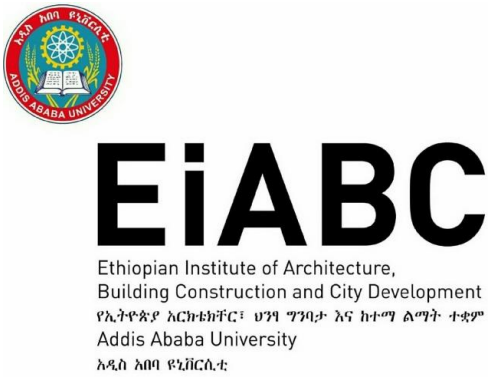




Ethiopian Institute of Architecture, Building Construction and City Development

Context Based Design and Performance of Fixed Exterior Shading Devices for Thermal Comfort

The case of radiation vulnerable full-glazed library or office buildings with shadings in Addis Ababa

By

Fitsum Gebreyohannes Mulat

A Thesis

Submitted to the Ethiopian Institute of Architecture Building Construction and City Development in partial fulfillment of the requirements for the degree of Master of Science

In

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This thesis is submitted to the Ethiopian Institute of Architecture, Building Construction and City Development (EiABC) and to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Architectural Engineering.

Title of Thesis

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Addis Ababa

August, 2021



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Confirmation

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ABSTRACT

With high incident solar radiation on the East-West building facades located especially in tropical climate regions like Ethiopia, the indoor spaces adjacent to glazed facades will become overheated. Among the various techniques of solar heat gain controls in the tropics, applications of fixed exterior shading devices play a major role in blocking incident solar radiation first hand. Through a descriptive research design, this study aims to investigate the effectiveness of such devices as a passive means of solar control as well as identify a context based shading approach that responds well during identified overheated periods in Addis Ababa. To this aim, investigations were conducted on full-glazed buildings that serve as library or office and used fixed exterior shading devices as a passive means of solar control. Questionnaires, secondary data and computer simulations were used to obtain quantitative data. These data were analyzed holistically to gain objective results. On the other hand, shading devices of selected case buildings were adopted and simulated for North, East, South, and West orientations on a mockup model to assess their performance. Their results were compared to a proposed shading design that based the identified overheated periods. This approach yielded a horizontal, Vertical, and End-profile shading angles of 82^0HSA, 65^0VSA and 38^0W EPA for North orientations, 65^0HSA, 83^0VSA and 60^0N & 55^0S EPA for East Orientations, 60^0HSA, 55^0VSA and 38^0W EPA for South Orientations, and 0^0HSA, 35^0VSA and 25^0N & 25^0S EPA for West Orientations. Proposed shadings using these shading angles were tested for each orientation on a mockup model. Simulation results showed an average shading of 57.4% North, 54% East, 75.7% South, and 84.2% West to be optimal. The results also showed a monthly total direct solar heat gain reduction ranging from 63.5KWhr/m^2 - 130.9KWhr/m^2 for zones facing North, 73.9KWhr/m^2 - 81.4KWhr/m^2 for zones facing East, 159.9KWhr/m^2 - 162.9KWhr/m^2 for zones facing South, and 159.9KWhr/m^2 - 108KWhr/m^2 for zones facing West. These findings can be used as shading design guidelines for radiation vulnerable glazed building facades in Addis Ababa and help improve thermal comfort.

Key Words: Fixed Exterior Shading Devices, Glazing, Shading Design, Simulation, Solar Control, Solar Radiation, Thermal Comfort

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ACRONYMS

API	Application Programming Interface
ASHRAE	American Society of Heating, Refrigerating and Air –Conditioning Engineers
BEST	Building Energy Software Tools
BIM	Building Information Modeling
BIPV	Building Integrated Photovoltaics
BPS	Building Performance Simulation
BTO	Building Technologies Office
CAD	Computer Aided Drawing
CIBSE	Chartered Institution of Building Services Engineers
CIE	Commission International del'Eclairage
DOE	Department of Energy
ECL-AA	Emerging City Lab – Addis Ababa
EiABC	Ethiopian Institute of Architecture, Building Construction, and City Development
EPA	End – Profile Angle
EPC	Energy Performance Certificate
HSA	Horizontal Shading Angle
IR	Infrared
PMV	Predicted Mean Vote
REVIT	Revised Instantly
UV	Ultraviolet
WHO	World Health Organization
VSA	Vertical Shading Angle

CHAPTER ONE

Introduction

CHAPTER ONE: Introduction

1.1. Introduction

Addis Ababa has been undergoing rapid growth and change in the construction industry. Among the changes, the construction of highly glazed buildings intended for library or office use have been a notable occurrence. Highly glazed building envelops greatly contribute to the energy demand for users' comfort. According to a research conducted on the application of building energy saving measures in walls (Tang & Wu, 2011), the proper design and selection of building envelopes can help in saving 50–60% of buildings' energy consumption used for cooling and heating purposes.

Among the various technological advancements in building skins, large windows and highly glazed facades have been increasingly used allowing access to daylight, solar gain and external view. However, this development has been constantly challenged by the existence of solar radiation especially in tropical climates thus causing high solar heat gain and indoor climate conditioning demands.

To tackle this challenge, different shading approaches have been developed. Among these, the use of exterior shading devices is preferred to block incident solar radiation first hand. Such devices block about 80 percent of the solar gain through clear windows as compared to internal shadings which are only about 20 percent efficient. (Lechner, 2015). In addition to this, using exterior shading devices on less expensive glazing would sometimes yield a shading performance equivalent to unshaded higher performance glazing. (Carmody & Haglund, 2012). Besides being expensive, application of higher performance glazing as a means of solar control may result in blocking or changing the natural light spectrum all year round. So, fixed exterior shading devices remain a valid choice, aside from first hand solar protection, due to their ease of construction, maintenance and are cost effective solutions by design. (Lechner, 2015) However, not all fixed exterior shading devices work in the same effectiveness. It is questionable which ones are preferable to others.

1.2. Background of the Study

Fixed shadings have been a prominent feature in the development of the architecture of buildings throughout history. In vernacular architecture, their design usually involved the use of locally accessible materials like clay, wood planks, concrete, tree branches and more to provide shade from solar radiation and other environmental situations. (Vandna & Shyam, 2016). In ancient Greek and Roman buildings, fixed shadings started out as porticoes and colonnades. Traditional designs around the world interpreted the Greek portico as porch, veranda (China), balcony, loggia, gallery, arcade and engawa (Japan). (Lechner, 2015). Since the early twentieth century, many great architects have understood the importance of shading and used it to create powerful visual statements. Of all architects, Le Corbusier was most closely linked with aesthetics based on sun shading. This came about in 1932 after he designed a multistory building in Paris called Cite' de Refuge with an all-glass south facade. He intended to allow as much sunlight as possible to warm and cheer the residents. In December, passive solar worked wonderfully. But in June, the building became unbearably hot. This made him realize the dual nature of the sun. As a result, he invented the structural sunshade now known as brise-soleil (Sun breaker). (Lechner, 2015) In the traditions of modern architecture, glass facades had been an iconic trend in the architecture of buildings. They portrayed order, hygiene and advancement. (Rayner, 1971). Building developments within the framework of this image made the use of fixed exterior shadings less eminent. Consequently, this led to users' discomfort and high building energy demands for air conditioning. Shortly after the energy crisis incident in 1973, the modern architectural movement started to show a keen interest in the application of passive design strategies. This revived the need for fixed exterior shading devices as a passive means of solar control for vulnerable glazed facades. Though such devices blocked solar radiation first hand, designing them required the fulfilment of certain context based shading principles to provide optimal shading performance. In this regard, a notable development was contributed by Antony Sealey in 1979. In his journal of building climatology, he stated four major principles that should be considered for the proper design of

fixed exterior shading systems. These principles remain adaptable for the climate context of any region as a passive means of solar control.

In the case of Addis Ababa, different applications of fixed exterior shading devices have been seen on different building facades over the years. Since they apply different design and employment techniques, their shading performance would vary as well. Therefore, to achieve an optimal context based shading performance, it is necessary to incorporate context based shading principles during design and implementation of such devices. As such, this study navigates through the major principles required for proper shading design and test a context-based proposal shading for the climate context of Addis Ababa.

1.3. Problem Statement

It is believed to be best practice that radiation vulnerable full-glazed library or office buildings aim at implementing suitable fixed exterior shading approaches that best respond to undesired solar heat gain periods of a geographic location. However, lack of overheated period-based application of such devices limits their efficiency in responding to undesired solar heat gain periods. This results in high solar heat gains and rise in indoor temperature.

1.4. Objectives of the Study

1.4.1. General Objective

The objective of this thesis is to assess the effectiveness of fixed exterior shading devices as a passive means of solar control for radiation vulnerable full-glazed library or office buildings in Addis Ababa. Furthermore, it also aims to identify a context based fixed exterior shading approach that responds well during identified overheated periods.

1.4.2. Specific Objectives

• Mapping full-glazed library or office buildings that have fixed exterior shading devices attached.

• Assessing occupant's thermal satisfaction in the mapped case buildings.

• Identify a context based shading approach for implementing fixed exterior shading devices for radiation vulnerable full-glazed facades.

1.5. Research Questions

1.5.1. Main Question

In the case of Addis Ababa's climate, what kind of fixed exterior shading approach is suitable to block undesired solar heat gains through radiation vulnerable full-glazed facades?

1.5.2. Specific Questions

In the climate context of Addis Ababa,

1. Which types of fixed exterior shading devices are implemented for full-glazed library or office buildings?
2. Which periods of the day and year feel overheated for users?
3. Which orientations and which fixed exterior shading approaches work best together?

1.6. Scope and Limitation of the Study

This paper solely focuses on radiation vulnerable full-glazed library or office buildings in Addis Ababa that have employed fixed exterior shading devices as a passive means of solar control and achieve indoor thermal comfort. In this regard, it covers an assessment of the efficiency of fixed exterior shading devices in reducing daily solar heat gains on exposed case buildings. However, this research is limited to assessing solar energy inputs and gains while other factors that affect acceptable indoor thermal comfort are not considered.

1.7. Significance of the Study

As of current trends, in the climate context of Addis Ababa, the construction industry has been leaning towards adopting glazing systems as a preferred façade approach. With regards to users' thermal comfort they provide, the drawbacks of such systems have been noticed on many buildings that are fully glazed and are highly vulnerable to solar radiation. In response, different shading approaches have been in play on some full-glazed building facades as a means of solar

control. Among these, it is a fact that fixed exterior shading devices remain a valid choice to block incident solar radiation first hand. In this regard, this study will shed a light on the importance of a context-based application of fixed exterior shading devices for glazing systems as passive means to regulate solar heat gains and contribute to indoor thermal comfort. Furthermore, findings of this research can be used as guidelines for academic purposes, policy makers, professionals and researchers.

1.8. Consecrative Terms

Conventional naming of seasons and their periods of occurrence are unique for different geographic locations. In the climate context of Addis Ababa, Ethiopia, months within a year are categorized in to four seasons based on major climatic changes they exhibit. Under listed are meanings, characteristics and occurrence periods of the seasons. (Learn Amharic - Learn English, 2019)

Kiremt – Also known as Ethiopia's Winter, represents the rainy season. It begins on June 21st and ends on September 23rd. Generally, these periods are very wet in Addis and highland areas.

Belg- Also known as Ethiopia's Autumn/Fall, represents the harvest season. It begins on September 23rd and ends on December 22nd.

Bega- Also known as Ethiopia's Summer, represents the dry season. It begins on December 22nd and ends on March 20th. Frost is experienced in mornings especially in the month of January.

Tsedey- Also known as Ethiopia's Spring, represents the hottest season. It begins on December 22nd and ends on June 21st. In this season, occasional showers are experienced.

1.9. Research Outline

This thesis is composed of seven chapters as shown in Figure 1.1. Chapter one consists of the study's background, problem statement, objectives and questions, scope and limitation, and significance. Chapter two consists of a comprehensive review of literatures. Chapter three consists of the research method used to conduct the study. Chapter four consists of case related prior studies and international case studies. Chapter five consists of the analysis and interpretations of gathered data. It also reveals findings and results which could be used as an input for design guidelines. Chapter six tests the guidelines developed through suitable shading design approaches. Finally, chapter seven presents conclusions, recommendations and future research ideas**.**

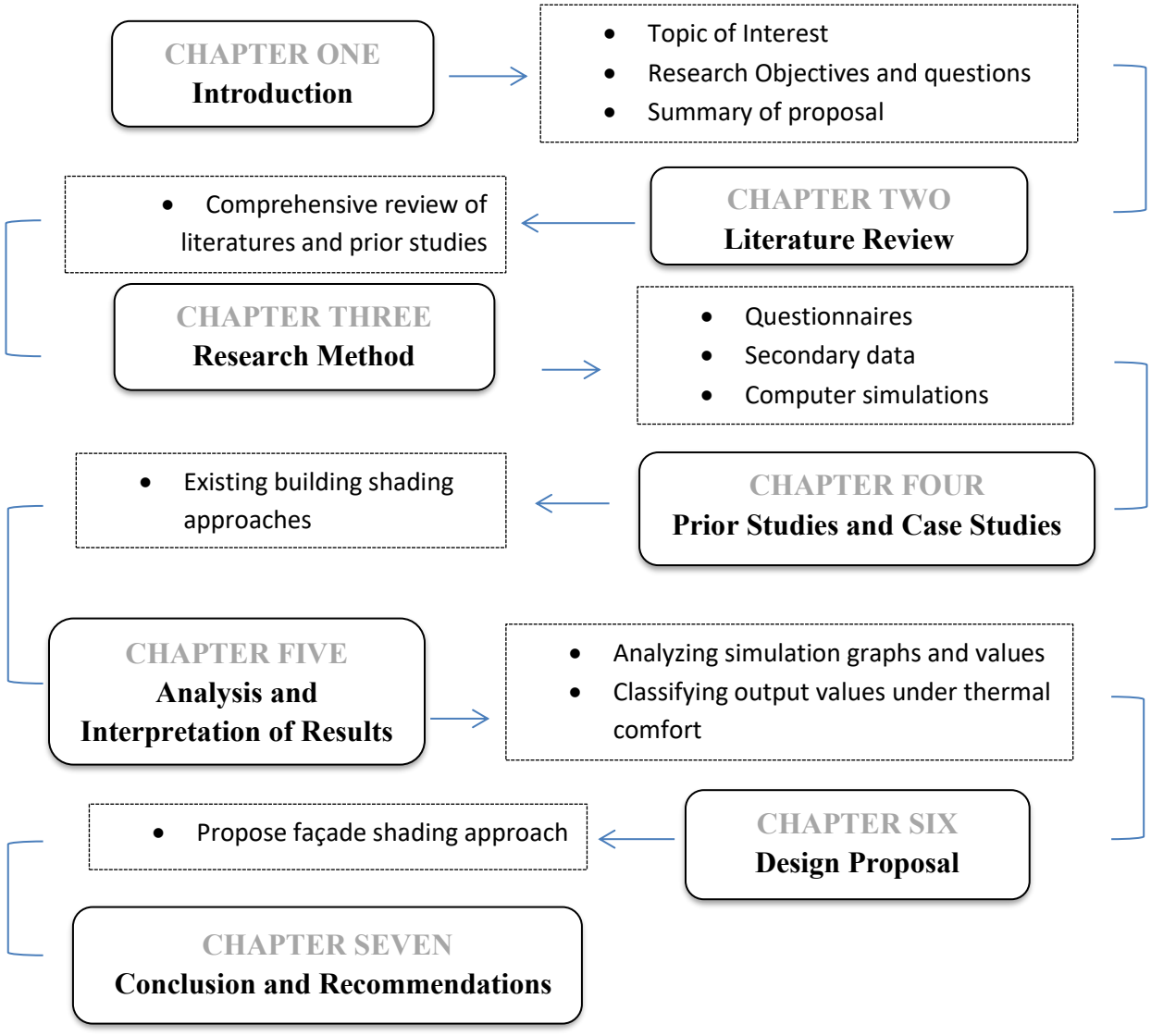


Figure 1.1. Research outline and hierarchy of study

CHAPTER TWO

Literature Review

CHAPTER TWO: Literature Review

2.1. Introduction

A comprehensive literature review is carried out through the aid of case related scientific journals, databases and online searches. The literatures are searched and filtered based on keywords such as fixed exterior shading devices, glazing, shading design, simulation, solar control, solar radiation, and thermal comfort**.**

2.2. Sun Light

Sunlight is the light and energy emitted from the sun. Insolation is the term given to this energy when it reaches the earth's surface. The heat energy we feel from the sun is the radiation emitted in the form of electromagnetic waves. (Szokolay, 2008).

2.2.1. Solar Radiation

Electromagnetic radiation can be divided in to different wavelength bands based on the intended fields of application. The majority of solar radiation is in between 0.3- 3μm wavelength and extends to parts of the ultraviolet (UV) and infrared (IR) ranges. In terms of importance in solar engineering, the wavelengths can simply be categorized in to short-wave and long wave radiations. Solar radiation is expressed by shortwave while other wavelengths are in the longwave category. Solar radiation, after reaching the earth's surface, will have two components; Beam radiation which has a well-defined direction, and Diffused radiation which is scattered in the earth's atmosphere. Solar radiation reaching the earth's surface is measured in two ways; Irradiance which is the energy flow density or instantaneous flux measured in W/m^2 and Irradiation which is an integrated quantity of energy over a specified period of time. (Widen & Munkhammar, 2019).

2.3. Solar Movement Identification

According to a journal of building climatology by Antony Sealey (1979), there are five ways that help to determine the position of the sun.

2.3.1. Calculations

With time, date and latitude, the altitude and sun's azimuth can be determined with mathematical formulae. In addition to this, the horizontal and vertical shading angles can also be calculated for different orientations. The use of this method for architectural purposes is known to be tedious.

2.3.2. Computer programs

There are different computer programs that make various computations and yield graphical outputs. Such programs are becoming more popular and are available on microcomputers.

2.3.3. From tables

Statistical or tabular solar angle information could be gathered from almanacs that may undergo yearly revisions.

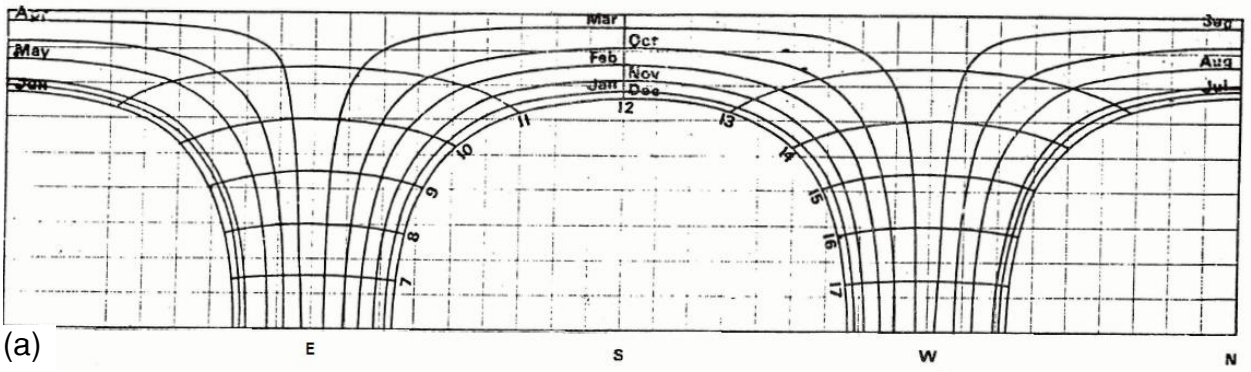
2.3.4. Experimental methods

Complex and lengthy researches on the Sun-Earth relationship is often carried out experimentally using the heliodon, the solarscope or some other device. Such devices are very popular for teaching purposes.

2.3.5. Sun-path diagrams

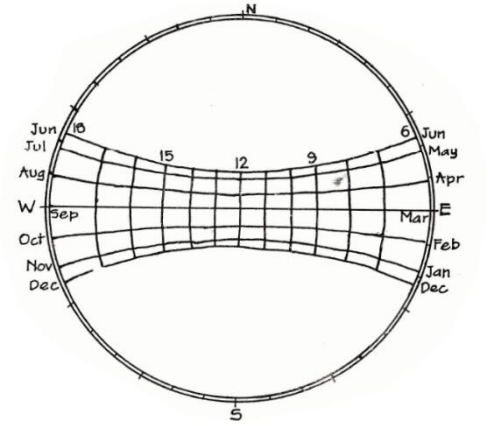
Are graphical projections of the hemisphere of the sky that show the sun's trajectory across the sky throughout the day and year. They are popular due to their simplicity. There are two types of projections used to obtain sun-path diagrams.

Orthogonal Projection. is the projection of the hemisphere on to a horizontal circle and is mostly used to visualize the sun's trajectory across the sky. (Sealey, 1979)



(a)

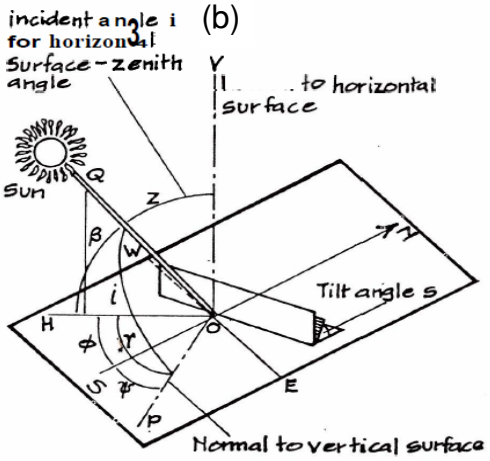
Stereographic projection. is the projection of the hemisphere on to a vertical surface. This is more useful for analyzing shading angles, glare and diffuse light from the sky. The most widely used sun path diagram is the stereographic chart. (Sealey, 1979)



(b)

The Use of Sun Path Diagram

For the design of shading devices, understanding and determining the position of the sun where shading is required is important. The position of the sun is defined by two angles; the solar altitude **B** (beta, measured from Q to 90 degrees above the horizon) and the solar azimuth ***e*** (theta). As shown in figure 2.1, the solar azimuth is measured from the south from 0 to -180 degrees (westward) and 0 to + 180 degrees (eastward). (Sealey, 1979)



(c)

Figure 2.1. (a)Orthogonal projection, (b)Stereographic projection, and (c)Solar angles for vertical, sloping, and horizontal surfaces (Source: Sealey,1979)

2.4. Climate of Addis Ababa

Ethiopia lies in the tropical zone between the equator and the tropic of cancer. Climate in the country varies greatly from region to region and is expressed in different seasons. In the climate context of Addis Ababa, the warm season lasts for four months, from February 7th to June 6th from which the hottest day lies around May 15th. The cool season lasts for 2 months, from July 7th to September 6th. The coldest day of the year lies around December 23rd. (Learn Amharic - Learn English, 2019). Climatic variations occur from year to year. To get near accurate climatic measurements and projections, it is necessary to observe climate change trends that had been occurring in previous years. Various studies on climate change trends had been conducted over the years. Climate change, especially temperature variations, significantly affect a building's energy performance. According to a study by Nahimi Feyissa (2019), trends of observed temperatures in 60 years (1957-2016) were analyzed. From this data, the average minimum temperature of Addis Ababa within this period was 10.38^{0}C and the mean temperature at Addis Ababa's observatory (Bole station) was 16.68^{0}C. The study showed that rise in temperature will exacerbate the urban heat highland effects in warm seasons. Figure 2.2. shows the average maximum temperature and average minimum temperature from 1957-2016.

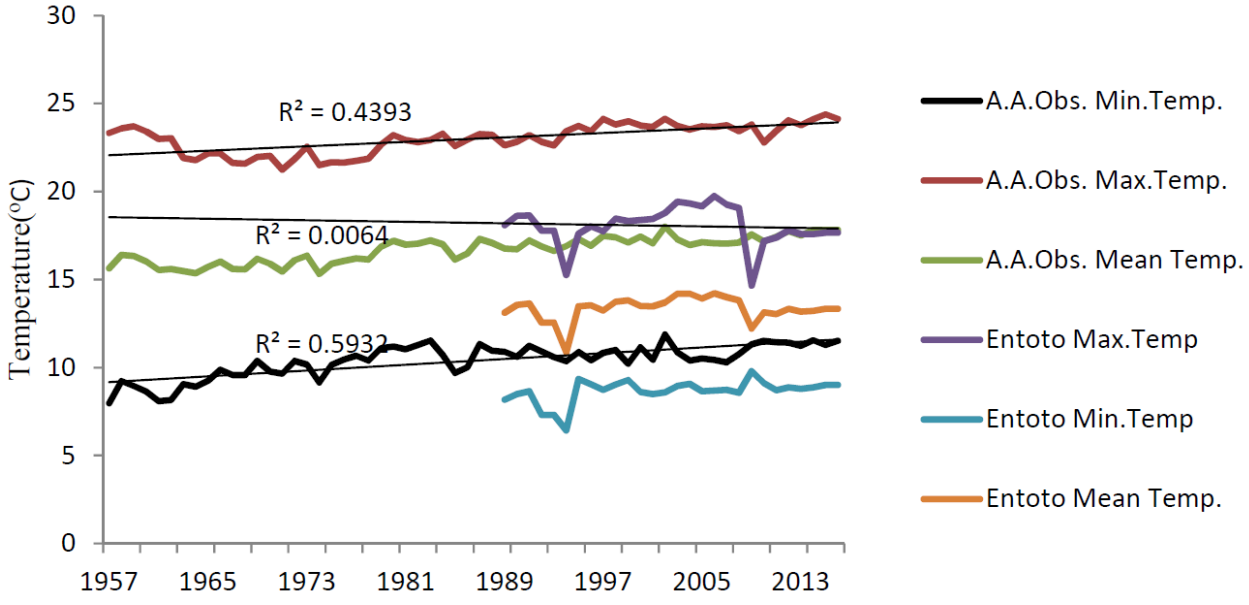


Figure 2.2. Maximum, mimimum and mean temperature trend of Addis Ababa (Source: Feyissa, 2019)

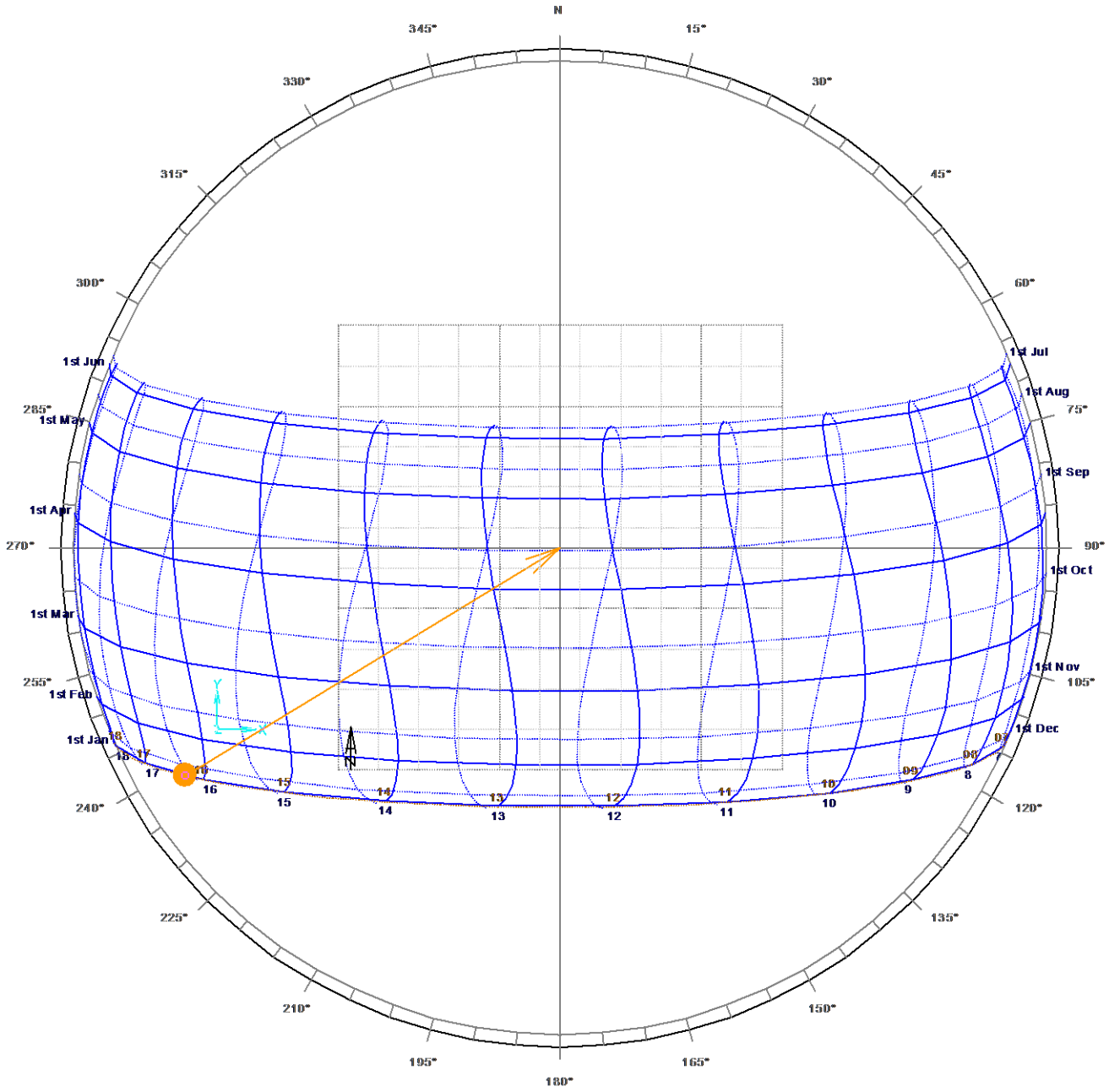


Figure 2.3. A stereographic sun-path diagram for latitude 8.98^0 N, Addis Ababa (Source: Ecotect Software)

2.5. Thermal Comfort and its Parameters

Thermal comfort can become very challenging to simply explain since there are a number of personal and environmental factors that should be considered. In the globally recognized ASHRAE55 and ISO 7730 standards, thermal comfort is defined as "*that condition of mind that expresses satisfaction with the thermal environment".* To analyze this condition, engineers must primarily identify the thermal limit for occupants living indoors. The comfort limits can be expressed by the Predicted Mean Vote (PMV) model. PMV is an index that aims to predict the mean value of votes of a group of occupants on a seven-point thermal sensation scale. It was created by P.O. Fanger. He hypothesized that the temperature of one's skin and sweat secretion determine thermal comfort. One could only be considered 'comfortable' if these two factors are balanced within a narrow range of acceptability. (Guenther, 2021)

According to ASHRAE 55, factors that affect thermal comfort are categorized in to two. personal factors and environmental factors. The personal factors are clothing insulation and metabolic rates were as the environmental factors are humidity, air speed, air temperature, and radiant temperature. The most commonly used indicator of thermal comfort is air temperature. It is easy to use and most people can relate to it. However, air temperature alone is not a valid or accurate indicator of thermal comfort or thermal stress. It should always be considered in relation to other environmental and personal factors.

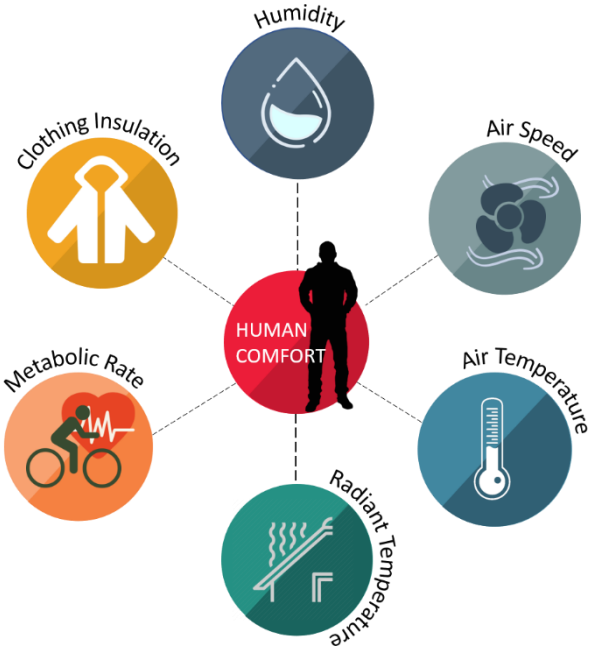


Figure 2.4. Factors affecting human comfort (Source:Kumar, 2019)

According to ASHRAE 55- 2010 Standards, under listed are definitions of the personal and the environmental factors that affect users' thermal comfort.

2.5.1. Personal Factors

Clothing Insulation. The type and amount of clothing affects thermal comfort as it hinders heat exchange to and from an immediate environment.

Metabolic Rate. Is the level of conversion of chemical energy into mechanical work and heat by metabolic activities within an organism. It depends on activity level, body shape, and environmental conditions.

2.5.2. Environmental Factors

Humidity. Is defined as the ratio of the quantity of water vapor in the air to the quantity of water vapor that the air could hold at a specific temperature and pressure.

Air Speed. Is the average speed of the air to which the body is exposed to, with respect to location and time.

Air Temperature. Is the average temperature of the air surrounding an occupant. It is measured with a dry-bulb thermometer and is also known as dry-bulb temperature.

Radiant Temperature. It relates to the amount of radiant heat transferred from a surface. It also depends on the material's ability to absorb or emit heat, or its emissivity. So, the mean radiant temperature experienced by a person in a room with sunlight streaming in varies based on how much of the body is in the sun.

2.6. Glazed Facades

Generally, the installed areas of windows and glass facades have increased in new buildings in recent years. This may be attributed to allowing adequate daylight access, solar gain and external view thus giving indoor users dignified experience. Glazed facades differ in the type of glass and the system of glazing used.

2.6.1. Types of Glass

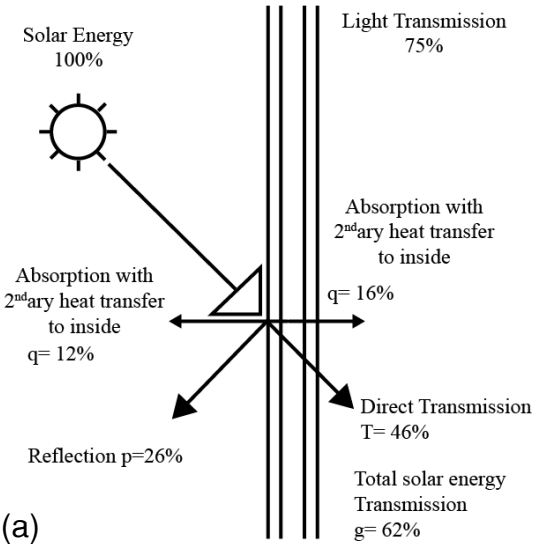
The thermal performance of a glazed building is determined by the shading coefficient of its glass type. This coefficient has a value ranging from 1.00 to 0.00. The closer this value is to zero, the greater the shading ability of the glass type used. Table 2.1. shows the different glass types with their respective shading coefficients.

Glass Type	Shading Coefficient
Single, Clear	0.69 – 0.73
Bronze	0.53 – 0.62
Green	0.50 – 0.61
Gray	0.48 – 0.60
Reflective	0.17 -0.28
Double, Clear	0.60 – 0.70
Bronze	0.43 – 0.53
Green	0.40 – 0.52
Gray	0.38 – 0.51
HP green	0.33
Reflective	0.12 – 0.20
Double-Low E, Clear	0.32 – 0.60
Bronze	0.23 – 0.48
Green	0.27 – 0.47
Gray	0.21 – 0.46
HP green	0.25 – 0.39

Table 2.1. Shading coefficient for typical windows (Source: ASHRAE, 1997)

2.6.2. Light and heat transmission through glass façade

The most influencial factors that determine the scale of transmitted radiation through a building skin are; the intensity and amount of the solar radiation avilable, the exposed skin area, the orientation of the building skin, and the skin's thermal characterstics. The ammount of solar energy gained through a glazed façade could reach up to 85% of the incident solar radiation. (Brown & Dekay, 2001)



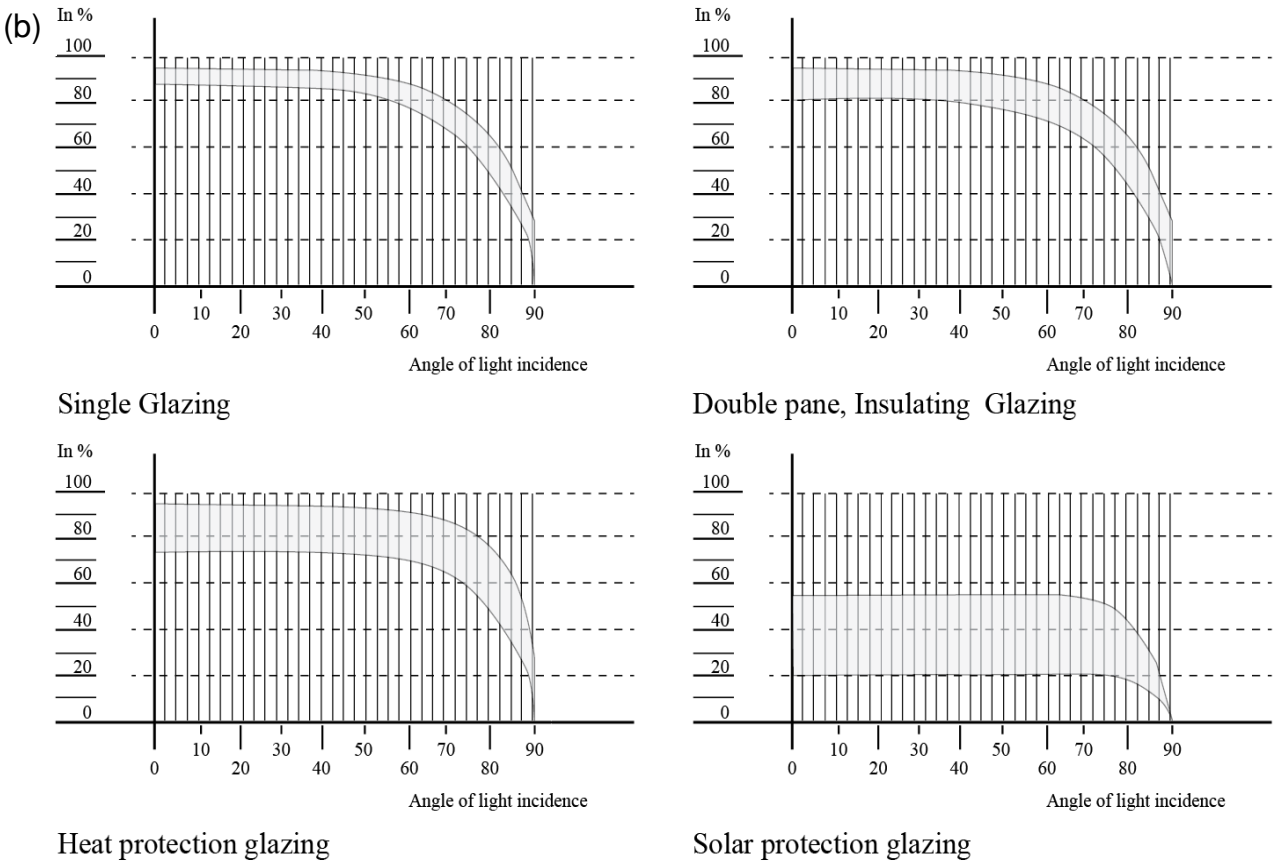


Figure 2.5. (a)Light transmission, absorption, and reflection values of different glazing types as a function of solar radiation incidence and (b)Total solar energy transmission of iplus neutral R (Source: Hindrichs & Daniels, 2007)

2.7. Solar Control

Prolonged exposure to solar radiation may result in rise of air temperature and cause severe overheating. This would dramatically increase cooling loads in the case of glazed buildings. Exposed wall and roof glazed surfaces, where solar energy is undesirable, should be reduced significantly to minimize cooling loads while allowing adequate daylight in to interior spaces. This helps reduce electrical lighting and energy consumption during the day. (Hindrichs & Daniels, 2007). Undesirable solar heat gain reductions could be achieved through the proper design of solar control systems. As a first step, it is the duty of an architect to find out when solar heat gain is desirable and when it is not. From there, an appropriate solar control mechanism can be provided. Prior to designing solar control systems, it is crucial to know the position of the sun at any time of the year along with the orientations of exposed building façades. (Watson, 1997)

2.7.1. Sun Shading Systems

Solar radiation plays a vital role in causing thermal discomfort and high energy demand for conditioning indoor spaces. Due to this fact, an efficient sun shading system that is capable of reducing solar radiation is required for windows and glass facades. It is commonly understood that people feel more comfortable in natural light than artificial light. Therefore, shading systems should not only be valid choices as a measure to protect against solar radiation but also consider adequate natural light allowance for the indoor environment. (Hindrichs & Daniels, 2007)

It would be an ideal condition if a sun-shading system

- can effectively reflect solar radiation regardless of solar angle and sky condition.
- can be fully transparent to allow entry of indirect light from any sky condition or surrounding.

But in reality, such conditions are difficult to achieve. Nevertheless, it’s important for designers to try to reach as close to these conditions as possible. (Hindrichs & Daniels, 2007)

2.7.2. Broad Classification of Sun Shading Systems

Based on location of shading systems, shading devices can be classified as internal, mid pane, external. This is further explained in Table 2.2.

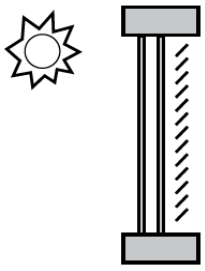
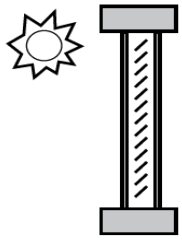
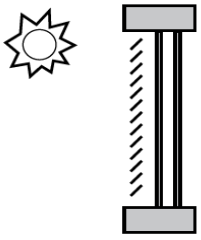
Shading device locations	Characteristics	Effect of sun shading
 Internal	• Less effective since solar radiation is absorbed on the inside of the shading element • Protected from wind, rain and other inclement environmental conditions. • Capable of providing sun shading and glare protection tasks • Venetian blinds, rolling shutters • Internal sun-shading systems may heat up and act as a radiator	Less effective, needs to be evaluated together with selected glazing type
 Mid-Pane	• Most effective sun-shading • Protected from wind, rain and other inclement environmental conditions • Capable of providing sun-shading and glare protection tasks • Venetian blinds, awnings, rolling shutters	Good
 External	• Most effective since solar radiation is intercepted before reaching the façade • Requires robust design and controls since elements are exposed to wind, rain and other inclement environmental conditions • often requires additional glare protection on inside Venetian blinds, awnings, fixed elements…	Excellent

Table 2.2. Positioning of sun shading systems (Source: Hindrichs & Daniels, 2007)

Based on movement of shading systems, shading devices can be classified as **active** or **passive**. (Dakheel & Aoul, 2017).

2.7.2.1. Active Shading Systems. Active shading systems are usually considered where there is a need to respond to multiple environmental situations. Such systems are also referred to as active, responsive, dynamic or kinetic systems. With Active shading strategies, balance between adequate daylight levels, solar protection, and user flexible shading approach could be achieved. Active systems can be within the glazing of the openings or as an exterior shading system. This is usually achieved through the use of smart glazing technologies, sensors and control systems, or through the application of smart dynamic shading devices. (Dakheel & Aoul, 2017). Figure 2.6. illustrates the classification of such systems.

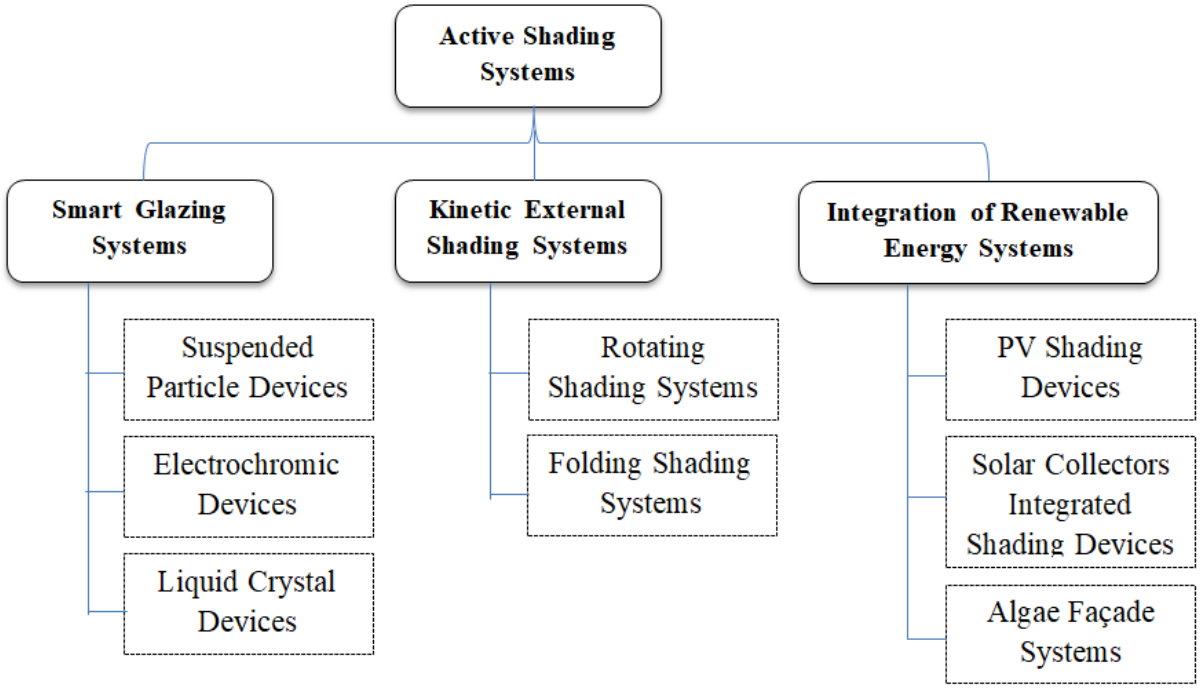


Figure 2.6. Active shading systems classification diagram (Source: Dakheel & Aoul 2017)

2.7.3. The Need for Passive Shading Approach

Various active and passive strategies by design can be implemented to improve a buildings energy efficiency. Active design strategies are basically comprised of heating and cooling systems, whereas passive approaches consider orientation of buildings, window to wall opening ratios, material adaptations, adequate light admissions, and the use of natural ventilation advantages. In doing so, contribution to reduced heating and cooling systems can be achieved through maintaining a balance between hot or cold air in indoor environments. For this reason, passive design approaches remain designer's first choice to improve a building's energy efficiency prior to implementing active systems. (Marro, 2018). Implementation of active systems even in shadings, requires high level of engineering, skilled labor, building energy, high initial cost, and proper maintenance all of which are challenging prerequisites in the context of developing countries.

2.7.4. Fixed Exterior Sun Shading Systems

Windows or glazed facades may contain several elements including shading devices. The design of these elements reflects various functions including thermal control. Generally, there are three types of fixed exterior shading devices used namely vertical, horizontal and egg-crate. There are different possible categories of external shading devices depending on location and position of windows. The different shading types for temperate climates are illustrated in Table 2.3. (Ramsey & Sleeper, 1988) Such systems are more advantageous for building facades exposed to high solar heat gains all year round especially in tropical climate regions.

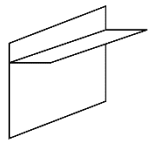
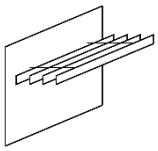
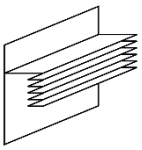
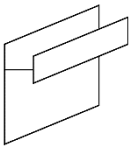
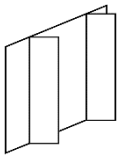
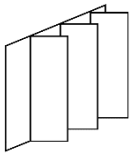
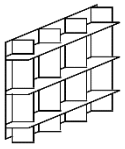
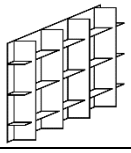
Shading Types	Description	Recommended Direction	Pros and Cons
	Overhang horizontal panel	South, East, West	Traps hot air, can be loaded by snow and wind
	Overhang horizontal louvers in horizontal plane	South, East, West	Free air movement, snow or wind load is small,
	Overhang horizontal louvers in vertical plane	South, East, West	Reduces length of overhang, view restricted and available in miniature louvers
	Overhang Vertical Panel	South, East, West	Free air movement, No snow load, view restricted
	Vertical fins	East, West, North	Restricted view; for north facades in hot climates only
	Vertical fin slanted	East, West	Slant toward north, restricts view significantly
	Egg crate	East, West	For very hot climates, view restricted and traps hot air
	Egg crate with slanted fins	East, West	Slant towards north. View restricted, traps hot air and also for every hot climate

Table 2.3. Fixed exterior shading device categories (Source: Ramsey & Sleeper, 1988)

Each face of a building requires different shading treatment as sunlight strikes each side from different angles. Exterior shading devices such as overhangs, louvers, and egg crates should be encouraged given their significant impact on improving internal thermal conditions. However, egg crate devices proved to be best for reducing indoor air temperature and decreasing the number of discomfort hours due to their configuration (i.e. combination of overhang and fin devices) This avoids solar radiation from varied sun angles. (Al-Tamimi, 2011).

2.7.5. Designing Sun Shading Systems

There are four steps to be followed in the design of shading devices.

Step One. It is necessary to determine when shading is required. That is, at which times of the year and during which hours of the day. This is usually done by defining the overheated and under heated periods.

Step Two. The position of the sun for the times when shading is required must be established. This is usually done with the aid of sun-path diagrams.

Step Three. The dimension and proportion of the shading device that will provide shading during the period earlier defined should be found. This is done with the aid of a shading angle protractor. The shading angle protractor is used to determine the horizontal and vertical shading angles of the shading device. The shading angles can be determined for only one orientation at a time.

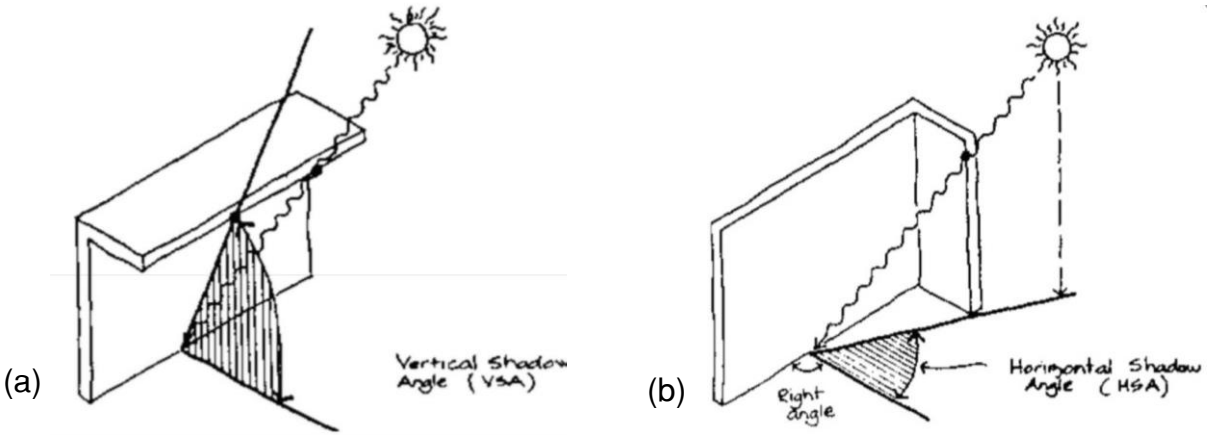


Figure 2.7. (a)Vertical and (b)Horizontal shading angle (Source : Antony, 1979)

Step Four. The choice of prefabricated devices or the design of new ones. The design of shading devices takes not only the required geometry into consideration but also aesthetics and structural factors.

2.8. Tools for Shading Systems Analysis

Now a days, hand calculation of thermal and visual parameters become more complex for multi zones or buildings due to dynamic environmental conditions. These include, variation of outside air temperature and solar radiation with time, shading by neighboring buildings, self-shading, and thermal capacity of a building. Computer-based simulation tools are now available to do quick and accurate assessment of a building's thermal and day lighting performance. These tools can estimate the performance of different designs of a building for a given environmental condition.

2.8.1. Simulation Tools

There are various simulation tools that have been developed till date to assess and make informed design decisions regarding energy performance of buildings during pre-design, design, and construction phases. It often becomes overwhelming for professionals to choose among a list of these tools. Many scientific studies have been conducted to help identify the needs of different users versus tool capabilities and limitations in order to facilitate the selection process for architects and engineers. According to a study by Shady Attia and others (2012), identification of user requirements, selection criteria for building performance simulation (BPS) tools and online survey of inter-group comparison between architects and engineers was conducted. Simulation tool parameters like accuracy, usability, and interoperability were considered the most important by architects and engineers. Popular and validated building energy simulation tools can be found listed on the U.S Department of Energy's (DOE) Building Energy Software Tools directory (BEST).

Under listed are a list of some of the most well-known simulation tools that are used for assessing building energy performance.

Autodesk Ecotect Analysis. Is a BIM environmental simulation tool that is open-source and capable of computing and analyzing thermal loads, lighting design, shadows and reflections, shading devices, and solar radiation. It uses the CIBSE Admittance Method to calculate heating and cooling loads and daylight factor method to calculate illuminance levels. (Vangimalla, et al. 2011) It provides an interactive visual experience to users and yields graphical results. It is also interoperable with other modeling and energy simulating applications for more detailed computations. According to a study conducted by Shady Attia and others (2012), Ecotect was mostly used during conceptual and design development stages to aid architects in making informed design decisions.

Autodesk Insight 360. Is a later development with evolved functionalities. Part of its functionality was adopted from Autodesk Ecotect, a software discontinued in 2012. Shortly after, Project Vasari was born and was around till 2015. Afterwards, concepts from Project Vasari were integrated to the REVIT family as a plugin called Autodesk Insight 360. It integrates workflows for solar analysis, lighting analysis, energy cost range and EnergyPlus Cloud capabilities to provide a holistic approach to building performance. (Egger, 2015)

EnergyPlus. Is a whole building simulation engine that is open-source and is free. It is one of the early developed softwares which still is funded by the U.S. Department of Energy's (DOE) Building Technologies Office (BTO). It is based on the well-known features and abilities of DOE-2.1E and BLAST. It has a rigid interface where inputs and outputs are computed as texts. Energy plus is a preferred engine due to its speed and accuracy. It is also used as a main computing engine in different building energy simulation applications. (EnergyPlus, n.d.)

Design Builder. It is one of the popular building performance simulation tools used to check building energy, CO_2, Lighting and comfort performance. It is the 1st comprehensive user interface to the EnergyPlus dynamic thermal simulation engine. As such, it is equipped with an advanced graphical user interface mainly intended to run simulations using EnergyPlus. Design Builder allows modeling of complex buildings with ease due to its innovative productivity features. In countries like UK and Republic of Ireland, users can use its interface to produce Energy Performance Certificates (EPCs) for compliance with building regulations. (Pawar & Kanade, 2018)

OpenStudio. Is another whole building simulation software that incorporates EnergyPlus as its main engine. It provides a graphical interface for conveying inputs and outputs to Energy Plus. Its development also comes with a plugin for SketchUp, Parametric Analysis Tool, and Results Viewer. It's make is based on programming languages like C++, Ruby and C#. It allows access to users and software developers through its multiple entry points. This helps to create OpenStudio Measures that can easily be shared and adopted to OpenStudio Models. (OpenStudio, 2021)

Honeybee. Is a building performance tool that creates, assesses and generates simulation results for daylight, heat flow, and energy models in Computer Aided Drawing (CAD) applications. It uses engines like Radiance for daylighting, Therm for heat flow, and EnergyPlus for energy models. This makes it comprehensive and much more valuable for mid or later design stages. It also provides an object-based Application Programming Interface (API) for its engines through Revit and Grasshopper plugins. (Honeybee, n.d.)

CHAPTER THREE

Research Method

CHAPTER THREE: Research Method

3.1. Introduction

This research is conducted through the help of knowledge gained from different journals, case related local prior studies and international case studies, and investigation of local case buildings. Careful observations and analysis are made on local case buildings in Addis Ababa using different scientific methods. These methods are further explained in the analysis plan of this chapter. The research method used is summarized in Figure 3.1.

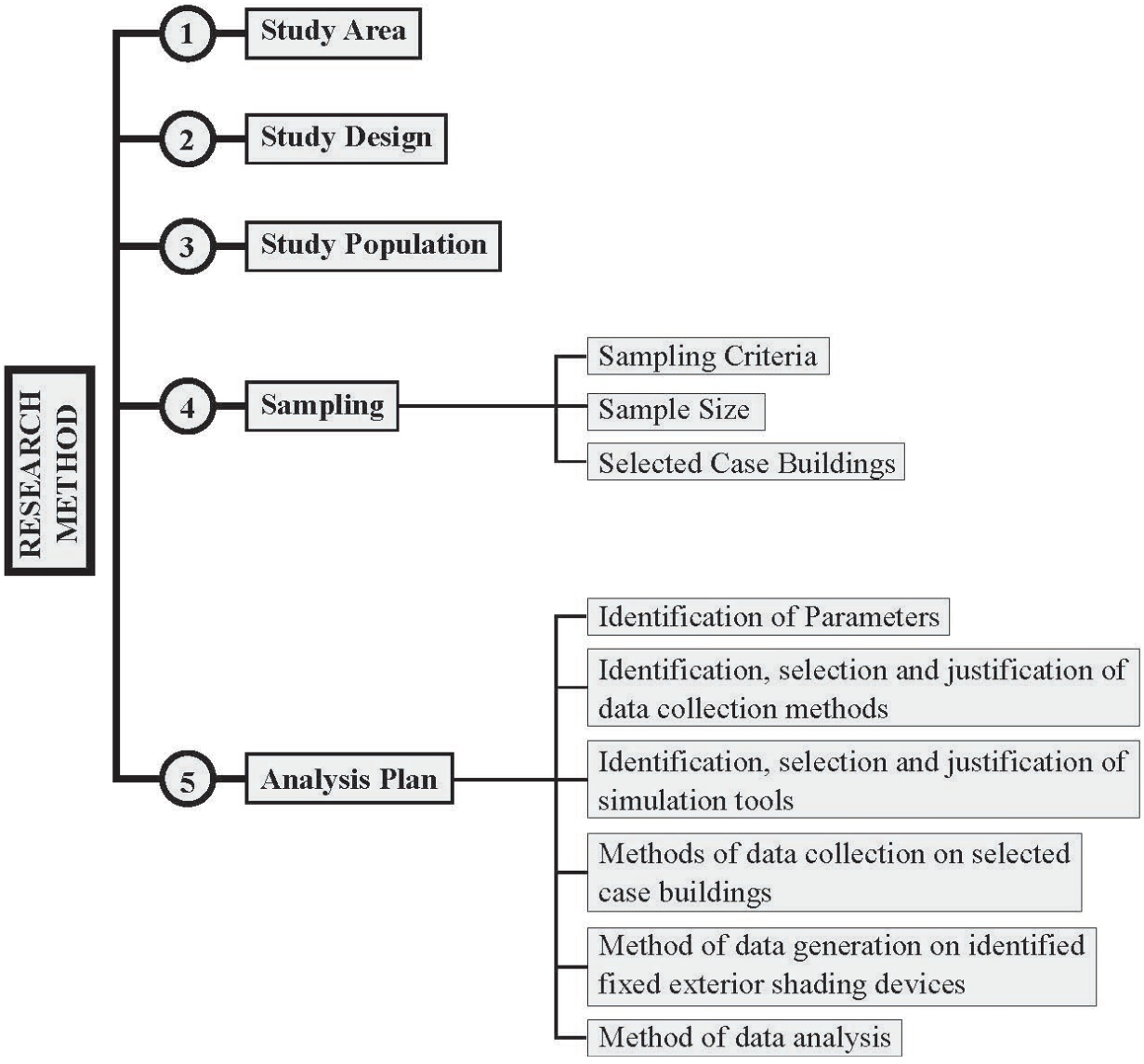


Figure 3.1. Research method outline

3.2. Study Area

The research focuses on the city of Addis Ababa as it has been undergoing big developments and transformations in the construction industry for the past few decades. Among many developments, the rise of fully glazed buildings, intended for library or office use, with different fixed exterior shading devices are well observed. These buildings are located in different sub-cities and different orientations thus making Addis choice of the study.

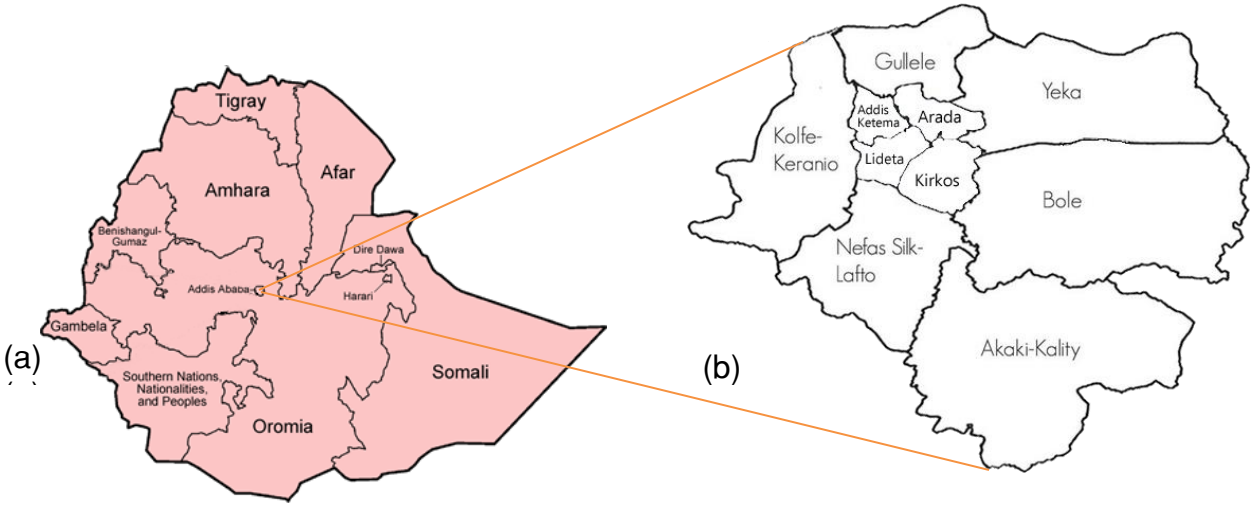


Figure 3.2. (a)Study arealocation map and (b)Map of Addis Ababa (Source: addisababa.gov.et)

3.3. Study Design

There are a number of scientific approaches which could be used to solve a specific problem. This research opts for a descriptive research study design as it tries to identify an existing problem and proposes a suitable approach to provide a scientific solution. (Zegeye, et al., 2009)

3.4. Study Population

The type of study population may vary from research to research depending on the problem and objective of the study. In this case, the study population considered are library or office buildings in the city of Addis that have radiation vulnerable full-glazed facades with fixed exterior shadings attached.

3.5. Sampling

Sampling is a process of selecting a number of study units from a clearly defined study population. (Zegeye, et al., 2009) In this research, the study population refers to full-glazed buildings intended for library or office use. These buildings are selected based on sampling criteria.

3.5.1. Sampling Criteria

There may be vast number of populations that relate to a problem in a research. Defining the sampling criteria helps narrow them down to manageable parts to investigate further. In this case, the population (case buildings) in Addis Ababa are chosen based on the fulfillment of the following criteria. The case buildings should:

- either serve as a library or an office.
- at least be occupied for a year.

  This is intended to have respondents which have gone through the thermal experience of each month and seasons within the year.
- at least have one radiation vulnerable full-glazed façade oriented in any direction.
- have fixed exterior shading devices attached as a means of solar control.

3.5.2. Sample Size

Sample size identification is important in a scientific investigation especially when the study population is vast, difficult and time consuming. With regard to this research, case buildings are selected based on the sampling criteria. Since the identified available case buildings are numbered and manageable, all of them are considered.

3.5.3. Selected Case Buildings

During the sampling process of case buildings in Addis Ababa, different types of buildings that have fixed exterior shading devices were identified. Selections were made after repeated excursions in different sub-cities. Under listed are a list of selected case buildings that are located in different sub-cities of Addis Ababa that fulfill the sampling criteria.

- Africa Insurance Building
- Finfinne Building
- Henk de Pagter Library
- John F. Kennedy Library
- Renaissance Building
- Wegagen Bank Head office

The listed case buildings have different fixed exterior shading devices attached to them. Information regarding their location, orientation, height, shading type, shading material, and layout is explained. These data are further used in the analysis plan of this chapter.



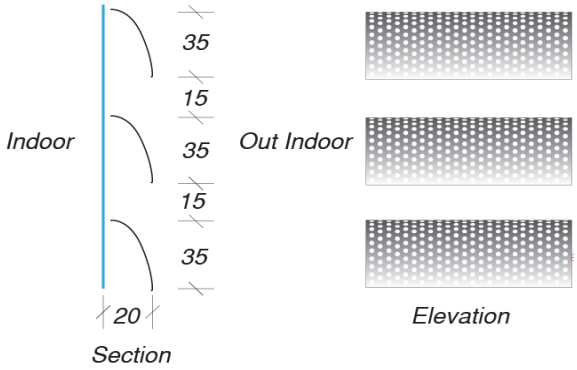
Building Information

. Location: Bole road Africa avenue
. Function: Office
. Stories: 13

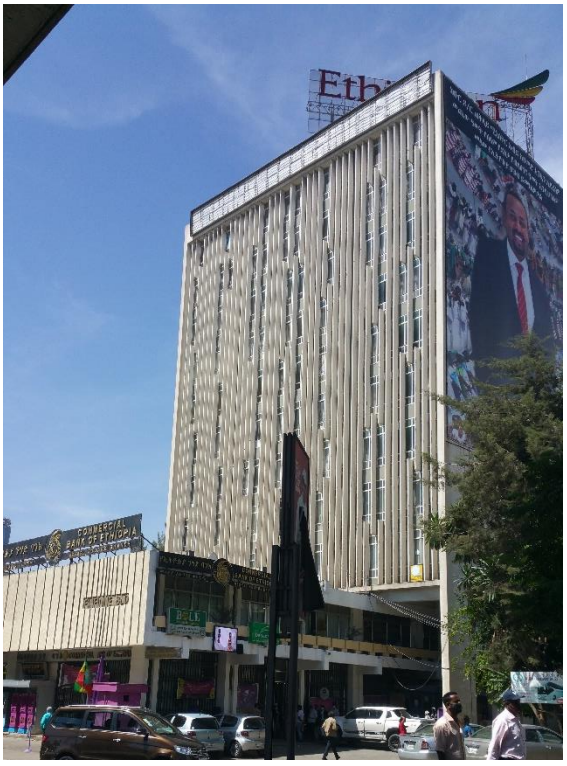
Shading Device Information

. Material: Aluminum
. Type: Horizontal
. Location: East, South and West

Shading Layout (in cm)



(a)



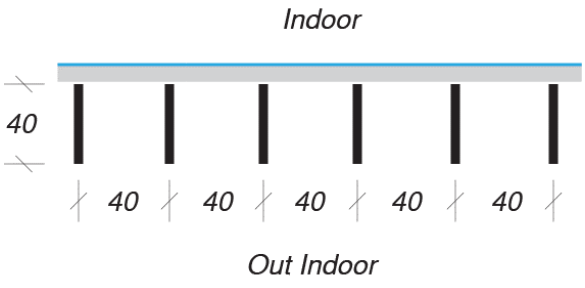
Building Information

. Location: Mesqel Square
. Function: Office
. Stories: 11

Shading Device Information

. Material: Coated Metal
. Type: Vertical
. Location: East, South and West

Shading Layout (in cm)



(b)

Figure 3.3. Shading adaptations (a)Africa Insurance building and (b)Finfinne building



Building Information

. Location: Jemo

. Function: Library

. Stories: 1

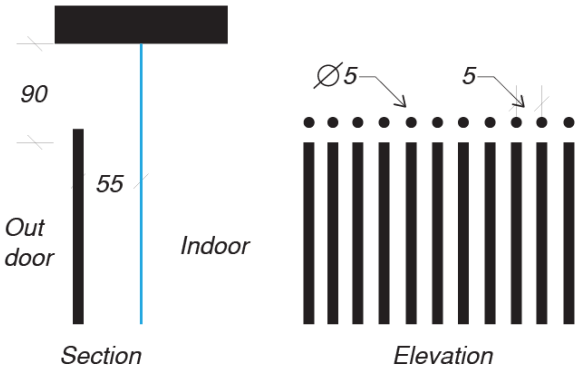
Shading Device Information

. Material: Bamboo

. Type: Vertical

. Location: East

Shading Layout (in cm)



(a)



Building Information

. Location: 6 Kilo

. Function: Library

. Stories: 2

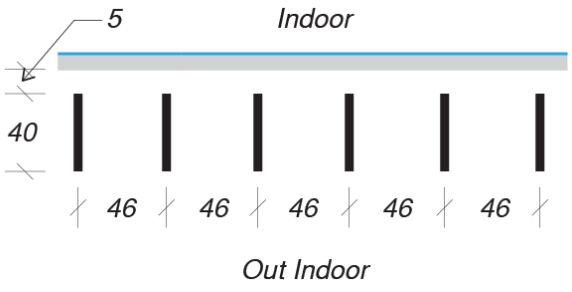
Shading Device Information

. Material: Aluminum

. Type: Vertical

. Location: North, East, South and West

Shading Layout (in cm)



(b)

Figure 3.4. Shading adaptations (a)Henk de Pagter library and (b)John F Kennedy library



(a)

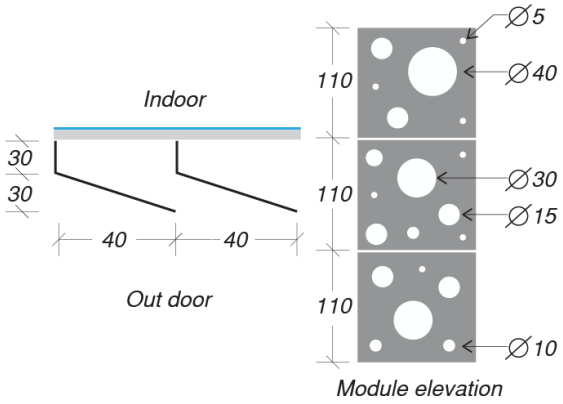
Building Information

. Location: Megenagna
. Function: Bank and meeting hall
. Stories: 15

Shading Device Information

. Material: Aluminum
. Type: Vertical
. Location: North, South and West

Shading Layout (in cm)





(b)

Building Information

. Location: Stadium
. Function: Head quarter Office
. Stories: 23

Shading Device Information

. Material: Aluminum
. Type: Vertical
. Location: East and West

Shading Layout (in cm)

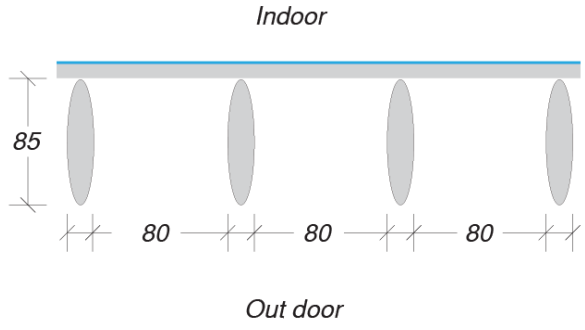


Figure 3.5. Shading adaptations (a)Renaissance building and (b)Wegagen Bank Head Office building

3.6. Analysis Plan

The analysis plan with in a scientific research is crucial to investigate sample cases related to the study. A logical and systematic approach would prove the validity of a research. In this research, the analysis of the chosen case buildings is conducted through a series of steps. These steps are further explained in the under mentioned stages.

- Identification of Parameters
- Identification, selection and justification of data collection methods
- Identification, selection and justification of simulation tools
- Methods of data collection on selected case buildings
- Method of Data Generation on Identified Fixed Exterior Shading Devices
- Method of data analysis

3.6.1. Identification of Parameters

There are many variables that should be considered while studying sample sizes in a research. It is challenging to work with all variables during a scientific study. It is important to identify the dependent and independent variables and decide which parameters to take as a constant. This helps to assess the impact of the variable in question and focus the study. In this research, the following parameters are identified.

Dependent. shading device type, shading device length, shading device orientation, and indoor temperature

Independent. solar radiation

Constant. glazing type, floor level, heat and shade from surrounding elements, glare, room size, construction materials, indoor colors, window sizes, and orientations to compare the different shading systems.

3.6.2. Identification, Selection and Justification of Data Collection Methods

In a scientific study, data could be collected using qualitative or quantitative ways. Both have their own category of methods.

3.6.2.1. Qualitative Data Collection Methods. Such methods require intimate relationship between the research, researched and situational circumstances that shape the enquiry. As a result, are often much more time consuming. Methods may include participant observation, semi-structured interviews, and introspection. Analysis is made while collecting data. (Zegeye, et al., 2009)

3.6.2.2. Quantitative Data Collection Methods. Favor systematic and scientific investigation of quantitative properties and relationships. They concentrate on measuring, collecting and analyzing numerical data. In general, methods include Laboratory observations, questionnaire, and scheduled or structured interviews. Analysis is made after collecting data. In relation to this research, the most popular methods used are real simulation, Experimental, questionnaires', case study, and computer simulations. (Zegeye, et al., 2009). Quantitative data collection methods are chosen because they provide objective means to gather accurate data and analyze it. Table 3.1. shows the evaluation of these methods depending on some parameters.

	Research Cost	Time Needed	Accuracy	Experience Needed
Real Simulation	Very Expensive	Time Consuming	Accurate	High Experience
Experimental	Expensive	Time Consuming	Most Accurate	Adequate Experience
Questionnaire	Affordable	Minimum Time	Less Accurate	Less Experience
Case Study	Affordable	Time Consuming	Least Accurate	Adequate Experience
Computer Simulation	Affordable	Minimum Time	Nearly Accurate	Software Experience

Table 3.1: Evaluation of quantitative data collection methods (Source: Melaku, 2016)

Due to time and budget limitations, this research will be limited to questionnaires, case studies, and computer simulations to obtain objective data.

3.6.3. Identification, Selection and Justification of Simulation Tools

According to a study made during the literature review, a number of building simulation applications have been developing rapidly to enhance options that are more flexible and accurate. The selection criteria for such applications vary from user to user. Referring to a study done by Shady Attia and others (2012), the most important parameters that architects and engineers focus on are found to be, usability and graphical visualization of the interface, accuracy of the tool, and interoperability of the building model. Taking these aspects into consideration, Autodesk Ecotect software is used for simulation.

3.6.4. Method of Data Collection on Selected Case Buildings

According to the data collection methods assessment made, questionnaires and local case building shading device measurements are chosen to gather qualitative data. Approaches on each method are explained below.

3.6.4.1. Questionnaires. Questionnaires are prepared for users of the selected case buildings. They relate to thermal comfort and follow ASHRAE standards for thermal comfort survey. They include questions categorized in two sections. (See **Appendix** B).

3.6.4.2. Measurements on case buildings' shading devices. Buildings related to this research are chosen based on the sample selection criteria. Necessary measurements are taken. These include location, orientation, height, type, material, and layout of the fixed exterior shading devices. Such details of the buildings supported by pictures are already discussed in this chapter under the "Selected Case Buildings" Topic.

3.6.5. Method of Data Generation on Identified Fixed Exterior Shading Devices

3.6.5.1. Computer Simulations. There are different existing fixed exterior shading devices in different orientations. This method helps assess their efficiency and generate quantitative data. For this purpose, a "Mockup" Model is used. It is an example room that helps to simulate different shading systems on different orientations. A model unit of 7.5x7.5x3 meters is proposed. The length and width of the model unit is the same to provide equal exposed surface for North,

East, South and West orientations. Its height is limited to three meters to depict an average clear height of a typical workspace. To assess the efficiency of the shading devices, annual solar assess analysis and monthly solar heat gain analysis are conducted on the four major orientations. This would help compare and analyze how they perform during overheated periods throughout the year. Based on the selection and justification criteria mentioned, Autodesk Ecotect software is used for simulation.

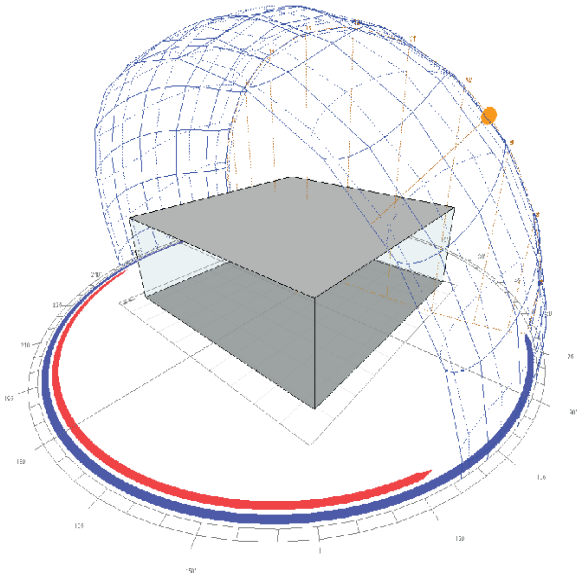


Figure 3.6. Mockup model for simulation

Mockup procedure

1. Modeling the identified fixed exterior shading types for Mockup use.
2. Simulating a bare mockup model for initial results. The simulations are annual solar assess analysis and thermal analysis.
3. Simulating each shading device for North, East, South, and West orientations on the mockup.
4. Conducting comparisons and discussions on the results of each orientation.
5. Proposing an optimal sun shading approach based on weather data of Addis Ababa and testing it on the mockup for North, East, South, and West orientations.
6. Comparison of results of the existing shading devices and the proposed design.

3.6.6. Method of data analysis

The quantitative results collected through case building measurements and questionnaires, and generated through computer simulations will be tabulated and organized. Then the output data will be compared and analyzed holistically to reach a valid outcome.

CHAPTER FOUR

Prior Studies and International Case Studies

CHAPTER FOUR: Prior Studies and International Case Studies

4.1. Introduction

This chapter explores two case related prior studies that are conducted some years apart in Addis Ababa. This helps to understand the climate context as well as necessary approaches and tools required to do such studies. It also explores exemplary international case buildings that have implemented fixed exterior shading devices. This helps to understand their extent of application as a passive means of solar control.

4.2. Prior Studies

Two local case related researches were considered during this study. One was a study done by Dawit Melaku (2016) which aimed at assessing the impact of glass façade on humans' thermal and visual comfort. In the study, 120 participants were involved. Around 78.33% of respondents were dissatisfied with the thermal environment. Furthermore, Computer simulation of selected case buildings showed the months of March, April, and May to be the hottest periods of the year. Similarly, another study was done by Samuel Getachew & Nebyou Yonas (2020) which aimed at comparing and evaluating naturally ventilated administration buildings in terms of thermal comfort. In the study, 5 Addis Ababa sub-city administration offices with different orientations were assessed. The study was conducted through field measurements, occupant survey, secondary data, and analysis. During the study, necessary field and survey measurements were taken during the month of May as it is considered to be the warmest month. In this time, the buildings oriented towards North-West showed better thermal environment for occupants than the other building orientations.

4.3. International Case Studies

4.3.1. The Ford Alumni Center

The Ford Alumni Center is a four-story, 60,000 sq. ft. alumni facility located in the heart of the University of Oregon campus. It was designed by architect Robert Thompson of TVA Architects, Inc. The facility provides gathering space for events, state of the art technology, artifact displays, a welcoming lobby and lounge area, a ballroom, a garden courtyard and lawn, conference rooms, a boardroom, and multi-purpose rooms. It is a sustainable design which is awarded LEED Gold Certification for its solar shading approach. Strong vertical and horizontal metal grilles and mesh screens are oriented appropriately for maximum sun control at the large expanses of glass. These woven metal fabric fins contributed to the LEED Gold criteria by reducing glare on the building's western elevation, limiting solar heat gain and providing natural day lighting and views. (Wormuth, 2021)

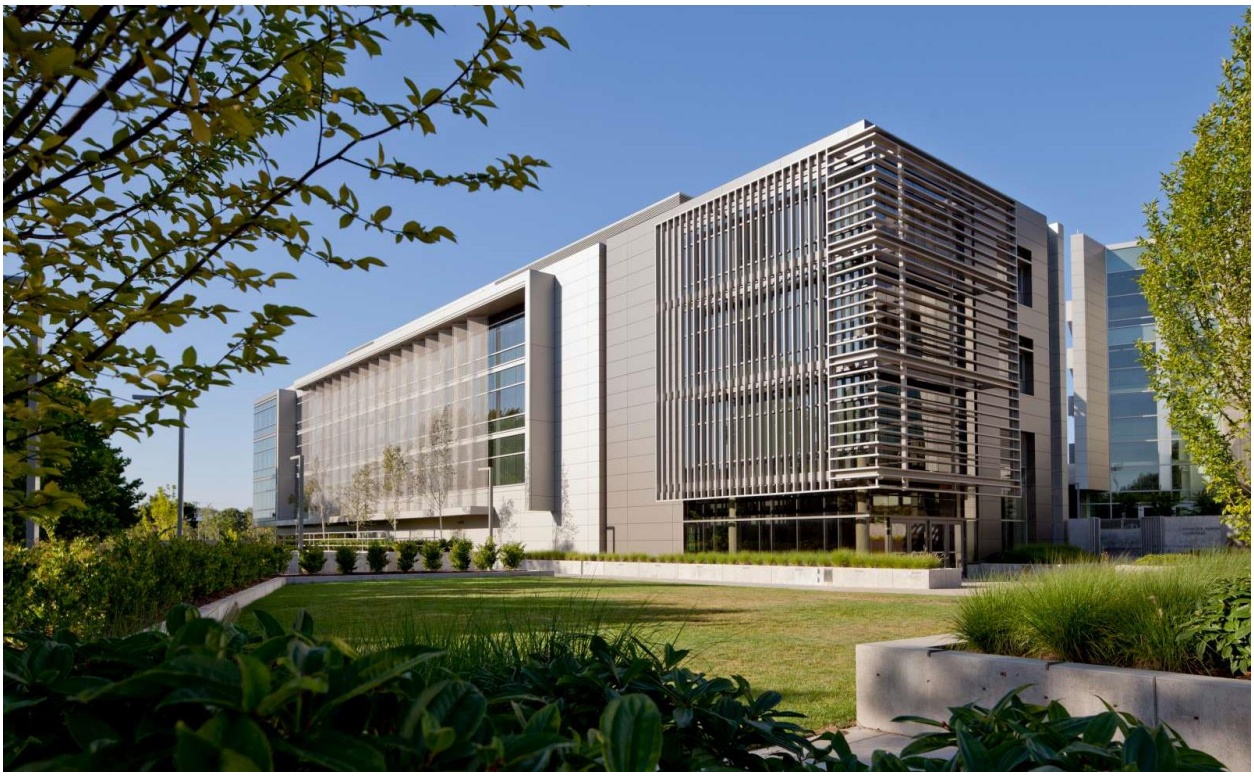


Figure 4.1. The Ford Alumni Center, Oregon University (Source: Gary, 2011)

4.3.2. Life Science University

The Life Science University building is a six-story, 207,000 sq. ft. building located in Washington. It was a collaborative work of different engineers with Perkins +Will design firm. It combines materials found in the Pacific Northwest and was named building of the year in 2018 by Seattle's daily journal of commerce. It is a sustainable design which is awarded LEED Gold Certification for its Building Integrated Photovoltaic (BIPV) shading approach. The building's south wall is partially comprised of a thin film of solar cells placed with in vertical glass fins.



(a)

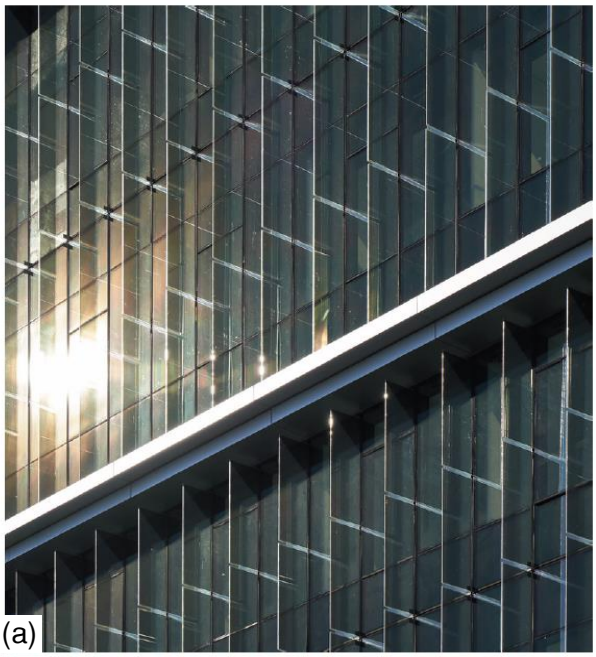


(b)

Figure 4.2. Life Science Building, University of Washington (a)Typical floor plan and (b)Human-eye perspective (Source: Guizlo, n.d.)

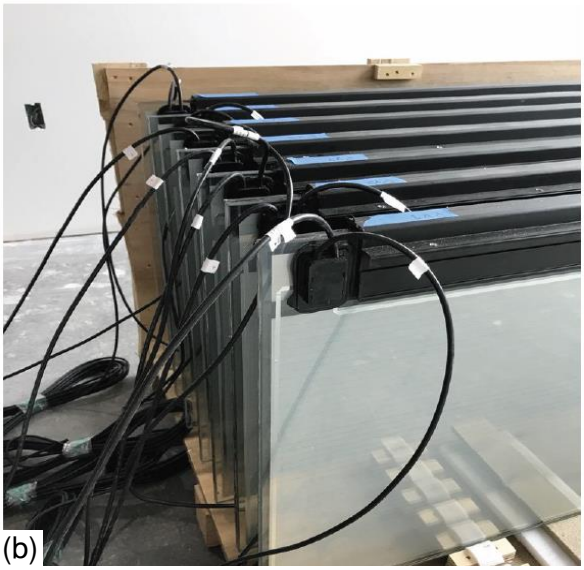
These fins use the energy of the sun to produce electricity that gets fed to the city's grid. This technology provides year-round electricity to 12,400 sq. ft. of open and privet offices along the perimeter of the building. (Guizlo, n,d.)

Northwest oriented Glass fins help reduce solar heat gain from low afternoon sun in summer whereas Southeast oriented glass fins produce energy from sunshine even with overcast skies. Amorphous Silicone solar cells are used because they are more effective than crystalline silicone cells in diffuse light conditions and are less obstructive to views. The thin solar film is encapsulated within two pieces of tempered glass.



(a)

The BIPV fins are supported within a Kawneer curtain wall vertical mullion custom designed to support the glass, encapsulate the junction box electrical connection, and provide a cap on the interior that can be snapped off for maintaining electrical conduit running vertically up to the ceiling. (Guizlo, n.d.)



(b)



(c)

Figure 4.3. Life Science Building solar shading (a)South-East orientation view of glass solar fins, (b)solar glass fins before installation, and (c)solar glass fins during installation(Source:Guizlo, n.d.)

CHAPTER FIVE

Analysis and Interpretation of Results

CHAPTER FIVE:Analysis and Interpretation of Results

5.1. Introduction

In this chapter, results from the data collecting and data generating methods explained in chapter three are analyzed and interpreted. Quantitative data are obtained using questionnaires, Secondary data and Computer simulations. Results of each method are tabulated separately. Discussions are made at the end of each summary of results. The overall workflow of this chapter is shown in Figure 5.1.

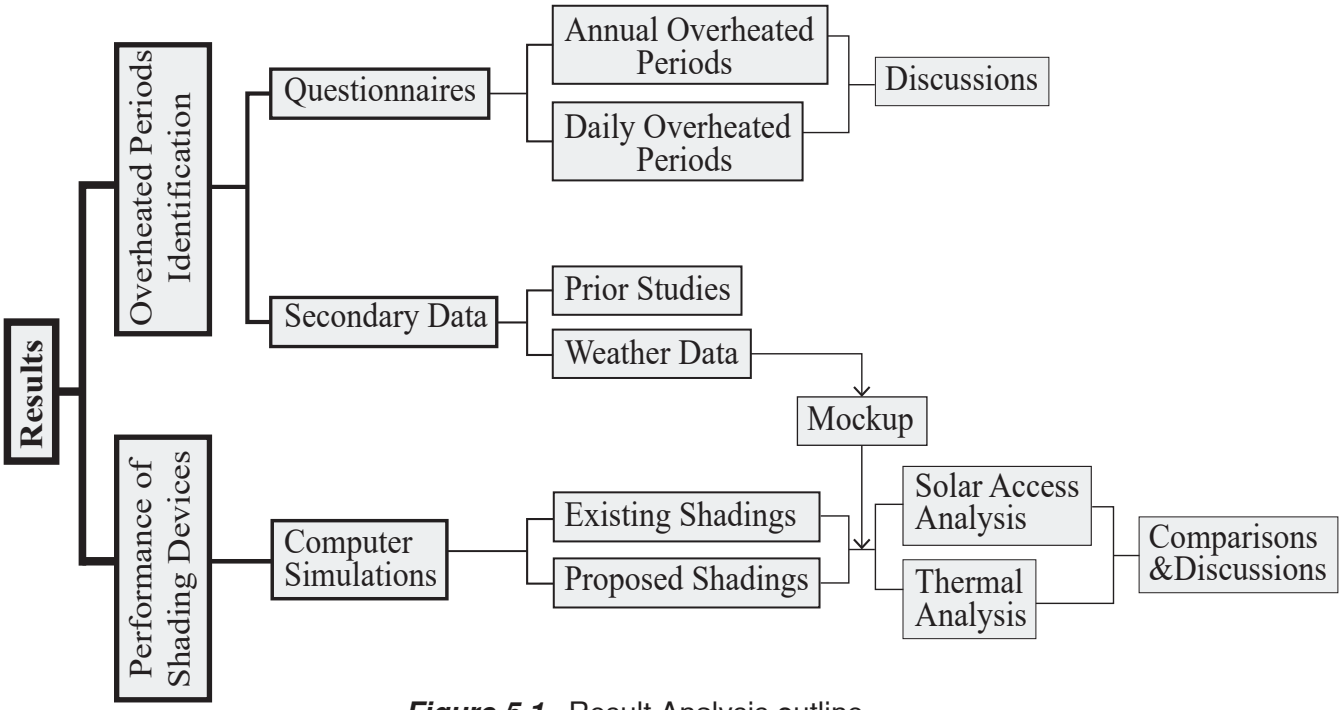


Figure 5.1. Result Analysis outline

5.2. Questionnaires

In collecting data using this method, a total of 6 case related buildings in Addis Ababa were surveyed and a total of 138 occupants were involved. The survey questions aimed at identifying and assessing the general perceptions of occupants regarding indoor thermal comfort in their respective work space. (See **Appendix** B).The response of occupants is tabulated. Table 5.1 shows the interior classroom of each case building, the number of respondents and their response on overheated periods.

Indoor Thermal Comfort Verification Survey Results																
Local Case Buildings' classroom	**Ppl.**	**Overheated Month**		**Response**				**Overheated Time(24hr.)**	**Response**			
	21	**Kiremt (Winter)**	June					**Morning**				
			July					08:00-09:00				
			August					09:00-10:00				
		Belg (Autumn)	September					10:00-11:00				
			October					11:00-12:00				
			November					**Afternoon**				
		Bega (Summer)	December					12:00-13:00		2		
			January					13:00-14:00	12			
			February					14:00-15:00			7	
		Tsedey (Spring)	March		3			15:00-16:00				
			April	8		6		16:00-17:00				
			May				4	17:00-18:00				
(a) Africa Insurance Building *(Datet taken:13/09/2020)*												
	20	**Kiremt (Winter)**	June					**Morning**				
			July					08:00-09:00				
			August					09:00-10:00				
		Belg (Autumn)	September					10:00-11:00				
			October					11:00-12:00				
			November					**Afternoon**				
		Bega (Summer)	December					12:00-13:00		7		
			January	2				13:00-14:00				
			February					14:00-15:00	10		3	
		Tsedey (Spring)	March		3			15:00-16:00				
			April			5		16:00-17:00				
			May				10	17:00-18:00				
(b) Finfine Building *(Date taken:04/09/2020)*												
	21	**Kiremt (Winter)**	June					**Morning**				
			July					08:00-09:00				
			August					09:00-10:00				
		Belg (Autumn)	September					10:00-11:00				
			October					11:00-12:00				
			November					**Afternoon**				
		Bega (Summer)	December	1				12:00-13:00			3	
			January	2				13:00-14:00		9		
			February					14:00-15:00	5			
		Tsedey (Spring)	March		5			15:00-16:00				4
			April			4		16:00-17:00				
			May				9	17:00-18:00				
(c) Henk de Pagter Building *(Date taken:16/09/2020)*												
	31	**Kiremt (Winter)**	June					**Morning**				
			July					08:00-09:00				
			August					09:00-10:00				
		Belg (Autumn)	September					10:00-11:00				
			October					11:00-12:00				
			November					**Afternoon**				
		Bega (Summer)	December					12:00-13:00		6		7
			January					13:00-14:00	13		5	
			February					14:00-15:00				
		Tsedey (Spring)	March		7			15:00-16:00				
			April	7		3		16:00-17:00				
			May				14	17:00-18:00				
(d) John F Kennedy Building *(Date taken:14/09/2020)*												

Indoor Thermal Comfort Verification Survey Results Cont.															
Local Case Buildings' classroom	**Ppl.**	**Overheated Month**		**Response**				**Overheated Time(24hr.)**	**Response**			
	23	**Kiremt (Winter)**	June					**Morning**				
			July					08:00-09:00				
			August					09:00-10:00				
		Belg (Autumn)	September					10:00-11:00				
			October					11:00-12:00				
			November					**Afternoon**				
		Bega (Summer)	December					12:00-13:00			4	
			January					13:00-14:00		3		
			February					14:00-15:00	11			5
		Tsedey (Spring)	March		2			15:00-16:00				
			April	6		5		16:00-17:00				
(e) Renaissance Building *(Date taken :11/09/2020)*			May				10	17:00-18:00				
	22	**Kiremt (Winter)**	June					**Morning**				
			July					08:00-09:00				
			August					09:00-10:00				
		Belg (Autumn)	September					10:00-11:00				
			October					11:00-12:00				
			November					**Afternoon**				
		Bega (Summer)	December					12:00-13:00		5		2
			January		1			13:00-14:00	12		3	
			February					14:00-15:00				
		Tsedey (Spring)	March	6		4		15:00-16:00				
			April					16:00-17:00				
(f) Wegagen Head Office Building *(Date taken :09/09/2020)*			May				11	17:00-18:00				

Survey Response Summary						
Surveyed Case Buildings	Total Number of Respondants	Results	Overheated Periods			
			Months	Ppl.	Time Ranges (24hr.)	Ppl.
6	138		March, April, May	6	12:00-17:00	26
			April, May	21	12:00-16:00	37
			March	24	12:00-15:00	9
			April	23	12:00-14:00	11
			May	58	13:00-15:00	11
			Other	6	One Hour Periods	44

Table 5.1. Thermal comfort verification survey results of selected case buildings (a-f)

Discussions

In identifying the overheated months, the following percentages were claimed by respondents. March,April & May by 4%, April & May by 15%, March by 18%, April by 17%, May by 42%, and other months by 4%. Overall, the month of May was claimed to be the hottest by 61% of the respondents. In identifying overheated time ranges , the following percentages were claimed. 12:00pm-5:00pm by 19%, 12:00pm-4:00pm by 27%, 12:00pm-3:00pm by 6%, 12:00pm-2:00pm by 8%, 1:00pm-3:00pm by 8% and one-hour periods found in the above stated ranges by 32%. Overall, the time from 12:00pm-4:00pm was claimed to be thermally uncomfortable by 46% of respondents.

5.3. Secondary Data

Regarding the climate context of Addis Ababa, secondary data were gathered from prior studies and weather data files obtained from the Department of Energy website. As discussed in Chapter Four, case related prior studies showed the month of May to be the hottest. This can also be observed in the interpreted data of the weather file by Climate Consultant software. It also shows periods of thermal discomfort during some months of the year. These periods are in correlation with the findings of the survey. Detailed interpretation of the weather file in Climate Consultant is discussed in Chapter Six of this paper.

5.4. Computer Simulations

Computer simulations help provide objective data in accessing the performance of fixed exterior shading devices in blocking incident solar radiation as well as optimizing indoor thermal comfort. In this regard, solar access analysis and thermal analysis simulations are performed using Ecotect software on a mockup model using weather file of Addis Ababa .

5.4.1. Solar Access Analysis

This analysis is intended to determine the availability of incident solar radiation (insolation), on surfaces and points on a geographically located model with and without fixed shading devices. Solar radiation calculations use hourly recorded direct and diffuse radiation data from a weather file. Calculations are performed and discussions are made for the four major orientations in the context of Addis Ababa. The simulations to follow are accompanied by solar input legends. These legends provide ranges of solar inputs per square meter of an exposed surface. Since the simulations take place only on vertical surfaces, the legend of the vertical surface that receives the maximum solar input is used. i.e. East oriented facade. Then the different shading devices are simulated for North, East, South, and West orientations.



Figure 5.2. Bare mockup surface exposure values in the climate context of Addis Ababa

5.4.1.1. Simulation Approach. A mockup model with a floor height of 3m is proposed in Ecotect software. It has equal exposed surfaces facing the four major orientations.A weather file of Addis Ababa is loaded. Sample shading devices from selected case buildings are imported for each orientation in different zones. A vertical surface of the mockup facing each orientation is selected. Calculations with and without shading devices are performed for each orientation. In this regard, only incident rays are calculated and values are displayed as hourly average temperatures for each month of the year.

5.4.1.2. Calculation

Step 1	Solar Access *(What to calculate ?)*	Incident Solar Radiation *(Calculates total,direct & diffuse radiation falling on objects.)*
Step 2	Calculation Period *(Over what period to calculate ?)*	For Specified Period *(Allows selection of particular date/time.)*
Step 3	Specific Date/ Time Period *(What days or times to use ?)*	Date Range/Time Range *(All year...../07:00-18:00)*
Step 4	Period Based Values *(Which period-based values to store?)*	Average Daily Values *(Calculates the sum of all values in each metric and divides it by the number of days for each months of the specified period.)*
Step 5	Model Objects or GRID *(What should values be calculated for ?)*	Objects in Model *(Stores results as object attributes.)*
Step 6	Object Overshadowing *(How to calculate overshadowing ?)*	Use Existing Shading Tables *(Uses shading masks from an inter-zonal adjecency calculation and /or those with in the sunpath dialogue.)*
Step 7	Summary	A dialogue showing all chosen steps is displayed.

Table 5.2. Solar access analysis calculation wizard steps

5.4.1.3. Result Interface

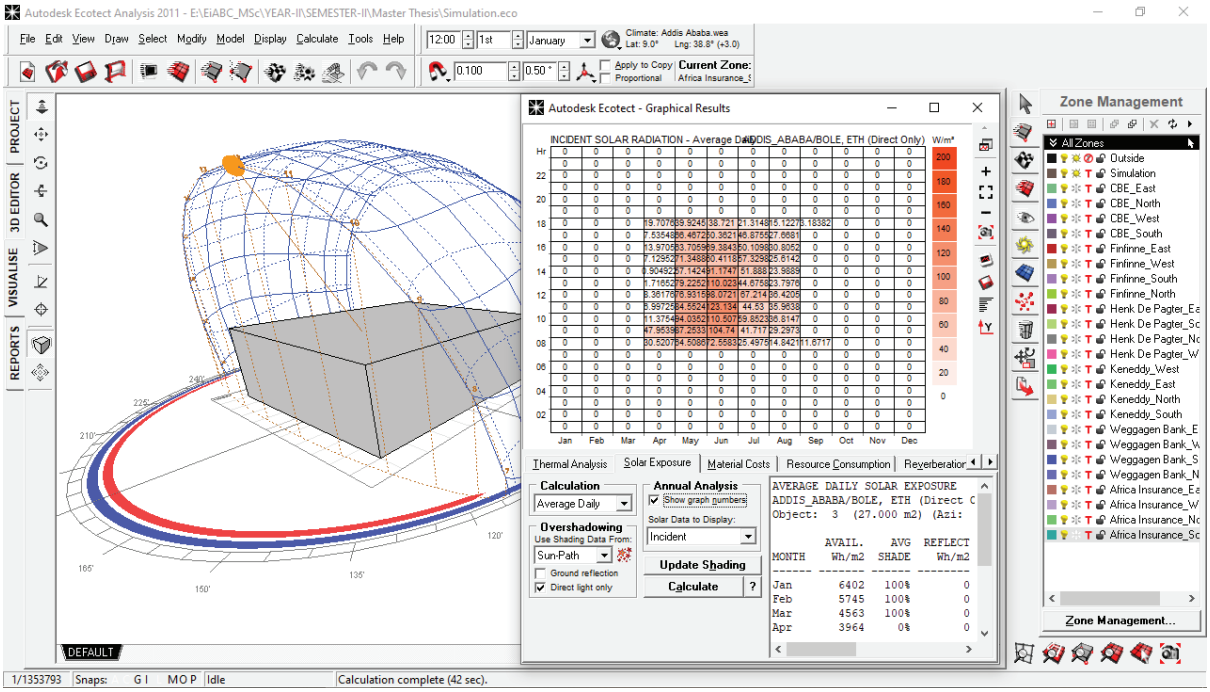
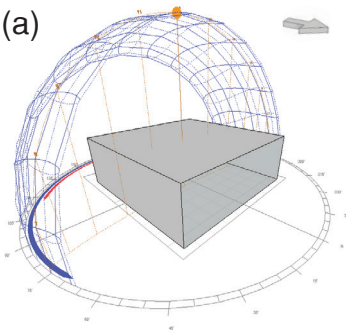


Figure 5.3. Solar access analysis output dialogue box (source: Ecotect software)

Shading Simulation- Solar Access Analysis- North oriented facade

(a)

BARE MOCKUP



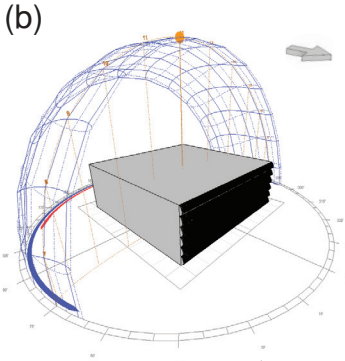
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	15.4377	40.3508	39.9266	21.5424	14.084	5.36223	0	0	0	540
	0	0	0	7.90642	64.7638	46.1729	42.9764	25.9951	0	0	0	0	480
16	0	0	0	11.2362	60.9636	62.3755	48.3769	26.7233	0	0	0	0	420
	0	0	0	4.4284	70.3927	57.8873	54.934	26.1776	0	0	0	0	360
14	0	0	0	0.730092	64.9768	105.197	48.8762	21.819	0	0	0	0	300
	0	0	0	2.29796	82.3348	104.139	46.4293	24.0855	0	0	0	0	240
12	0	0	0	10.314	76.9244	97.4157	67.8541	42.6368	0	0	0	0	180
	0	0	0	8.79174	79.5275	121.715	48.6587	32.3374	0	0	0	0	120
10	0	0	0	11.0522	84.9192	111.658	60.4757	36.2927	0	0	0	0	60
	0	0	0	40.557	99.4092	107.229	38.3293	29.1056	0	0	0	0	0
08	0	0	0	24.595	75.4312	71.2276	25.0299	17.1792	9.99313	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	4	0	0	0	0	82	100	100	100

(b)

Africa Insurance MOCKUP



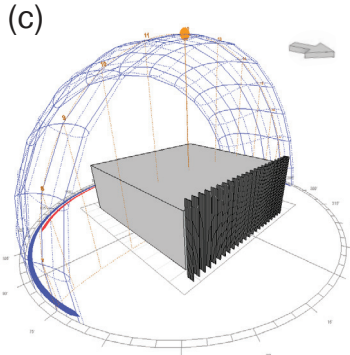
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	6.43239	21.8567	16.6361	11.6688	5.28151	2.23426	0	0	0	540
	0	0	0	2.75006	26.9849	21.1626	19.6975	9.74815	0	0	0	0	480
16	0	0	0	4.21358	22.8614	25.9898	18.1413	10.0212	0	0	0	0	420
	0	0	0	1.34777	20.5312	16.8838	16.0224	7.63514	0	0	0	0	360
14	0	0	0	0.283925	18.9516	35.0656	14.2556	6.36388	0	0	0	0	300
	0	0	0	1.14898	37.7368	47.7306	21.2801	11.0392	0	0	0	0	240
12	0	0	0	4.72725	35.257	44.6489	33.9271	19.5418	0	0	0	0	180
	0	0	0	4.20474	36.4501	65.9288	22.3019	14.8213	0	0	0	0	120
10	0	0	0	5.0656	38.9213	51.1765	27.718	16.6342	0	0	0	0	60
	0	0	0	21.9684	49.7046	53.6145	19.1646	13.3401	0	0	0	0	0
08	0	0	0	14.3471	44.0015	41.5494	14.6008	10.737	5.41295	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	58	56	55	55	58	91	100	100	100

(c)

Finfine Bldg. MOCKUP



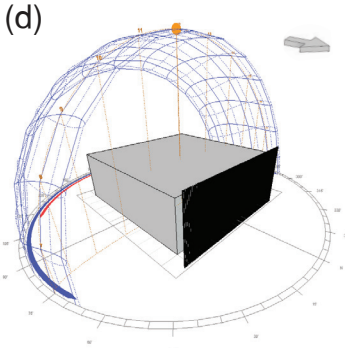
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	1.28648	3.36256	3.32721	1.7952	1.17367	0.446853	0	0	0	540
	0	0	0	0.343757	5.39699	3.84774	3.58136	2.16626	0	0	0	0	480
16	0	0	0	1.8727	10.1606	12.9949	8.06281	5.56734	0	0	0	0	420
	0	0	0	1.15523	17.5982	12.0598	11.4446	7.63514	0	0	0	0	360
14	0	0	0	0.446167	32.4884	39.4488	22.4016	11.8186	0	0	0	0	300
	0	0	0	1.35789	58.3205	73.7654	32.8874	17.0606	0	0	0	0	240
12	0	0	0	3.00825	28.8467	40.5899	22.618	14.2123	0	0	0	0	180
	0	0	0	1.91125	16.5682	35.5002	12.1647	8.08436	0	0	0	0	120
10	0	0	0	2.30255	17.6915	23.2621	12.5991	7.56099	0	0	0	0	60
	0	0	0	8.44938	20.7102	22.3394	7.98526	6.06367	0	0	0	0	0
08	0	0	0	5.12396	15.7148	14.8391	5.21456	3.57901	2.0819	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	76	73	73	73	72	97	100	100	100

(d)

Henk de Pagter Library MOCKUP



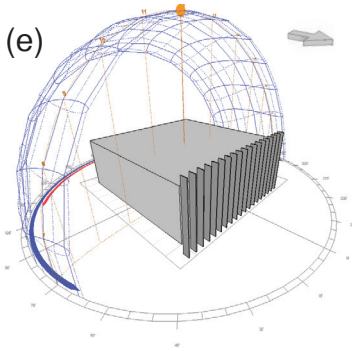
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	10.9351	16.8128	8.31803	8.97601	7.04202	5.13881	0	0	0	540
	0	0	0	7.90642	32.3819	23.0864	21.4882	16.2469	0	0	0	0	480
16	0	0	0	11.2362	43.1826	38.9847	30.2355	24.4963	0	0	0	0	420
	0	0	0	4.4284	55.7275	36.1795	34.3338	26.1776	0	0	0	0	360
14	0	0	0	0.730092	59.5621	92.0472	40.7302	21.819	0	0	0	0	300
	0	0	0	2.29796	75.4736	86.7829	42.5602	24.0855	0	0	0	0	240
12	0	0	0	10.314	67.3089	81.1798	50.8906	42.6368	0	0	0	0	180
	0	0	0	8.79174	59.6456	91.2861	36.4941	29.6427	0	0	0	0	120
10	0	0	0	11.0522	63.6894	69.7862	37.7973	27.2196	0	0	0	0	60
	0	0	0	33.7975	62.1308	62.5503	23.9558	18.191	0	0	0	0	0
08	0	0	0	17.4215	25.1437	23.7425	8.34329	5.72641	9.57675	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	11	31	38	36	21	83	100	100	100

Shading Simulation- Solar Access Analysis- North oriented facade cont.

(e)



John F Kennedy Library MOCKUP

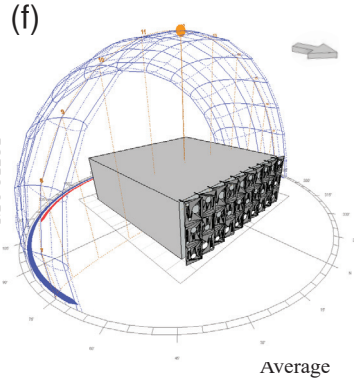
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	4.50268	3.36256	3.32721	1.7952	1.17367	2.68112	0	0	0	540
	0	0	0	5.84387	8.09548	3.84774	3.58136	7.5819	0	0	0	0	480
16	0	0	0	9.36351	15.2409	18.1929	12.0942	11.1347	0	0	0	0	420
	0	0	0	4.4284	35.1963	28.9436	27.467	15.2703	0	0	0	0	360
14	0	0	0	0.730092	46.0253	70.1312	34.6207	18.1825	0	0	0	0	300
	0	0	0	2.29796	72.0429	82.4437	40.6256	21.0748	0	0	0	0	240
12	0	0	0	10.314	44.8726	52.7669	28.2725	24.8714	0	0	0	0	180
	0	0	0	8.79174	39.7638	50.7145	22.3019	18.8635	0	0	0	0	120
10	0	0	0	10.1312	31.8447	32.5669	17.6388	12.0976	0	0	0	0	60
	0	0	0	16.8988	20.7102	22.3394	7.98526	6.06367	0	0	0	0	0
08	0	0	0	7.17354	15.7148	14.8391	5.21456	3.57901	4.58019	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	27	60	63	63	55	91	100	100	100

(f)



Renaissance Bldg. MOCKUP

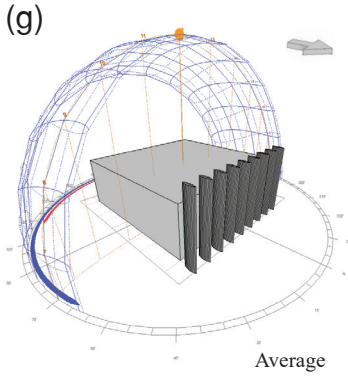
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	9.64859	31.9444	31.6085	17.0544	10.563	4.46853	0	0	0	540
	0	0	0	7.56266	53.9699	40.4013	37.6043	25.9951	0	0	0	0	480
16	0	0	0	10.2999	53.3432	54.5786	46.3612	25.6098	0	0	0	0	420
	0	0	0	4.4284	67.4596	50.6513	48.0673	26.1776	0	0	0	0	360
14	0	0	0	0.689532	59.5621	70.1312	38.6937	20.0008	0	0	0	0	300
	0	0	0	2.29796	75.4736	65.0871	42.5602	24.0855	0	0	0	0	240
12	0	0	0	9.88424	60.8985	64.9438	42.4088	39.0837	0	0	0	0	180
	0	0	0	8.79174	59.6456	96.3576	36.4941	29.6427	0	0	0	0	120
10	0	0	0	9.21018	63.6894	65.1338	35.2775	24.1952	0	0	0	0	60
	0	0	0	28.7279	62.1308	67.0181	25.5528	20.6165	0	0	0	0	0
08	0	0	0	15.3719	34.5726	38.5816	13.5578	8.58962	7.49485	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	17	21	28	24	15	86	100	100	100

(g)



Wegagen Bank(HQ) MOCKUP

INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	1.28648	3.36256	3.32721	1.7952	1.17367	0.446853	0	0	0	540
	0	0	0	0.343757	5.39699	3.84774	3.58136	2.16626	0	0	0	0	480
16	0	0	0	1.8727	10.1606	10.3959	8.06281	4.45388	0	0	0	0	420
	0	0	0	1.15523	17.5982	14.4718	13.7335	7.63514	0	0	0	0	360
14	0	0	0	0.405607	35.1958	56.9816	30.5476	13.6369	0	0	0	0	300
	0	0	0	1.9846	68.6123	86.7829	38.6911	20.0713	0	0	0	0	240
12	0	0	0	5.157	38.4622	56.8259	33.9271	21.3184	0	0	0	0	180
	0	0	0	2.67575	23.1955	35.5002	14.1921	9.43175	0	0	0	0	120
10	0	0	0	2.30255	17.6915	23.2621	12.5991	7.56099	0	0	0	0	60
	0	0	0	8.44938	20.7102	22.3394	7.98526	6.06367	0	0	0	0	0
08	0	0	0	5.12396	15.7148	14.8391	5.21456	3.57901	2.0819	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	71	69	69	69	68	97	100	100	100

Table 5.3. Solar access analysis of North oriented glazed facades(a-g)

Interpretation

Table 5.3. shows the different shading typologies tested for performance against incident solar radiation on a mockup model facing North. Comparisons are made among tabulated results of each shading typologies. Table 5.3. shows the solar access performance of each device for every month. Results of each shading device are processed and interpreted to a diagram using Microsoft Excel software. These devices are represented by different colors. Figure 5.4. shows the average shading provided by each shading device every month for this orientation.

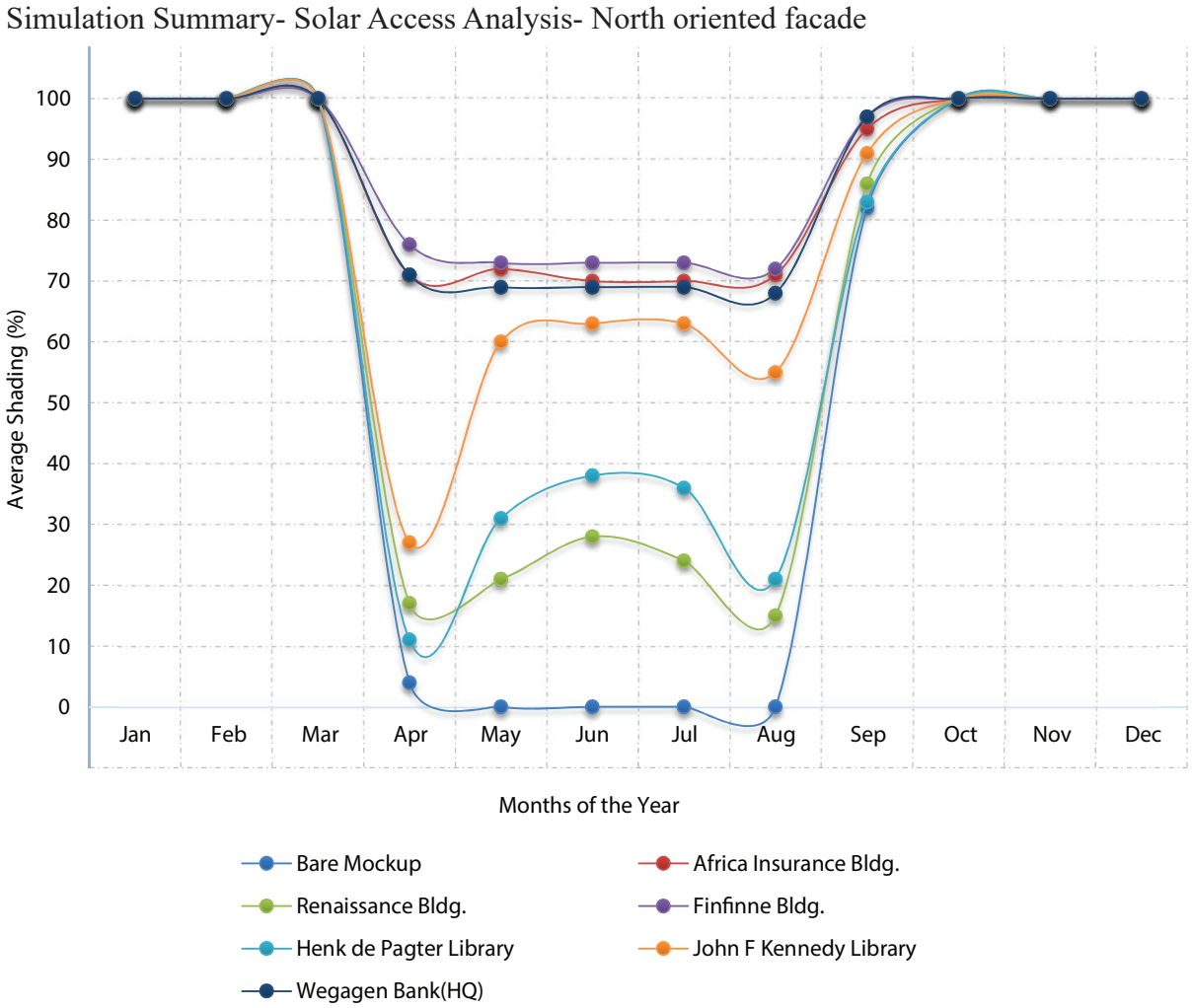


Figure 5.4. Solar shading performance summary for North oriented glazed facades

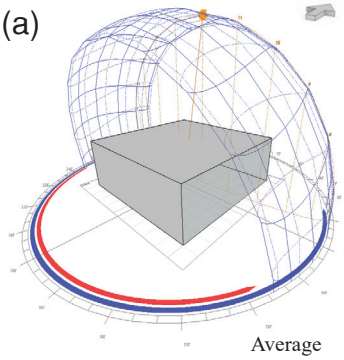
Discussion

For annual solar access analysis of North oriented glazed facades, Figure 5.4. shows the shading device sample adopted from Finfinne building proved to be more effective in blocking direct solar radiation during periods of solar exposure. Given the geographic location of Addis Ababa, simulations conducted on this orientation showed solar input for 5 months of the year namely April, May, June, July and August. Compared to other orientations, surfaces facing North received the least solar input per square meter of exposure ranging from 0 - 200W/m^2. During these months, the sun's trajectory is tilted to the North. The simulation of the bare mockup showed an annual average shading of 0.8% during these periods. Compared to this, the shading device adopted from Finfinne building improved it to an annual average shading of 73.4%.

Shading Simulation- Solar Access Analysis- East Facade

(a)

BARE MOCKUP



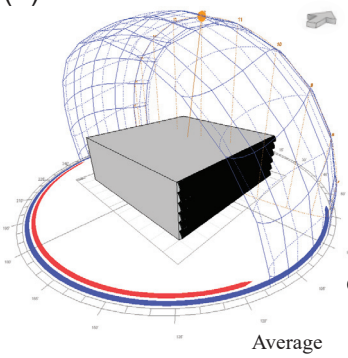
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	0	0	0	0	0	0	0	0	0	540
	0	0	0	0	0	0	0	0	0	0	0	0	480
16	0	0	0	0	0	0	0	0	0	0	0	0	420
	0	0	0	0	0	0	0	0	0	0	0	0	360
14	0	0	0	0	0	0	0	0	0	0	0	0	300
	108.791	87.6018	74.9402	44.8646	40.8339	44.3343	23.0266	30.5201	29.6164	22.1931	22.3996	43.3333	240
12	271.618	246.173	192.847	163.183	145.553	123.929	108.508	123.838	158.119	145.094	222.567	246.159	180
	427.686	410.807	287.299	316.867	251.498	243.53	110.775	145.365	237.276	313.71	359.958	381.763	120
10	495.181	484.546	377.423	341.447	294.818	251.05	135.973	146.989	318.16	436.33	508.727	479.893	60
	539.249	482.326	334.811	318.244	294.795	265.311	133.094	138.088	294.948	438.792	565.299	516.199	0
08	368.315	307.5	255.586	225.379	220.427	176.903	62.165	69.1597	191.299	343.557	453.791	391.507	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	45	45	45	45	45	45	45	45	45	45	40	45

(b)

Africa Insurance MOCKUP



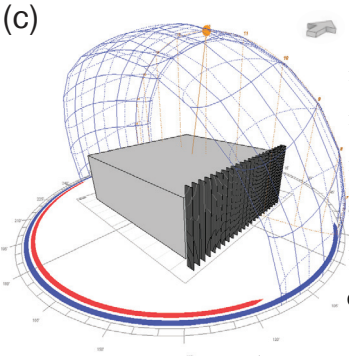
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	0	0	0	0	0	0	0	0	0	540
	0	0	0	0	0	0	0	0	0	0	0	0	480
16	0	0	0	0	0	0	0	0	0	0	0	0	420
	0	0	0	0	0	0	0	0	0	0	0	0	360
14	0	0	0	0	0	0	0	0	0	0	0	0	300
	40.7966	25.5505	21.8576	16.8242	18.7156	20.3199	10.5539	13.9884	8.63813	6.47298	6.53321	16.25	240
12	113.174	92.315	64.2823	88.3909	72.7767	56.8008	54.254	56.7592	46.118	42.3192	74.189	123.08	180
	142.562	136.936	95.7664	171.636	157.186	142.059	64.6186	90.8533	118.638	117.641	179.979	143.161	120
10	288.856	262.463	157.26	213.404	159.693	156.906	84.983	79.6193	172.337	163.624	190.773	199.955	60
	224.687	241.163	153.455	185.642	159.681	154.765	83.1839	86.3048	147.474	255.962	259.095	215.083	0
08	230.197	140.937	106.494	140.862	146.951	125.307	44.0336	43.2248	119.562	171.778	226.895	195.754	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	75	77	80	70	70	69	68	70	75	78	75	77

(c)

Finfine Bldg. MOCKUP



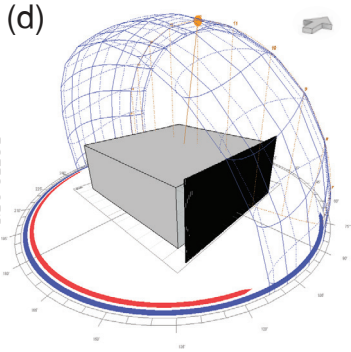
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	0	0	0	0	0	0	0	0	0	540
	0	0	0	0	0	0	0	0	0	0	0	0	480
16	0	0	0	0	0	0	0	0	0	0	0	0	420
	0	0	0	0	0	0	0	0	0	0	0	0	360
14	0	0	0	0	0	0	0	0	0	0	0	0	300
	22.6648	21.9005	28.1026	37.3871	17.0141	18.4726	9.59442	22.8901	17.2763	6.47298	4.66658	7.22222	240
12	56.587	82.0578	104.459	135.986	78.8414	51.6371	54.254	72.239	98.8242	54.4104	46.3681	30.7699	180
	142.562	188.287	155.62	264.056	167.665	121.765	55.3874	96.9101	148.297	156.855	104.988	63.6272	120
10	165.06	262.463	204.438	284.539	196.545	125.525	67.9864	97.9929	278.39	236.346	169.576	159.964	60
	269.625	261.26	292.96	225.423	159.681	132.656	88.7295	92.0584	270.369	237.679	306.203	258.099	0
08	199.504	166.562	223.637	169.034	119.398	88.4516	31.0825	46.1065	159.416	300.612	245.803	212.066	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	81	76	66	56	69	74	72	64	59	72	79	83

(d)

Henk de Pagter Library MOCKUP



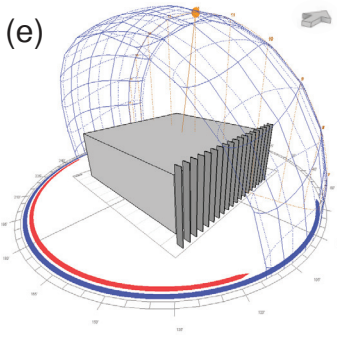
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	0	0	0	0	0	0	0	0	0	540
	0	0	0	0	0	0	0	0	0	0	0	0	480
16	0	0	0	0	0	0	0	0	0	0	0	0	420
	0	0	0	0	0	0	0	0	0	0	0	0	360
14	0	0	0	0	0	0	0	0	0	0	0	0	300
	95.1922	87.6018	71.8177	44.8646	40.8339	44.3343	23.0266	30.5201	29.6164	22.1931	22.3996	43.3333	240
12	135.809	133.344	104.459	95.1902	121.294	92.9467	85.9022	98.0387	131.766	96.7296	139.104	123.08	180
	249.484	222.521	179.562	184.839	188.624	182.648	78.4655	115.081	148.297	169.926	194.977	174.975	120
10	288.856	323.031	251.615	156.497	147.409	135.986	73.652	79.6193	212.107	199.985	339.151	259.942	60
	157.281	140.678	83.7029	172.382	147.397	154.765	66.5471	80.5511	208.922	310.811	447.528	150.558	0
08	260.89	243.437	149.092	131.471	110.213	103.194	36.2629	37.4615	79.7079	100.204	321.435	277.318	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	68	65	67	66	63	62	62	61	61	67	57	68

Shading Simulation- Solar Access Analysis- East Facade cont.

(e)



John F Kennedy Library MOCKUP

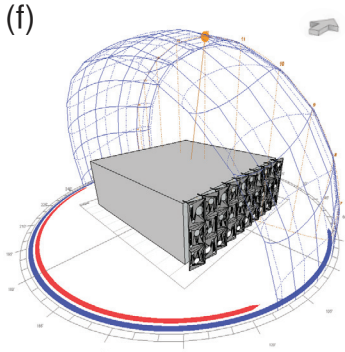
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	0	0	0	0	0	0	0	0	0	540
	0	0	0	0	0	0	0	0	0	0	0	0	480
16	0	0	0	0	0	0	0	0	0	0	0	0	420
	0	0	0	0	0	0	0	0	0	0	0	0	360
14	0	0	0	0	0	0	0	0	0	0	0	0	300
	49.8626	47.451	43.7151	41.1259	27.2226	29.5562	15.3511	27.9767	24.6804	21.2683	21.4663	28.8889	240
12	79.2219	153.858	136.6	142.785	97.0356	77.4556	72.3387	103.199	85.6476	90.684	92.7362	71.7965	180
	196.023	256.755	167.591	277.258	199.103	142.059	78.4655	121.138	148.297	222.211	194.977	174.975	120
10	226.958	282.652	204.438	298.766	233.398	135.986	73.652	116.367	212.107	254.526	275.56	219.951	60
	381.968	261.26	223.208	265.203	208.813	165.819	105.366	109.319	208.922	237.679	329.758	365.641	0
08	214.85	166.562	170.39	187.816	156.135	110.565	38.8532	54.7515	167.387	229.038	264.711	228.379	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	73	69	66	53	61	67	64	55	61	63	64	71

(f)



Renaissance Bldg. MOCKUP

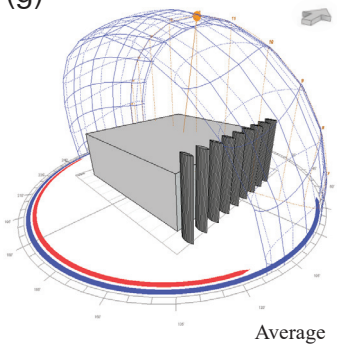
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	0	0	0	0	0	0	0	0	0	540
	0	0	0	0	0	0	0	0	0	0	0	0	480
16	0	0	0	0	0	0	0	0	0	0	0	0	420
	0	0	0	0	0	0	0	0	0	0	0	0	360
14	0	0	0	0	0	0	0	0	0	0	0	0	300
	86.1262	76.6516	65.5726	44.8646	40.8339	44.3343	23.0266	29.2484	27.1484	22.1931	22.3996	41.5278	240
12	158.444	153.858	120.529	129.187	97.0356	98.1105	67.8175	87.7188	92.2359	84.6385	139.104	153.85	180
	249.484	222.521	155.62	211.244	167.665	152.206	69.2342	90.8533	98.865	156.855	194.977	206.788	120
10	226.958	222.084	188.712	213.404	184.261	146.446	79.3175	91.8684	159.08	236.346	296.757	259.942	60
	157.281	80.3876	97.6533	159.122	159.681	143.71	72.0927	74.7975	159.764	164.547	188.433	150.558	0
08	61.3858	64.0624	74.5458	84.5171	91.8444	73.7097	25.9021	25.9349	71.7371	14.3149	56.7238	48.9384	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	74	74	72	64	64	64	66	65	70	72	68	72

(g)



Wegagen Bank(HQ) MOCKUP

INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	0	0	0	0	0	0	0	0	0	540
	0	0	0	0	0	0	0	0	0	0	0	0	480
16	0	0	0	0	0	0	0	0	0	0	0	0	420
	0	0	0	0	0	0	0	0	0	0	0	0	360
14	0	0	0	0	0	0	0	0	0	0	0	0	300
	18.1318	25.5505	40.5926	42.9952	30.6255	27.7089	17.27	25.4334	18.5103	6.47298	5.5999	7.22222	240
12	45.2696	71.8006	80.3529	142.785	115.23	92.9467	81.381	103.199	118.589	48.3648	37.0945	41.0266	180
	89.1013	154.053	179.562	290.461	199.103	192.795	87.6967	121.138	187.843	130.712	74.9913	79.534	120
10	165.06	201.894	283.067	312.993	245.682	198.748	107.645	122.491	265.133	272.706	169.576	159.964	60
	202.219	301.454	251.109	291.723	233.379	210.038	110.912	120.827	258.08	329.094	235.541	193.575	0
08	153.465	230.625	212.988	206.597	174.504	140.048	49.214	57.6331	175.357	257.668	189.079	163.128	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	85	75	64	50	57	59	57	54	56	71	82	85

Table 5.4. Solar access analysis of East oriented glazed facades(a-g)

Interpretation

Table 5.4. shows the different shading typologies tested for performance against incident solar radiation on a mockup model facing East. Comparisons are made among tabulated results of each shading typologies. Table 5.4. shows the solar access performance of each device for every month. Results of each shading device are processed and interpreted to a diagram using Microsoft Excel software. These devices are represented by different colors. Figure 5.5. shows the average shading provided by each shading device every month for this orientation.

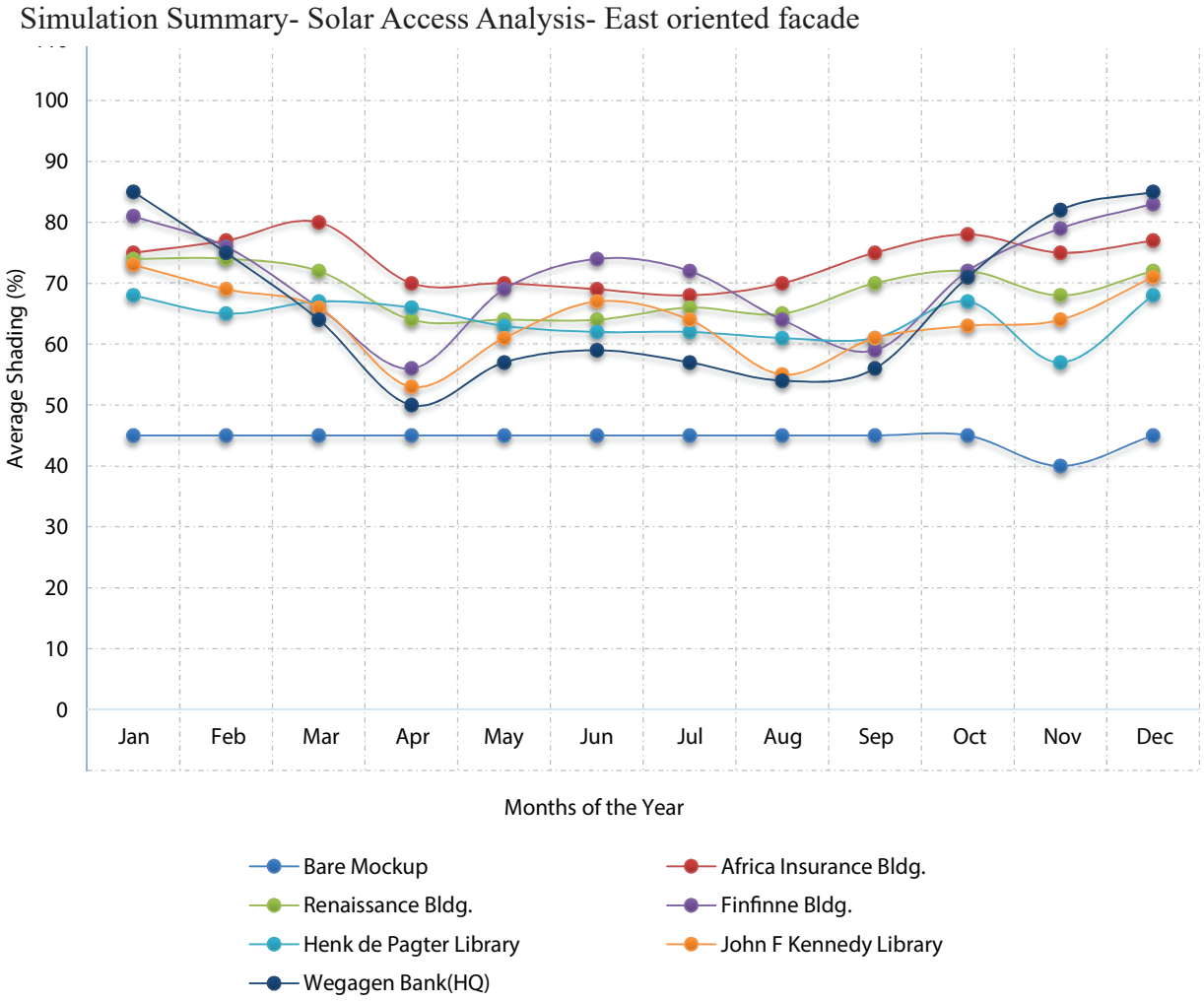


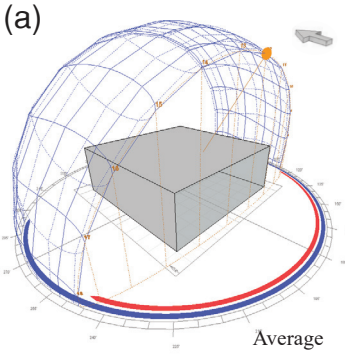
Figure 5.5. Solar shading performance summary for East oriented glazed facades

Discussion

For annual solar access analysis of East oriented glazed facades, Figure 5.5. shows that the shading device sample adopted from Africa Insurance building proved to be more effective in blocking direct solar radiation during periods of solar exposure. Given the geographic location of Addis Ababa, simulations conducted on this orientation showed solar input all year round from morning till solar noon. Compared to other orientations, surfaces facing East received the most solar input per square meter of exposure ranging from 0 - 600W/m^2. The simulation of the bare mockup showed an annual average shading of 44.6% all year-round during morning periods. Compared to this, the shading device adopted from Africa Insurance building improved it to an annual average shading of 73.7%.

Shading Simulation- Solar Access Analysis- South Facade

(a) BARE MOCKUP

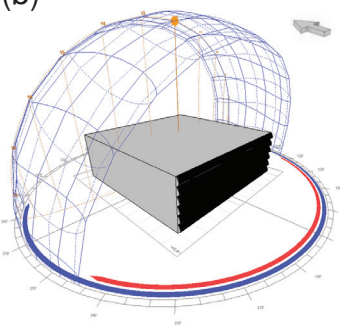


INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	133.781	66.9105	31.1253	0	0	0	0	0	0	26.2324	0	133.127	540
	203.22	134.552	59.8257	0	0	0	0	0	3.49028	67.2239	182.768	249.678	480
16	293.521	184.048	78.4846	0	0	0	0	0	21.366	110.033	252.317	337.033	420
	294.963	213.984	82.9458	0	0	0	0	0	40.1871	143.135	260.686	381.921	360
14	334.223	228.9	99.5753	0	0	0	0	0	37.6068	170.984	292.168	349.254	300
	334.155	221.463	93.7335	0	0	0	0	0	32.9213	183.112	334.154	394.122	240
12	348.185	224.337	97.0291	0	0	0	0	0	38.15	131.356	331.456	375.67	180
	328.043	217.812	98.8306	0	0	0	0	0	36.2465	155.111	320.837	351.22	120
10	327.23	197.515	88.8954	0	0	0	0	0	11.1107	149.234	306.754	304.885	60
	269.258	152.895	41.9825	0	0	0	0	0	5.63253	99.2354	235.07	257.748	0
08	150.901	67.1389	11.6622	0	0	0	0	0	0	45.3165	185.999	160.47	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	0	0	0	100	100	100	100	100	19	0	0	0

(b) Africa Insurance MOCKUP

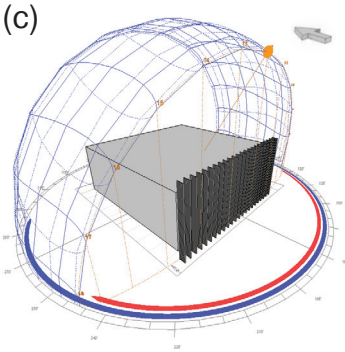


INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	78.0391	27.8794	12.9689	0	0	0	0	0	0	13.1162	0	72.1102	540
	93.1426	67.276	22.4346	0	0	0	0	0	1.21401	28.01	76.1531	93.6292	480
16	122.3	84.3555	29.4317	0	0	0	0	0	8.01225	45.8469	105.132	140.43	420
	98.3209	62.412	24.1925	0	0	0	0	0	15.0702	53.6757	76.0333	159.134	360
14	125.334	76.3	29.0428	0	0	0	0	0	10.9687	56.9947	85.2155	145.523	300
	181.001	101.504	42.9612	0	0	0	0	0	15.0889	83.9262	153.154	197.061	240
12	174.093	102.821	44.4717	0	0	0	0	0	17.4854	60.205	151.917	172.182	180
	177.69	99.8304	45.2974	0	0	0	0	0	16.613	71.0927	147.05	190.244	120
10	177.25	98.7576	40.7437	0	0	0	0	0	5.09242	80.8353	140.595	177.849	60
	134.629	89.1889	22.7405	0	0	0	0	0	3.05095	49.6177	137.124	128.874	0
08	62.8754	25.1771	6.31704	0	0	0	0	0	0	24.5464	54.2496	46.8038	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	53	56	58	100	100	100	100	100	66	55	59	54

(c) Finfine Bldg. MOCKUP

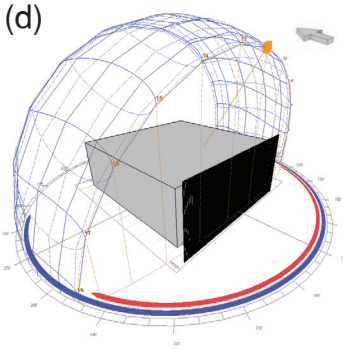


INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	11.1484	5.57588	2.59377	0	0	0	0	0	0	2.18603	0	11.0939	540
	8.46751	11.2127	4.98547	0	0	0	0	0	0.151751	5.60199	15.2306	10.4033	480
16	24.4601	15.3374	13.0808	0	0	0	0	0	3.561	9.16938	10.5132	14.043	420
	73.7407	44.58	20.7365	0	0	0	0	0	10.0468	23.8559	32.5857	63.6536	360
14	167.112	133.525	45.6387	0	0	0	0	0	14.1026	42.7461	97.3892	130.97	300
	222.77	156.87	50.7723	0	0	0	0	0	24.691	144.963	250.616	312.014	240
12	188.6	84.1265	32.343	0	0	0	0	0	12.7167	60.205	179.538	234.794	180
	68.3423	45.3775	20.5897	0	0	0	0	0	9.06163	32.3149	93.5776	73.1707	120
10	68.1729	41.149	18.5199	0	0	0	0	0	2.31473	31.0905	63.907	63.5176	60
	56.0954	31.8532	8.74636	0	0	0	0	0	1.17344	20.674	48.9729	53.6975	0
08	31.4377	13.9873	2.42963	0	0	0	0	0	0	9.44093	38.7497	33.4313	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	73	73	75	100	100	100	100	100	77	75	72	73

(d) Henk de Pagter Library MOCKUP



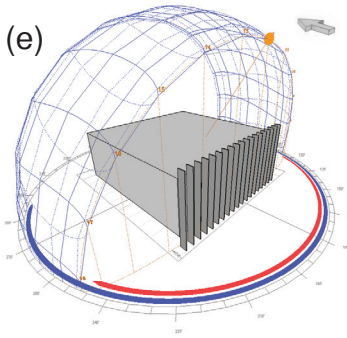
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	16.7227	30.6673	20.7502	0	0	0	0	0	0	13.1162	0	16.6408	540
	76.2076	67.276	37.3911	0	0	0	0	0	3.49028	39.2139	76.1531	41.613	480
16	171.221	84.3555	58.8635	0	0	0	0	0	21.366	64.1857	105.132	196.602	420
	196.642	106.992	69.1215	0	0	0	0	0	40.1871	107.351	184.652	222.788	360
14	222.816	152.6	91.2774	0	0	0	0	0	37.6068	142.487	170.431	261.941	300
	250.616	166.097	82.0169	0	0	0	0	0	32.9213	137.334	264.539	312.014	240
12	217.616	177.6	80.8576	0	0	0	0	0	38.15	103.991	262.402	266.1	180
	232.364	136.132	74.123	0	0	0	0	0	36.2465	109.871	213.892	263.415	120
10	149.98	123.447	66.6715	0	0	0	0	0	11.1107	99.4896	191.721	190.553	60
	89.7526	82.8183	34.9854	0	0	0	0	0	5.63253	62.0221	127.329	85.916	0
08	50.3003	22.3796	11.6622	0	0	0	0	0	0	32.0992	61.9996	53.49	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	49	43	20	100	100	100	100	100	19	32	41	48

Shading Simulation- Solar Access Analysis- South Facade cont.

(e)



John F Kennedy Library MOCKUP

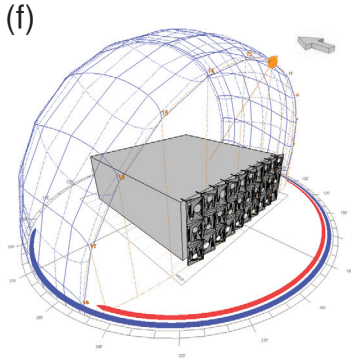
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	11.1484	5.57588	2.59377	0	0	0	0	0	0	2.18603	0	11.0939	540
	16.935	11.2127	17.4492	0	0	0	0	0	3.33853	11.204	15.2306	20.8065	480
16	48.9202	46.0121	19.6212	0	0	0	0	0	12.4635	13.7541	21.0264	42.1291	420
	172.062	133.74	48.3851	0	0	0	0	0	20.0936	59.6397	97.7571	206.874	360
14	181.038	123.988	78.8305	0	0	0	0	0	23.5043	99.7408	182.605	189.179	300
	264.539	175.325	70.3002	0	0	0	0	0	30.1778	167.852	292.385	344.857	240
12	159.585	84.1265	44.4717	0	0	0	0	0	25.4333	76.6246	193.349	203.488	180
	82.0108	63.5285	41.1794	0	0	0	0	0	24.1643	64.6297	120.314	102.439	120
10	68.1729	41.149	25.9278	0	0	0	0	0	9.25894	49.7448	63.907	63.5176	60
	56.0954	31.8532	12.2449	0	0	0	0	0	5.16315	20.674	48.9729	53.6975	0
08	31.4377	13.9873	3.88741	0	0	0	0	0	0	13.2173	38.7497	33.4313	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	67	67	59	100	100	100	100	100	40	62	64	66

(f)



Renaissance Bldg. MOCKUP

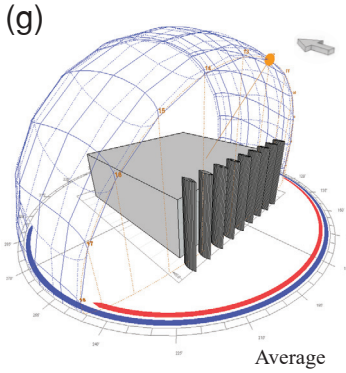
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	44.5938	27.8794	15.5626	0	0	0	0	0	0	13.1162	0	61.0163	540
	101.61	61.6697	39.8838	0	0	0	0	0	3.33853	33.6119	68.5378	104.032	480
16	158.991	99.6929	52.3231	0	0	0	0	0	20.4758	55.0163	115.645	196.602	420
	135.191	133.74	65.6654	0	0	0	0	0	35.1637	89.4595	119.481	190.961	360
14	153.186	143.063	74.6815	0	0	0	0	0	36.0399	128.238	182.605	174.627	300
	208.847	156.87	82.0169	0	0	0	0	0	30.1778	129.704	194.923	229.905	240
12	203.108	177.6	84.9005	0	0	0	0	0	38.15	103.991	248.592	234.794	180
	218.695	190.585	86.4768	0	0	0	0	0	34.7362	129.259	213.892	219.512	120
10	299.961	189.285	85.1914	0	0	0	0	0	11.1107	136.798	281.191	292.181	60
	224.381	133.783	34.9854	0	0	0	0	0	5.63253	95.1006	215.481	214.79	0
08	125.751	53.1516	10.2045	0	0	0	0	0	0	28.3228	154.999	133.725	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	39	30	21	100	100	100	100	100	22	30	34	37

(g)



Weggagen Bank(HQ) MOCKUP

INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	11.1484	5.57588	2.59377	0	0	0	0	0	0	2.18603	0	11.0939	540
	16.935	11.2127	4.98547	0	0	0	0	0	0.151751	5.60199	15.2306	20.8065	480
16	61.1502	30.6747	13.0808	0	0	0	0	0	3.561	13.7541	21.0264	70.2151	420
	98.3209	62.412	24.1925	0	0	0	0	0	10.0468	23.8559	43.4476	111.394	360
14	250.667	171.675	62.2346	0	0	0	0	0	20.3704	64.1191	121.736	218.284	300
	264.539	184.553	74.2057	0	0	0	0	0	27.4344	167.852	292.385	361.279	240
12	217.616	121.516	44.4717	0	0	0	0	0	19.075	87.571	248.592	281.753	180
	68.3423	45.3775	20.5897	0	0	0	0	0	10.5719	45.2408	160.419	175.61	120
10	68.1729	41.149	18.5199	0	0	0	0	0	2.31473	31.0905	63.907	63.5176	60
	56.0954	31.8532	8.74636	0	0	0	0	0	1.17344	20.674	48.9729	53.6975	0
08	31.4377	13.9873	2.42963	0	0	0	0	0	0	9.44093	38.7497	33.4313	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	66	67	70	100	100	100	100	100	72	70	65	63

Table 5.5. Solar access analysis of South oriented glazed facades(a-g)

Interpretation

Table 5.5. shows the different shading typologies tested for performance against incident solar radiation on a mockup model facing South. Comparisons are made among tabulated results of each shading typologies. Table 5.5. shows the solar access performance of each device for every month. Results of each shading device are processed and interpreted to a diagram using Microsoft Excel software. These devices are represented by different colors. Figure 5.6. shows the average shading provided by each shading device every month for this orientation.

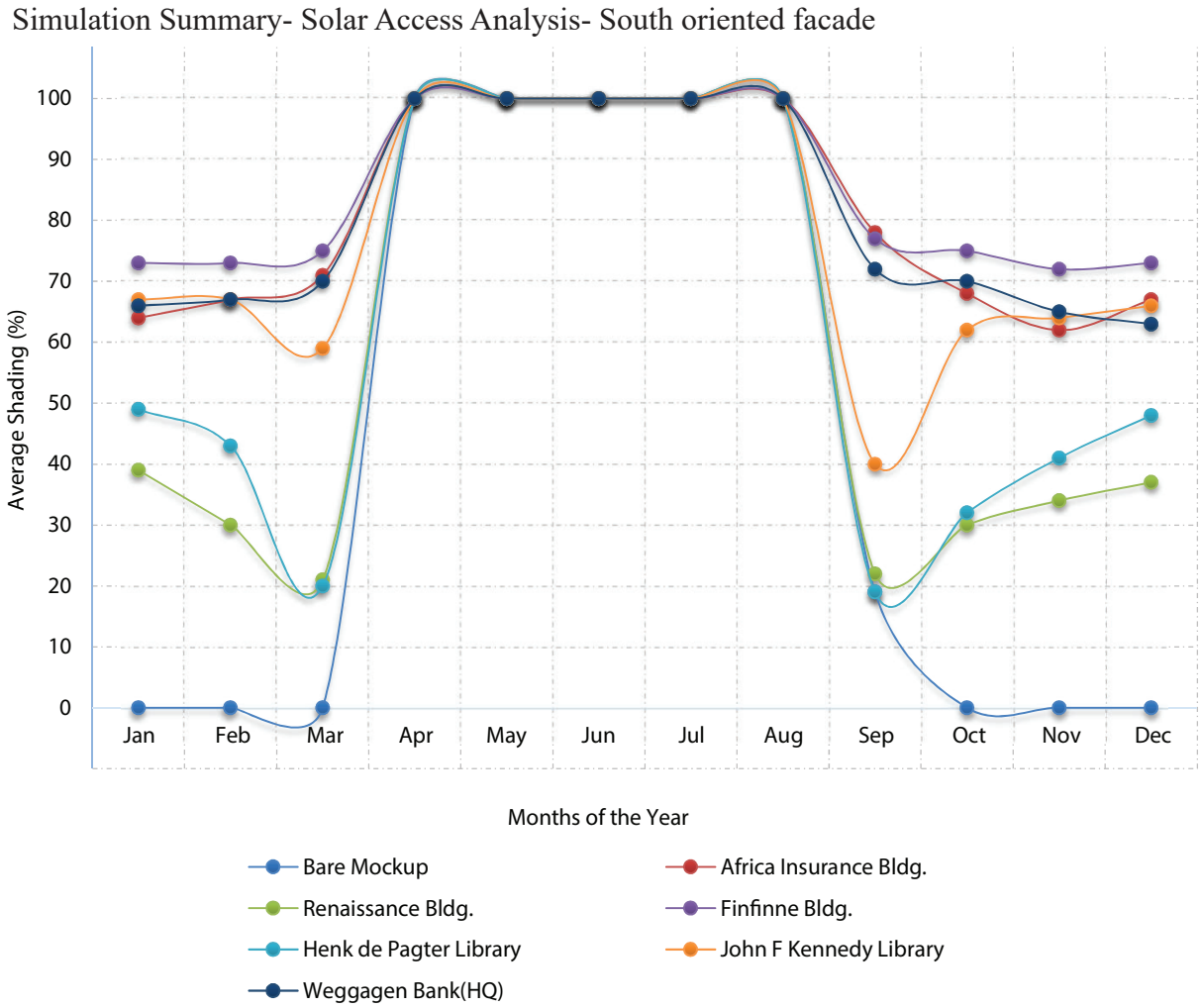


Figure 5.6. Solar shading performance summary for South oriented glazed facades

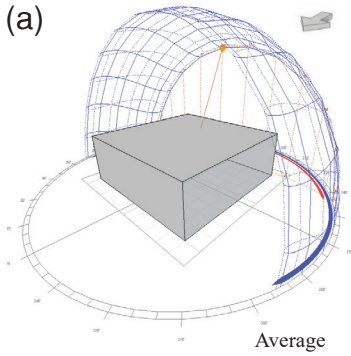
Discussion

For annual solar access analysis of South oriented glazed facades, Figure 5.6. shows that the shading device sample adopted from Finfinne building proved to be more effective in blocking direct solar radiation during periods of solar exposure. Given the geographic location of Addis Ababa and the sun's trajectory, simulations conducted on this orientation showed solar input all day except for 5 months where the sun's trajectory is tilted to the North. Compared to other orientations, surfaces facing South received moderate solar input per square meter of exposure ranging from 0 - 400W/m^2. The simulation of the bare mockup showed an annual average shading of 2.7% during exposure periods. Compared to this, the shading device adopted from Finfinne building improved it to an annual average of 74%.

Shading Simulation- Solar Access Analysis- West Facade

(a)

BARE MOCKUP



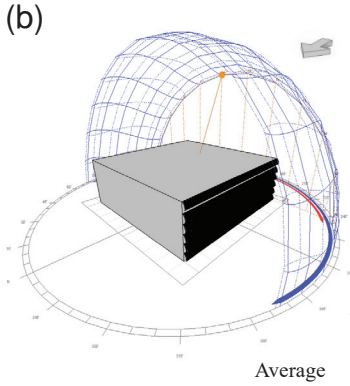
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	251.363	230.215	220.266	145.614	125.593	94.9154	67.0512	70.9128	95.3559	127.755	0	251.728	540
	328.344	311.321	280.017	219.605	204.162	115.613	107.61	119.418	147.088	275.45	369.382	379.857	480
16	304.441	284.826	261.748	202.918	197.505	121.988	118.146	135.693	163.073	270.486	377.535	352.011	420
	196.347	205.411	160.196	142.738	160.02	95.3261	90.4628	89.4296	168.463	215.161	287.72	291.934	360
14	82.1307	56.7969	48.8714	47.8502	61.5676	54.9019	24.9341	29.3639	68.1735	128.262	122.464	116.618	300
	0	0	0	0	0	0	0	0	0	0	0	0	240
12	0	0	0	0	0	0	0	0	0	0	0	0	180
	0	0	0	0	0	0	0	0	0	0	0	0	120
10	0	0	0	0	0	0	0	0	0	0	0	0	60
	0	0	0	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0	0	0	

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Average Shading(%)	55	55	55	55	55	55	55	55	55	55	60	55

(b)

Africa Insurance MOCKUP



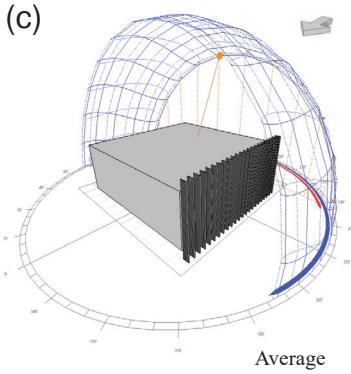
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	125.682	95.9228	119.311	84.9412	68.0293	63.2769	36.3194	44.3205	63.5706	53.2314	0	136.353	540
	109.448	129.717	116.674	109.802	110.588	72.2584	67.256	64.6846	42.9006	149.202	138.518	189.928	480
16	114.165	106.81	98.1556	126.824	106.982	55.9113	63.9957	62.1927	47.563	112.703	125.845	146.671	420
	73.6302	68.4702	46.7239	77.3163	73.3425	43.6911	41.4621	44.7148	63.1736	71.7202	83.9184	121.639	360
14	30.799	16.5658	14.2542	13.9563	28.2185	25.1633	11.4281	13.4585	19.884	37.4099	40.8213	43.7316	300
	0	0	0	0	0	0	0	0	0	0	0	0	240
12	0	0	0	0	0	0	0	0	0	0	0	0	180
	0	0	0	0	0	0	0	0	0	0	0	0	120
10	0	0	0	0	0	0	0	0	0	0	0	0	60
	0	0	0	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0	0	0	

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Average Shading(%)	82	83	83	77	77	76	76	77	83	82	87	80

(c)

Finfine Bldg. MOCKUP



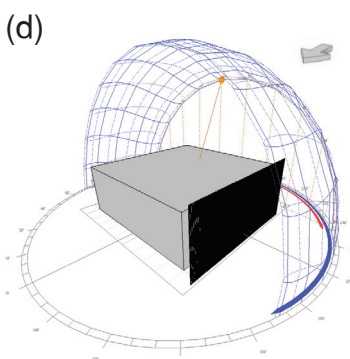
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	115.208	124.7	192.733	109.21	83.7283	47.4577	44.7008	47.2752	79.4633	74.524	0	115.376	540
	109.448	155.661	151.676	183.004	136.108	62.6239	58.2885	79.6118	128.702	149.202	184.691	126.619	480
16	38.0552	94.942	141.78	169.099	131.67	60.9942	59.0729	90.4622	142.689	146.513	125.845	44.0014	420
	40.9057	51.3526	80.098	118.948	86.6775	47.663	45.2314	63.346	98.2701	89.6502	83.9184	36.4917	360
14	13.6885	16.5658	20.3631	41.8689	25.6532	20.5882	10.3892	20.7994	39.7679	32.0656	30.616	24.2953	300
	0	0	0	0	0	0	0	0	0	0	0	0	240
12	0	0	0	0	0	0	0	0	0	0	0	0	180
	0	0	0	0	0	0	0	0	0	0	0	0	120
10	0	0	0	0	0	0	0	0	0	0	0	0	60
	0	0	0	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0	0	0	

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Average Shading(%)	88	83	74	62	73	78	76	69	66	79	86	89

(d)

Henk de Pagter Library MOCKUP



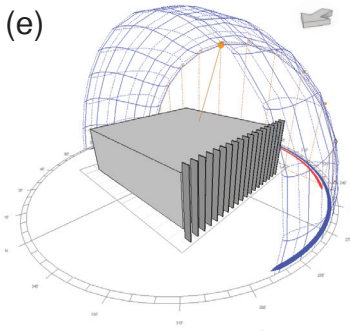
INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	62.8409	143.884	73.4222	84.9412	68.0293	51.4125	36.3194	41.3658	35.7585	53.2314	0	62.9321	540
	150.491	220.519	128.341	100.652	110.588	67.4412	62.7722	69.6604	110.316	195.111	215.473	189.928	480
16	139.536	225.487	196.311	118.369	148.129	86.4084	88.6094	107.424	81.5366	123.973	204.498	161.338	420
	139.079	128.382	113.472	95.1586	126.682	71.4945	67.8471	59.6197	140.386	161.37	203.802	170.295	360
14	75.2865	56.7969	48.8714	47.8502	59.0023	50.3267	24.9341	29.3639	56.8113	80.164	96.9506	92.3223	300
	0	0	0	0	0	0	0	0	0	0	0	0	240
12	0	0	0	0	0	0	0	0	0	0	0	0	180
	0	0	0	0	0	0	0	0	0	0	0	0	120
10	0	0	0	0	0	0	0	0	0	0	0	0	60
	0	0	0	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0	0	0	

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Average Shading(%)	75	66	70	70	67	68	67	67	70	73	74	77

Shading Simulation- Solar Access Analysis- West Facade cont.

(e)



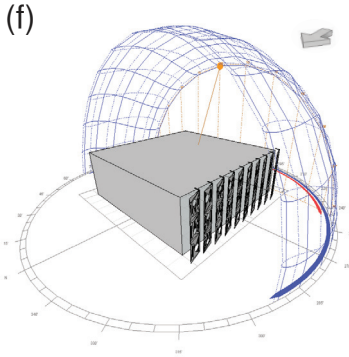
John F Kennedy Library MOCKUP

INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	146.629	124.7	137.667	121.345	88.9614	55.3673	47.4946	56.1393	83.4364	69.2008	0	146.842	540
	150.491	233.491	151.676	192.154	144.615	72.2584	67.256	94.539	98.0586	149.202	261.646	174.101	480
16	126.851	166.149	141.78	177.553	148.129	71.1599	83.6867	113.078	108.715	157.784	173.037	132.004	420
	73.6302	85.5877	106.797	124.896	113.347	63.5507	60.3085	74.5246	91.2508	125.51	179.825	60.8196	360
14	37.6433	33.1316	32.5809	41.8689	38.4798	34.3137	15.5838	26.9169	45.449	69.4755	61.2319	34.0135	300
	0	0	0	0	0	0	0	0	0	0	0	0	240
12	0	0	0	0	0	0	0	0	0	0	0	0	180
	0	0	0	0	0	0	0	0	0	0	0	0	120
10	0	0	0	0	0	0	0	0	0	0	0	0	60
	0	0	0	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	79	74	72	61	68	72	70	62	69	75	77	83

(f)



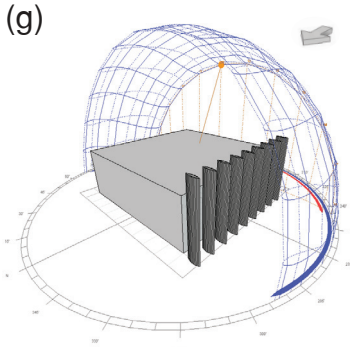
Renaissance Bldg. MOCKUP

INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	73.3143	76.7383	73.4222	72.8068	68.0293	59.3221	36.3194	38.4111	55.6243	37.262	0	41.9547	540
	177.853	168.632	140.009	137.253	127.601	72.2584	67.256	74.6361	73.5439	114.771	153.909	158.274	480
16	164.906	154.281	130.874	126.824	131.67	76.2427	83.6867	90.4622	67.9472	146.513	204.498	190.673	420
	130.898	128.382	100.123	113.001	106.68	63.5507	60.3085	63.346	91.2508	116.545	143.86	133.803	360
14	68.4423	56.7969	46.8351	45.8564	56.437	54.9019	24.9341	28.1404	56.8113	96.1968	91.8479	82.6042	300
	0	0	0	0	0	0	0	0	0	0	0	0	240
12	0	0	0	0	0	0	0	0	0	0	0	0	180
	0	0	0	0	0	0	0	0	0	0	0	0	120
10	0	0	0	0	0	0	0	0	0	0	0	0	60
	0	0	0	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	74	72	73	68	69	68	68	68	74	77	78	79

(g)



Wegagen Bank(HQ) MOCKUP

INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	94.2613	172.661	165.2	133.479	99.4274	75.1413	53.0822	65.0034	87.4096	95.8165	0	94.3982	540
	109.448	129.717	210.013	201.305	161.629	91.5273	85.1909	104.491	128.702	206.588	138.518	126.619	480
16	63.4253	94.942	174.499	186.008	156.358	96.5741	93.5322	124.385	122.305	112.703	125.845	73.3356	420
	32.7245	59.9114	73.4232	130.843	126.682	71.4945	67.8471	74.5246	126.347	71.7202	83.9184	48.6557	360
14	13.6885	14.1992	26.472	45.8564	48.741	32.0261	18.7005	24.4699	39.7679	37.4099	30.616	19.4363	300
	0	0	0	0	0	0	0	0	0	0	0	0	240
12	0	0	0	0	0	0	0	0	0	0	0	0	180
	0	0	0	0	0	0	0	0	0	0	0	0	120
10	0	0	0	0	0	0	0	0	0	0	0	0	60
	0	0	0	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	89	81	71	58	64	66	65	60	65	77	88	89

Table 5.6. Solar access analysis of West oriented glazed facades(a-g)

Interpretation

Table 5.6. shows the different shading typologies tested for performance against incident solar radiation on a mockup model facing West. Comparisons are made among tabulated results of each shading typologies. Table 5.6. shows the solar access performance of each device for every month. Results of each shading device are processed and interpreted to a diagram using Microsoft Excel software. These devices are represented by different colors. Figure 5.7. shows the average shading provided by each shading device every month for this orientation.

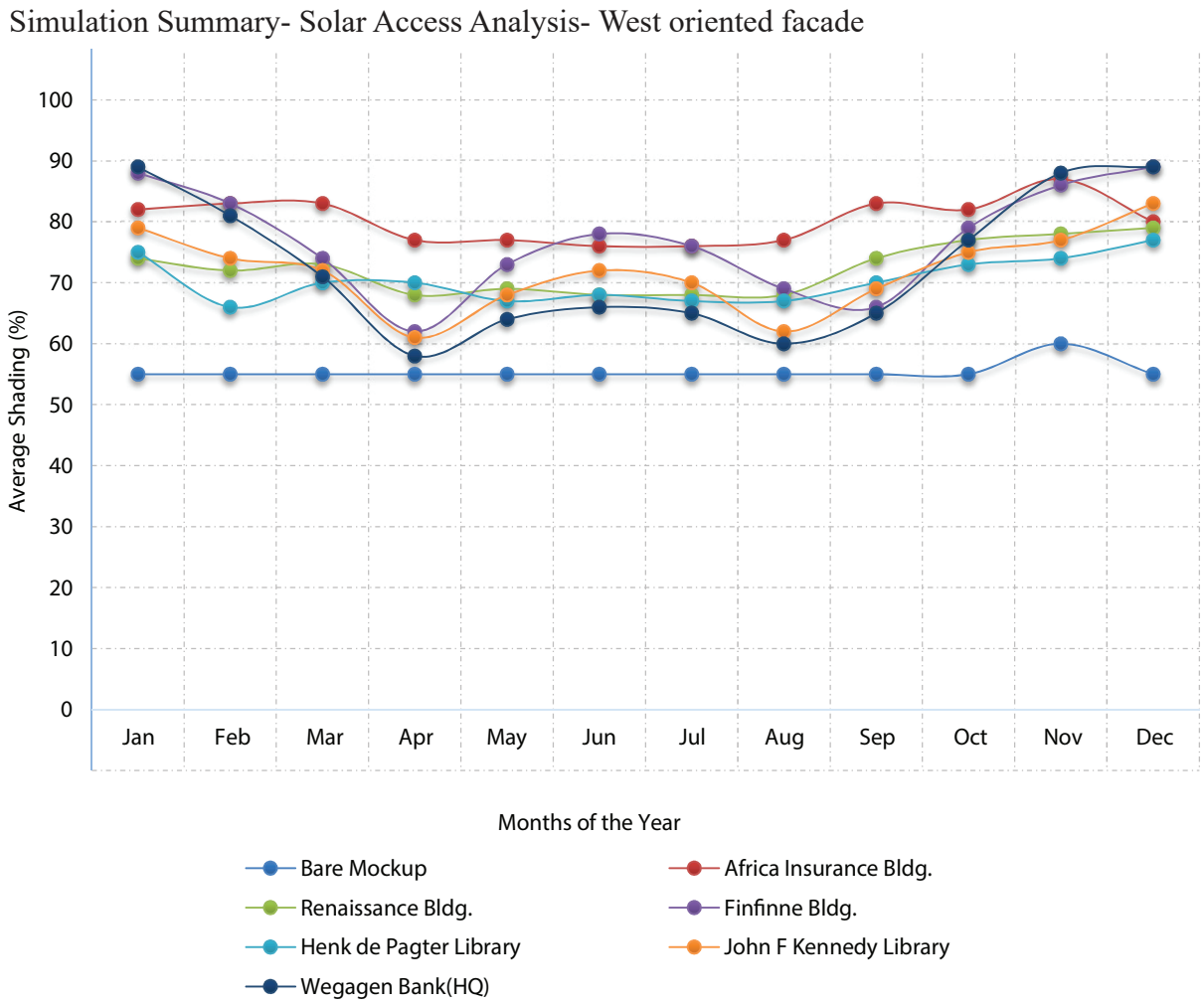


Figure 5.7. Solar shading performance summary for West oriented glazed facades

Discussion

For annual solar analysis of West oriented glazed facades, Figure 5.7. shows that the shading device sample adopted from Africa Insurance building proved to be more effective in blocking direct solar radiation during periods of solar exposure. Given the geographic location of Addis Ababa and sun's trajectory, simulations conducted on this orientation showed solar input all year round after solar noon. Compared to other orientations, surfaces facing West received moderate solar input per square meter of exposure ranging from 0 - 400W/m^2. The simulation of the bare mockup showed an annual average shading of 55.4% all year-round during afternoon periods. Compared to this, the shading device adopted from Africa Insurance building improved it to an annual average shading of 80.3%.

5.4.2. Thermal Analysis

As discussed in chapter 2, heat gain from direct solar radiation through glazed surfaces contributes the most to the heat gained in internal spaces. Ecotect provides a wide range of thermal calculations to compute thermal analysis for different spaces using the admittance method. It calculates the direct (Sunshine) and diffused (Skylight) component striking a glazed surface. For the purpose of this study, a direct solar heat gain analysis is conducted to assess the contribution of different fixed shading devices towards optimizing internal heat gains of spaces with an exposed facade to incident solar radiation. Due to the shift of the sun's trajectory within a year, surfaces are exposed to different sun positions each month. For this reason, performance of shading devices are assessed for each month of the year. Calculations are performed and discussions are made for the four major orientations in the context of Addis Ababa.

5.4.2.1. Simulation Approach. A mockup model with 7.5m x7.5m x3m is proposed in Ecotect program. It has equal exposed surfaces that face the four major orientations. Each orientation is comprised of an exposed single glazing facade with other sides assigned to a material with high R value. This helps to minimize heat gain options other than through the glazed surface. Furthermore, it also aids in assessing the contribution of the various shading device options in internal heat gains.

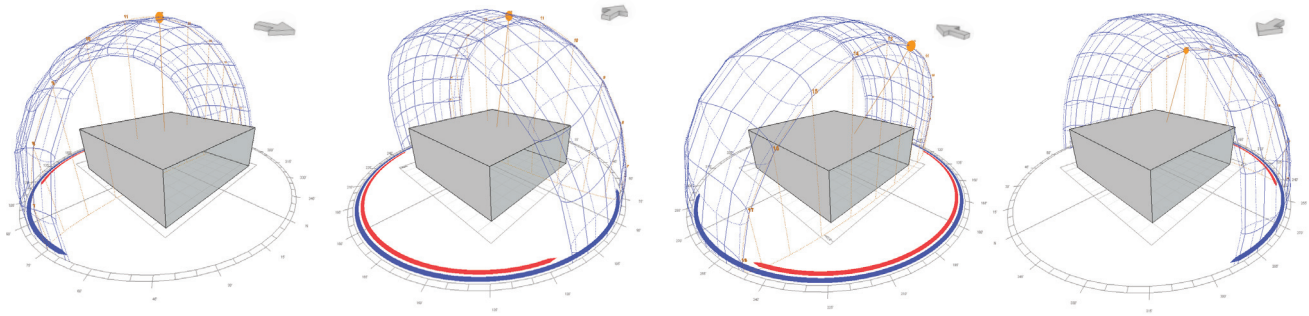


Figure 5.8. Mockup model setups of the major orientations for thermal analysis

Within Ecotect program, a weather file of Addis Ababa is loaded. Sample shading devices from selected case buildings are imported for each orientation. In the Analysis dialogue box(see figure 5.9.),Monthly degree days thermal calculation is made for direct solar gains of the selected mockup zone. Calculations with and without shading devices are performed for each orientation. In this regard, direct solar gains for each month is displayed for each orientation.

5.4.2.2. Calculation

Step 1	Thermal Analysis *(What to calculate ?)*	Losses and Gains *(Shows relative contribution of different heat flow paths.)*
Step 2	Losses and Gains *(What losses/gains to display?)*	Indi vidual Gains Distribution *(Shows a grid of hourly losses/gains for a particular component over the whole year with Average Monthly or Actual Hourly output options.)*
Step 3	Heat Flow Paths *(Which heatflow path to display?)*	Direct Solar Gains *(Calculates heat flow through windows and other transparent external surfaces due to the transmission of incident solar radiation directly in to each space.)*

Table 5.7. Thermal analysis calculation wizard steps

There are different types of heat flow paths. Internal gain calculations would require setting up zone properties of the space with in the zone management tab. This requires the setting of internal design conditions, occupancy and operation, HVAC, and hours of operation.

5.4.2.3. Result Interface. Results of this data collection method are shown as Figure 5.9.

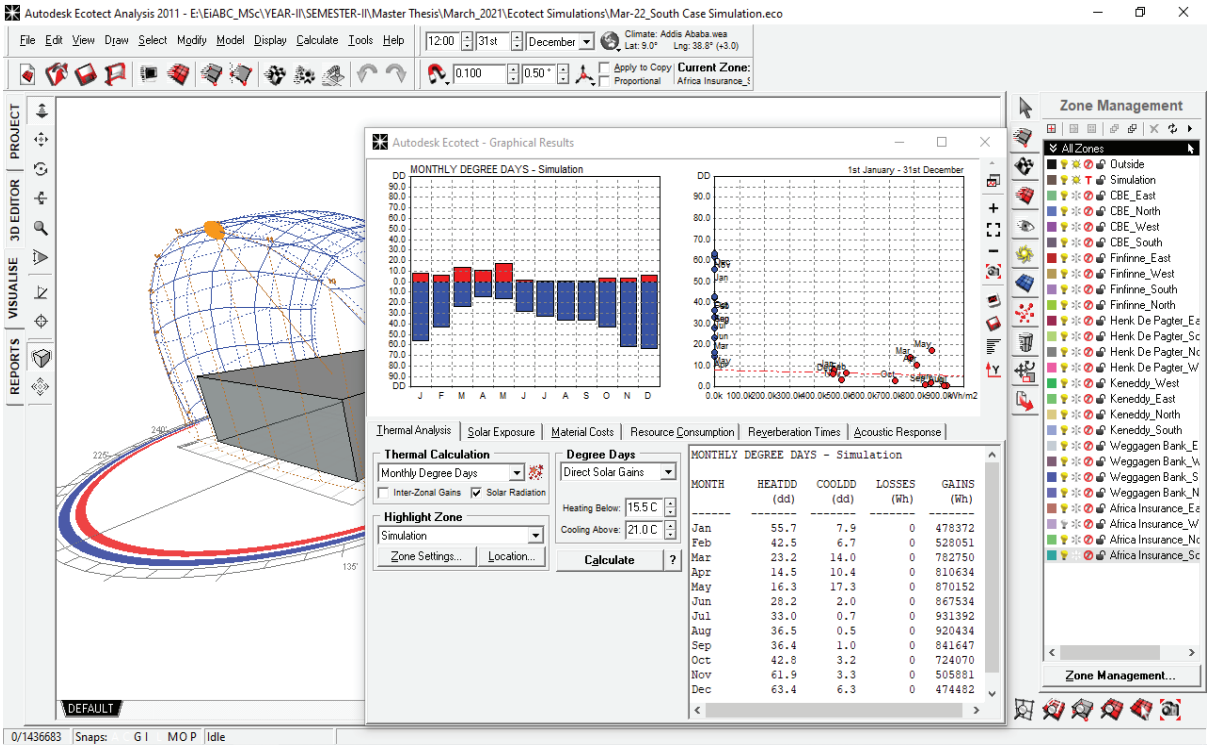
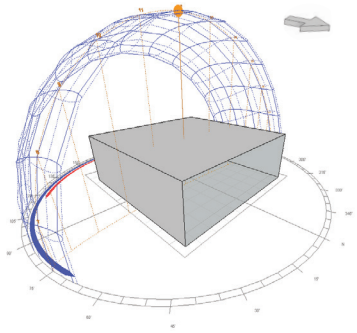


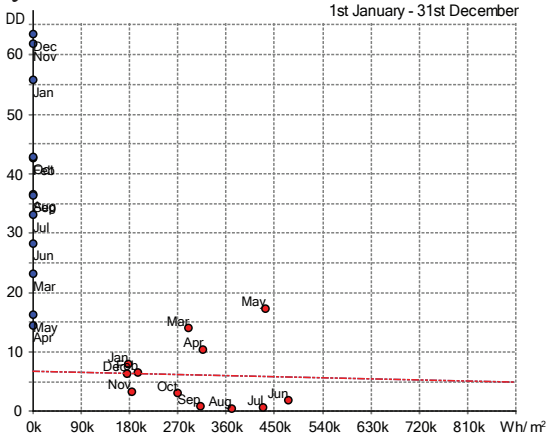
Figure 5.9. Thermal analysis output dialogue box (source: Ecotect software)

Shading Simulation- Thermal Analysis- North oriented zone

(a)

BARE MOCKUP



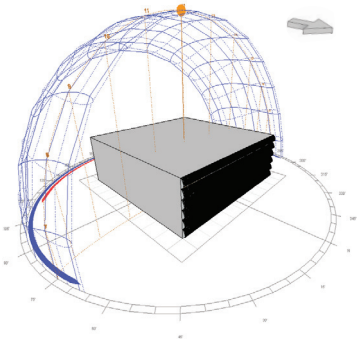


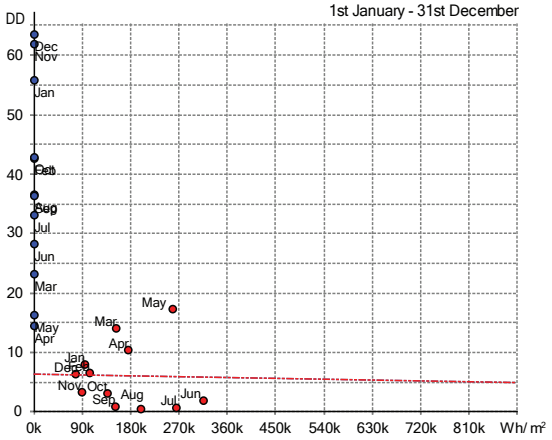
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 177.578
Feb..... 196.019
Mar..... 290.566
Apr 317.992
May 433.994
Jun 477.073
Jul 428.325
Aug..... 370.401
Sep..... 313.097
Oct..... 268.783
Nov..... 185.733
Dec..... 175.538

(b)

Africa Insurance MOCKUP



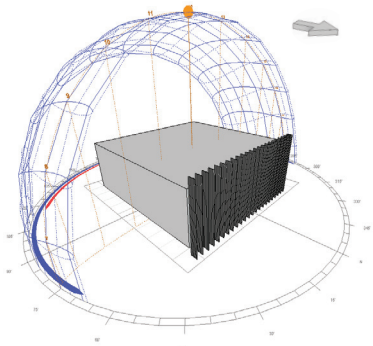


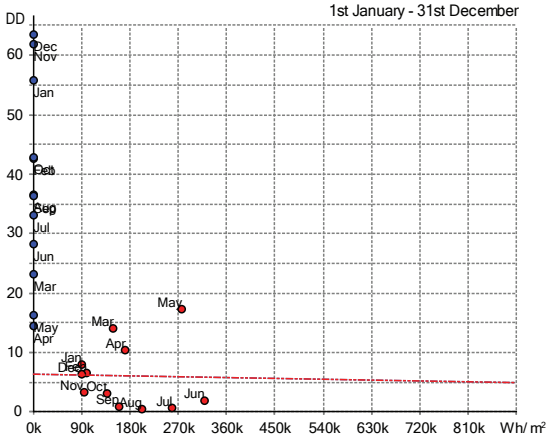
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 86.977
Feb..... 96.009
Mar..... 142.318
Apr 162.233
May 267.296
Jun 310.416
Jul 251.412
Aug..... 194.907
Sep..... 153.598
Oct..... 131.649
Nov..... 90.952
Dec..... 85.978

(c)

Finfine Bldg. MOCKUP



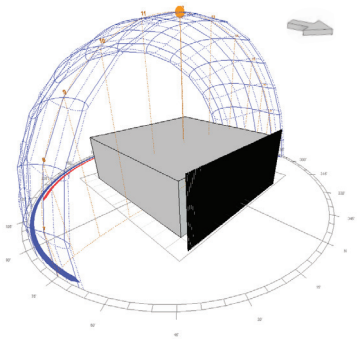


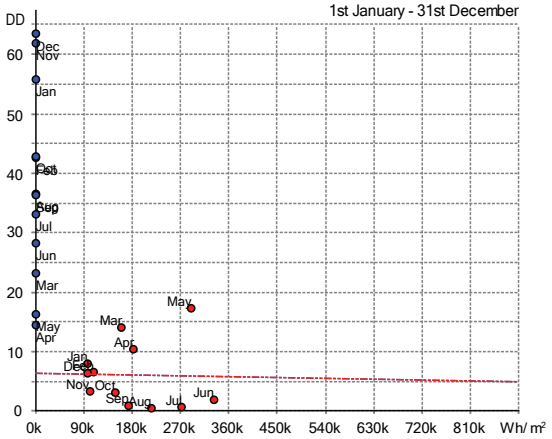
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 90.601
Feb..... 100.010
Mar..... 148.248
Apr 170.571
May 275.785
Jun 319.339
Jul 258.981
Aug..... 203.050
Sep..... 160.070
Oct..... 137.134
Nov..... 94.743
Dec..... 89.560

(d)

Henk de Pagter Library MOCKUP





DIRECT SOLAR GAINS (In KWhr/m²)

Jan 105.097
Feb..... 116.012
Mar..... 171.968
Apr 193.386
May 300.635
Jun 343.748
Jul 286.795
Aug..... 230.006
Sep..... 185.498
Oct..... 159.076
Nov..... 109.908
Dec..... 103.890

Shading Simulation- Thermal Analysis- North oriented zone cont.

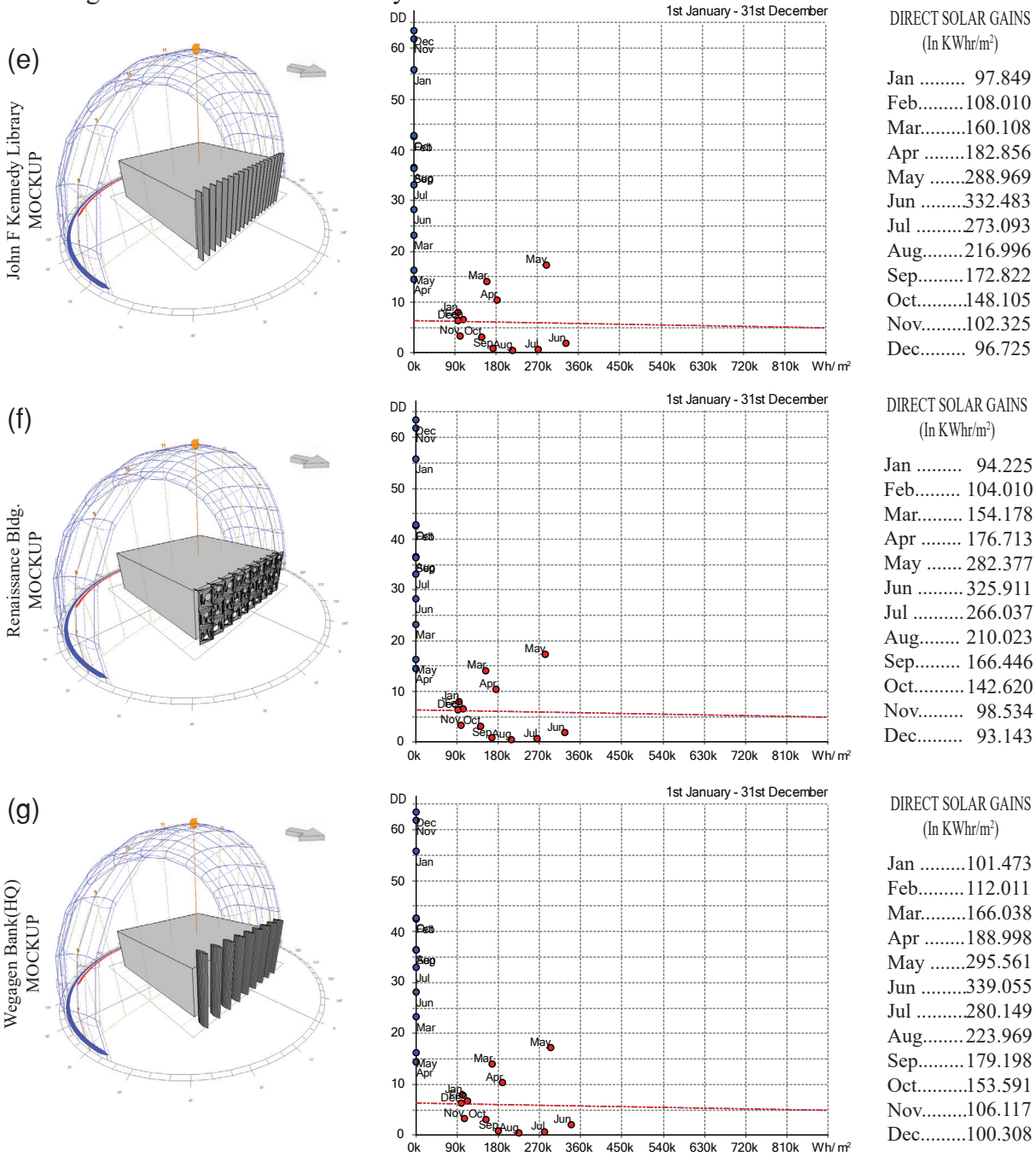


Figure 5.10. Direct solar heat gain analysis of North oriented glazed zones(a-g)

Interpretation

Figure 5.10. shows the different shading typologies tested for performance on direct solar heat gains through a full-glazed surface on a mockup model facing North. The thermal performance of each shading typology is assessed for all months of the year. The graphs show monthly total direct solar heat gains occurring in the mockup model. The trendline shows the axis of distribution of the months with in a year. Direct solar heat gain values are processed and interpreted to a diagram in Microsoft Excel software with different colors. Figure 5.11. shows a summary of the efficiency of each shading device against direct solar heat gains occurring in the mockup zone oriented North.

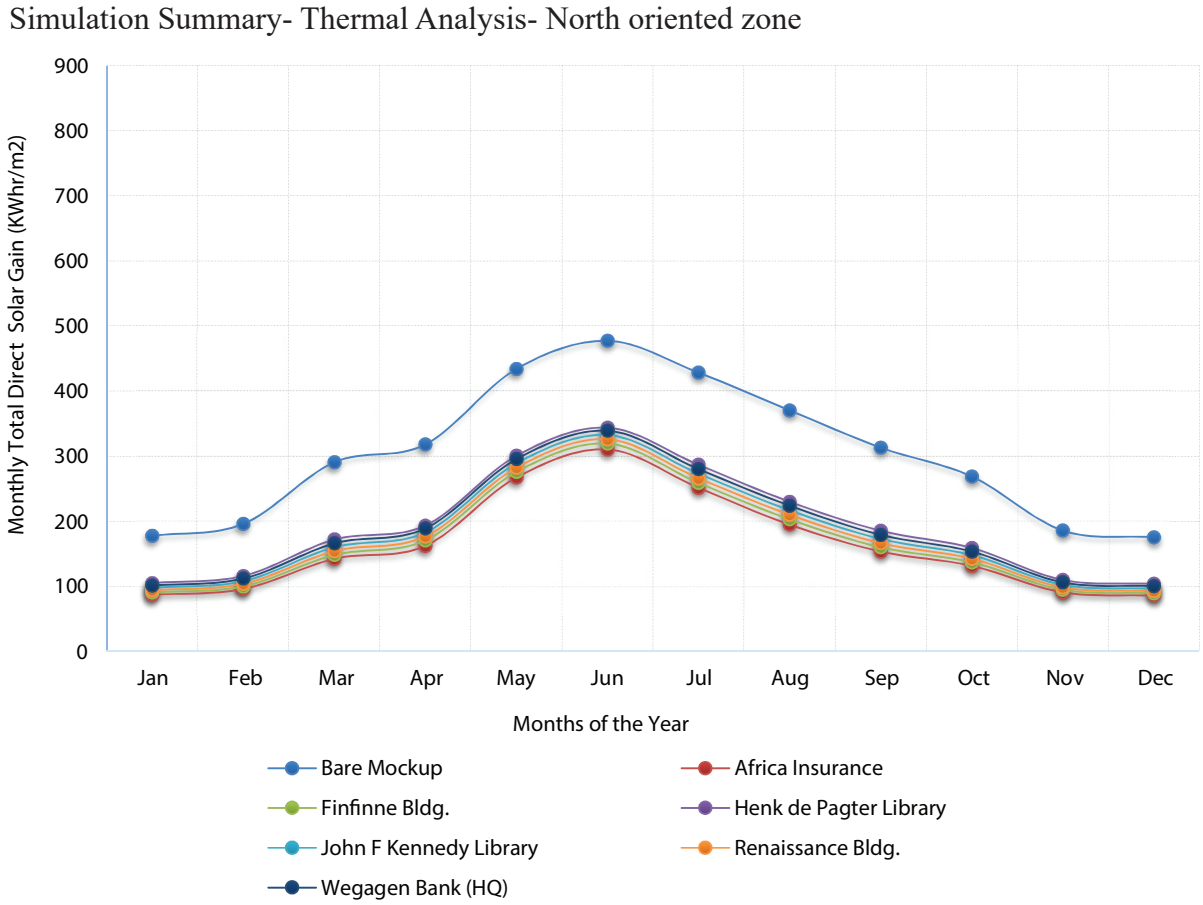


Figure 5.11. Direct solar heat gain analysis summary of North oriented glazed zones

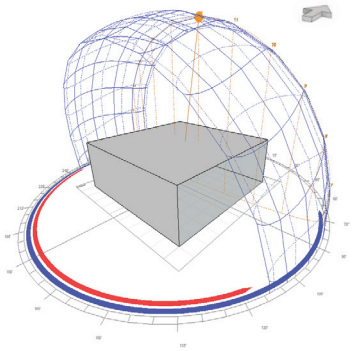
Discussion

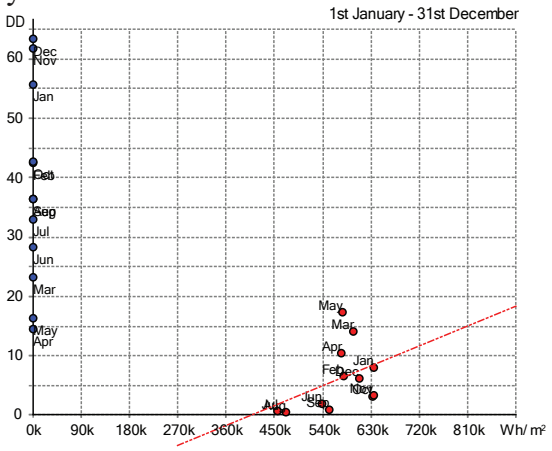
To assess the direct solar heat gains of North oriented glazed zones, monthly total direct solar heat gain values of the different shading typologies were simulated and mapped along the entire year. The mapped zonal heat gain values showed different layouts for the bare mockup and shaded mockup throughout the year. Figure 5.11. shows variable heat gain patterns for each month. Peak direct solar heat gain was registered in the month of June where the sun's trajectory was further to the North while the least value was registered in the month of January where the sun's trajectory was further to the South. Among the simulated shading typologies, the shading device adopted from Africa Insurance building performed best in reducing direct solar heat gains for North oriented glazed zones. During the month of June, this shading device resulted in a total solar heat gain reduction of 166.6 KWhr/m^2 whereas in the month of January, it resulted in a total solar heat gain reduction of 90.6 KWhr/m^2.

Shading Simulation- Thermal Analysis- East oriented zone

(a)

BARE MOCKUP



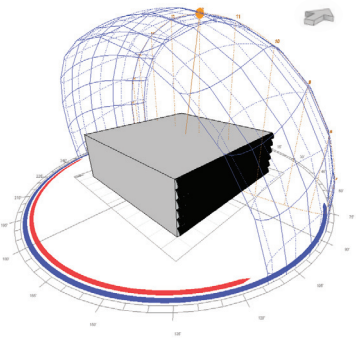


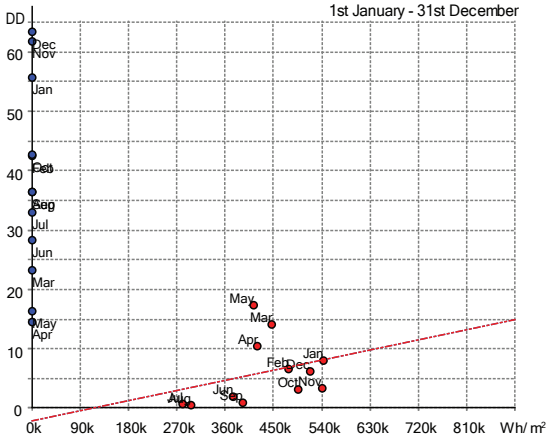
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 634.359
Feb..... 579.232
Mar..... 595.903
Apr 574.137
May 577.184
Jun 539.478
Jul 456.432
Aug..... 471.231
Sep..... 551.877
Oct..... 632.510
Nov..... 635.668
Dec..... 607.812

(b)

Africa Insurance MOCKUP



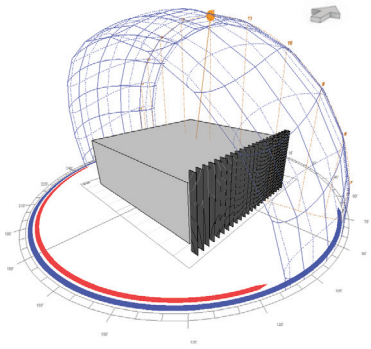


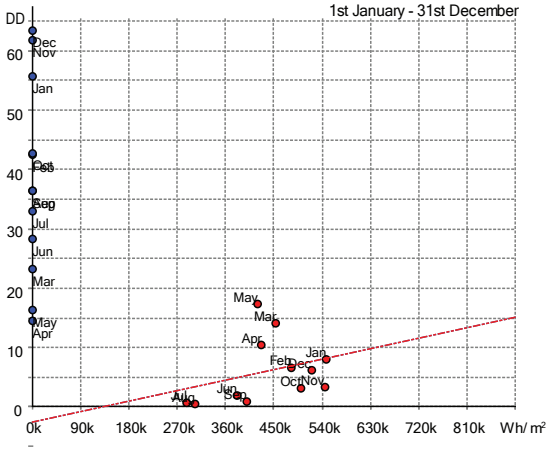
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 531.192
Feb..... 467.366
Mar..... 436.870
Apr 411.113
May 403.977
Jun 367.725
Jul 271.530
Aug..... 287.630
Sep..... 382.383
Oct..... 484.032
Nov..... 528.597
Dec..... 505.559

(c)

Finfine Bldg. MOCKUP



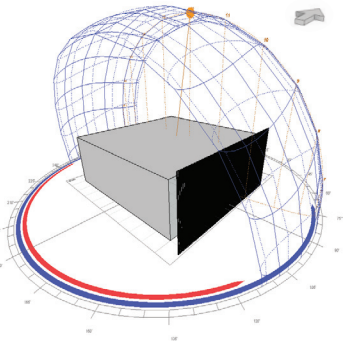


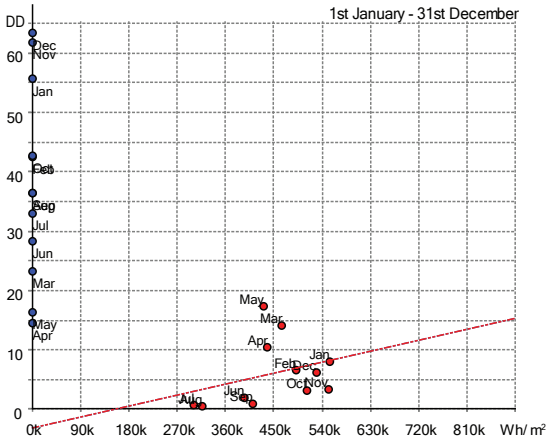
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 547.382
Feb..... 483.223
Mar..... 453.585
Apr 426.716
May 418.974
Jun 381.744
Jul 287.088
Aug..... 303.879
Sep..... 398.851
Oct..... 500.861
Nov..... 544.333
Dec..... 521.749

(d)

Henk de Pagter Library MOCKUP





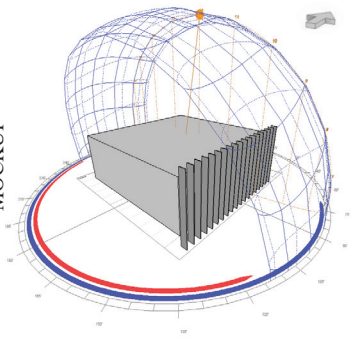
DIRECT SOLAR GAINS (In KWhr/m²)

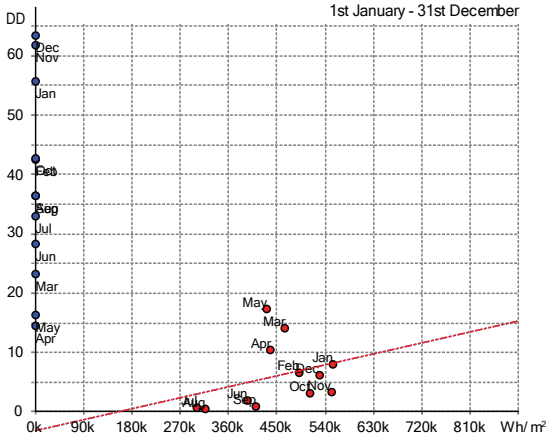
Jan 559.826
Feb..... 497.739
Mar..... 476.677
Apr 451.718
May 446.618
Jun 410.076
Jul 316.510
Aug..... 332.351
Sep..... 424.282
Oct..... 521.727
Nov..... 558.010
Dec..... 534.010

Shading Simulation- Thermal Analysis- East oriented zone cont.

(e)

John F Kennedy Library
MOCKUP



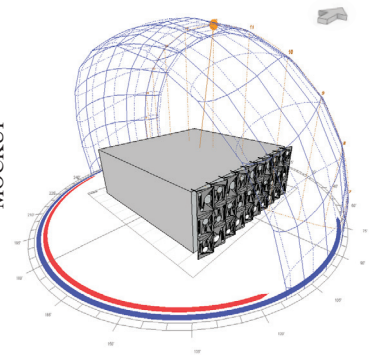


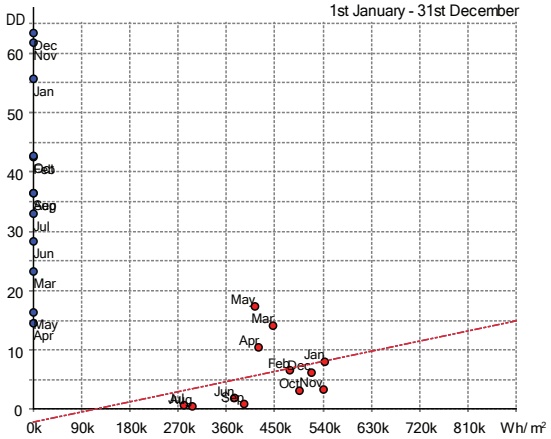
DIRECT SOLAR GAINS
(In KWhr/m²)

Jan 554.630
Feb.....491.224
Mar.....465.445
Apr 439.001
May 432.158
Jun 394.889
Jul 301.200
Aug.....317.825
Sep.....411.603
Oct.....511.832
Nov.....551.944
Dec.....528.921

(f)

Renaissance Bldg.
MOCKUP



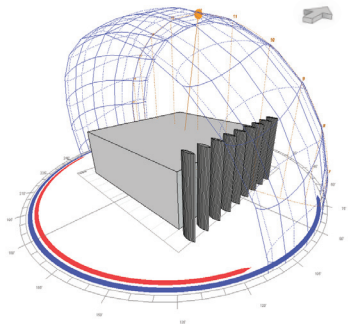


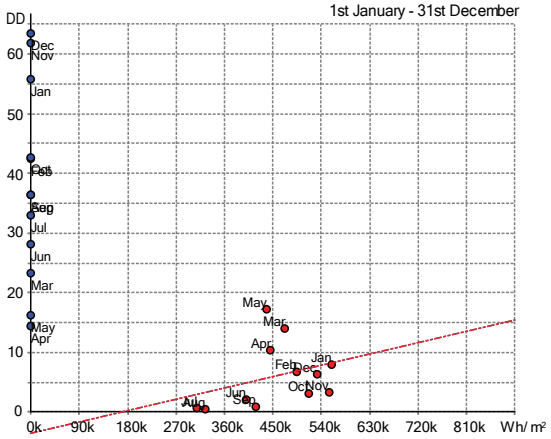
DIRECT SOLAR GAINS
(In KWhr/m²)

Jan 543.758
Feb.....479.223
Mar.....447.655
Apr 420.573
May 412.382
Jun 375.172
Jul 280.032
Aug.....296.906
Sep.....392.474
Oct.....495.376
Nov.....540.527
Dec.....518.163

(g)

Wegagen Bank(HQ)
MOCKUP





DIRECT SOLAR GAINS
(In KWhr/m²)

Jan 558.254
Feb.....495.224
Mar.....471.375
Apr 445.143
May 438.750
Jun 401.461
Jul 308.256
Aug.....324.798
Sep.....417.979
Oct.....517.317
Nov.....555.750
Dec.....532.507

Figure 5.12. Direct solar heat gain analysis of East oriented glazed zones(a-g)

Interpretation

Figure 5.12. shows the different shading typologies tested for performance on direct solar heat gains through a full-glazed surface on a Mockup model facing East. The thermal performance of each shading typology is assessed for all months of the year. The graphs show monthly total direct solar heat gains occurring in the mockup model. The trendline shows the axis of distribution of the months with in a year. Direct solar heat gain values are processed and interpreted to a diagram in Microsoft Excel software with different colors. Figure 5.13. shows a summary of the efficiency of each shading device against direct solar heat gains occurring in the mockup zone oriented East.

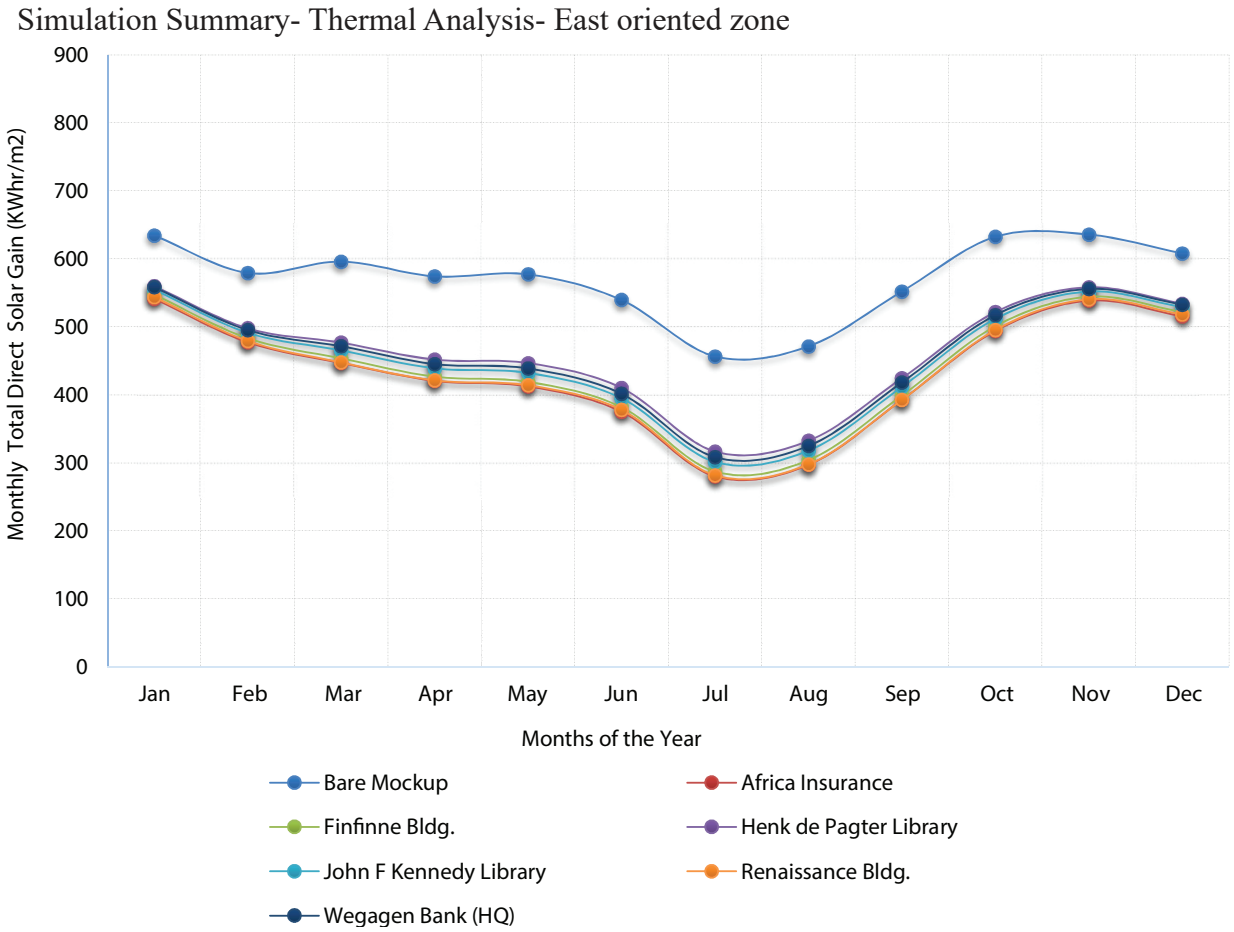


Figure 5.13. Direct solar heat gain analysis summary of East oriented glazed zones

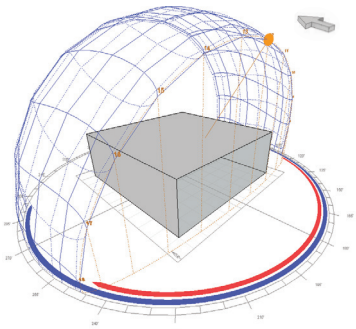
Discussion

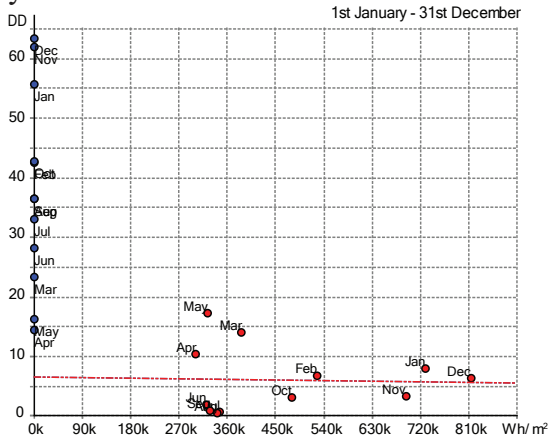
To assess the direct solar heat gains of East oriented glazed zones, monthly total direct solar heat gain values of the different shading typologies were simulated and mapped along the entire year. The mapped zonal heat gain values showed different layouts for the bare mockup and shaded mockup throughout the year. Figure 5.13. shows variable heat gain patterns for each month. Peak direct solar heat gain was registered in the month of November where the sun's trajectory was further to the South at low angles while the least value was registered in the month of July where the sun's trajectory was further to the North at high angles. Among the simulated shading typologies, the shading device adopted from Africa Insurance building performed best in reducing direct solar heat gains for East oriented glazed zones. During the month of November, this shading device resulted in a total solar heat gain reduction of 97.1 KWhr/m^2 whereas in the month of July, it resulted in a total solar heat gain reduction of 176.4 KWhr/m^2.

Shading Simulation- Thermal Analysis- South oriented zone

(a)

BARE MOCKUP



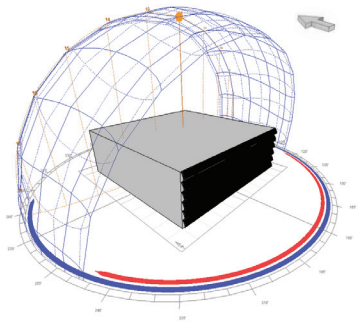


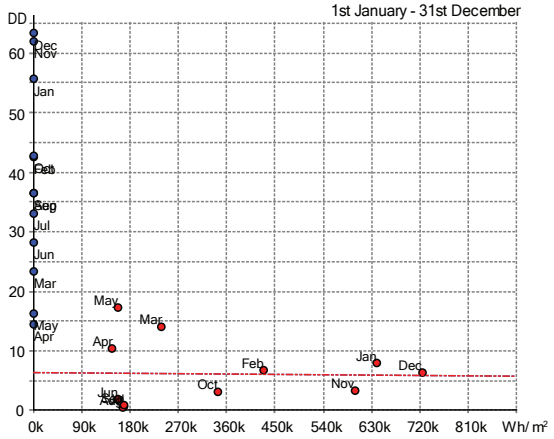
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 730.022
Feb..... 527.974
Mar..... 387.257
Apr 300.831
May 323.011
Jun 322.039
Jul 345.744
Aug..... 341.676
Sep..... 329.115
Oct.....480.596
Nov.....693.311
Dec..... 814.632

(b)

Africa Insurance MOCKUP



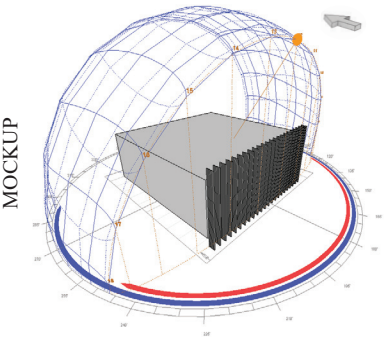


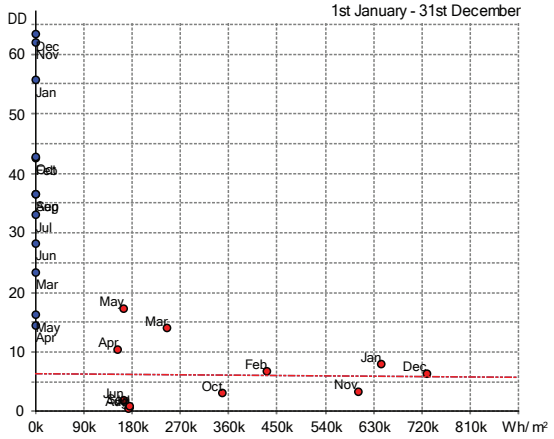
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 640.801
Feb.....429.789
Mar.....240.840
Apr 147.277
May 158.209
Jun 157.733
Jul 169.344
Aug..... 167.352
Sep..... 169.756
Oct.....345.980
Nov.....599.556
Dec.....725.880

(c)

Finfine Bldg. MOCKUP



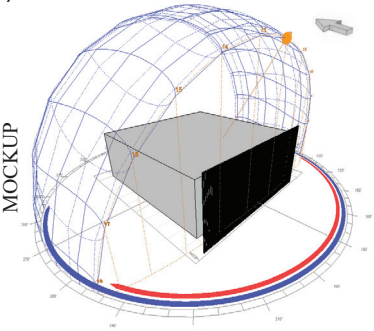


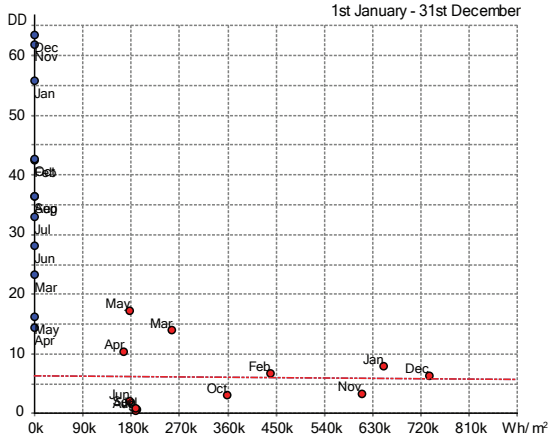
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 643.045
Feb..... 431.965
Mar..... 244.939
Apr 153.418
May 164.802
Jun 164.306
Jul 176.400
Aug..... 174.325
Sep..... 176.089
Oct.....348.947
Nov.....601.976
Dec..... 728.569

(d)

Henk de Pagter Library MOCKUP





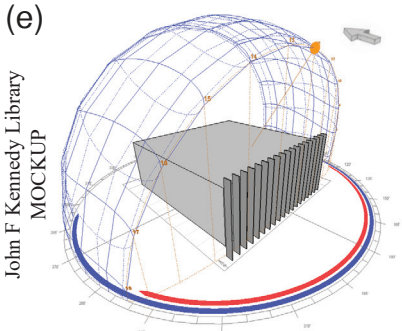
DIRECT SOLAR GAINS (In KWhr/m²)

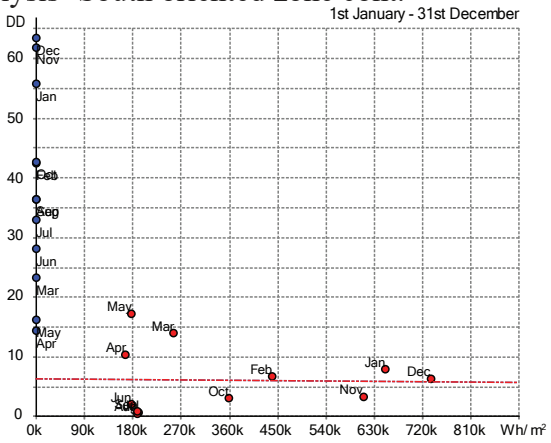
Jan 658.644
Feb.....449.425
Mar.....270.123
Apr 177.984
May 191.170
Jun 190.594
Jul 204.624
Aug..... 202.217
Sep..... 201.628
Oct.....372.903
Nov.....618.307
Dec.....743.631

Shading Simulation- Thermal Analysis- South oriented zone cont.

(e)

John F Kennedy Library MOCKUP



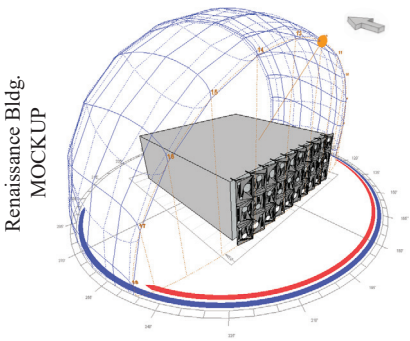


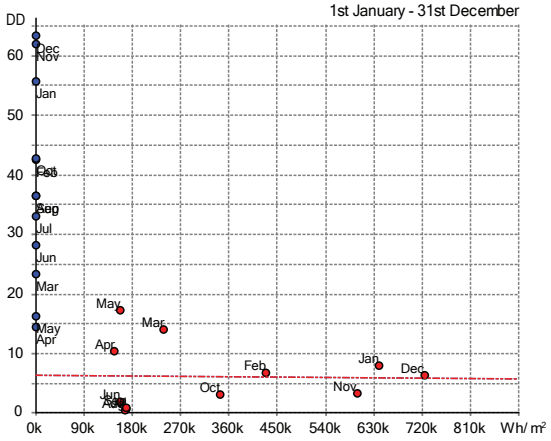
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 650.293
Feb..... 439.966
Mar..... 256.799
Apr 165.701
May 177.986
Jun 177.450
Jul 190.512
Aug..... 188.271
Sep..... 188.841
Oct.....359.918
Nov.....609.587
Dec..... 735.741

(f)

Renaissance Bldg. MOCKUP



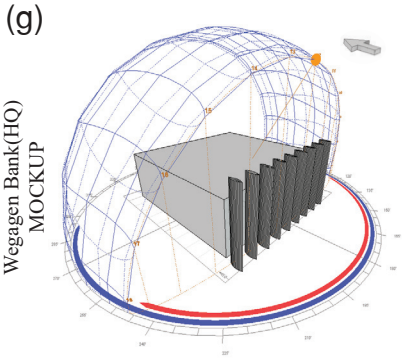


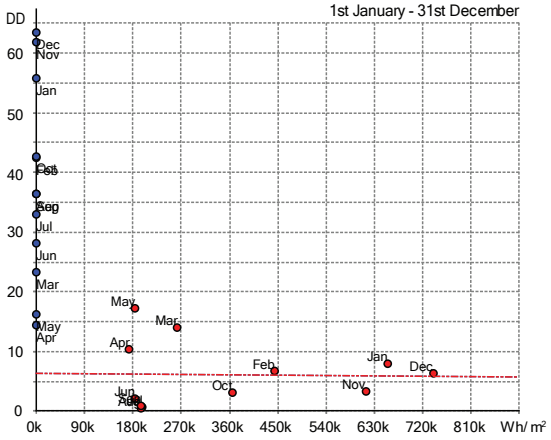
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 639.421
Feb..... 427.965
Mar..... 239.009
Apr 147.277
May 158.209
Jun 157.733
Jul 169.344
Aug..... 167.352
Sep..... 169.713
Oct.....343.461
Nov.....598.170
Dec..... 724.984

(g)

Wegagen Bank(HQ) MOCKUP





DIRECT SOLAR GAINS (In KWhr/m²)

Jan 653.917
Feb..... 443.967
Mar..... 262.729
Apr 171.842
May 184.578
Jun 184.022
Jul 197.568
Aug..... 195.244
Sep..... 195.217
Oct.....365.403
Nov.....613.393
Dec..... 739.327

Figure 5.14. Direct solar heat gain analysis of South oriented glazed zones(a-g)

Interpretation

Figure 5.14. shows the different shading typologies tested for performance on direct solar heat gain through a full-glazed surface on a Mockup model facing South. The thermal performance of each shading typology is assessed for all months of the year. The graphs show monthly total direct solar heat gains occurring in the mockup model. The trendline shows the axis of distribution of the months with in a year. Direct solar heat gain values are processed and interpreted to a diagram in Microsoft Excel software with different colors. Figure 5.15 shows a summary of the efficiency of each shading device against direct solar heat gains occurring in the mockup zone oriented South.

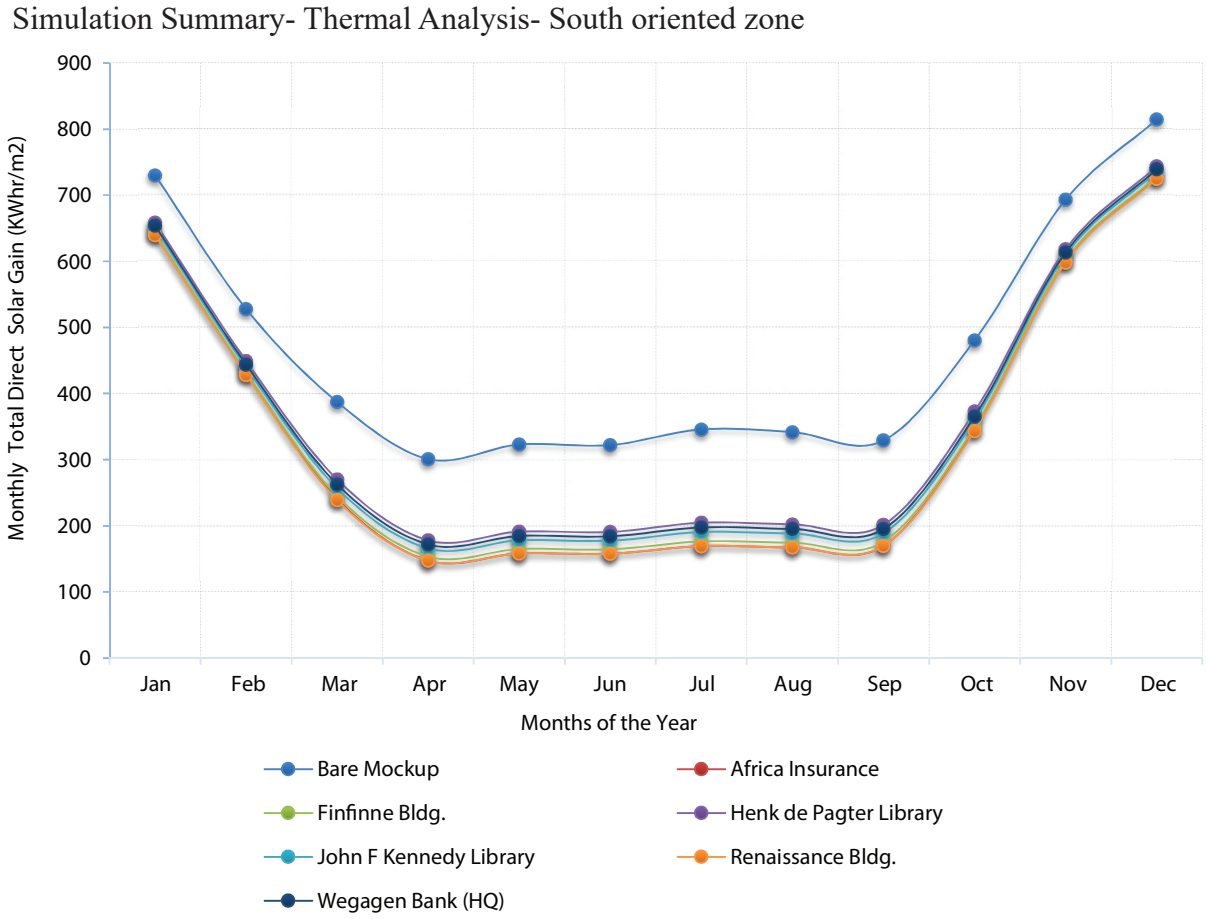


Figure 5.15. Direct solar heat gain analysis summary of South oriented glazed zones

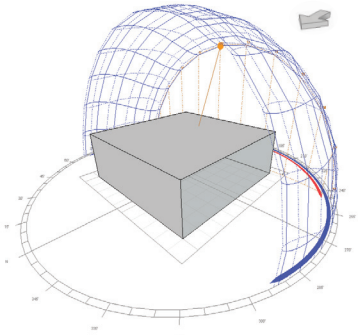
Discussion

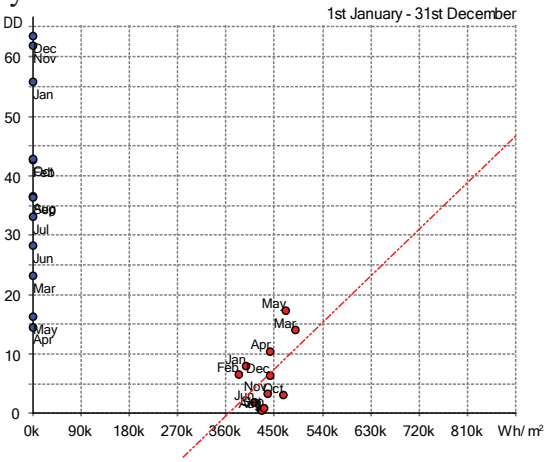
To assess the direct solar heat gains of South oriented glazed zones, monthly total direct solar heat gain values of the different shading typologies were simulated and mapped along the entire year. The mapped zonal heat gain values showed different layouts for the bare mockup and shaded mockup throughout the year. Figure 5.15. shows variable heat gain patterns for each month. Peak direct solar heat gain was registered in the month of December where the sun's trajectory was further to the South while the least value was registered in the month of April where the sun's trajectory was overhead. Among the simulated shading typologies, the shading device adopted from Africa Insurance building performed best in reducing direct solar heat gains for South oriented glazed zones. During the month of December, this shading device resulted in a total solar heat gain reduction of 88.7 KWhr/m^2 whereas in the month of April, it resulted in a total solar heat gain reduction of 153.5 KWhr/m^2.

Shading Simulation- Thermal Analysis- West oriented zone

(a)

BARE MOCKUP



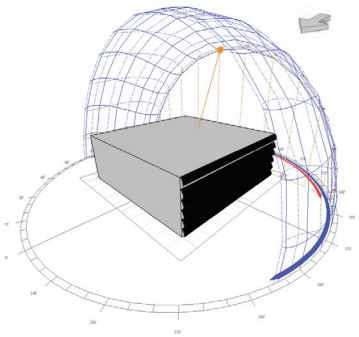


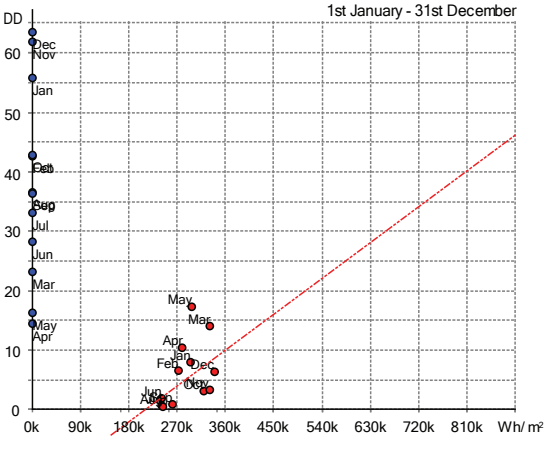
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 396.793
Feb..... 383.329
Mar.....489.215
Apr 442.575
May 471.259
Jun 413.383
Jul 425.234
Aug..... 426.244
Sep..... 430.736
Oct.....466.303
Nov.....436.898
Dec.....441.757

(b)

Africa Insurance MOCKUP



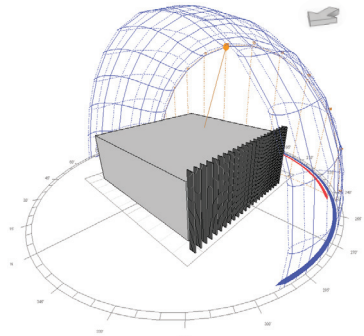


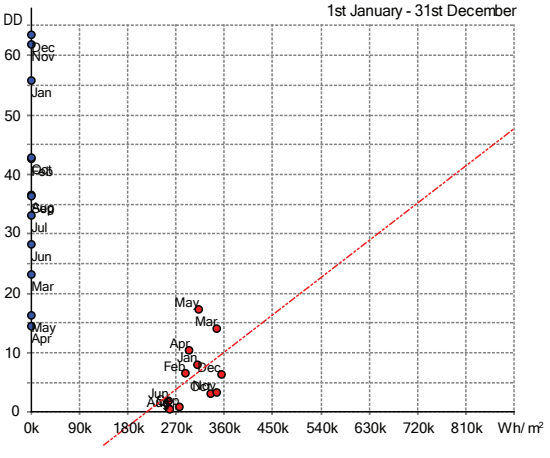
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 305.826
Feb..... 273.744
Mar..... 312.648
Apr 246.680
May 257.445
Jun 197.109
Jul 192.424
Aug..... 198.229
Sep..... 226.182
Oct.....304.110
Nov.....340.791
Dec..... 351.831

(c)

Finfine Bldg. MOCKUP



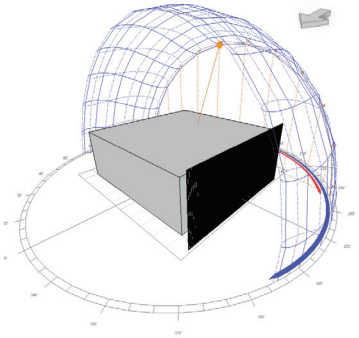


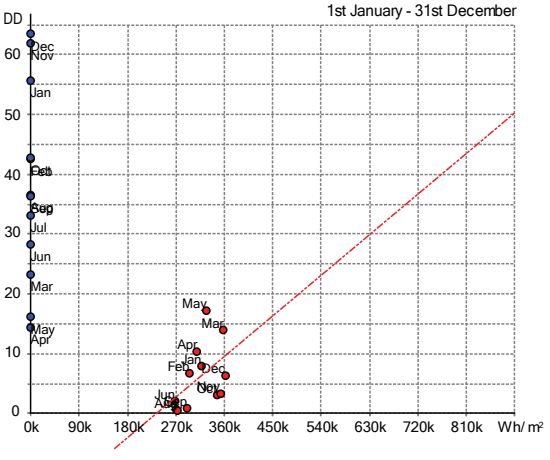
DIRECT SOLAR GAINS (In KWhr/m²)

Jan 313.439
Feb..... 281.218
Mar.....337.164
Apr 283.197
May 298.940
Jun 241.506
Jul 240.638
Aug..... 244.629
Sep..... 265.444
Oct.....325.414
Nov.....348.607
Dec.....369.126

(d)

Henk de Pagter Library MOCKUP





DIRECT SOLAR GAINS (In KWhr/m²)

Jan 326.818
Feb..... 304.781
Mar.....372.248
Apr 319.969
May 338.706
Jun 281.170
Jul 283.237
Aug..... 286.540
Sep..... 303.588
Oct.....357.927
Nov.....362.970
Dec.....372.583

Shading Simulation- Thermal Analysis- West oriented zone cont.

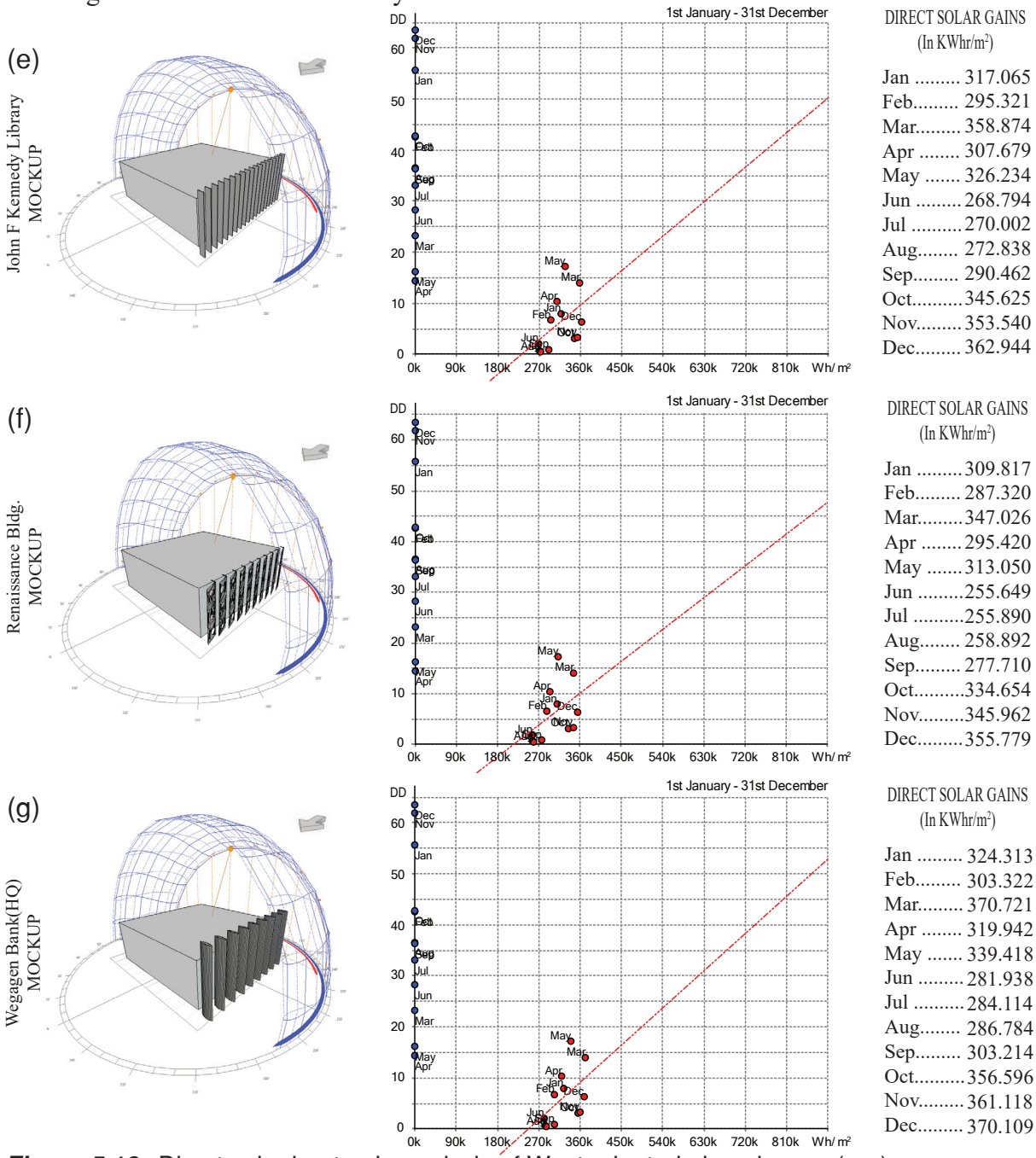


Figure 5.16. Direct solar heat gain analysis of West oriented glazed zones(a-g)

Interpretation

Figure 5.16. shows the different shading typologies tested for performance on direct solar heat gains through a full-glazed surface on a Mockup model facing West. The thermal performance of each shading typology is assessed for all months of the year. The graphs show monthly total direct solar heat gains occurring in the mockup model. The trendline shows the axis of distribution of the months with in a year. Direct solar heat gain values are processed and interpreted to a diagram in Microsoft Excel software with different colors. Figure 5.17. shows a summary of the efficiency of each shading device against direct solar heat gains occuring in the mockup zone oriented West.

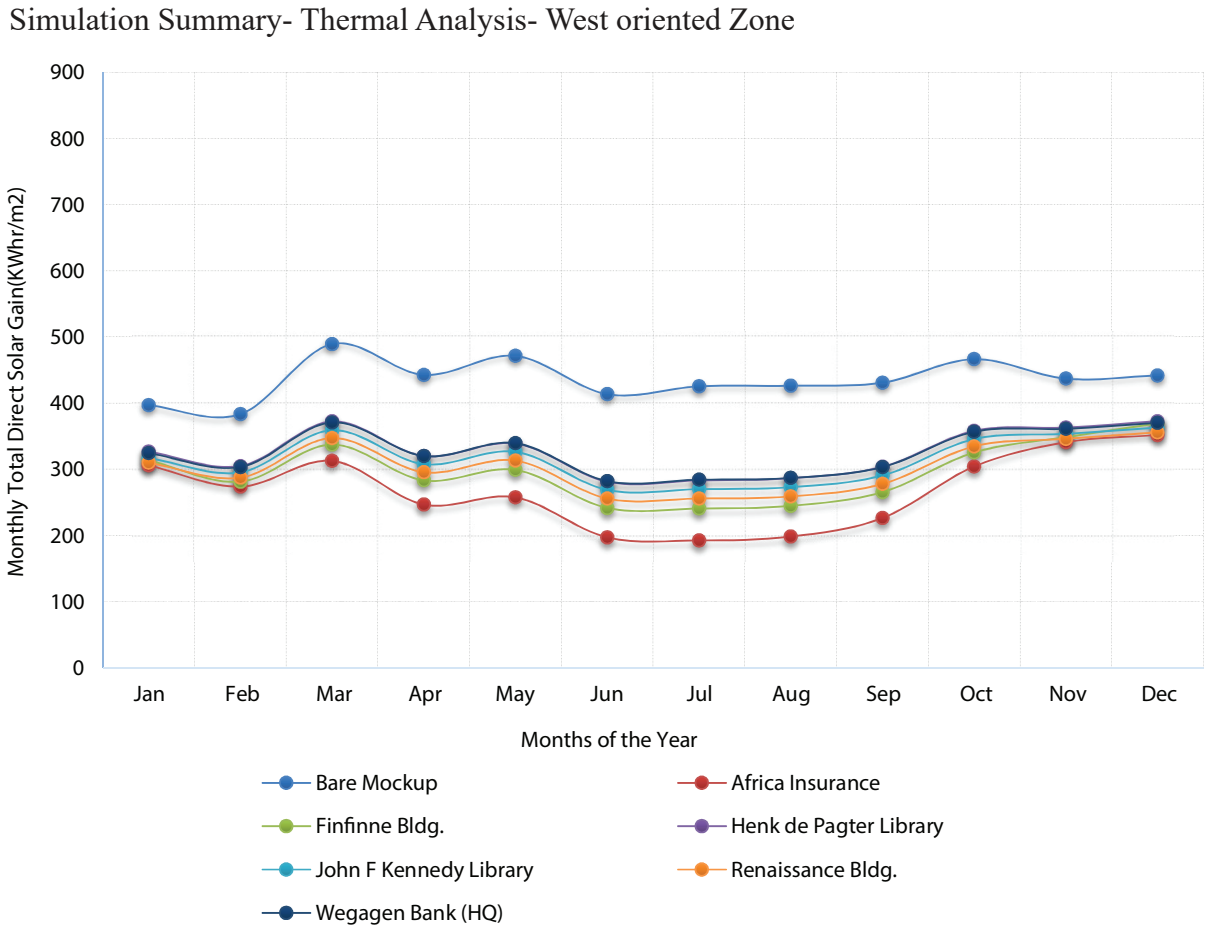


Figure 5.17. Direct solar heat gain analysis summary of West oriented glazed zones

Discussion

To assess the direct solar heat gains of West oriented glazed zones, monthly total direct solar heat gain values of the different shading typologies were simulated and mapped along the entire year. The mapped zonal heat gain values showed different layouts for the bare mockup and shaded mockup throughout the year. Figure 5.17. shows variable heat gain patterns for each month. Peak direct solar heat gain was registered in the month of March where the sun's trajectory was overhead while the least value was registered in the month of February where the sun's trajectory was further to the South. Among the simulated shading typologies, the shading device adopted from Africa Insurance building performed best in reducing direct solar heat gains for West oriented glazed zones. During the month of March, this shading device resulted in a total solar heat gain reduction of 176.5 KWhr/m^2 whereas in the month of February, it resulted in a total solar heat gain reduction of 109.6 KWhr/m^2.

5.5. Summary

This chapter focused on the means to identify overheated periods and performance of fixed exterior shading devices for radiation vulnerable glazed facades in the climate context of Addis Ababa. Three major data collection methods were conducted to gather and analyze objective data. Overheated periods were identified through the use of questionnaires and secondary data whereas performance of shading devices were analyzed by computer simulations in two ways namely Solar Access Analysis and Thermal Analysis. Results with respect to the location and climate context of Addis Ababa are summarized as follows.

5.5.1. Overheated Periods

To identify overheated periods, survey questions were distributed to occupants of six local case buildings in Addis Ababa. Of the 138 respondents, the majority claimed the month of May to be the hottest. This also held true for other studies related to the climate context of Addis Ababa. In relation to the registered overheated periods on the weather file of Addis Ababa, thermal comfort suvey results from the majority of respondents correlate to the interpreted results using Climate Consultant software. i.e. 11:30 - 16:30 (24hr. format).

5.5.2. performance of shading devices

Different full-glazed office buildings in Addis Ababa with fixed exterior shading devices were studied. To assess their performance, samples of the shading devices were developed and simulated in Ecotect software for North, East, South, and West orientations. Each orientation was exposed differently through out the year due to the shift of the sun path trajectory. Simulations for solar and thermal performance are conducted for each months to observe how each shadings perform. Following are result summaries for the mentioned orientations.

5.5.2.1. North Orientation. North oriented facade simulations showed solar inputs for 5 months (April, May, June, July, August) of the year throughout the day. In relation to the other orientations, surfaces facing North received the least solar input during these months ranging from 0 - 200 W/m^2. Results also showed the solar exposure hours during afternoon periods to be within range of the identified overheated periods. The shading typology from Finfinne building resulted in the highest average solar shading performance of 73.4%. This resulted in a maximum of 86.2 W/m^2 reduction from daily average incident solar inputs.

North oriented glazed zones gained the most heat during the month of June when the sun's trajectory is tilted to the North and least during the month of January when the sun's trajectory is to the South . Among the tested fixed exterior shading devices, the shading adopted from Africa Insurance proved to be more effective in reducing zonal solar heat gains during exposure periods. It resulted in a total solar heat gain reduction of 166.6 KWhr/m^2 during the month of June and 90.6 KWhr/m^2 during the month of January.

5.5.2.2. East Orientation. East oriented facade simulations showed solar inputs for all mornings of the year. In relation to the other orientations, surfaces facing East recieved the highest solar inputs ranging from 0 - 600 W/m^2. Results also showed the solar exposure hours during mornings to be out of range of the identified overheated periods. The shading typology adopted from Africa Insurance building resulted in the highest average solar shading performance of 73.7%. This resulted in a maximum of 306.2 W/m^2 reduction in incident solar inputs.

East oriented glazed zones gained the most heat during the month of November when the sun's trajectory is tilted further to the South at low angles and least during the month of July when the sun's trajectory is tilted further to the North at high angles. Among the tested fixed exterior shading devices, the shading adopted from Africa Insurance proved to be more effective in reducing zonal solar heat gains during exposure periods. It resulted in a total solar heat gain reduction of 97.1 KWhr/m^2 during the month of November and 176.4 KWhr/m^2 during the month of July.

5.5.2.3. South Orientation. South oriented facade simulations showed solar inputs all day except the 5 months(April, May, June, July, August) of the year where the sun's trajectory is tilted to the North. In relation to the other orientations, surfaces facing South received above average solar inputs ranging from 0 - 400 W/m^2. Results also showed the solar exposure hours during afternoon periods to be within range of the identified overheated periods. The shading typology from Finfinne building resulted in the highest average solar shading performance of 74%. This resulted in a maximum of 82.1 W/m^2 reduction in incident solar inputs.

South oriented glazed zones gained the most heat during the month of December when the sun's trajectory is tilted to the South and least during the month of April when the sun's trajectory is Overhead. Among the tested fixed exterior shading devices, the shading adopted from Africa Insurance proved to be more effective in reducing zonal solar heat gains during exposure periods. It resulted in a total solar heat gain reduction of 88.7 $KWhr/m^2$ during the month of December and 153.5 $KWhr/m^2$ during the month of April.

5.5.2.4. West Orientation. West oriented facade simulations showed solar inputs for all afternoons of the year. In relation to the other orientations, surfaces facing West received above average solar inputs ranging from 0 - 400 W/m^2. Results also showed the solar exposure hours during afternoon periods to be within range of the identified overheated periods. The shading typology from Africa Insurance building resulted in the highest average solar shading performance of 80.3%. This resulted in a maximum of 190 W/m^2 reduction in solar inputs.

West oriented glazed zones gained the most heat during the month of March when the sun's trajectory is overhead and least during the month of February when the sun's trajectory is tilted further to the South. Among the tested fixed exterior shading devices, the shading adopted from Africa Insurance proved to be more effective in reducing zonal solar heat gains during exposure periods. It resulted in a total solar heat gain reduction of 176.5 $KWhr/m^2$ during the month of March and 109.6 $KWhr/m^2$ during the month of February.

CHAPTER SIX

Design Proposal

CHAPTER SIX: Design Proposal

6.1. Introduction

In this chapter, an intervention design is proposed for a strategic site in the climate context of Addis Ababa. The proposal is intended to show a suitable design approach and implementation of fixed exterior shading devices for full glazed building facades. This indeed requires the identification and harmonized execution of key design factors that are otherwise difficult to consider all at once during design. To Simplify this process, these factors are sequentially categorized and executed in three major stages. Figure 6.1. shows an outline of the organization of these stages.

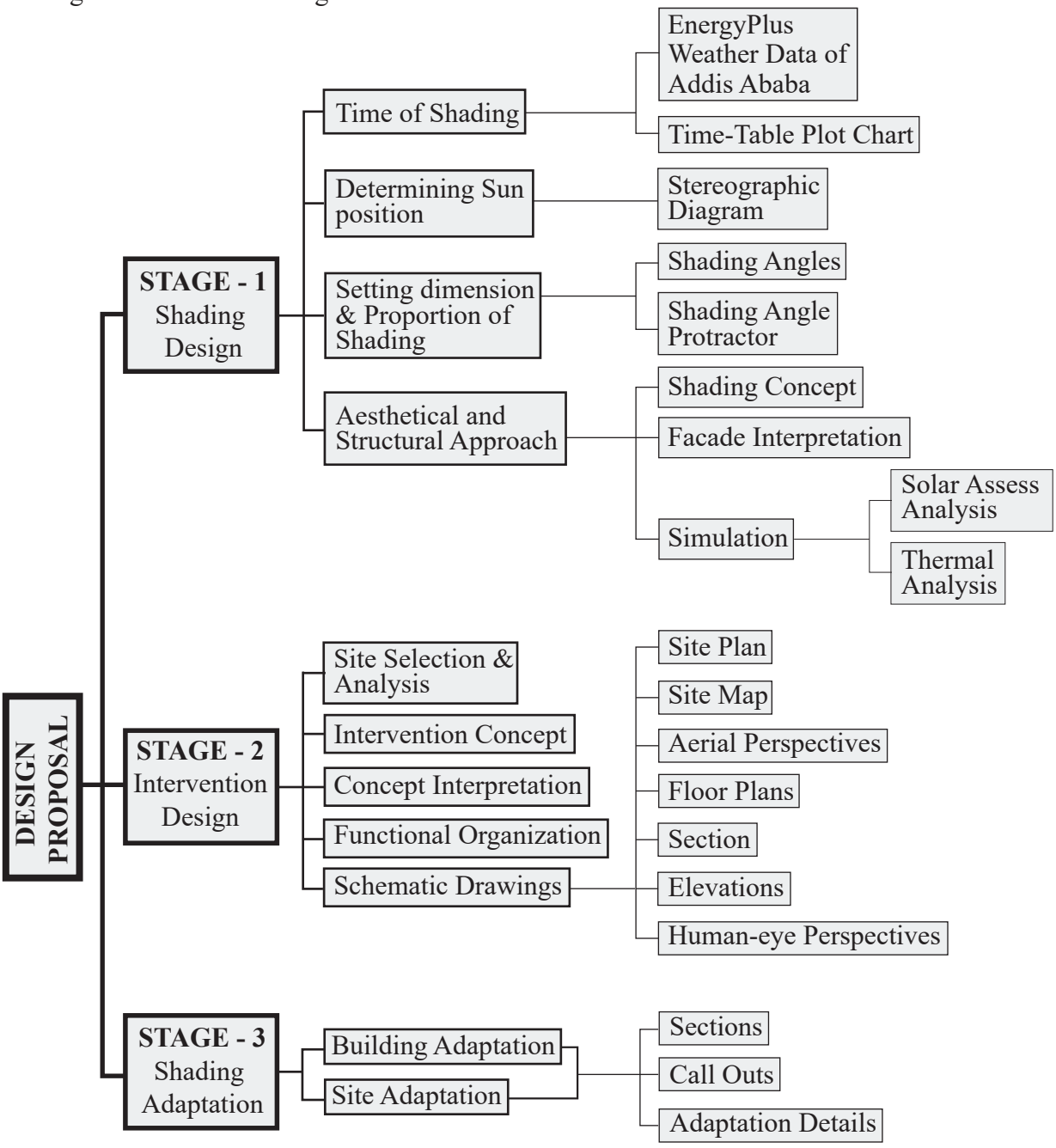


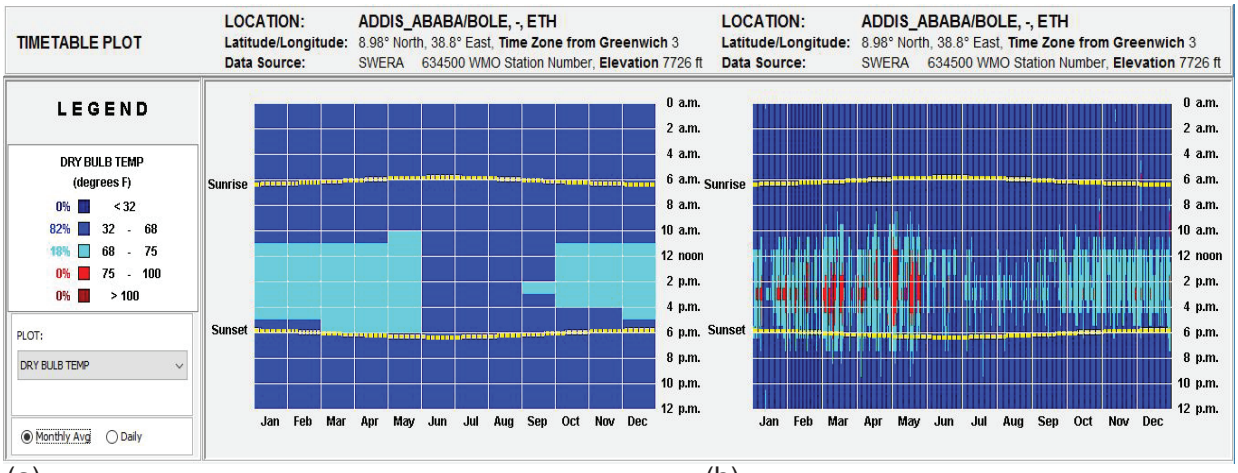
Figure 6.1. Design proposal outline

6.2. Stage 1 - Shading Design

According to a journal of building climatoloty by Antony Sealey(1979),This stage explores four necessary steps that are required for the proper design of shading devices.

6.2.1. Determining When Shading is Required

Different regions exhibit different weather conditions depending on their location. As a result, occurrence of overheated periods varies from place to place. Now a days, weather data of a location is easily accessible on the web. Different weather conditions are registered and updated periodically on weather stations. The United States Department of Energy(DOE) has been one of the earliest and trusted sources that provides weather data of a region. Proper analysis and interpretation of such data is vital to identify comfort and discomfort periods of a region. There are a number of applications that help interpret weather data from DOE. One of which is Climate Consultant software. It is the most used and user friendly application that helps interpret weather data through four comfort model options. In the context of passive design approaches, an Adaptive Comfort Model option in ASHRAE Standard 55-2010 is used since it applies to user's comfort standards for naturally ventilated spaces. Climate Consultant shows a variety of graphic representations of hourly climate data for a chosen location in different charts. In this case, weather data of Addis Ababa is downloaded from US-DOE and presented in a Time-Table Plot chart. It is a plot of average daily and monthly temperatures of EnergyPlus weather data. Based on the Adaptive Comfort Model chosen, it displays information in three color zones namely Blue(Cold/Underheated), Turquoise(Comfortable), and Red(Hot/Overheated). Figure 6.2 shows the monthly and daily average temperatures of Addis Ababa. The monthly average temperature chart shows cold and comfortable periods throughout the year whereas the daily average temperature chart shows overheated periods in Spring months.



(a) (b)

Figure 6.2. Time-Table Plot chart of Addis Ababa (a)average monthly temperature and (b)average daily temperature (Source: Climate Consultant software)

6.2.2. Determining Position of the Sun When Shading is Required

As explained in Chapter 2, the sun's position could be determined in five ways. Among these, the most simplistic and widely used option is the stereographic projection. Figure 6.3.(a) shows the location of Addis Ababa at the center with respect to the globe. The darker horizontal lines represent trajectory of the sun and the vertical hidden lines represent hours of the day.

Figure 6.3.(b) shows daily overheated periods in Red. It will not be advisable to shade all red zones as their complimenting months will be shaded too. To minimize this, compromises have been made on the range of red zones. Overheated periods are often registered in months from January to May. Considering periods of occurrence for each month, repetitive overheated periods are mapped. (See Figure 6.3.(c))

When mapping the information on the Time-Table Plot to the stereographic diagram, the sun's trajectory and hour lines should carefully be considered. The time gap between each consecutive sun trajectory is one month. Months that are written in black are read above the line and those written in gray are read below the line. First,periods of comfort are mapped followed by periods of discomfort. Underheated periods are left blank for ease of presentation.

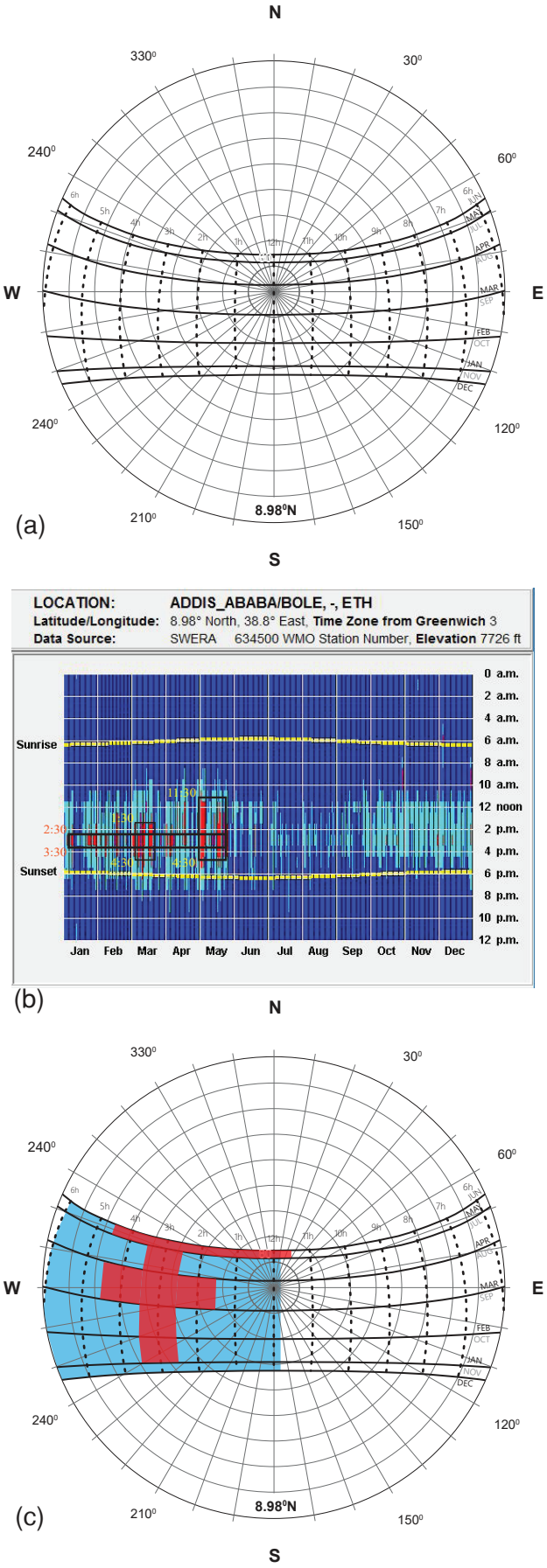


Figure 6.3. (a)Stereographic diagram of Addis Ababa (Source: University of Oregon), (b)mapped Time-Table Plot chart, and (c)mapped stereographic diagram

6.2.3. Determining Dimensions and Proportions of Shading Devices for the Required Period

During the sun's trajectory form sunrise to sun set, the sun will have different elevations and azimuth angles during the day. This trajectory will create different exposure angles on vulnerable surfaces. Since we are considering to shade full glazed vertical facades, the possible scenarios where the sun creates shadow angles are shown in Figure 6.4..

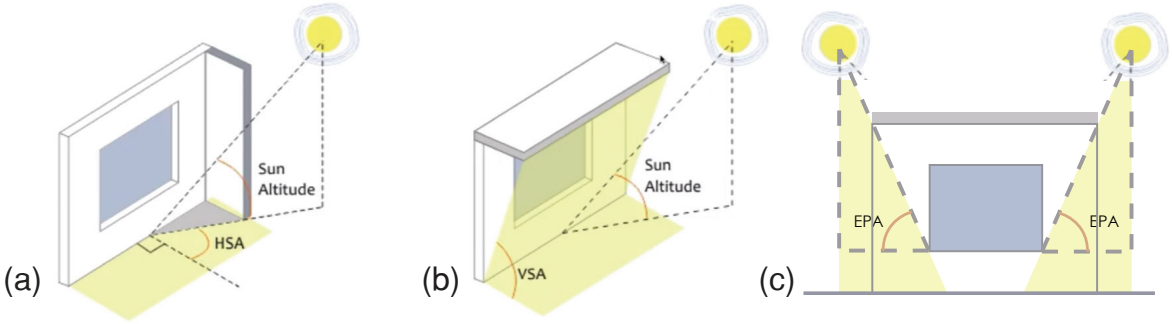


Figure 6.4. Shading angles created by the sun's movement (a)horizontal shading angle, (b)vertical shading angle and (c)end-profile shading angle (Source: University of Oregon)

6.2.3.1.The shading angle protractor

It is a useful tool used to determine the HSA, VSA and EP angles of a given facade orientation. To use the protractor, the following prerequisites are required.

- a stereographic diagram of a location.

-Interpret weather data of location to a Time -Table Plot chart.

-mapping of the Time -Table Plot chart on the stereograhic diagram.

-Identify for which orientation you want to find the shadow angles. (North, East ,South or West.) If you choose North orientation, carefully place the center of the stereographic diagram and orient the protractor to North.

-Read the lines of the protractor in relation to the mapped chart. Now, Lets try to identify these shading angles for each major orientations.

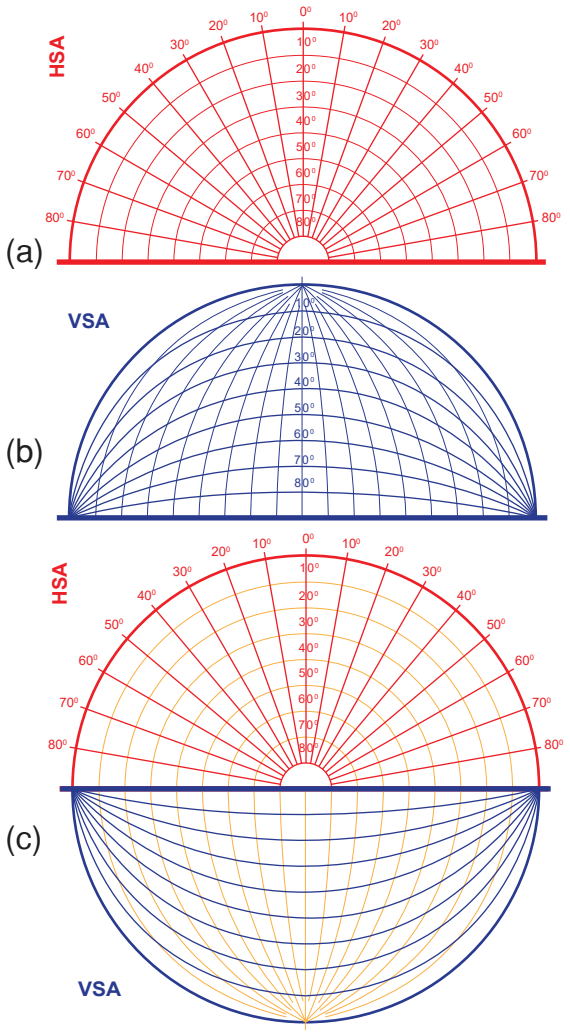
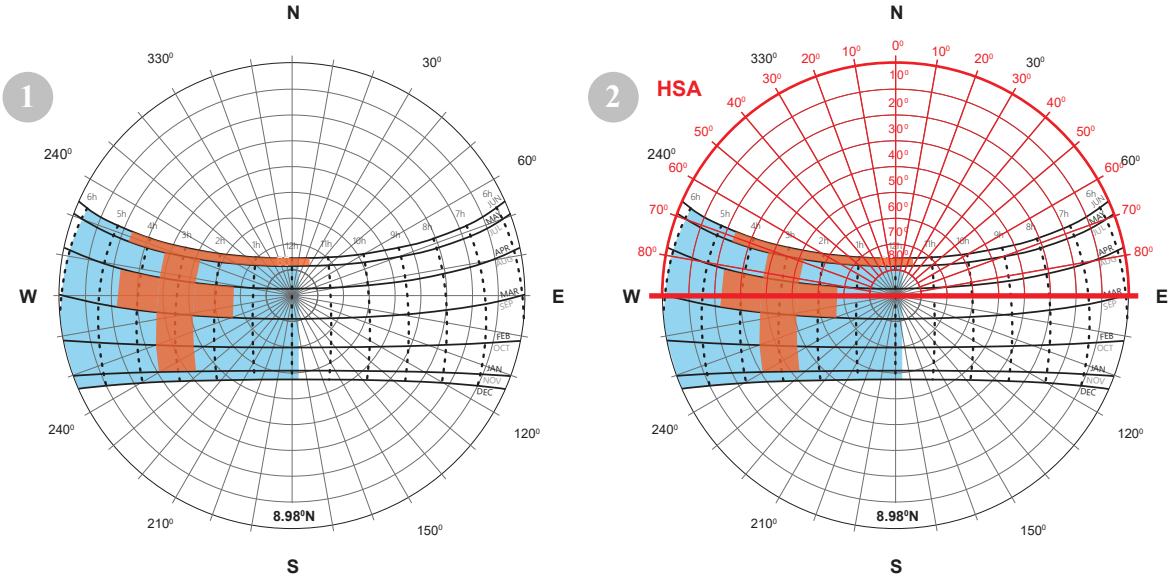
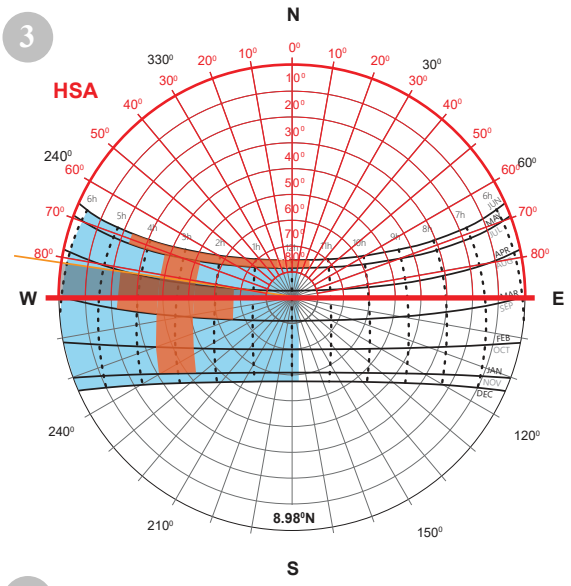
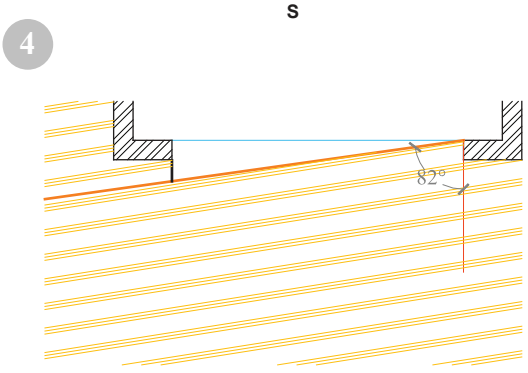


Figure 6.5. Shading angle protractors (a)horizontal shading angle protractor (b)vertical shading angle protractor, and (c)end-profile shading angle protractor (Source: University of Oregon)

6.2.3.1.1. North Orientation (HSA Identification). To find the horizontal shading angle for North facing glazed facades, the center of the protractor is overlaid on the stereographic diagram facing North direction. Readings are performed in the steps shown in Figure 6.6.







As shown in Figure 6.6.(3), the HSA protractor starts reading the mapped overheated periods around 30^0. An 82^0 angle is chosen not to shade periods of comfort in the month of April and July. In addition to this, Northern facades in Addis Ababa are only exposed to the sun's trajectory for 5 months in a year.

Figure 6.6.(4) shows a plan view of a full glazed wall. The projection of the HSA from Figure 6.6.(3) is drawn using the following steps.

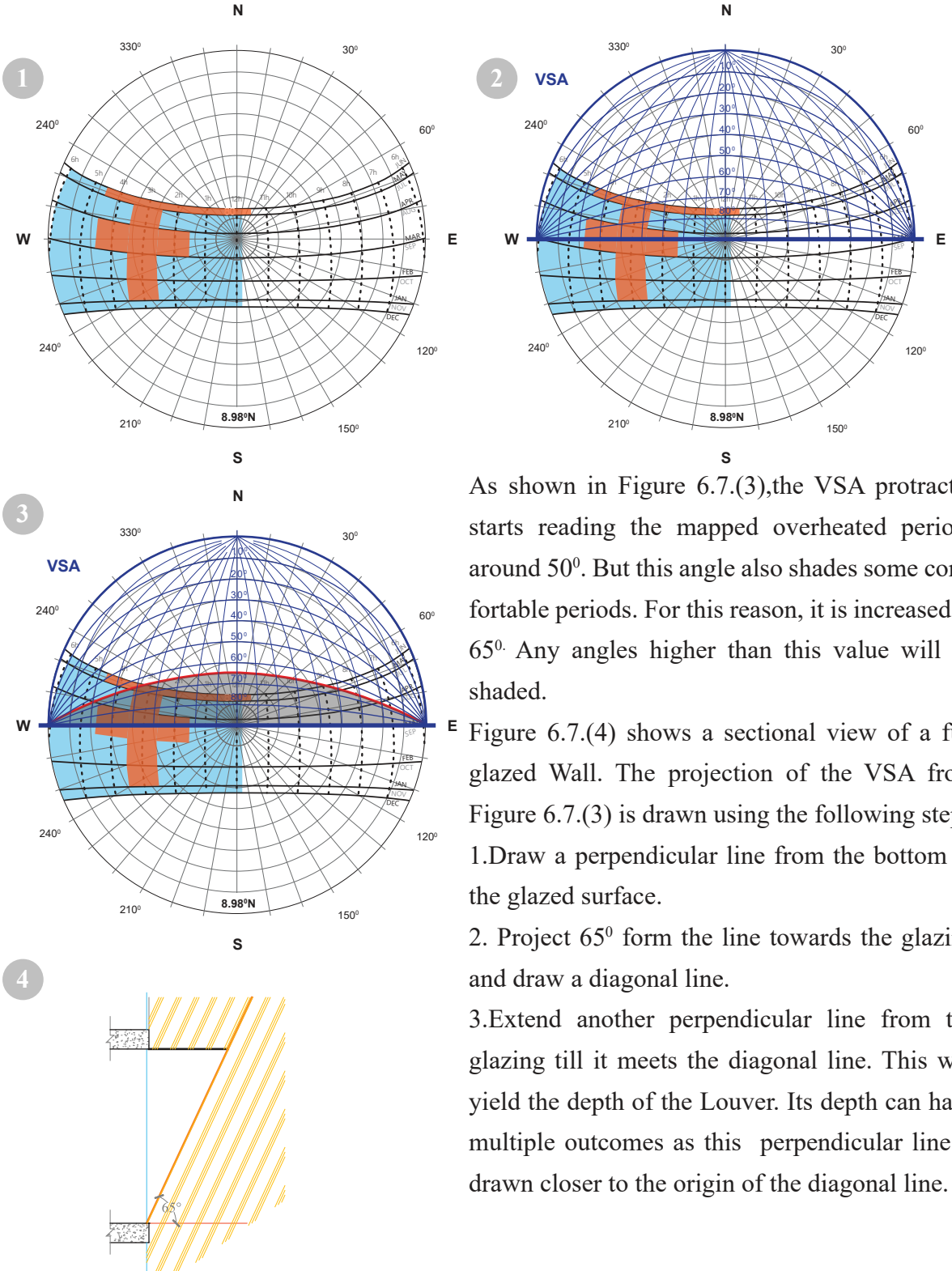
1.Draw a line perpendicular to the glazed surface.

2. Project 82^0 form the line towards the glazing and draw a diagonal line.

3.Extend another perpendicular line from the glazing till it meets the diagonal line. This will yield the depth of the vertical fin. Its depth can have multiple outcomes as this perpendicular line is drawn closer to the origin of the diagonal line.

Figure 6.6. North orientation horizontal shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)plan view

6.2.3.1.2. North Orientation (VSA Identification). To find the vertical shading angle for North facing glazed facades, the center of the protractor is overlaid on the stereographic diagram facing North direction. Readings are performed in the steps shown in Figure 6.7.



As shown in Figure 6.7.(3),the VSA protractor starts reading the mapped overheated periods around 50^0. But this angle also shades some comfortable periods. For this reason, it is increased to 65^0. Any angles higher than this value will be shaded.

Figure 6.7.(4) shows a sectional view of a full glazed Wall. The projection of the VSA from Figure 6.7.(3) is drawn using the following steps.

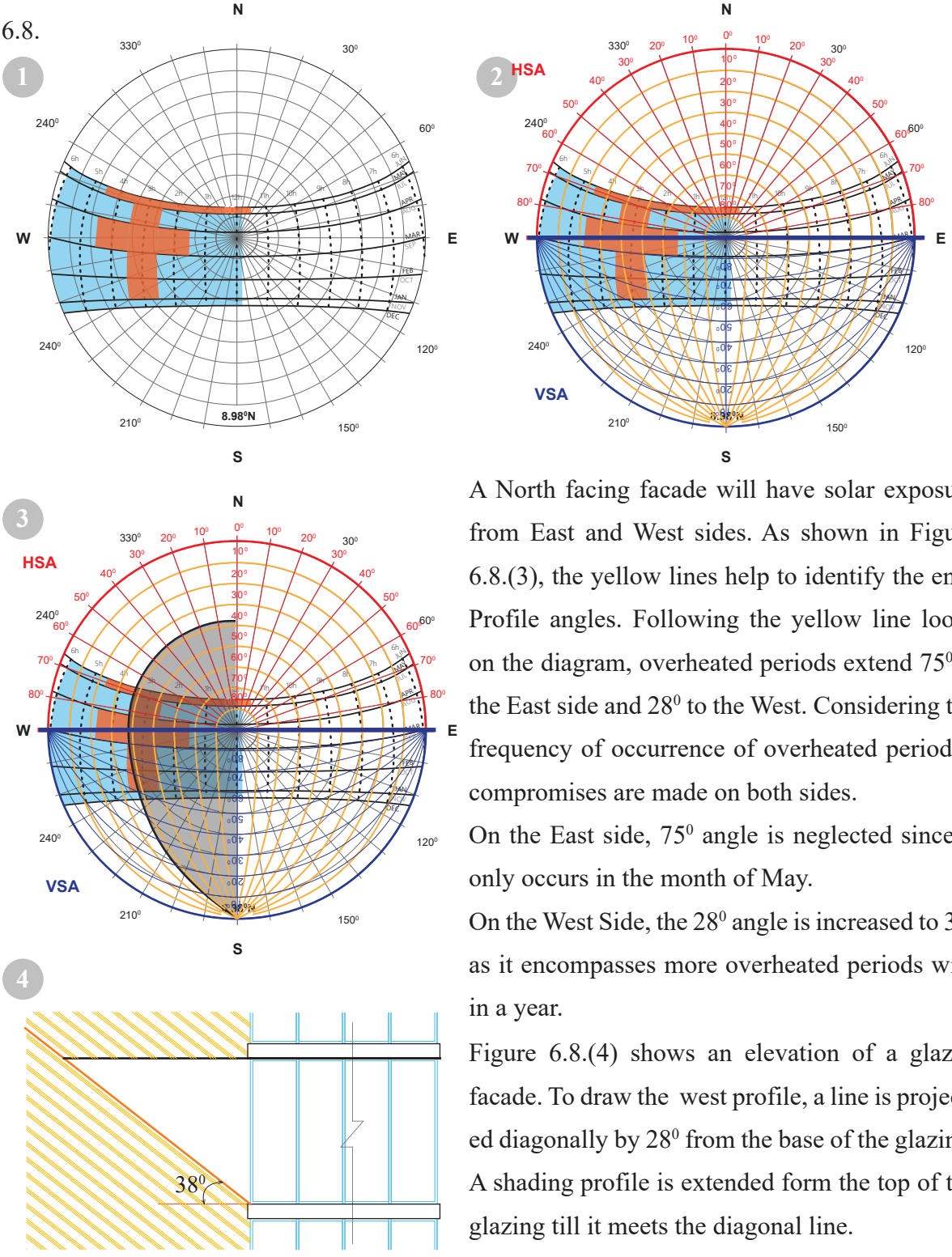
1.Draw a perpendicular line from the bottom of the glazed surface.

2. Project 65^0 form the line towards the glazing and draw a diagonal line.

3.Extend another perpendicular line from the glazing till it meets the diagonal line. This will yield the depth of the Louver. Its depth can have multiple outcomes as this perpendicular line is drawn closer to the origin of the diagonal line.

Figure 6.7. North orientation vertical shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)section view

6.2.3.1.3. North Orientation (EPA Identification). To find the end-profile angles for North facing glazed facades, the center of the protractor is overlaid on the stereographic diagram aligned to the North - South axis. Readings are performed in the steps shown in Figure 6.8.



A North facing facade will have solar exposure from East and West sides. As shown in Figure 6.8.(3), the yellow lines help to identify the end-Profile angles. Following the yellow line loops on the diagram, overheated periods extend 75^0 in the East side and 28^0 to the West. Considering the frequency of occurrence of overheated periods,- compromises are made on both sides.

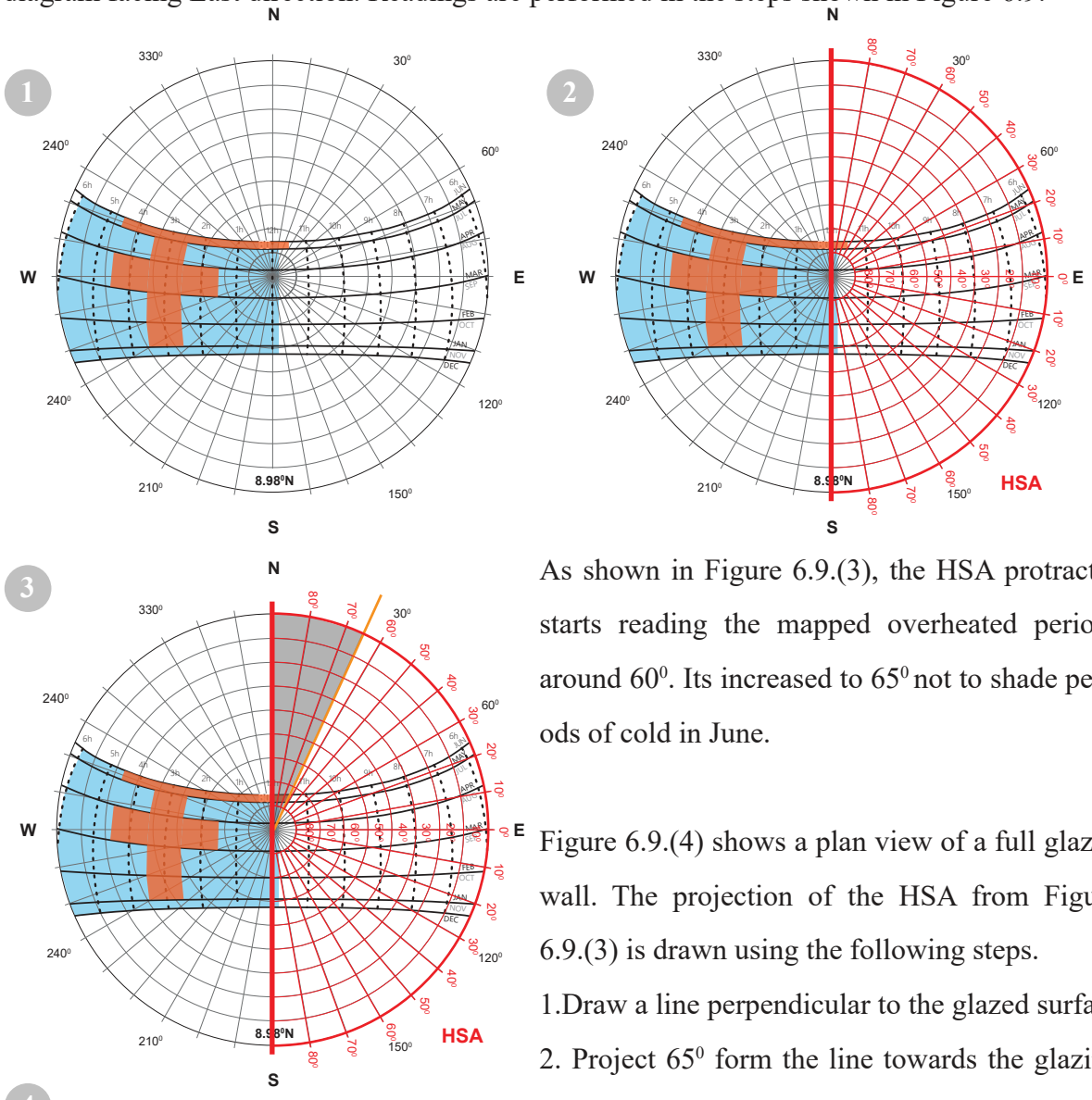
On the East side, 75^0 angle is neglected since it only occurs in the month of May.

On the West Side, the 28^0 angle is increased to 38^0 as it encompasses more overheated periods with in a year.

Figure 6.8.(4) shows an elevation of a glazed facade. To draw the west profile, a line is projected diagonally by 28^0 from the base of the glazing. A shading profile is extended form the top of the glazing till it meets the diagonal line.

Figure 6.8. North orientation end-profile shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)elevation view

6.2.3.1.4. East Orientation (HSA Identification). To find the horizontal shading angle for East facing glazed facades, the center of the protractor is overlaid on the stereographic diagram facing East direction. Readings are performed in the steps shown in Figure 6.9.



As shown in Figure 6.9.(3), the HSA protractor starts reading the mapped overheated periods around 60^0. Its increased to 65^0 not to shade periods of cold in June.

Figure 6.9.(4) shows a plan view of a full glazed wall. The projection of the HSA from Figure 6.9.(3) is drawn using the following steps.

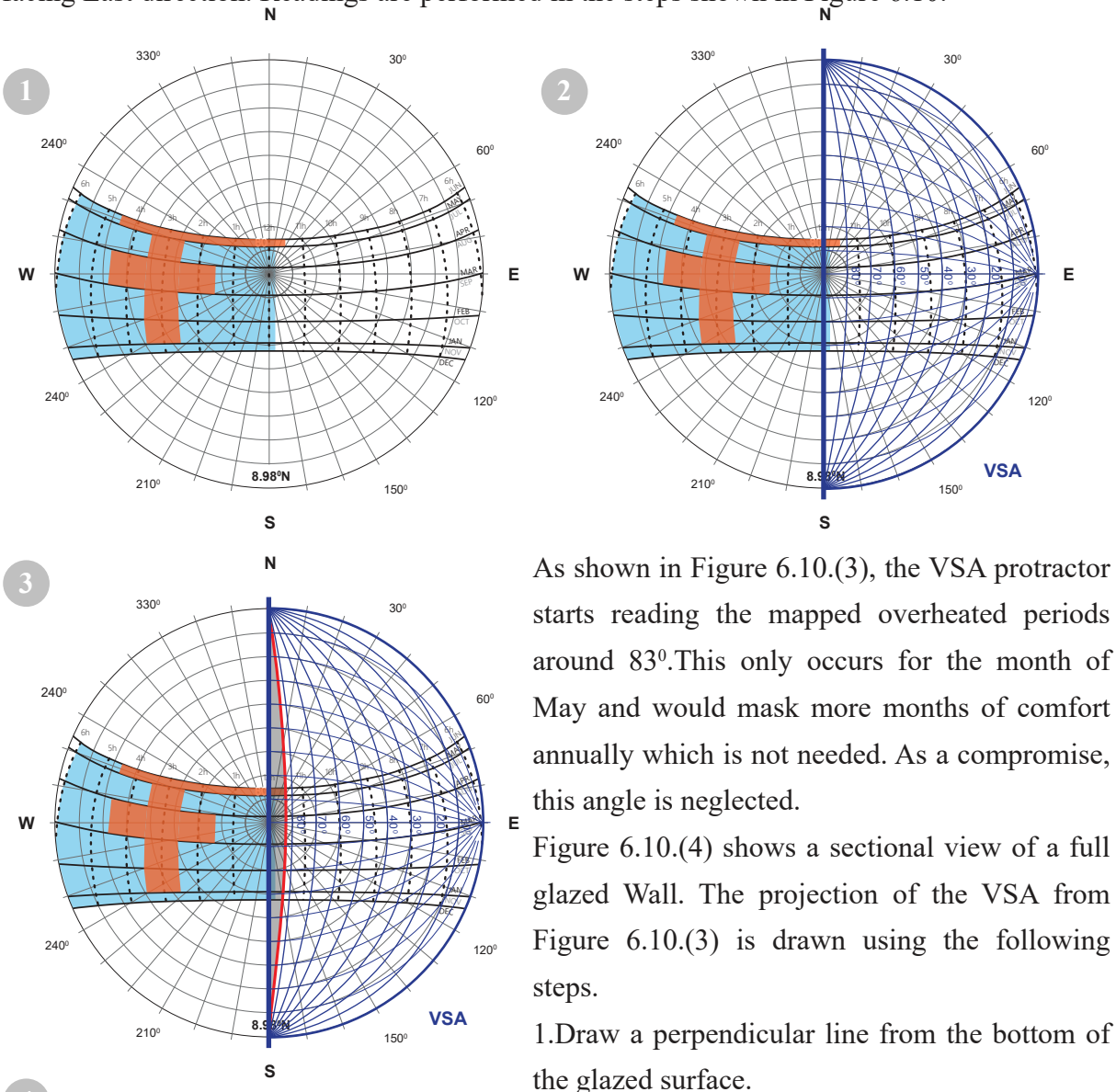
1.Draw a line perpendicular to the glazed surface.

2. Project 65^0 form the line towards the glazing and draw a diagonal line.

3.Extend another perpendicular line from the glazing till it meets the diagonal line. This will yield the depth of the vertical fin. Its depth can have multiple outcomes as this perpendicular line is drawn closer to the origin of the diagonal line.

Figure 6.9. East orientation horizontal shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)plan view

6.2.3.1.5. East Orientation (VSA Identification). To find the vertical shading angle for East facing glazed facades, the center of the protractor is overlaid on the stereographic diagram facing East direction. Readings are performed in the steps shown in Figure 6.10.



As shown in Figure 6.10.(3), the VSA protractor starts reading the mapped overheated periods around 83^0.This only occurs for the month of May and would mask more months of comfort annually which is not needed. As a compromise, this angle is neglected.

Figure 6.10.(4) shows a sectional view of a full glazed Wall. The projection of the VSA from Figure 6.10.(3) is drawn using the following steps.

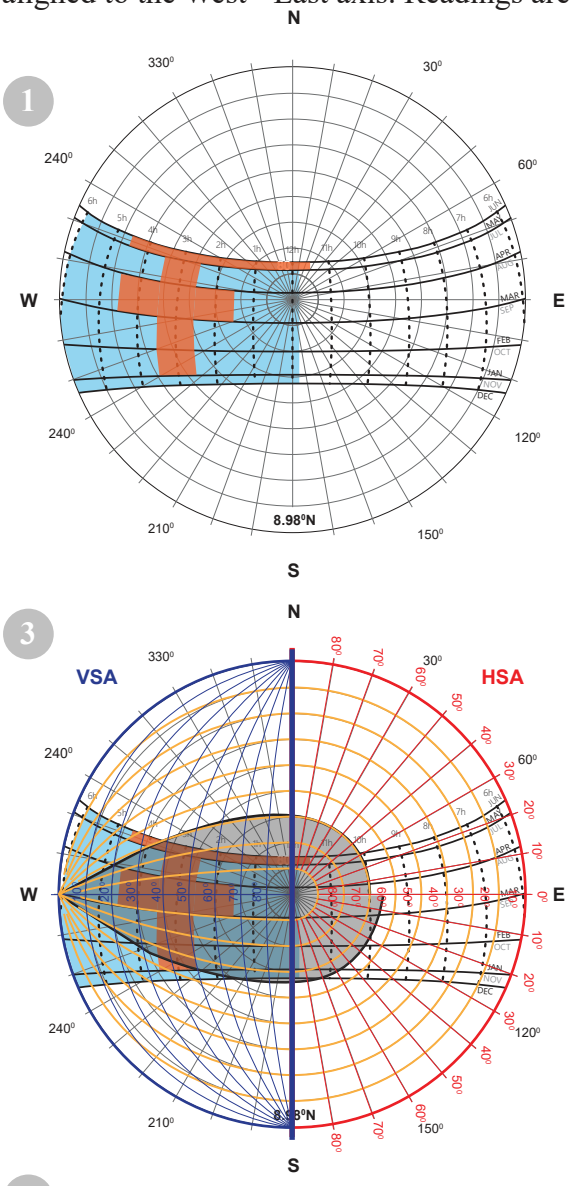
1.Draw a perpendicular line from the bottom of the glazed surface.

2. Project 83^0 form the line towards the glazing and draw a diagonal line.

3.Extend another perpendicular line from the glazing till it meets the diagonal line. This will yield the depth of the Louver. Its depth can have multiple outcomes as this perpendicular line is drawn closer to the origin of the diagonal line.

Figure 6.10. East orientation vertical shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)section view

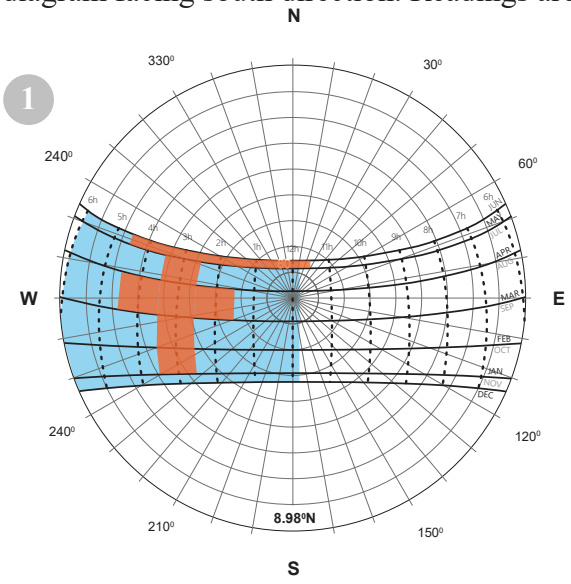
6.2.3.1.6. East Orientation (EPA Identification). To find the end-profile angles for East facing glazed facades, the center of the protractor is overlaid on the stereographic diagram aligned to the West - East axis. Readings are performed in the steps shown in Figure 6.11.

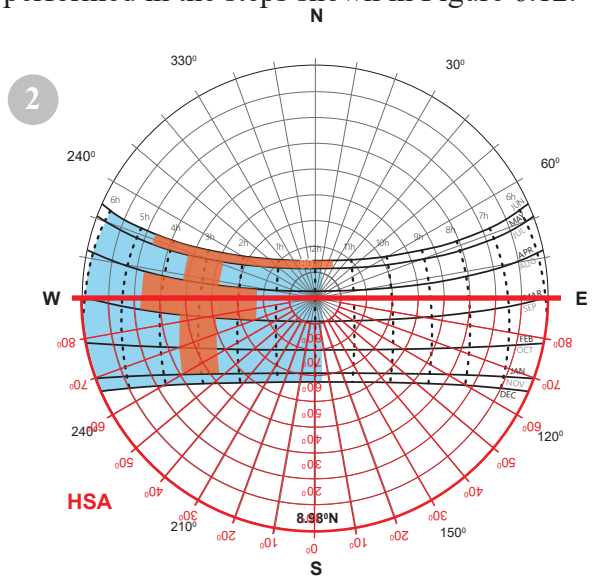


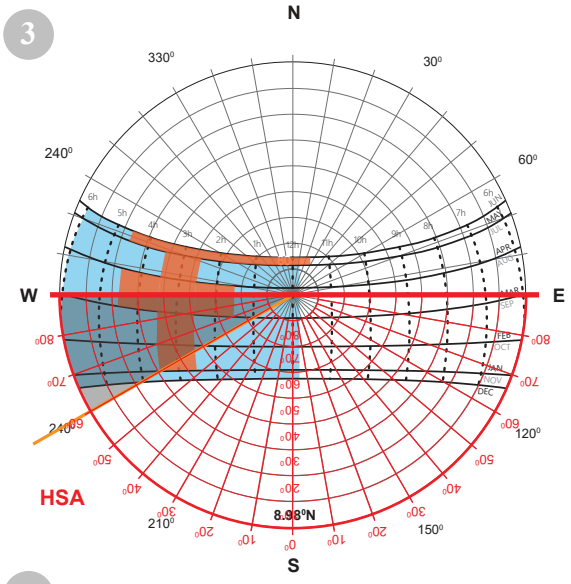
An East facing facade will have solar exposure from North and South sides. On the shaded stereographic diagram, the yellow line loops help to identify the end-profile angles. Taking the center on the diagram, overheated periods extend 50^0 in the North side and 50^0 on the South. Considering the frequency of occurrence of overheated periods,compromises are made on both sides. On the North side, the angle is increased to 60^0. On the South Side, the angle is increased to 55^0. Figure 6.11.(4) shows an elevation of a glazed facade. To draw the North profile, a line is projected diagonally by 60^0 from the base of the glazing. A shading profile is extended form the top of the glazing till it meets the diagonal line. Same step is repeated using a 55^0 angle to identify the South profile.

Figure 6.11. East orientation end-profile shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)elevation view

6.2.3.1.7. South Orientation (HSA Identification). To find the horizontal shading angle for South facing glazed facades, the center of the protractor is overlaid on the seterographic diagram facing south direction. Readings are performed in the steps shown in Figure 6.12.







As shown in Figure 6.12.(3), the HSA protractor starts reading the mapped overheated periods around 55^0. A 60^0 angle is chosen not to shade periods of comfort in November.

Figure 6.12.(4) shows a plan view of a full glazed wall. The projection of the HSA from Figure 6.12.(3) is drawn using the following steps.

1.Draw a line perpendicular to the glazed surface.

2. Project 60^0 form the line towards the glazing and draw a diagonal line.

3.Extend another perpendicular line from the glazing till it meets the diagonal line. This will yield the depth of the vertical fin. Its depth can have multiple outcomes as this perpendicular line is drawn closer to the origin of the diagonal line.

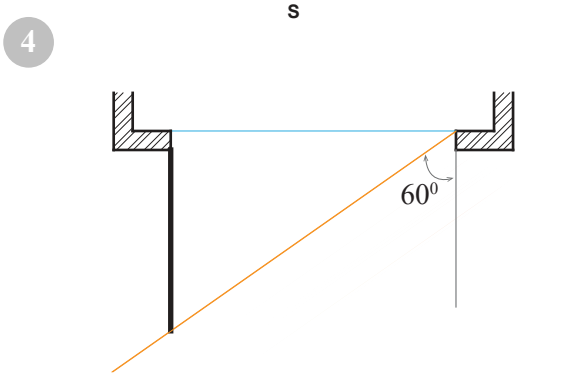
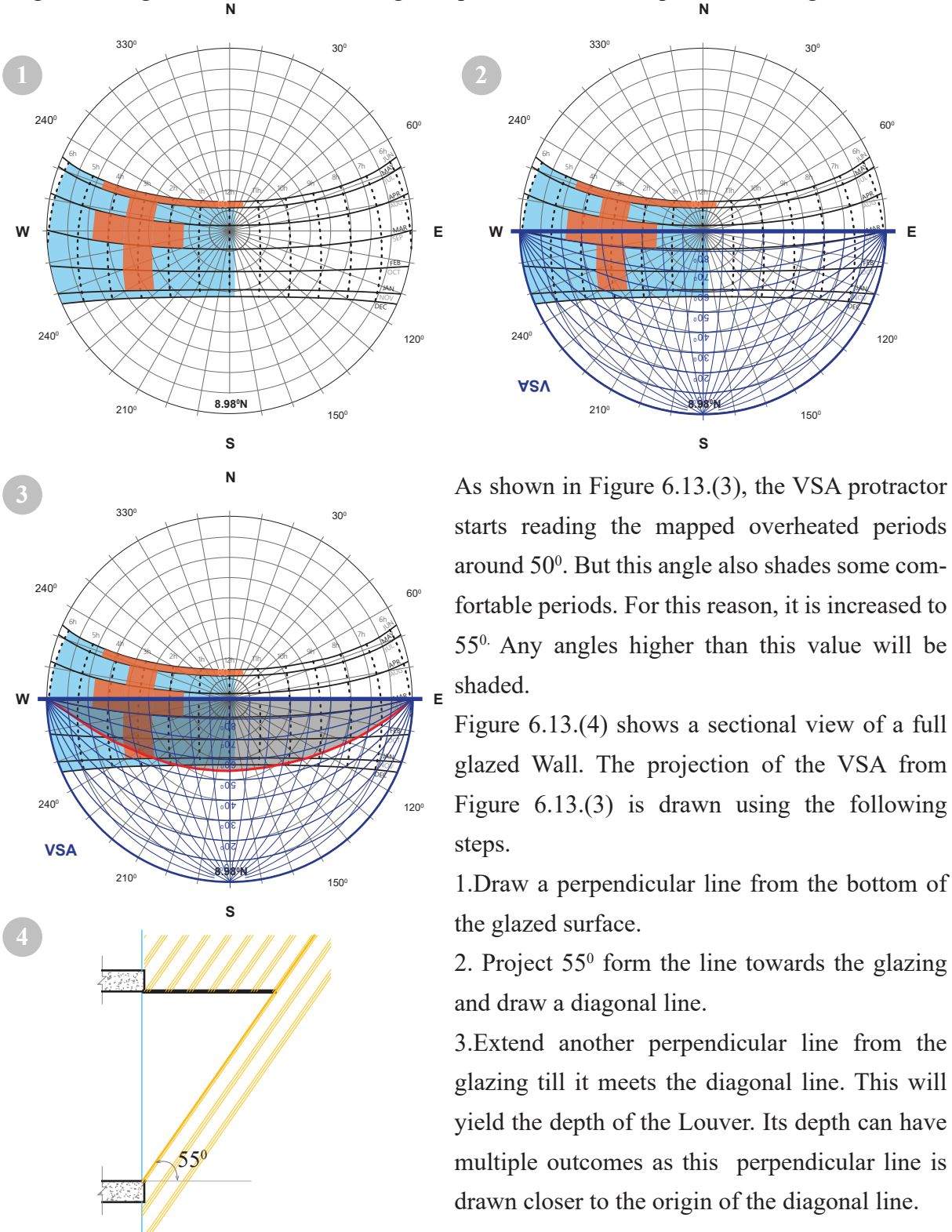


Figure 6.12. South orientation horizontal shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)plan view

6.2.3.1.8. South Orientation (VSA Identification). To find the vertical shading angle for South facing glazed facades, the center of the protractor is overlaid on the stereographic diagram facing south direction. Readings are performed in the steps shown in Figure 6.13.



As shown in Figure 6.13.(3), the VSA protractor starts reading the mapped overheated periods around 50^0. But this angle also shades some comfortable periods. For this reason, it is increased to 55^0. Any angles higher than this value will be shaded.

Figure 6.13.(4) shows a sectional view of a full glazed Wall. The projection of the VSA from Figure 6.13.(3) is drawn using the following steps.

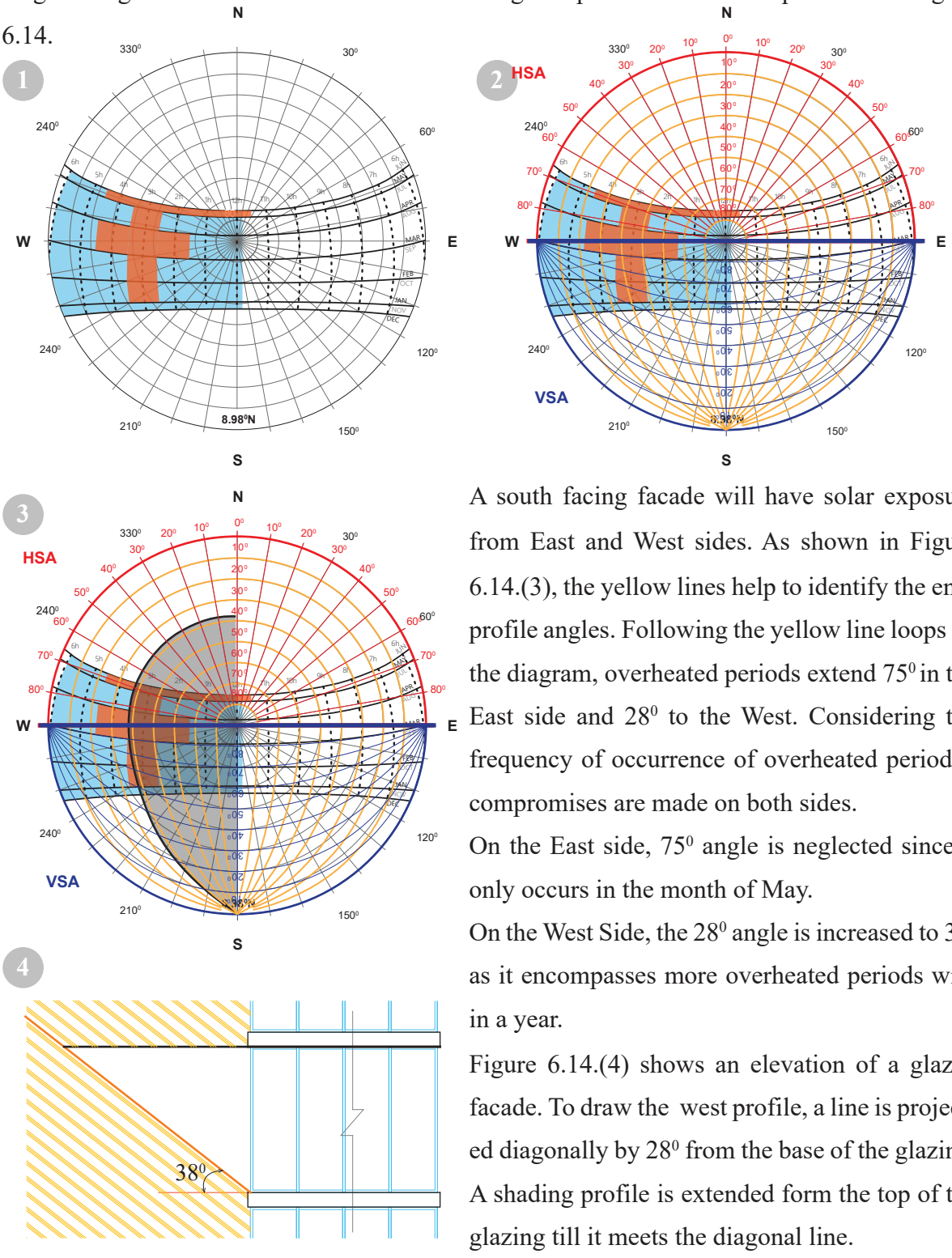
1.Draw a perpendicular line from the bottom of the glazed surface.

2. Project 55^0 form the line towards the glazing and draw a diagonal line.

3.Extend another perpendicular line from the glazing till it meets the diagonal line. This will yield the depth of the Louver. Its depth can have multiple outcomes as this perpendicular line is drawn closer to the origin of the diagonal line.

Figure 6.13. South orientation vertical shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)section view

6.2.3.1.9. South Orientation (EPA Identification). To find the end-profile angles for South facing glazed facades, the center of the protractor is overlaid on the stereographic diagram aligned to the North - South axis. Readings are performed in the steps shown in Figure 6.14.



A south facing facade will have solar exposure from East and West sides. As shown in Figure 6.14.(3), the yellow lines help to identify the end-profile angles. Following the yellow line loops on the diagram, overheated periods extend 75^0 in the East side and 28^0 to the West. Considering the frequency of occurrence of overheated periods,- compromises are made on both sides.

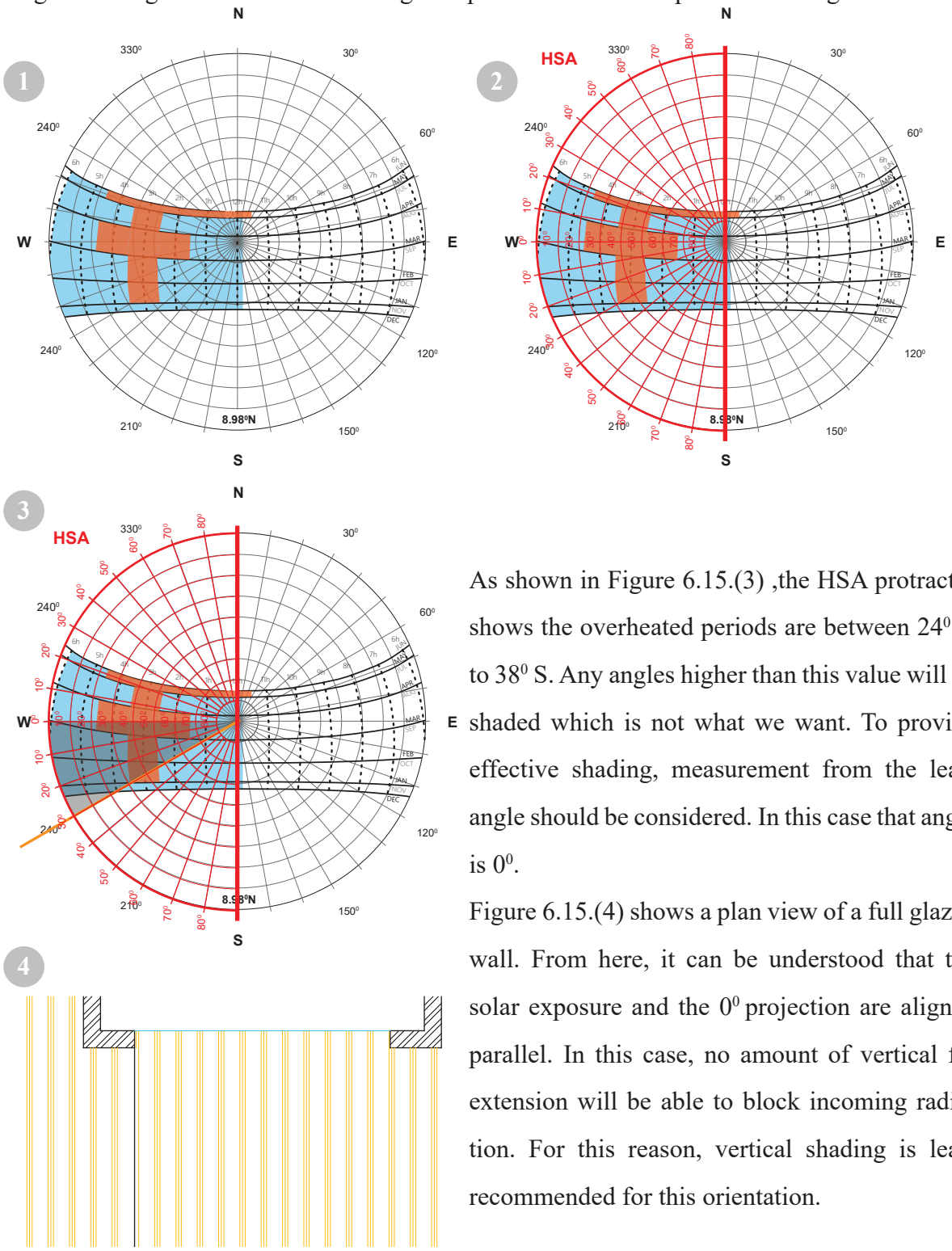
On the East side, 75^0 angle is neglected since it only occurs in the month of May.

On the West Side, the 28^0 angle is increased to 38^0 as it encompasses more overheated periods with in a year.

Figure 6.14.(4) shows an elevation of a glazed facade. To draw the west profile, a line is projected diagonally by 28^0 from the base of the glazing. A shading profile is extended form the top of the glazing till it meets the diagonal line.

Figure 6.14. South orientation end-profile shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)elevation view

6.2.3.1.10. West Orientation (HSA Identification). To find the horizontal shading angle for West facing glazed facades, the center of the protractor is overlaid on the stereographic diagram facing West direction. Readings are performed in the steps shown in Figure 6.15.

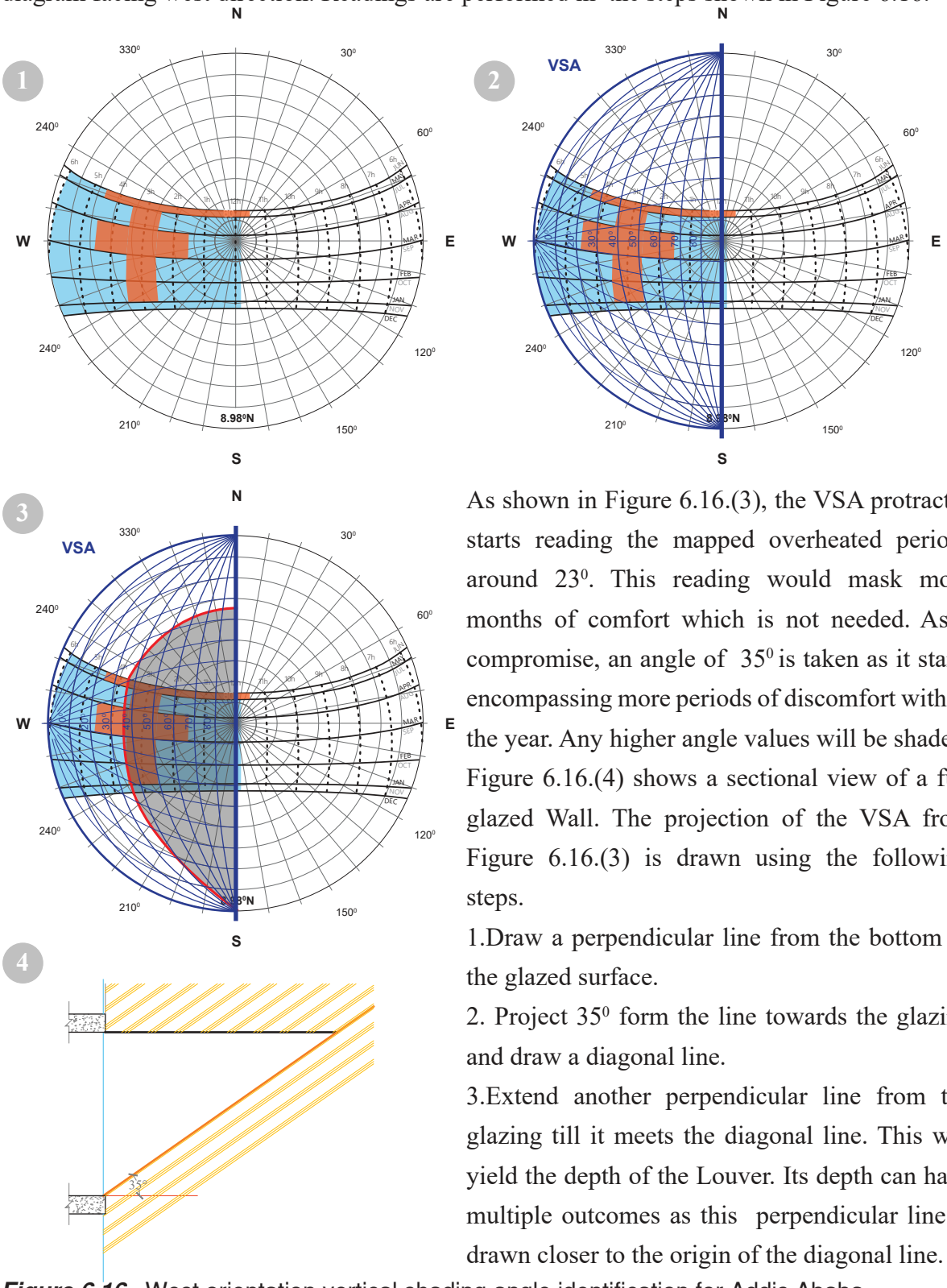


As shown in Figure 6.15.(3) ,the HSA protractor shows the overheated periods are between 24^0 N to 38^0 S. Any angles higher than this value will be shaded which is not what we want. To provide effective shading, measurement from the least angle should be considered. In this case that angle is 0^0.

Figure 6.15.(4) shows a plan view of a full glazed wall. From here, it can be understood that the solar exposure and the 0^0 projection are aligned parallel. In this case, no amount of vertical fin extension will be able to block incoming radiation. For this reason, vertical shading is least recommended for this orientation.

Figure 6.15. West orientation horizontal shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram and (3)shaded stereographic diagram, and (4)plan view

6.2.3.1.11. West Orientation (VSA Identification). To find the vertical shading angle for west facing glazed facades, the center of the protractor is overlaid on the stereographic diagram facing west direction. Readings are performed in the steps shown in Figure 6.16.



As shown in Figure 6.16.(3), the VSA protractor starts reading the mapped overheated periods around 23^0. This reading would mask more months of comfort which is not needed. As a compromise, an angle of 35^0 is taken as it starts encompassing more periods of discomfort with in the year. Any higher angle values will be shaded. Figure 6.16.(4) shows a sectional view of a full glazed Wall. The projection of the VSA from Figure 6.16.(3) is drawn using the following steps.

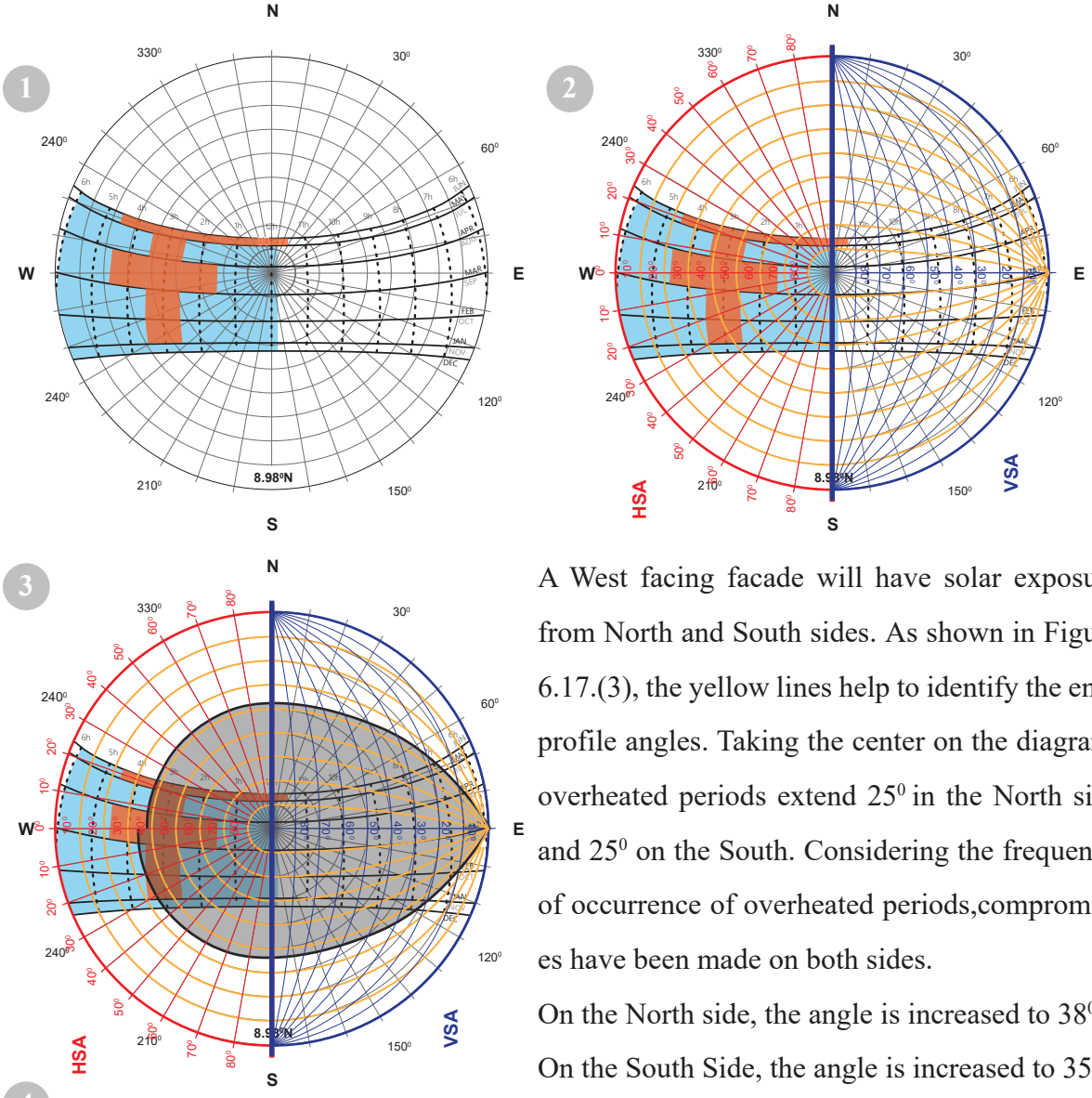
1.Draw a perpendicular line from the bottom of the glazed surface.

2. Project 35^0 form the line towards the glazing and draw a diagonal line.

3.Extend another perpendicular line from the glazing till it meets the diagonal line. This will yield the depth of the Louver. Its depth can have multiple outcomes as this perpendicular line is drawn closer to the origin of the diagonal line.

Figure 6.16. West orientation vertical shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)section view

6.2.3.2.12. West Orientation (EPA Identification). To find the end-profile angles for West facing glazed facades, the center of the protractor is overlaid on the stereographic diagram aligned to the West - East axis. Readings are performed in the steps shown in Figure 6.17.



A West facing facade will have solar exposure from North and South sides. As shown in Figure 6.17.(3), the yellow lines help to identify the end-profile angles. Taking the center on the diagram, overheated periods extend 25^0 in the North side and 25^0 on the South. Considering the frequency of occurrence of overheated periods,compromises have been made on both sides.

On the North side, the angle is increased to 38^0.

On the South Side, the angle is increased to 35^0.

Figure 6.17.(4) shows an elevation of a glazed facade. To draw the North profile, a line is projected diagonally by 35^0 from the base of the glazing. A shading profile is extended form the top of the glazing till it meets the diagonal line. Same step is repeated to identify the South profile.

Figure 6.17. West orientation end-profile shading angle identification for Addis Ababa (1)mapped stereographic diagram, (2)overlaid stereographic diagram, (3)shaded stereographic diagram, and (4)elevation view

6.2.4. Designing Shading Devices Considering Aesthetic and Structural Considerations

6.2.4.1. Introduction. There are multiple shading device design possibilities with the angles identified for the four major orientations. Major factors that affects how they are composed on a building facade are aesthetics and structure. These concepts are discussed as follows.

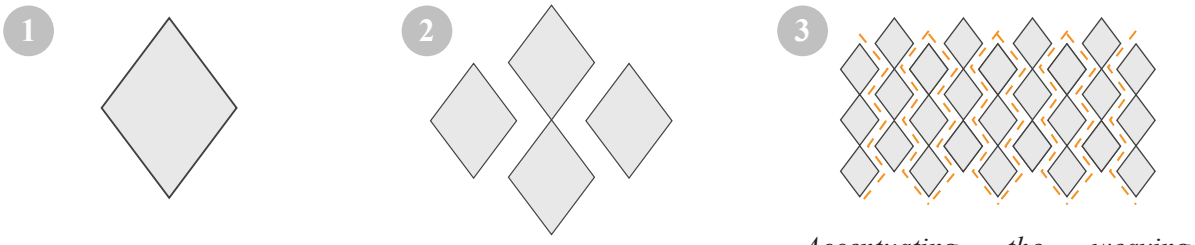
6.2.4.2.Shading Design Concept. This research intends to show the potential of fixed exterior shading devices not only as a passive means of solar control but also as a tool to portray identity of a location or create sense of place. To help mainfest this idea, a **"Weaving"** concept is used.

Among the many traditional clothing styles practiced in Ethiopia, the earliest are know to be"Netella" or "Gabbi". The most distinct signature is the rhombus like pattern composed in different scales, proportions, textures and colors.



Figure 6.18. Example of the Ethiopian "Tillet" pattern

Formal Approach. Is interpreated in three steps.



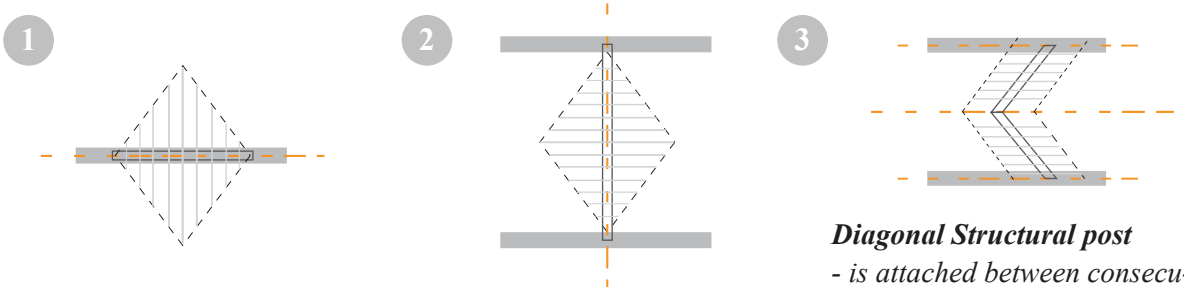
Conforming the scale and proportion of shading devices in this rhombus shape

Alternating the placement of the shading devices to create a weaving pattern.

Accentuating the weaving pattern through horizontal and vertical repetition of the shapes.

Figure 6.19. Formal approaches for shading design concept

Structural Approach. Is interpreated in three ways.



Horizontal Structural post
- is attached to a single floor slab horizontally.
- has vertical fins attached along its length.

Vertical Structural post
- is attached to two consecutive slabs.
- has horizontal louvers attached along its height.

Diagonal Structural post
- is attached between consecutive slabs.
- has horizontal louvers attached along its height.
- fills the gap between the alternating patterns.

Figure 6.20. Structural approaches for shading design concept

6.2.4.3. Concept Interpretation.

6.2.4.3.1. North Facade. Shading angle identification for North orientation has yielded 82^0 HSA, 65^0 VSA, and EPA of 38^0 only for west side. There are multiple possible projection sizes of shading devices for the identified shading angles. These angles are composed based on the formal and structural shading approaches. In this regard, a fixed shading for North facing glazing is proposed.

Shading Approaches

1. Rhombus pattern fixed on one slab

   This approach favors the attachment of vertical fins along its length. Projection of 82^0 HSA is made to yield 14cm deep fins spaced 1m apart.

2. Rhombus pattern fixed in between slabs

   This favors the use of horizontal louvers. Projection of 65^0 VSA is made to yield 35cm deep louvers spaced 75cm apart.

3. Space in between rhombus patterns

   This space is filled with horizontal shadings spaced closer to each other. This is intended to define the weaving pattern and accentuate the rhombus. Projection of 65^0 VSAis made to yield 14cm deep louvers spaced 30cm apart.

4. Repeating pattern composition

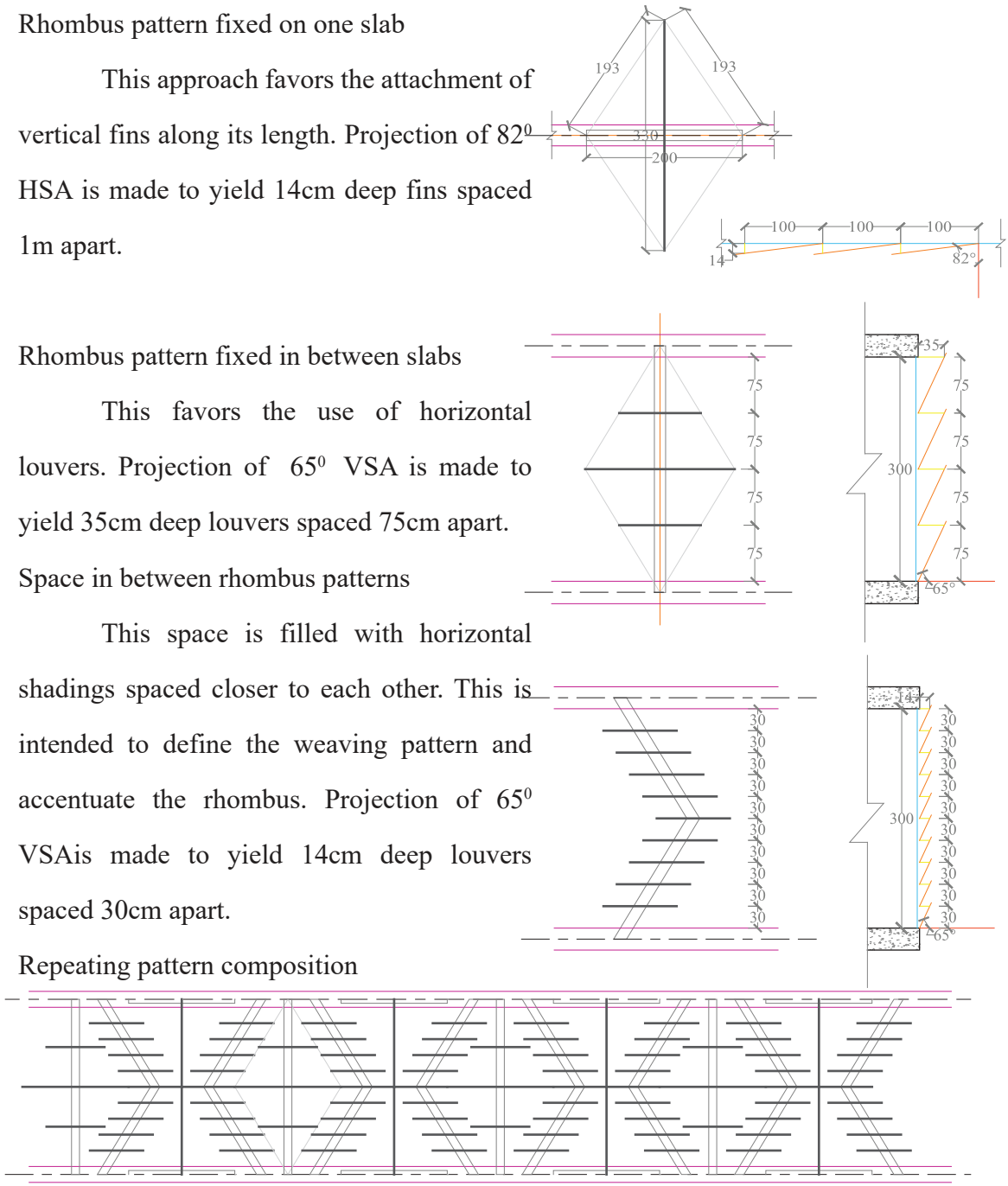


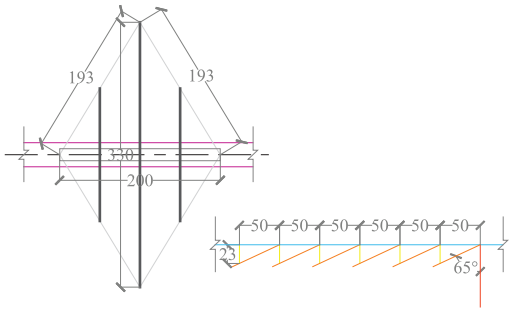
Figure 6.21. Shading approaches interpretation for a North oriented facade

6.2.4.3.2. East Facade. Shading angle identification for East orientation has yielded 65^0 HSA, 83^0 VSA, and EPA of 60^0 North and 55^0 South side. There are multiple possible projection sizes of shading devices for the identified shading angles. These angles are composed based on the formal and structural shading approaches. In this regard, a fixed shading for South facing glazing is proposed.

Shading Approaches

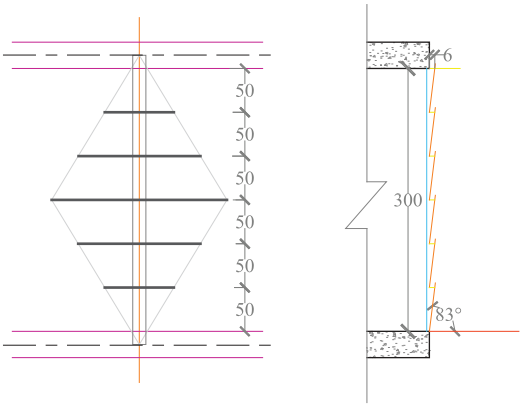
1. Rhombus pattern fixed on one slab

   This approach favors the attachment of vertical fins along its length. Projection of 65^0 HSA is made to yield 23cm deep fins spaced 50cm apart.



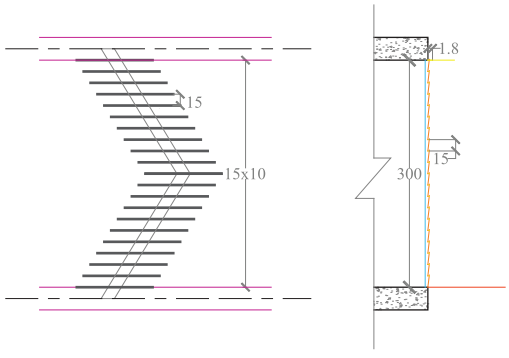
2. Rhombus pattern fixed in between slabs

   This favors the attachment of horizontal louvers along its height. This angle was neglected in the shading angle identification stage. Here, it is considered for aesthetics only. Projection of 83^0 VSA is made to yield 6cm deep louvers spaced 50cm apart.



3. Space in between rhombus patterns

   This space is filled with horizontal shadings spaced closer to each other. This is intended to define the weaving pattern and accentuate the rhombus. Projection of 83^0 VSAis made to yield 1.8cm deep louvers spaced 15cm apart.



4. Repeating pattern composition

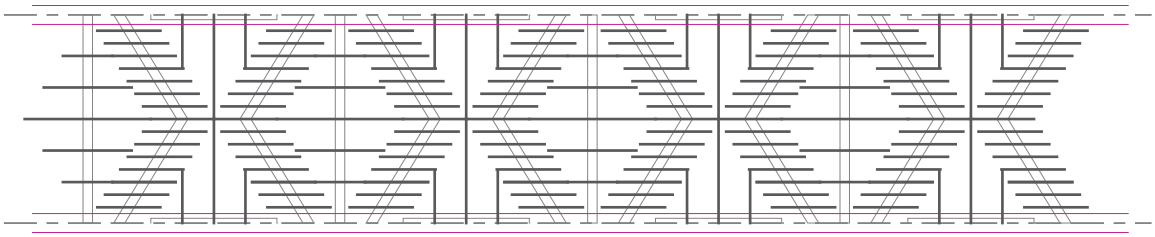


Figure 6.22. Shading approaches interpretation for a East oriented facade

6.2.4.3.3. South Facade. Shading angle identification for south orientation has yielded 60^0 HSA, 55^0 VSA, and EPA of 28^0 only for west side. There are multiple possible projection sizes of shading devices for the identified shading angles. These angles are composed based on the formal and structural shading approaches. In this regard, a fixed shading for south facing glazing is proposed.

Shading Approaches

1. Rhombus pattern fixed on one slab

   This approach favors the attachment of vertical fins along its length. Projection of 60^0 HSA is made to yield 29cm deep fins spaced 50cm apart.

2. Rhombus pattern fixed in between slabs

   This favors the attachment of horizontal louvers along its height. Projection of 55^0 VSA is made to yield 35cm deep louvers spaced 50cm apart.

3. Space in between rhombus patterns

   This space is filled with horizontal shadings spaced closer to each other. This is intended to define the weaving pattern and accentuate the rhombus. Projection of 55^0 VSA is made to yield 18cm deep louvers spaced 25cm apart.

4. Repeating Pattern composition

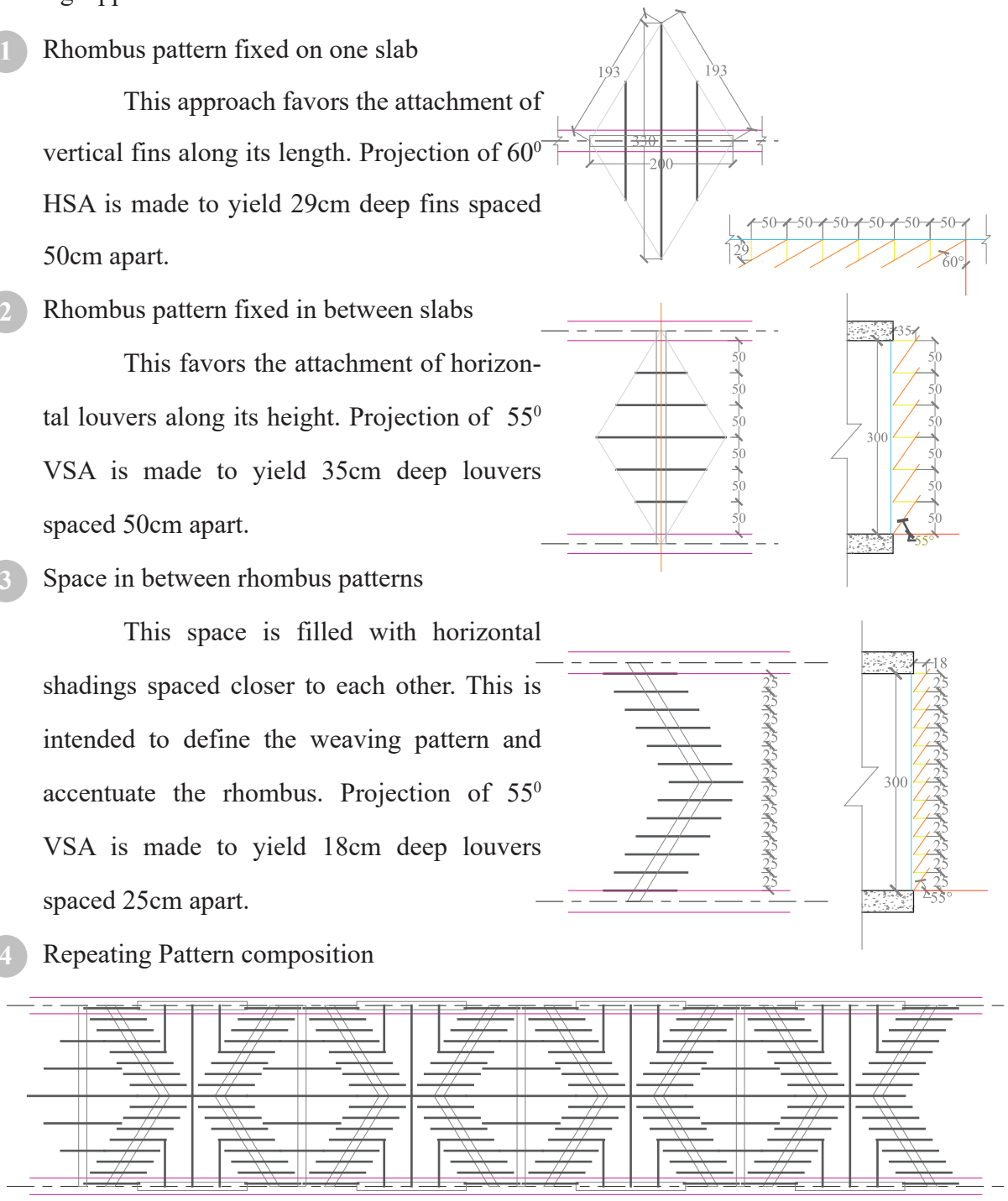


Figure 6.23. Shading approaches interpretation for a South oriented facade

6.2.4.3.3. West Facade. Shading angle identification for West orientation has yielded 0^0 HSA, 83^0 VSA, and EPA of 60^0 North and 55^0 South side. There are multiple possible projection sizes of shading devices for the identified shading angles. These angles are composed based on the formal and structural shading approaches. In this regard, a fixed shading for South facing glazing is proposed.

Shading Approaches

1. Rhombus pattern fixed on one slab

   Even though this approach favors the attachment of vertical fins, they proved ineffective for west orientation. Instead, adjustments to the rhombus post was made to accommodate louvers.

2. Rhombus pattern fixed in between slabs

   This favors the attachment of horizontal louvers along its height. Projection of 35^0 VSA is made to yield 43cm deep louvers spaced 30cm apart.

3. Space in between rhombus patterns

   This space is filled with horizontal shadings spaced closer to each other. This is intended to define the weaving pattern and accentuate the rhombus. Projection of 35^0 VSA is made to yield 21cm deep louvers spaced 15cm apart.

4. Repeating Pattern composition

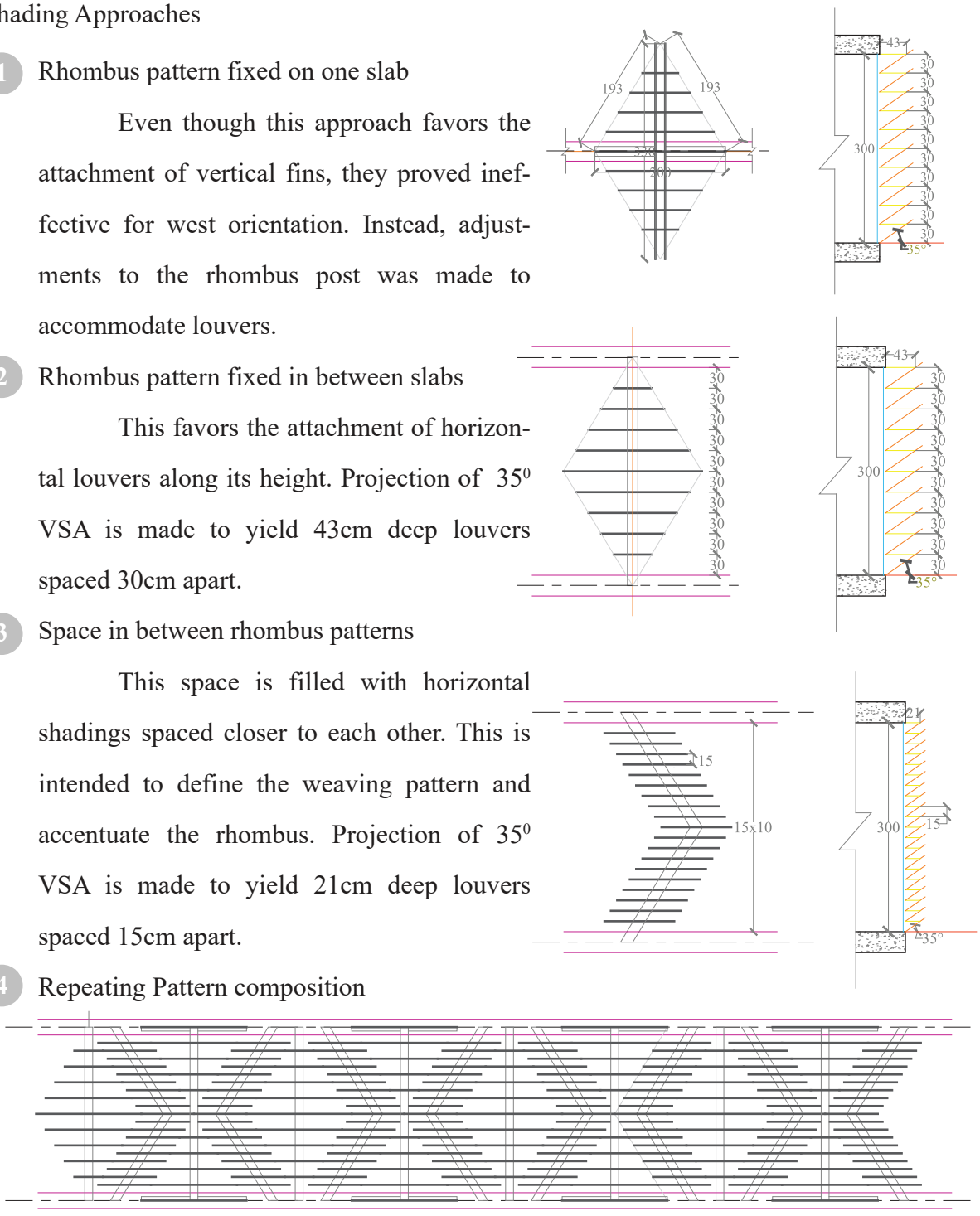


Figure 6.24. Shading approaches interpretation for a West oriented facade

6.2.4.4. Shading Simulations

6.2.4.4.1. *Solar Access Analysis- North Facade*

BARE MOCKUP

(a)

INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	15.4377	40.3508	39.9266	21.5424	14.084	5.36223	0	0	0	540
	0	0	0	7.90642	64.7638	46.1729	42.9764	25.9951	0	0	0	0	480
16	0	0	0	11.2362	60.9636	62.3755	48.3769	26.7233	0	0	0	0	420
	0	0	0	4.4284	70.3927	57.8873	54.934	26.1776	0	0	0	0	360
14	0	0	0	0.730092	64.9768	105.197	48.8762	21.819	0	0	0	0	300
	0	0	0	2.29796	82.3348	104.139	46.4293	24.0855	0	0	0	0	240
12	0	0	0	10.314	76.9244	97.4157	67.8541	42.6368	0	0	0	0	180
	0	0	0	8.79174	79.5275	121.715	48.6587	32.3374	0	0	0	0	120
10	0	0	0	11.0522	84.9192	111.658	60.4757	36.2927	0	0	0	0	60
	0	0	0	40.557	99.4092	107.229	38.3293	29.1056	0	0	0	0	0
08	0	0	0	24.595	75.4312	71.2276	25.0299	17.1792	9.99313	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	4	0	0	0	0	82	100	100	100

DESIGN PROPOSAL MOCKUP

(b)

INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH

													W/m²
	0	0	0	0	0	0	0	0	0	0	0	0	600
18	0	0	0	5.14591	26.9005	26.6177	14.3616	6.45518	1.56398	0	0	0	540
	0	0	0	2.4063	32.3819	23.0864	21.4882	11.9144	0	0	0	0	480
16	0	0	0	3.27723	27.9417	31.1878	24.1884	12.2482	0	0	0	0	420
	0	0	0	0.57761	35.1963	26.5317	25.1781	10.9073	0	0	0	0	360
14	0	0	0	0.08112	29.781	48.2152	22.4016	6.36388	0	0	0	0	300
	0	0	0	0.41781	34.3062	47.7306	19.3455	7.02494	0	0	0	0	240
12	0	0	0	2.14875	32.0518	44.6489	28.2725	17.7653	0	0	0	0	180
	0	0	0	1.14675	33.1365	50.7145	20.2745	13.4739	0	0	0	0	120
10	0	0	0	2.30255	42.4596	60.4814	32.7577	16.6342	0	0	0	0	60
	0	0	0	13.519	45.5625	49.1466	17.5676	10.9146	0	0	0	0	0
08	0	0	0	7.17354	47.1445	44.5172	15.6437	9.30542	1.66552	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	100	100	100	78	51	50	50	58	96	100	100	100

Table 6.1. Solar access analysis of North oriented glazed facades (a)bare mockup, (b)proposed shading

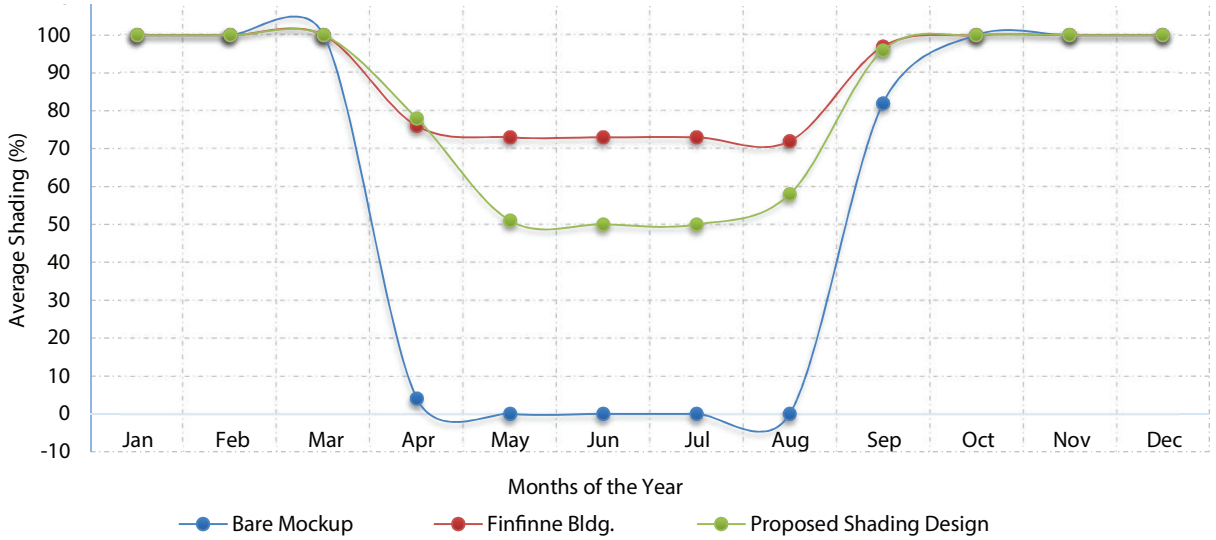


Figure 6.25. Solar shading performance summary of North oriented glazed facades

Discussion

From the Analysis chapter, results from the shading performance analysis of North oriented glazed facades showed the highest annual average shading improvement using the shading adopted from Finfinne building i.e. 73.4%. Following literature steps for the design of shading devices, a proposal shading was designed and tested. It showed an annual average shading improvement around 57.4% to be optimal for this orientation. (See *Figure 6.25.*)

6.2.4.4.2. *Solar Access Analysis- East Facade*

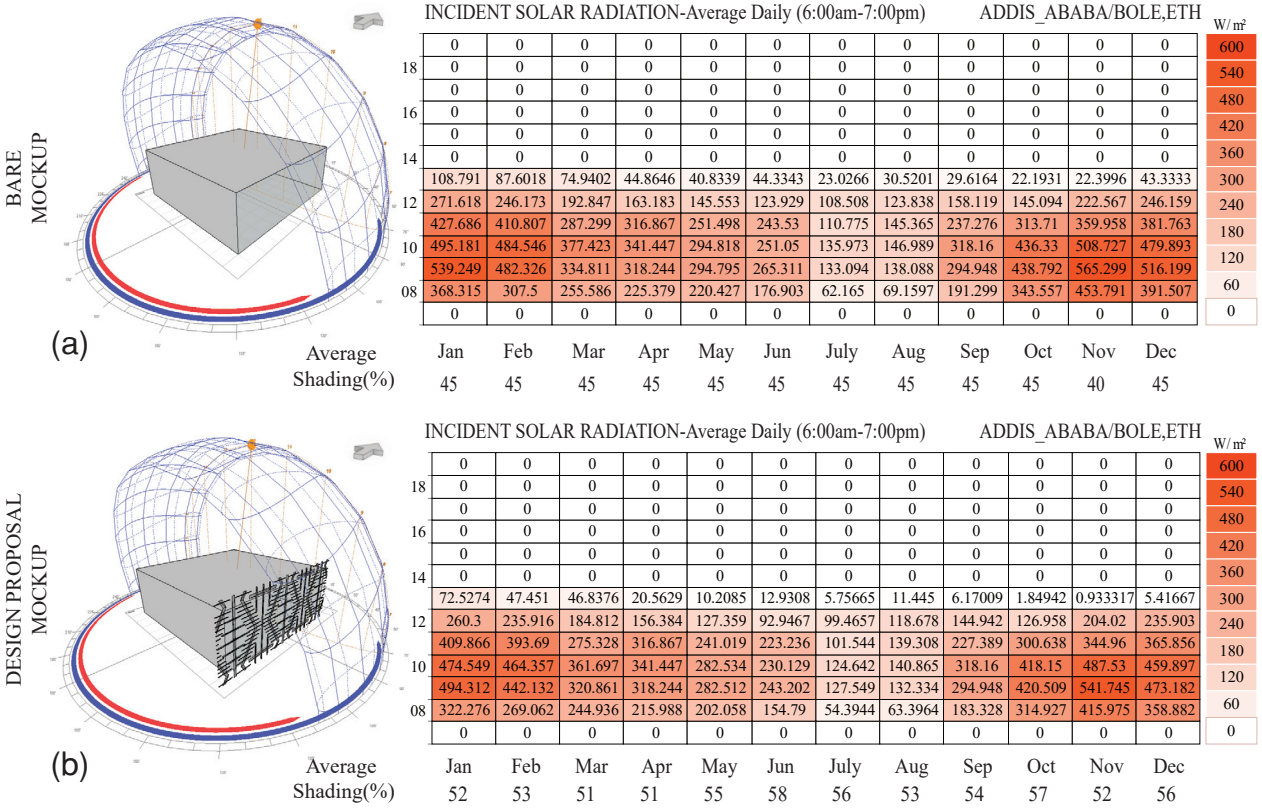


Table 6.2. Solar access analysis of East oriented glazed facades (a)bare mockup, (b)proposed shading

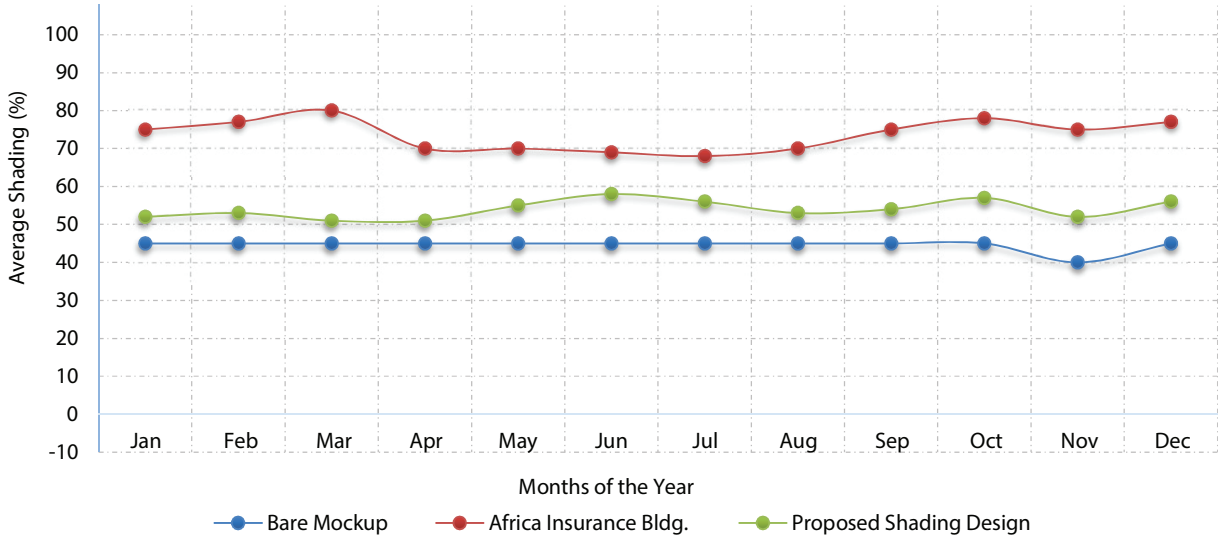
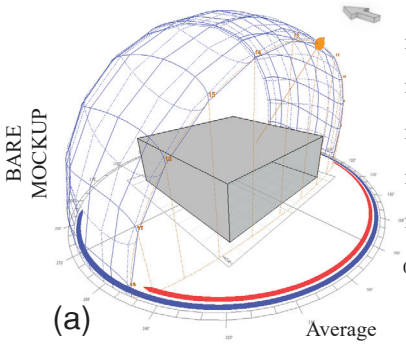


Figure 6.26. Solar shading performance summary of East oriented glazed facades

Discussion

From the Analysis chapter, results from the shading performance analysis of East oriented glazed facades showed the highest annual average shading improvement using the shading adopted from Africa Insurance building i.e. 73.7%. Following literature steps for the design of shading devices, a proposal shading was designed and tested. It showed an annual average shading improvement around 54% to be optimal for this orientation. (See *Figure 6.26.*)

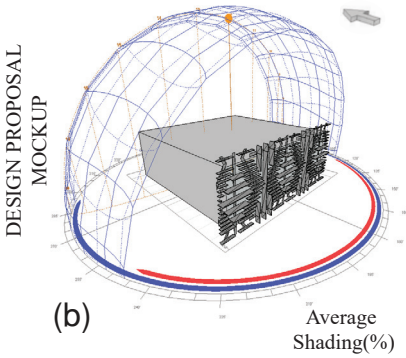
6.2.4.4.3. *Solar Access Analysis- South Facade*



INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	133.781	66.9105	31.1253	0	0	0	0	0	0	26.2324	0	133.127	540
	203.22	134.552	59.8257	0	0	0	0	0	3.49028	67.2239	182.768	249.678	480
16	293.521	184.048	78.4846	0	0	0	0	0	21.366	110.033	252.317	337.033	420
	294.963	213.984	82.9458	0	0	0	0	0	40.1871	143.135	260.686	381.921	360
14	334.223	228.9	99.5753	0	0	0	0	0	37.6068	170.984	292.168	349.254	300
	334.155	221.463	93.7335	0	0	0	0	0	32.9213	183.112	334.154	394.122	240
12	348.185	224.337	97.0291	0	0	0	0	0	38.15	131.356	331.456	375.67	180
	328.043	217.812	98.8306	0	0	0	0	0	36.2465	155.111	320.837	351.22	120
10	327.23	197.515	88.8954	0	0	0	0	0	11.1107	149.234	306.754	304.885	60
	269.258	152.895	41.9825	0	0	0	0	0	5.63253	99.2354	235.07	257.748	0
08	150.901	67.1389	11.6622	0	0	0	0	0	0	45.3165	185.999	160.47	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	0	0	0	100	100	100	100	100	19	0	0	0



INCIDENT SOLAR RADIATION-Average Daily (6:00am-7:00pm) ADDIS_ABABA/BOLE,ETH W/m²

	0	0	0	0	0	0	0	0	0	0	0	0	600
18	78.0391	33.4553	1.29689	0	0	0	0	0	0	8.74414	0	88.751	540
	76.2076	44.8507	2.49274	0	0	0	0	0	0	2.801	68.5378	124.839	480
16	134.53	30.6747	9.81058	0	0	0	0	0	2.67075	18.3388	115.645	140.43	420
	110.611	44.58	13.8243	0	0	0	0	0	5.02339	23.8559	97.7571	143.221	360
14	125.334	47.6875	16.5959	0	0	0	0	0	6.26781	28.4974	60.8682	130.97	300
	97.4619	27.6829	3.90557	0	0	0	0	0	2.74344	22.889	125.308	131.374	240
12	101.554	18.6948	0	0	0	0	0	0	0	5.47319	96.6746	109.571	180
	95.6793	54.453	12.3538	0	0	0	0	0	1.51027	6.46298	93.5776	117.073	120
10	109.077	32.9192	7.40795	0	0	0	0	0	0.462947	18.6543	89.4698	88.9247	60
	123.41	44.5945	3.49854	0	0	0	0	0	0.234689	12.4044	58.7674	118.135	0
08	81.738	27.9745	0.485926	0	0	0	0	0	0	7.55275	100.749	86.9213	
	0	0	0	0	0	0	0	0	0	0	0	0	

Average Shading(%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	60	75	92	100	100	100	100	100	94	86	65	58

Table 6.3. Solar access analysis of South oriented glazed facades (a)bare mockup, (b)proposed shading

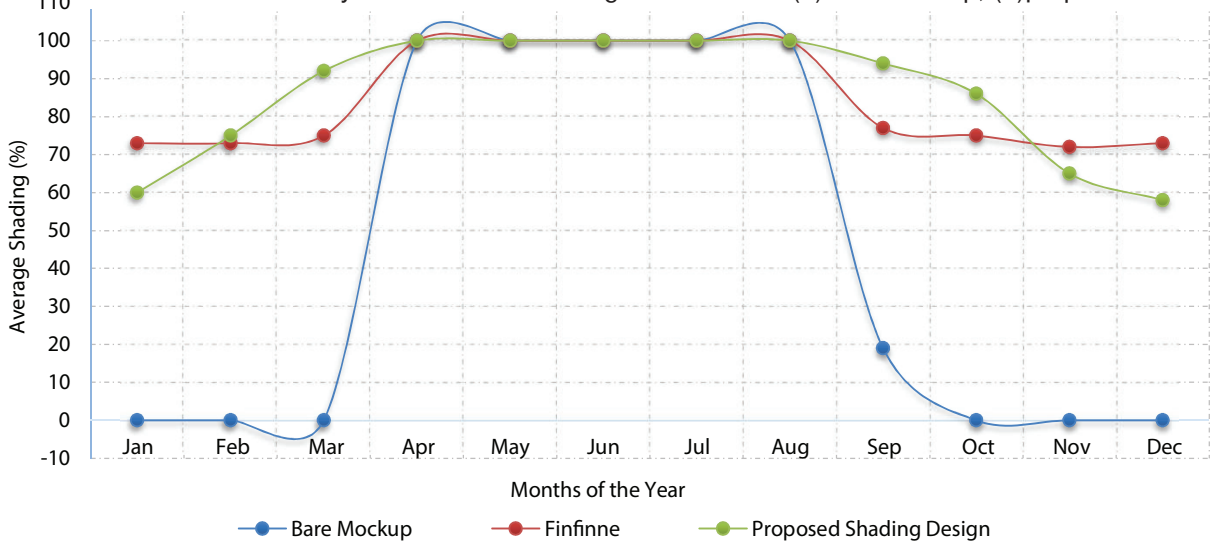


Figure 6.27. Solar shading performance summary of South oriented glazed facades

Discussion

From the Analysis chapter, results from the shading performance analysis of South oriented glazed facades showed the highest annual average shading improvement using the shading adopted from Finfinne building i.e. 74%. Following literature steps for the design of shading devices, a proposal shading was designed and tested. It showed an annual average shading improvement around 75.7% to be optimal for this orientation. (See *Figure 6.27.*)

6.2.4.4.4. *Solar Access Analysis- West Facade*

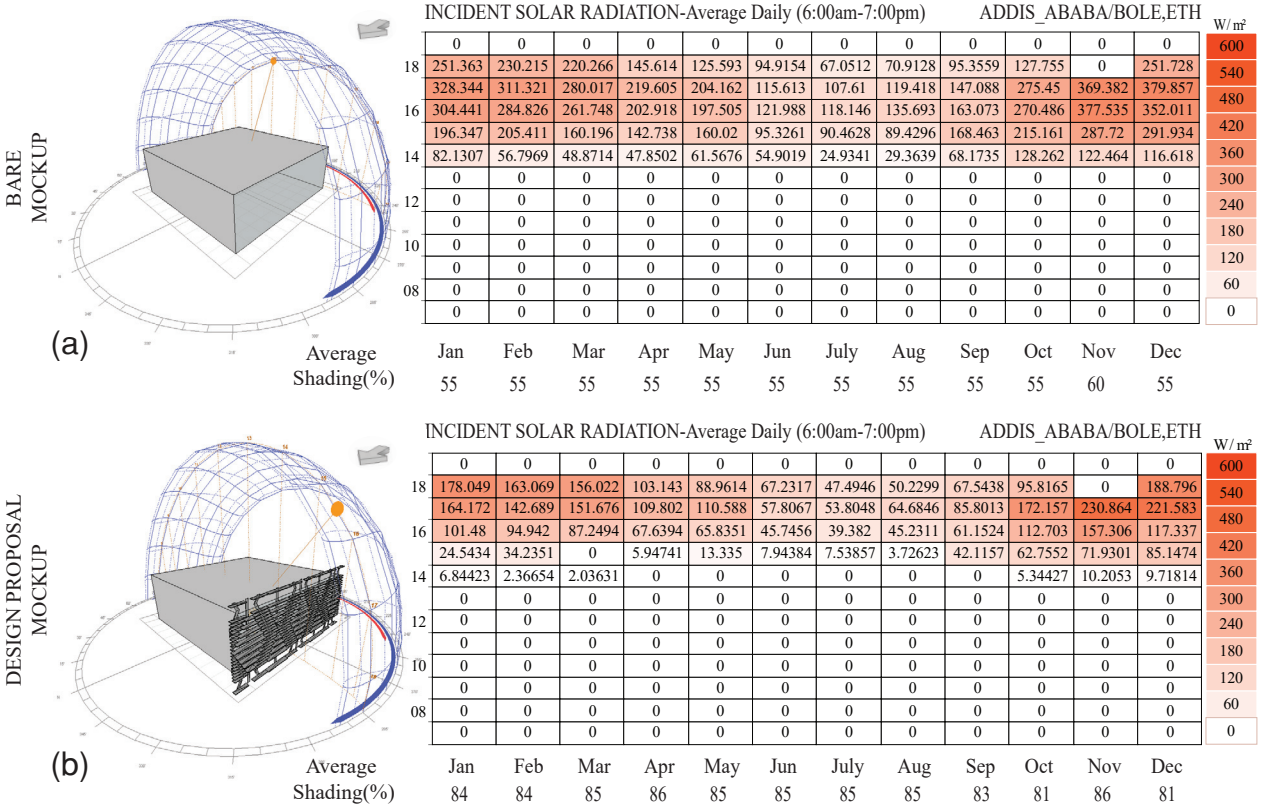


Table 6.4. Solar access analysis of West oriented glazed facades (a)bare mockup, (b)proposed shading

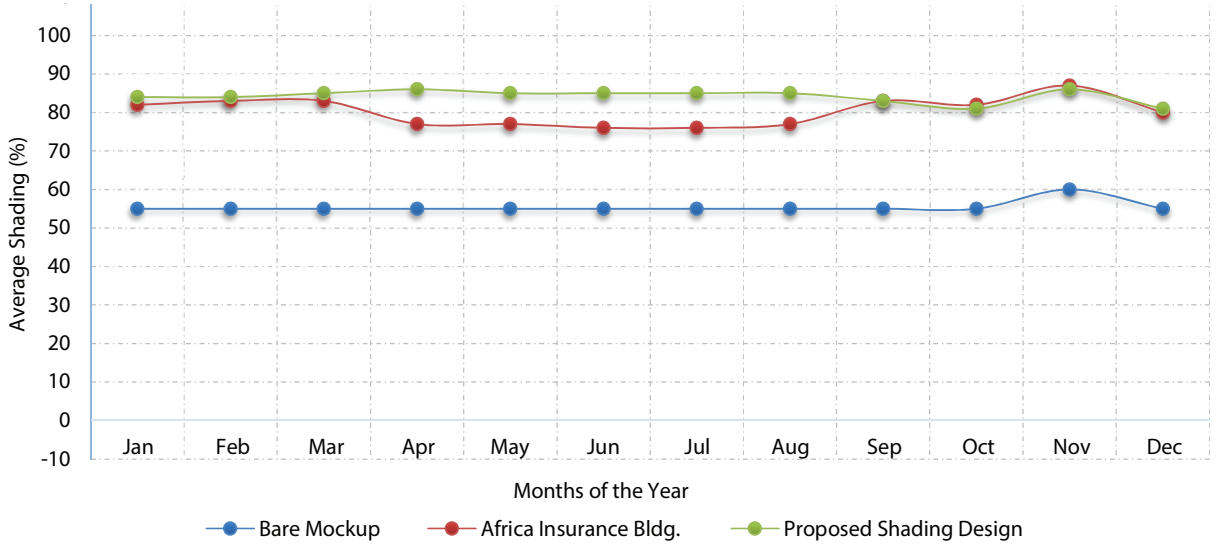


Figure 6.28. Solar shading performance summary of West oriented glazed facades

Discussion

From the Analysis chapter, results from the shading performance analysis of West oriented glazed facades showed the highest annual average shading improvement using the shading adopted from Africa Insurance building i.e. 80.3%. Following literature steps for the design of shading devices,a proposal shading was designed and tested. It showed an annual average shading improvement around 84.2% to be optimal for this orientation. (See *Figure 6.28*)

6.2.4.4.5. *Thermal Analysis- North oriented zone*

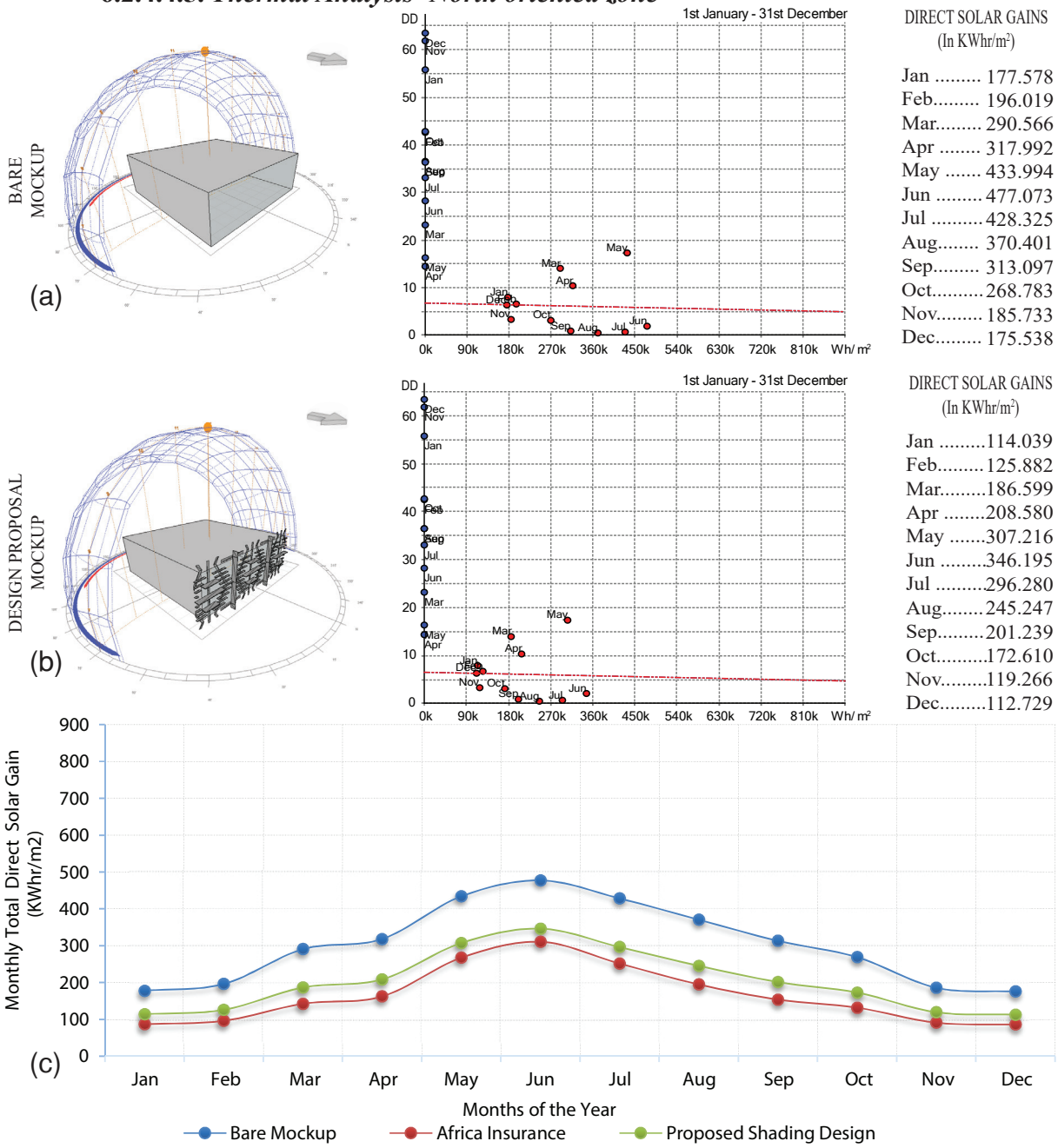


Figure 6.29. Direct solar heat gain analysis of North oriented glazed zones (a)bare mockup, (b)proposed shading, and (C)summary

Discussion

From the analysis chapter, simulations of North facing glazed zones showed the most direct solar heat gains during the month of June and the least during the month of January. Among the different shading typologies tested, the shading adopted from Africa Insurance building showed the most reduction of monthly total direct solar heat gains. i.e. 166.6 KWhr/m^2 during June and 90.6 KWhr/m^2 during January. Following literature steps for the design of shading devices, a proposal shading was designed and tested. It showed a monthly total direct solar heat gain reduction of 130.9 KWhr/m^2 during June and 63.5 KWhr/m^2 during January to be optimal for this orientation. (See *Figure 6.29.*)

6.2.4.4.6. *Thermal Analysis- East oriented zone*

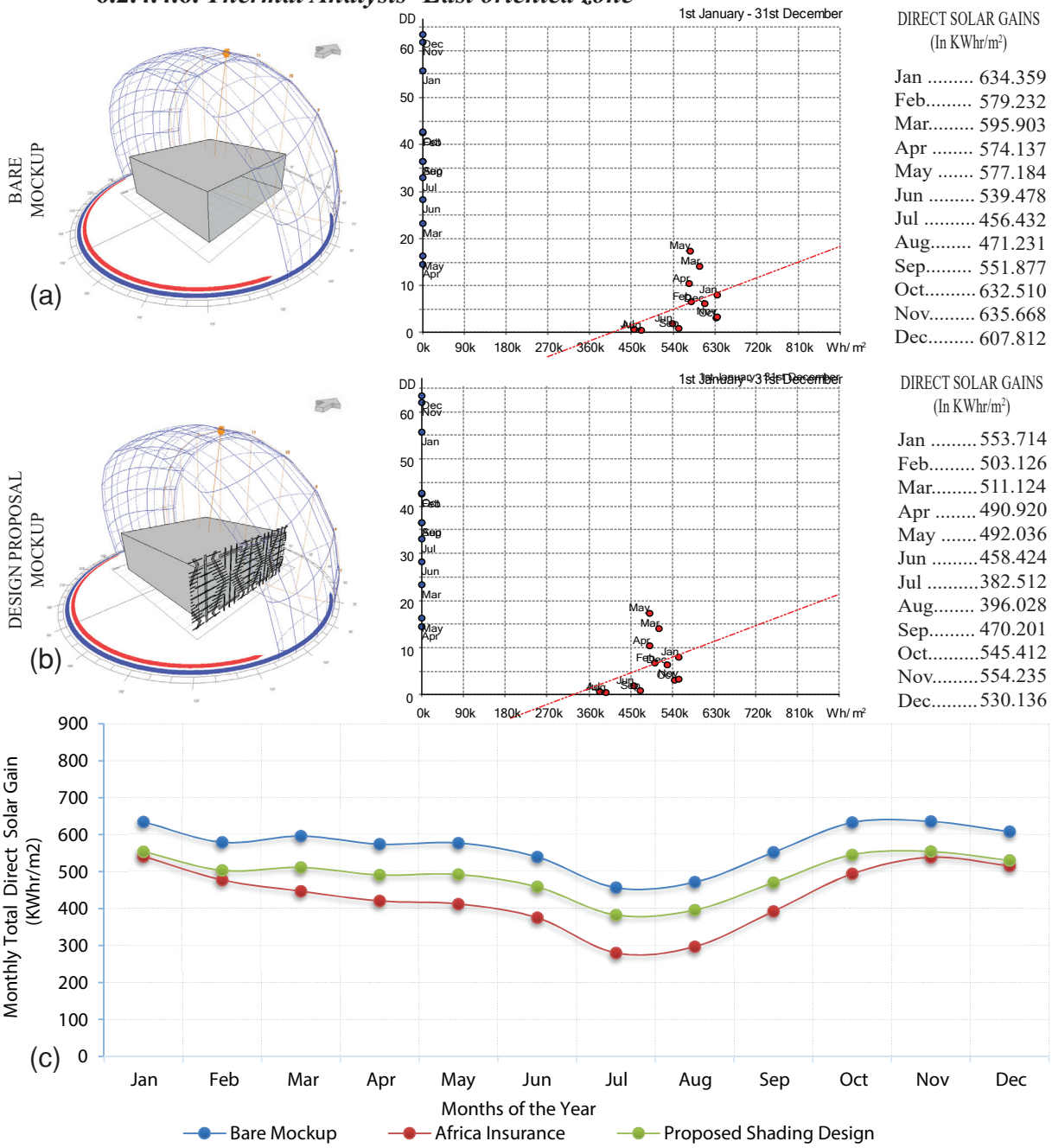


Figure 6.30. Direct solar heat gain analysis of East oriented glazed zones (a)bare mockup, (b)proposed shading, and (C)summary

Discussion

From the analysis chapter, simulations of East facing glazed zones showed the most direct solar heat gains during the month of November and the least during the month of July. Among the different shading typologies tested, the shading adopted from Africa Insurance building showed the most reduction of monthly total direct solar heat gains. i.e. 97.1 KWhr/m^2 during November and 90.6 KWhr/m^2 during July. Following literature steps for the design of shading devices,a proposal shading was designed and tested. It showed a monthly total direct solar heat gain reduction of 81.4 KWhr/m^2 during November and 73.9 KWhr/m^2 during July to be optimal for this orientation. (See *Figure 6.30.*)

6.2.4.4.7. *Thermal Analysis- South oriented zone*

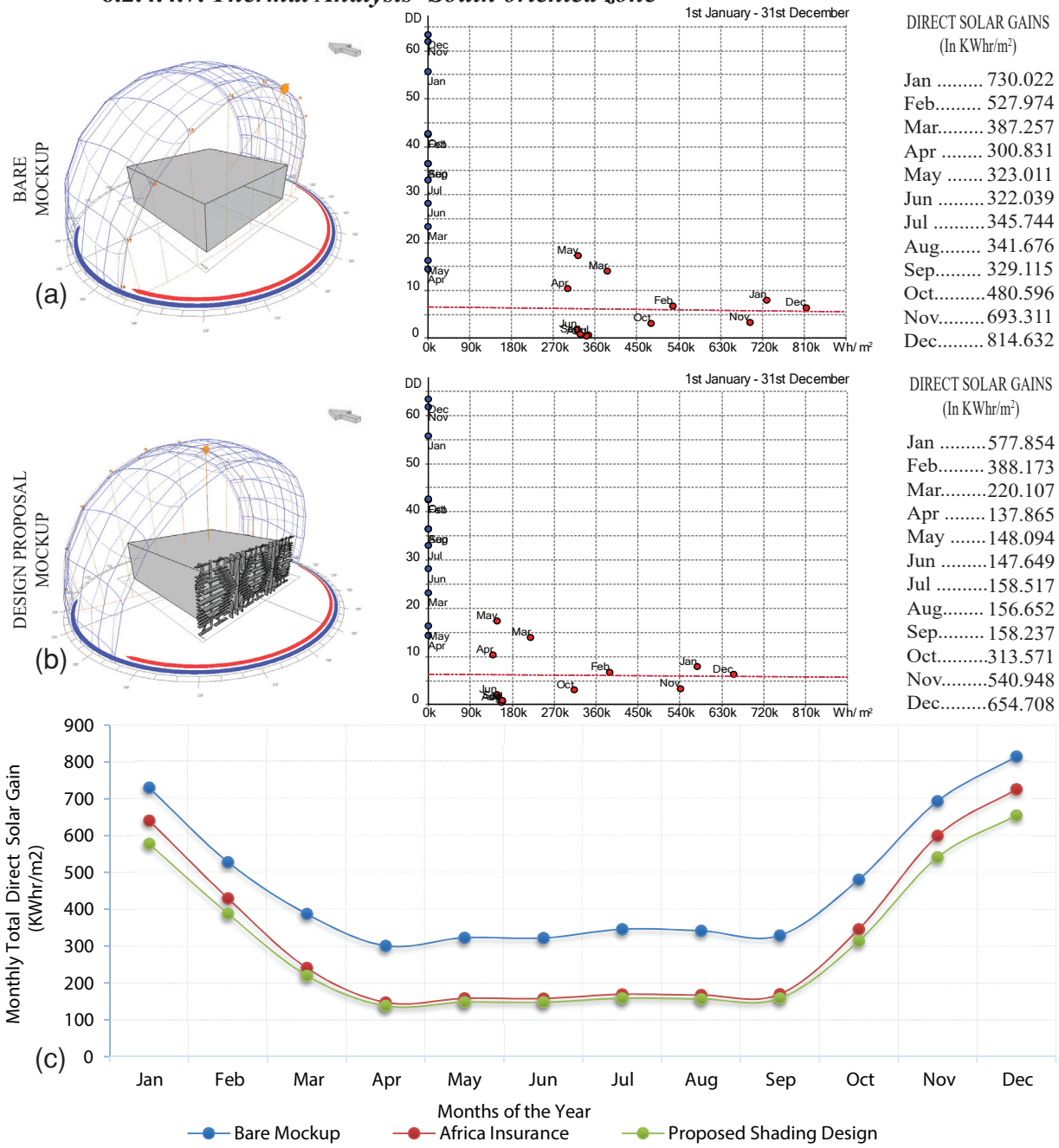


Figure 6.31. Direct solar heat gain analysis of South oriented glazed zones (a)bare mockup, (b)proposed shading, and (C)summary

Discussion

From the analysis chapter, simulations of South facing glazed zones showed the most direct solar heat gains during the month of December and the least during the month of April. Among the different shading typologies tested, the shading adopted from Africa Insurance building showed the most reduction of monthly total direct solar heat gains. i.e. 88.7 KWhr/m^2 during December and 153.5 KWhr/m^2 during April. Following literature steps for the design of shading devices,a proposal shading was designed and tested. It showed a monthly total direct solar heat gain reduction of 159.9 KWhr/m^2 during December and 162.9 KWhr/m^2 during April to be optimal for this orientation. (See *Figure 6.31.*)

6.2.4.4.8. *Thermal Analysis- West oriented zone*

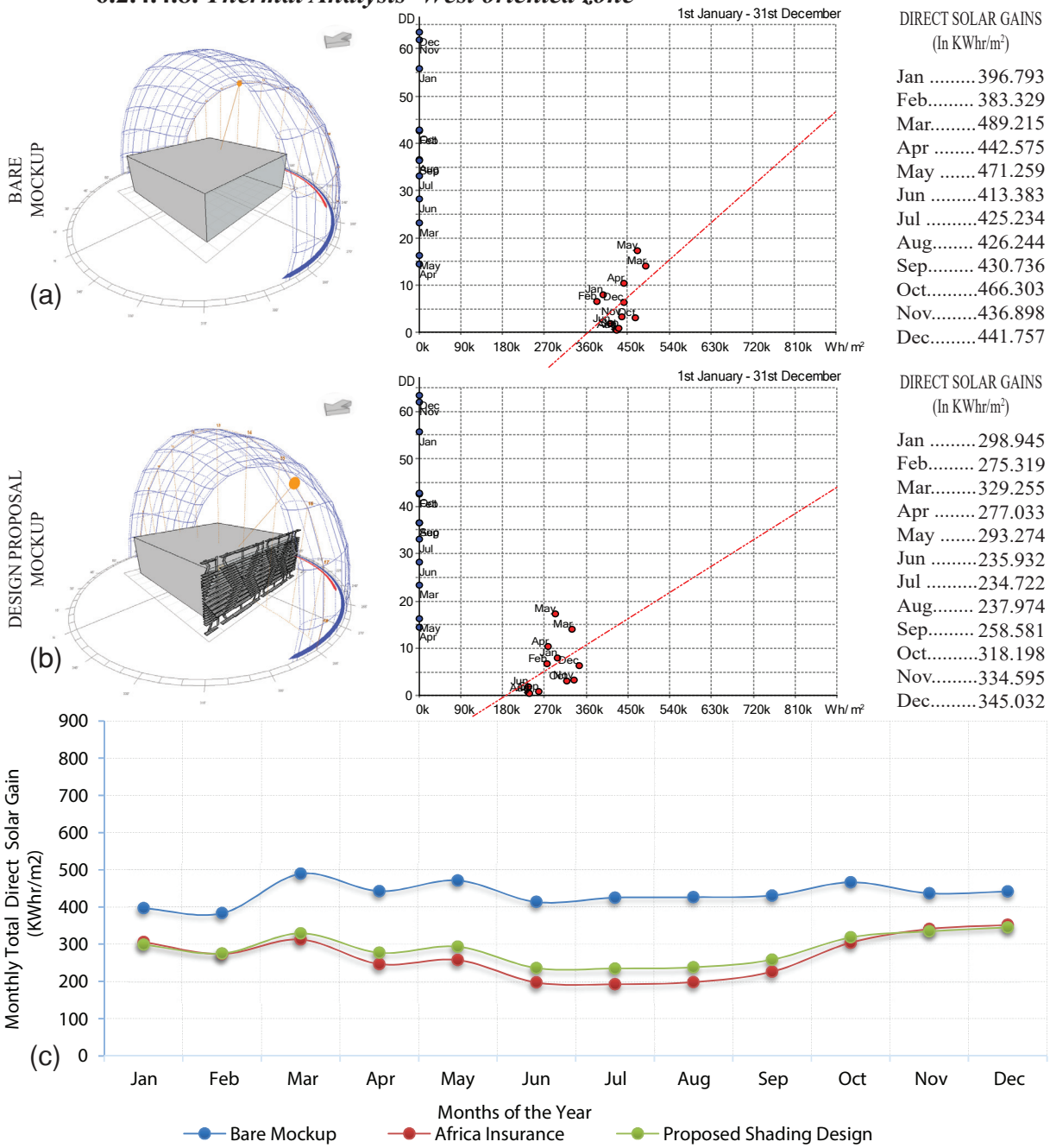


Figure 6.32. Direct solar heat gain analysis of West oriented glazed zones (a)bare mockup, (b)proposed shading, and (C)summary

Discussion

From the analysis chapter, simulations of West facing glazed zone showed the most direct solar heat gains during the month of March and the least during the month of February. Among the different shading typologies tested, the shading adopted from Africa Insurance building showed the most reduction of monthly total direct solar heat gains. i.e. 176.5 KWhr/m^2 during March and 109.6 KWhr/m^2 during February. Following literature steps for the design of shading devices,a proposal shading was designed and tested. It showed a monthly total direct solar heat gain reduction of 159.9 KWhr/m^2 during March and 108 KWhr/m^2 during February to be optimal for this orientation. (See *Figure 6.32.*)

6.3. Stage 2 - Intervention Design

In the first stage, necessary steps for designing fixed exterior shading devices were discussed. Based on the findings and design concepts from stage 1, this stage explores the design of a full glazed building and site proposal on a strategic site in Addis Ababa.

6.3.1. Site Selection

The chosen site is located at the boundary of Lideta sub city around Mexico Square. This is one of the areas in Addis undergoing fullglazed building constructions for office use. Its location, area and exposure makes it a strategic choice for the theme of this research.

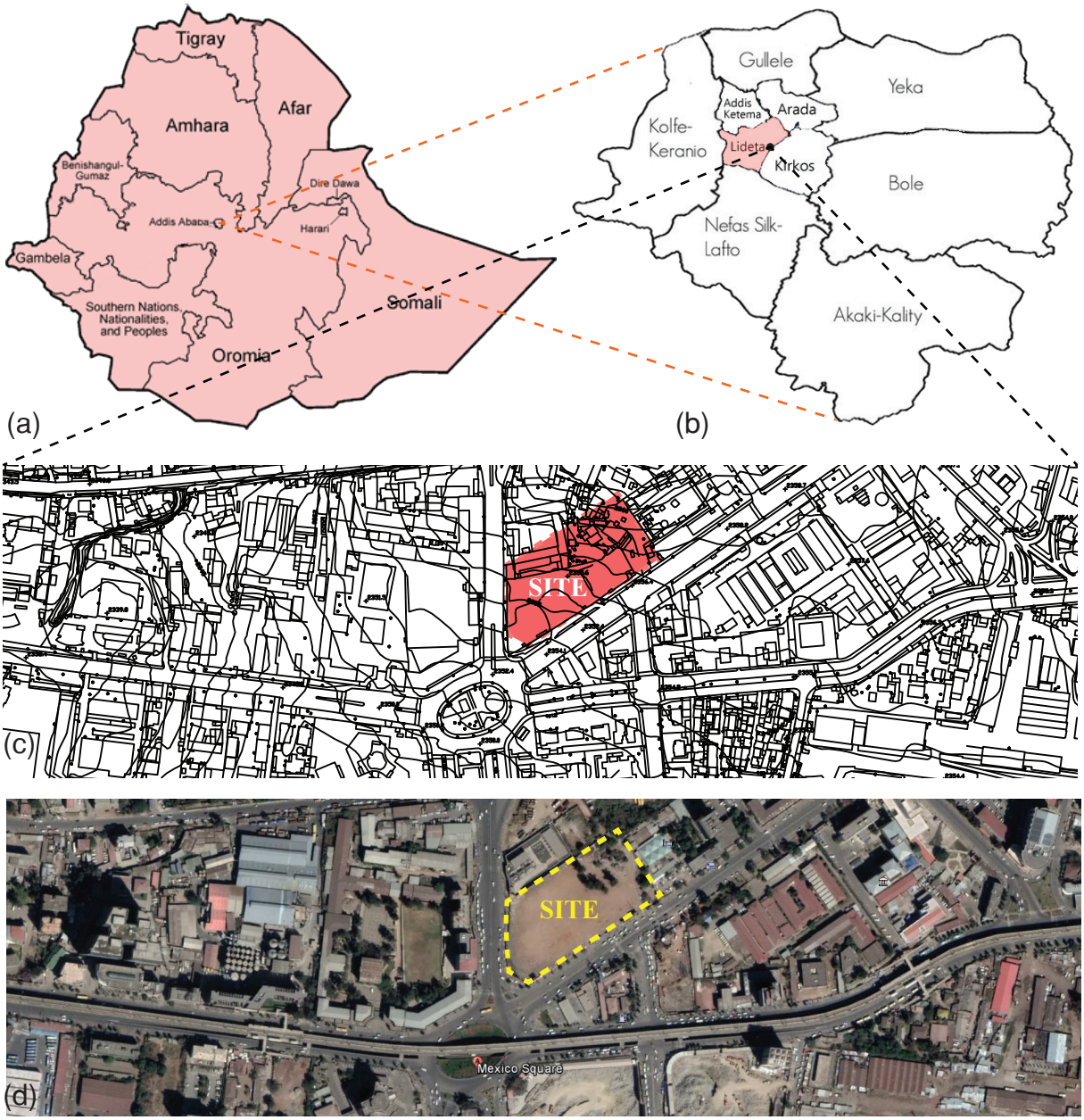
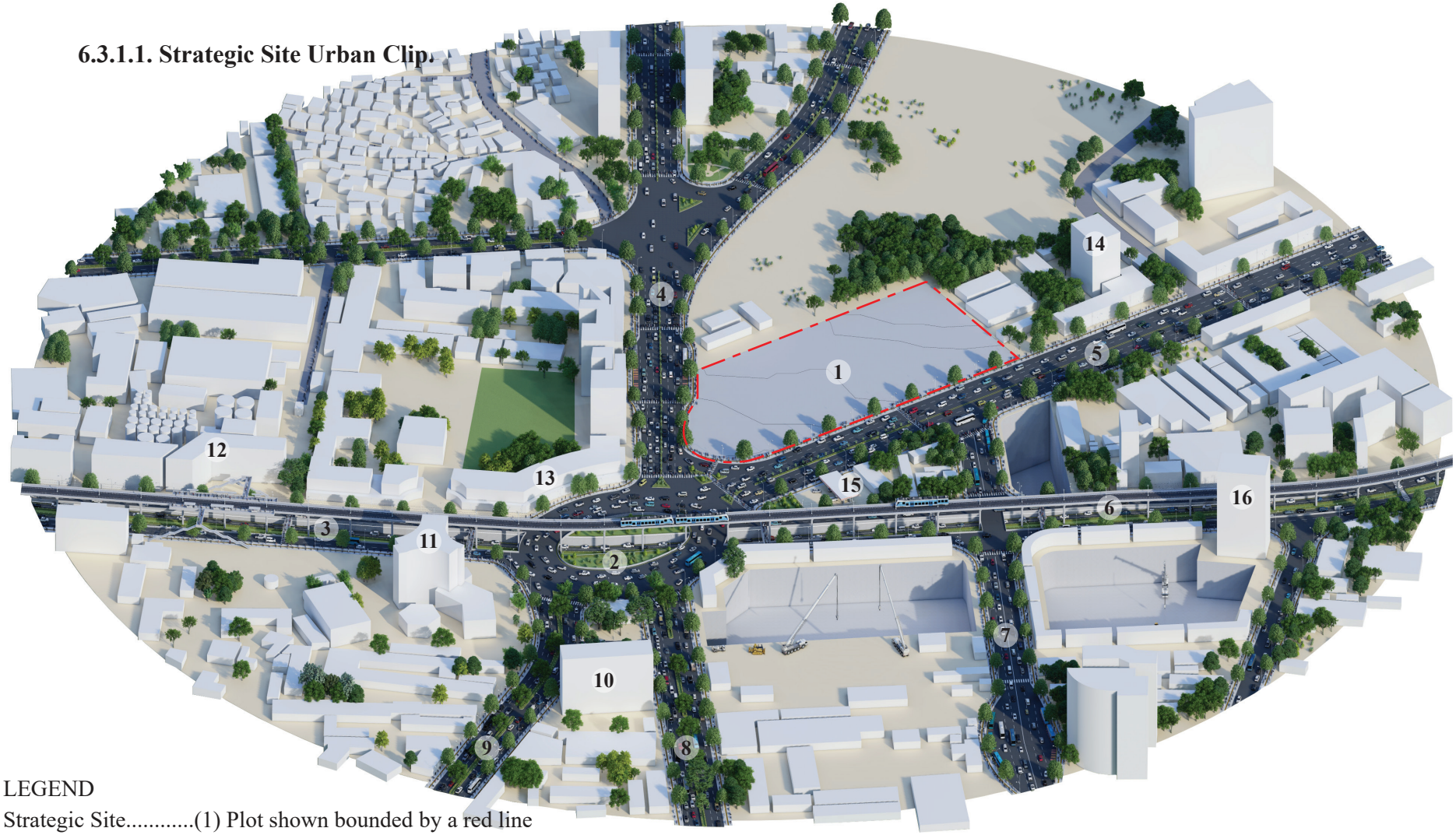


Figure 6.33. Location maps of strategic site (a) Map of Ethiopia, (b) Map of Addis Ababa, (c) NORTEC map of location and (d) Google Earth image of location (Source: (a)addisababa.gov-.et, (b) NORTEC 2007 AutoCAD File, and(c)googlearth.com)

6.3.1.1. Strategic Site Urban Clip.



LEGEND

Strategic Site.....(1) Plot shown bounded by a red line

Road Network.....(2)Mexico Square, (3)To Torhiloach, (4)To Abenet, (5)To Biherawi, (6)To Stadium, (7)To Qera, (8)To Afican Union, and (9)To Sarbet,

Existing Buildings...(10)Chamber of Commerce & Associations, (11)Federal Police Commission Head Office, (12)B.G.I. Ethiopia Head Office, (13)Tegbared School, (14)Wabe Shebelle Hotel, (15)Total Gas Station, and (16)Debrewerq Tower

Figure 6.34. Urban clip aerial view of strategic site

6.3.2. Site Analysis

The site occupies a total area of 1.451 hectares. It measures a maximum of 85 x 187 meters with some irregular edges. Its boundary faces the Mexico square and can easily be seen from 5 major roads that converge to the square. It has a level difference of 5 meters along the diagonal of its longest side. This makes the slope of the site around 2.5% which is very gentle. There is high level of pedestrian movement and informal market activities along its boundaries. It is currently being used as a parking space for public buses and a station for long road duty buses. Figure 6.35. shows the day to day activities in and around the site.



Figure 6.35. Strategic site existing conditions (1)view from Shebele Hotel, (2)view from gas station, and (3)view form the train



Figure 6.36. Site analysis

6.3.3. Intervention Concept

To compose a concept and context based exemplary design for the public that portrays identity through the expression of space, form and facade to help mainfest sense of place.

6.3.4. Concept Interpretation

6.3.3.1. Site Planning. The site planning is proposed using two zoning approaches namely above ground and below ground zoning.

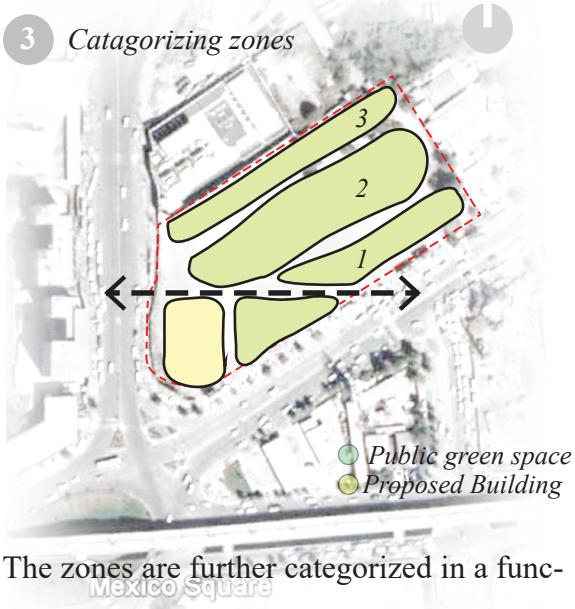
6.3.3.1.1 Above ground zoning. In this zoning process , the surface of the site is organized in the steps shown in Figure 6.44.



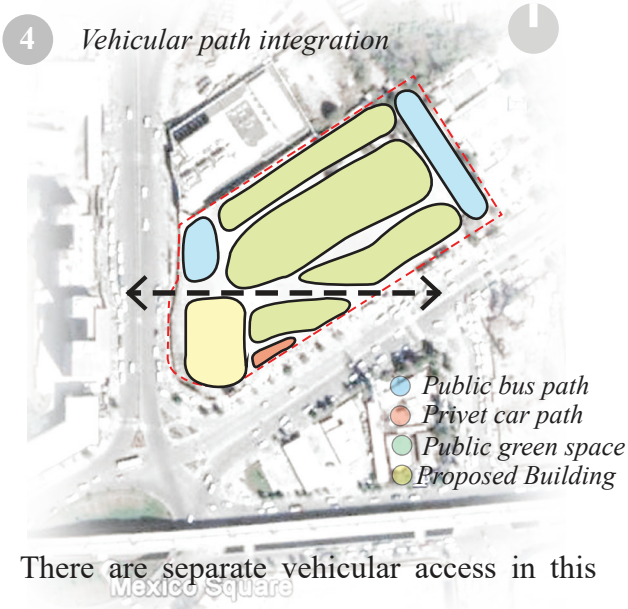
Pedestrians have been crossing the site on their way to the taxi stations near by. The first step in organizing the site is by accentuating the shortest path within the site to guide pedestrians to their taxi stations.



The site is divided in to two major zones.The zone south of the pathway is left for the building proposal and the other zone is for recreational public space that accomodates various routes for public use.



The zones are further categorized in a functional hierarchy in 3 sections. The 1st is for nearby pedestrian users, the 2nd is for public use and other activities and the 3rd is mostly for people waiting for public bus service.



There are separate vehicular access in this site. One is for the public buses and the other is for the proposed building. Entry and exit points are situated in a way they don't congest the main traffic.

5 *Sub zone refinement*

To create a public space that has identity and sense of place, multiple foot paths and functions are created in each zones. The paths are laid out to portray an overarching concept of "Tillet" pattern through out the site.

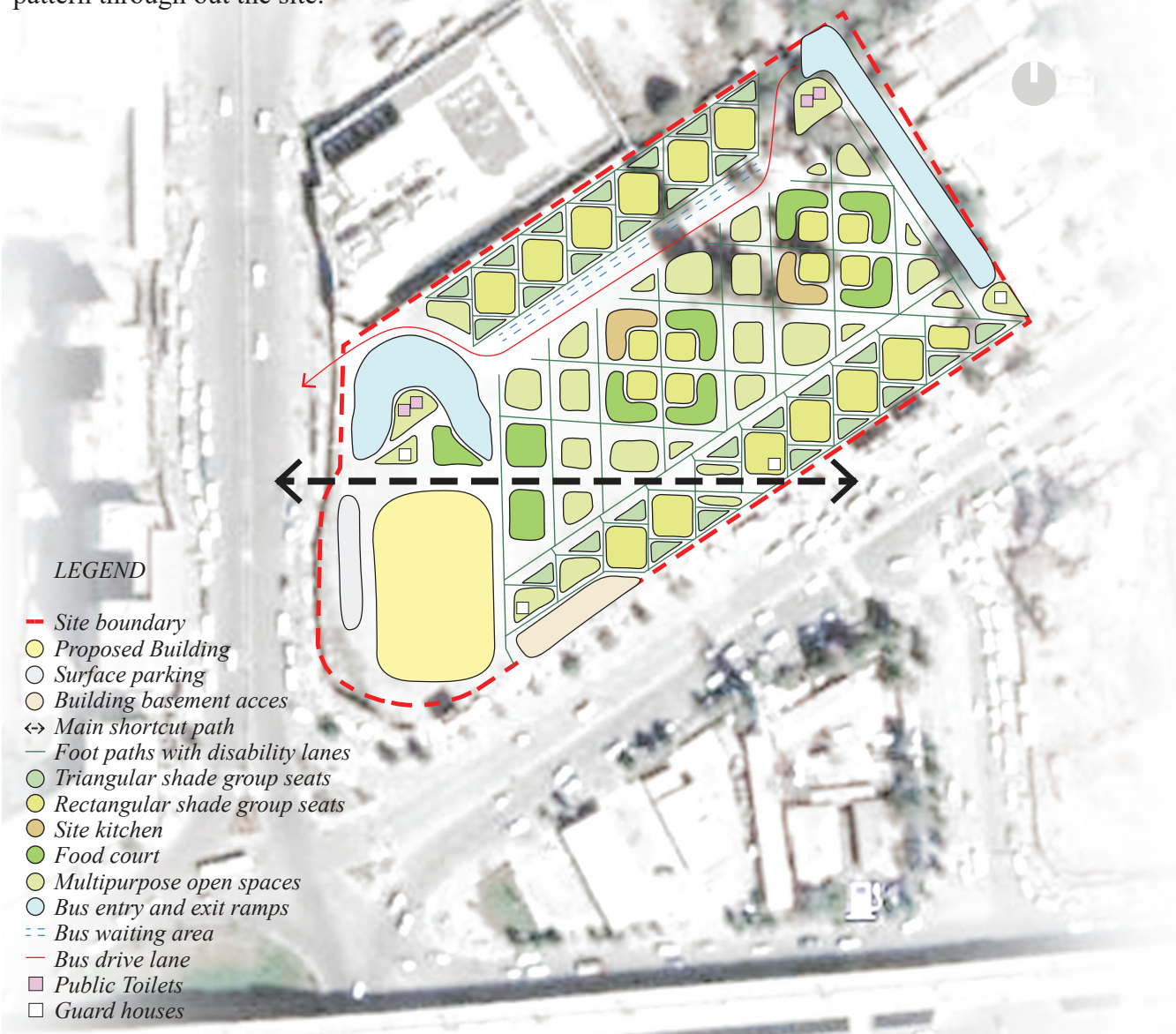


Figure 6.37. Above ground site planning evolution of strategic site(1-5)

The site layout is the overall integration of the understated functions.

-Check points (Guard Houses)

-Public toilets

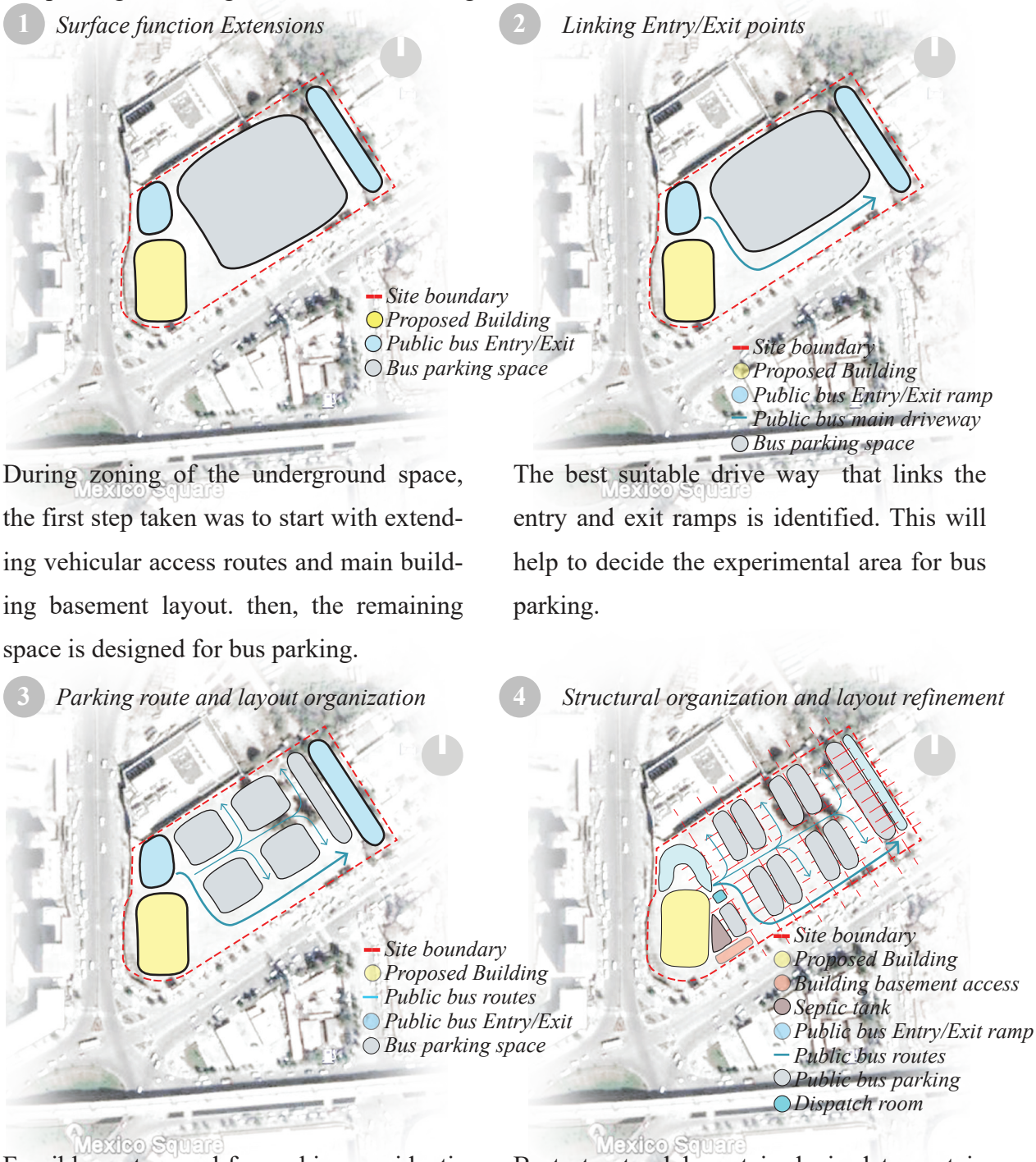
-Central food services

-Foot paths with reserved lanes for the physically challenged

-Vehicle routes

-Shaded and unshaded multifunctional outdoor spaces

6.3.4.1.2. Below ground zoning. In this zoning process, a 6m deep space is created for bus parking and is organized as shown in Figure 6.45.



During zoning of the underground space, the first step taken was to start with extending vehicular access routes and main building basement layout. then, the remaining space is designed for bus parking.

The best suitable drive way that links the entry and exit ramps is identified. This will help to decide the experimental area for bus parking.

Feasible routes used for parking are identified with in the experimental area. This will help to narrow down possible parking alignments with in the remaining spaces. A 90^0 alignment is proposed for maximum accommodation.

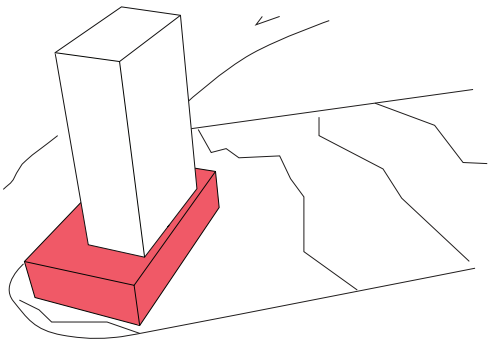
Best structural layout is devised to sustain aboveground functions, drive lanes,bus parking and enough spanning for drive throughs. Pocket spaces are strategically used for septic tank and battery room accommodations.

Figure 6.38. Below ground site planning evolution of strategic site (1-4)

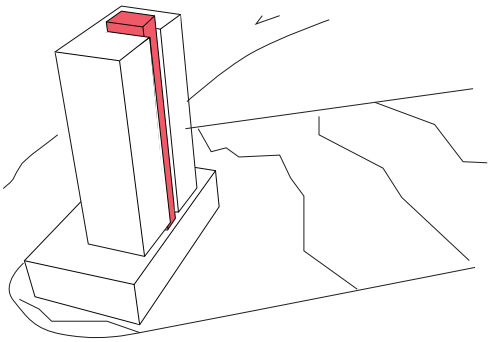
6.3.4.2. Building Planning. The building proposal is intended to create an iconic and examplary design that carries out the intervention concept through a concept and context based scientific application of fixed exterior shading devices for full glazed building facades.

Form Evolution

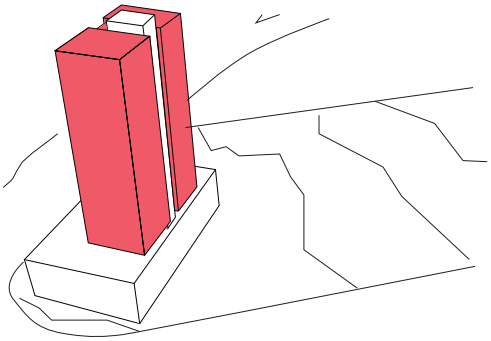
1 *Podium*



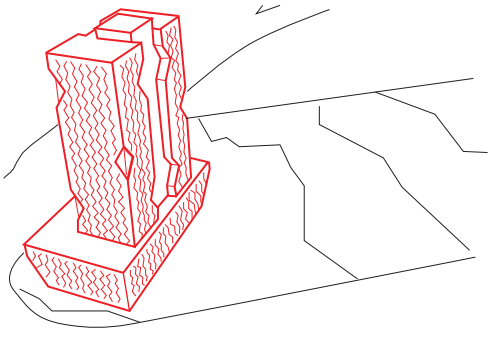
2 *Core Placement*



3 *Tower*



4 *Shading Concept Adaptation*



The Podium is sited at the edge of the site and has its sides aligned to the four major orientations. It is limited to three stories to give a reasonable scale for pedestrians. It has four accesses. Two of them are on its longest sides and the other two are at its corners. These are the main entrance and are located at the South-West edge and North-East edge of the podium. This makes one visible from the roundabout and the other from within the site.

The core provides vertical circulation, services, and storage spaces. It is placed at the eastern edge of the podium to provide passive lighting,ventilation, and immediate exit from the building.

The core being its center, it comprises of two blocks along the North- South axis. They are linked together west of their orientation. The depth of the tower is aligned in a way it provides shade to the site greenery from an afternoon sun.

The Ethiopian traditional **"Tillet"** concept implemented on the site also extends both on the building form and its shading. The building portrays the rhombus pattern at is corners. The shading devices are composed of alternating rhombus patterns and are unique by design to each orientation. This overall composition gives the building a sense of place.

Figure 6.39. Building proposal formal evolution (1-4)

6.3.5. Functional Organization

6.3.5.1. Site Organization. The site design intervention is organized in a way it accommodates outdoor public seating and open spaces in three zones. These spaces are organized strategically to portray identity and create sense of place. The overall functional organization of the site is shown in Figure 6.40.

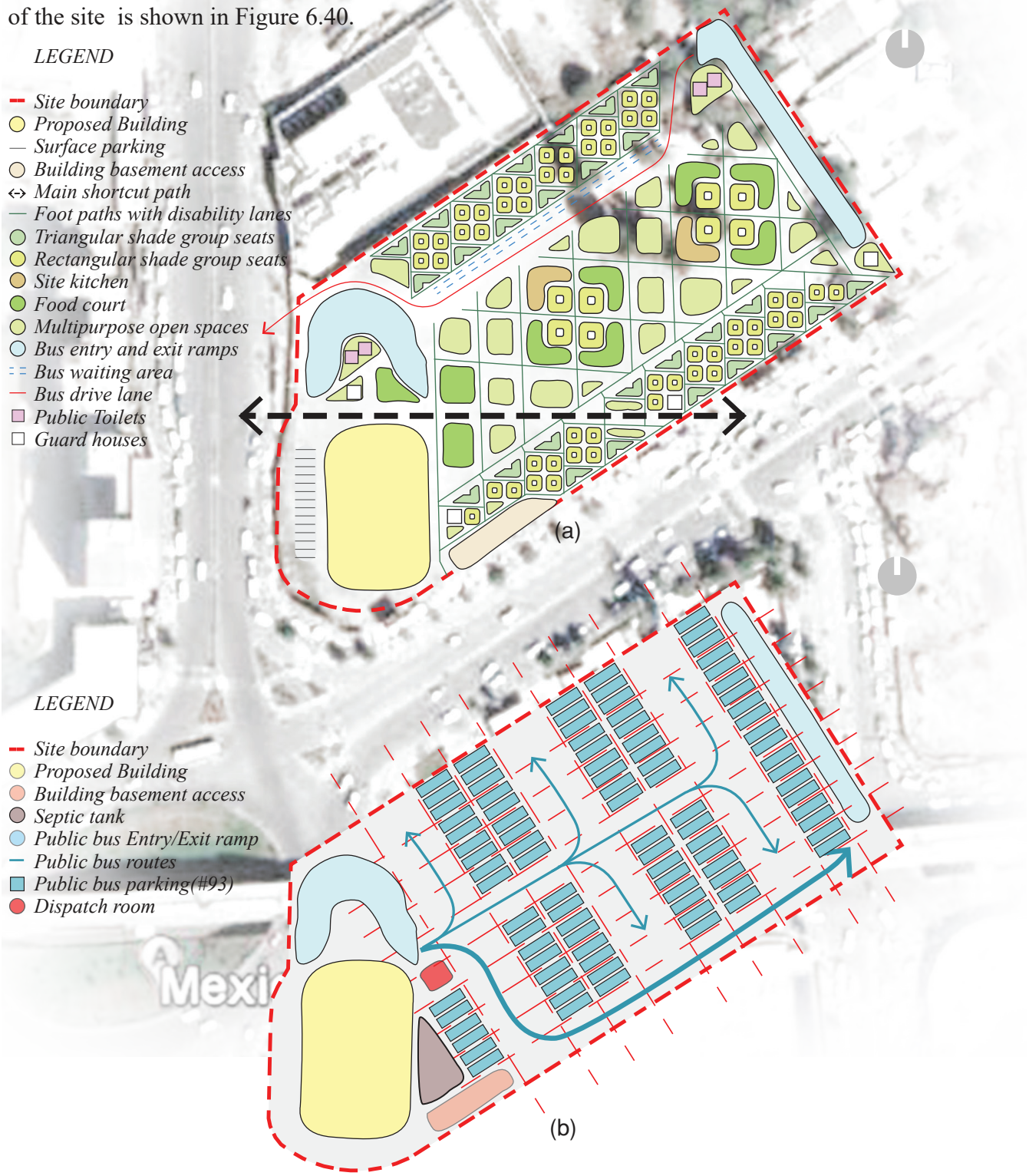


Figure 6.40. Proposed Design Functional organizations (a)Site level layout and (b)Site basement layout

6.3.5.2. Building Proposal Organization. The building proposal is organized in a way it accommodates office spaces related to the theme of this research and other spaces that serve the public at large.The building has 19 stories and its functional organization is shown in Table 6.5.

PROGRAM LIST

Catagory	Program	Level	Area(m^2)
Recreation	Roof Top	19th Floor	440
	VIP Lounge	18th Floor	440
	Lounge	17th Floor	438
Climate Research Platform	Management	16th Floor	438
	Lab	15th Floor	438
	Workpool	14th Floor	440
	Hall	13th Floor	440
	Exhibition	12th Floor	438
	Exhibition	11th Floor	438
Library	Computer Station	10th Floor	438
	Reading Station	9th Floor	440
Co-Work Office Space	Rental	8th Floor	440
	Rental	7th Floor	438
	Rental	6th Floor	438
	Rental	5th Floor	438
Recreation	Restaurant	4th Floor	440
Commerical	Outdoor Cafe	3th Floor	1228
	Shops	2th Floor	1245
	Shops	1th Floor	1174
	Shops	Ground Floor	1310
	Workshop	Basement 1	1008
	Parking	Basement 2	1123
	Parking	Basement 3	1271

Table 6.5. Building proposal functional organization

6.3.6. Schematic Drawings

6.3.6.1. Design Proposal Site Plan.

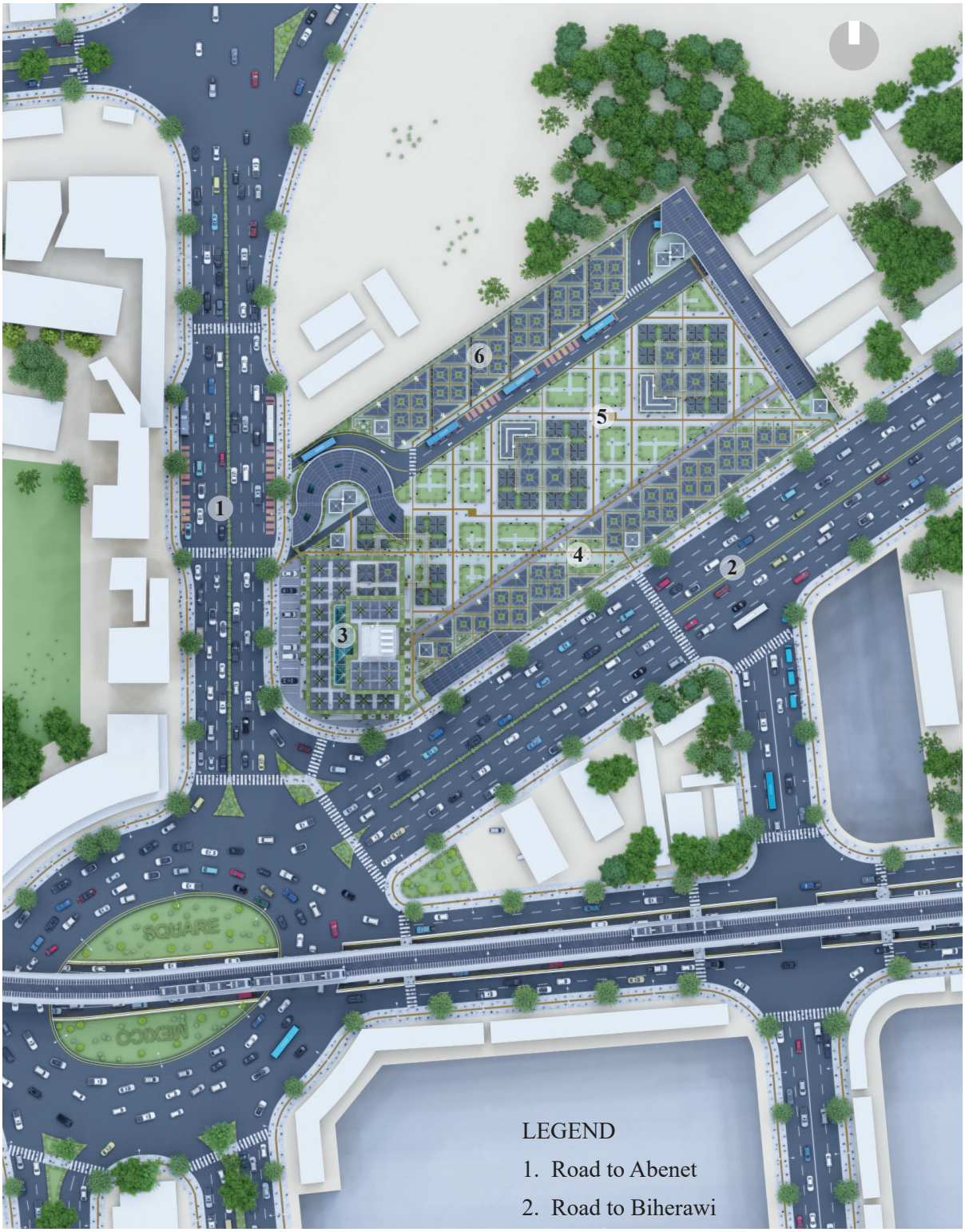


Figure 6.41. Design proposal site plan

6.3.6.2. Design Proposal Aerial Plan.

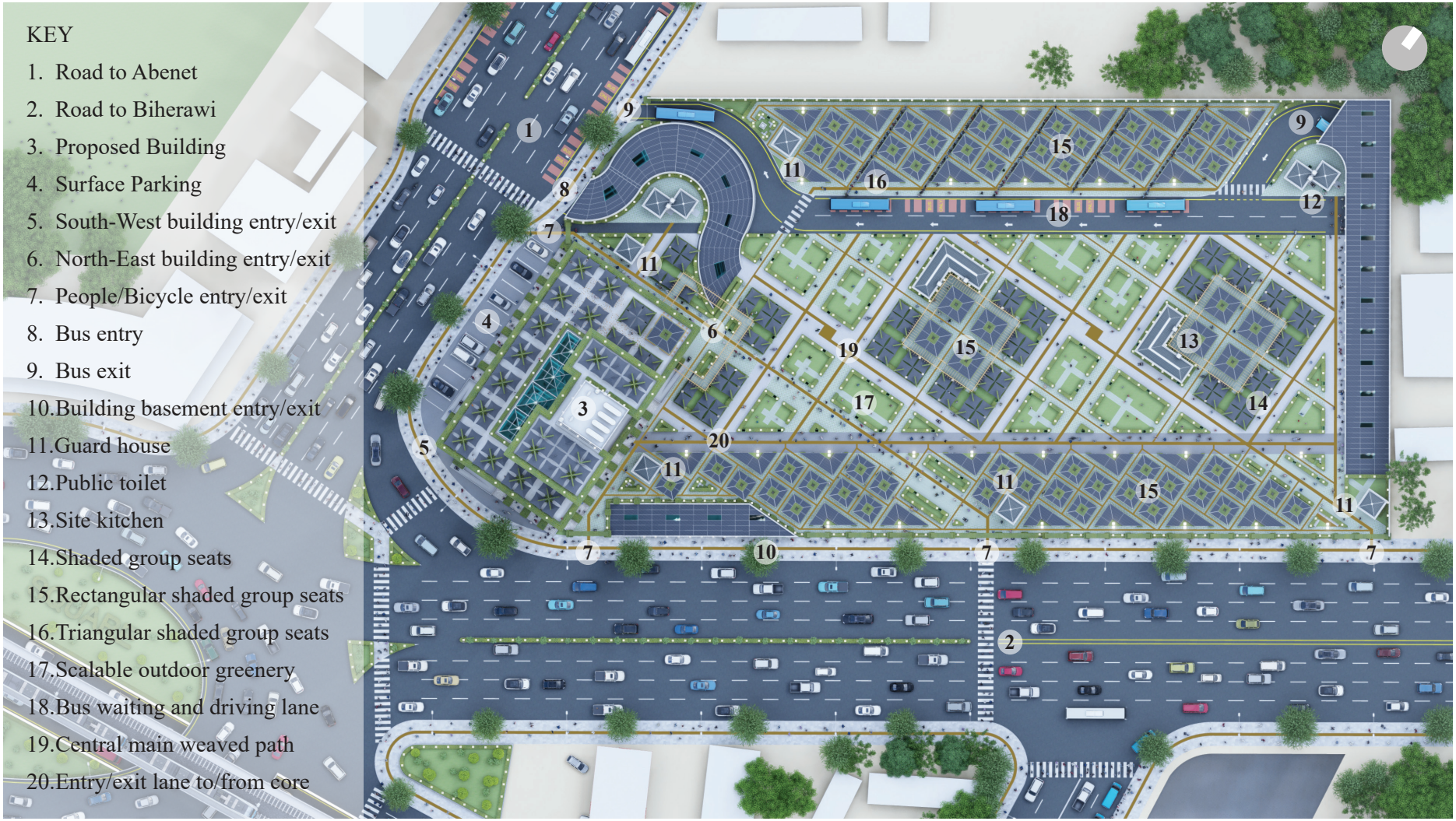


Figure 6.42. Design proposal site map

6.3.6.3. Design Proposal Aerial Perspectives.



Figure 6.43. Design proposal aerial view from (a)North-West and (b)South-East

6.3.6.3. Design Proposal Aerial Perspectives.



Figure 6.44. Design proposal aerial view from (a)North-East and (b)South-West

6.3.6.4. Building Proposal Floor Plan.

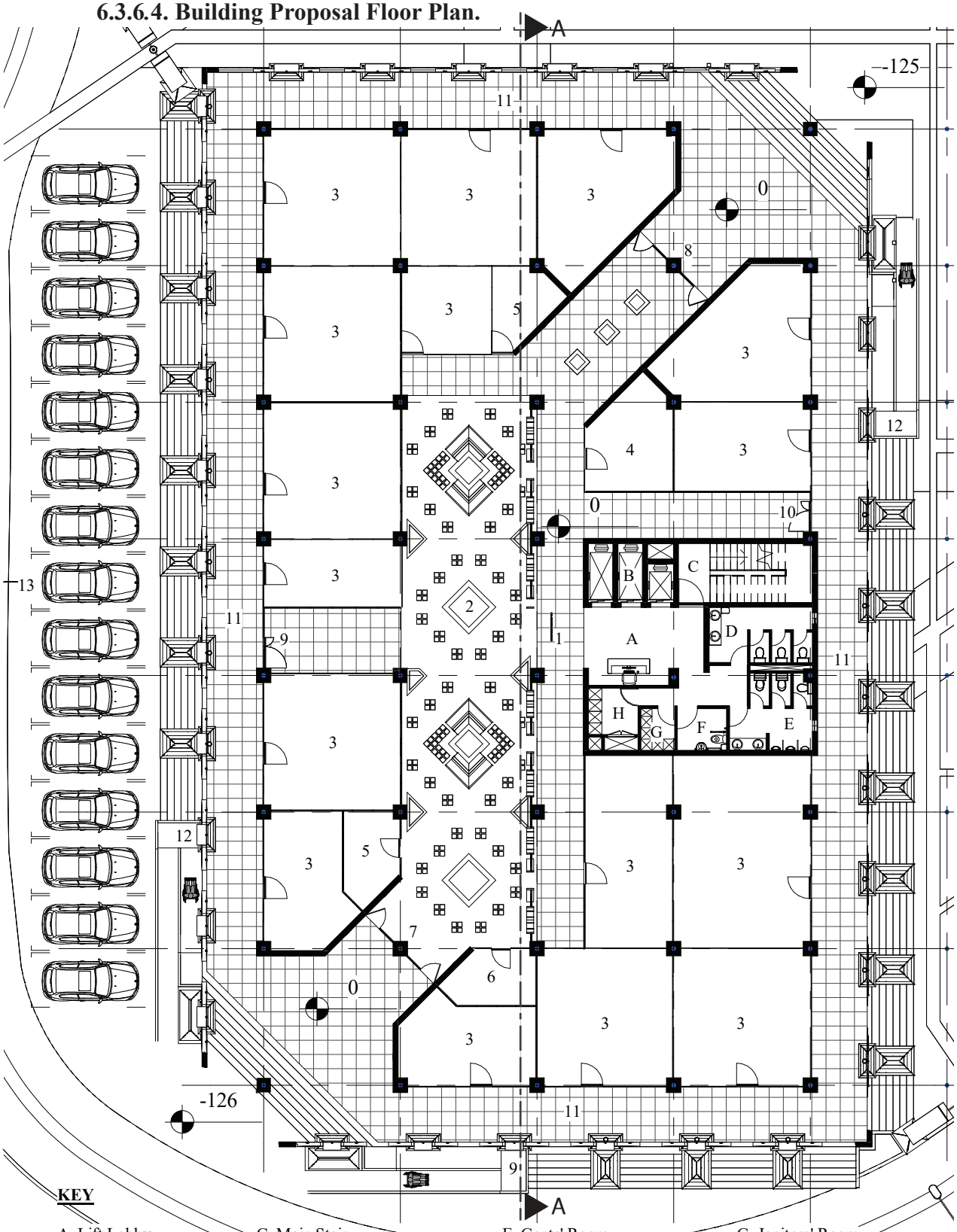


Figure 6.45. Building proposal ground floor plan Scale 1 : 250

6.3.6.5. Design Proposal Section.

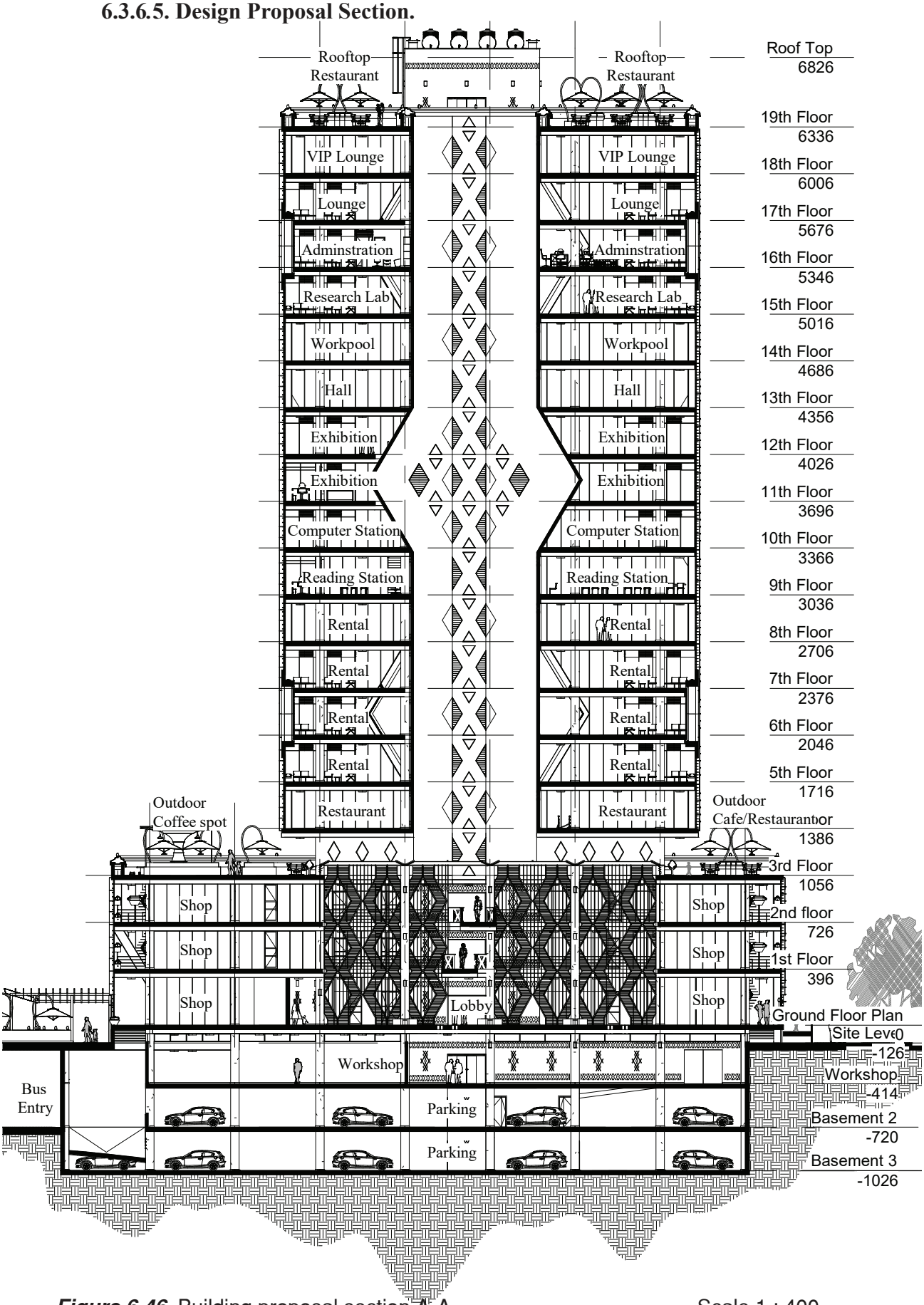


Figure 6.46. Building proposal section A-A Scale 1 : 400

6.3.6.6. Building Proposal Elevations.

6.3.6.6.1. Building Proposal Elevation 1.



Figure 6.47. Building proposal North elevation Scale 1 : 500

6.3.6.6.2. Building Proposal Elevation 2.



Figure 6.48. Building proposal East elevation Scale 1 : 500

6.3.6.6.3. Building Proposal Elevation 3.

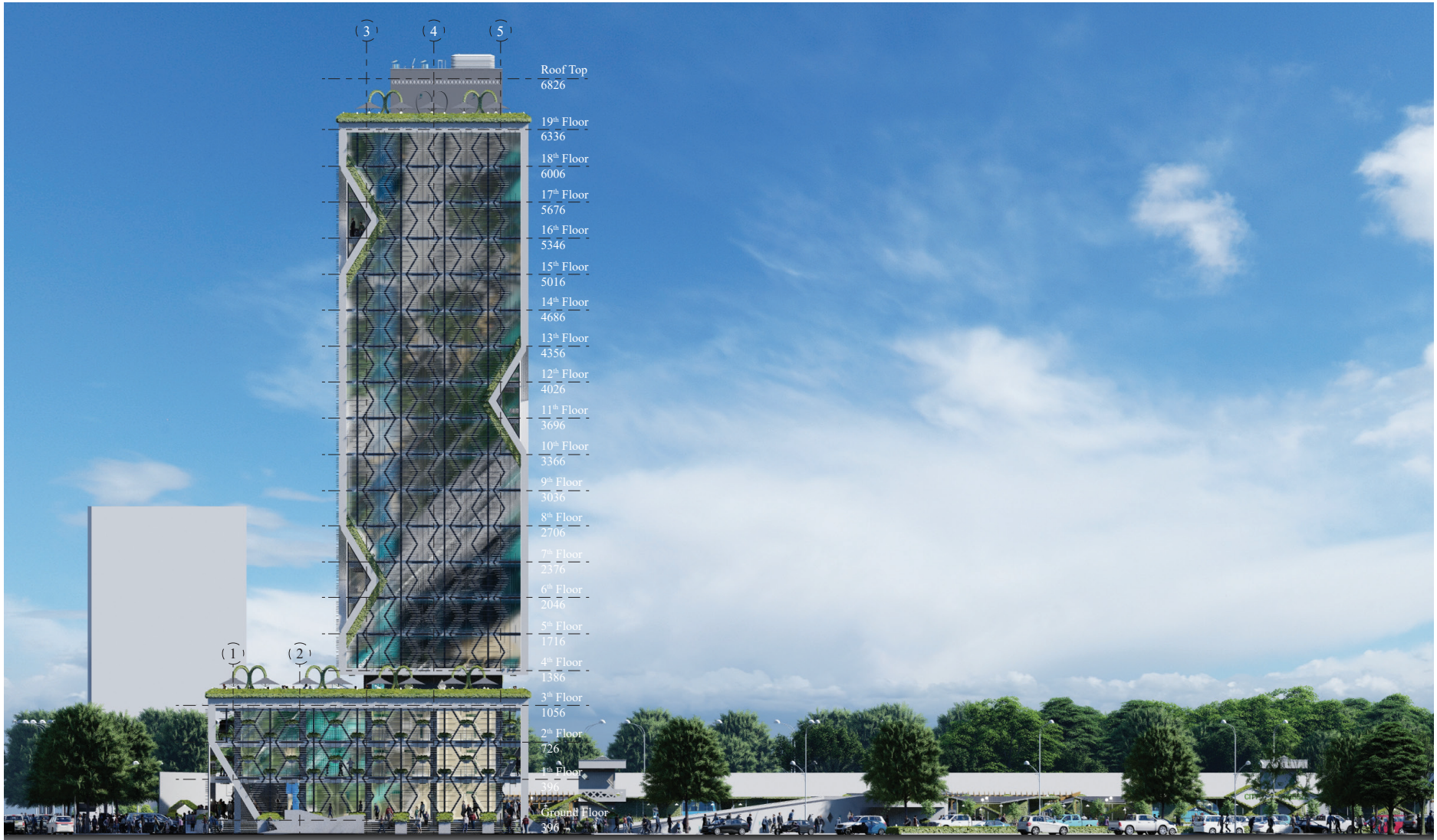


Figure 6.49. Building proposal South elevation Scale 1 : 500

6.3.6.6.4. Building Proposal Elevation 4.



Figure 6.50. Building proposal West elevation Scale 1 : 500

6.3.6.7. Building Proposal Aerial Perspective for View Transition.



Figure 6.51. Building proposal South-West aerial view

6.3.6.8. Building Proposal Human-eye Perspectives



Figure 6.52. Building proposal view from (a)South-West, (b)North-East, (c) South-East, and(d)North-West

6.3.6.9. Strategic Site Intervention Urban Clip



LEGEND

Strategic Site.....(1) Design proposal shown bounded by a red line

Road Network.....(2)Mexico Square, (3)To Torhiloach, (4)To Abenet, (5)To Biherawi, (6)To Stadium, (7)To Qera, (8)To Afican Union, and (9)To Sarbet,

Existing Buildings...(10)Chamber of Commerce & Associations, (11)Federal Police Commission Head Office, (12)B.G.I. Ethiopia Head Office, (13)Tegbared School, (14)Wabe Shebelle Hotel, (15)Total Gas Station, and (16)Debrewerq Tower

Figure 6.53. Urban aerial view of strategic site intervention

6.4. Stage 3 - Shading Adaptation

This stage of the design proposal explores how the proposed shading design approaches are adopted on the full-glazed facades of the proposed building. It also explores the application of such approaches on zonal features of the site to provide comfortable outdoor shaded experience during overheated periods.

6.4.1. Building Adaptation

From the previous stages, proper shading design guides were implemented on the proposed building. As can be seen from the building elevations, the shading designs differ in depth and spacing for each orientation. Comparing depth of shading devices, the least deep shading is found on the East side whereas the most compact and deep shading is found on the West. Comparing spacing of shading devices on elevations, West facade has the least spacing where as North facade has the most. The protrusion of such devices provide more exposed surface for solar gain during the day. Such facades are integrated with solar photovoltaic (PV) cells to generate electricity. Figure 6.54. shows the adaptation of such shading extremes on the tower of the proposed building.



Figure 6.54. Shading adaptation on North-West side of building proposal

6.4.2. Site Adaptation

The site is functionally organized in three zones. These zones offer different recreational and resting spaces with various settings. Some of these spaces are shaded with photovoltaics (PV) to enhance their functionality as well as gain more surface area to extract as much solar energy as possible.

In general, below are a list of functions where shadings are provided.

- Site edge public benches
- Semi enclosed spaces with group seats
- Vehicular entry and exit points
- Spaced light boxes that allow light and ventilation for basement parking

Figure 6.55. shows the above mentioned spaces.



Figure 6.55. Shading adaptation on site

key places, from the proposed building and the site, that adequately show the adaptation principles, are chosen. Namely,

- the South facade of the proposed building podium,
- shaded rectangular group seat of the site and
- the wall shading on the bus exit route.

Each key place is explained thoroughly through a perspective view, facade section and details.

KEY
01. Shading post
02. L- Shaped metal connector
03. Bolt
04. Concrete embedded bolt
05. Groove
06. Photovoltaic panel
07. Floor finish
08. Screed
09. Reinforced concrete slab
10. Ceiling plaster
11. Aluminum window frame
12. Clear glass
13. Alternative bolt openings
14. Electrical Installation gap
15. Vine
16. L-Shaped metal anchor
17. Post footing metal plate
18. Fermented soil
19. Lighting pole



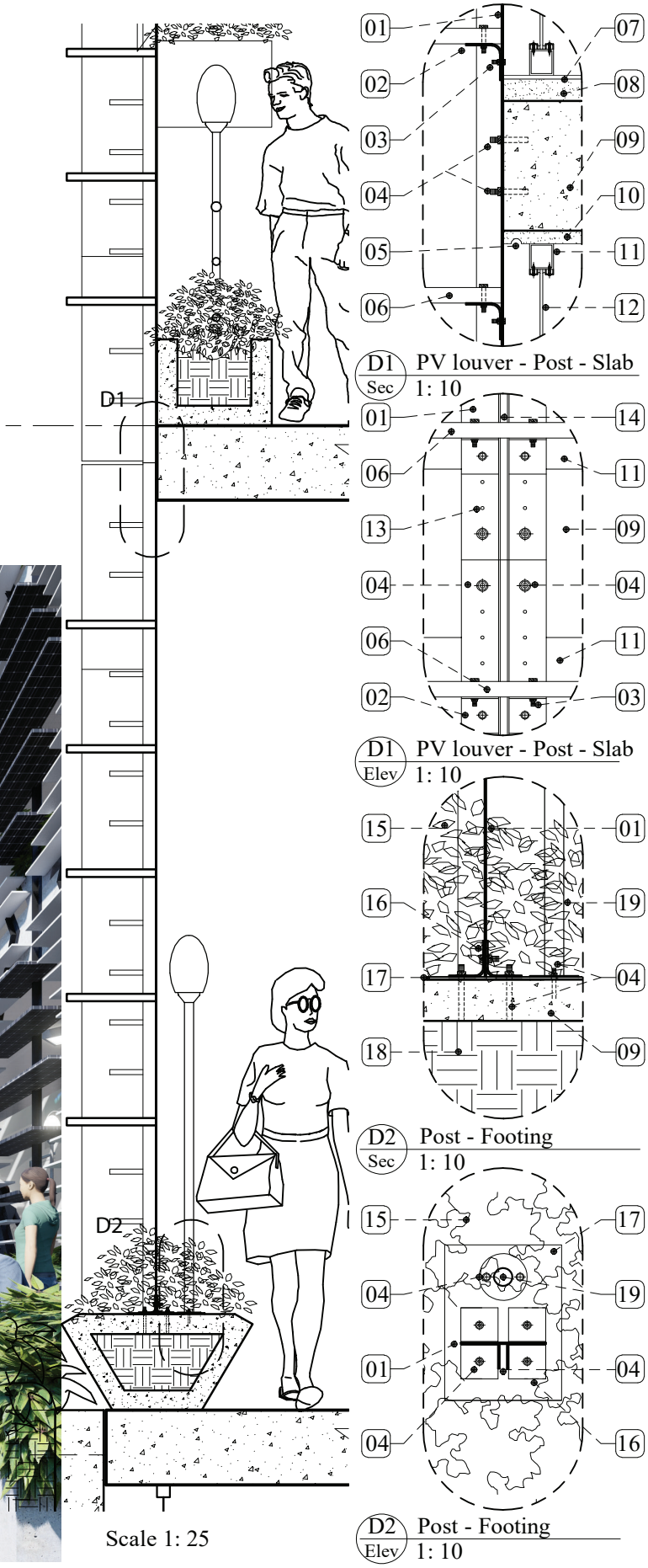


Figure 6.56. Building proposal facade shading adaptation (a)southern building podium view (b)facade section, and (c)details

KEY

01. Horizontal RHS metal post
02. Wiremesh for vine growth
03. Bolt
04. PV pannel
05. PV pannel frame
06. Curved metal post
07. Vertical RHS metal post
08. PV louver frame
09. L-Shaped metal anchor
10. Alternative bolt opening
11. Bolt
12. L-Shaped metal frame
13. Bolt
14. Louver post
15. Reinforced concrete
16. Translucent glass
17. Skylight frame
18. Tilted metal louver
19. Louver-post connecting screw
20. Footing plate
21. Groove
22. Concrete embeded bolt
23. Bolt
24. Marble Top
25. Reinforced concrete

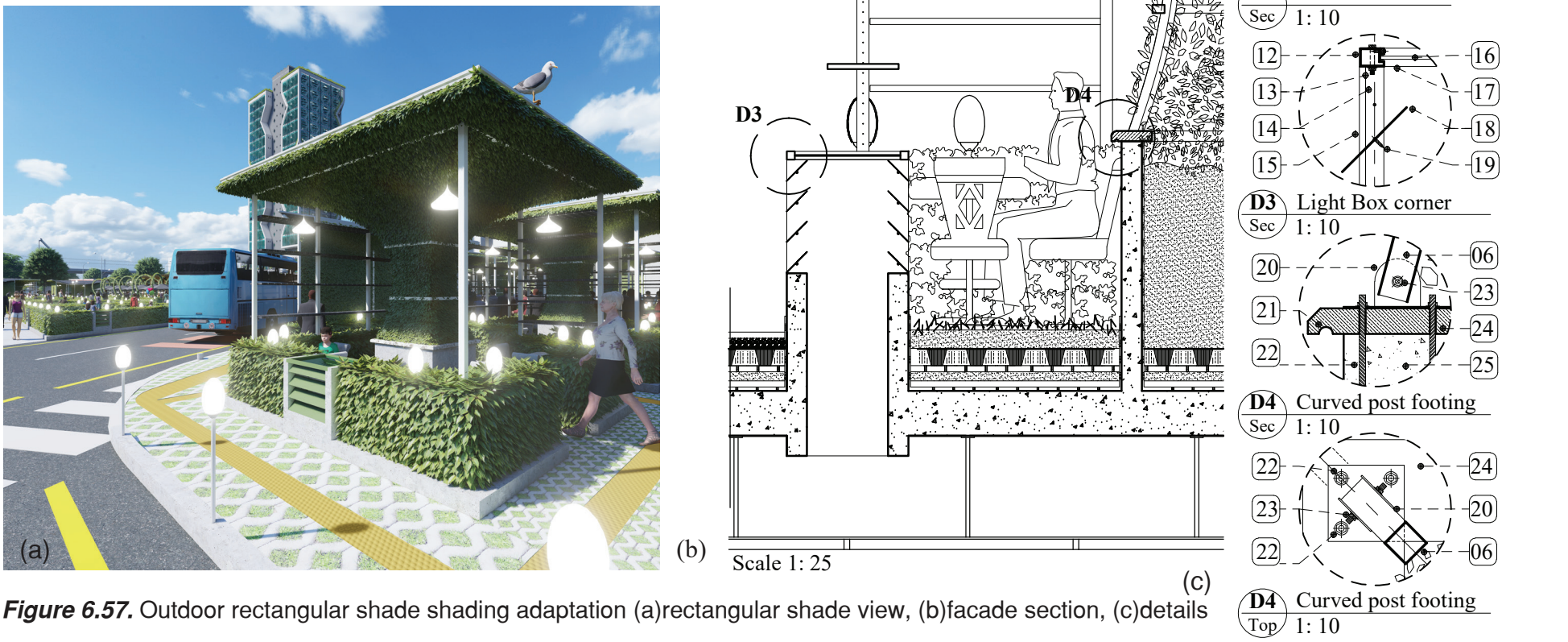


Figure 6.57. Outdoor rectangular shade shading adaptation (a)rectangular shade view, (b)facade section, (c)details

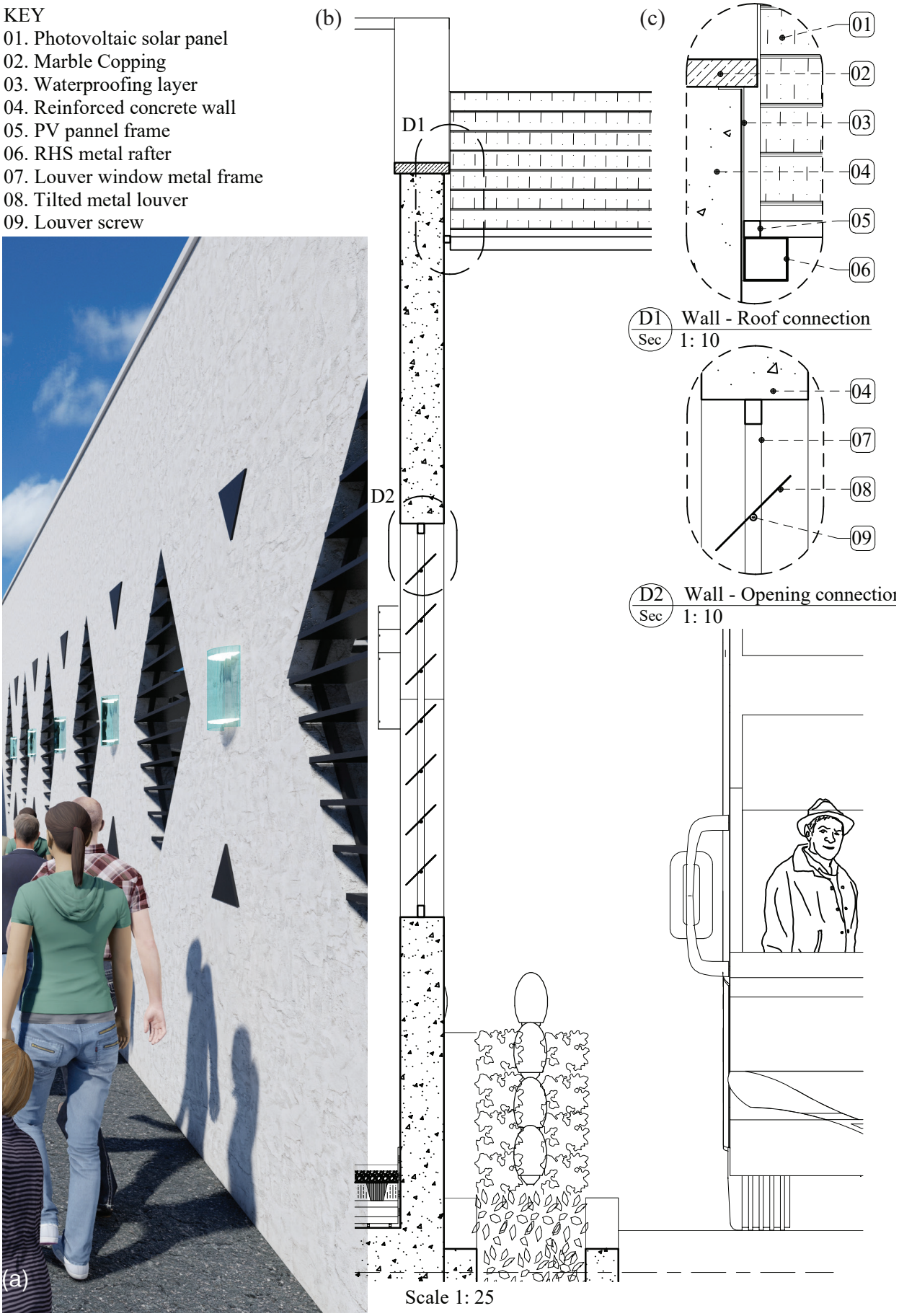


Figure 6.58. Wall louver adaptation (a)wall louver opening view, (b)facade section, and (c)details

CHAPTER SEVEN

Conclusion and Recommendations

CHAPTER SEVEN: Conclusion and Recommendations

7.1. Conclusion

The purpose of this paper is to assess the solar shading and thermal performance of fixed exterior shading devices found on radiation vulnerable full-glazed buildings intended for library or office use in Addis Ababa. Further more it aims to identify a suitable shading approach by design that helps to provide an optimal indoor thermal comfort for users in the local context. Findings of this research showed the month of May to be the hottest month of the year and periods from Noon to 4:00pm to be thermally uncomfortable. The best way to avoid incident solar radiation as a cause for solar heating is to block it firsthand before it reaches a glazed surface.

In the geographic location and climate context of Addis Ababa, fixed exterior shading devices on North, East, South, and West orientated glazed facades perform differently in terms of incident solar shading and direct solar heat gain optimizations. The design and layout of shading devices affects the shading angles they provide. These shading angles namely horizontal (HSA), vertical (VSA) and end-profile (EPA) determine how shading devices perform during identified overheated periods.

North facing facades receive solar inputs for 5 months of the year all day. During this time, the amount of solar input is minimum due to the steep angle of solar exposure from the sun's trajectory. Solar exposure hours are within the range of the identified overheated periods i.e. from 12:00pm to 4:00pm. For such facades, identified overheated period based shading design yields shading angles of 82^0HSA, 65^0VSA, and 38^0W EPA. This results in an optimal average shading of 57.4% and a monthly total direct solar heat gain reduction ranging from 63.5KWhr/m^2 - 130.9KWhr/m^2 throughout the year for North facing glazed zones.

East facing facades receive solar input all mornings of the year. In relation to other orientations, these facades receive the highest amount of solar input. Most solar exposure hours are not within range of the identified overheated periods. For such facades, identified overheated period based shading design yields shading angles of 65^0HSA, 83^0VSA, and 60^0N &55^0S EPA. This results in an optimal average shading of 54% and a monthly total direct solar heat gain reduction ranging from 73.9KWhr/m^2 - 81.4KWhr/m^2 throughout the year for East facing glazed zones.

South facing facades receive solar input all day except for 5 months of the year. In relation to other orientations, these facades receive above average amount of solar input. Solar exposure hours during afternoon periods are within range of the identified overheated periods. For such facades, identified overheated period based shading design yields shading angles of 60^0HSA,55^0VSA, and 38^0W EPA. This results in an optimal average shading of 75.7% and a monthly total direct solar heat gain reduction ranging from 159.9KWhr/m^2 - 162.9KWhr/m^2 throughout the year for South facing glazed zones. On the other hand, during the 7 months of the year where South facing facades receive solar inputs all day, heat gain during morning hours is desired where as during the afternoon is undesired. In this case, implementing over-heated period based fixed shading approaches would help avoid undesired solar heat gains in the afternoon but will block desired solar heat gains during morning hours. For this reason, it is challenging to achieve user desired thremal comfort using fixed exterior shading approaches for South oriented glazed zones. In this regard, kinetic shading approaches would provide more flexibility in responding accordingly to solar exposure during desired and undesired periods.

West facing facades receive solar input all afternoon of the year. In relation to other orientations, these facades receive above average solar input. All solar exposure hours are within range of the identified overheated periods. For such facades, identified overheated period based shading design yields shading angles of 0^0HSA,35^0VSA, and 25^0N &25^0S EPA. This results in an optimal average shading of 84.2% and a monthly total direct solar heat gain reduction ranging from 159.9KWhr/m^2 - 108KWhr/m^2 throughout the year for West facing glazed zones.

Application of fixed exterior shading devices through studied literature steps could be achieved in different shapes and sizes within the framework of priorly identified shading angles. Such approaches not only contribute in blocking incident solar radiation during over-heated periods but also reduce direct solar heat gains in indoor spaces which would otherwise cause thermal discomfort.

7.2. Recommendations and Future Works

Optimal solar shading and thermal performance for radiation vulnerable glazed facades could be achieved through climate-based shading approaches. This requires the understanding of the local climate and overheated periods. Within the context of the same region, solar shading demand for each orientation is unique. This is due to the exposure angle and period during the annual sun's trajectory. In this research, overheated period based shading approach was conducted for North, East, South, and West orientations in the climate context of Addis Ababa. This was brought through the application of studied literature steps for the design of shading devices in accordance to a journal of building climatology by Antony Sealey (1979). In this regard, prior to making context based shading design decisions, I recommend architects, engineers and researchers to:

- become updated with the recent weather and climate data of the building location they intend to design a shading for.
- know which periods of the day and year are desired and undesired by users for solar heat gain.
- identify times when shading is required, the position of the sun during the time of shading, and shading angles.
- identify dimensions of shading devices based on the identified shading angles.
- consider the structure and aesthetics of the shading device with respect to the building and its local context.

I suggest further studies and experiments to be made on the potential of passive solar control strategies as a means to provide optimal thermal comfort for users. Such strategies would help reduce daytime energy demands for radiation vulnerable glazed buildings. On the other hand, alternative shading strategies should be explored for South oriented vulnerable glazed zones in the climate context of Addis Ababa. Such zones get exposed all day for 7 months of the year during which solar heat gains are desired in mornings and undesired in afternoons. Therefore, it is difficult to provide optimal thermal shading all day during the 7 months in the framework of fixed exterior shading devices. All in all, the findings from overheated period based shading design approaches could be valuable additions to context-based building design guidelines. This would also create an opportunity for young architects and engineers to find new alternative design solutions which consider case related literature findings to help optimize the visual and thermal performance of vulnerable glazed facades.

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APPENDICES

APPENDICES:

APPENDIX - A : **Research Schedule**

APPENDIX - B : **Verification Survey Questionnaire and Respondents' Information**

APPENDIX - C : **Site Proposal Floor Plans and Sections**

APPENDIX - D : **Building Proposal Floor Plans and Sections**

APPENDIX - E : **Site Utilities' Floor Plans and Sections**

APPENDIX - F : **Supplementary Visualizations**

APPENDIX - G : **Design Proposal's BIPV Organization and Sanitary Flow Diagram**

APPENDIX - A

Research Schedule

APPENDIX - A: Research Schedule

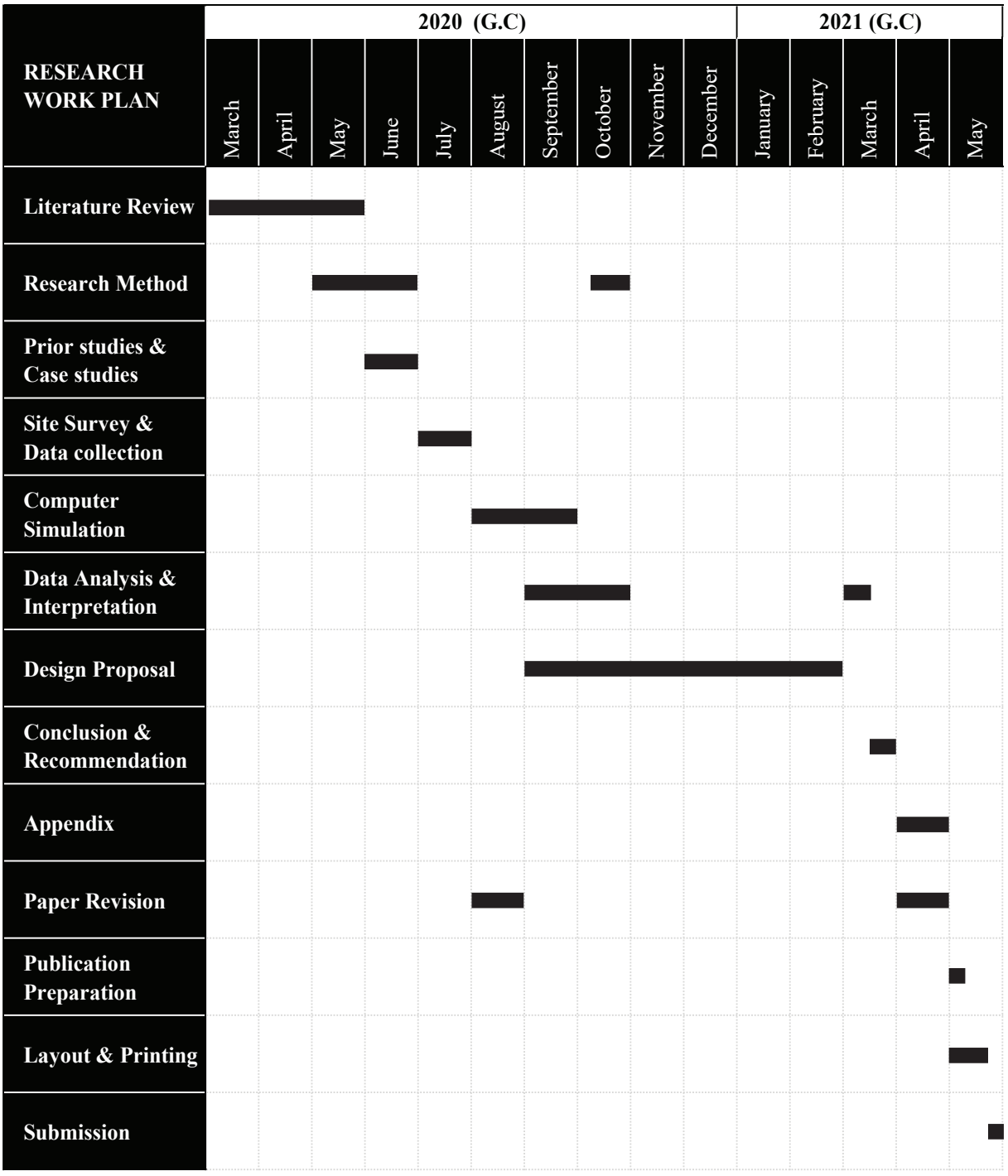


Table A1. Research work plan

APPENDIX - B

Verification Survey Questionnaire and Respondents' Information

APPENDIX - B: Verification Survey Questionnaire and Respondents' Information

Building Indoor Thermal Comfort - Verification Survey

This survey is intended to provide an assessment of the indoor thermal comfort provided by this building to its occupants. Answers to these survey questions provides an indication as to the thermal performance of this building's façade while providing direction for making improvements to systems in an attempt to provide a continual comfortable environment for building occupants.

Thank you for your participation.

BLDG. Name_____

Occupant Name_____Sex_____ Age_____

Section 1 - Background Information

1. How many years have you been working/studing in this building?

☐ Less than 1 year ☐1-2 year's ☐ 3-4 year's ☐ 4-5 year's ☐ More than 5 years

In which area of the building is your workspace located?

☐ East ☐ West ☐ North ☐ South

☐ Northeast Corner ☐ Southwest Corner ☐ Southeast Corner ☐ Northwest Corner

2. Which of the following do you use to adjust or control your office environment?

(Check any that apply)

☐ Window blinds / shades ☐ Thermostat ☐ Portable heater ☐ Room air-conditioning unit

☐ Portable fan ☐ Ceiling fan ☐ Windows ☐ Adjustable air vents

☐ other

Section 2 - Thermal Comfort

The following questions refer to your general perception of overheated periods in your office environment throughout the year.

1. Which season of the year do you feel is the most overheated?

☐ Autumn (September, October, November) ☐ Spring (March, April, May)

☐ Winter (December, January, February) ☐ Summer (June, July, August)

APPENDIX - B: Verification Survey Questionnaire and Respondents' Information

Building Indoor Thermal Comfort - Verification Survey Cont...

2. Which month of the year do you feel is the most overheated?

☐ September ☐ October ☐ November

☐ December ☐ January ☐ February

☐ March ☐ April ☐ May

☐ June ☐ July ☐ August

3. In which time range of the day do you start experiencing overheated periods?

(Circle all that apply)

8:00am…...9:00…...10:00…...11:00…...12:00…...1:00……2:00…...3:00…...4:00…5:00pm

Morning Noon After Noon

4. In which time range of the day do you experience the most overheated periods?

(Circle all that apply)

8:00am…...9:00…...10:00…...11:00…...12:00…...1:00……2:00…...3:00…...4:00…5:00pm

Morning Noon After Noon

5. How would you best describe the source of overheated periods in your classroom?

(Check all that apply)

☐ Air movement too high ☐ Air movement too low ☐ Incoming sun

☐ Drafts from window ☐ Drafts from vents

☐ Hot/cold surrounding surfaces (floor, ceiling, walls or windows)

☐ Heating/cooling system does not respond quickly enough to the thermostat

☐ Uneven temperature (some parts always hot while others always cold)

☐ Other. Please Describe:

_____

_____

6. Assuming you are not using internal shading devices, how satisfied would you be with the performance of the fixed shading devices outside your classroom during overheated periods?

Very Satisfied ☐ ☐ ☐ ☐ ☐ ☐ ☐ Very Dissatisfied

APPENDIX - B: Verification Survey Questionnaire and Respondents' Information

Respondents' Information

Thermal comfort verification survey questions were randomly distributed to willing case building respondents found on different building classroom locations. A total of 138 respondents participated in this survey. Among the respondents, 50.7% were found to be male and 49.3% were found to be female. Table B1. shows information regarding respondents' age, sex, service period, quantity and percentages on each case buildings.

KEY

M Male

F Female

% Percentage

SURVEYED CASE BUILDINGS' RESPONDENTS' INFORMATION																	
Africa Insurance Bldg.			Finfine Bldg.			Henk de Pagter Bldg.			John F Kennedy Bldg.			Renaissance Bldg.			Wegagen Bank Bldg.		
Sex	Age	Period Served	Sex	Age	Period Served	Sex	Age	Period Served	Sex	Age	Period Served	Sex	Age	Period Served	Sex	Age	Period Served
F	29	b/n 3-4yrs.	F	33	> 5yrs.	M	28	< 1yr.	F	23	b/n 4-5yrs.	M	43	b/n 4-5yrs.	M	26	< 1yr.
M	36	b/n 1-2yrs.	M	31	< 1yr.	M	40	b/n 4-5yrs.	F	20	< 1yr.	F	25	b/n 3-4yrs.	M	30	> 5yrs.
M	31	> 5yrs.	F	30	> 5yrs.	M	23	b/n 3-4yrs.	F	21	b/n 3-4yrs.	M	29	b/n 3-4yrs.	M	26	b/n 1-2yrs.
F	25	b/n 1-2yrs.	F	29	> 5yrs.	F	22	b/n 3-4yrs.	F	23	b/n 3-4yrs.	M	24	b/n 1-2yrs.	M	40	b/n 4-5yrs.
M	29	b/n 1-2yrs.	M	41	> 5yrs.	M	25	b/n 4-5yrs.	M	27	b/n 1-2yrs.	F	26	< 1yr.	M	34	> 5yrs.
F	28	< 1yr.	F	44	> 5yrs.	M	24	< 1yr.	M	35	> 5yrs.	M	53	b/n 4-5yrs.	F	30	b/n 3-4yrs.
F	33	> 5yrs.	M	31	b/n 1-2yrs.	M	23	< 1yr.	F	24	b/n 4-5yrs.	F	27	< 1yr.	M	30	> 5yrs.
M	27	b/n 1-2yrs.	M	33	b/n 1-2yrs.	F	21	b/n 4-5yrs.	M	41	b/n 4-5yrs.	M	31	> 5yrs.	F	28	b/n 1-2yrs.
F	26	b/n 1-2yrs.	F	32	< 1yr.	F	23	b/n 3-4yrs.	F	23	b/n 1-2yrs.	M	30	b/n 3-4yrs.	F	30	b/n 1-2yrs.
M	29	b/n 4-5yrs.	F	59	b/n 4-5yrs.	F	30	> 5yrs.	M	24	b/n 3-4yrs.	M	26	< 1yr.	M	40	< 1yr.
F	29	b/n 1-2yrs.	F	20	b/n 1-2yrs.	F	23	b/n 4-5yrs.	F	25	b/n 4-5yrs.	M	40	< 1yr.	F	32	b/n 4-5yrs.
M	31	b/n 3-4yrs.	F	35	> 5yrs.	M	27	b/n 4-5yrs.	M	43	> 5yrs.	F	36	b/n 1-2yrs.	M	32	b/n 1-2yrs.
M	24	< 1yr.	F	34	> 5yrs.	M	27	b/n 1-2yrs.	F	24	b/n 1-2yrs.	F	31	b/n 3-4yrs.	M	27	b/n 3-4yrs.
M	33	> 5yrs.	F	23	< 1yr.	F	24	< 1yr.	M	29	> 5yrs.	M	24	< 1yr.	M	35	> 5yrs.
F	30	b/n 4-5yrs.	M	42	> 5yrs.	M	31	> 5yrs.	M	23	b/n 4-5yrs.	F	29	< 1yr.	F	30	b/n 4-5yrs.
F	27	b/n 3-4yrs.	M	30	> 5yrs.	M	30	b/n 3-4yrs.	F	21	b/n 1-2yrs.	M	28	b/n 3-4yrs.	F	28	b/n 1-2yrs.
F	26	b/n 1-2yrs.	F	27	b/n 1-2yrs.	F	25	< 1yr.	F	31	> 5yrs.	F	35	b/n 1-2yrs.	M	41	> 5yrs.
M	35	> 5yrs.	M	40	b/n 3-4yrs.	F	22	b/n 1-2yrs.	M	20	b/n 1-2yrs.	M	41	> 5yrs.	F	37	< 1yr.
F	32	b/n 1-2yrs.	F	25	< 1yr.	F	34	> 5yrs.	F	22	< 1yr.	M	47	> 5yrs.	F	29	b/n 3-4yrs.
M	29	b/n 1-2yrs.	M	34	> 5yrs.	M	29	b/n 4-5yrs.	F	29	> 5yrs.	M	34	b/n 1-2yrs.	M	30	b/n 3-4yrs.
M	31	b/n 3-4yrs.	20ppl.	M- 40%	F- 60%	M	20	< 1yr.	F	24	b/n 4-5yrs.	F	39	> 5yrs.	M	31	> 5yrs.
21ppl.	M- 52.4%	F- 47.6%				21ppl.	M- 57.1%	F- 42.9%	M	40	> 5yrs.	F	30	b/n 3-4yrs.	M	28	b/n 3-4yrs.
									F	23	b/n 1-2yrs.	F	35	> 5yrs.	22ppl.	M- 63.6%	F- 36.4%
									F	25	b/n 1-2yrs.	23ppl.	M- 56.5%	F- 43.5%			
									F	20	b/n 3-4yrs.						
									F	32	b/n 3-4yrs.						
									M	21	< 1yr.						
									F	33	b/n 3-4yrs.						
									M	42	> 5yrs.						
									F	27	> 5yrs.						
									M	25	b/n 4-5yrs.						
									31ppl.	M- 38.7%	F- 61.3%						

Table B1. Respondents' Information

APPENDIX - C

Site Proposal Floor Plans and Sections

APPENDIX - C: Site Proposal Floor Plans and Sections

Site Level and Basement Level Floor Plans

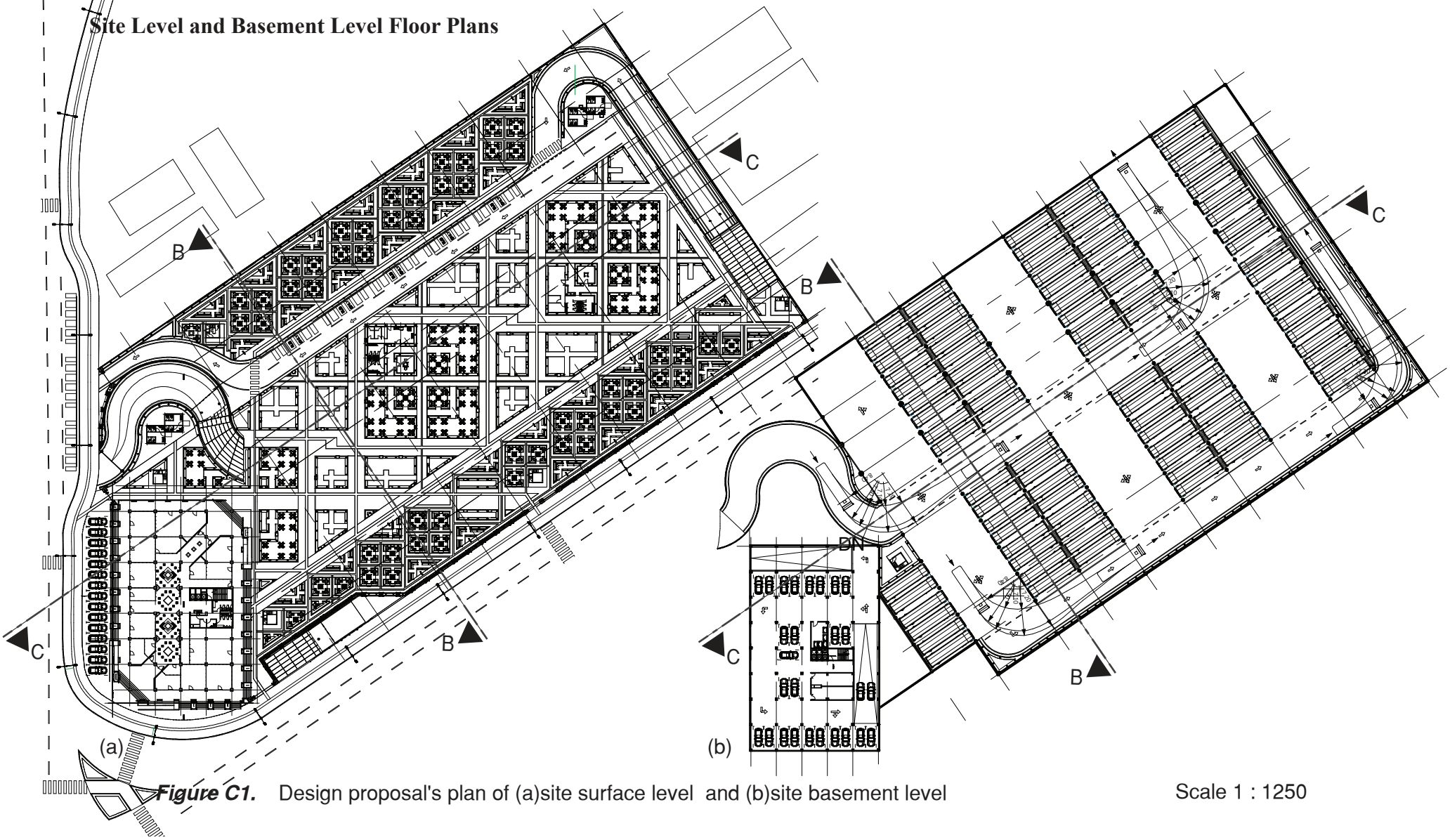


Figure C1. Design proposal's plan of (a)site surface level and (b)site basement level Scale 1 : 1250

APPENDIX - C: Site Proposal Floor Plans and Sections

Site Level and Basement Level Sections

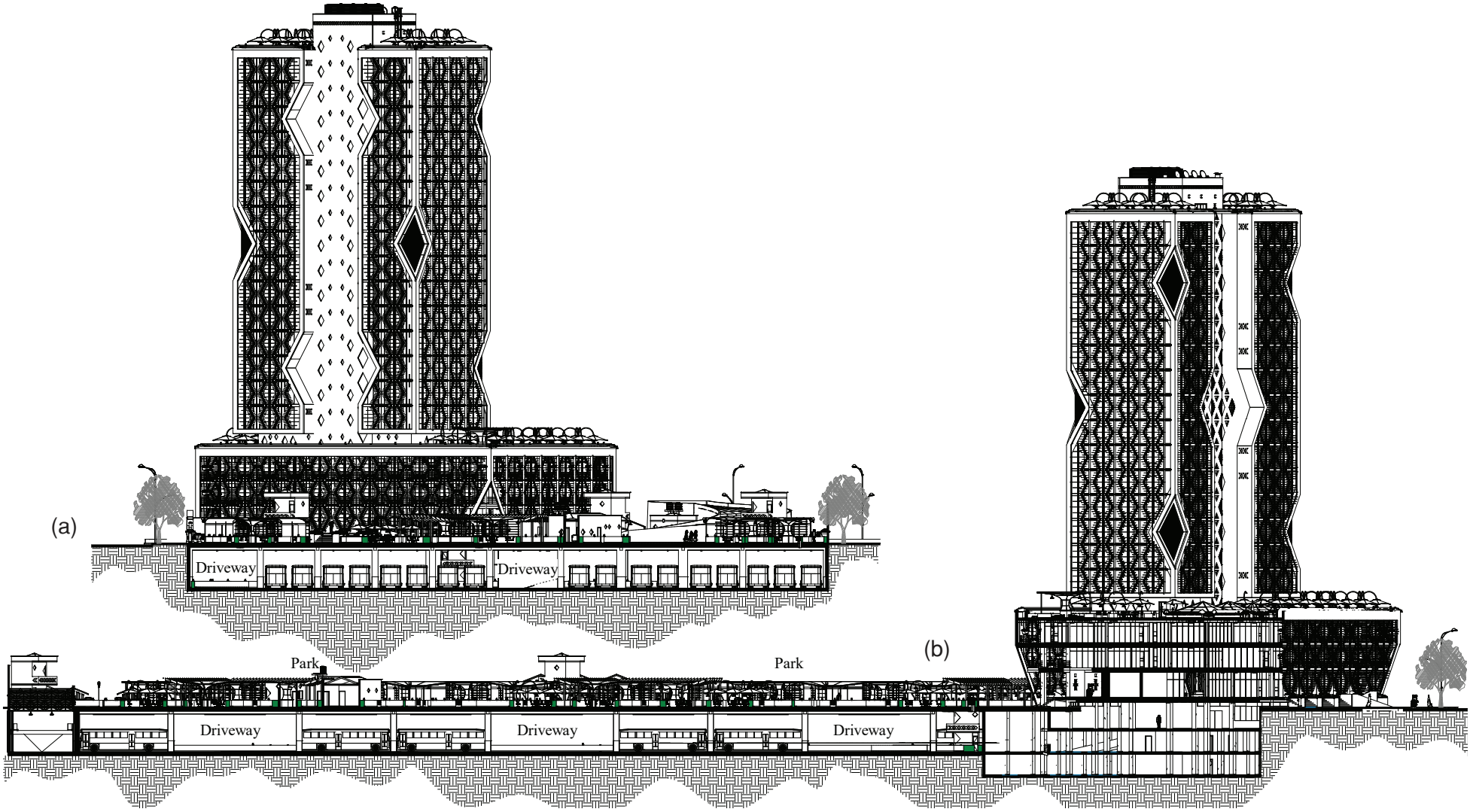


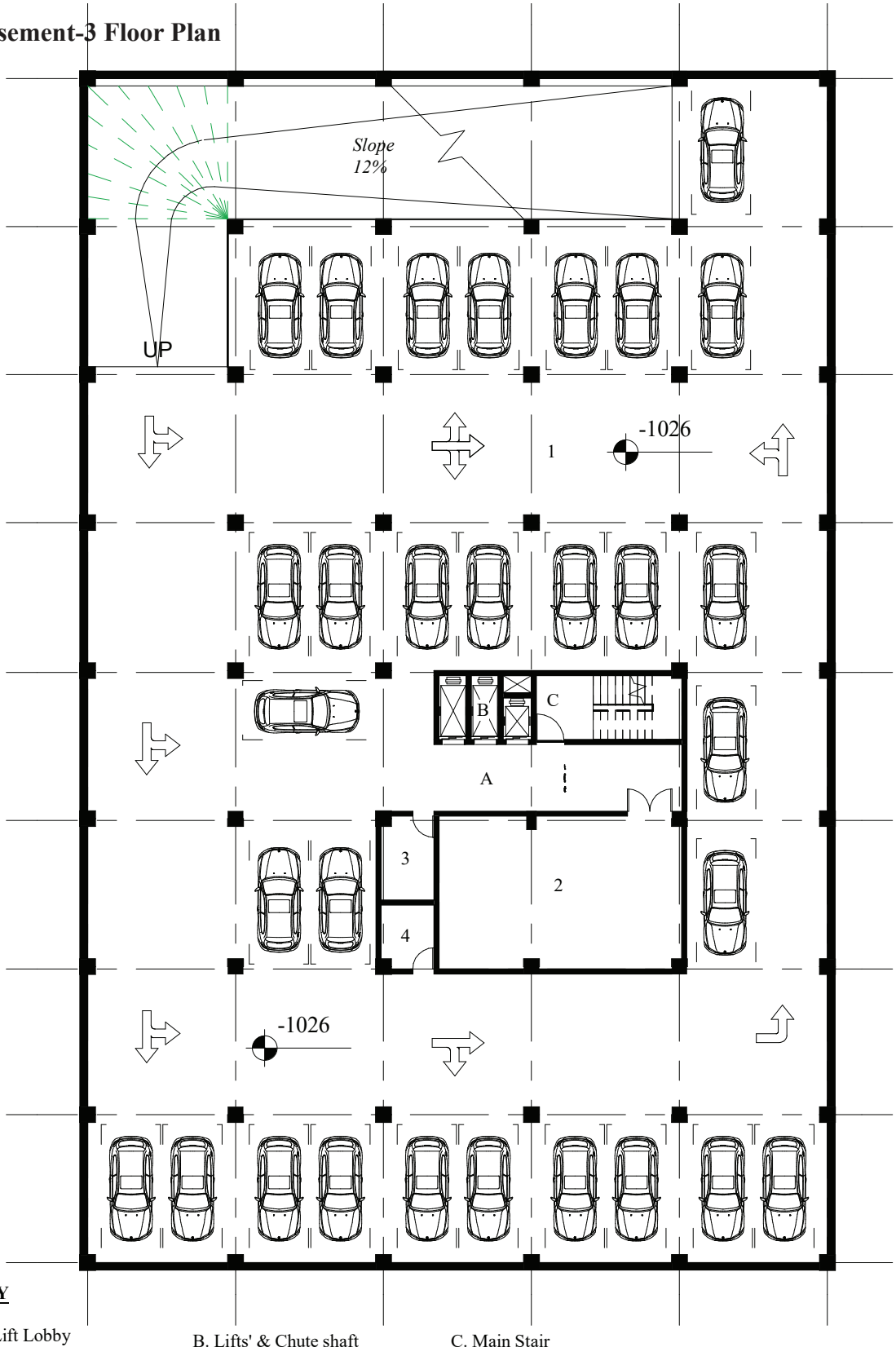
Figure C2. Design proposal (a)section B-B and (b)section C-C Scale 1 : 750

APPENDIX - D

Building Proposal Floor Plans and Sections

APPENDIX - D: Building Proposal Floor Plans and Sections

Basement-3 Floor Plan



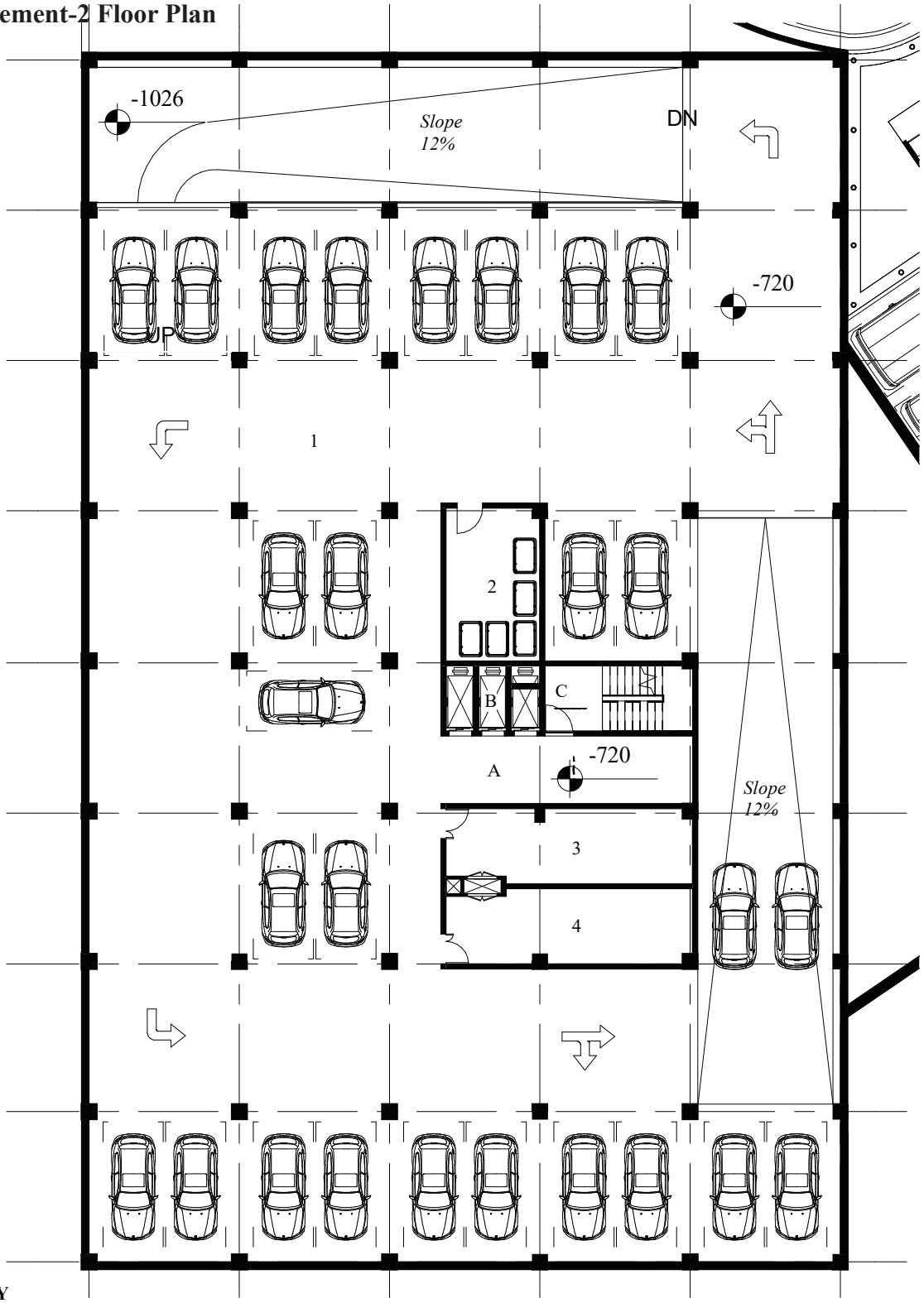
KEY

A. Lift Lobby
B. Lifts' & Chute shaft
C. Main Stair
1. Basement Parking
2. Battery Room
3. Ventilation Room
4. Equipment Store

Figure D1. Building proposal 3rd basement parking plan Scale 1 : 250

APPENDIX - D: Building Proposal Floor Plans and Sections

Basement-2 Floor Plan



KEY

A. Lift Lobby
B. Lifts' & Chute shaft
C. Main Stair

1. Basement Parking
2. Garbage Room
3. Main Telecommunication Room
4. Main Electrical Room

Figure D2. Building proposal 2nd basement parking plan Scale 1 : 250

APPENDIX - D: Building Proposal Floor Plans and Sections

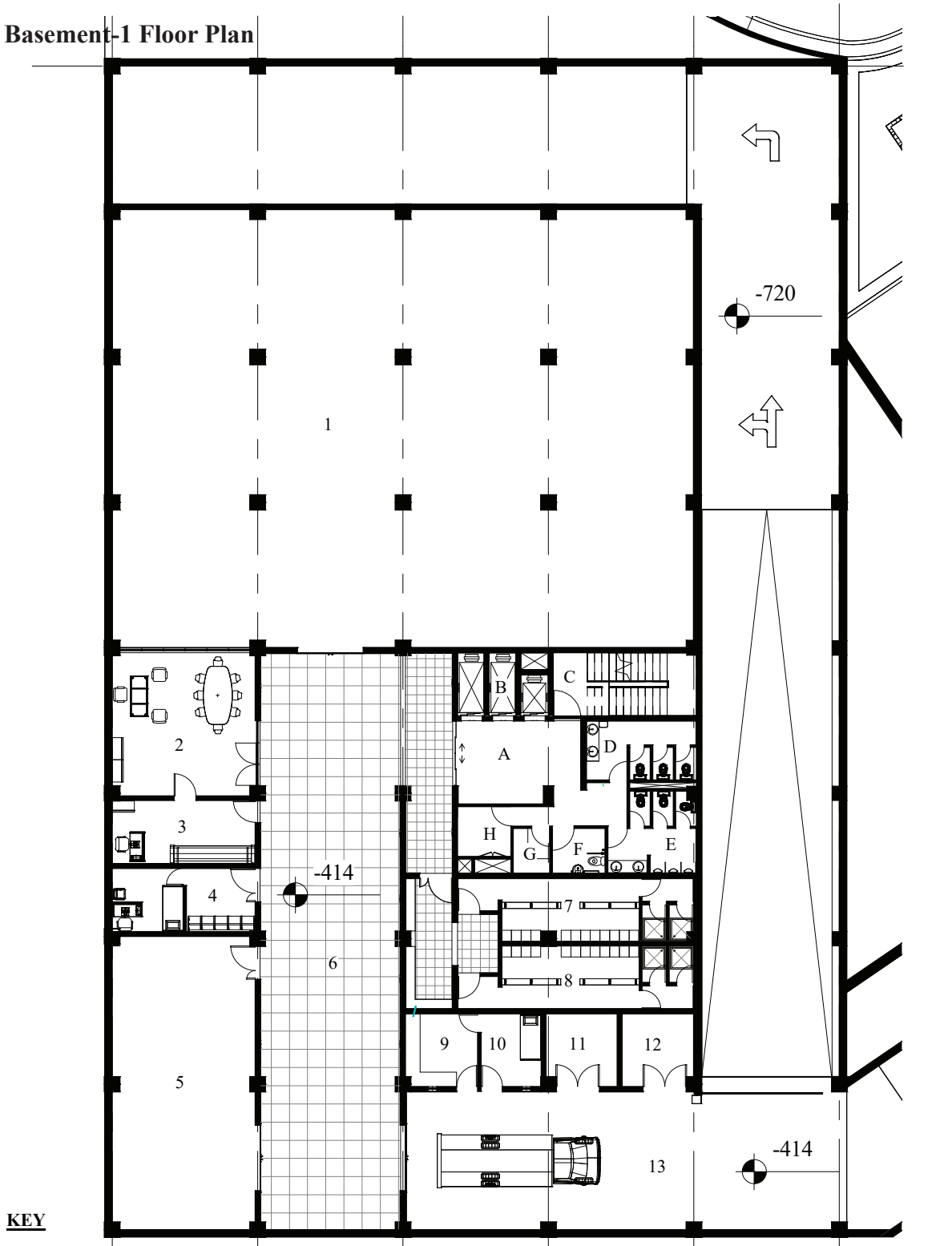
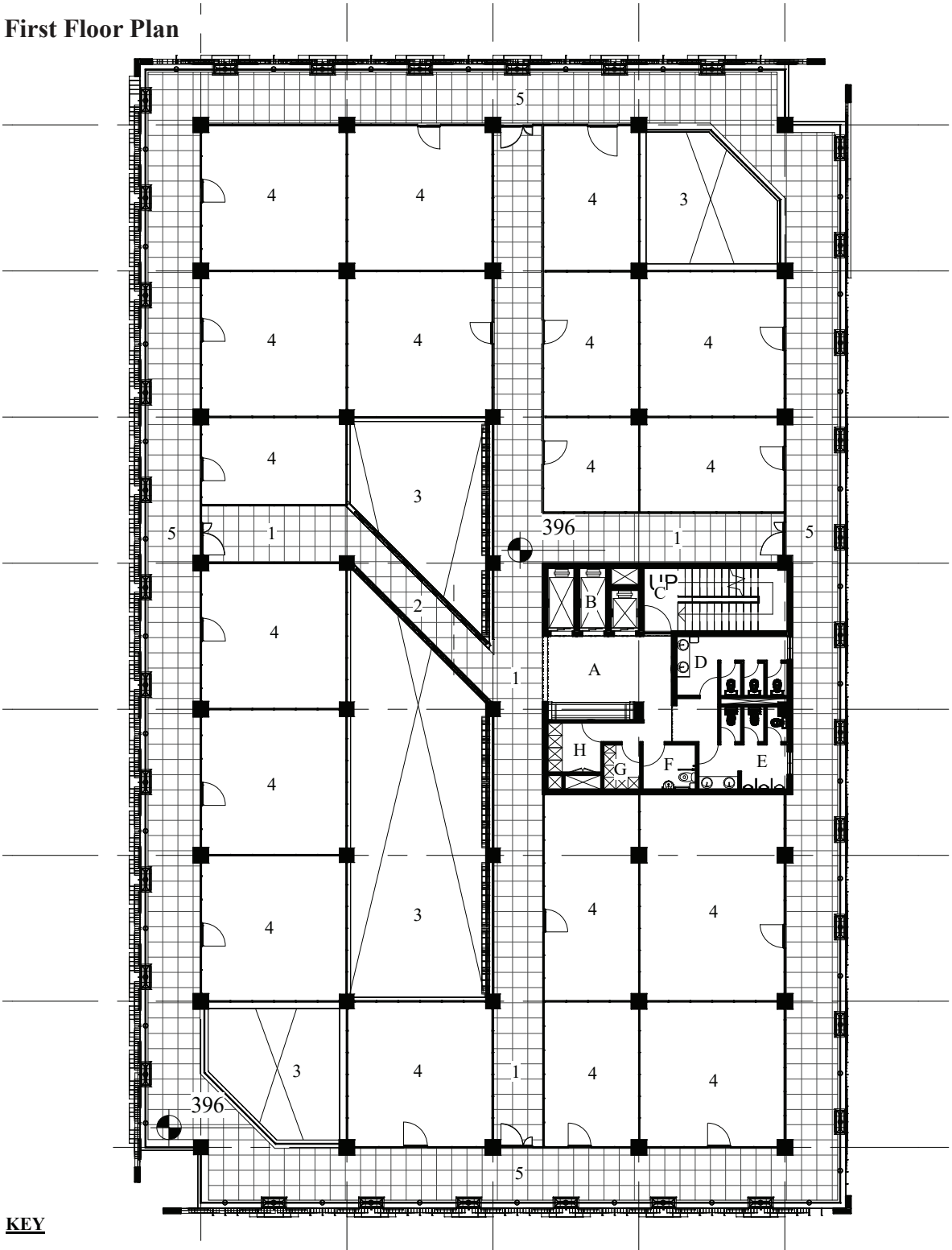


Figure D3. Building proposal Workshop plan Scale 1 : 250

APPENDIX - D: Building Proposal Floor Plans and Sections

First Floor Plan



KEY

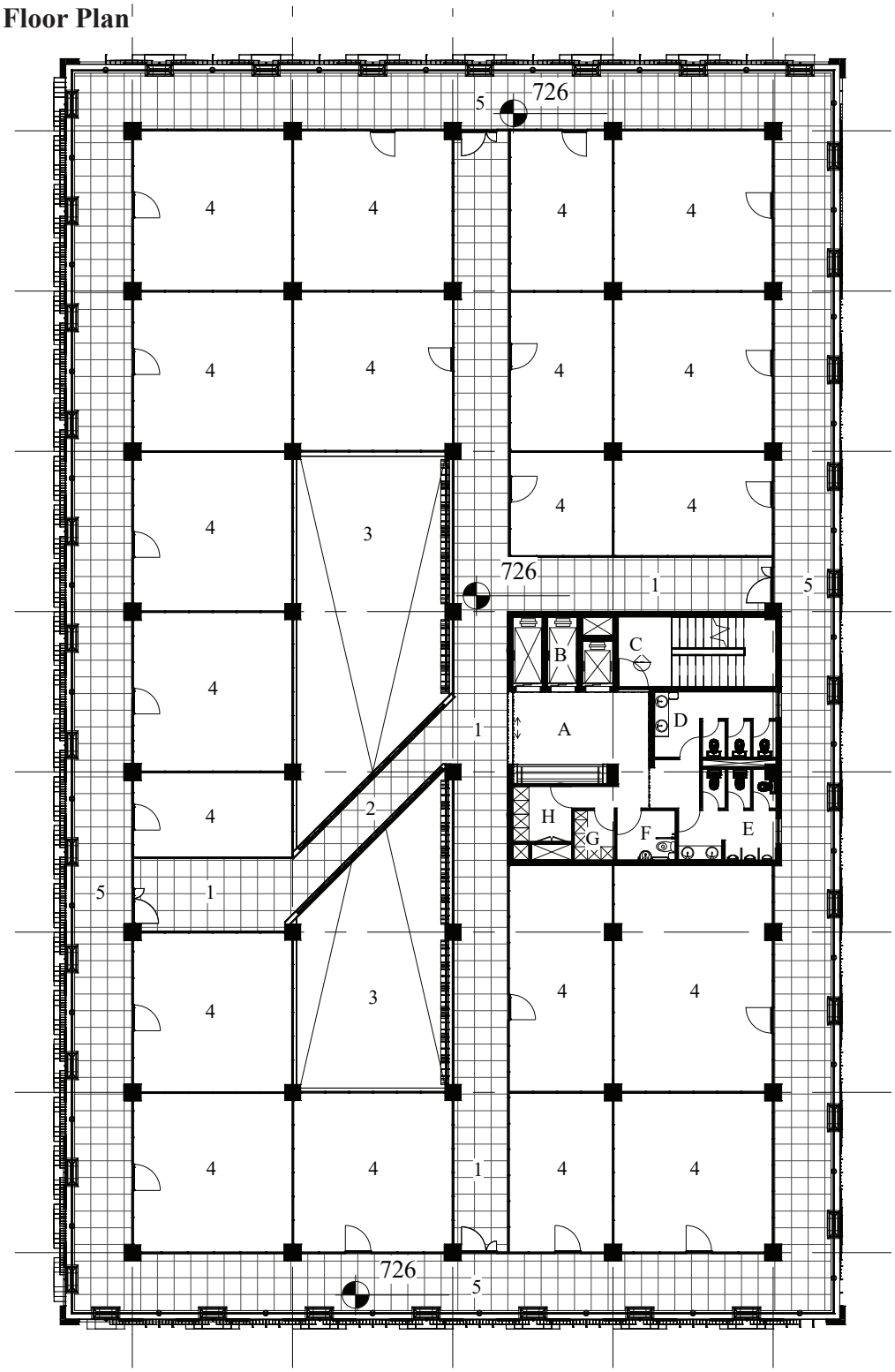
A. Lift Lobby	C. Main Stair	E. Gents' Room	G. Janitors' Room
B. Lifts' & Chute shaft	D. Ladies' Room	F. Physcally challenged ppl. Toilet	H. Service Room with H_2 Shaft

1. Internal Corridor	2. Atrium Cross Bridge	3. Void	4. Shop
5. Outdoor Corridor			

Figure D4. Building proposal 1st floor plan Scale 1 : 250

APPENDIX - D: Building Proposal Floor Plans and Sections

Second Floor Plan



KEY

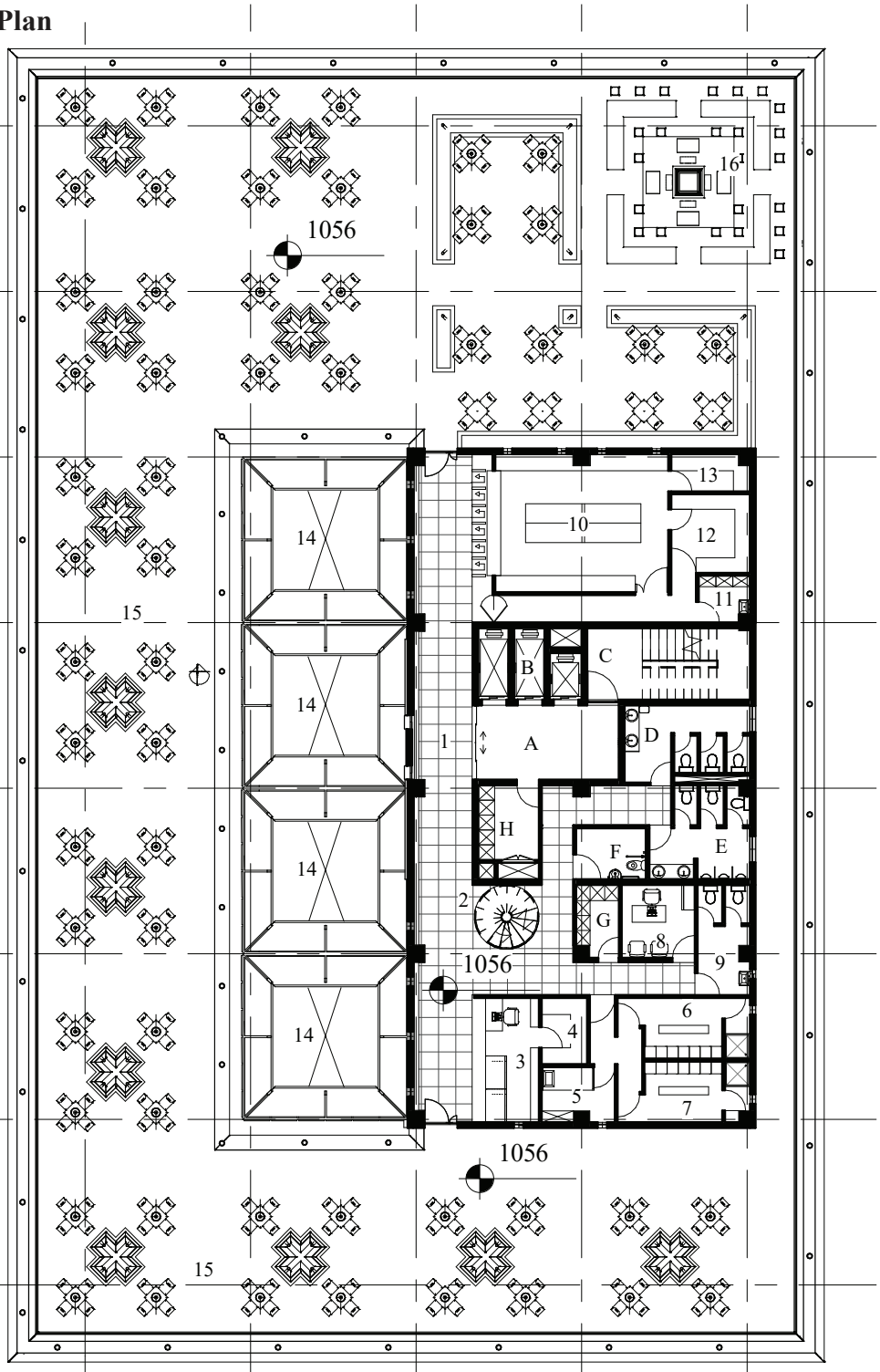
A. Lift Lobby	C. Main Stair	E. Gents' Room	G. Janitors' Room
B. Lifts' & Chute shaft	D. Ladies' Room	F. Physcally challenged ppl. Toilet	H. Service Room with H_2 Shaft

1. Internal Corridor	2. Atrium Cross Bridge	3. Void	4. Shop
5. Outdoor Corridor			

Figure D5. Building proposal 2nd floor plan Scale 1 : 250

APPENDIX - D: Building Proposal Floor Plans and Sections

Third Floor Plan



KEY

A. Lift Lobby	C. Main Stair	E. Gents' Room	G. Janitors' Room
B. Lifts' & Chute shaft	D. Ladies' Room	F. Physcally challenged ppl. Toilet	H. Service Room with H_2 Shaft

1. Internal Corridor	5. Staffs' Bed Room	8. Managers Office	11. First Aid Kit Room
2. Stair to Upper Resaurant	6. Females' Changing Room	9. Staff Toilet	12. General Store
3. Display	7. Males' Changing Room	10. Main Kitchen	13. Cold Room
4. Beverage Store			14. Void

Figure D6. Building proposal 3rd floor plan Scale 1 : 250

APPENDIX - D: Building Proposal Floor Plans and Sections

Tower Floor Plans Configuration

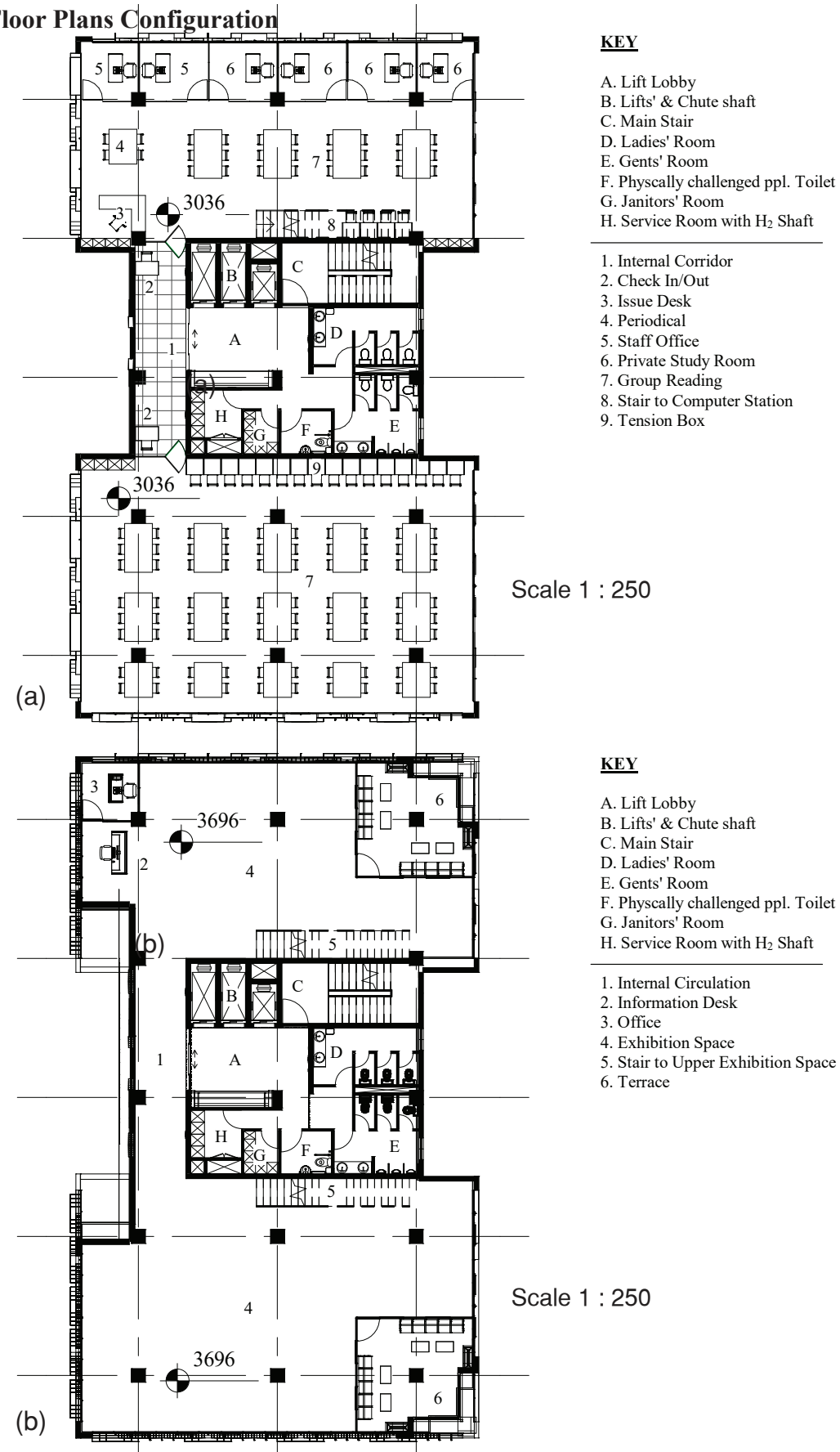
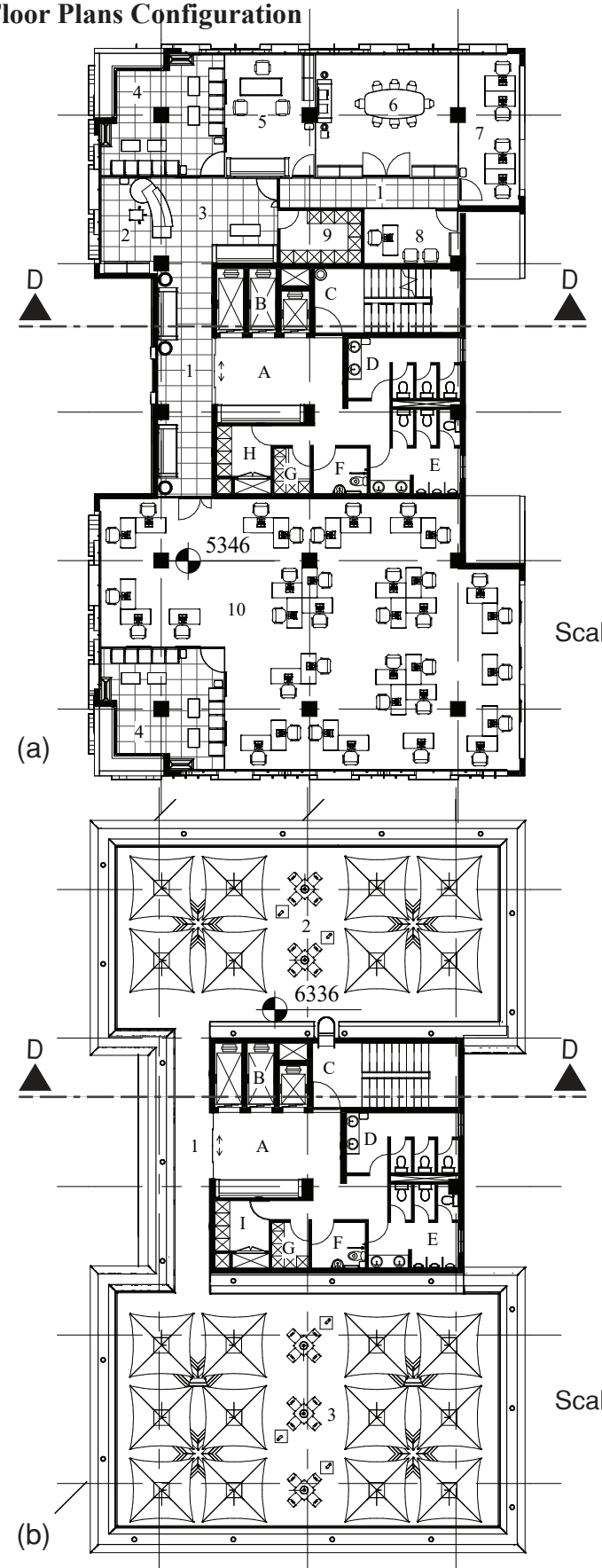


Figure D7. Building proposal floor plan (a)9th and (b)11th

APPENDIX - D: Building Proposal Floor Plans and Sections

Tower Floor Plans Configuration



KEY

A. Lift Lobby
B. Lifts' & Chute shaft
C. Main Stair
D. Ladies' Room
E. Gents' Room
F. Physcally challenged ppl. Toilet
G. Janitors' Room
H. Service Room with H_2 Shaft

1. Internal Corridor
2. Reception
3. Lobby
4. Terrace
5. General Manager's Office
6. Meeting Room
7. IT Department
8. Finance Office
9. Store
10. Work Pool

KEY

A. Lift Lobby
B. Lifts' & Chute shaft
C. Main Stair
D. Ladies' Room
E. Gents' Room
F. Physcally challenged ppl. Toilet
G. Janitors' Room
I. Control Room with H_2 Shaft

1. External Corridoor
2. North Wing Outdoor Seats
3. South Wing Outdoor Seats

Figure D8. Building proposal floor plan (a)16th and (b)19th

APPENDIX - D: Building Proposal Floor Plans and Sections

Section

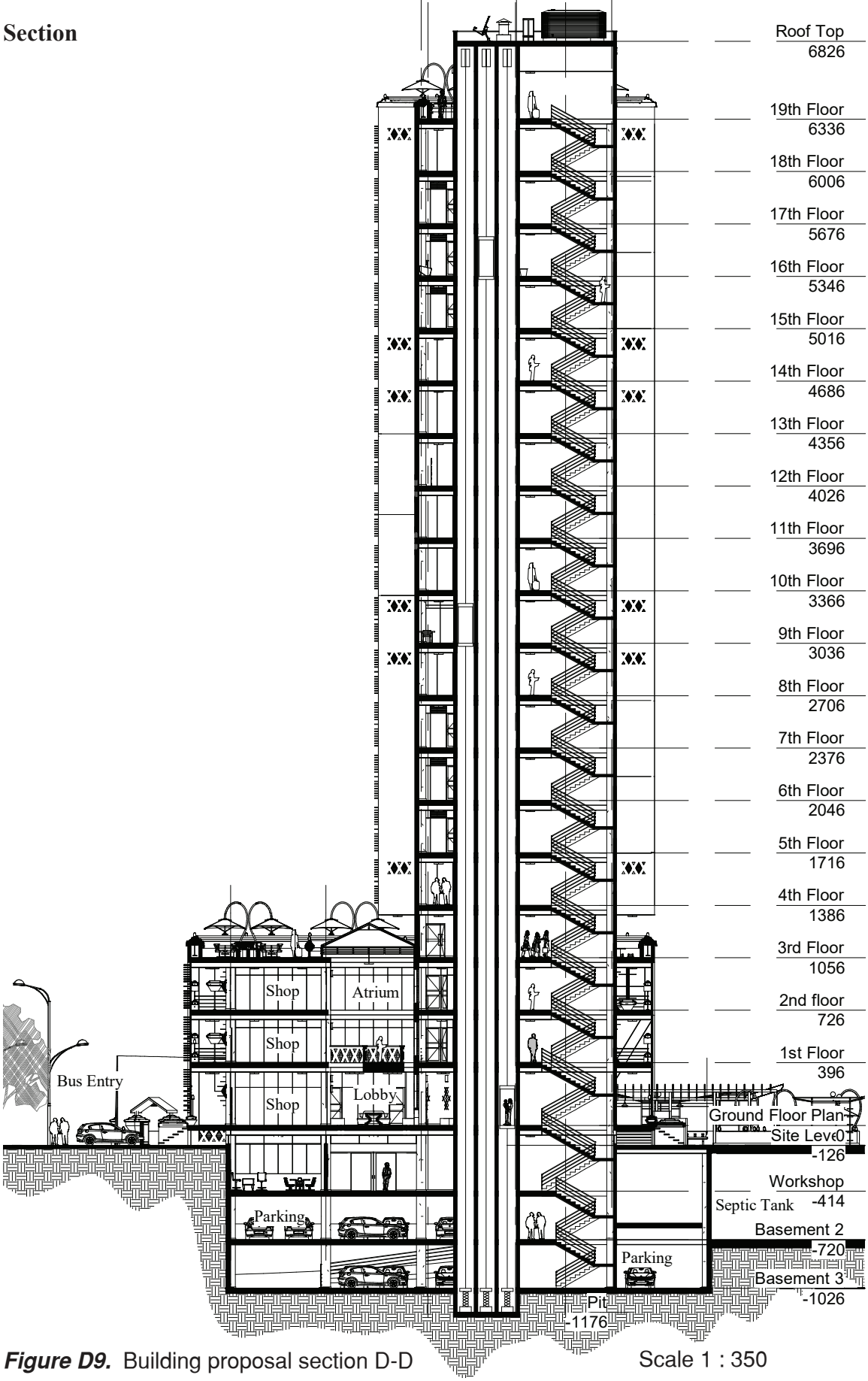


Figure D9. Building proposal section D-D Scale 1 : 350

APPENDIX - E

Site Utilities' Floor Plans and Sections

APPENDIX - E: Site Utilities' Floor Plans and Sections

Outdoor Triangular Shade (Scale 1:100)

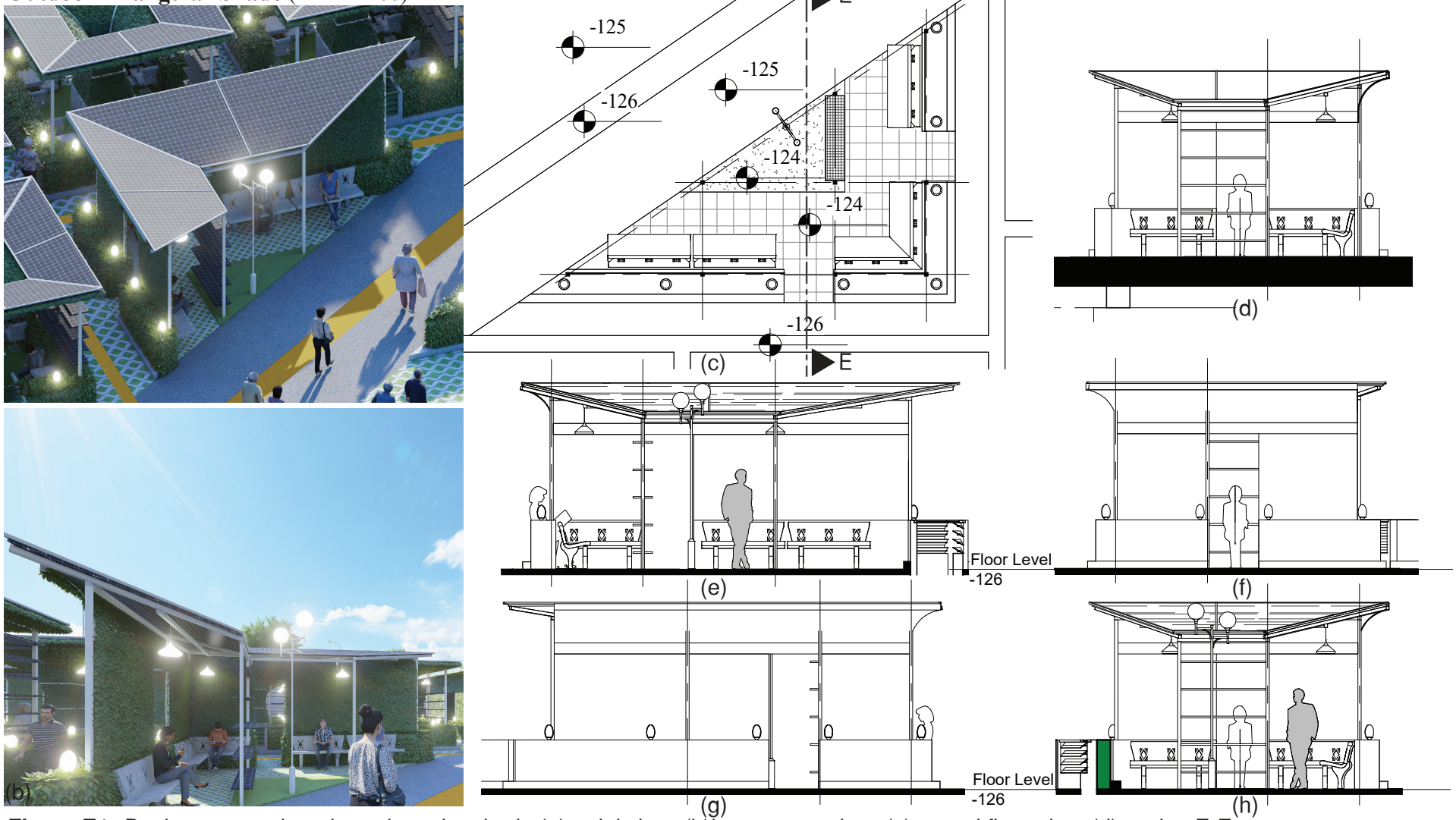


Figure E1. Design proposal outdoor triangular shade (a)aerial view, (b)human-eye view, (c)ground floor plan, (d)section E-E, (e)North elevation, (f)East elevation, (h)South elevation, and (i)West elevation

APPENDIX - E: Site Utilities' Floor Plans and Sections

Outdoor Rectangular Shade (Scale 1:100)

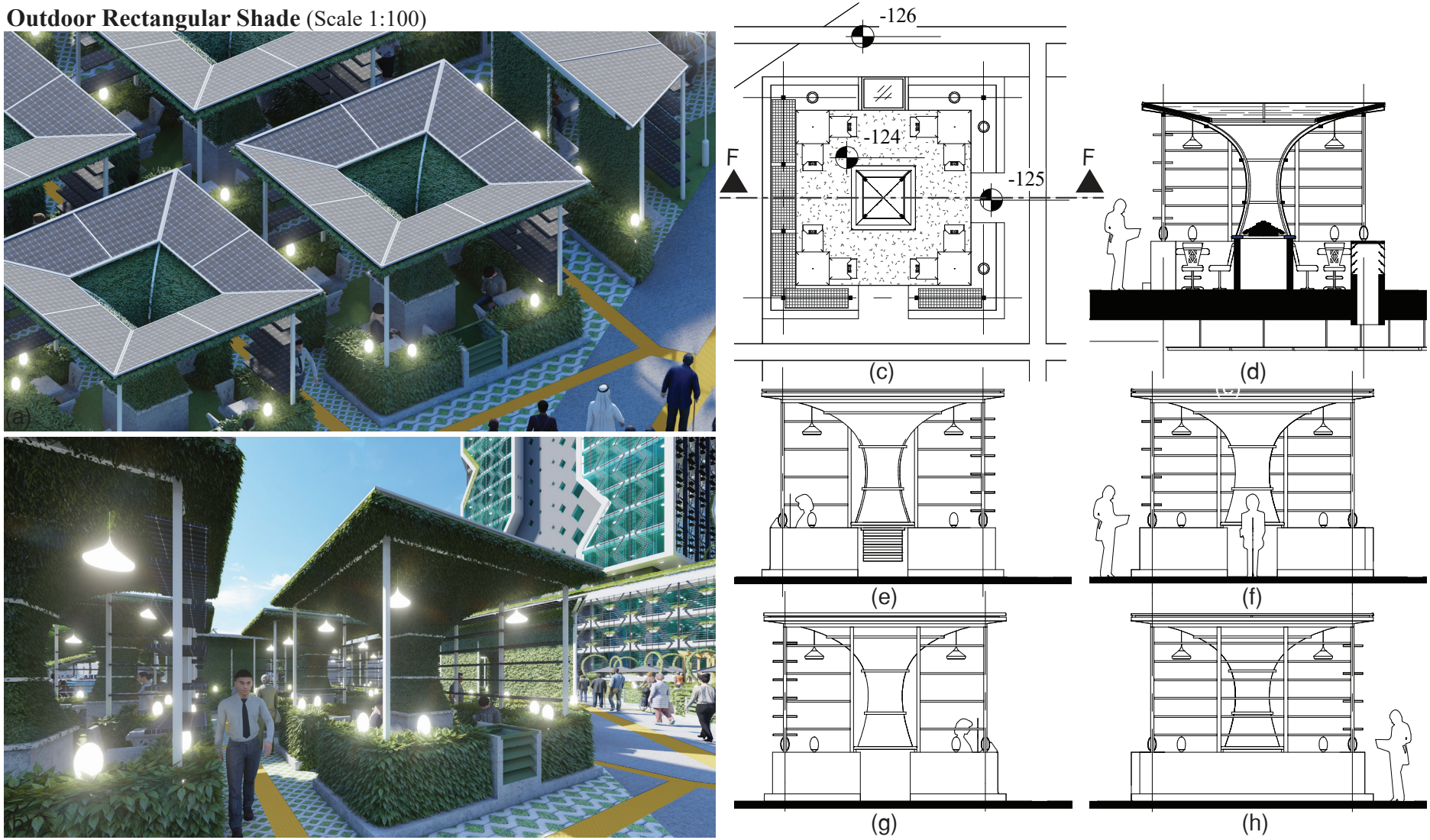


Figure E2. Design proposal outdoor rectangular shade (a)aerial view, (b)human-eye view, (c)ground floor plan, (d)section F-F, (e)North elevation, (f)East elevation, (h)South elevation, and (i)West elevation

APPENDIX - E: Site Utilities' Floor Plans and Sections

Site Kitchen (Scale 1:100)

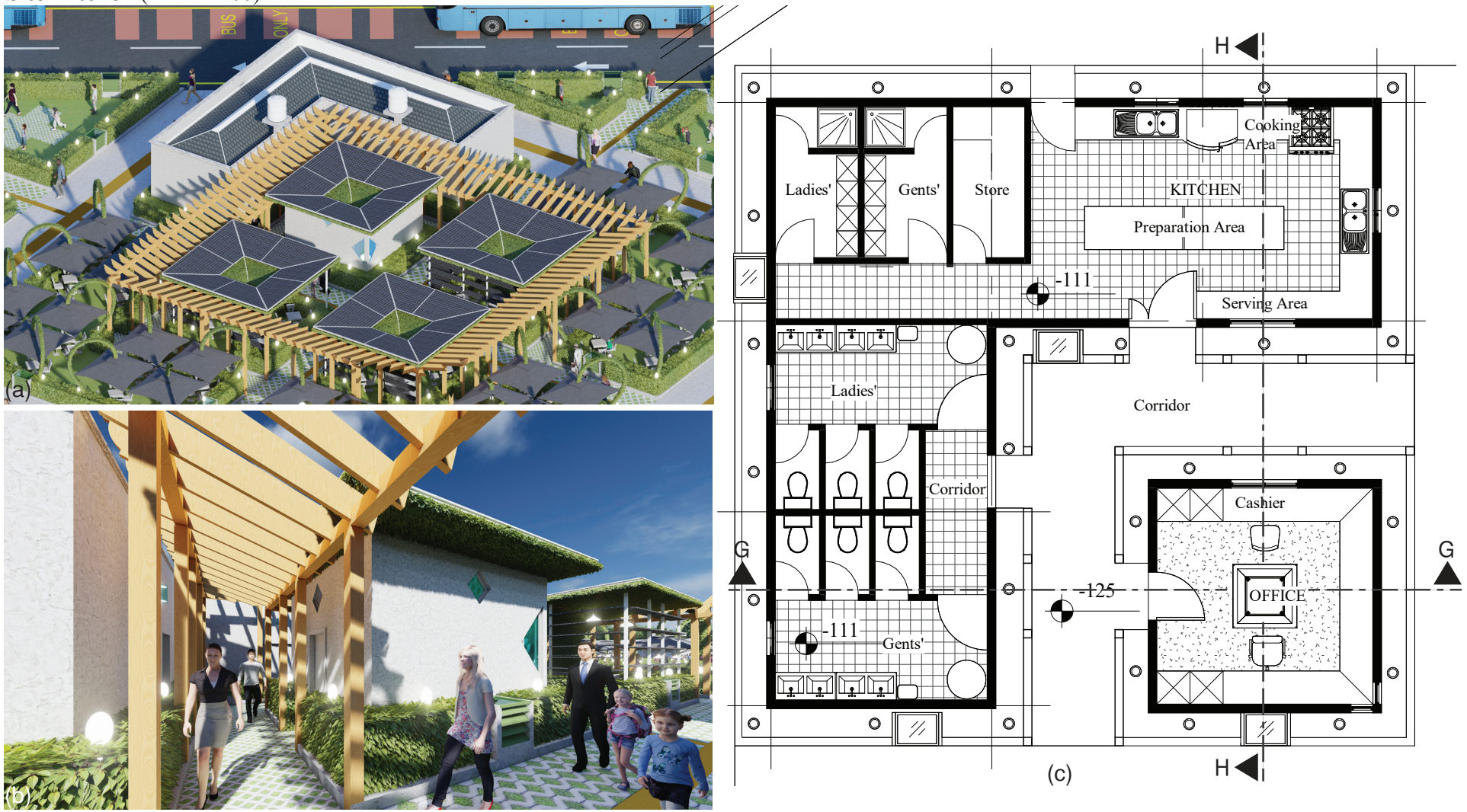


Figure E3. Design proposal site Kitchen (a)aerial view, (b)human-eye view, and (c)ground floor plan

APPENDIX - E: Site Utilities' Floor Plans and Sections

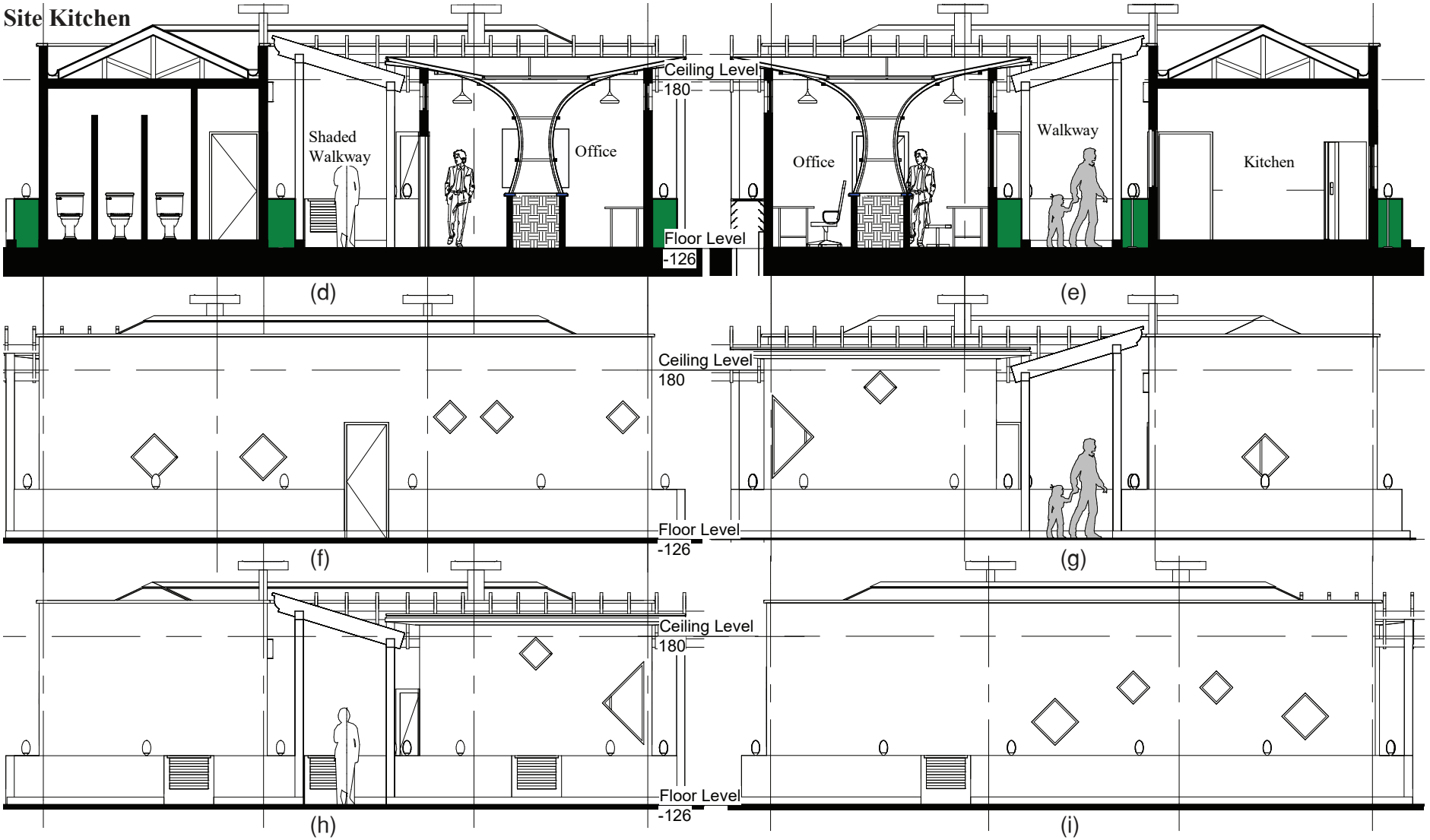


Figure E4. Design proposal site kitchen (d)section G-G, (e)section H-H, (f)North elevation ,(g)East elevation ,(h)South elevation, and (i)West elevation

APPENDIX - E: Site Utilities' Floor Plans and Sections

Public Toilet (Scale 1:100)

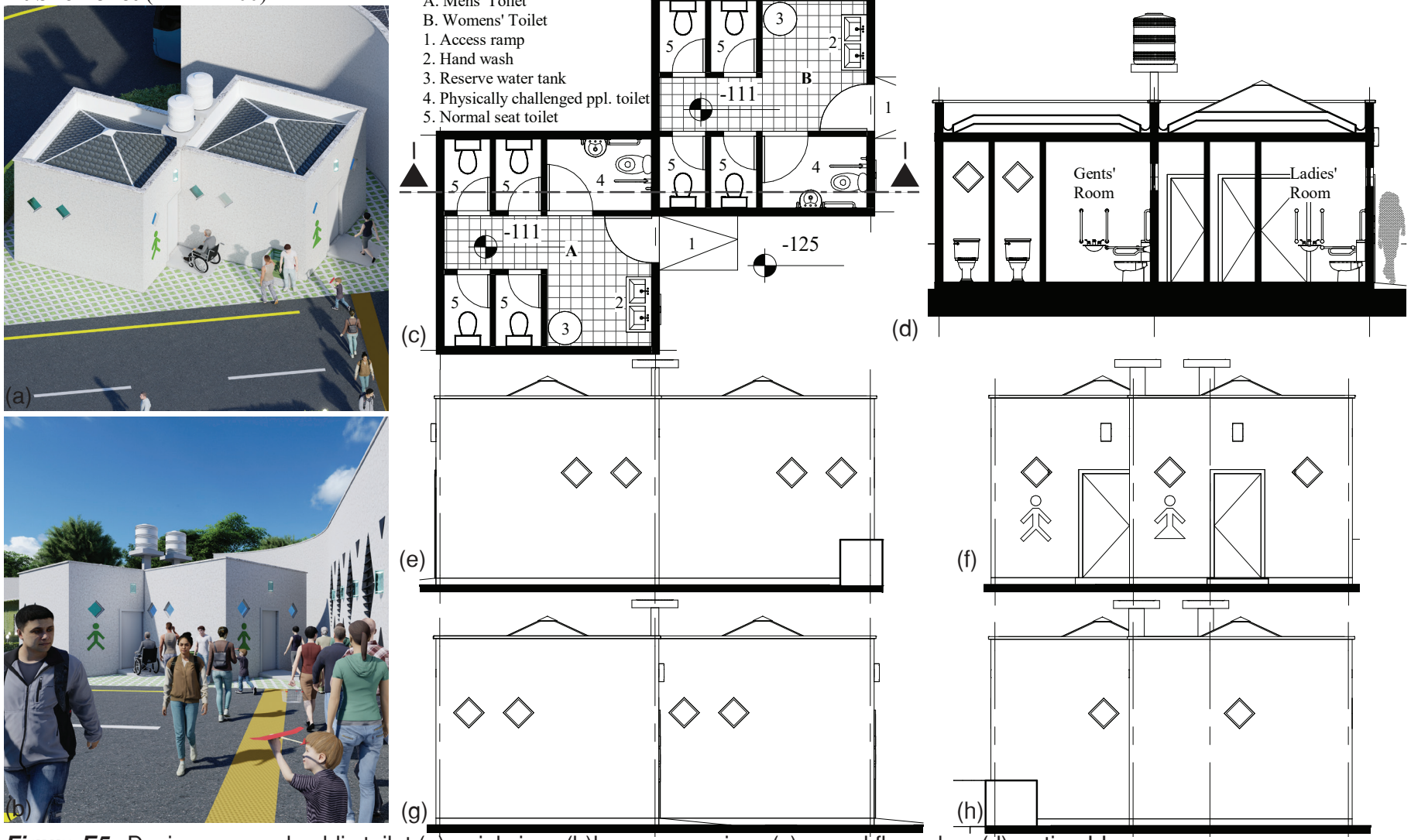


Figure E5. Design proposal public toilet (a)aerial view, (b)human-eye view, (c)ground floor plan, (d)section I-I , (e)North elevation, (f)East elevation, (g)South elevation, and (h)West elevation

APPENDIX - E: Site Utilities' Floor Plans and Sections

Guard House (Scale 1:100)



Figure E6. Design proposal guard house (a)aerial view, (b)human-eye view, (c)ground floor plan ,(d)1st floor plan, (e)section J-J , (f)North elevation, (g)South elevation, (h)East elevation, and (i)West elevation

APPENDIX - F

Suplementary Visualizations

APPENDIX - F: Suplementary Visualizations

Design Intervention Zoomed out Aerial Perspective



Figure F1. Strategic site design intervention urban aerial view

APPENDIX - F: Suplementary Visualizations

Building Proposal Human Eye Perspectives from Urban Surroundings



Figure F2. Building proposal view from (a) roundabout, (b)submerged driveway, (c)Federal bldg. entrance, and (d)construction site

APPENDIX - F: Suplementary Visualizations

Building Proposal Human Eye Perspectives from its Urban Surroundings & Streets



Figure F3. Building proposal view from (a)LRT lane, (b)LRT lane, (c)South-Eastern walkway street, and (d)Western walkway street

APPENDIX - F: Suplementary Visualizations

Building Proposal Entrance human Eye Perspectives



Figure F4. Building proposal view from (a)South-Western entrance, (b)North-Eastern entrance, (c)ground floor arcade, and (d)1st floor arcade

APPENDIX - F: Suplementary Visualizations

Building Proposal Interior human Eye Perspectives



Figure F5. Building proposal view from (a)South-Western main entrance, (b)North-Eastern main entrance, (c)Western entrance, and (d)the center of the main lobby to atrium skylight

APPENDIX - F: Suplementary Visualizations

Building Proposal Interior human Eye Perspectives



Figure F6. Building proposal's view of (a)workshop lobby, (b)main lobby reception, (c)1st floor atrium bridge, and (d)1st floor atrium bridge

APPENDIX - F: Suplementary Visualizations

Building Proposal Interior human Eye Perspectives



Figure F7. Building proposal's view of (a)2nd floor atrium corridor, (b)typical lift lobby, (c)typical office reception, and (d)typical office pool

APPENDIX - F: Suplementary Visualizations

Design Proposal Entrance human Eye Perspectives



Figure F8. Design proposal's view of (a)South-Eastern site edge entrance, (b)Southern side central entrance, (c)Southern side park entrance, and (d)Western side park entrance

APPENDIX - F: Suplementary Visualizations

Site Proposal Basement Entrance, Bus Parking and Exit Perspectives



Figure F9. Site proposal's view of (a) site basement entrance, (b)basement bus parking and driveway, (c)basement bus parking exit, and (d)site level bus exit

APPENDIX - F: Suplementary Visualizations

Proposed Park Paths Perspectives



Figure F10. Proposed park view (a)from Southern park edge path, (b)between rectangular shade structures, (c)of main entrance path, and (d)of central zone path

APPENDIX - F: Suplementary Visualizations

Proposed Park Paths Perspectives



Figure F11. Proposed park view from (a)Southern site edge exit, (b)Southern site central exit, (c)building side Southern edge park exit, and (d)building side Western edge park exit

APPENDIX - G

APPENDIX - G : Design Proposal's BIPV Organization and Sanitary Flow Diagram

APPENDIX - G : Design Proposal's BIPV Organization and Sanitary Flow Diagram

Design Proposal's BIPV Organization

As Addis Ababa is geographically located close to the equator, it receives more solar radiation throughout the year. Such radiation can be a valuable free resource that has the potential to be converted in to solar energy. Figure G1. shows the long term average distribution of direct normal irradiation and photovoltaic power potential of Ethiopia from 1994 - 2018. (Global Solar Atlas, 2019)

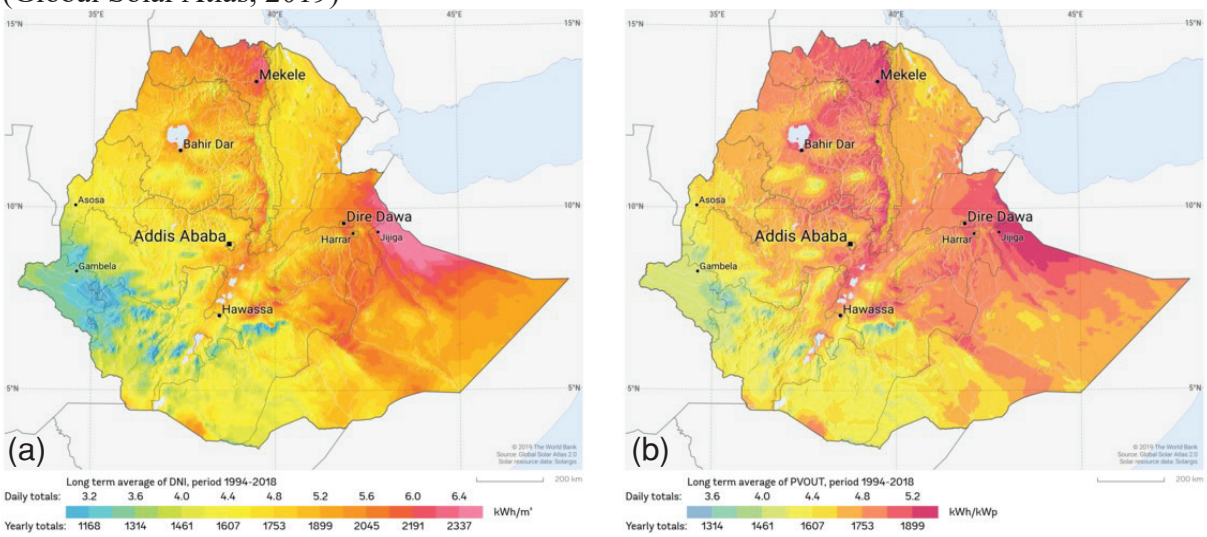


Figure G1. Solar exposure map of Ethiopia (a)direct normal irradiation map and (b)photovoltaics power potential (Source: globalsolaratlas.info)

The electrical system of the building and the site incorporates the solar energy harvested via photovoltaics adopted shadings to help minimize building energy demands. The shading devices are equipped with first generation monocrystalline solar cells for their high efficiency per square meter. (Tascroglu, A., et al., 2016). Considering the functional complexity of the proposed design, a grid-tied electrical system with a battery backup is proposed. Table G1. shows information on the type of monocrystalline phtovoltaic modules used, available surface area of solar panels and their orientations.

Type	**Building Adaptation**						**Site Adaptation**				
Orientations	**North**	**East**	**South**		**West**		**North**	**East**	**South**	**West**	**Top**
Shading orientation	Hor	Hor	Hor	Ver	Hor		Hor	Hor	Hor	Hor	Hor
Exposed PV surface	Single	Single	Single	Dual	Single		Single	Single	Single	Single	Single
Available PV surface(m2)	60.48	0	113.4	95.13	926.64		0	0	131	260	2061
PV Type	Mono crystal silcon	Mono crystal silcon	Mono crystal silcon	Mono crystal silcon	Mono crystal silcon		Mono crystal silcon	Mono crystal silcon	Mono crystal silcon	Mono crystal silcon	Mono crystal silcon
TOTAL AREA(PV)	**1195.65m2**						**2452m2**				
	3647.65m2										

Table G1. Information on adopted solar panels on proposed building and site

APPENDIX - G : Design Proposal's BIPV Organization and Sanitary Flow Diagram

Design Proposal's BIPV Organization Diagram

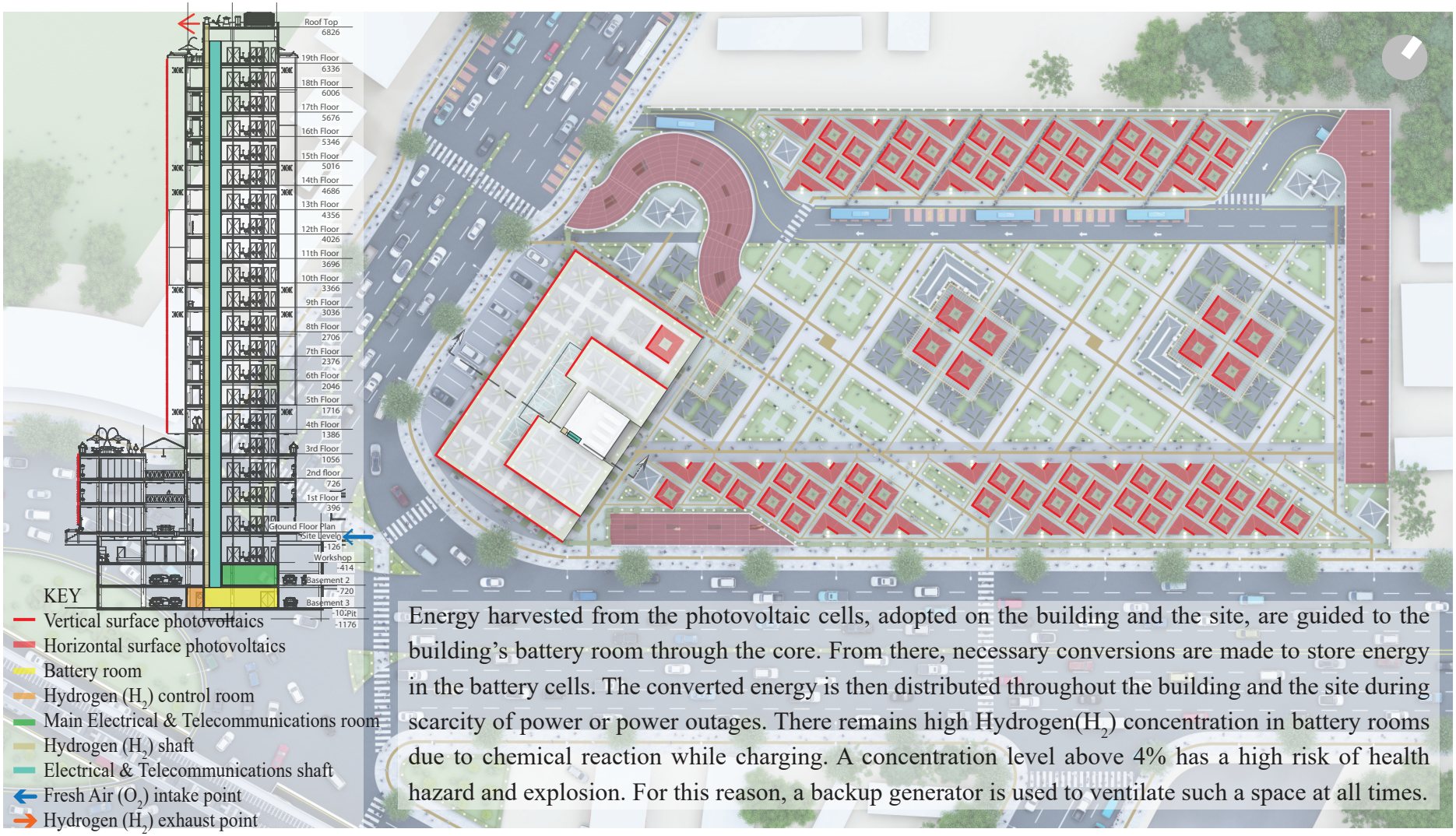


Figure G2. Design proposal's BIPV organization layout

APPENDIX - G : Design Proposal's BIPV Organization and Sanitary Flow Diagram

Sanitary Flow Diagram

The surface water drainage system comprises of open grill ditches and embedded perforated pipes. It is laid out in conjunction with the site slope and is guided out of the site at multiple points. The organizational layout is shown in Figure G3.

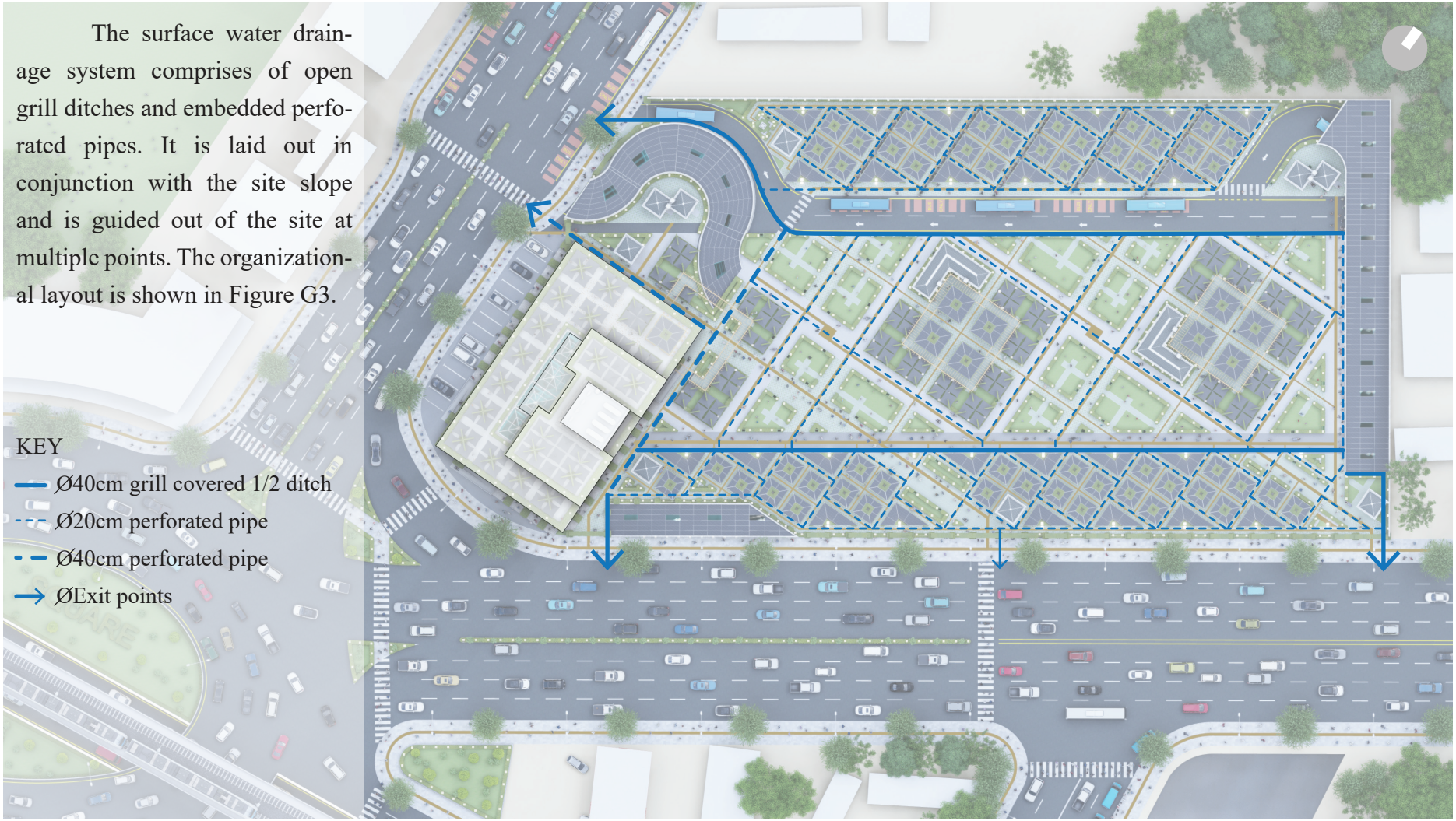


Figure G3. Design proposal's surface and rain water drainage layout

APPENDIX - G : Design Proposal's BIPV Organization and Sanitary Flow Diagram

Sanitary Flow Diagram

The sewage system comprises separate disposal systems for gray water and dark water wastes. Grey water from the building and site services is guided to the main road ditches whereas dark water waste is made to join the septic tank that is linked to the main road sewer system. The organizational layout is shown in Figure G4.

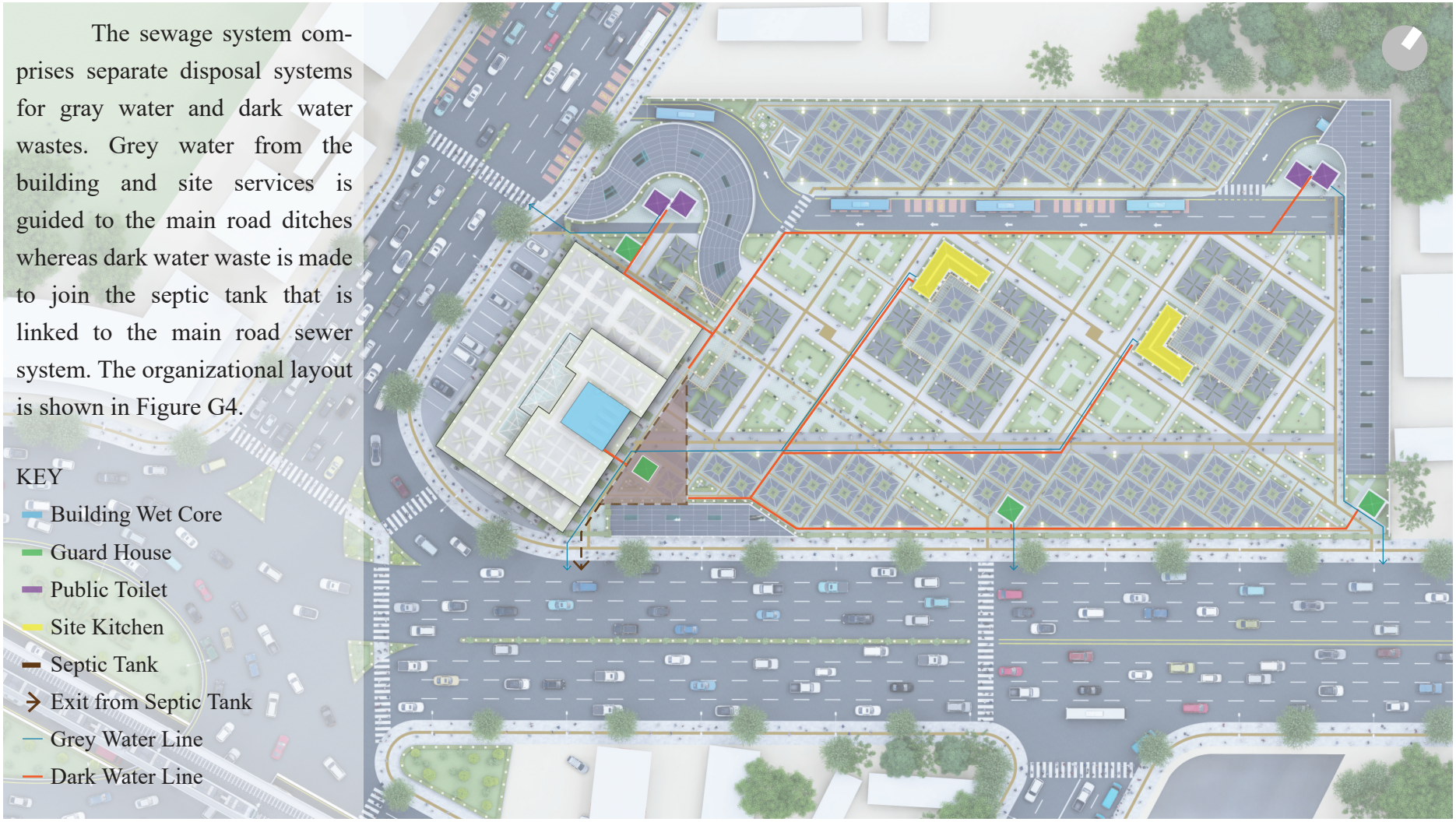


Figure G4. Design proposal's sewage drainage layout

ANNEX 1: Publishable Manuscript

Context Based Design and Performance of Fixed Exterior Shading Devices for Thermal Comfort in Addis Ababa

Fitsum Gebreyohannes Mulat

Abstract— With high incident solar radiation on the East-West building facades located especially in tropical climate regions like Ethiopia, the indoor spaces adjacent to glazed facades will become overheated. Among the various techniques of solar heat gain controls in the tropics, applications of fixed exterior shading devices play a major role in blocking incident solar radiation first hand. Through a descriptive research design, this study aims to investigate the effectiveness of such devices as a passive means of solar control as well as identify a context based shading approach that responds well during identified overheated periods in Addis Ababa. To this aim, investigations were conducted on full-glazed buildings that serve as library or office and used fixed exterior shading devices as a passive means of solar control. Questionnaires, secondary data and computer simulations were used to obtain quantitative data. These data were analyzed holistically to gain objective results. On the other hand, shading devices of selected case buildings were adopted and simulated for North, East, South, and West orientations on a mockup model to assess their performance. Their results were compared to a proposed shading design that based the identified overheated periods. This approach yielded a horizontal, Vertical, and End-profile shading angles of 82^0HSA, 65^0VSA and 38^0W EPA for North orientations, 65^0HSA, 83^0VSA and 60^0N & 55^0S EPA for East Orientations, 60^0HSA, 55^0VSA and 38^0W EPA for South Orientations, and 0^0HSA, 35^0VSA and 25^0N & 25^0S EPA for West Orientations. Proposed shadings using these shading angles were tested for each orientation on a mockup model. Simulation results showed an average shading of 57.4% North, 54% East, 75.7% South, and 84.2% West to be optimal. The results also showed a monthly total direct solar heat gain reduction ranging from 63.5KWhr/m^2 - 130.9KWhr/m^2 for zones facing North, 73.9KWhr/m^2 - 81.4KWhr/m^2 for zones facing East, 159.9KWhr/m^2 - 162.9KWhr/m^2 for zones facing South, and 159.9KWhr/m^2 - 108KWhr/m^2 for zones facing West. These findings can be used as shading design guidelines for radiation vulnerable glazed building facades in Addis Ababa and help improve thermal comfort.

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Index Terms— Fixed Exterior Shading Devices, Glazing, Shading Design, Simulation, Solar Control, Solar Radiation, Thermal Comfort

1 Introduction

1.1 Introduction

Addis Ababa has been undergoing rapid growth and change in the construction industry. Among the changes, the construction of highly glazed buildings intended for library or office use have been a notable occurrence. Highly glazed building envelops greatly contribute to the energy demand for users' comfort. According to a research conducted on the application of building energy saving measures in walls [1], the proper design and selection of building envelopes can help in saving 50–60% of the buildings' energy consumption used for cooling and heating purposes.

Among the various technological advancements in building skins, large windows and highly glazed facades have been increasingly used allowing access to daylight, solar gain and external view. However, this development has been constantly challenged by the existence of solar radiation especially in tropical climates thus causing high solar heat gain and indoor climate conditioning demands.

To tackle this challenge, different shading approaches have been developed. Among these, the use of exterior shading devices is preferred to block incident solar radiation first hand. Such devices block about 80 percent of the solar gain through clear windows as compared to internal shadings which are only about 20 percent efficient [2]. In addition to this, using exterior shading devices on less expensive glazing would sometimes yield a shading performance equivalent to unshaded higher performance glazing [3]. Besides being expensive, application of higher performance glazing as a means of solar control may result in blocking or changing the natural light spectrum all year round. So, fixed exterior shading devices remain a valid choice, aside from first hand solar protection, due to their ease of construction, maintenance and are cost effective solutions by design [2]. However, not all fixed exterior shading devices work in the same effectiveness. It is questionable which ones are preferable to others.

1.2 Background of the Study

Fixed shadings have been a prominent feature in the development of the architecture of buildings throughout history. In vernacular architecture, their design usually involved the use of locally accessible materials like clay, wood planks, concrete, tree branches and more to provide shade from solar radiation and other environmental situations [4]. In ancient Greek and Roman buildings, fixed shadings started out as porticoes and colonnades. Traditional designs around the world interpreted the Greek portico as porch, veranda (China), balcony, loggia, gallery, arcade and engawa (Japan) [2]. Since the early twentieth century, many great architects have understood the importance of shading and used it to create powerful visual statements. Of all architects, Le Corbusier was most closely linked with aesthetics based on sun shading. This came about in 1932 after he designed a multistory building in Paris called Cite' de Refuge with an all-glass south façade. He intended to allow as much sunlight as possible to warm and cheer the residents. In December, passive solar worked wonderfully. But in June, the building became unbearably hot. This made him realize the dual nature of the sun. As a result,

he invented the structural sunshade now known as brise-soleil (Sun breaker) [2]. In the traditions of modern architecture, glass facades had been an iconic trend in the architecture of buildings. They portrayed order, hygiene and advancement [5]. Building developments within the framework of this image made the involvement of fixed exterior shading devices less eminent. Consequently, this led to user discomfort and high building energy demand for air conditioning. Shortly after the energy crisis incident in 1973, the modern architectural movement started to show a keen interest in the application of passive design strategies. This revived the need for fixed exterior shading devices as a passive means of solar control for vulnerable glazed facades. Though such devices blocked solar radiation first hand, designing them required the fulfilment of certain context-based shading principles to provide optimal shading performance. In this regard, a notable development was contributed by Antony Sealey in 1979. In his journal of building climatology [6], he stated four major principles that should be considered for the proper design of fixed exterior shading systems. These principles remain adaptable for the climate context of any region as a passive means of solar control.

In the case of Addis Ababa, different applications of fixed exterior shading devices have been seen on different building facades over the years. Since they apply different design and employment techniques, their shading performance would vary as well. Therefore, to achieve an optimal context based shading performance, it is necessary to incorporate context based shading principles during design and implementation of such devices. As such, this study navigates through the major principles required for proper shading design and test a context-based proposal shading for the climate context of Addis Ababa.

1.3 Problem Statement

It is believed to be best practice that radiation vulnerable full-glazed library or office buildings aim at implementing suitable fixed exterior shading approaches that best respond to undesired heat gain periods of a geographic location. However, lack of overheated period-based application of such devices limits their efficiency in responding to undesired solar heat gain periods. This results in high solar heat gains and rise in indoor temperature.

1.4 Objectives of the Study

1. **General objectives**

The objective of this thesis is to assess the effectiveness of fixed exterior shading devices as a passive means of solar control for radiation vulnerable full-glazed library or office buildings in Addis Ababa. Furthermore, it also aims to identify a context based fixed exterior shading approach that responds well during identified overheated periods.

2. **Specific objectives**

- Mapping full-glazed library or office buildings that have fixed exterior shading devices attached.
- Assessing occupant's thermal satisfaction in the mapped case buildings.
- Identify a context based shading approach for implementing fixed exterior shading devices for radiation vulnerable full-glazed facades.

1.5 Research Questions

1. **Main question**

In the case of Addis Ababa's climate, what kind of fixed exterior shading approach is suitable to block undesired solar heat gains through radiation vulnerable full-glazed facades?

2. **Specific questions**

In the climate context of Addis Ababa,

- Which types of fixed exterior shading devices are implemented for full-glazed library or office buildings?
- Which periods of the day and year feel overheated for users?
- Which orientations and which fixed exterior shading approaches work best together?

1.6 Scope and limitation of the study

This paper solely focuses on radiation vulnerable full-glazed library or office buildings in Addis Ababa that have employed fixed exterior shading devices as a passive means of solar control and achieve indoor thermal comfort. In this regard, it covers an assessment of the efficiency of fixed exterior shading devices in reducing daily solar heat gains on exposed case buildings. However, this research is limited to assessing solar energy inputs and gains while other factors that affect acceptable indoor thermal comfort are not considered.

1.7 Significance of the study

As of current trends, in the climate context of Addis Ababa, the construction industry has been leaning towards adopting glazing systems as a preferred façade approach. With regards to users' thermal comfort they provide, the drawbacks of such systems have been noticed on many buildings that are fully glazed and are highly vulnerable to solar radiation. In response, different shading approaches have been in play on some full-glazed building facades as a means of solar control. Among these, it is a fact that fixed exterior shading devices remain a valid choice to block incident solar radiation first hand. In this regard, this study will shed a light on the importance of a context-based application of fixed exterior shading devices for glazing systems as passive means to regulate solar heat gains and contribute to indoor thermal comfort. Furthermore, findings of this research can be used as guidelines for academic purposes, policy makers, professionals and researchers.

2 Literature Review

2.1 Solar Radiation

The sun emits electromagnetic radiation. This radiation is divided in to different wavelength bands based on intended fields of application. Solar radiation is expressed by shortwave while other wavelengths are in the longwave category. This radiation, after reaching the earth's surface, will have two components; Beam radiation which has a well-defined direction and Diffused radiation which is scattered in the earth's atmosphere. Solar radiation reaching the earth's surface is measured in Irradiance or Irradiation [7].

2.2 Solar Movement Identification

According to a journal of building climatology [6], there are five ways to determine the sun's position. Namely; calculations, computer programs, tables, experimental methods and sun-path diagrams. Among these, sun-path diagrams are the popular choice due to their simplicity. There are two projection types used to obtain sun-path diagrams.

Orthogonal projection - is the projection of the hemisphere on to a horizontal circle and is mostly used to visualize the sun's trajectory across the sky.

Stereographic projection -. is the projection of the hemisphere on to a vertical surface. This is more useful for analyzing shading angles, glare and diffused light from the sky. The most widely used sun path diagram is the stereographic chart.

2.3 Thermal Comfort and its Parameters

According to ASHRAE 55[8]., thermal comfort is defined as the state of the mind that expresses satisfaction with the thermal environment and is affected by two factors.

Personal factors – include clothing insulation and metabolic rate.

Environmental factors – include humidity, air speed, air temperature and radiant temperatue.

2.2 Glazed Facades

Generally, the installed areas of windows and glass facades have increased in new buildings in recent years. This may be attributed to allowing adequate daylight access, external view and solar heat gain through transmitted radiation. The most influencial factors that determine the scale of transmitted radiation are; the intensity and amount of the solar radiation avilable, the exposed skin area, the orientation of the building skin and the skins thermal characterstics. The ammount of solar energy gained through a glazed façade could reach up to 85% of the incident radiation [9].

2.3 Solar Control

Solar radiation plays a vital role in causing thermal discomfort and high energy demand for conditioning indoor spaces. Due to this fact, an efficient sun shading system that is capable of reducing solar radiation is required for windows and glass facades. Such systems can be classified as internal, external or mid pane based on location [10], where as active or passive based on movement [11]. Active design strategies are basically comprised of heating and cooling systems, whereas passive approaches consider orientation of buildings, window to wall opening ratios, material adaptations, adequate light admissions and make use of natural ventilation advantages. In doing so, contribution to reduced heating and cooling systems can be achieved through maintaining a balance between hot or cold air in indoor environments. For this reason, passive design approaches remain designer's first choice to improve a building's energy efficiency prior to implementing active systems [12]. On the otherhand, implementation of active shading systems requires high level of engineering, skilled labor, building energy, high initial cost and proper maintenance all of which are challenging prerequisites in the context of developing countries.

Generally, there are three types of fixed exterior shading devices used namely vertical, horizontal and egg-crate.

According to a journal of building climatology [6], the design of shading systems requires four major steps.

1. Determining when shading is required.
2. Determining the sun's position when shading is required.
3. Determining the dimensions and proportions of shading devices that respond to the identified periods.
4. Considering aesthetical and structural factors.

2.4 Tools for Shading Systems Analysis

There are various simulation tools that have been developed till date to assess and make informed design decisions regarding energy performance of buildings during pre-design, design and construction phases. It often becomes overwhelming for professionals to choose among a list of these tools. Many scientific studies have been conducted to help identify the needs of different users versus tool capabilities and limitations in order to facilitate the selection process for architects and engineers. According to a study by Shady Attia and others [13], identification of user requirements, selection criteria for building performance simulation (BPS) tools and online survey of inter-group comparison between architects and engineers was conducted. Simulation tool parameters like accuracy, usability, and interoperability were considered the most important by architects and engineers. Popular and validated building energy simulation tools can be found listed on the U.S Department of Energy's (DOE) Building Energy Software Tools directory (BEST). Some of the most well-known simulation tools that are used for assessing building energy performance are shown in Fig. 1.

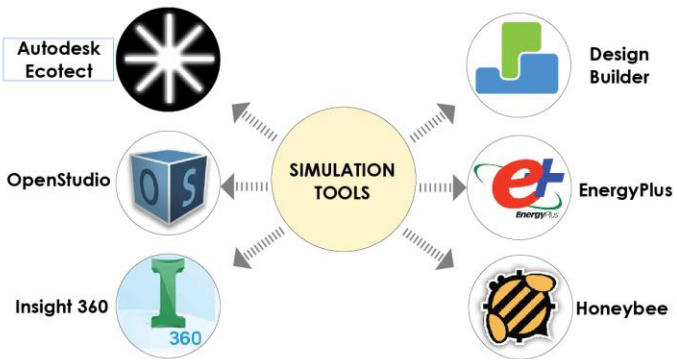


Fig.1. Popular building energy simulation tools

3 RESEARCH METHOD

This research is conducted through the help of knowledge gained from different journals, international case and prior studies, and investigation of local case buildings. Careful observation and analysis are made on local case buildings in Addis Ababa using different scientific methods.

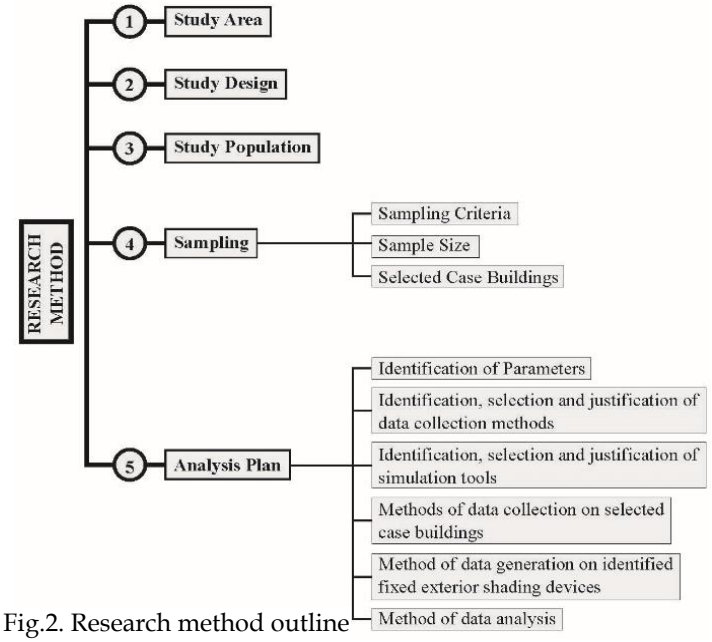
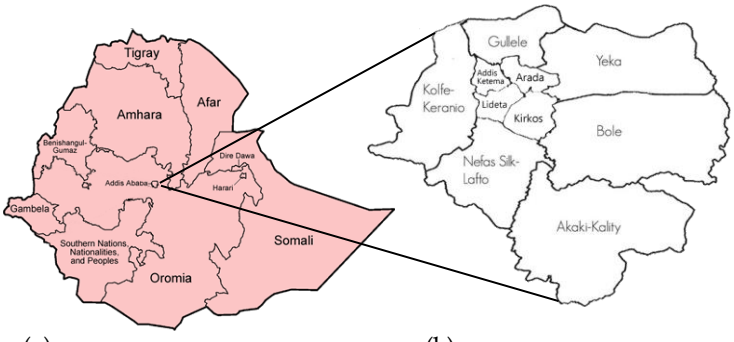


Fig.2. Research method outline

3.1 Study Area

The research focuses on the city of Addis Ababa as it has been undergoing big developments and transformations in the construction industry the past few decades. Among many developments, the rises of full-glazed office buildings with different fixed exterior shading devices are well observed. These buildings are located in different sub cities and different orientations thus making Addis Ababa the focus of study.



(a) (b)

Fig. 3. Location (a)map of Ethiopia and (b)map of Addis Ababa

3.2 Study Design

There are a number of scientific approaches which could be used to solve a specific problem. This research opts for a descriptive research study design as it tries to identify an existing problem and proposes a suitable approach to provide a scientific solution.

3.3 Study Population

The type of study population may vary from research to research depending on the problem and objective of the study. In this case, the study populations considered are library or office buildings in the city of Addis that have radiation vulnerable full-glazed facades with fixed exterior shadings attached.

3.4 Sampling

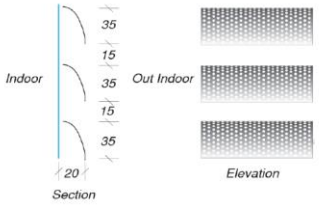
Sampling is a process of selecting a number of study units from a clearly defined study population [14]. In this research, the study population refers to full-glazed buildings intended for library or office use. These buildings are selected based on a sampling criterion.

1. **Sampling criteria-** The case buildings in Addis Ababa are chosed depending on the following criteria.
   - Either serve as a library or an office.
   - At least be occupied for a year.
   - At least have one vulnerable full-glazed façade.
   - Have fixed exterior shading device as solar control.
2. **Sampling size-** in a scientific investigation, identifying sample size is important especially when the study population is vast. In this study, since the identified case buildings are numbered and manageable, all are considered.
3. **Selected case buildings-**during sampling process of office buildings, there were different types of buildings with fixed exterior shadings attached. A sample image of the selected case buildings with a layout of shading they implemented is provided.



(a)

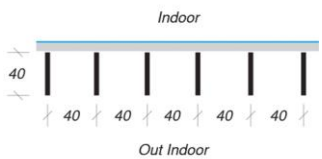
Building Information
. Location: Bole road Africa avenue
. Function: Office
. Stories: 13
Shading Device Information
. Material: Aluminum
. Type: Horizontal
. Location: East, South and West
Shading Layout (in cm)





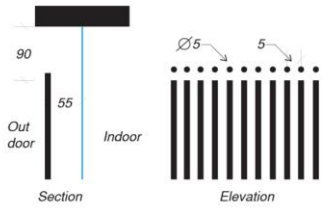
(b)

Building Information
. Location: Mesqel Square
. Function: Office
. Stories: 11
Shading Device Information
. Material: Coated Metal
. Type: Vertical
. Location: East, South and West
Shading Layout (in cm)

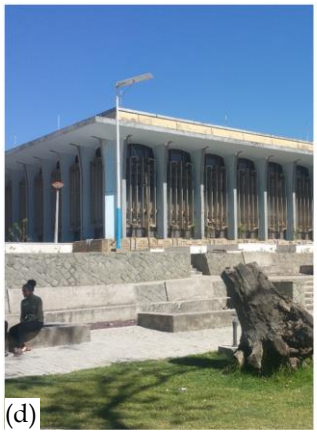




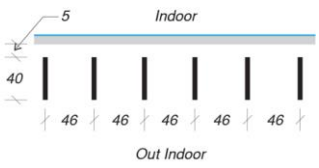
Building Information
. Location: Jemo
. Function: Library
. Stories: 1
Shading Device Information
. Material: Bamboo
. Type: Vertical
. Location: East
Shading Layout (in cm)



(c)



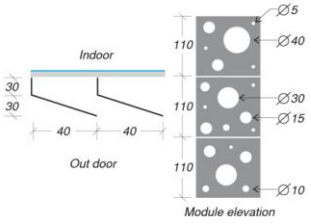
Building Information
. Location: 6 Kilo
. Function: Library
. Stories: 2
Shading Device Information
. Material: Aluminum
. Type: Vertical
. Location: North, East, South and West
Shading Layout (in cm)



(d)



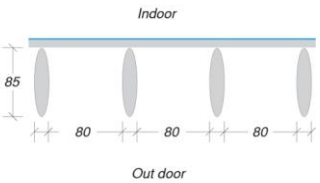
Building Information
. Location: Megenagna
. Function: Bank and meeting hall
. Stories: 15
Shading Device Information
. Material: Aluminum
. Type: Vertical
. Location: North
Shading Layout (in cm)



(e)



Building Information
. Location: Stadium
. Function: Head quarter Office
. Stories: 23
Shading Device Information
. Material: Aluminum
. Type: Vertical
. Location: East and West
Shading Layout (in cm)



(f)

Fig. 4. Selected case buildings (a)Africa Insurance, (b)Finfine building, (c)Henk de pagter ligrary, (d)Kennedy library, (e)Renaissance building, and (f)Wegagen bank head office

3.5 Analysis Plan

In this research, analysis of the selected case buildings is conducted in five ways.

1. **Identification of parameters-** variables are identified and categorized in to three.
   - **Dependent-** includes shading device type, length and orientation and Indoor temperature.
   - **Independent-** includes solar radiation
   - **Constant-**includes glazing type, floor level. Heat and shade form surrounding elements, glare, roomsize, construction materials, indoor colors, window sizes and orientations
2. **Identification, Selection and Justification of Data Collection Methods –** In a scientific study, data could be collected:
   - **Qualitatively-** requires intimate relationship between the research, researched and situational circumstances. Analysis is made while collecting data [14].
   - **Quantitatively**- Favor systematic and scientific investigation of quantitative properties and relationships. Analysis is made after collecting data [14]. In relation to this research, the most popular methods used are real simulation, Experimental, questionnaires, case study, and computer simulations [14]. Due to time and budget limitations, this research will be limited to questionnaires, case studies and computer simulations to obtain objective data.
3. **Identification, Selection and Justification of Simulation Tools-** Referring to a study done by Shady Attia and others [13], the most important parameters that architects and engineers focus on are found to be, usability and graphical visualization of the interface, accuracy of the tool and interoperability of building model. Taking these aspects into consideration, Autodesk Ecotect software is used for simulation.
4. **Methods of Data Collection on Selected Case Buildings**
   According to the data collection methods assessment made, objective data is gathered through;
   - **Questionnaires-** are prepared for users of the selected case buildings in accordance to ASHRAE standards for thermal comfort.
   - **Measurements on case buildings' shading devices-** Necessary measurements are taken on the selected case buildings. These include location, orientation, height, shading type, shading material and layout. Such details of the buildings supported by pictures are already discussed under the "Selected Case Buildings" Topic.
5. **Method of Data Generation on Identified Fixed Exterior Shading Devices**
   - **Computer simulations**- There are different external shading devices in different orientations. This method helps assess the efficiency of selected fixed exterior shading devices and drive quantitative data for anal-

ysis. For this purpose, a "Mockup" Model is used. It is an example room that helps to simulate different shading systems on different orientations. A model unit of 7.5x7.5x3 meters is proposed. The length and width of the model unit is the same to provide equal exposed surface for North, East, South and West orientations. Its height is limited to three meters to depict an average clear height of a typical workspace. To assess the efficiency of the shading devices, annual solar access analysis and monthly solar heat gain analysis are conducted on the four major orientations. This would help compare and analyze how they perform during overheated periods throughout the year. Fig.5 shows a mockup model in Ecotect set for the geographical location of Addis Ababa.

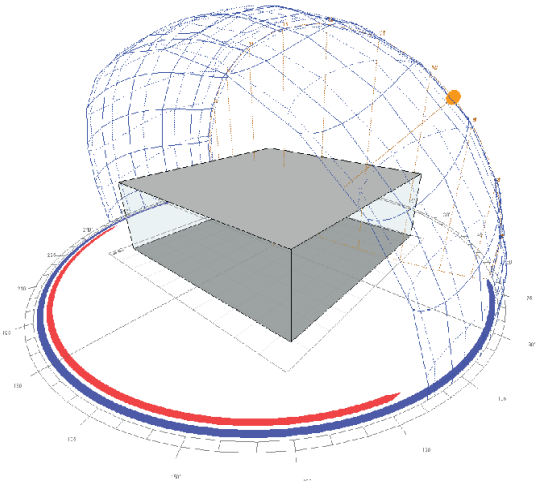


Fig.5. Mockup model in Autodesk Ecotect software

Mockup procedure

1. Modeling the identified fixed external shading types for Mockup use.
2. Simulating a bare Mockup model for initial result. The simulations are annual solar access analysis and thermal analysis.
3. Simulating each shading device on each major orientations of the mockup.
4. Conducting comparisons and discussions on the results of each orientation. North, East, South and West orientations are considered here.
5. Proposing an optimal sun shading approach based on weather data of Addis and testing it on the mockup. This is done for North, East, South and West orientations.
6. Comparison of results of the existing shading devices and the proposed design.

6. Method of Data Analysis

The quantitative results collected through case building measurements and questionaries, and generated through computer simulations will be tabulated and organized. Then output data will be compared and analyzed holistically to reach a valid outcome.

4 Analysis and Discussion of Results

4.1. Introduction

Data was collected using questionnaires, secondary data and Computer simulations. Results of each method are tabulated separately. Discussions are made for each method used. The overall workflow is shown in Fig. 5.

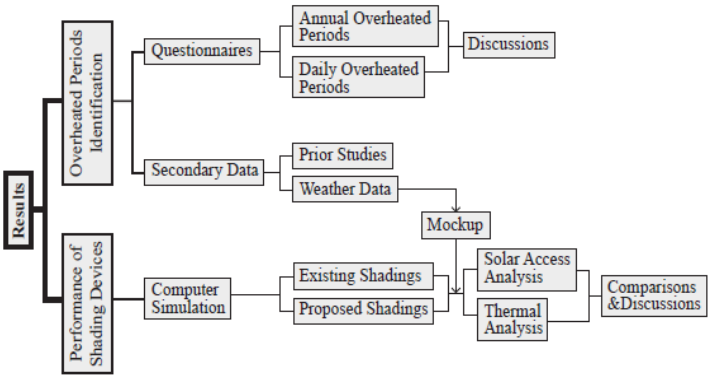


Fig. 6. Result analysis outline

4.2. Questionnaires

In collecting data using this method, a total of 6 case related office buildings in Addis Ababa were surveyed and total of 138 occupants were involved. The questions aimed at identifying and assessing the general perceptions of occupants regarding indoor thermal comfort in their respective workspace.

In identifying the overheated months, the following percentages were claimed by respondents. March, April & May by 4%, April & May by 15%, March by 18%, April by 17%, May by 42% and other months by 4%. Overall, May was claimed to be the hottest by 61% of respondents. In identifying overheated time ranges, the following percentages were claimed by respondants. 12:00pm-5:00pm by 19%, 12:00pm-4:00pm by 27%, 12:00pm-3:00pm by 6%, 12:00pm-2:00pm by 8%, 1:00pm-3:00pm by 8% and one-hour periods found in the above stated ranges by 32%. Overall, the time from 12:00pm-4:00pm was claimed to be thermally uncomfortable by 46% of respondents.

TABLE 1
THERMAL COMFORT VERIFICATION SURVEY SUMMARY

Survey Response Summary						
Surveyed Case Buildings	Total Number of Respondants	Results	Overheated Months		Overheated Periods	
6	138		March, April, May	6	12:00-17:00	26
			April, May	21	12:00-16:00	37
			March	24	12:00-15:00	9
			April	23	12:00-14:00	11
			May	58	13:00-15:00	11
			Other	6	One Hour Periods	44

4.3. Secondary Data

Regarding the climate of Addis Ababa, secondary data were gathered from case related prior studies and weather data files obtained from the Department of Energy website. The studies showed the month of May to be the hottest. This can also be observed in the interpreted weather file of Addis by Climate Consultant software. It also shows periods of thermal discomfort during some months of the year. These periods are in correlation with the findings of the survey.

4.5. Computer Simulations

Computer simulations help provide objective data in assessing the performance of fixed exterior shading devices in blocking incident solar radiation as well as optimizing indoor thermal comfort. In this regard, solar access analysis and thermal analysis simulations are performed in Ecotect on a mockup model using weather file of Addis Ababa.

1. **Solar access analysis-** This analysis is intended to determine the availability of incident solar radiation (insolation), on surfaces and points on a geographically located model with and without fixed shading devices. Solar radiation calculations use hourly recorded direct and diffuse radiation data from a weather file. Calculations are performed and discussions are made for the four major orientations. Fig.6. shows incident exposure values per square meter of vulnerable surfaces in the context of Addis Ababa.

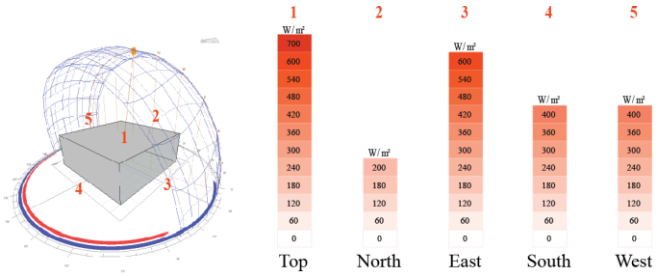


Fig. 7. Mockup model surface solar access analysis

2. **Thermal Analysis** -As already discussed, heat gain from direct solar radiation through glazed surface contributes the most to the heat gained in internal spaces. Ecotect provides a wide range of thermal calculations to compute thermal analysis for different spaces using the admittance method. It calculates the direct (Sunshine) and diffused (Skylight) components striking a glazed surface. For the purpose of this study, a direct solar heat gain analysis is conducted to assess the contribution of different fixed shading devices towards optimizing internal heat gains of spaces with an exposed facade to incident solar radiation. Each orientation is comprised of an exposed single glazing facade with other sides assigned to a material with high R value. This not only helps to minimize heat gain options other than through the glazed surface but also aids in assessing the contribution of the various shading device options in internal heat gains. Due to the shift of the sun path trajectory within a year, surfaces are exposed to different sun positions each month. For this reason, performance of shading devices is assessed for each month of the year. Calculations are performed and discussions are made for the four major orientations in the context of Addis Ababa.

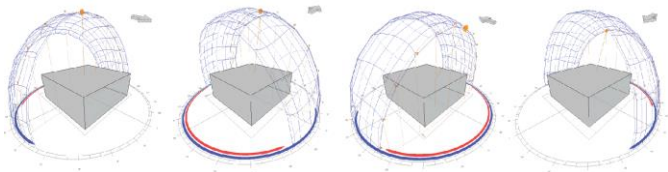


Fig. 8. Mockup model thermal zone configrations

North orientation- North oriented facade simulations showed to receive solar inputs for 5 months (April, May, June, July, August) of the year throughout the day. In relation to the other orientations, it received the least solar input during these months ranging from 0 - 200 W/m². Results also showed the solar exposure hours during afternoon periods to be within range of the identified discomfort periods. The shading typology from Finfinne building resulted in the highest average solar shading performance of 73.4% causing a maximum of 86.2 W/m² reduction of daily average incident solar inputs.

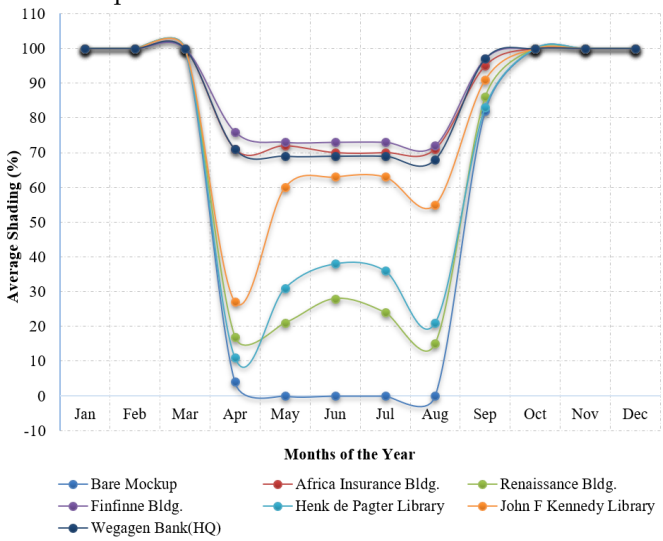


Fig.9. Shading performance summary of north facades

North oriented glazed zones showed to gain the most heat during June when the sun trajectory is to the north and least during January when the sun trajectory is to the south. Among the tested fixed exterior shading devices, the shading adopted from Africa Insurance proved to be more effective in reducing zonal solar heat gains during exposure periods. It resulted in a total solar heat gain reduction of 166.6 KWhr/m² during June and 90.6 KWhr/m² during January.

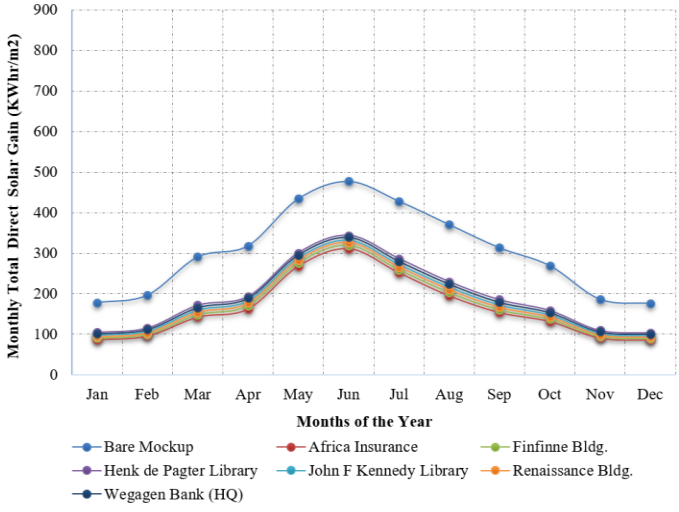


Fig.10. Direct solar heat gain summary of northern zones

East Orientation. East oriented facade simulations showed to receive solar inputs for all mornings of the year. In relation to the other orientations, it recieved the highest solar inputs ranging from 0 - 600 W/m². Results showed the solar exposure hours during mornings to be out of range of the identified discomfort periods. The shading typology adopted from Africa Insurance building resulted in the highest average solar shading performance of 73.7% causing a maximum of 306.2 W/m² reduction in incident solar inputs.

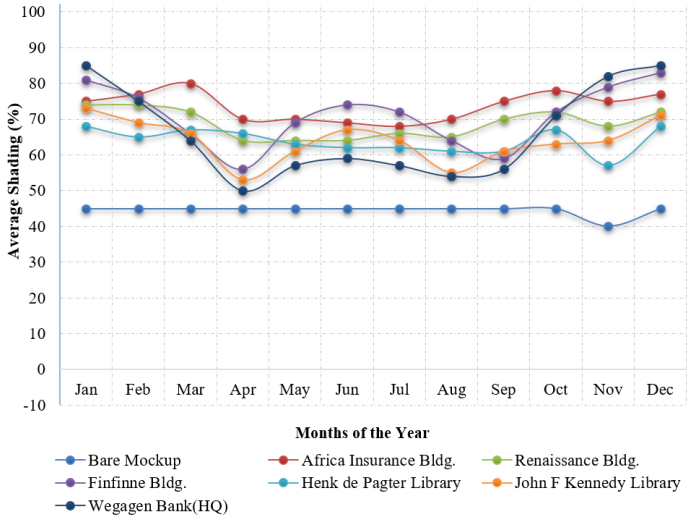


Fig.11. Shading performance summary of east facades

East oriented glazed zones showed to gain the most heat during November when the sun trajectory is fur ther to the south at low angles and least during July when the sun's trajectory is further to the north at high angles. Among the tested fixed exterior shading devices, the shading adopted from Africa Insurance proved to be more effective in reducing zonal solar heat gains during exposure periods. It resulted in a total solar heat gain reduction of 97.1 KWhr/m² during November and 176.4 KWhr/m² during July.

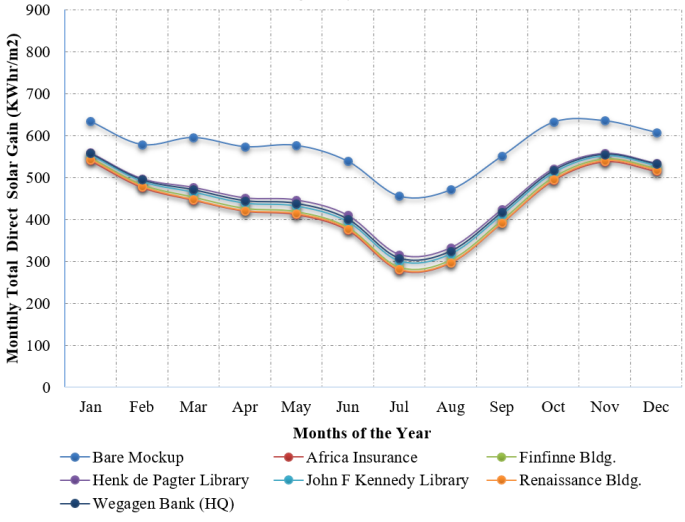


Fig.12. Direct solar heat gain summary of eastern zones

South Orientation. South oriented facade simulations showed to receive solar inputs all day except the five months of the year(April, May, June, July, August) where the sun's trajectory is tilted to the North. In relation to the other orientations, it received above average solar inputs ranging from 0 - 400 W/m². Results showed the solar exposure hours during afternoon periods to be within range of the identified overheated periods. The shading typology from Finfinne building resulted in the highest average solar shading performance of 74% causing a maximum of 82.1 W/m² reduction in incident solar heat gains.

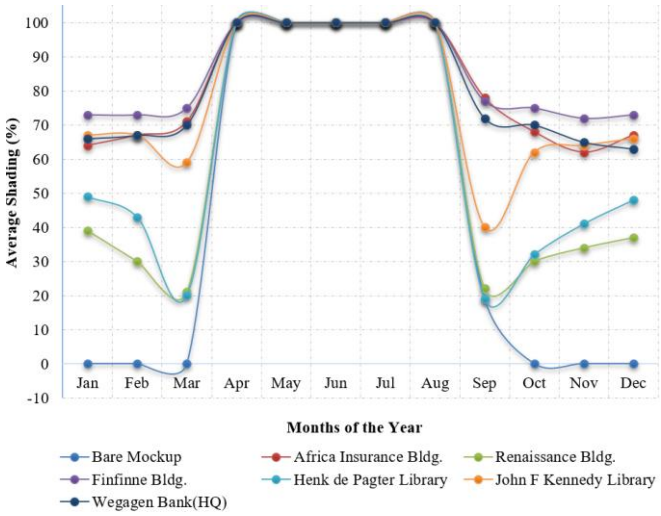


Fig.13. Shading performance summary of south facades

South oriented glazed zones showed to gain the most heat during December when the sun's trajectory is to the south and least during April when the sun's trajectory is Overhead. Among the tested fixed exterior shading devices, the shading adopted from Africa Insurance proved to be more effective in reducing zonal solar heat gains during exposure periods. It resulted in a total solar heat gain reduction of 88.7 KWhr/m² during December and 153.5 KWhr/m² during April.

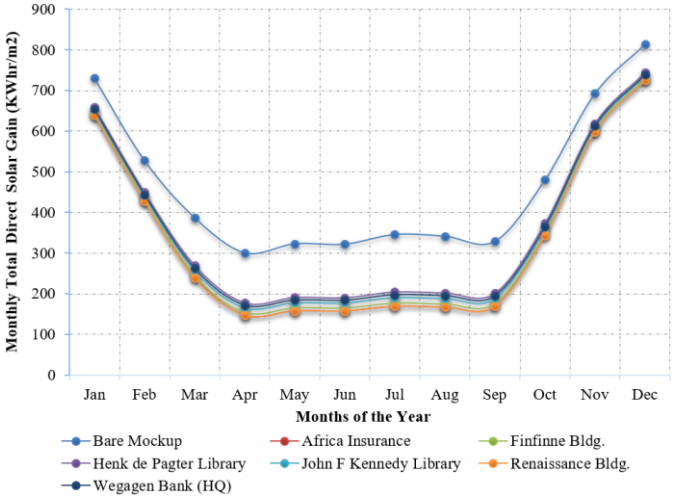


Fig.14. Direct solar heat gain summary of southern zones

West Orientation. West oriented facade simulations showed to receive solar inputs for all afternoons of the year. In relation to the other orientations, it received above average solar inputs ranging from 0 - 400 W/m². Results showed the solar exposure hours during afternoon periods to be within range of the identified overheated periods. The shading typology from Africa Insurance building resulted in the highest average solar shading performance of 80.3% causing a maximum of 190 W/m² reduction in incident solar heat gains.

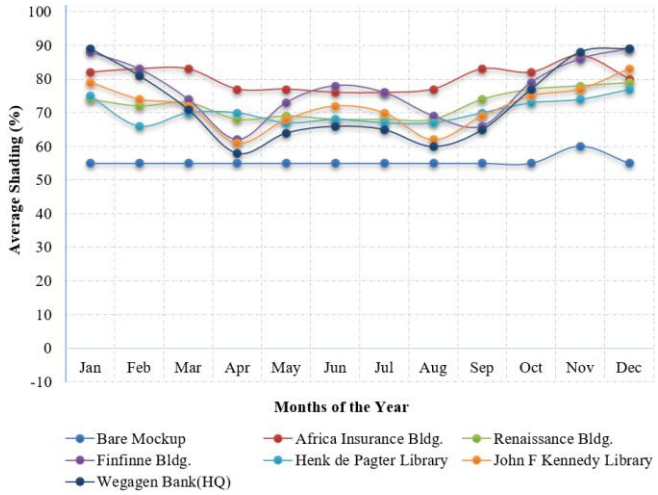


Fig.15. Shading performance summary of west facades

West oriented glazed zones showed to gain the most heat during March when the sun trajectory is overhead and least during February when the sun's trajectory is further to the south. Among the tested fixed exterior shading devices, the shading adopted from Africa Insurance proved to be more effective in reducing zonal solar heat gains during exposure periods. It resulted in a total solar heat gain reduction of 176.5 KWhr/m² during March and 109.6 KWhr/m² during February.

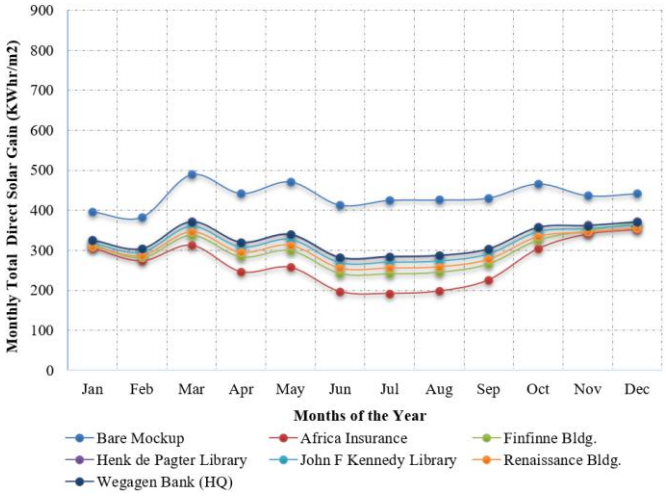


Fig.16. Direct solar heat gain summary of western zones

5 Design Proposal

A building design proposal is made for the climate of Addis Ababa. It is intended to show a suitable design approach and implementation of fixed exterior shading devices for full-glazed building facades. This requires the identification and harmonized execution of key shading design factors that are otherwise difficult to consider all at once during design. To Simplify this process, these factors are sequentially categorized and executed in three major stages. Fig.17. shows an organizational outline of these stages.

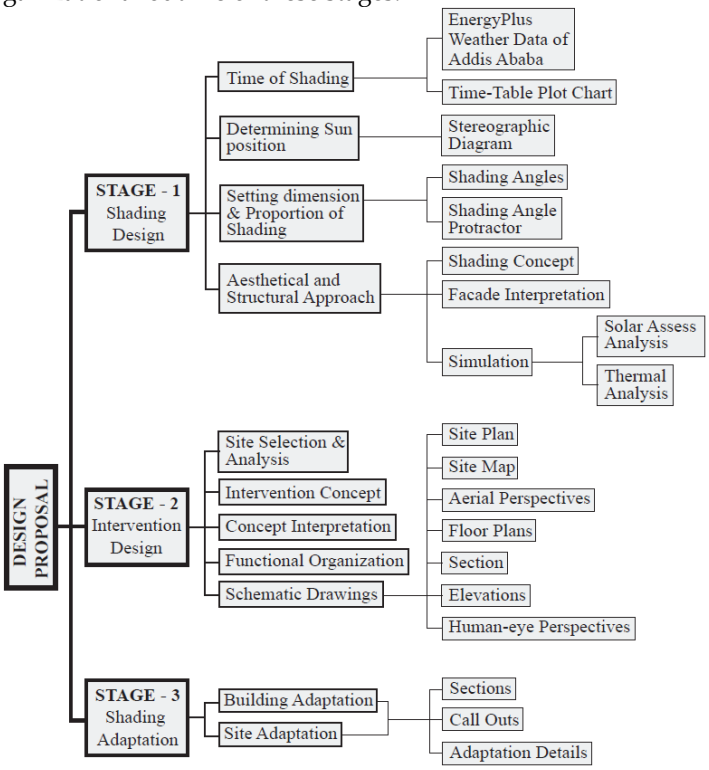


Fig.17. Design proposal outline

5.1. Stage-1_Shading design

1. **Identifing when shading is required-** EnergyPlus weather data of Addis Ababa is interpreted using Climate Consultant software.

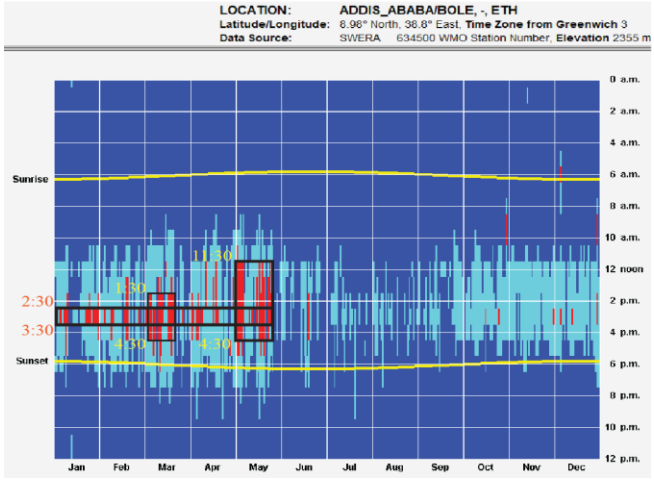


Fig.18. Average daily temperature chart of Addis Ababa

2. **Determining position of the sun when shading is required –** The average daily Time Table Plot chart of Addis Ababa is mapped on to the stereographic diagram of Addis Ababa. This helps to identify the sun's position during overheated periods.

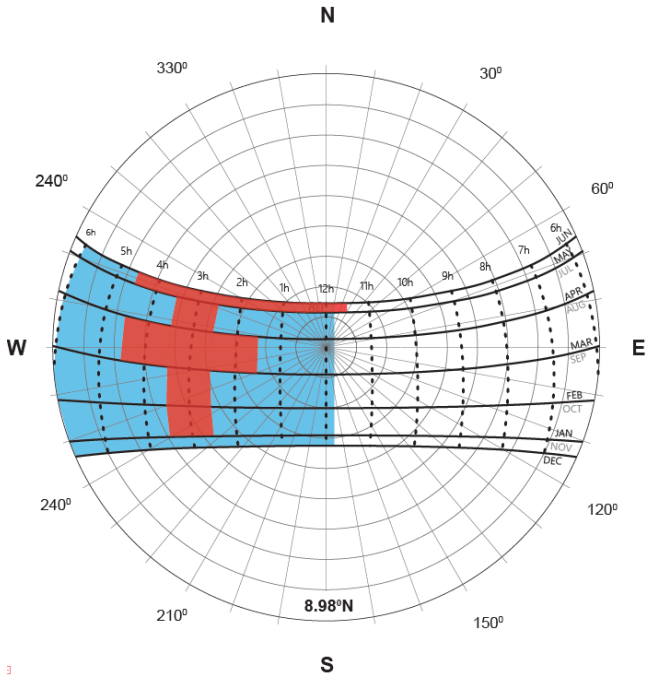


Fig.19. Mapped stereographic diagram of Addis Ababa

3. **Determining dimensions and proportions of shading devices for the required period-** The shadow angle protractor is a useful tool used to determine the Horizontal (HAS), Vertical (VSA) and End-profile (EP) angles of a given facade orientation. Measurment of the mapped stereographic diagram yielded the following results.

• North orientation
HSA- 82⁰
VSA- 65⁰
EPA- 38⁰ W

•East orientation
HSA- 65⁰
VSA- 83⁰
EPA- 60⁰ N & 55⁰S

•South orientation
HSA- 60⁰
VSA- 55⁰
EPA- 38⁰ W

•West orientation
HSA- 0⁰
VSA- 35⁰
EPA- 25⁰ N & 25⁰S

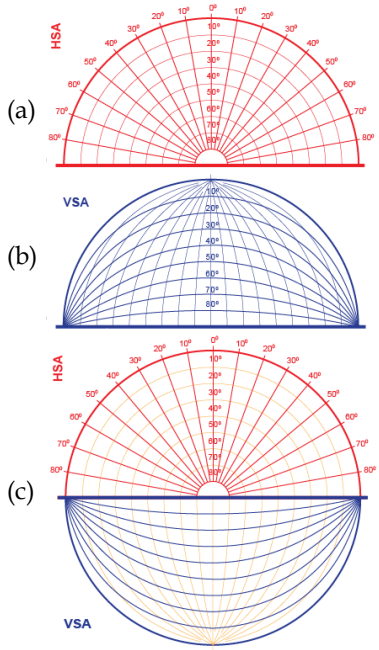
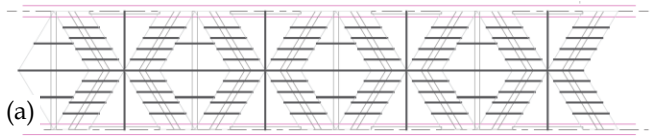


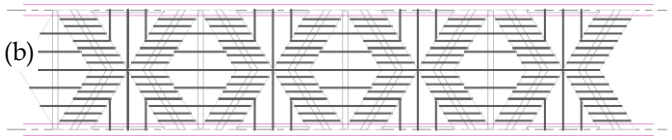
Fig.20. Shading angle protractors (a)horizontal, (b)vertical, (c)end-profile

4. **Designing shading devices considering aesthetic and structural considerations-**There are multiple shading design possibilities with the identified shadow angles. Aesthetical and structural concepts guide how they are composed. As a shading design concept, its intended to show the potential of fixed exterior shading devices not only as a mean of solar protection but also as a tool to portray identity and create sense of place. In this regard, a "**Weaving**" concept is used to convey the Ethiopian traditional "**Tillet**" pattern which depicts rhombus shapes as basic elements. These elements are interpreted through conforming shading devices within and between alternating rhombus shapes using the identified shading angles.

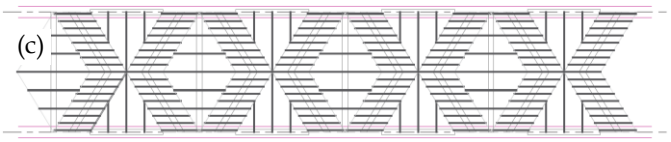
• **North orientation interpretation-**
82⁰ HSA yielded 14cm deep fins spaced 1m apart.
65⁰ VSA yielded 35cm deep louvers spaced 75cm apart.
65⁰ VSA projection yielded 14cm deep louvers spaced 30cm apart.



•**East orientation interpretation-**
65⁰HSA yielded 23cm deep fins spaced 50cm apart.
83⁰ VSA yielded 6cm deep louvers spaced 50cm apart.
83⁰VSA projection yielded 1.8cm deep louvers spaced 15cm apart.



•**South orientation interpretation-**
60⁰HSA yielded 29cm deep fins spaced 50cm apart.
55⁰VSA yielded 35cm deep louvers spaced 50cm apart.
55⁰ VSA projection yielded 18cm deep louvers spaced 25cm apart.



•**West orientation interpretation-**
35⁰VSA yielded 43cm deep louvers spaced 30cm apart.
35⁰VSA projection has yielded 21cm deep louvers spaced 15cm apart.

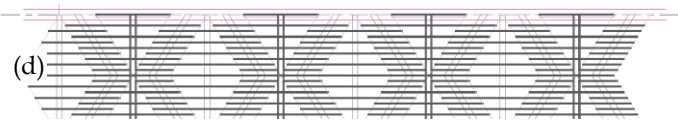


Fig.21. Façade interpretation and repeating pattern composition (a)North, (b)East, (c)South, and (d)West

Proposal shading simulations

North facades-Proposed shading design showed an annual average shading improvement around 57.4% and a monthly total direct solar heat gain reduction of 130.9 KWhr/m² during June and 63.5 KWhr/m² during January to be optimal.

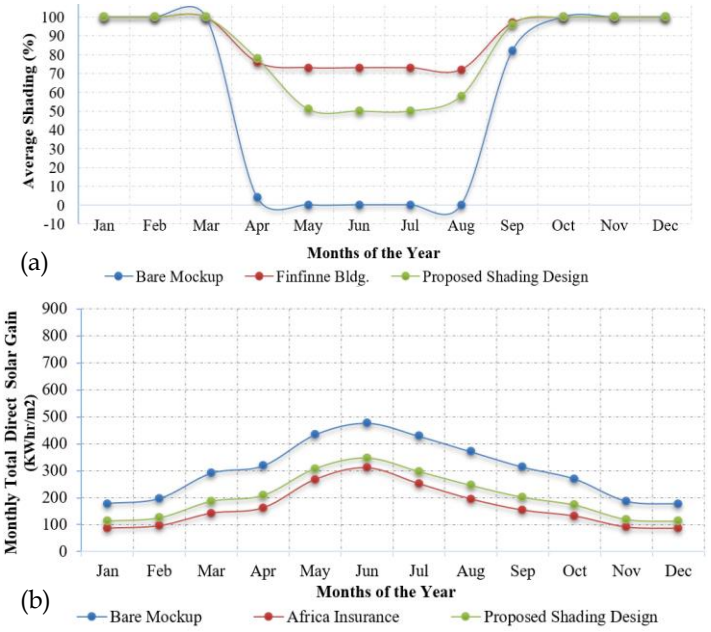


Fig.22. (a)Solar shading performance summary for north facades & (b)Direct solar heat gain summary for northern zones

East facades-Proposed shading design showed an annual average shading improvement around 54% and a monthly total direct solar heat gain reduction of 81.4 KWhr/m2 during November and 73.9 KWhr/m2 during July to be optimal.

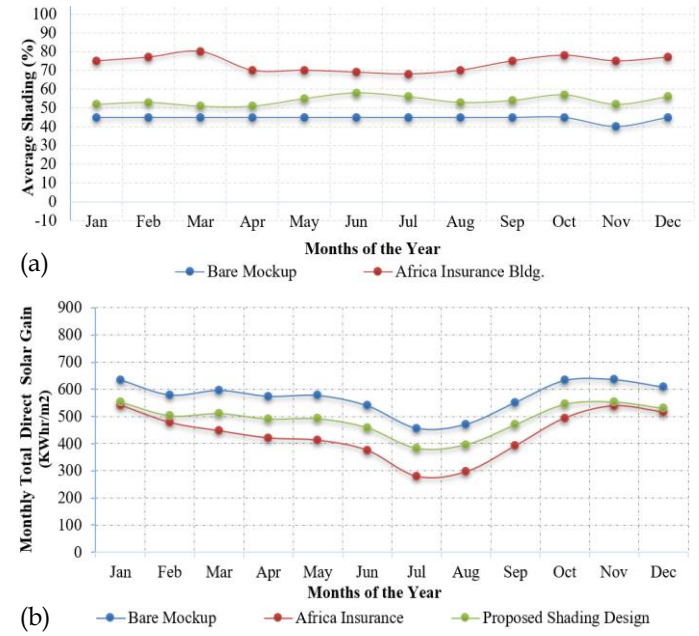


Fig.23. (a)Solar shading performance summary for east facades & (b)Direct solar heat gain summary for eastern zones

South facades-Proposed shading design showed an annual average shading improvement around 75.7% and a monthly total direct solar heat gain reduction of 159.9 KWhr/m2 during December and 162.9 KWhr/m2 during April to be optimal.

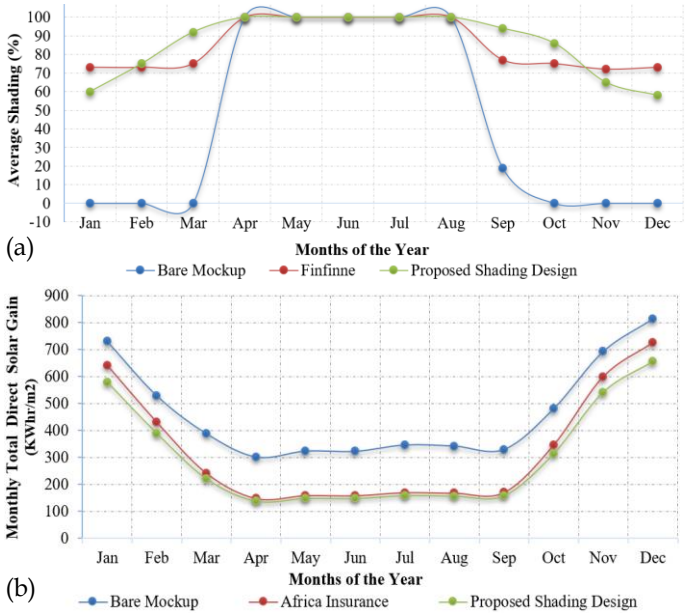


Fig.24. (a)Solar shading performance summary for south facades & (b)Direct solar heat gain summary for southern zones

West facades-Proposed shading design showed an annual average shading improvement around 84.2% and a monthly total direct solar heat gain reduction of 159.9 KWhr/m2 during March and 108 KWhr/m2 during February to be optimal.

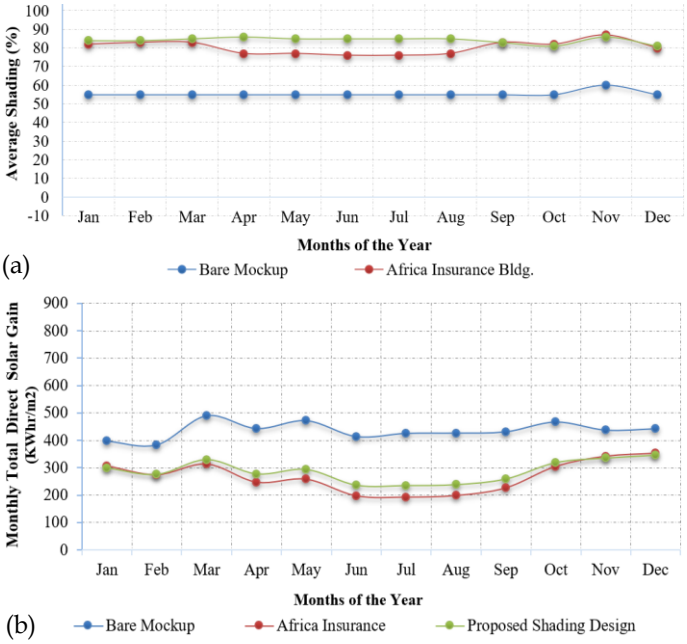


Fig.25. (a)Solar shading performance summary for west facades & (b)Direct solar heat gain summary for western zones

5.2. Stage-2_Intervention design

The chosen site is located at the boundary of Lideta sub city around Mexico Square. It occupies a total area of 1.451 hectares and has a gentle slope of 2.5%. As the citiy's business district, this area is vastly undergoing fullglazed multi-storey building constructions for office use. In this regard, a 20 storey mixed-use building is propsed.


(a)

Intervention concept- To create a concept and context based exemplary design for the public that portrays identity through the expression of space, form and facade to help mainfest sense of place**.** This is achieved through the implementation of "**Tillet**" patterns using rhombus shapes with in the site and proposed building.


(b)


(c)

Fig.26. (a)Aerial view of strategic site, (b)Proposal design intervention, and (c)Building proposal interior lobby view

5.3. Stage-3_Shading adaptation

This stage of the design proposal explores how the proposed shading design approaches are adopted on the fullglazed facades of the proposed building.

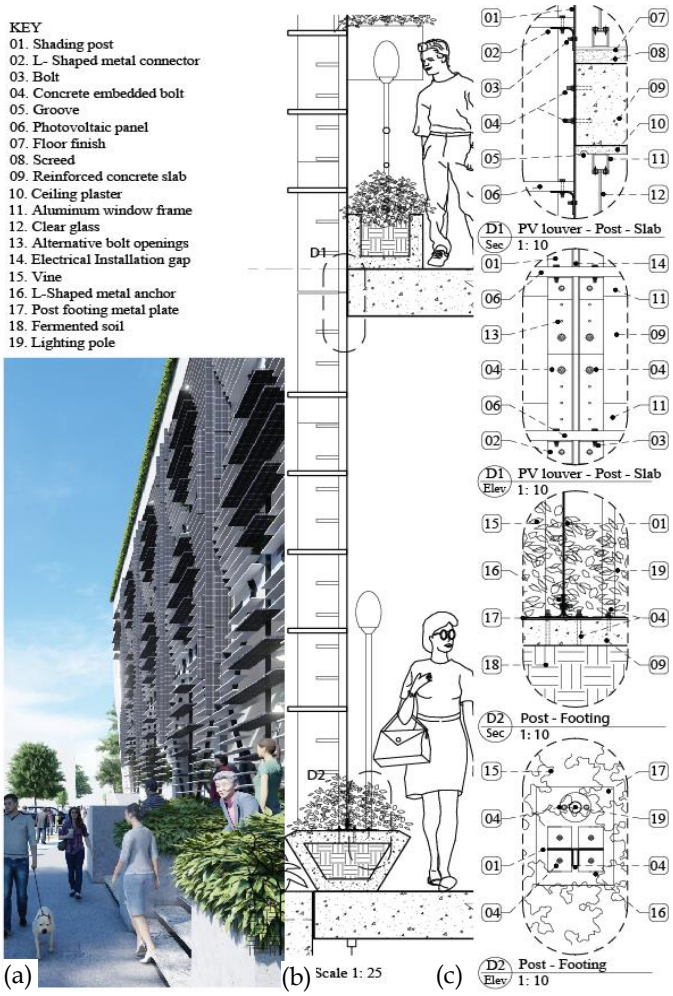


Fig.27. Proposed building shading adaptation, (a)southern building podium view, (b)façade section, and (c)details

6 Conclusion

In the climate context of Addis Ababa, overheated period-based application of fixed exterior shading devices varies for North, East, South and West orientations. Periods from noon – 4:00pm are usually identified as thermally undesirable. Solar heat gain is desired for north and east oriented glazed zones all year round wereas undesired for west oriented glazed zones at all times. South oriented glazed zones are exposed to solar radiation all day for seven months of the year. In this time, solar heat gain is desired until noon and undesired during after noon periods. Application of discomfort period based fixed shadings would reduce undesired heat gains in afternoon periods but will also hinder desired heat gains during morning periods. For this reason, it is challenging to achieve user desired thermal comfort using fixed exterior shading approaches for South oriented glazed zones. In this regard, kinetic shading approaches would provide more flexibility in responding accordingly to solar exposure during desired and undesired periods.

ACKNOWLEDGMENT

First and for most, I praise and thank God, the Almighty, for giving me the strength and courage to finish this paper.

I would like to express my deepest gratitude to my advisor Ingo Helmedag (Prof.) who gave me the vision to deal with this thesis. He has continuously motivated and guided me in the study process. I would like to extend my deepest gratitude for the staffs of Emerging City Lab – Addis Ababa (ECL-AA) program at the Ethiopian Institute of Architecture Building Construction and City Development (EiABC) for making the time to assess and comment on my work. I would also like to thank my family who were consistently supporting me till the end of my study. Last but not least, special thanks to those I had the privilege to meet during the course of my work who helped make my journey easier.

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