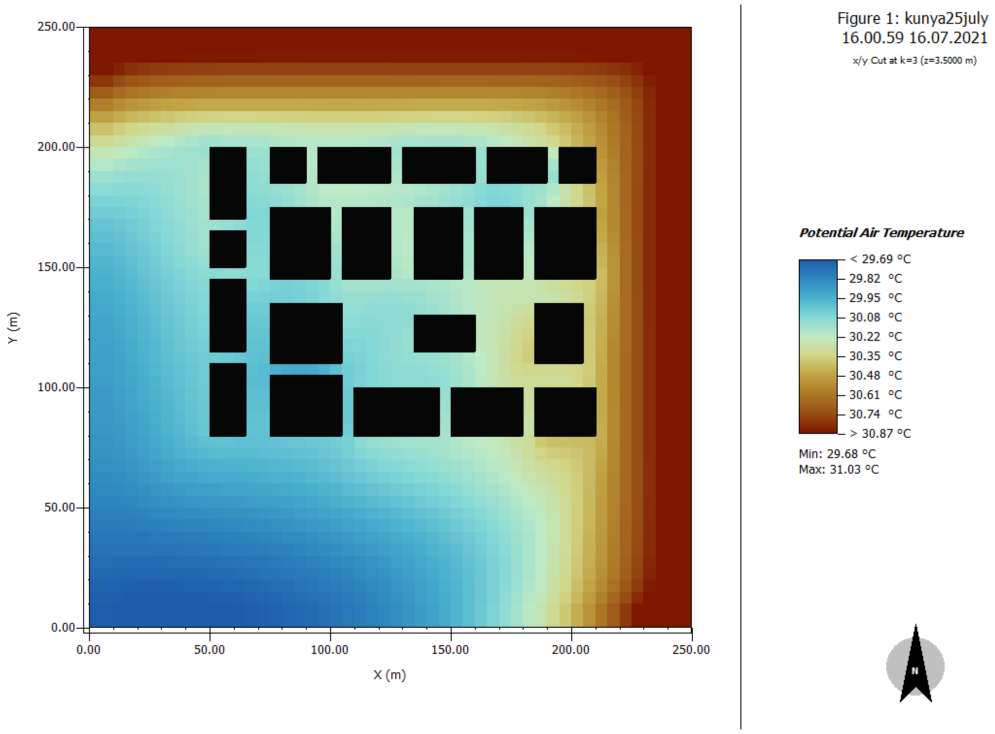


Figure 6.32a: Envi Met output from Leonardo: Temperature at 4:00 pm

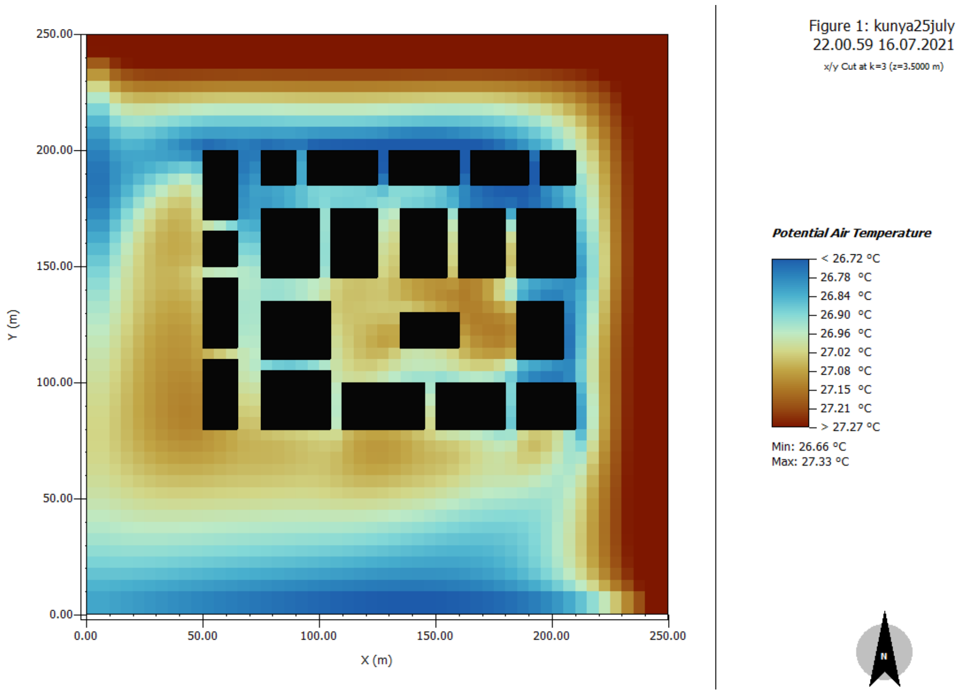


Figure 6.32b: Envi Met output from Leonardo: Temperature at 10:00 pm

6.3.11.2 Wind speed Analysis

Wind speeds exhibited discernible variation across the time periods. At 6:00 am they ranged from 0.29 m/s to 2.33 m/s, which is similar to the reading at 4:00 pm when they varied from 0.33 m/s to 2.77 m/s, and at 10:00 pm when they ranged from 0.30 m/s to 2.64 m/s (illustrated in Figures 6.33, 6.33a and 6.33b respectively). Notably, the areas characterised by a staggered arrangement of buildings experienced a significant reduction in wind speed.

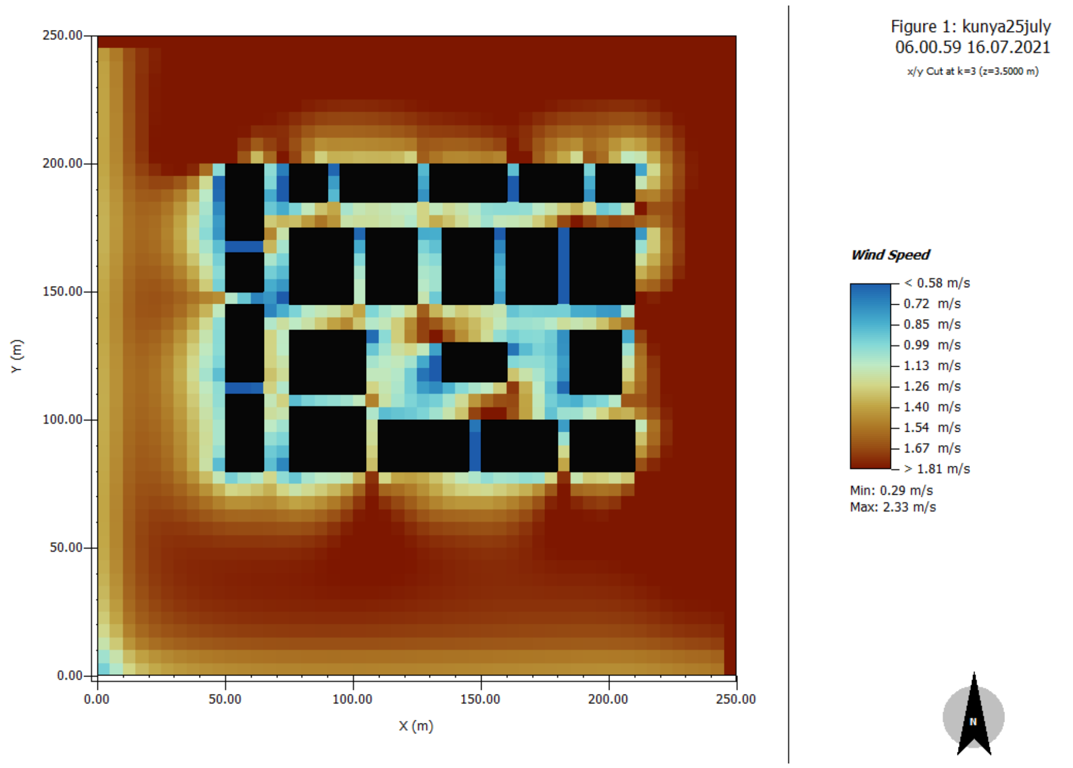


Figure 6.33: Envi Met output from Leonardo: Wind Speed at 6:00 am

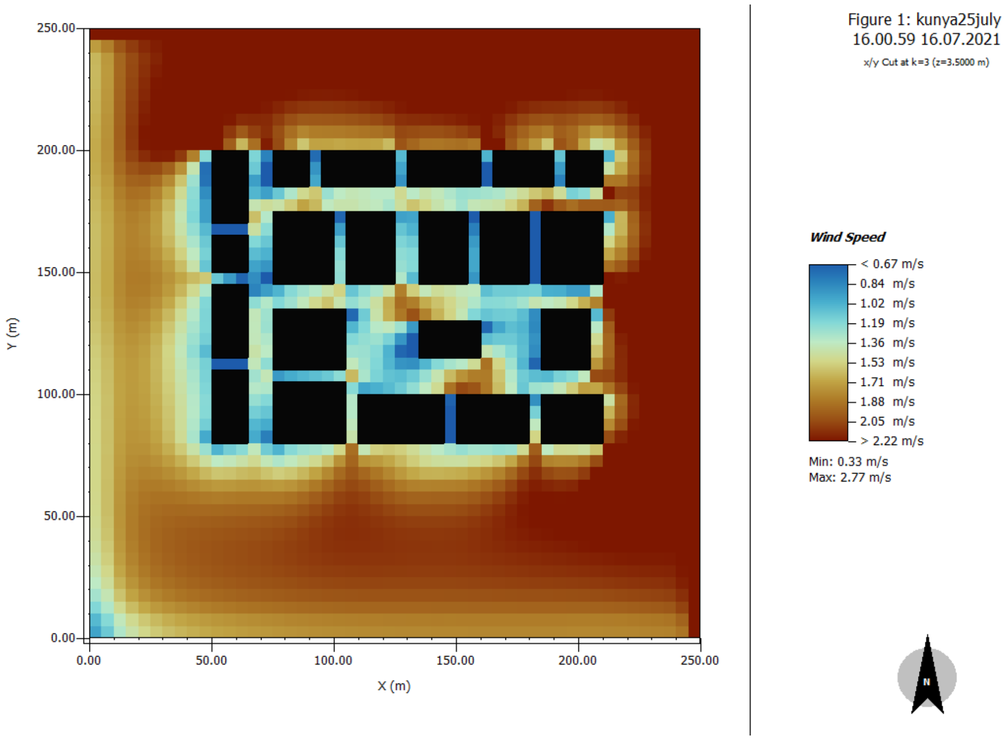


Figure 6.33a: Envi Met output from Leonardo: Wind Speed at 4:00 pm

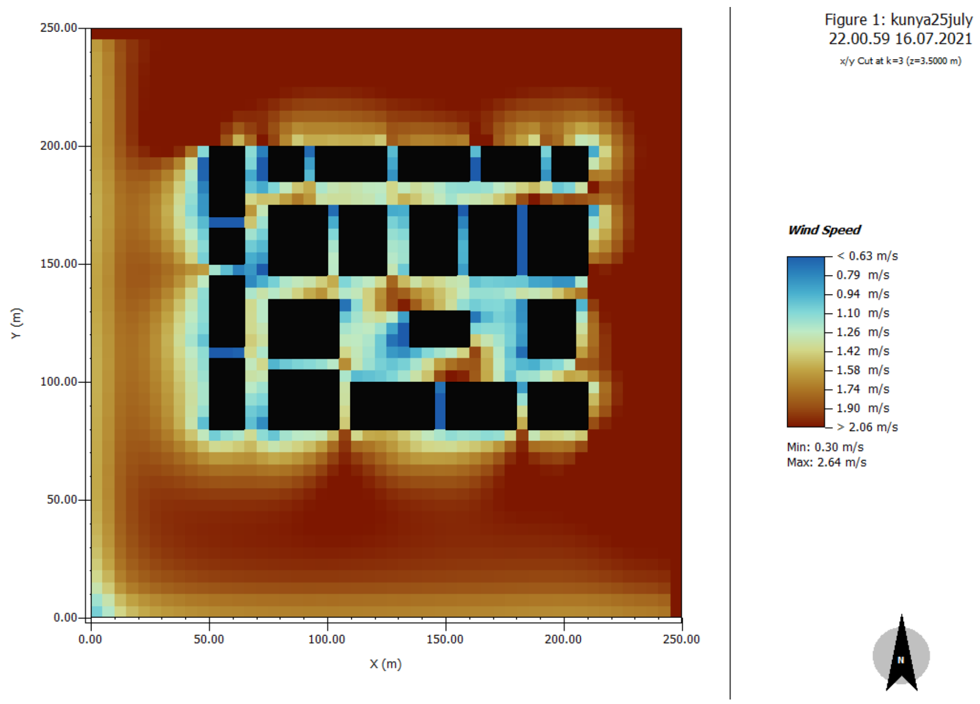


Figure 6.33b: Envi Met output from Leonardo: Wind Speed at 10:00 pm

6.3.11.3 Relative Humidity Analysis

The relative humidity recorded at 6:00 am ranged from 88.20% to 92.50%, and at 4:00 pm from 56.96% to 64.92%, whilst at 10:00 pm it fluctuated from 77.14% to 80.83% (as illustrated in Figures 6.34, 6.34a and 6.34b respectively). The average relative humidity across these temporal points was calculated at 76.76%, although the lowest value was captured during the evening at 56.96%, and the highest in the morning at 92.50%.

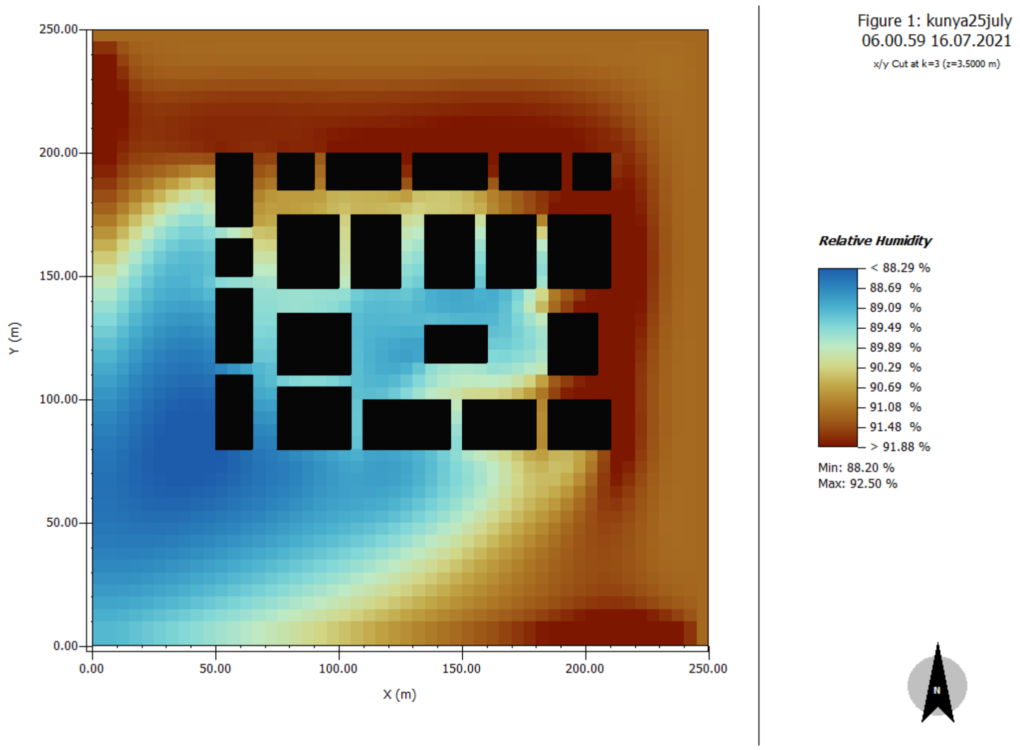


Figure 6.34: Envi Met output from Leonardo: Relative Humidity at 6:00 am

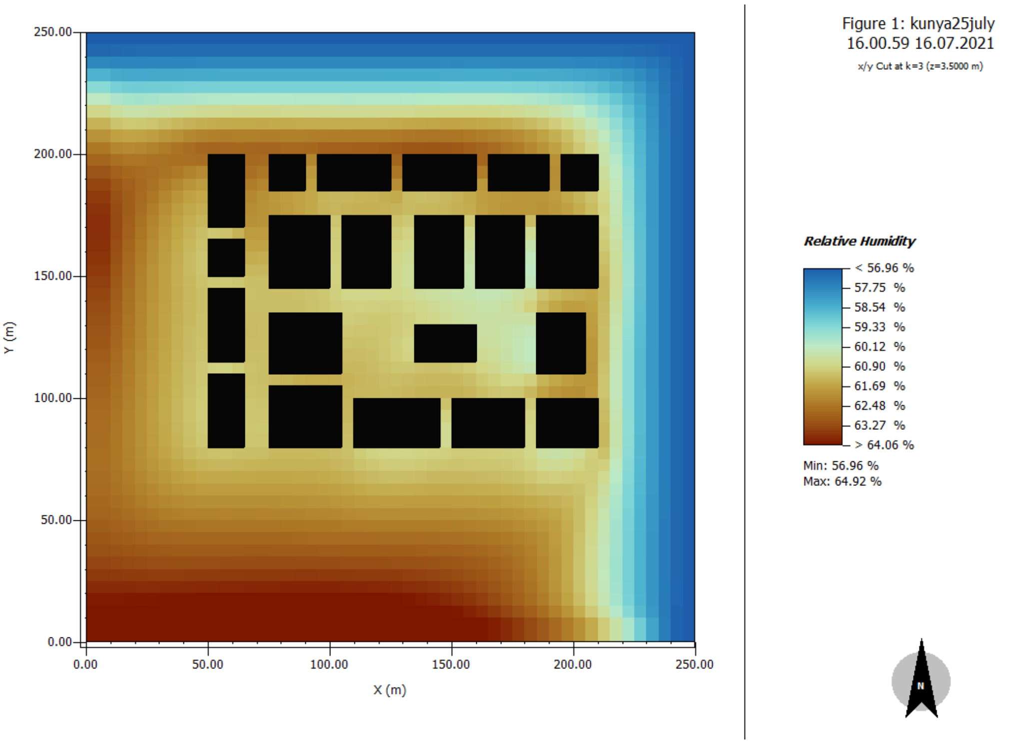


Figure 6.34a: Envi Met output from Leonardo: Relative Humidity at 4:00 pm

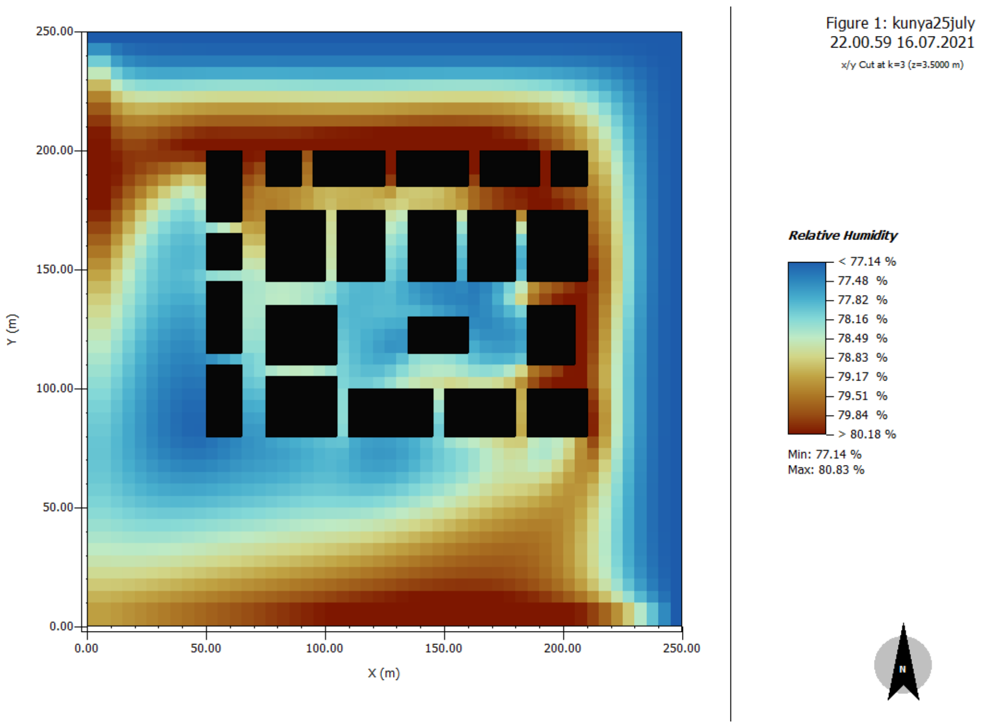


Figure 6.34b: Envi Met output from Leonardo: Relative Humidity at 10:00 pm

6.3.12 The simulation outcome of Ibrahim Kunya Estate for 50% coverage in the month of July

6.3.12.1 Air temperature

Air temperatures fluctuated noticeably across the different time periods. At 6:00 am they ranged from 24.23°C to 24.83°C, while at 4:00 pm they widened to 29.68°C and 31.03°C, and at 10:00 pm they varied from 26.6°C to 27.33°C (shown in Figures 6.35, 6.35a and 6.35b respectively). The daily mean temperature was calculated at a comfortable 27.39°C, although the afternoon registered the highest at 31.03°C and the morning recorded the lowest at 24.23°C.

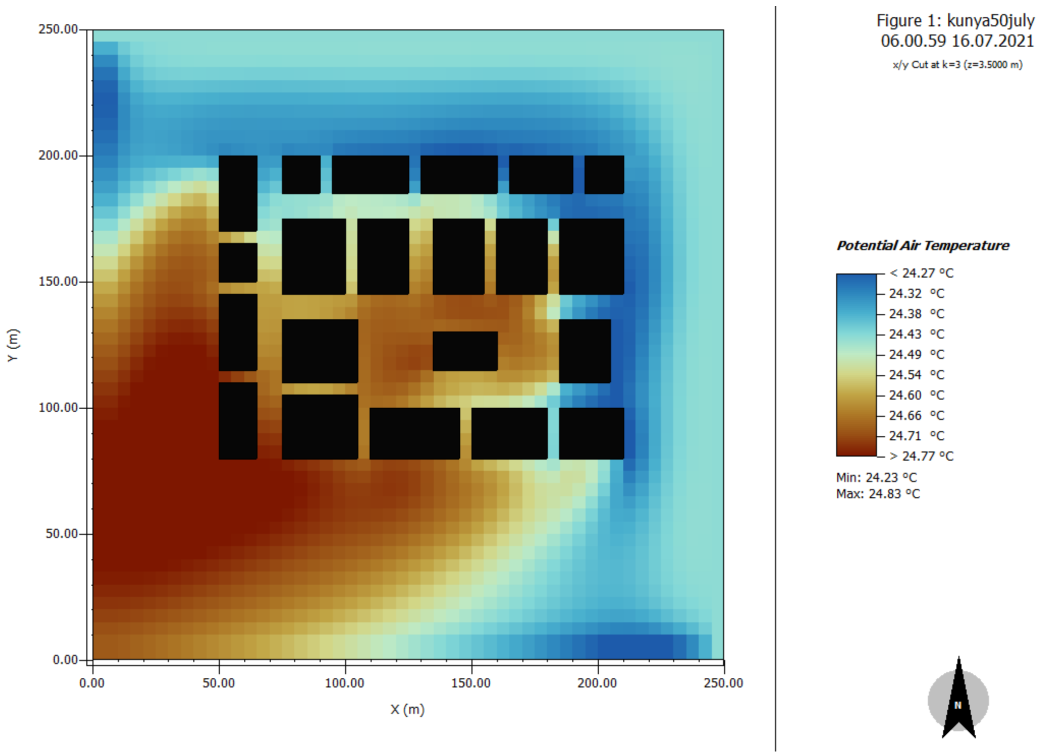


Figure 6.35: Envi Met output from Leonardo: Temperature at 6:00 am

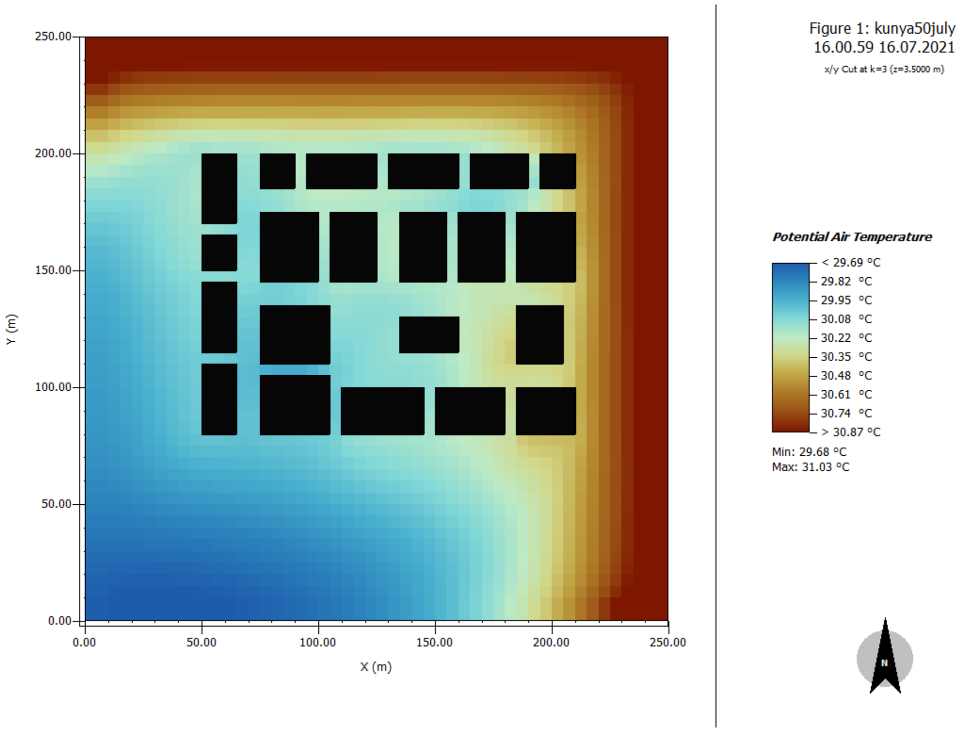


Figure 6.35a: ENVI-Met output from Leonardo: Temperature at 4:00 pm

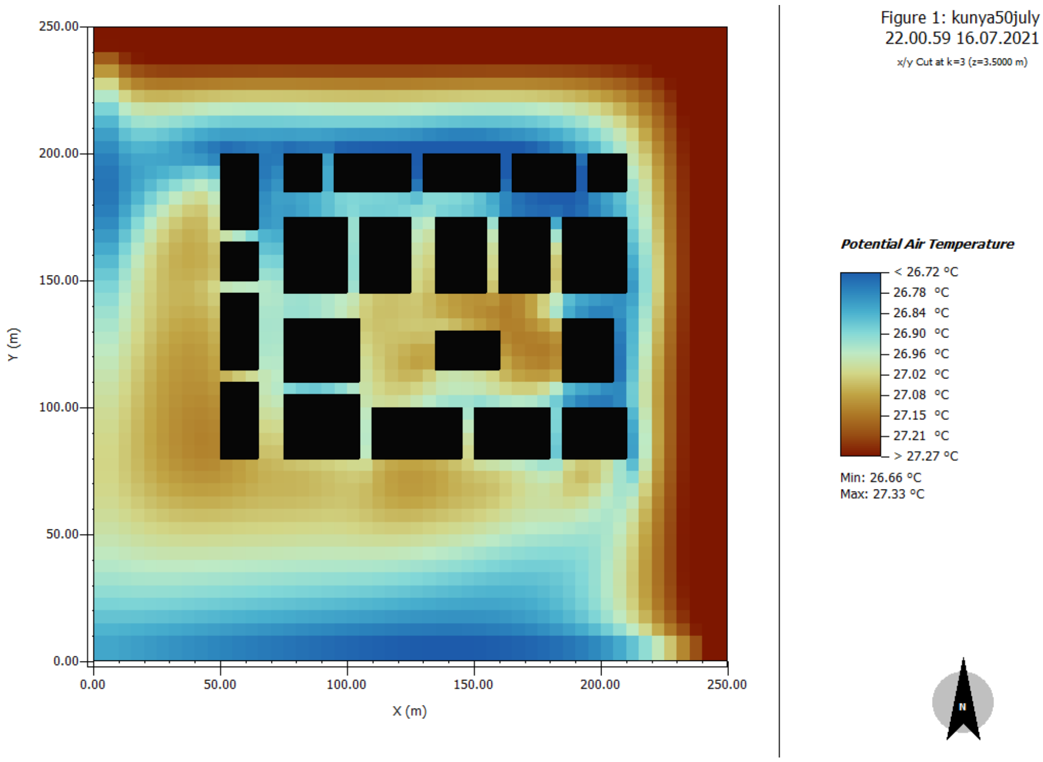


Figure 6.35b: ENVI-Met output from Leonardo: Temperature at 10:00 pm

6.3.12.2 Wind speed Analysis

Distinct variations were recorded for wind speed across the time periods. At 6:00 am they ranged from 0.29 m/s to 2.33 m/s, and at 4:00 pm they varied between 0.33 m/s and 2.77

m/s, whilst at 10:00 pm they ranged from 0.30 m/s to 2.64 m/s (shown in Figures 6.36, 6.36a and 6.36b respectively). In addition, areas characterised by a staggered arrangement of buildings experienced a noteworthy reduction in wind speed.

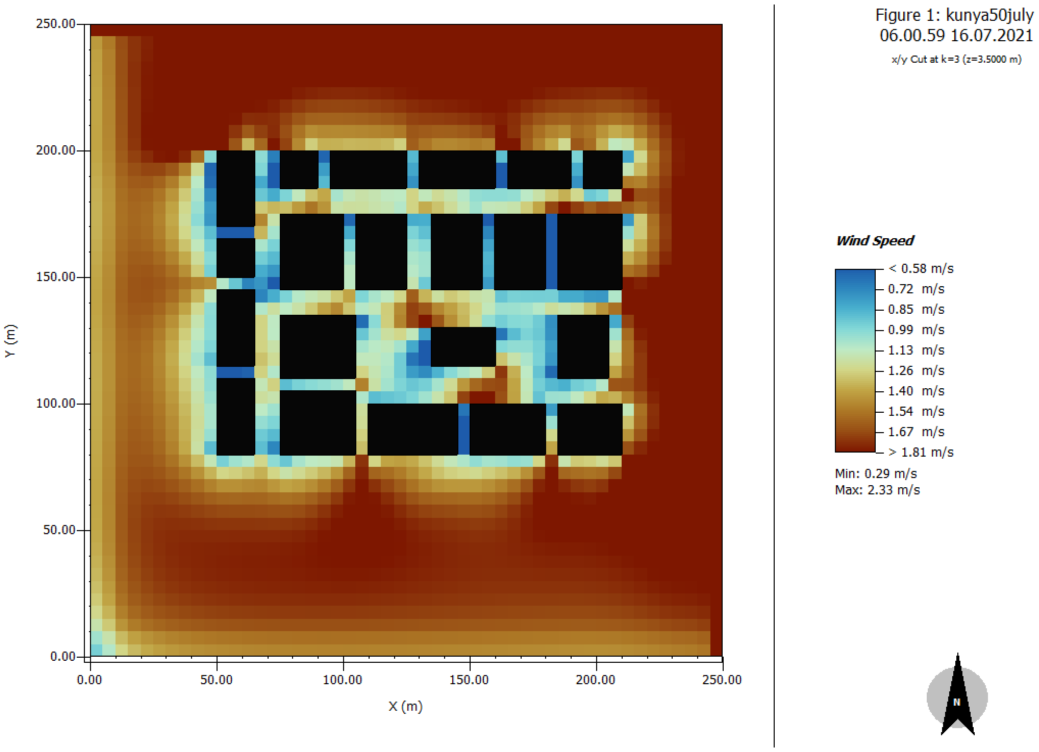


Figure 6.36: ENVI-Met output from Leonardo: Wind speed at 6:00 am

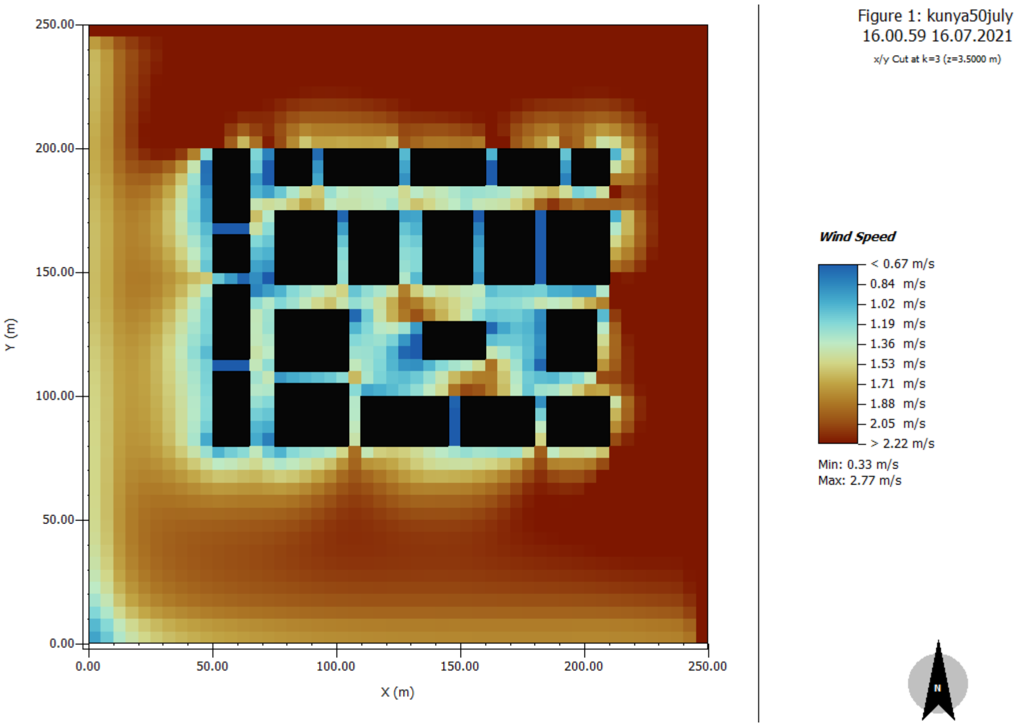


Figure 6.36a: ENVI-Met output from Leonardo: Wind speed at 4:00 pm

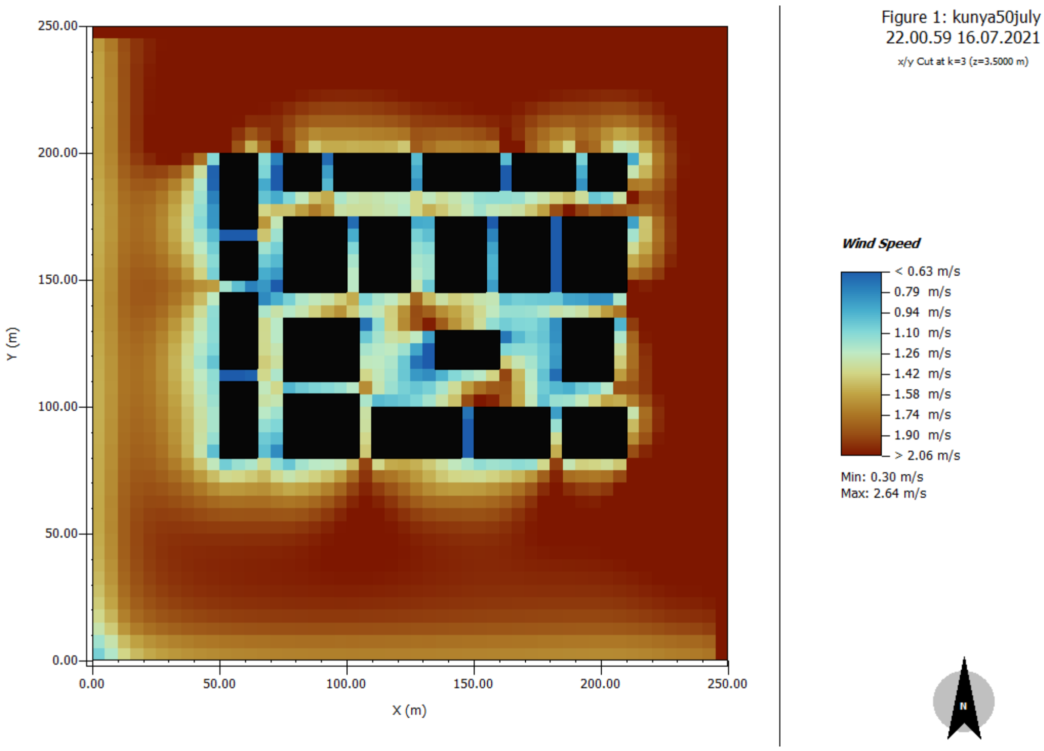


Figure 6.36b: ENVI-Met output from Leonardo: Wind speed at 10:00 pm

6.3.12.2 Relative Humidity Analysis

The relative humidity levels captured for 6:00 am ranged from 88.20% to 92.50%, while at 4:00 pm they fluctuated between 56.96% and 64.92%, and at 10:00 pm from 77.14% to 80.83% (illustrated in Figures 6.37, 6.37a and 6.37b respectively). The average relative humidity across these time periods was calculated at 76.76%, although the lowest was recorded for the afternoon at 56.96%, and the highest for the morning at 92.50%.

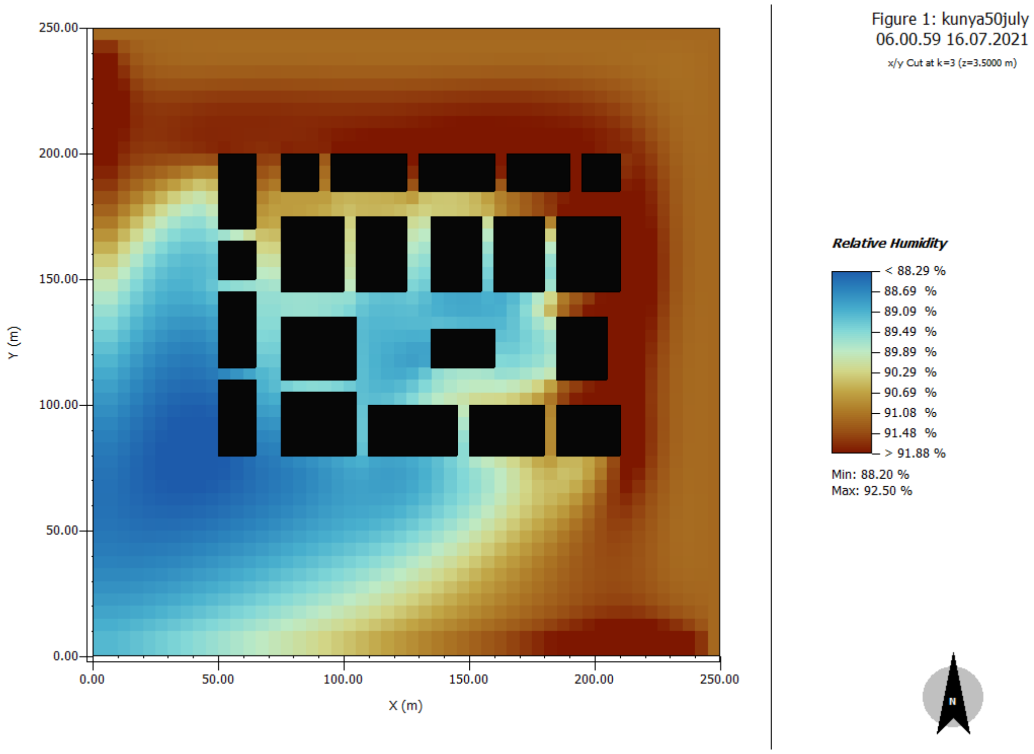


Figure 6.37: ENVI-Met output from Leonardo: Relative humidity at 6:00 am

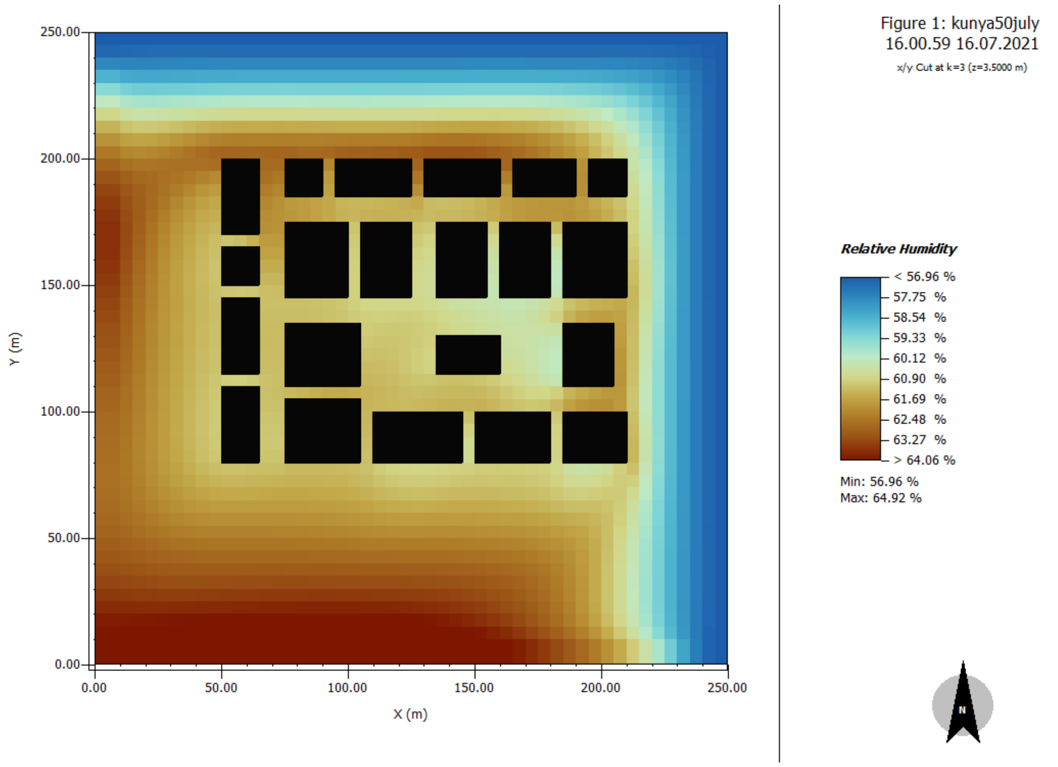


Figure 6.37a: ENVI-Met output from Leonardo: Relative humidity at 4:00 pm

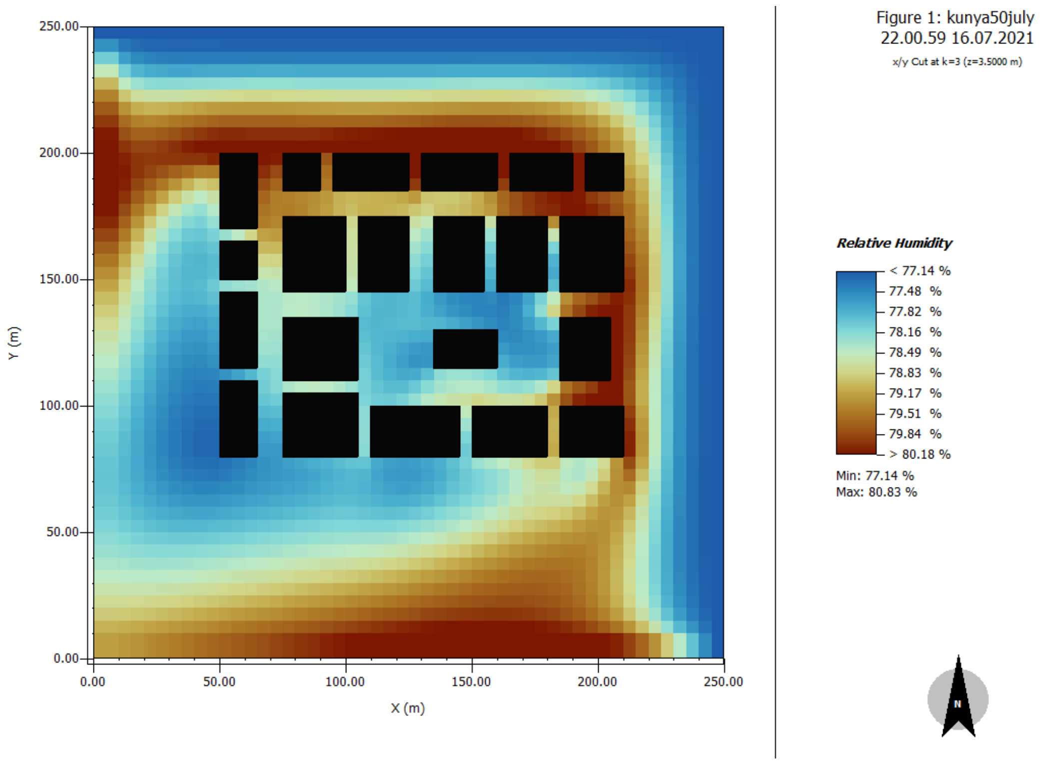


Figure 6.37b: ENVI-Met output from Leonardo: Relative humidity at 10:00 pm

There were no differences in the minimum and maximum temperatures, wind speed, or relative humidity across various percentage coverages throughout the rainy season, which is marked by elevated relative humidity levels. While the readings were recorded under time constraints, it is evident that further investigation is imperative to elucidate the underlying reasons for these consistent results. Despite various degrees of coverage, the variations in climatic parameters during the rainy season emphasise the need for a thorough investigation to determine the mechanisms underlying these patterns. This investigation could provide insightful information about the special interactions between vertical greening and the weather during the rainy season, which could guide future decisions about urban development and environmental management.

6.4 Discussion of Simulation Result

6.4.1 Assessment of Climate Change Mitigation Potential

By drawing insights from the simulation results, this investigation assesses the impact of vertical greening on the microclimate in the semi-arid region of Northern Nigeria. Tian et al. (2014) argued that the distribution, transformation, and removal of pollutants in the atmosphere are greatly influenced by meteorological conditions such as temperature, wind speed, and humidity, which can thus improve air quality. Moreover, elevated temperatures significantly influence the pace of heat-stress-related diseases by expediting the conversion of pollutants, leading to the heightened formation of ground-level ozone in warmer environments (Swamy et al., 2017). Within this simulation, the introduction of vertical greening resulted in a modest temperature decrease. When implemented within neighbourhoods in localised areas, this temperature reduction could yield a perceptible cooling effect in the broader urban landscape. Additionally, lowered temperatures contribute to a lower demand for cooling energy, which reduces the reliance on fossil fuels and helps to mitigate global warming. Furthermore, the integration of vertical greening induced a slight reduction in wind speed. Around the greening, wind speed decreases (Morankinyo et al., 2019) due to physical obstructions from branches and leaves. Turbulence and friction are produced by the wind as it moves through the vegetation, slowing the speed.

Humidity impacts both the process of evaporation and the size and weight of particles in the air. In environments with low humidity (40% RH), such as dry interior spaces, the airborne transmission of diseases is greater compared with humid locations (i.e., > 90% RH) (Ahlawat et al., 2020). Higher humidity can cause particles to grow larger and settle quicker by reducing their concentration in the air. The assessment of relative humidity dynamics in this simulation revealed a marginal increase. The implementation of vertical greening, in conjunction with other urban greening strategies like green roofs, trees, and hedges, could substantially help mitigate the effect of climate change in a semi-arid region. Moreover, while offering shade to buildings and attenuating heat absorption, vertical greening also enhances local biodiversity. Nevertheless, a comprehensive evaluation of climate change mitigation extends beyond numerical outcomes. To effectively address climate change challenges at a local level, a nuanced understanding of the interdependencies among microclimate variations, local resilience, and the broader sustainability implications of vertical greening is imperative.

6.4.2 Impact of Vertical Greening on Microclimate

The simulation results presented in this chapter achieved the objective 'to investigate the impact of vertical greening on the microclimate such as the temperature, humidity, air quality as well as its ability for climate change mitigation'. It is important to note the results from the qualitative data in Chapter 5 are also critical to the study as they are supported by the results of this simulation. Accordingly, the simulation results show the direct influence of the microclimate at different periods of the day and over different seasons for two different estates within the chosen location. The simulation results for the dry season in Kundila Housing Estate show a similar trend with Ibrahim Kunya Housing estate in temperature changes. This suggests a consistent impact by VGS on temperature irrespective of the estate, or period of day or night. In Kundila Housing Estate during the dry season, the absence of vertical greening (VG) at 4 pm resulted in the entire neighborhood's minimum temperature of 25.92°C. Introducing 25% VG coverage led to a decrease to 21.95°C, and with 50% VG coverage, the temperature further dropped to 20.04°C. This data indicates a notable reduction in minimum temperature—specifically, a 3.97°C decrease with 25% VG coverage and a more significant 5.88°C reduction with 50% VG coverage. These findings are relevant to the general neighborhood's minimum temperature, and variations may occur based on specific grid or measurement points. Similarly, at Ibrahim Kunya Housing Estate during the dry season, without VG, the minimum temperature at 4 pm was 26.83°C. With 25% VG coverage, it reduced to 26.82°C, and with 50% VG coverage, it further dropped to 24.40°C. The data suggests a marginal 0.01°C reduction with 25% VG coverage and a more significant 2.43°C reduction with 50% VG coverage. These results are specific to the entire neighborhood's minimum temperature, with potential variations based on measurement points. Despite different in location, the results for this study echoes those of Groeve et al. (2023) which focused on experimental vertical greening in the city of Ghent in Belgium. Their results found that vertical greening helped to reduce incoming solar radiation, and thereby reduced daytime temperatures.

Contrastingly, during the rainy season at both estates, no variations were observed in minimum and maximum temperatures, wind speed, and relative humidity across different VG coverages. Further investigation is crucial to understand these consistent results, emphasizing the need for in-depth analysis during the rainy season. The study may uncover valuable insights into the interaction between vertical greening and climatic conditions, influencing future decisions on urban planning and environmental management in the respective regions.

In addition, the simulation outcomes show a slight change in wind velocity in the simulated environment at zero vertical greening and 25% vertical greening coverage in the dry seasons at Kundila Housing Estate. However, there was a slight decrease in wind speed during the day and a slight decrease at night as the vertical greening coverage increased from 25% to 50%. The decreased wind speed from greater VGS coverage indicates that vertical green systems present an obstacle or deflect the propagating wind, thereby reducing wind speed. While the simulation results agree with some findings amongst the literature on the influence of vertical greening in wind velocity, it was also reported that the VGS could reduce wind speed (Wang et al., 2022; Perini et al., 2011). However, other significant factors include the density of VGS coverage, the nature or porosity of foliage, and the VGS layers. If the vertical greening is porous, the wind speed around it is usually high. Perini et al., (2011).

Nevertheless, during the dry season there were minor changes in relative humidity as the VGS coverage increased from 0% to 25% and 50%; this was evident in the early morning (6:00 am) and at night (10:00 pm). However, the results show that vertical greening does influence relative humidity at all times across any of the coverage categories. During the wet season, the results for the simulation showed that a VGS has no influence on relative humidity nor did it increase with greater coverage. However, the simulation result of the dry season showed that the impact of vertical greening on relative humidity in the semi-arid region of northern Nigeria in agreement with other findings showing some similarities with the United Kingdom (Thomsit-Ireland et al., 2020; De Groeve et al., 2023). This highlights the importance of vertical greening and its impact on relative humidity which is a critical component of any microclimate.

The results from Ibrahim Kunya Estate and those from Kundila Estate indicated the consistency of the tool by showing similar results (due to similar building settings and arrangements although the nature of the buildings differ slightly). Despite small differences, the similarities between the results agree with the findings and are consistent with the qualitative data. This confirms the impact on the microclimate, although it depends on the parameters assessed. Accordingly, the impact of vertical greening on the microclimate has been demonstrated within the simulation results for the selected housing estate settings in Kano. The results present new data for academics and professionals to facilitate further research or utilise the results for decision-making at policy, strategic or operational levels for the semi-arid region of northern Nigeria.

6.5. Summary of Findings

This chapter has described the methodology employed to simulate the microclimates, which forms an important aspect of the investigation into the impact of vertical greening on the microclimate in the semi-arid region of Northern Nigeria. The data collection, modelling, and analysis procedures played a crucial role in assessing the potential for vertical greening on the urban microclimate and its climate change mitigation potential. However, after simulating the microclimate this chapter evaluated the impact of various levels of vertical greening coverage (0%, 25% and 50%) on the microclimate in the dry and wet seasons of 2021. The findings derived from this simulation indicated the performance of certain parameters in the microclimate (relative humidity, temperature, and wind speed) in relation to vertical greening. The morning and then the night periods recorded the coolest and second coolest temperatures, while the afternoon period recorded the warmest. Therefore, this chapter has demonstrated the impact of vertical greening on temperature, humidity, and wind speed by specifying the difference in each simulated parameter. Thus, the presence of vertical greening led to a slight decrease in temperature in some instances and negligible decrease in other instances which agrees with several existing studies in this field (Eumorfopoulou & Kontoleon, 2009; de Jesus et al., 2017; Wakui et al., 2007; Blanco et al., 2017; Alexandri & Jones, 2008). In addition, Koch et al. (2022), Jimenez (2021), Cuce (2017), Schettini (2018) and Brown (2008) affirm that the cooling effect of vertical greening on buildings and street level poses a beneficial mitigation and adaptation strategy for climate change. According to Pugh et al. (2012) there seems to be a higher deposition of nitrogen oxide (N02) and particulate matter (PM) on vegetation, which leads to improved air quality around vegetation. In this study, the presence of vertical greening led to a slight increase in relative humidity, which agrees with the findings by Proova et al. (2020), although the degree of change is quite small. A large amount of coverage and the integration of other forms of urban greening is recommended to create a greater impact.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This study investigated the feasibility of vertical greening as a sustainable approach to mitigate the effects of climate change and influence the microclimate of the streetscape in Northern Nigeria and similar semi-arid regions. The study formulated five relevant research inquiries - outlined in the introduction chapter - to explore the distinctive meteorological challenges associated with the region which is impacted by the effects of climate change. The inquiries functioned as navigational indicators, directing the research towards the study's specified objectives. This chapter provides the conclusion to this investigation by answering the research questions which inspired the study. It summarises the conclusions from the research process by outlining the results and contributions to knowledge. In addition, the chapter outlines the constraints encountered throughout the research process and provides practical advice for the successful implementation of vertical greening in Nigeria and similar semi-arid regions. This advice is designed for a range of professionals, encompassing policy makers, urban planners, and architects, and estate agents. The chapter also offers suggestions for further research in this field. Thus, the chapter structure comprises four main sections: an overview of the research objectives and findings; an analysis of the contribution to knowledge; recommendations for future study; and the study's limitations.

7.2 Review of the Research Objectives

The potential for implementing vertical greening as a nature-based solution is gaining popularity in Europe and other parts of the world, partly due to its importance as a climate change mitigation measure. However, the minimal implementation of vertical greening initiatives in sub-Saharan Africa is notable. Furthermore, there is limited research on vertical greening and insufficient data on its implementation in semi-arid regions, including Northern Nigeria, which prompted this research.

This study's primary aim was to investigate the viability of vertical greening as a sustainable approach to mitigate the effects of climate change and influence the microclimate of the streetscape in Northern Nigeria and similar semi-arid regions. It was successfully achieved through five objectives:

(i) Evaluating the impact of vertical greening on the ecological and visual appeal of the urban environment in Northern Nigeria and other semi-arid regions.

(ii) Identifying suitable plant species for vertical greening in the semi-arid region of Northern Nigeria.

(iii) Evaluating the factors that impact the integration of vertical greening in the semi-arid region of Northern Nigeria.

(iv) Investigating the impact of vertical greening on the urban microclimate, namely temperature, humidity, and air quality, and its ability to mitigate climate change.

(v) Providing guidance for policy makers, urban planners, Estate agents and architects on how to successfully implement vertical greening in Northern Nigeria and other semi-arid regions.

Chapter one introduced the study and established the framework by providing relevant background information, the rationale, and the wider context of the study. Chapter 2 provided evidence to address each objective by exploring the specific climatic characteristics of the semi-arid region and situating the study within the wider academic context. Chapter 3 analysed the theoretical framework in relation to theories that addressed the integration of vertical greening in buildings in semi-arid regions. Specifically, it addressed the concept of sustainability and the human environment system. Chapters five and six provided empirical data from interviews and microclimate simulations, respectively. The findings were analysed against the study's objectives and existing body of literature. This chapter summarises the essential qualities of the study, presents the key findings, and relates them to the overall aims, objectives, and research questions. This chapter not only concludes the study, but also broadens its scope to include recommendations, acknowledgments of the limitations, and a path for future research. Essentially, it provides a unified and comprehensive overview of the entire research process.

7.3 Summary of Major Findings of the Study

Major Findings

1. **Reduction of Temperature:** Vertical greening consistently reduces temperature in urban areas with increased percentage coverage as suggested by stakeholders and confirmed by ENVI-Met simulations.
2. **Enhanced Cooling and Thermal Comfort:** Stakeholders reported improved thermal comfort due to vertical greening while simulations showed significant cooling effects, corroborating qualitative data.
3. **Improved Air Quality and Humidity Levels:** Vertical greening positively impacts air quality and relative humidity as observed across different scenarios and times of day.
4. **Ecological and Aesthetic Enhancement:** Vertical greening enhances the ecological and visual appeal of urban environments adding distinctive features that connect with environment making urban areas more pleasant.
5. **Impact on Wind Speed:** Vertical greening influences wind speed, varying by situation and time of day affecting the overall microclimate.
6. **Challenges in Implementation:** Barriers include lack of community awareness, water scarcity, high costs, and poor policy implementation and difficulty in selecting appropriate plant species due to specific regional climatic conditions.

7. **Importance of Plant Selection:** Choosing plant species with traits like drought tolerance and adaptability is crucial. Proper selection tailored to the region's climate can maximize the benefits of vertical greening.

The objectives of the study were achieved in part through an extensive literature review to establish research gaps and findings from existing empirical data. Furthermore, qualitative data from interviews and quantitative data from a simulation were generated and analyzed. Findings from the qualitative data analysis indicated that all stakeholders agreed that vertical greening offers unequivocal benefits, including the reduction of temperature, enhancement of cooling, and improvement of thermal comfort. Furthermore, stakeholders stated that it plays a role in mitigating the intensity of weather phenomena, enhancing the ecological and aesthetic appeal of urban environments, and adding distinctive visual features which connect with the neighborhood and make the urban environment more pleasant. In addition, vertical greening has a wider influence on microclimate, positively impacting air quality, humidity levels, and the general environmental conditions of metropolitan areas. The results - echoed by microclimate simulations conducted across different scenarios - support the effectiveness of vertical greening in establishing a more sustainable and comfortable urban environment. However, qualitative data revealed that the effect of VGS on the microclimate can vary depending on factors such as plant type. Nevertheless, the extent of the influence requires further investigation to ascertain the level and type of influence. The selection of plant species is a crucial factor, with particular emphasis on traits like drought tolerance and adaptability which should be tailored to the specific climatic conditions of the region. Some of the barriers or challenges mitigating the successful implementation of VGS in the semi-arid region of Northern Nigeria include a lack of awareness of its benefits within the community, a lack of sufficient water for plants, the high cost of initial installation and maintenance, difficulties in the selection of appropriate plant species, and poor policy implementation.

In addition, findings from the quantitative investigation using the ENVI-Met microclimate simulation tool showed that vertical greening consistently affects the microclimate of the semi-arid region of northern Nigeria, regardless of the particular location (in this study, in the different housing estates). The study shows that when vertical greening increases, the temperature in the chosen area decreases. Furthermore, it is evident that vertical greening affects variables like wind speed and relative humidity, which change depending on the situation and time of day. These results are consistent with the qualitative data, which indicates a relationship between microclimate dynamics and vertical greening. The findings of the research offer important contributions to well-informed decisions on sustainable development, urban planning, and climate change mitigation.

7.4 Implications for this Research

This research conducted analysis the implementation of vertical greening in the semi-arid region of northern Nigeria. It offered an understanding from professionals and stakeholders in the built environment on the implementation of VGS in the region. The unique climatic conditions of the semi-arid region largely affect the environment and microclimate, thereby influencing the choice of plant species, and the arrangement of vertical greening patterns. In addition, the deforestation of northern Nigeria and the need to encourage afforestation also prompted this research. Further research into the assessment of VGS as a critical tool for mitigating or minimising the impact of climate change in the semi-arid region of Northern Nigeria would boost the country's capacity for more sustainable approaches to environmental protection. Additionally, understanding the impact of vertical greening would also enhance the performance and impact across several aspects of the built environment.   Accordingly, this research has a range of implications for building professionals, a positive impact on the environment, and improved building functionality and policy.

7.4.1 Contribution to Knowledge

Considering the limited research on vertical greening and its implementation in the semi-arid region this study generated additional empirical data on Northern Nigeria. The work focused on northern Nigeria with its two distinct annual seasons: the dry season has extreme temperatures and wind while the wet season has scant rainfall at some points and heavy rainfall leading to flooding at others. Compared with temperate climates or other areas in Europe, these climatic conditions and seasons present a difficult terrain for the survival of common plant species in vertical greening. This may explain the insufficient research and limited data on the semi-arid region of Northern Nigeria. While there are increased concerns to address the challenges of desertification in this region, there is minimal effort and existing gaps in the development and implementation of nature-based solutions like vertical greening to mitigate the impact of climate change in this region. Hence, this research provides data to fill these gaps. The findings from these investigations reveal that vertical greening in the semi-arid region of Northern Nigeria offers significant benefits. These findings align with the study by Rupasinghe and Halwatura (2020) and contribute new knowledge to the impact of vertical greening in Northern Nigeria, a region where such documentation has been previously lacking.

It is important to highlight that the findings from this research have highlighted the impact of vertical greening on the environment and microclimate, and the challenges to implementing VGS in the semi-arid region of Northern Nigeria. Some challenges include the high cost of installing and maintaining VGS, and the lack of understanding and knowledge of the benefits of this system. Furthermore, the findings from this research identified key research gaps concerning suitable plant species, the microclimate, and the sustainability of the environment.

The study has contributed to knowledge on research into appropriate plant species for VGS, and found that most drought tolerance plants and species with the highest survival rates in extreme weather conditions (high temperature and relative humidity) are suitable. Furthermore, this research also revealed that the adaptability of plant species to different seasons of the year is a critical factor in the selected region. These findings offer valuable data for the academic body of knowledge, and the study provides insights into appropriate plant species for the implementation of VGS in semi-arid regions of northern Nigeria.

In addition, the impact of the microclimate - specifically the influence of temperature, wind speed, and relative humidity - provided useful quantitative data. Alongside generating new data sets peculiar to the semi-arid region of Northern Nigeria, the quantitative results is in agreement with the qualitative data from this study, and findings from previous studies. Hence, the deliverables from this research will contribute to the existing body of knowledge for researchers, and academia, and the recommendations will be useful to institutions, the Nigerian Government, and other stakeholders in the building industry.

7.4.2 Contributions to Practice

This research provides valuable empirical data which address a gap in knowledge, and contribute to the practices of professionals including architects, urban planners, estate owners, landscape architects, horticulturists, and governments. The developed framework is an outline of assessment and planning, design and implementation, policy and regulation, monitoring and evaluation, community engagement as discussed in the stakeholders' views on the implementation of vertical greening. For example, the study has examined vertical greening as an innovative and sustainable tool to: regulate the temperature in and around buildings and the environment, enhance local aesthetics, and attract visitors to boost tourism and therefore the economy. For urban planners, the study has provided additional knowledge on the inherent benefits of nature-based solutions such as vertical greening in the design of cities. For architects, it highlights that sustainable and energy-efficient buildings can be enhanced by the implementation of vertical greening alongside a building's ecological and visual appeal, its effect on the urban microclimate, and its possible mitigation of some of the negative impacts of climate change.

In addition, the findings from this research provide valuable information for the government and policymakers - as critical stakeholders - on the opportunities and challenges associated with vertical greening in semi-arid regions such as Northern Nigeria. This study has shown that vertical greening offers a measure to address the challenges of climate change in Nigeria and contribute to the attainment of the UN's SDG. It was further noted that the absence of policy and regulatory frameworks on nature-based solutions like vertical greening constitutes a gap that the Nigerian government should address to ensure the achievement of the SDG. The study also highlighted the challenges of vertical greening in the semi-arid region of Northern Nigeria including the high cost of implementation, the lack of awareness amongst critical stakeholders of the benefits of VGS, and difficulties in choosing appropriate plant species. Addressing these challenges would have a direct positive impact on the environment and stakeholders, and offer several other benefits. Given the aforementioned, it is evident that this research has significantly contributed to practice by identifying the benefits for critical stakeholders, namely professionals, communities, government and academia.

7.5 Recommendations from the Study

This research investigated vertical greening as a potential strategy to help mitigate the effects of climate change and impact the microclimate of the streetscape in Northern Nigeria and other semi-arid regions. All research objectives were achieved through the generation of qualitative and quantitative data sets, and the findings answered the research questions. Consequently, it is important for future work to consider practical studies and to conduct further simulations to validate the findings. Accordingly, the following are key recommendations from the findings of this research:

1. Policy interventions that support and encourage vertical greening projects should be created and implemented by government agencies and legislators. These might involve integrating VG into frameworks for urban planning, offering financial incentives, and ensuring regulatory assistance.
2. Programmes should be launched to develop community awareness, and public education campaigns should be aimed at local government officials as well as the general public to highlight the advantages of vertical greening. Community involvement is extremely important to overcome resistance and ensure effective implementation. As such, small-scale demonstration projects could be implemented to provide the local community with real-world examples demonstrating the advantages of vertical greening. These initiatives may serve as catalysts for broader, more extensive adoption, and should be supervised by a monitoring and evaluation system over an extended period of time to develop significant insights into the projects' long-term effects. This could help the field of sustainable urban development evolve and provide insights for future initiatives.
3. Funding for vertical greening initiatives and the implementation of sustainable water management techniques should be carefully allocated to address resource constraints. Resource mobilisation can be aided by cooperation between the public and private sectors, as well as Non-Governmental Organisations (NGOs).
4. It is imperative to carry out more studies on plant species, irrigation methods, and maintenance strategies which are appropriate for semi-arid regions. Research collaborations between universities, government organisations, and business associates could add to the growing body of knowledge.

5. Skills to execute and maintain vertical greening initiatives should be improved through the establishment of training programmes for architects, urban planners, horticulturists, and members of the local community.

7.6 Limitations of the Study

This study has several contextual and methodological limitations, which highlights the need for more research in this field. Although a range of nature-based solutions exist, the scope of the study was limited to vertical greening - or VGS - to ensure an exclusive approach. Thus, research into other complementary, important areas are also considered necessary to fully understand the impact of such solutions in mitigating the effects of climate change.

One of the main strengths of the research was the qualitative data generated from semi-structured interviews with professionals associated with VGS and working with government parastatals and private firms in the building industry and urban planning. Their participation provided invaluable data which helped to achieve the research objectives. However, the exclusion of the senior management staff of the government parastatals responsible for the development and implementation of legal and regulatory frameworks as well as direct end users or citizens was considered a limitation.

In addition, the restriction of movement in the early days of this research due to the COVID-19 pandemic meant limited direct contact with some of the respondents. Furthermore, there was a time constraint on the conduct of the practical aspect of this research. For example, the growth of selected plants requires sufficient time to ensure effective monitoring and reporting. This would provide an environment for appropriate long-term assessment, and a greater understanding of the findings from the qualitative analysis.

It was important to note that the microclimate simulation was undertaken after the qualitative analysis using the ENVI-Met tool; this provided invaluable data, enriched the quality of the research, and supported the qualitative data. However, due to time constraints, other findings from the qualitative analysis could not be tested using models or simulation tools. Hence, these could be considered critical areas for future research.

7.7 Scope for Further Studies Several factors were considered for further study. This study suggests that further research is necessary in crucial areas to improve the comprehension and implementation of vertical greening, and encourage sustainability. Thus, the following are potential areas of future research:

1. Practical research could be conducted in specific locations of the selected region to examine how different plant species impact the microclimate. Such research could also consider different factors, scenarios, and parameters, and compare different vertical greening positions and urban contexts, while extending the monitoring periods for long-term impact assessment.
2. Using appropriate simulation models or applications, future research could consider the simulation of various identified plant species which are compatible with the climatic conditions of semi-arid regions in Northern Nigeria. This might involve testing various parameters and scenarios across the two - wet and dry - seasons. The results of such research could validate the qualitative analysis of this research, and thereby enhance the quality of the data.
3. Future studies could gather qualitative data from a wider range stakeholders, by including the senior management staff of both government and private organisations responsible for policy development and implementation, academics with knowledge of vertical greening, and end users. This would ensure more comprehensive insights into the implementation of VGS which could enrich the findings and facilitate better informed decisions.
4. The social and economic aspects of vertical greening could be investigated to develop a more holistic view of its direct and indirect impacts. This would provide a better understanding of the implementation of initiatives with long-term social and economic benefits.
5. Innovative or cutting-edge technologies could also be investigated to enhance the performance of vertical greening in the semi-arid region of Northern Nigeria. This could include issues relating to the design and implementation of VGS, enhancements to the irrigation process (to address the challenges of insufficient water), and a more sustainable approach to enhance the system.
6. Research could be conducted into the governance framework and existing efforts to implement and adopt VGS in the semi-arid region of Northern Nigeria. This

would provide an insight into current work with a view to proffering solutions to improve VGS implementations in the future.

7. An investigation and comparative study of the implementation of VGS could be conducted in all climatic regions in Nigeria. Data from the proposed research could offer a better understanding of the challenges, prospects, benefits and gaps, with a view to providing a comprehensive framework to the Government and professionals to facilitate the adoption of VGS across all regions in Nigeria.
8. As the implementation of VGS is a vital part of the nature-based solutions to address climate change, research could be conducted into its viability as a mitigation measure or tool in semi-arid regions. Results from the proposed research could guide policymakers, stakeholders, and governments towards informed decisions that facilitate the efforts of nations to meet their global commitments on climate action and the UN's SDG.
9. Future research could investigate the impact of VGS on the performance of buildings or building functionality and its use as a viable tool for sustainable housing in semi-arid regions. The results from such research could offer solutions and guidance towards energy efficiency, enhanced building performances and environmental protection thereby moving towards a more sustainable housing regimen.

7.8 Conclusion

This study explored the complex dynamics of the implementation of vertical greening and its major impact on the urban microclimate in Northern Nigeria's semi-arid region. By combining qualitative findings from interviews with quantitiative data from microclimate simulations, the study provided a better understanding of the advantages of vertical greening, which include reduced temperatures, increased biodiversity, better air quality, and aesthetically pleasing environments. Results highlighted the significance of context-specific factors, especially when choosing plant species for vertical greening systems. The findings also recognise the critical role that drought tolerance plants have in the semi-arid region. This study highlights the necessity for customised, region-specific methods while also illuminating the immediate benefits of vertical greening as nations face the ongoing, changing challenges of urban expansion and climate change. Such challenges call for further research and an integrated approach to urban planning, to promote sustainable environments that complement the climate peculiarities of every place. Conclusively, the process of comprehending and harnessing vertical greening's potential is nonetheless continuous, and presents a viable path toward building robust, aesthetically appealing, and environmentally vibrant urban environments.

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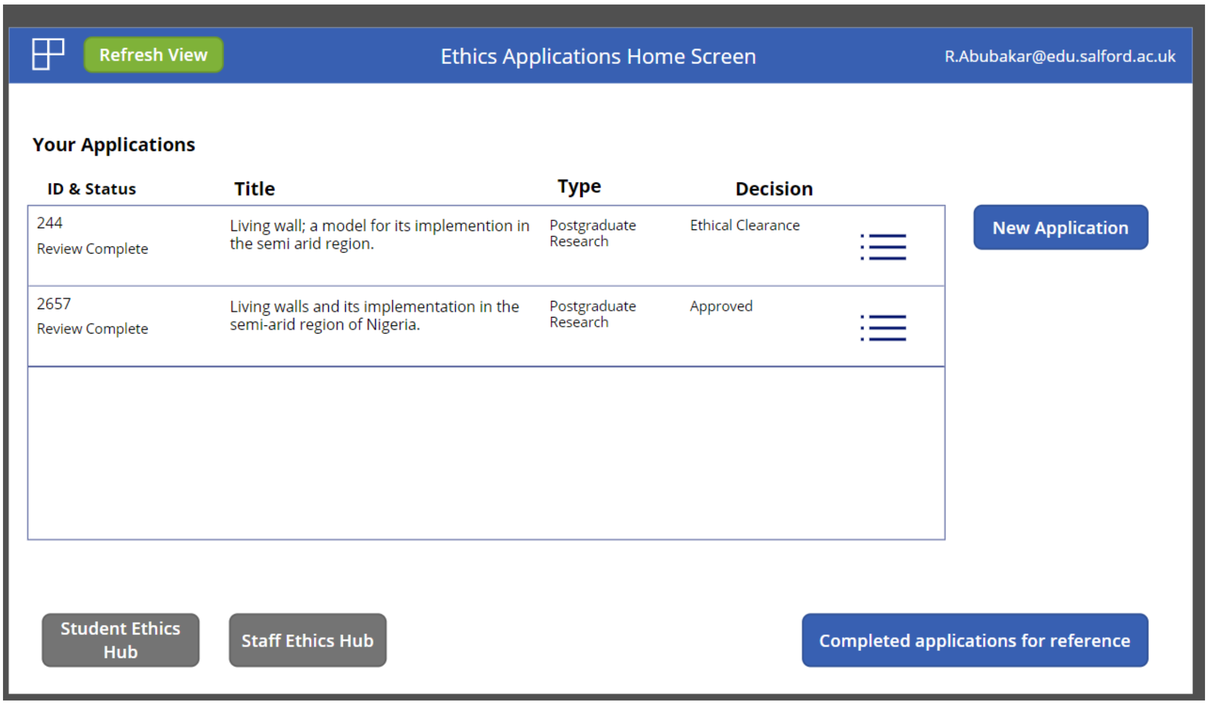
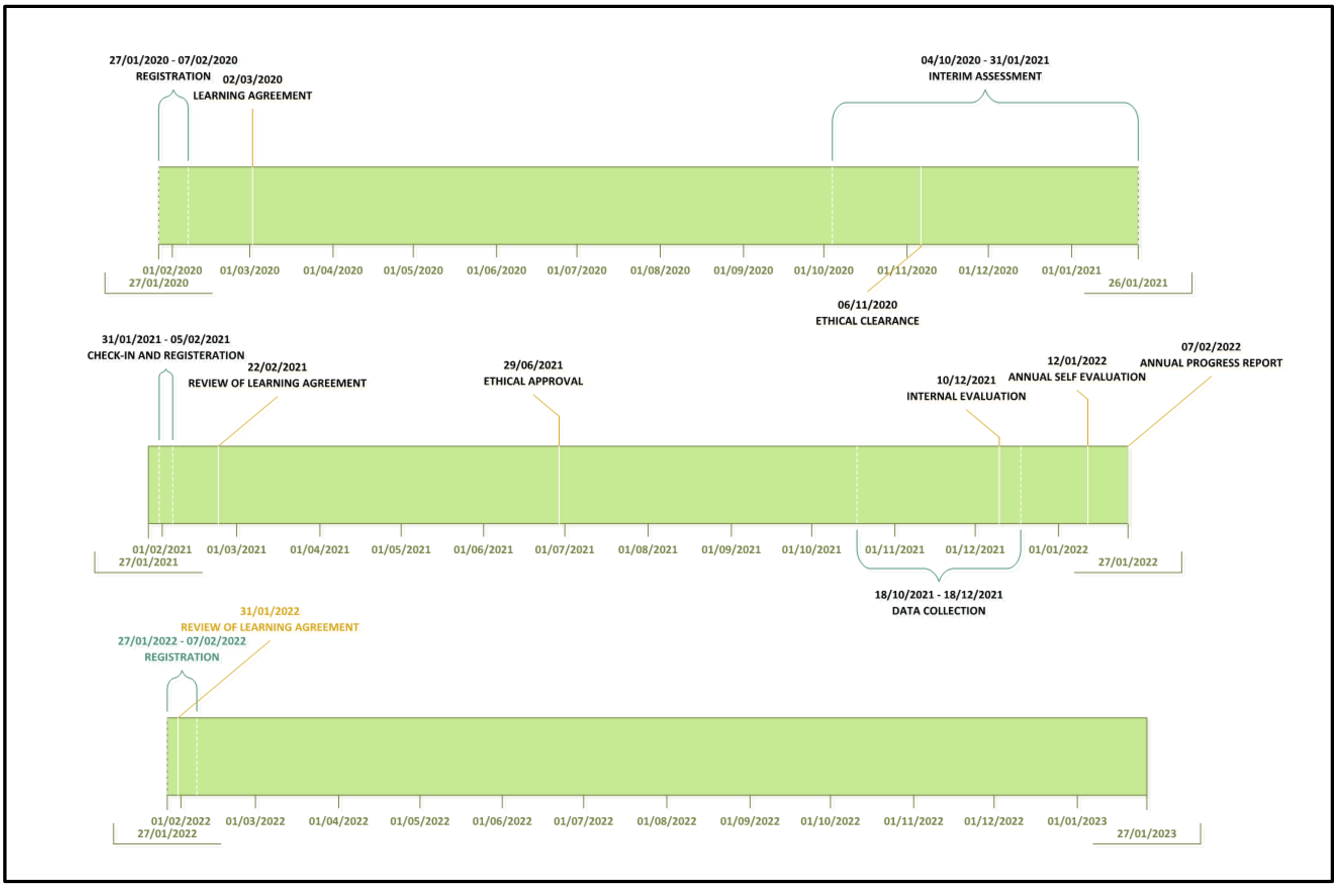
1. APPENDIX 1: Ethical Clearance



APPENDIX 2: Gant Chart Showing the Research Time Line



APPENDIX 3: Consent for Interview Participation

The school of Science, Engineering and Environment,

University of Salford
Manchester,
M5 4wt
Tel: +447767794260
Email: r.abubakar@edu.salford.ac.uk
October 2021

Dear Sir,

RE-LIVING WALLLS AND ITS IMPLEMETATION IN THE SEMI-ARID REGION OF NIGERIA.

I would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Ask questions if anything you read is not clear or if you would like more information. Take time to decide whether to take part.

I am a PhD research student at the school of Science, Engineering and Environment, University of Salford Greater Manchester, United Kingdom. I am currently undertaking research to investigate the drivers and barriers of living wall implementation in Nigeria. I chose to interview building professionals because it is my anticipation that the outcome will provide design recommendations for the implementation of living walls in Nigeria for building professionals and policy makers to mitigate the impact of climate change in line with the United Nations Sustainable Development Goals.

Taking part in the research is entirely voluntary. We will describe the study and go through the information sheet, which we will give to you. We will then ask you to sign a consent form to show you agreed to take part. You are free to withdraw at any time, without giving a reason. The data collection method will be through a structured interview which will be recorded, and it is expected to last an hour.

I would be very grateful if you could confirm your interest and willingness to participate in this research, as your participation will contribute immensely to this study and timely completion of the PhD programme. For further inquiry or clarifications, you can contact me through the above address or my supervisor Dr Yingchun Ji (y.ji@salford.ac.uk).

This research will not disrupt your working environment and all information collected as part of the data for this research purpose will remain confidential, as your identity will be anonymous. This shall remain same both in this research and in any publications. If you withdraw from the study we will destroy all your identifiable audio recorded interviews, but we will need to use the data collected up to your withdrawal. After the completion of the thesis, all data will be destroyed.

Please kindly complete attached consent form to indicate that you grant permission for the information provided to be used for the purpose of this study.

Yours faithfully,

Rakiya Abubakar

APPENDIX 4: Consent form Interview Participation

Title of Project: VERTICAL GREENING AND ITS IMPLEMENTATION IN THE SEMI-ARID REGION OF NORTHERN NIGERIA.

Name of Researcher: Rakiya Abubakar

(Delete as appropriate)

1. I confirm that I have read and understood the information sheet for the above study and what my contribution will be.

Yes	**No**

2. I have been given the opportunity to ask questions (face to face, via telephone and e-mail).

Yes	**No**

3. I agree to take part in the interview.

Yes	**No**	**NA**

4. I agree to the interview being tape recorded.

Yes	**No**	**NA**

5. I agree to digital images being taken during the research exercises.

Yes	**No**	**NA**

6. I understand that my participation is voluntary and that I can withdraw from the research at any time **without giving any reason.**	**Yes**	**No**
7. **I agree to take part in the above study.**	**Yes**	**No**

Name of participant:
Signature
Date:

Name of researcher taking consent: Rakiya Abubakar

Researcher's email address: r.abuabkar@edu.salford.ac.uk

If you have any concerns about this research that have not been addressed by the researcher, please contact the researcher's supervisor via the contact details below:

Supervisor's Name Dr. Yingchun Ji

Supervisor's: Email address y.ji@salford.ac.uk

APPENDIX 5: Interview Schedule

A. **Background Information.** Tick where appropriate

- What is your academic/professional qualification?

Architect	
Builder	
Engineer	
Interior designer	
Landscape Architect	
Others (describe please)	

- For how long have you been working in this capacity?

0-5 Years	
5-10 Years	
10-20 Years	
20 and above	

- Please describe your workplace.

Private firm	
Government agency	
others	

- What is your work schedule place?

Field work	
Design	
Administrative work	
Others (please describe)	

YES	NO

B. **Information on Green infrastructure.**

- Have you been involved with green infrastructure?

- What aspect of green infrastructure have you applied in your work?
- What are the common aspects of green infrastructure included in construction in Nigeria?
- What factors influence the choice of green infrastructure in Nigeria?
- Do you know of any pro-environmental sensitization program?
- Have you attended any pro-environmental sensitization seminar/ workshop?
- If yes, what is your assessment of such workshop/seminar?

C. Information on Living Walls systems.

- What can you say about living walls?
- What is the level of awareness on the benefits of living walls in Nigeria?
- In your view, are living walls likely to be acceptable socially and economically in Nigeria?

What is your assessment of living walls in comparison to other environmental sustainability options?

- Are Living walls suitable for the types of buildings and climate in semi-arid region of Nigeria?
- List any plants species you know that are suitable for living walls in semi-arid region of Nigeria?
- How well can living walls be integrated into design and construction of new buildings in the semi-arid region of Nigeria?
- How feasible is applying living walls to existing buildings?

- What medium of planting can easily be integrated into the types of buildings in Nigeria and why?

  ☐ Continuous living walls systems (lightweight absorbent screens e.g., cloth or felt)

  ☐ Modular living walls systems (e.g., trays, jars, planter tiles, or flexible bags)

- Do you know of any living wall system in Nigeria?
- Where is it located?
- On what direction of the building are living walls situated? (North, East, South or West)

D. Information on drivers and barriers of Living Wall Systems in Nigeria.

- Is the cost of installation and maintenance of living walls sustainable?
- In your opinion, what could be the drivers of living walls implementation in semi-arid region of Nigeria?
- In your opinion, what could be the barriers for the implementing living walls in semi-arid region of Nigeria?

E. Information on personal involvement with living walls.

- Have you worked on a project that incorporated a living wall?
- If **YES:** What type of building and where is it located?
- What was the approximate size of the living wall?
- When was the project completed? What type of living wall was specified? (tick as appropriate)

  ☐ Continuous living walls systems (lightweight absorbent screens e.g., cloth or felt)

  ☐ Modular living walls systems (e.g., trays, jars, planter tiles, or flexible bags)

- What challenges did you face during design and construction?
- What were the main reasons for incorporation?
- To date, is the client happy with the installation?
- Have there been any technical or maintenance issues that you know of?
- Which living wall features do you find most important?
- If given the opportunity, would you incorporate a living wall into a project again?
- Do you have any preference on the type of buildings to incorporate living walls? (Please explain)

F. Are there any suggestions or comments you would make regarding living walls?

For the Real Estate Agent:

1. From your expertise, what is the influence of sustainable techniques such as vertical greening on property values and marketability in cities?

2. What are the potential advantages associated with the integration of vertical greening within real estate developments, taking into account the distinct climate and environmental circumstances prevalent in Northern Nigeria?
3. Could you kindly provide instances of real estate developments that have effectively incorporated vertical greening? Which factors made it successful?

4. In your opinion what is the potential impact of ecological and visual appeal of urban areas on property demand and pricing in Northern Nigeria?
5. How do you envision promoting and selling buildings that have implemented vertical greening in this area?

For the Urban Planner:

1. What are the potential approaches to incorporating vertical greening into urban development initiatives in Northern Nigeria and other semi-arid locations to achieve climate action?
2. What are the most significant obstacles to vertical greening implementation from the standpoint of urban planning, and how can these obstacles be effectively overcome?
3. What do you think are the most important things that might make it harder or easier to use vertical greening in this area?
4. From an urban planning perspective, what ways can vertical greening impact the urban environment and contribute to the mitigation of climate change in Northern Nigeria?
5. What are the key factors and suggestions that policymakers, urban planners, and architects should take into account when integrating vertical greening into their projects in Northern Nigeria and comparable regions?

THANK YOU

APPENDIX 6: METROLOGICAL DATA

WEATHER DATA FOR THE RAINY SEASON

kano state nigeria 2021-07-16 to 2021-07-16

	name	datetime	temp	feelslike	dew	humidity	precip	precipprol	preciptype
2	kano state	2021-07-16T00:00:00	26	26	21	73.97	0	0	
3	kano state	2021-07-16T01:00:00	25	25	21.8	82.43	0	0	
4	kano state	2021-07-16T02:00:00	25	25	22	83.45	0	0	
5	kano state	2021-07-16T03:00:00	25	25	22	83.45	0	0	
6	kano state	2021-07-16T04:00:00	24.2	24.2	22.2	88.61	0	0	
7	kano state	2021-07-16T05:00:00	24	24	23	94.15	0	0	
8	kano state	2021-07-16T06:00:00	24	24	23	94.15	0	0	
9	kano state	2021-07-16T07:00:00	24	24	21.7	87.24	221	100	rain
10	kano state	2021-07-16T08:00:00	25	25	21	78.5	0	0	
11	kano state	2021-07-16T09:00:00	26	26	22	78.64	0	0	
12	kano state	2021-07-16T10:00:00	26.8	28.6	21.1	70.79	0	0	
13	kano state	2021-07-16T11:00:00	28	29.7	20	61.84	0	0	
14	kano state	2021-07-16T12:00:00	30	33.3	22	62.28	0	0	
15	kano state	2021-07-16T13:00:00	29	32.2	22.2	66.44	0	0	
16	kano state	2021-07-16T14:00:00	30	33.3	22	62.28	0	0	
17	kano state	2021-07-16T15:00:00	32	34.9	21	52.27	0	0	
18	kano state	2021-07-16T16:00:00	31.9	35.4	21.7	55.03	0	0	
19	kano state	2021-07-16T17:00:00	32.1	35.9	22.1	55.58	0	0	
20	kano state	2021-07-16T18:00:00	26.5	26.5	23.8	85.14	0	0	
21	kano state	2021-07-16T19:00:00	29.1	31.5	21.2	62.46	0	0	
22	kano state	2021-07-16T20:00:00	29	32	22	65.98	0	0	
23	kano state	2021-07-16T21:00:00	28	31.3	23	74.3	0	0	
24	kano state	2021-07-16T22:00:00	27.2	30	23.1	78.74	0	0	
25	kano state	2021-07-16T23:00:00	27	29.2	22	74.14	0	0	

	datetime	snow	snowdeptl	windgust	windspeec	winddir	sealevelpr	cloudcove	visibility	solarradiat	solarenerg	uvindex	severe
2	2021-07-16T00:00:00				11.2	210	1014	96.5	10	0	0	0	
3	2021-07-16T01:00:00				13	220	1014.3	40	4.9	0	0	0	
4	2021-07-16T02:00:00				18.4	110	1013	91.6	10	0	0	0	
5	2021-07-16T03:00:00				14.8	220	1013	86	10	0	0	0	
6	2021-07-16T04:00:00				14.8	200	1013.4	80	10	0	0	0	
7	2021-07-16T05:00:00				16.6	220	1014	81.5	10	0	0	0	
8	2021-07-16T06:00:00				27.7	230	1014	85.1	10	32.7	0.1	0	
9	2021-07-16T07:00:00				33.5	255	1015	80	12	167.8	0.6	2	
10	2021-07-16T08:00:00				24.1	230	1015	27.5	10	358.9	1.3	4	
11	2021-07-16T09:00:00				14.8	240	1016	27.5	10	499.4	1.8	5	
12	2021-07-16T10:00:00				22.3	240	1015.5	52.8	10	690.8	2.5	7	
13	2021-07-16T11:00:00				25.9	210	1015	27.5	10	785	2.8	8	
14	2021-07-16T12:00:00				24.1	210	1016	27.5	10	793	2.9	8	
15	2021-07-16T13:00:00				9.4	220	1015.4	90	10	730.8	2.6	7	
16	2021-07-16T14:00:00				14.8	220	1015	50	10	607.3	2.2	6	
17	2021-07-16T15:00:00				9.4	200	1014	50	10	470.8	1.7	5	
18	2021-07-16T16:00:00				9.4	290	1013.8	70.2	10	275.1	1	3	
19	2021-07-16T17:00:00				13	220	1013	30	10	126	0.5	1	
20	2021-07-16T18:00:00				4	164		90.9		19.9	0.1	0	
21	2021-07-16T19:00:00				20.5	220	1013	80	10	0	0	0	
22	2021-07-16T20:00:00				16.6	210	1014	88.9	10	0	0	0	
23	2021-07-16T21:00:00				16.6	220	1015	83.9	10	0	0	0	
24	2021-07-16T22:00:00				14.8	210	1016.1	80	10	0	0	0	
25	2021-07-16T23:00:00				22.3	220	1016	41.8	10	0	0	0	

Weather Data

WEATHER DATA FOR THE DRY SEASON

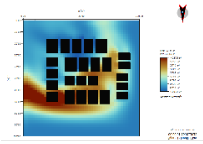
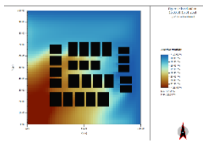
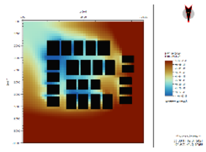
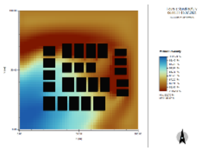
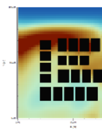
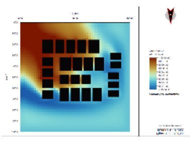
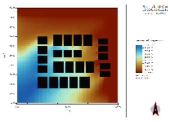
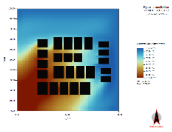
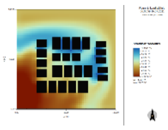
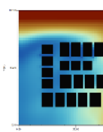
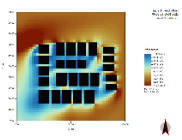
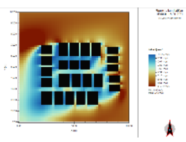
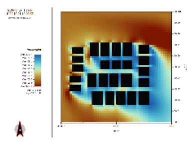
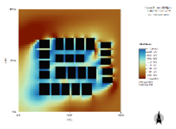
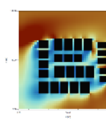
kano state nigeria 2021-01-16 to 2021-01-16

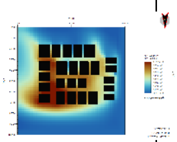
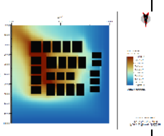
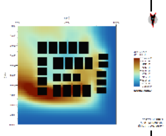
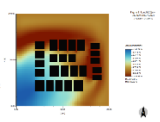
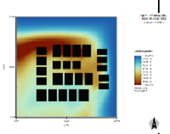
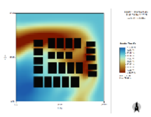
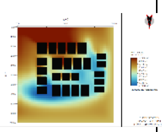
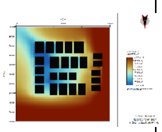
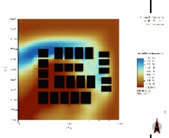
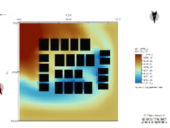
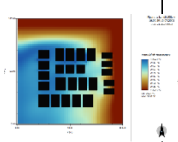
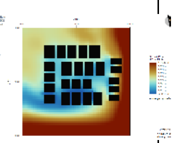
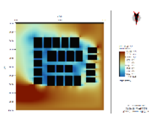
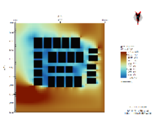
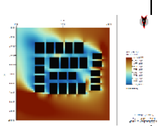
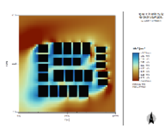
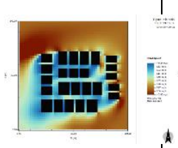
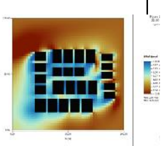
	name	datetime	temp	feelslike	dew	humidity	precip	precipprol	preciptype	snow	snowdeptl	windgust
2	kano state	2021-01-1	17	17	7	51.75	0	0				
3	kano state	2021-01-1	14	14	5.9	58.14	0	0				
4	kano state	2021-01-1	12.4	12.4	1.7	48.02	0	0				
5	kano state	2021-01-1	13	13	6	62.48	0	0				
6	kano state	2021-01-1	13	13	5	58.3	0	0				
7	kano state	2021-01-1	13	13	5	58.3	0	0				
8	kano state	2021-01-1	11	11	5	66.51	0	0				
9	kano state	2021-01-1	13	13	4	54.36	0	0				
10	kano state	2021-01-1	14	14	6	58.55	0	0				
11	kano state	2021-01-1	20	20	3	32.46	0	0				
12	kano state	2021-01-1	22.9	22.9	4	29.16	0	0				
13	kano state	2021-01-1	26	26	-1	16.93	0	0				
14	kano state	2021-01-1	28	26.6	-1	15.05	0	0				
15	kano state	2021-01-1	28	26.7	1.1	17.47	0	0				
16	kano state	2021-01-1	29	27.4	1	16.42	0	0				
17	kano state	2021-01-1	30	28.1	-3	11.57	0	0				
18	kano state	2021-01-1	30.8	28.8	-2.8	11.18	0	0				
19	kano state	2021-01-1	30	28.2	3	17.88	0	0				
20	kano state	2021-01-1	28	26.7	3	20.07	0	0				
21	kano state	2021-01-1	23.7	23.7	2.9	25.64	0	0				
22	kano state	2021-01-1	21	21	8	43.17	0	0				
23	kano state	2021-01-1	18	18	4	39.46	0	0				
24	kano state	2021-01-1	16	16	3	41.74	0	0				
25	kano state	2021-01-1	16	16	4	44.79	0	0				

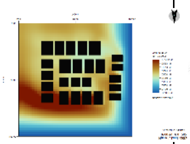
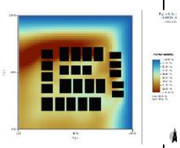
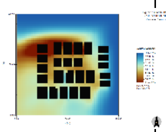
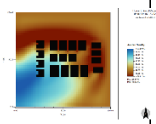
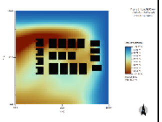
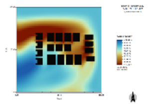
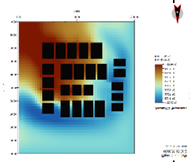
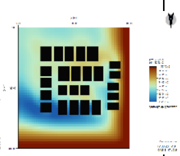
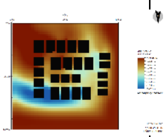
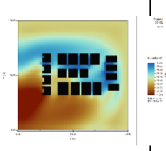
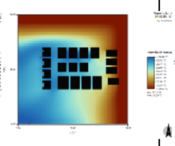
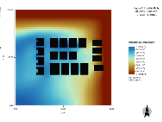
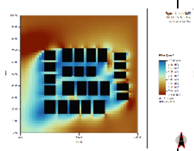
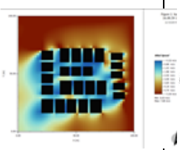
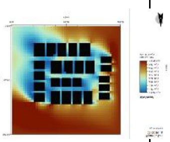
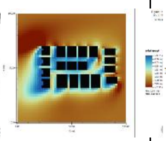
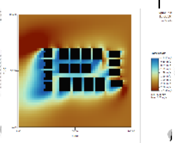
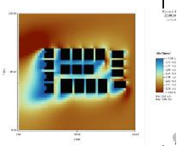
	windspeed	winddir	sealevelpr	cloudcove	visibility	solarradiat	solarenerg	uvindex	severerisk	conditions	icon	statio
2	5.4	300	1015	0	6	0	0	0		Clear	clear-night	6504
3	4.5	300	1015.3	80	6	0	0	0		Partially cl	partly-clou	6504
4	9.4	46.1		0		0	0	0		Clear	clear-night	remo
5	5.4	310	1014	0	6	0	0	0		Clear	clear-night	6504
6	0	55.7	1014	0	6	0	0	0		Clear	clear-night	6504
7	5.4	230	1014	0	6	0	0	0		Clear	clear-night	6504
8	3.6	68.8	1014	0	6	3.4	0	0		Clear	clear-night	6504
9	3.6	76.4	1015	0	6	119.6	0.4	1		Clear	clear-day	6504
10	0	0	1016	0	6	349.6	1.3	3		Clear	clear-day	6504
11	14.8	60	1017	0	6	578.5	2.1	6		Clear	clear-day	6504
12	16.6	50	1016.9	80	6	784	2.8	8		Partially cl	partly-clou	6504
13	22.3	70	1016	0	8	895.3	3.2	9		Clear	clear-day	6504
14	18.4	110	1016	0	8	927.3	3.3	9		Clear	clear-day	6504
15	24.1	70	1015	80	10	876.5	3.2	9		Partially cl	partly-clou	6504
16	16.6	80	1013	93.6	10	752	2.7	8		Overcast	cloudy	6504
17	20.5	40	1012	93.4	10	563.5	2	6		Overcast	cloudy	6504
18	16.6	40	1012.5	80	10	331.6	1.2	3		Partially cl	partly-clou	6504
19	11.2	40	1012	93.3	10	99.8	0.4	1		Overcast	cloudy	6504
20	11.2	50	1013	93.6	10	0.6	0	0		Overcast	cloudy	6504
21	9.4	70	1013.6	80	10	0	0	0		Partially cl	partly-clou	6504
22	5.4	50	1014	68.1	10	0	0	0		Partially cl	partly-clou	6504
23	3.6	28.4	1015	15.4	10	0	0	0		Clear	clear-night	6504
24	3.6	31.5	1015	0	10	0	0	0		Clear	clear-night	6504
25	3.6	33.9	1015	7.4	10	0	0	0		Clear	clear-night	6504

Weather Data

APPENDIX 7: SIMULATION RESULT MATRIX

0% Kundila Estate	Dry season			Wet season	
	Morning 6:00am	Afternoon 4:00pm	Night 10:00pm	Moring 6:00am	Afterno
Humidity					
Temperature					
Wind speed					

25% Kundila estate	Dry season			Wet season		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening
Humidity						
Temperature						
Wind speed						

50% Kundila estate	Dry season			Wet season		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening
Humidity						
Temperature						
Wind speed						

APPENDIX 8: Supervisory Record

Below are the dates for supervision meeting and discussions' undertaken.

Serial number	**Date**	**Discussion**
1.	16/03/20	Discussion on trainings to attend, important milestones and expectations from students and supervisors.
2.	14/04/2020	Discussion on learning agreement and research methodology.
3.	18/05/2020	Discussion on ethics and Research design
4.	22/06/2020	Research Methodology and thesis writing
5.	28/07/2020	Discussion on Research Methodology
6.	24/08/2020	Discussion on Simulation software
7.	28/09/2020	Discussion on research methodology and interim assessment report.
8.	26/10/2020	Discussion on Envi-met simulation software
9.	23/11/2020	Discussion on Envi-met and I.A.
10.	/12/2020	Discussion on I.A.
11.	28/01/2021	Discussion on interim assessment and having a good understanding of Envi-met.
12.	12/02/2021	Discussion on necessary steps to take after the interim assessment.
13.	19/03/2021	Discussion on envi-met model, the idea of case study research and the idea to include the perception of building professional in the research.
14.	27/04/2021	Discussion on envi-met model which include project creation, modification of data base such as vegetation, materials, greenery, soil and surfaces and also designing of the model area.
15.	24/05/2021	Discussion on envi-met model, the simulation progress and preparation for the SPARC.
16.	23/6/21	Discussion on envi-met and the simulation progress.

17.	09/07/21	Discussion on envi-met challenges and the decision to include interview in the research and the decision to travel to Nigeria.
18.	16/08/21	Discussion on interview questions and ethical approval.
19.	23/09/21	Discussion on envi-met simulation process.
20.	29/10/21	Discussion on envi-met and upcoming assessment (Internal Evaluation)
21.	30/09/22	Discussed on the progress in simulation and work so far on chapter one.
22.	31/10/22	Discussed on the progress in simulation and the various scenarios.
23.	30/11/2022	General progress in research and work towards Huddersfield PGR conference.
24.	16/12/2022	General progress in research and the upcoming winter break, conference paper preparation, Envi-Met input and output
25.	23/1/2023	Progress in research and rounding up.
26.	3/3/2023	Progress in research and preparations towards rounding up and preparations for the Huddersfield conference.
27.	3/30/2023	Progress in research and preparations towards rounding up and preparations for the Huddersfield conference and the various engagement in the academic citizenship programme.
28.	25/5/2023	Progress in research writing up phase and some corrections to effect before the next meeting.
29.	26/6/2023	Progress in research writing up phase and some corrections to effect before the next meeting.
30.	03/08/2023	Progress in research writing up phase and discursion on extension of submission.
31.	01/11/2023	General progress in rounding up the research work and the intension to submit.

APPENDIX 9: List of Trainings Attended and Learning Outcome

Serial Number	Date	Training	Learning Outcome
1.	31 Jan 2020	Careers Symposium:	Tips to improve credibility at interviews, meetings and presentations and Steps on how to make contacts from the beginning and to take to ensure successful publishing
2.	3 Feb 2020	Project Management	Strategies for effective project management
3.	5 Feb 2020	IA Preparation Workshop	Requirements for IA
4.	5 Feb 2020	Introduction to Learning and Teaching in Higher Education PGR)	
5.	6 Feb 2020	Introduction to Qualitative Research	Qualitative research methods
6.	7 Feb 2020	Introduction to Quantitative Research	Quantitative research methods
7.	10 Feb 2020	Parents Network Group	Useful tips of parenting while studying
8.	10 Feb 2020	PGR Welcome and Induction + Your researcher roadmap - planning ahead	
9.	10 Feb 2020	Research Ethics Workshop	Introduction to ethics and ethical consideration
10.	11 Feb 2020	Researcher Development Day - Writing for your IA and IE	Strategies for IA and IE Writing.
11.	12 Feb 2020	Researcher Development Day - Designing and presenting a poster	

12.	13 Feb 2020	Excel: The Basics	Working with excel, inserting formulas, making charts and formatting work sheets
13.	24 Feb 2020	Introduction to research design planning using NVivo and SPSS data analysis software	Selection of appropriate tools and challenges to be aware of
14.	24 Feb 2020	Data Collection Using NVivo & SPSS	Tips to utilize NVivo for qualitative data analysis
15.	24 Feb 2020	Data Analysis using NVivo & SPSS	Tips to utilize SPSS for quantitative data analysis
16.	24 Feb 2020	What is Structural Equation Modelling?	Multiple of statistical techniques to explore quantitative data
17.	26 Feb 2020	Introduction to EndNote X9	Using the Endnote software to manage information sources, citations and references
18.	4 Mar 2020	The Use and Design of Questionnaires	Designing questionnaire for quantitative research
19.	13 Mar 2020	Methodology Challenges	
20.	1 Apr 2020	30 minute focus: Making the most of Library Search! [online workshop]	Strategies for online library search.
21.	14 Apr 2020	Idea Puzzle Demonstration and Webinar	Designing PhD with the idea puzzle software which assist in aligning theory, method data in the line of philosophy of science.
22.	22 Apr 2020	PGR Inter-disciplinary Research Seminar Series	
23.	27 Apr 2020	Short Introduction to Academic Resilience	The purpose was to learn how to deal with setbacks and stress and coping with multiple deadlines.
24.	27 Apr 2020	30-minute	Introduced to various data bases where study materials

			can sourced through the library
25.	28 Apr 2020	How to avoid plagiarism in your work [online workshop]	Strategies to avoid plagiarism in academic writing.
26.	1 May 2020	The what, why, when and how of referencing [online workshop]	Strategies for academic referencing.
27.	4 May 2020	Turbocharge Your Writing	Strategies to boasting the writing skills, clarify your thinking and increase output.
28.	13 May 2020	Communication Skills - Giving confident presentations with impact	Strategies for confident presentation.
29.	14 May 2020	30 minute focus: Evaluating the information you find [online workshop]	
30.	21 May 2020	Thesis and Beyond Researcher Development Day - Thesis Writing Retreat	Strategies for thesis writing.
31.	21 May 2020	30 minute focus: Take your pick of online courses with LinkedIn Learning [online workshop]	Accessing LinkedIn online courses.
32.	3 Jun 2020	Meet the author 'Career advantages of doing quantitative research'	
33.	10 Jun 2020	Research Methods and Measurement	
34.	17 Jun 2020	Fundamental ideas quantitative methodology	Basics of quantitative methodology.
35.	18 Jun 2020	Introduction to Critical and Analytical Skills [online workshop]	Writing critically and analytically
36.	9 Jul 2020	Developing your research during social distancing: outputs, impact and collaboration	Strategies to progress your research and increase the impact opportunities
37.	14 Jul 2020	Word scope Group Four T3 2019-20 Workshop 1 (AD)	Writing workshop

38.	16 Jul 2020	"How to make the best impression in a video interview”	Tactics for best virtual presentation
39.	21 Jul 2020	Preparing for Assessments: Viva’s, IA, IE and (new) online formats	Preparation and support for online format of assessment
40.	4 Aug 2020	Writing & Thriving, Writing as Editing & Editing as Writing: Redrafting your writing for submission	Writing and editing strategies
41.	11 Aug 2020	Writing Retreat Online	
42.	12 Aug 2020	Developing your researcher identity – ORCID	Importance of Orcid and how to develop one.
43.	21 Aug 2020	Battling Procrastination and Boosting Motivation [online workshop]	Time management strategies, battling procrastination and motivation boosters
44.	20 Oct 2020	Open Access Week 2020 - Using Open Access Resources in your Research	How to locate open access resources.
45.	21 Oct 2020	Word: Formatting your dissertation or thesis - PART 2 of 2 [Online]	Formatting the thesis, creating tables, content and heading styles
46.	23 Nov 2020	Word: Formatting your dissertation or thesis - PART 1 of 2 [Online]	Formatting the thesis, creating tables, content and heading styles
47.	18 May 2021	LEAP webinar series	How to paraphrase and summaries in academic writing.
48.	17 May 2021	Philosophical stance for research methodology	Introducing students to axiological foundation of research.
49.	10 May 2021	Philosophical stance for research methodology	Introducing students to ontological and epistemological research philosophy
50.	10 June 2021	Working for yourself	How students can develop relevant skills to be self employed

51.	9 July 2021	Reflective writing	Understanding the principles of reflective writing and its usage in academic writing.
52.	4 October 2021	Maximising your Time at University	The session was a guide for students through making the most of their time at University so they can look as attractive as possible to employers.
53.	27 Sep 2022	Wordscope Group Five T1 2022-23 Workshop 1	
54.	4 Oct 2022	Wordscope Group Five T1 2022-23 Workshop 2	
55.	11 Oct 2022	Wordscope Group Five T1 2022-23 Workshop 3	
56.	18 Oct 2022	Wordscope Group Five T1 2022-23 Workshop 4	
57.	27 Oct 2022	Final Year (3rd Year) PGR Induction	
58.	27 Oct 2022	Final Year (3rd Year) PGR Induction	
59.	1 Nov 2022	Wordscope Group Five T1 2022-23 Workshop 4	
60.	1 Nov 2022	Top Tips for Writing Success	
61.	1 Nov 2022	Choosing a journal for publication	
62.	8 Nov 2022	Wordscope Group Five T1 2022-23 Workshop	
63.	9 Nov 2022	Writing/presenting qualitative	
64.	15 Nov 2022	Wordscope Group Five T1 2022-23 Workshop 6	

65.	22 Nov 2022	Wordscope Group Five T1 2022-23 Workshop 7	
66.	30 Nov 2022	Top Tips for Writing Success	
67.	30 Nov 2022	Meeting new People	
68.	30 Nov 2022	Top Tips for Writing Success	
69.	1 Dec 2022	Qualitative Data Analysis	
70.	6 Dec 2022	Working Freelance	
71.	6 Dec 2022	Developing your academic profile	
72.	6 Dec 2022	Working Freelance	
73.	6 Dec 2022	Wordscope Group Five T1 2022-23 Workshop 9	
74.	7 Dec 2022	Avoiding plagiarism in your work	
75.	12 Dec 2022	SPSS Statistics	
76.	24 Jan 2023	School of Health & Society PGR Journal Club	
77.	8 Feb 2023	Better Academic Writing	
78.	9 Feb 2023	Vox Viva Training	
79.	10 Feb 2023	Managing your research data	
80.	22 Feb 2023	Theories of learning and teaching in HE (IUT2)	
81.	24 Feb 2023	Developing your academic profile	
82.	27 Feb 2023	Introduction to the Learning and Teaching	

83.	1 Mar 2023	Large Group and Small Group Teaching (IUT3)	
84.	15 Mar 2023	Blended and Online Learning (IUT4)	
85.	29 Mar 2023	Inclusive Teaching and Learner Engagement (IUT5)	
86.	4 October 2021	Maximising your Time at University	The session was a guide for students through making the most of their time at University so they can look as attractive as possible to employers.
87.	19 Apr 2023,	Assessment and Feedback in HE (IUT6)	
88	15 May 2023,	Academic Citizenship Writing Retreat	