EFFECT OF SHADING DEVICES ON INDOOR THERMAL COMFORT IN CONDOMINIUM BUILDINGS: THE CASE OF ADAMA CITY, ETHIOPIA

Jebesa Obsa Hundesa

A Thesis Submitted to the Department of Architecture
School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Environmental Architecture

Office of Graduate Studies
Adama Science and Technology University

July, 2023
Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled **“Effect of Shading Device on Indoor thermal comfort in Condominium Building: The case of Adama city, Ethiopia** “is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Jebesa Obsa Hundesa____	________________________	____________________
Name of student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Effect of Shading Device on Indoor Thermal Comfort in Condominium Building: The case Adama city, Ethiopia"** prepared under my guidance by Jebesa Obsa submitted in partial fulfillment of the requirements for the degree of Master's in Environmental Architecture. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Belay Zeleke (Ph.D.)		
Major Advisor	Signature	Date

APPROVAL SHEET

I, the advisors of the thesis entitled **"Effect of Shading Devices on Indoor Thermal Comfort in Condominium Buildings: The Case of Adama City, Ethiopia"** and developed by Jebesa Obsa Hundesa, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Belay Zeleke (Ph.D.)	____________________	______________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Jebesa Obsa have read and evaluated the thesis entitled **"Effect of Shading Devices on Indoor Thermal Comfort in Condominium Buildings: The Case of Adama City, Ethiopia"** and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Environmental Architecture.

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ABBREVIATIONS

ITQ – Indoor Thermal Quality

IEQ - Indoor Environmental Quality

ITC – Indoor Thermal Comfort

ITE – Indoor thermal environment

IAQ – Indoor Air quality

LWS - Living wall systems

VSA- Vertical Shadow Angle

HSA- Horizontal Shadow Angle

AZI - Azimuth

ALT- Altitude

ZEN - Zenith angle

HVAC - Heating ventilation air conditioning

ASHRAE - American Society of Heating, Refrigerating and Air-conditioning Engineers

PMV - Predicted mean vote

PPD - Predicted people dissatisfied

RH - Relative humidity

MR - Metabolic Rate

IAQ - Indoor air quality

ABSTRACT

Indoor thermal comfort has a significant impact on individuals' moods and working conditions. Indoor thermal comfort can be improved through appropriate building materials, optimal sizing of openings, and the incorporation of outdoor spaces that offer shade and natural ventilation. One effective strategy for creating a friendly atmosphere is through the utilization of shading devices. In this study, the effect of shading devices on thermal comfort in Adama condominium buildings is evaluated, as is the efficiency of these sun shading elements in creating a thermally comfortable atmosphere. The scope of the study is limited to condominium buildings in Adama, Ethiopia. This study identifies shading devices' effects and influences on thermal comfort depending on their type, orientation, and location. In order to achieve the study's objective, using a questionnaire, occupant perception and indoor climate variables (temperature, humidity, daylight illuminance, and air velocity) were measured using thermal media. Instruments and data collected from April 20 to May 10 and the extent to which shading devices affect thermal comfort were analyzed using simulation software (Ecotect software) and sun paths of location. From 122 blocks in Adama City, 21 blocks used shading devices, and simulations were performed on south, west, and south west-facing rooms. Collected data on occupant satisfaction shows that occupants are uncomfortable with the existing shading device. Dimension and proportion of the new shading device for the required overheated month for south-facing rooms identify HSA = 45°, VSA = 58°, and EPA = 30° W and 88°E; southwest-facing rooms have HSA = no, VSA = 32°, and EPA = 53° NW and 78° SE; and west-facing rooms have HSA = - VSA = 32°, and EPA = 53° NW and 58° SE have good performance and were evaluated using simulation software. South-facing room temperatures range from 15.6°C to 18.40°C for the new overhang shading device; west-facing room temperatures range from 19.5°C to 23°C for the new overhang shading device; and southwest-facing room temperature 19.6°C to 22.8°C for the new overhang shading device. This study concluded that the effects of the shading device in the Adama condominium building on occupant satisfaction have no desired performance and are thermally uncomfortable. From this finding, it's recommended that during the design process simulation of the building model, understating the sun's trajectory helps to improve thermal comfort and reduce excessive solar radiation.

Keywords: Condominium buildings, Climate variables, Occupants, shading device, Simulating software, sun paths, Thermal Comfort

CHAPTER ONE

INTRODUCTION

This research was carried out in Adama City, located in Oromia Regional, Ethiopia, for partial fulfillment of the requirements for the degree of master's in environmental architecture at Adama Science and Technology University. This study examined the effect of shading devices on indoor thermal comfort in Adama condominium buildings as well as how residents respond to regulating the surrounding temperature and reducing solar radiation. Adama is a growing city, and as a result, the population and housing demand have also increased(Barka & Senthil Kumar, 2020). To address this issue, the government constructed numerous condominium buildings for the community, and these condominium buildings have to be safe and comfortable residences(Barka & Senthil Kumar, 2020).

According to research undertaken on Condominium Building (Potential, 2022) Condominium buildings play an important role in creating a safe and comfortable indoor environment. However, climate change-related warming not only reduces residents' productivity and causes heat-related illnesses but also puts a burden on electricity generation and increases the risk of power outages by filling high heating and cooling requirements(Jessel et al., 2019).

Proper building design and material selection can help save 50–60% of the energy consumed by buildings for heating and cooling systems(Tang & Wu, 2011). As a result, it is critical to carefully assess sustainability and energy efficiency and develop energy-saving alternatives. In this case, heating and cooling installations are the biggest consumers of energy. It is difficult to imagine a comfortable living environment without proper and suitable thermal conditions within the building(De Dear & Brager, 2002).

According to a study, buildings consumed approximately 40% of total global energy, with buildings accounting for 40%–60% of total heat loss or gain (Cuce, 2019). As a result, the motivation for this study paper is to encourage designers and occupants to use shading devices in order to improve building indoor environments and energy consumption.

This chapter presents an overview of the research, including the background of the study, the statement of the problem, the objective, the research questions, the significance of conducting the study, the scope, the outcomes, and the limitations of the research.

1.1 Background of the study

Thermal comfort in ancient civilizations is achieved through the practice of passive solar building design for thousands of years. They recognized the importance of capturing solar energy in cold seasons and blocking it in hot seasons, and they designed their architecture based on the sun's trajectory throughout the year. Passive architecture is now extensively utilizing passive solar elements that were identified in buildings dating back to 7000B.C. (Petros A. Lapithis, 2002).

The Experimental Solar House incorporates energy-saving architectural principles based upon the historically and traditionally strong architectural characteristics of past models. These characteristics serve as a foundation for the modern approach to energy-efficient design. However, between 4000 and 2000 BC, the Chinese were the first known culture to perfect passive building tactics. Research findings reveal that aligning a building in a southward direction can increase internal thermal comfort during winter months. Additionally, construction of overhanging roof lines, akin to present-day covered porches, has the potential to reduce excessive overheating during the summer season. Buildings were eventually arranged in rows so that each had a southern exposure. The demand for heating and Cooling in buildings worldwide necessitates a significant amount of energy. Furthermore, the cost of various forms of energy is continuously escalating (Kirimtat et al., 2016; Liddament, 2000; Pérez-Lombard et al., 2008).

A shading device can be a crucial tool in reducing a building's energy consumption, especially in hot climates. Shading mechanisms act as a barrier for windows against the harsh effects of solar radiation, especially during the summer season. At the same time, it allows the optimal amount of solar radiation during the winter season. The application of shading devices has been widely adopted in various Building (Baniyounes et al., 2012;

Mateus & Oliveira, 2009). Shading against solar radiation plays significant roles in reducing the cooling loads of a building(Datta, 2001; Mehrotra, 2005).

Antony Sealey made a notable contribution in 1979 concerning the design of exterior shading systems. In his journal (building climatology), Sealey identified four important criteria that had to be taken into account for appropriate design. Solar shading systems are utilized to regulate the level of natural light that enters a building and to manage the view of the surrounding environment. Additionally, they effectively diminish the yearly solar gains and modify the heat exchange within the glazed opening. It's crucial to remember that solar radiation can easily pass-through glass in structures. The type of glazing utilized in a building determines the quantity of solar radiation and visible light that is able to penetrate through. Appropriate solutions that limit incoming solar radiation must be implemented to avoid excessive solar gains and glare issues for occupants(Szokolay, 2007).

On the way to address this issue, it is first essential to determine which areas of the façade or penetration of the building must be shaded or exposed to the sun in order to drive full design strategies. To create this understanding, we need to know the relationship of sun and earth with the understanding Loco-Centric view in the specific building and site area. Depending on this the shading device and Building Orientation will be more efficient to the building we apply on. Second, over time, a number of shading techniques have been developed. One popular approach involves utilizing exterior shading devices to prevent solar radiation from penetrating into a building's interior spaces. This method can be quite effective, blocking up to 80% of potential solar gain through a transparent clear window. By comparison, internal shading solutions are only approximately 20% efficient at reducing this type of solar exposure (Lechner, 2015).

Regarding Adama City, several shading device applications have been observed on various building openings over the years. They use various design and employment methods; thus, their shading performance would also change. Therefore, it is very important to examine such devices to evaluate their effect on thermal comfort. As a result, this study examined the key ideas needed for an appropriate shading design as well as the effects of shading devices on thermal comfort in the Adama condominium building.

1.2 Statement of problem

A building's indoor thermal comfort is influenced by several factors, such as the site location, building materials, opening size, and building orientation. If any of these aspects are not properly taken into account during the building design, it may cause occupants discomfort or lead to greater energy use in an effort to achieve the most comfortable circumstances. In Adama, most condominium buildings are built repetitively. This is the result of design and building without consideration of the climate condition, building material, environment, and orientation(Hailu et al., 2021).

Regions located near the equator, such as Adama (8.55° N, 39.27° E), gain more solar radiation. Solar radiation can penetrate easily through glazed surfaces. It is crucial to implement proper measures that regulate the incoming solar radiation in order to prevent excessive solar gains and glare problems for the occupants. There are some trends being taken by the residents to minimize the problem of high or low temperatures. This process is causing the residents' discomfort and health problems, and it increases the need for energy sources for indoor thermal quality in the buildings. In this process, there is a knowledge gap, which is the implication of shading devices without considering sun angle and sun path (the sun's trajectory) throughout the year.

Adama City is described as having a warm dry season, a hot zone, and uncomfortable temperatures throughout the winter season, with the majority of the hours falling outside the thermal comfort zone, according to metrology data(Shewa, 2020). This resulted in extremely high or low temperatures indoors, which affected residents' comfort and productivity. The recent development trends in the built-up area include using shading devices to block solar radiation without considering sun angle and harsh sun hours. Because of this, condominium buildings in Adama are facing the penetration of solar radiation and high temperatures in the indoor spaces.

1.3 Objective

1.3.1 General Objective

The general objective of the study is to assess the effect of shading devices on indoor thermal comfort in condominium buildings for regulating indoor comfort.

1.3.2 Specific Objective

- ✓ To measure the thermal satisfaction of residents in condominium building in Adama.
- ✓ To analyse the existing environmental variables to be considered in building shading effects.
- ✓ To develop design approach strategies on Shading device to indoor thermal comfort.

1.4 Research Questions

1) What is the level of satisfaction of occupants in the thermal environment of condominium buildings in Adama?
2) What are the existing environmental variables measurments to be considered in building shading effects?
3) Which design approaches and strategies for shading devices improve thermal quality and control solar radiation in the selected buildings under this study?

1.5 Significance of the study

The significance of this study is that it fills the knowledge gap about the shading device on selected buildings and lays the baseline for further research. This research investigation has demonstrated the critical importance of glazing shading devices as passive approaches for reducing solar heat gains and improving thermal comfort inside. The outcomes of this investigation can be employed as guiding principles for academic objectives, policymakers, professionals, and researchers. The findings will contribute to further research on the sustainable performance of the built environment. Professionals can use it to develop their designs in order to maximize the use of opportunities for natural light and energy efficiency to improve buildings' performance in daylight design, thermal comfort, and energy savings. Due to this, there has not been enough research conducted or published on this topic that uses the keywords in shading devices. Therefore, this study is great for enhancing shading devices. It is better that engineers as well as architects consider the shading device for buildings from the start. But for existing buildings and buildings that are being built without such consideration, think of techniques to apply such a device. The research can be seen as bridging the gap between human nature and establishing equilibrium.

1.6 Scope of the study

Spatial Scope

This paper focused on solar radiation-exposed condominium buildings in Adama City that have used shading devices to achieve passive solar control and indoor thermal comfort. An analysis was conducted to evaluate the effectiveness of shading mechanisms in minimizing the amount of solar heat absorbed by sun-exposed buildings throughout the day.

Thematic scope

The scope of this investigation is constrained to the evaluation of solar energy inputs and their corresponding gains. However, this analysis does take into account other variables, such as shading devices, which can effectively reduce the amount of daily solar heat gains on exposed buildings, leading to an improvement in indoor thermal comfort. Secondly, developed design of the shading device by using simulation software for condominium buildings to determine the effect of thermal quality and solar radiation reduction.

1.7 Limitation of the study

The study has faced many problems. During the measurement period, it was difficult to measure every environmental variable hourly and minutely. The lack of time and resources and people’s unwillingness to allow measurements, were major impediments to collecting detailed survey data and occupant responses. unable to get measuring equipment on time for measurements. Furthermore, certain informants' willingness was difficult to obtain throughout the data collection stage.

1.8 Operational definition of the study

The vertical shadow angle (VSA) (or 'profile angle' for some authors) is measured on a plane perpendicular to the building face.(Szokolay, 2007)

Horizontal shadow angle (HSA): is the azimuth difference between the Position of the sun and the direction of the building's face, when the edge of the shadow falls on the point considered.(Szokolay, 2007)

Azimuth (AZI): The direction of the sun measured in the horizontal plane from north in a clockwise direction (thus east = 90°, south= 180° and west = 270°, whilst north can be 0° or 360°); also referred to as 'bearing' by some; many authors use 0° for south (in the northern hemisphere) and have -90° for east and +90° for west, or the converse for the southern hemisphere, taking 0° for north and going through east to +180° and through west to -180°. The convention here adopted is the only one universally valid.(Szokolay, 2007)

Altitude (ALT): Measured in the vertical plane, between the sun's direction and the horizontal; in some texts this is referred to as 'elevation' or 'profile angle.(Szokolay, 2007)

Zenith angle (ZEN): is measured between the sun's direction and the vertical and it is the supplementary angle of altitude:(Szokolay, 2007)

ASHRAE Scale: The ASHRAE seven-point scale is a set of seven options available to people to relate their perception of thermal comfort to a given environment (cold, cool, slightly cool, neutral, warmth, warmth and warmth)(Turner et al., 1979).

Indoor thermal comfort: according to ASHRAE, it is "a state of mind expressing satisfaction with the indoor thermal environment (ITE). " That is, the state of having people neither too hot nor too cold and assessed by subjective and objective evaluation"(Edition et al., 2013).

Relative Humidity: The ratio of the actual water vapor content in the air to the maximum water vapor content that the air can hold at that air temperature, expressed as a percentage(Nugent & Russell, n.d.).

Air Speed/velocity: speed of air movement at a point, regardless of direction (Candido et al., 2010). The faster the air moves, the greater the heat exchange between the person and the air that the person is in contact with (measured in m/s) (Candido et al., 2010).

1.9 Organization of the Study

This thesis is categorized into three chapters. Each chapter systematically and effectively examines the content and data of the study accordingly. The fundamental chapters in the thesis are further demonstrated as follows

Chapter One: Introduction to the study was introduced the thesis by lighting the main topic of the study, research problems, objectives, questions, significance, scope, limitation and research design in detail.

Chapter Two: Literature Review is a chapter that discusses key definitions relating to Indoor Thermal Comfort, shading device, and parameters of Thermal Comfort, Solar control and case study.

Chapter Three: Research Methodology is a chapter that discusses the methodology of the research. The chapter explains the methods used for the study and the process of data collection and analysis in detail.

Chapter Four: Result and Discussion is a chapter that discusses the results of qualitative and quantitative data findings. The subjective qualitative data are analyzed based on a questionnaire survey, field observation notes, and printed documents from different sectors. The objective quantitative data are analyzed based on field observation, measurements of environmental variables, sun path analysis, shadow analysis, and software simulation. Further, the chapter illustrates a discussion based on the findings of the results.

Chapter Five: Conclusion and recommendation are the concluding parts of the thesis. The chapter reached a conclusion based on the findings from the literature review and the results of the discussions. Additionally, the study recommends optimal shading device design approaches and strategies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Literature Review

2.1.1 Introduction

This literature assessment was conducted with scientific journals relating to case studies, online databases, and targeted internet queries. The scope of the research encompassed a range of factors, including shading devices, glazing materials, shading design, simulated processes, solar management, solar irradiation, and thermal conditions.

2.1.2 What is Sun Light?

Sunlight refers to the visible light and other forms of energy that emanate from the sun. When this energy reaches the earth's surface, it is known as insolation. The heat energy that we feel from the sun results from the transmission of electromagnetic waves from the sun to the earth(Szokolay, 2007).

2.1.2.1 Solar Radiation

Electromagnetic radiation can be categorized into different wavelength bands, depending on the intended field of application. The vast majority of solar radiation lies within the 0.3–3 m wavelength range and extends into the ultraviolet (UV) and infrared (IR) ranges. Short-wave and long-wave radiations are the two classifications of importance in solar engineering. Shortwave wavelengths are used to express solar radiation, while other wavelengths are expressed in longwave wavelengths. After solar radiation reaches the earth's surface, it has two components: beam radiation with a well-defined direction and diffuse radiation that scatters in the earth's atmosphere. Solar radiation can be measured in two ways: irradiance, which is the energy flow density or instantaneous flux measured in W/m2, and irradiation, which is an integrated quantity of energy over a specified period of time.

2.1.3. Identification of Solar Movement

According to Antony Sealey (1979) in a journal of building climatology, there are five methods for determining the position of the sun.

1. Sun-path diagrams
2. Experiment Methods
3. Calculation
4. Computer programs
5. From table

2.3.1.1 Sun-path diagrams

Are graphical projections of the sky's hemisphere that show the sun's path across the sky throughout the day and year. They are popular because they are simple. To obtain sun-path diagrams, two types of projections are used.

A. Orthogonal Projection. is a projection of the hemisphere onto a horizontal circle that is commonly used to depict the sun's path across the sky (Sealey, 1979).

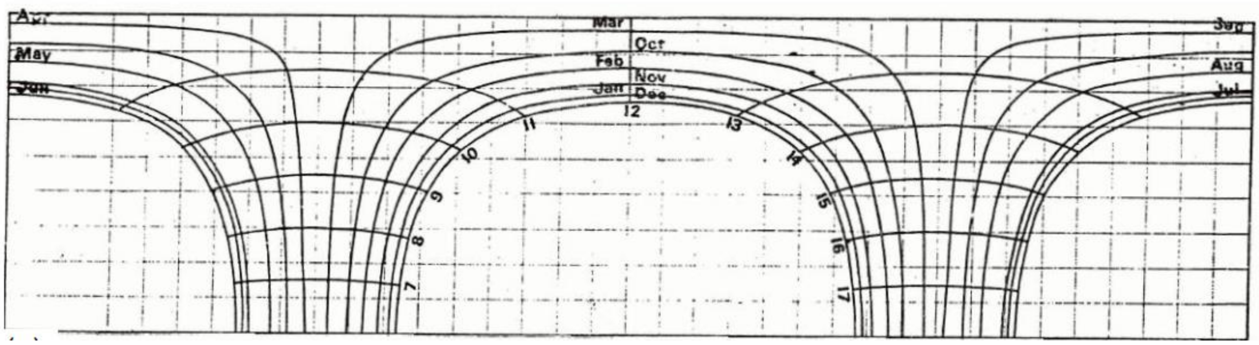


Figure 2:1:Orthogonal Projection(Sealey, 1979)

B. Stereographic projection. is the hemisphere's projection onto a vertical surface. This is more useful for analyzing shading angles, glare, and diffuse skylight. The stereographic chart is the most commonly used sun path diagram(Sealey, 1979).

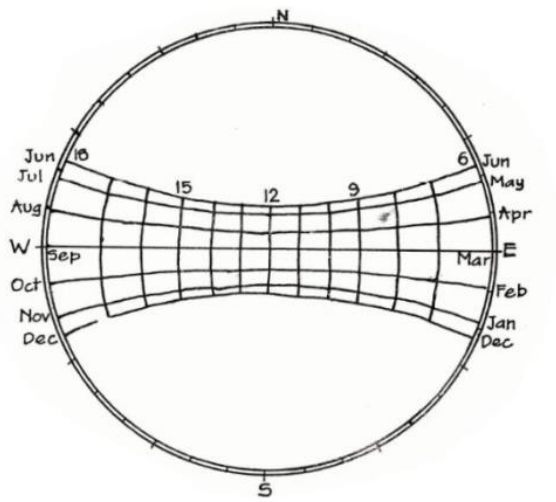


Figure 2:2:Stereographic Projection(Sealey, 1979)

2.1.4 The Use of Sun Path Diagram

Understanding and determining the position of the sun where shading is required is critical for the design of shading devices. The solar altitude B (beta, measured from Q to 90 degrees above the horizon) and the solar azimuth define the sun's position (theta). The solar azimuth is measured from the south from 0 to -180 degrees (westward) and 0 to +180 degrees (eastward),(Sealey, 1979) as shown in Figure 2:3.

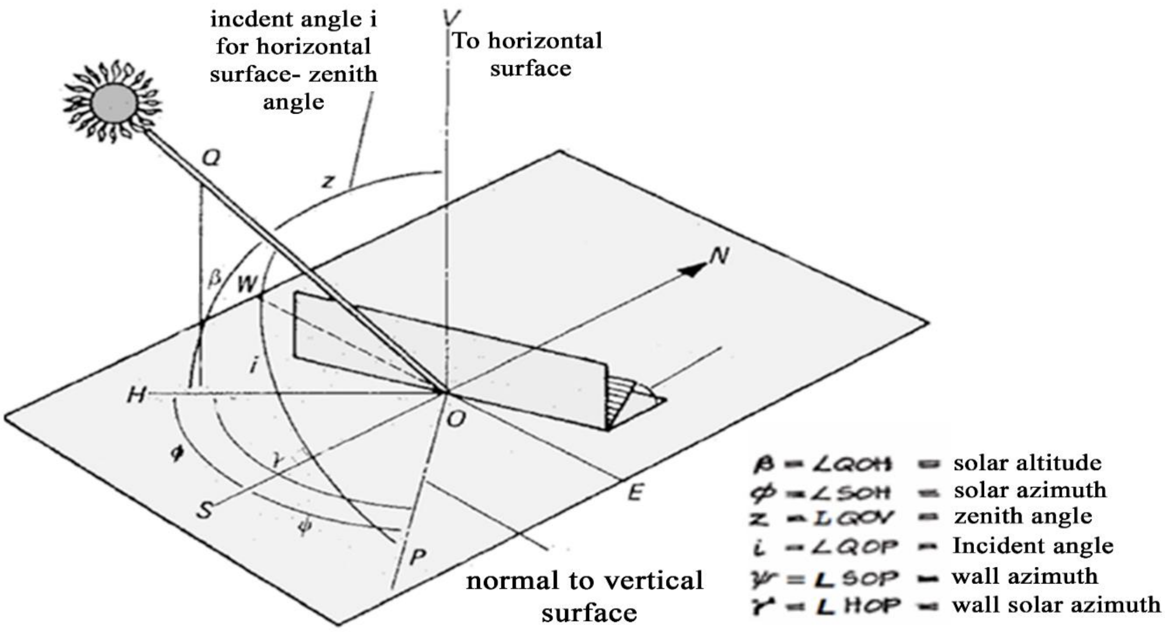


Figure 2:3:Solar For Vertical, Sloping and Horizontal surfaces(Sealey, 1979)

2.2 Parameters of Thermal Comfort

Thermal comfort can be difficult to explain because a variety of personal and environmental factors must be considered. Defined Thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment" in the globally recognized ASHRAE55 and ISO 7730 standards. The first step for engineers is to determine the thermal limit for indoor occupants in order to analyze this condition. The Predicted Mean Vote (PMV) model can express the comfort levels. PMV is an index that attempts to predict the mean value of votes cast by a group of occupants on a seven-point thermal sensation scale. P.O. Fanger created it. Guenther proposed that thermal comfort is determined by skin temperature and sweat secretion. Only when these two factors are balanced within a narrow range of acceptability can one be considered "comfortable." (Guenther, 2021).

ASHRAE 55 divides thermal comfort factors into two categories: personal factors and environmental factors. Clothing insulation and metabolic rates are personal factors, while humidity, air speed, air temperature, and radiant temperature are environmental factors. Air temperature is the most commonly used indicator of thermal comfort. It is simple to use and most people can understand it. Air temperature, on the other hand, is not a valid or accurate indicator of thermal comfort or thermal stress. It must always be weighed against other environmental and personal factors(Turner et al., 1979).

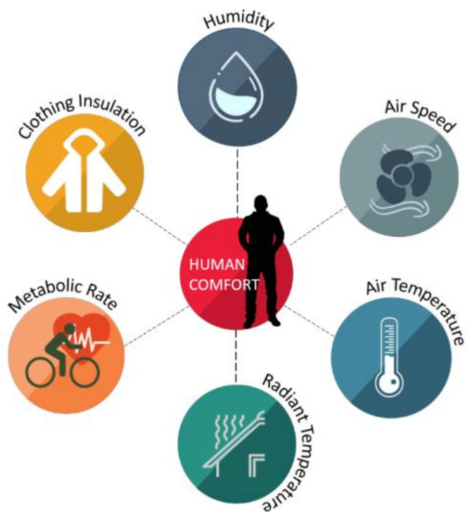


Figure 2:4: Factors Affecting human Comfort(Source:Kumar, 2019)

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

2.2.1 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(Turner et al., 1979).

Air Speed is the average speed of the air to which the body is exposed to, with respect to location and time(Turner et al., 1979).

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(Turner et al., 1979).

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(Turner et al., 1979).

2.2.2 Personal Factors

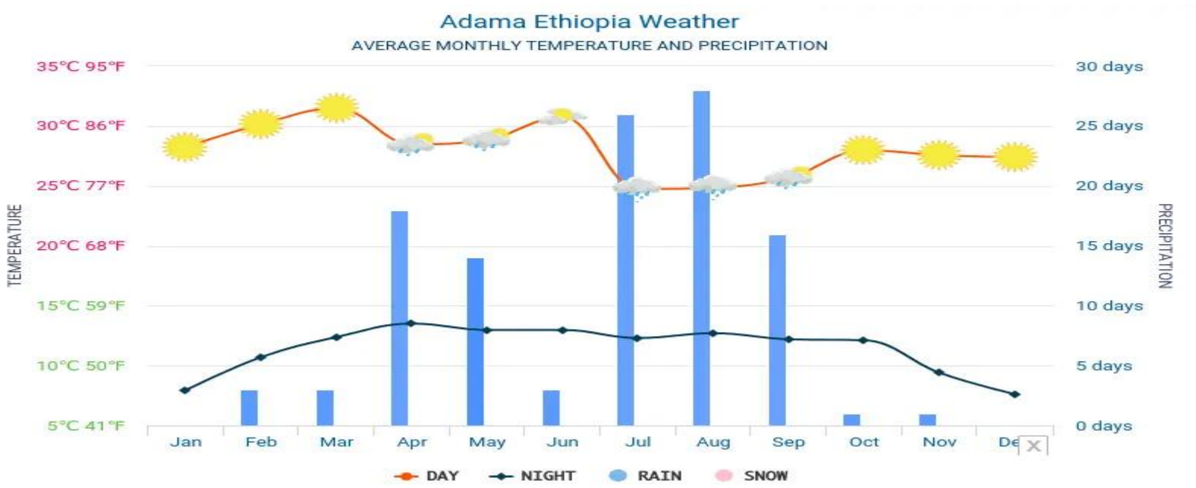
Clothing Insulation. The type and amount of clothing affects thermal comfort as it hinders heat exchange to and from an immediate environment(Turner et al., 1979).

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(Turner et al., 1979).

2.3 Climate Condition of Adama City

In Adama, the month with the most daily hours of sunshine is June with an average of 10.79 hours of sunshine. In total there are 334.63 hours of sunshine throughout June. The month with the fewest daily hours of sunshine in Adama is January with an average of 9.86 hours of sunshine a day. In total there are 295.9 hours of sunshine in January. Around 3742.14 hours of sunshine are counted in Adama throughout the year.

On average there are 123.03 hours of sunshine per month(Adama Weather & Climate | Temperature & Weather By Month - Climate-Data.Org, n.d.).



Graph 2-1 Average Monthly Temperature and Precipitation

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	19 °C (66.1) °F	20.6 °C (69.2) °F	21.9 °C (71.4) °F	22.5 °C (72.5) °F	22.7 °C (72.8) °F	22 °C (71.5) °F	20.7 °C (69.3) °F	20.2 °C (68.4) °F	20.7 °C (69.3) °F	20.8 °C (69.4) °F	19.5 °C (67.2) °F	18.3 °C (65) °F
Min. Temperature °C (°F)	12.4 °C (54.3) °F	13.7 °C (56.6) °F	15.5 °C (59.9) °F	16.7 °C (62.1) °F	16.5 °C (61.6) °F	15.8 °C (60.4) °F	15.7 °C (60.2) °F	15.3 °C (59.5) °F	15.2 °C (59.4) °F	15.3 °C (59.5) °F	13.6 °C (56.5) °F	12.1 °C (53.8) °F
Max. Temperature °C (°F)	26.2 °C (79.1) °F	28 °C (82.5) °F	28.7 °C (83.7) °F	28.9 °C (84) °F	29.1 °C (84.5) °F	28.5 °C (83.4) °F	26.8 °C (80.3) °F	26.1 °C (79) °F	26.8 °C (80.3) °F	26.8 °C (80.2) °F	26 °C (78.9) °F	25.3 °C (77.5) °F
Precipitation / Rainfall mm (in)	5 (0)	10 (0)	27 (1)	34 (1)	30 (1)	20 (0)	59 (2)	88 (3)	69 (2)	19 (0)	7 (0)	3 (0)
Humidity(%)	46%	37%	40%	46%	46%	51%	60%	64%	58%	43%	41%	44%
Rainy days (d)	1	2	3	5	4	3	11	14	11	2	1	1
avg. Sun hours (hours)	9.7	10.1	10.3	10.5	10.8	10.9	10.5	10.3	10.2	10.1	9.9	9.7

Table 2:1 Adama Monthly temperatures 1999-2019 Source :(*Adama Weather & Climate | Temperature & Weather By Month - Climate-Data.Org*, n.d.)

The mean monthly relative humidity over the year in Adama, Ethiopia.

- ✓ On average, August is with 80.0% the most humid.
- ✓ On average, February is with 50.0% the least humid month.
- ✓ The average annual percentage of humidity is: 61% Source (https://weather-and-climate.com/)

2.4 Solar Control

Long-term exposure to solar radiation may cause an increase in air temperature and severe overheating. In the case of glazed buildings, this would significantly increase cooling loads. Exposed wall and roof glazed surfaces should be reduced significantly to minimize cooling loads while allowing adequate daylight into interior spaces. This helps to reduce daytime electrical lighting and energy consumption (Hindrichs & Daniels, 2007).

Unwanted solar heat gain reductions could be achieved with proper solar control system design. As a first step, an architect must determine when solar heat gain is desirable and when it is not. An appropriate solar control mechanism can then be provided.

Prior to designing solar control systems, it is critical to understand the position of the sun throughout the year, as well as the orientations of exposed building façades. (Watson, 1997).

2.4.1. Sun Shading Systems

Solar radiation is critical in causing thermal discomfort and high energy demand for indoor space conditioning. As a result, windows and glass facades require an efficient sun shading system capable of reducing solar radiation. Natural light is generally thought to be more comfortable than artificial light. As a result, shading systems should be considered not only as a measure to protect against solar radiation, but also as an 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.

However, such conditions are difficult to achieve in practice. Nonetheless, designers must strive to achieve as close to these conditions as possible (Hindrichs & Daniels, 2007).

2.4.2. Sun Shading Systems & Classification

Based on location of shading systems, shading devices can be classified as internal, mid pane, external. This is further explained in Table 2:2 .

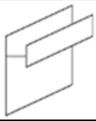
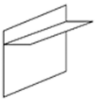
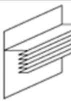
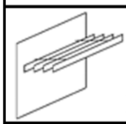
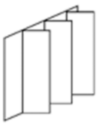
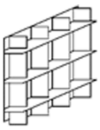
Table 2:2 Positioning of sun shading systems (Source: Hindrichs & Daniels,2007)

Shading device locations	**Characteristics**	**Effect of sun shading**
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
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
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

2.4.3. Fixed Exterior Sun Shading Systems

Windows or glazed facades may include a variety of elements, including shading devices. These elements' designs reflect a variety of functions, including thermal control. In general, three types of fixed exterior shading devices are used: vertical, horizontal, and egg-crate. Depending on the location and position of the windows, there are various types of external shading devices. The different shading types for temperate climates are illustrated in Table 2:3 (Charles & Sleeper, 1970) Such systems are more advantageous for building facades exposed to high solar heat gains all year round especially in tropical climate regions.

Table 2:3:Exterior shading Device(Source: (Charles & Sleeper, 1970))

Description	Recommended Direction	Advantage and disadvantage
 Overhang Vertical Panel	S, E & W	Free air movement, No snow load, view restricted
 Overhang horizontal panel	S, E & W	Traps hot air, can be loaded by snow and wind
 Overhang horizontal louvers in vertical plane	S, E & W	Reduces length of overhang, view restricted and available in miniature louvers
 Overhang horizontal louvers in horizontal plane	S, E & W	Free air movement, snow or wind load is small,
 Vertical fins	S, E & W	Restricted view; for north facades in hot climates only
 Vertical fin slanted	E & W	Slant toward north, restricts view significantly
 Egg crate	E & W	For very hot climates, view restricted and traps hot air

Because sunlight strikes each side of a building from different angles, each face requires a different shading treatment. Encouraging the use of exterior shading devices such as overhangs, louvers, and egg crates can greatly enhance internal thermal conditions. Among these shading devices, egg crate devices, which combine overhang and fin features, are the most effective in reducing indoor air temperature and alleviating discomfort during high temperatures (Al-Tamimi, 2011).

2.4.4 Designing Sun Shading Systems

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

- ✓ **Step One**. When shading is required, it must be determined. That is, at what times of year and at what hours of the day. Typically, this is accomplished by defining the overheated and underheated periods.
- ✓ **Step Two**. The sun's position must be determined for times when shading is required. This is usually accomplished with the help of sun-path diagrams.
- ✓ **Step Three.** The dimension and proportion of the shading device that will provide shading during the previously defined period must be determined. This is accomplished with the help of a shading angle protractor. The shading angle protractor is used to determine the shading device's horizontal and vertical shading angles. The shading angles can only be calculated for one orientation at a time.

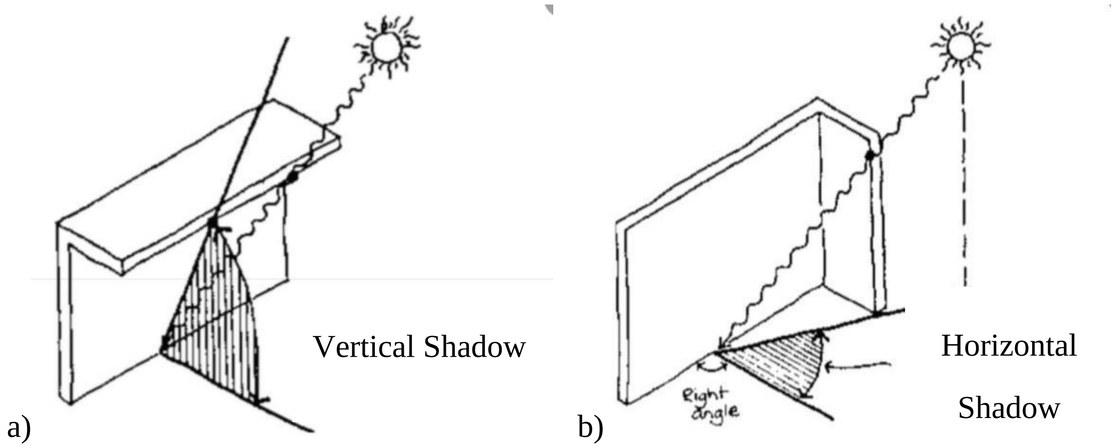


Figure 2:5: (a) vertical & (b) Horizontal shading angle (Source: Sealey, 1979)

- ✓ **Step Four.** The option of using prefabricated devices or designing new ones. Shade devices are designed with not only the required geometry in mind, but also aesthetics and structural factors.

2.5 Tools for Shading Systems Analysis

Due to changing environmental conditions, the manual calculation of temperature and visibility parameters for many zones or buildings has become more complicated. These include changes in outside air temperature and solar radiation over time, shading from neighboring buildings, self-shading and the thermal capacity of the building. Computer-based simulation tools are now available to quickly and accurately assess a building's thermal and daylighting performance. These tools can estimate the performance of different building designs for a specific environmental condition.

2.5.1. Simulation Tool

Various simulation tools have been developed to date to assess and make informed design decisions about building energy performance during the pre-design, design, and construction phases. Choosing from a list of these tools can be overwhelming for professionals. Many scientific studies have been conducted to help identify the needs of different users versus tool capabilities and limitations in order to aid architects and engineers in their selection process. Shady Attia and his colleagues (2012) conducted a study that included the identification of user requirements, selection criteria for building performance simulation (BPS) tools, and an online survey of inter-group comparison between architects and engineers. Architects and engineers ranked accuracy, usability, and interoperability as the most important simulation tool parameters. 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). A list of some of the most well-known simulation tools for assessing building energy performance is provided below.

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 Energy Plus Cloud capabilities to provide a holistic approach to building performance(*Revit Add-Ons: Introducing Autodesk InSight 360*, n.d.).

Energy Plus: Is a whole building simulation engine that is open-source and is free. It is one of the early developed software 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(*Energy Plus*, 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 Energy Plus dynamic thermal simulation engine. As such, it is equipped with an advanced graphical user interface mainly intended to run simulations using Energy Plus. 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).

2.6 Empirical Literature review

2.6.1 International Practice on shading Device

As research conducted (Ishaq & Alibaba, 2017) in Nigeria on thermal comfort on residential building regarding shading device. This study was conducted in Zaria of Nigeria, Kaduna state on residential building how thermal comfort can be attained through the integration of sun shading device in external building elements by modelling building using Autodesk Revit software and later on simulating with Ecotect simulation software by comparing the thermal comfort of building with shading device and with out shading device using weather data of the location. This study used only simulation software without addressing thermal comfort satisfaction of occupant and with out instrumental measurement of Environmental variables (Temperature, Humidity, Air velocity & day light illuminance). This paper finding show that effects of shading device and it can improve thermal comfort. However, this study is not addressed occupant perception, so to mitigate this research gaps its necessary to understand occupant perception with thermal preference scale, taking measurement on environmental variables and understanding sun projector and existing shading device angles of horizontal shadow and vertical shadow to come up with new solution.

As stated (Tzempelikos & Athienitis, 2007) a shade system's design and control are significantly influenced by the climate and the amount of daylight available. Both daylighting and thermal performance of peripheral spaces are significantly influenced by the positioning, characteristics, and control of the shading device. Simple shading modeling techniques have shown to be unreliable in predicting the impact on thermal and daylighting (ASHRAE, 2001). The most efficient way to determine the annual energy performance of fenestration and shading is through dynamic, hourly computer simulations tailored to the target building and climate.

As research conducted in Iwan, Persian (Eskandari et al., 2017) by simulating several forms of Iwan for various climates and orientations, the effects of the shade element on the decrease of energy consumption in a building and on the thermal comfort of the building's occupants were assessed. The data obtained show that the from various shading device overhang shading device is the key component of Iwan's design. In hot and humid, cold and mountainous, temperate and humid, and dry and hot regions, respectively, overhangs can reduce a building's yearly thermal load by 18%, 14%, 28%, and 24%.

2.7 Summary of literature and research gaps

As different research tried to assess on related thermal comfort and shading device, study by (Tzempelikos & Athienitis, 2007, Eskandari et al., 2017 and Ishaq & Alibaba, 2017) where reviewed as literature from these study research gap is summarized as continued.

- ✓ In research entitle ” Effects Of Shading Device On Thermal Comfort Of Residential Building” In Northern Nigeria(Ishaq & Alibaba, 2017).To assess effects of shading device used software simulation with temperature distribution and this study is not conducted through thermal preference of occupants, there is no field measurement on environmental variable.
- ✓ As (Tzempelikos & Athienitis, 2007) stated that Simple shading modeling techniques have shown to be unreliable in predicting the impact on thermal and daylighting (ASHRAE, 2001). The most efficient way to determine the annual energy performance of fenestration and shading is through dynamic, hourly computer simulations tailored to the target building and climate.

CHAPTER THREE

METHODS AND MATERIALS

3.1 Description of study Area

This research was conduct in Adama city, Adama is a city located in central Oromia Regional state of Ethiopia. Located in the East Shewa Zone, southeast of the capital city, Addis Ababa. It is situated between an escarpment to the west and the Great Rift Valley to the east. It is located at (8.54°N 39.27°E) at an elevation of 1712 meters, 99 km southeast of Addis Ababa.

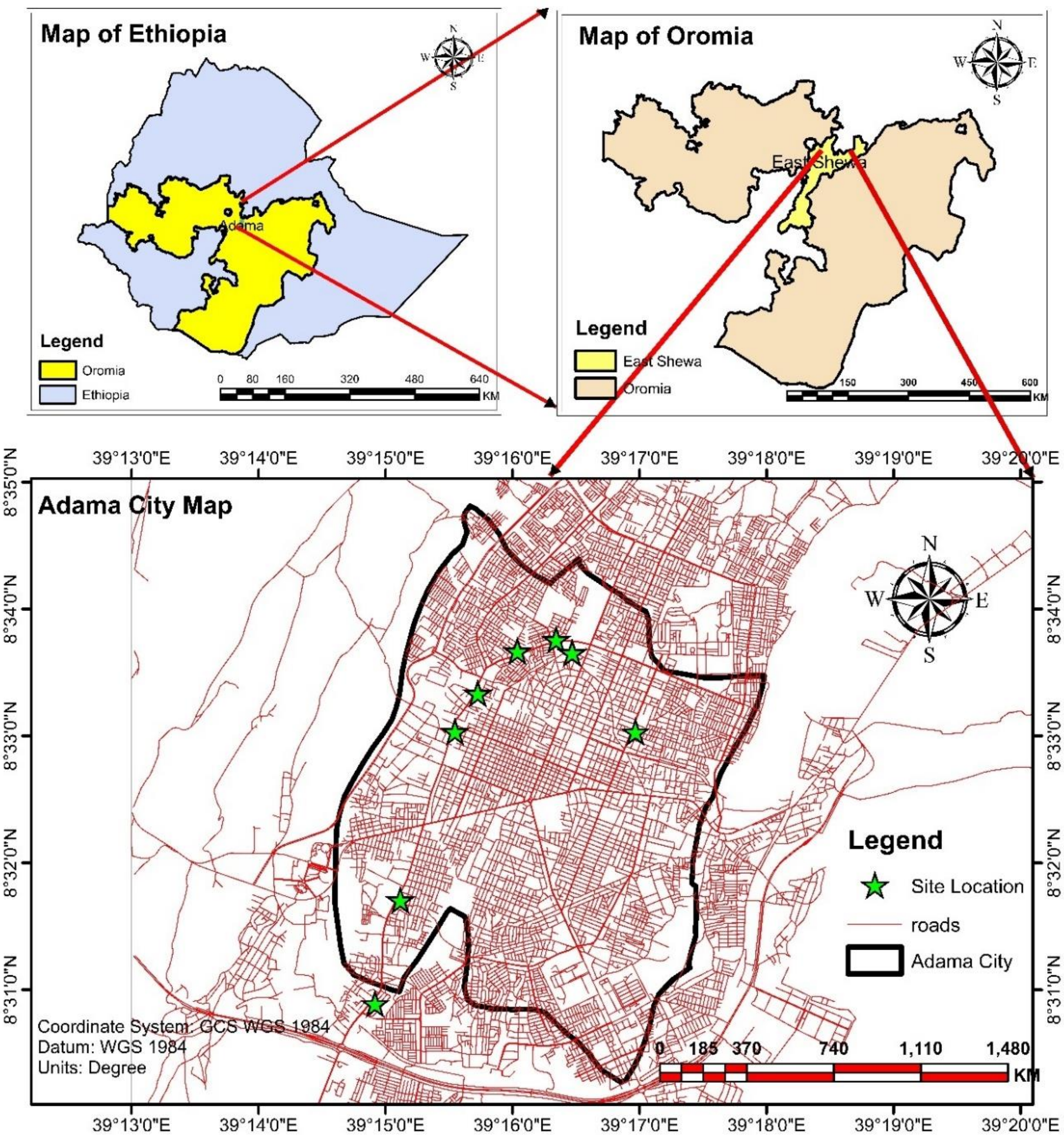


Figure 3:1 Location Map of Adama city (Source: author, (2022))

3.2 Research Design

The work flow of this paper is as shown in Figure 3:2 Thermal comfort and shading devices are inter-reliant. Shading devices with consideration of sun path, window size, overheating month, and orientation have a direct impact on indoor thermal comfort, so starting with reviewing related work and standards, a design solution is provided.

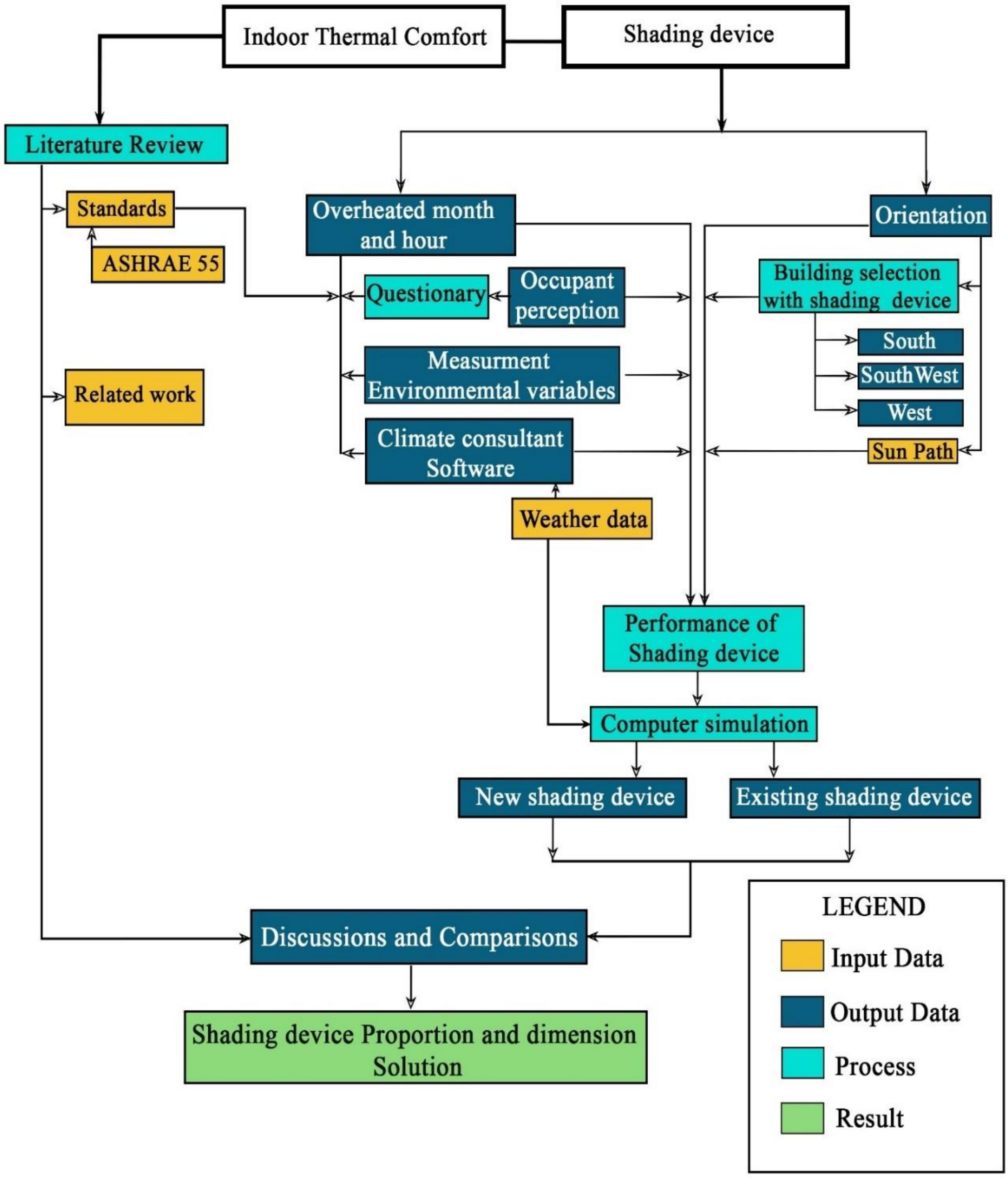


Figure 3:2: Research design framework chart (Source: Author:2023)

In this research categories of the method were used as the specific objective of the study are.

- The main environmental factors listed as the factors influencing thermal performance of particular space in international standards like ASHER and ISO are temperature, day light illuminance, humidity, and solar radiation. The thermal occupant satisfaction is evaluated using a questionnaire and selected condominium buildings' indoor thermal comfort levels were examined. According to ISO 7726 (Ergonomics of Thermal Media Instruments for Measuring Physical Quantities), the measurement was completed. was measured at a height of 1.2 meters in the middle of the room, away from any heat sources, in accordance with the prescribed specifications.
- Second objective is simulated and designed shading device. (Based on the analysis of indoor thermal quality, it' is used for simple processes and spatial interpretation through modeling (Ecotect, Energy plus, ENV-Met, and IES-VE simulation)). conducted based on indicators such as solar radiation, Visual comfort, humidity, Air velocity, and temperature.

3.3 Research Approach

To identify thermal satisfaction of occupants and impacts of shading device this study was used a descriptive research Approach as attempts to identify existing problem and proposed appropriate scientific solution approach.

3.4 Methods

For this study, all condominium sites observed and the sample size selected depending on Several criteria. The National Metrology Agency of Adama and weather data from the city of Adama have been gathered to provide the necessary data concerning the dry bulb temperature, relative humidity, daylight hours, and wind speed with their maximum, minimum, and average values for every month. This can be seen in the weather file data that Climate Consultant and Ecotect software have evaluated. Condominium's building was selected as their design is very critical in terms of how shading device is affect temperature, humidity, airspeed, and solar radiation due to perimeter, window size, shading device height and width, and sun path location. The Condominium buildings have different exterior shading devices attached to them. Information regarding their location, orientation, height, shading type, shading material, and layout is explained.

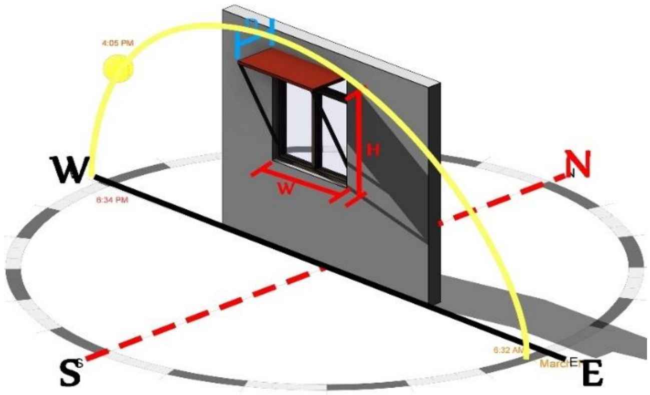


Figure 3:3.Shading device type and window size measurement

From April 20 to May 10, 2023, the measured data was collected three times daily at 3:00 AM to 4:00 AM, 6:00 AM to 7:00 PM, and 9:00 PM to 10:00 PM local time. The measuring device were placed in the center of room including both room with shading device.

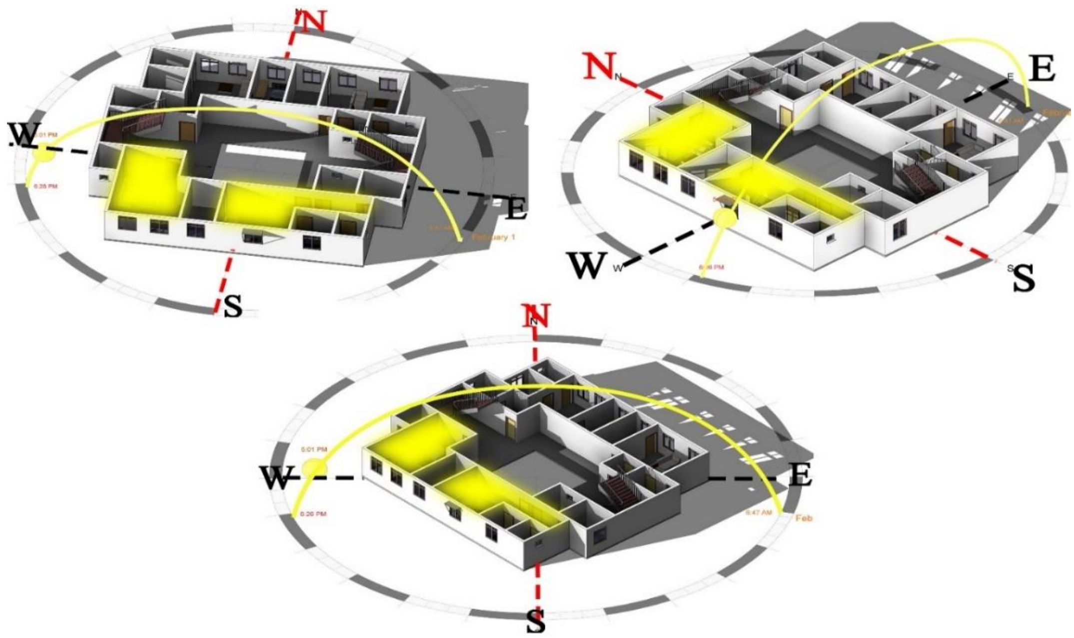


Figure 3:4 Sample blocks and room orientation used shading device

3.5 Sample techniques

Although there may be many buildings that are related to a topic in research, this study only looked at condominium buildings. The choice of a building was based on the following determining variables. Numerous issues, such as unregulated room temperatures, solar radiation, and shading device used building, are present in repetitive buildings in varied locations. In Adama city There are eight (8) condominiums site located in four kebele. those are located.

Figure 3:5 Adama Condominium Site Location (Source: Google Earth)

Table 3:1:List Adama Condominium Building & site location

Site Name	**Kebele 01**			**Kebele 04**		**Kebele 05**	**Kebele 09**	
	Atenatera	**Goro**	**Silase**	**Ganda Gara**	**Cherkacerk**	**Moenko**	**Duket**	**Sodo Ber**
No. Of Blocks	**11 Blocks**	**22 Blocks**	**12 Blocks**	**15 Blocks**	**7 Blocks**	**9 Blocks**	**39 Blocks**	**7 Blocks**
Blocks	**45 Blocks**			**22 Blocks**		**9 Blocks**	**46 Blocks**	
	122 Blocks							

From those different sites of condominium Building the building site are selected by observation depending by the following criteria

- ✓ Building orientation (building that facing direct to the sun)
- ✓ The building that has shading devices as solar control.
- ✓ At least the occupied for a year
- ✓ Location

Based on the above criteria 4 sites of Condominium Building are selected

Table 3:2: Selected Condominium site location

	Kebele 04		Kebele 05	Kebele 09	
Site Name	Ganda Gara Condominium	Cherkacerk Condominium	Moenko Condominium	Duket Condominium	SodoBer Condominium
Numbers of blocks	15 Blocks	7 Blocks	9 Blocks	39 Blocks	7 Blocks
Numbers of blocks Selected	4 Blocks	2 Blocks	2 Blocks	5 Blocks	2 Blocks

Kebele 01			
Site Name	Atena tera Condominium	Goro Condominium	Silase Condominium
Numbers of blocks	11 Blocks	22 Blocks	12 Blocks
Numbers of blocks Selected	3 Blocks	1 Block	2 Blocks

For subjective measurement, the study used a random sampling method for selected buildings with different functions. The random sampling technique selected based on

- ✓ to collect data from selected buildings who living there,
- ✓ Whom the questionary respondents who filled out the surveys would have chosen based on their experience living in condominium,
- ✓ To reach the targeted issues of specific objectives.

From total 122 blocks of buildings 21 blocks selected for as show Figure 3:3, From 21 blocks Sample building and room For field measurement two similar room typology Selected by sampling out the building and orientation which used most of shading device repetitively.

3.6 Sample size

The number of the size is determined according to Kothari (as cited in Gosaye B, 2007), kish (1665) (Asgedom, 2014). As research conducted by (Barka & Dr. C. Senthil Kumar, 2020).Accordingly, Adama City office for Housing and Urban Development has already constructed 2788 condominium houses.

Formula 1: $\mathbf{N_t} = \frac{n}{1} + \frac{N}{n}$……Equation (1) …Estimated household size (Singh & Masuku, 2014).

Where:

- **n**= the chosen sample of household
- **N** = total households, (Total Household of condominium 2788)
- $\mathbf{N_t}$= Estimated household size

Formula 2: $\mathbf{n} = \frac{(Z^{2} * p * q)}{d^2}$… (2) …Cochran Equation the selected sample of households (Singh & Masuku, 2014)

Where:

Z= standard normal variable at the required confidence level,**90% (Z=1.96)**

- **p**= estimated characteristics of target population, **(0.50)**
- **d**= level of statistical significance **(i.e., 10%)**
- **q**= maximum standard deviation

Formula 3: q= 1-p…. Maximum standard deviation (Singh & Masuku, 2014)

q=1-0.5=0.5

$$: \mathbf{n} = \frac{(1.96)^{2} * 0.5 * 0.5}{0.1^{2}} = 96.04$$

$$: \mathbf{N_t} = \frac{96.04}{1} + \frac{2788}{96.04} \ldots\ldots$$

$$: \mathbf{N_t} = 96.04 + 29.04$$

$$: \mathbf{N_t} = 125.08$$

=125.08 ≈ 126 (household sample size)

A sample of 126 households (n=126) is selected from a total household of N=2,788, within the condominium housing. The sample households are chosen using a stratified random sampling method and it's used to select the sample houses. Based on the following, sampling technique used for questionnaires distributed based on

A) Harsh Sun facing building room occupant (opening using shading device)
B) Who would have been the experienced of living in condominium house more than years.
C) For the need to reach the targeted issues of specific objectives

3.7 Data Type and Sources

Research Data collected from related literature reviews, site visits and observations, sample surveys, and other sources used in the research. Primary data sources used throughout the procedure in this study and include (questioners, observation, interviews and field-survey). Secondary data from Research journals, published studies, articles, books, and websites with standards like ASHRAE and ISO, as well as videos on shade design.

3.8 Data Collection

This paper used primary and secondary data sources regarding this qualitative and quantitative data types appplied.

A. Qualitative Data Collection Methods

Such methods require close relationship between the research, the research, and the situational factors that influence the inquiry. are hence frequently far more time-consuming. This paper Methods include participant observation, semi-structured interviews, and introspection.

B. Quantitative Data Collection Methods

The systematic and scientific study of quantitative qualities and correlations. They are primarily concerned with measuring, collecting, and evaluating numerical data. In general, methods include Laboratory observations and questionnaire. After collecting data, the Analysis is made. In relation to this research, the most popular methods used are real simulation, Experimental, questionnaires and computer simulations.

3.8.1 Primary data

3.8.1.1 Methods of Primary Data Collection

The primary data collection methods are assessments, questionnaires, and selected building measurements of shading device to gather qualitative data. The methods for each method are explained below.

A. Questionnaire and Interview

The interview focused on giving valuable information about the problem, the solution they thought, and whether or not the solution they used is comfortable.

- To understand scale of thermal Comfort satisfaction.
- To know impact of shading device and their perception.
- To know other solution, they are using beside shading device and technique the used.

For carefully chosen sample houses, questionnaires are delivered. The questions are intended to help understand how satisfied people is with the way that buildings manage indoor temperature and their indoor thermal quality. Survey sample questionnaires are distributed for 126 households. The questionnaires from each respondent are evaluated according to ASHRAE thermal sensational scale. It involved a seven-point scale of Thermal Preference:/Thermal Satisfaction/ thermal sensation vote (TSV): from -3,-2,-1,0,1,2,3, cold / Much too cool, slightly cold/ Too cool, cool/ Slightly cool, neutral, warm/ Slightly warm, slightly hot/ Too warm, and Much too warm/hot respectively. The questionnaires are written in English.

B. Measurements on buildings' shading devices.

Buildings related to this paper are selected depending on the selection criteria Essential measurements have been recorded encompassing the location orientation height type material and shading devices layout

C. Observation

Data collected from 21 Blocks out of 122 Building blocks in 8 condominium sites based on factors including building mass, opening size, direction, climate, and shading devices, among others. Because of the field measurement is time consuming two similar room typology used by sampling out the building and orientation which used most of shading device repetitively. Opening size, shading device size, room temperatures, air velocity, and relative humidity would be determined from all of these data. Measuring Equipment used to measure the room's environmental variable. This Data's was automatically recorded every 10 to 20 minutes.

D. Field Survey

On Field study observed that the way of life of the Adama society who live in the chosen building and how their indoor thermal comfort challenges them. It also observed that the methods employed by the residents in order to heat and cool their homes as well as the various ways in which they utilize shading devices on their buildings. The criteria Mentioned above, blocks were picked for the study during the field survey.

- ✓ This method used to observe the current circumstances of the chosen building under investigation by traveling to the chosen buildings and independently evaluating the present state based on thermal quality and shading device principles. Compared the existing building with that of shading device integration principles, a standard checklist for thermal comfort created, which was defined shading device integration on building concepts like indoor air quality, indoor environmental quality, dissatisfaction percentage PPD, and percentage of mean vote PMV.
- ✓ Environmental variable (Temperature, air velocity, daylight illuminance and humidity) data collection

Using a digital thermo-hygrometer (Appendix II), interior temperature and humidity data are gathered. Because of the average of the sun's light, the data were recorded over a period of 20 consecutive days with a two-hour interval beginning at 3:00 pm and ending at 10:00 am (the data will record manually) Air temperature (Ta), Instrument=HOLDPEAK Digital Anemometer Heat Stress Meter, Handheld Wind Speed Meter HVAC, HP-881W CFM Anemometer, Range=0°C – 50°C, Accuracy +/-0.6°C °C Relative Humidity (RH), Range=0.1%~99.9%RH, Accuracy ±10.0%~90.0%@25°C: Typical 5%.Others 7% RH Instruments used to measure Environmental variables.


Figure 3:6: HOLDPEAK Digital Anemometer Heat Stress Meter, Handheld Wind Speed Meter HVAC, HP-881W CFM Anemometer and LX-1010B Digital Light Lux Meter 0 - 50,000 Lux

Table 3:3 Instruments used to measure Environmental variables

Environmental indicator	Indoor Temperature and Relative humidity	Air Speed	Daylight illumination
Testing instrument	Thermometer	Anemometer	Lux meter
Specific objective	To measures air temperature of room. Hot-Cold (°C). And relative humidity (Water vapor in air) of room. Percentage.	To measure the speed or volume of air movement of room.	To measuring the level of daylight illuminance) which is affect indoor thermal comfort.

3.8.2 Secondary data

Literature such as journals and guide books are used to relate the situation of the area with different researchers used also help to figure out what kind of approach help. Climate data used as input for simulation software.

3.9 Data quality assurance

Even if there are different confounding variables regarding the nature of the topic this study used methods that can enhance better quality data. The value of measuring instruments was cross checked with the standard like ASHRAE 55.

3.10 Data analysis

A state of mind reflecting happiness with the thermal environment is known as thermal comfort in the house. Ensuring appropriate indoor thermal quality is essential for sustaining a good indoor environmental quality. Additionally, one should be aware that a variety of environmental conditions, including heat from the sun, inadequate ventilation, high humidity, and solar radiation, can have a negative impact on people using interior spaces in terms of their health and performance (Sangowawa and Adebamowo 2012).

Our body’s metabolic activities are responsible almost completely for the heat we produce and we lose to maintain normal body temperatures. Skin temperature greater than 113°F or less than 64.5°F causes pain (ASHRAE, 2009). In contrast, internal temperatures rise with activity. Depending on the things such as the activity of a person and what they are wearing occupants are generally comfort in room temperatures of 20-22oC (68-72oF). The collected data from primary and secondary are analyzed in qualitative and quantitative data forms. the data analyzed using different software is presented in maps, graphs, and tables. Combining subjective and objective measurements can produce excellent prediction results when evaluating indoor thermal quality (Verheyen et al., 2011).

With the comfort zone as described by the ASHRAE 55 Standard, the indoor thermal environment characteristics found in the building (air temperature, relative humidity, and air velocity) are analyzed. The study determined the relationship between temperature perception level and environmental factors that could be assessed.

Table 3.3. Data analysis tools and outputs

No	Software types	Input	Output
1	Microsoft office Word, MS Excel	Raw Data	Graphs, Tables, Text
2	Revit Architecture and AUTO CAD	CAD files	3D models, 2D models
3	Ecotect 2011 Simulation	Models	2D models, 3D models

In scientific research, analysis is essential to evaluate study-related samples. A rational and methodical methodology would demonstrate a study's validity. Building analysis is carried out in this study using a set of steps.

The stages listed below go into additional detail about these steps.

- ✓ Identification of Parameters
- ✓ The process of identifying, selecting, and justifying simulation software tools
- ✓ The methodology for generating data on shading devices
- ✓ The procedure for analyzing data

3.10.1 Identification of Parameters

While analyzing sample sizes in research, there are numerous factors that need be taken into account. Working with all the variables throughout a scientific inquiry is difficult. It's crucial to determine the independent and dependent variables as well as which variables should be treated as constants. This aids in determining the effect of the relevant variable and helps to narrow the study's focus. The study recognizes the following parameters.

- ✓ **Dependent.** Thermal Comfort
- ✓ **Independent**. Shading device type, shading device length, shading device orientation solar radiation
- ✓ **Constant**. glazing type, room size, construction materials, indoor colors and window sizes**.**

3.10.2 The process of identifying, selecting, and justifying simulation software tools

During the literature review, it was observed that several buildings used simulation applications have been evolving swiftly to offer more flexible and precise options. According to the findings of a research carried out by (Shady Attia et al. in 2012), architects and engineers prioritize to graphical visualization of interface and usability, accuracy of the tool, and compatibility of the building model as the most crucial parameters in their work. Based on these factors, Autodesk Ecotect 11 software is preferred for simulation purposes.

3.10.3 The methodology for generating data on shading devices

3.10.3.1. Computer Simulations

There are different existing shading devices with in different orientations. This method helps assess their efficiency and generate quantitative data. For this purpose, a “Sample” Model is used. It enables the simulation of various shading schemes in various orientations. Southwest, South and West orientations. To assess the effects of shading devices, and monthly temperature distribution analysis are simulated on the three major orientations. This would help to analyze and compare how they perform during overheated months throughout the year. Based on the selection and justification criteria mentioned, Autodesk Ecotect 11 is used for simulation.

Procedures

1. Creating models of the determined fixed exterior shading type for usage in samples.
2. Simulating a sample model for initial results. The simulations are temperature distribution of hottest month.
3. Simulating for each shading device for West Southwest and South orientations on the sample.
4. Comparing and Discussing about the results of orientation.
5. Recommending the best sun shading strategy based on meteorological data from Adama and testing on a sample for orientations in the southwest, south, and west.
6. Results of the suggested shading device and the currently used shading devices are compared.

3.10.4 The procedure for analyzing data

The data obtained from building measurements and questionnaires, as well as simulations, will be quantified and systematically arranged. Subsequently, the resulting output will be evaluated comprehensively to derive a credible conclusion.

3.11 Ethical Considerations and interpretations.

For quality output the study has given prior concern on awareness creation on purpose and goals of the research. Consent from each study participants have obtained, before data collection. The anonymity and confidentiality of information are secured. Legal permission is attained from Adama Condominium building. All material used throughout the study are acknowledged. The measuring equipment’s are located in a way that doesn't disturb households. The data analyzed relatively to the standards without manipulation

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This chapter explains the results of the data and presents the collected and analyzed data to confirm the research objectives during the study. Subjective approaches were used, according to ISO 7730 and ASHRAE 55. The occupancy thermal satisfaction of Adama condominium residents, the thermal preference scale of occupants gathered using PMV (predicted mean vote), the thermal sensational scale of occupants gathered using PMV (predicted mean vote), the thermal discomfort hours and overheated months, Sun paths and building orientation with shading device information and measurement

4.2 Respondents' information

4.2.1 Gender of the respondents'

According to Chart 4:1, 21 block condominium buildings in Adama were surveyed to collect data. A total of 126 occupants were involved in the survey, of which 55 were male, accounting for 44%, and 71 were female, accounting for 56%. The objective of this survey was to determine and evaluate the occupants' overall perceptions of indoor thermal comfort in their living areas.

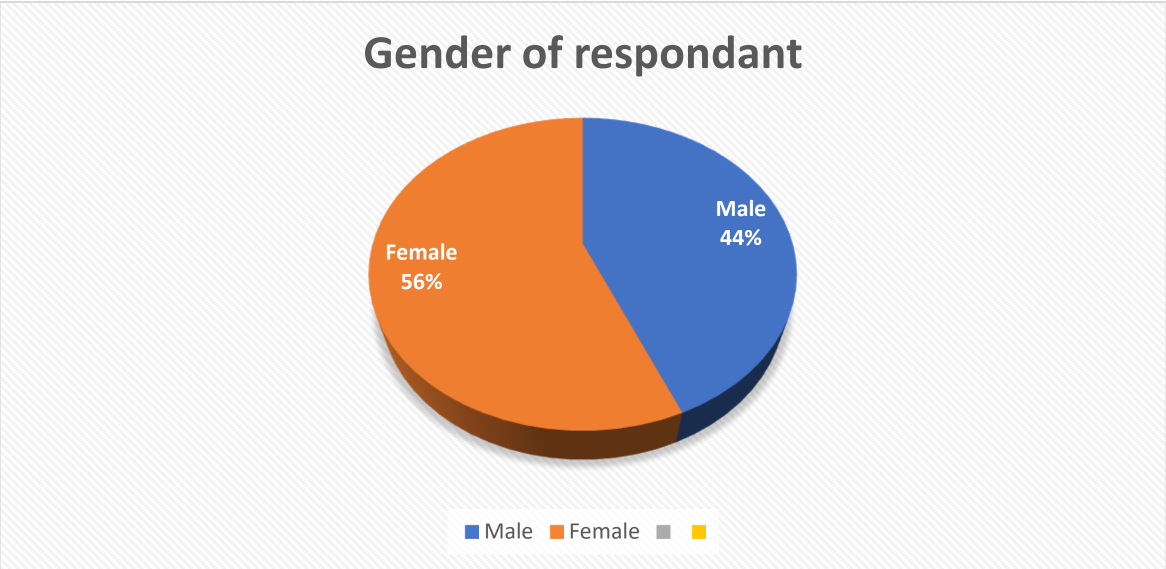


Chart 4:1: Gender of respondent (Source: Data Survey)

According to research conducted (Karjalainen, 2007), females are less satisfied with room temperatures than males and feel both uncomfortably cold and uncomfortably hot more often. This suggests that females tend to be more critical of their thermal environments and are more sensitive to both cold and hot room temperatures. For this reason, the majority of respondents to this research are female.

4.2.2 Age of respondents

According to research conducted by (Havenith, 2001) and (Hoof & Hensen, 2006) Typically, the activity level and metabolic rate of older adults are lower compared to younger individuals, resulting in their need for higher ambient temperatures. Moreover, as age increases, the ability to regulate body temperature tends to decline. According to the data collected, as shown in Chart 4:2, The respondent range is from 15 to over 61 years old. From a total of 126 people, most of them were between the ages of 15 and 30 (48.5% = 61 people), 31–45 (35.71%) = 45 people, and 46–60 (15.8% = 20 people).

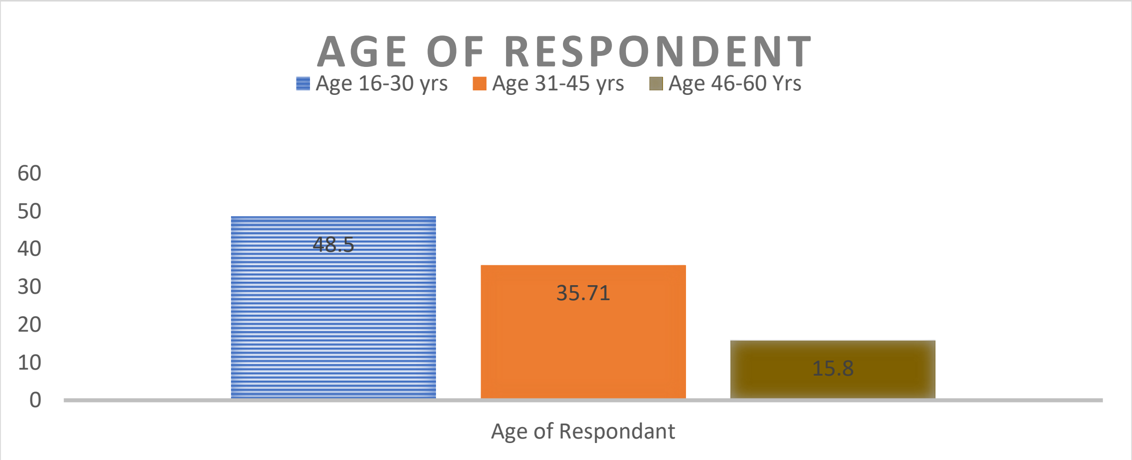


Chart 4:2: Age of respondents (Source: Data Survey)

4.3 Occupant's perception

In collecting data using this method, a total of 21 building blocks in Adama City were surveyed, and a total of 126 occupants were involved. The survey questions aimed to identify and assess the general perceptions of occupants regarding indoor thermal comfort in their respective living environments. In the table below, it shows the number of respondents and their responses during overheated periods.

4.3.1 Thermal preference Scale

The preferred thermal environment is defined by the ASHRAE 55 standard. As a result, the survey data of the respondents is provided in Table 4:1.

Table 4:1: ASHRAE 55 thermal Preference scale (Humphreys, 2007)

PMV Value	Thermal Preference	Time					
		3:00am-4:00am		7:00pm-8:00pm		10:00pm-11:00pm	
3	Hot	0	0.0%	65	51.6%	32	25.4 %
2	Warm	0	0.0%	26	20.6%	46	36.5 %
1	Slightly warm	52	41.3%	23	18.2%	27	21.4 %
0	Neutral	57	45.2%	12	9.5%	21	16.6 %
-1	Slightly cool	17	13.5%	0	0.0%	0	0.0%
-2	Cool	0	0.0%	0	0.0%	0	0.0%
-3	Cold	0	0.0%	0	0.0%	0	0.0%

According to Table 4:1 the thermal comfort response over south west, south and west facing 7:00pm-8:00pm shows the highest thermal preference about 65=51.6%, 26=20.6%, 23=18.2%, 12=9.5%, 0=0.0%, 0=0.0% and 0=0.0% of respondent where feel hot (+3), warm (+2), slightly warm (+1) neutral (0), slightly cool (-1), cool (-2) and cold (-3) respectively. The thermal comfort response of a building has the weakest performance.

4.3.2 Thermal sensational Scale

The ASHRAE 55 standard specifies the optimal thermal environment. As a result, the survey data of the respondents is provided in Table 4:2.

Table 4:2: ASHRAE 55 Sensational scale (Series & Science, 2018)

Level of Scale	Thermal Sensational	Time					
		3:00am-4:00am		7:00pm-8:00pm		10:00pm-11:00pm	
-3	Very Uncomfortable	0	0.0%	21	16.6%	12	9.6 %
-2	Uncomfortable	12	9.6%	53	42.1%	37	29.4 %
-1	Slightly Uncomfortable	15	11.90%	42	33.3%	50	39.7 %
0	Comfort	70	55.5%	10	7.9%	27	21.3 %
1	Slightly comfortable	21	16.6%	0	0.0%	0	0.0%
2	comfortable	8	6.3%	0	0.0%	0	0.0%
3	Very comfortable	0	0.0%	0	0.0%	0	0.0%

According to Table 4:2, The collected data on sun-facing orientation, 7:00 p.m.–8:00 p.m., concerning the satisfaction scale indicates that 21 = 16.6% were said to be very uncomfortable, 53 = 42.1% were uncomfortable, 42 = 33.3% were slightly uncomfortable, 10 = 7.9% were neutral, 0 = 0.0% were slightly comfortable, 0 = 0.0% were comfortable, and 0 = 0.0% were very uncomfortable. Accordingly, the residents of the Sun facing west, south west, or south (south-oriented) are not comfortable, as the result shows that the respondents highly answered uncomfortably than comfort.

4.3.3 Thermal discomfort hours and overheated month

Table 4:3 demonstrates that from January to May, from 6:00 to 10:00 pm is the most thermally unpleasant hour in all buildings, while April and May are the most excessively hot month. According to the findings of the subjective investigation, residents' temperature perception in the morning is generally within a comfortable range.

Table 4:3: Overheated hours and month result (Source: Data Survey)

Overheated hours and month result											
PPL	Overheated Month		Response				Overheated Time(24hr.)	Response			
126	Kiremt (Winter)	JUN					Morning				
		JUL					08:00-09:00				
		AUG					09:00-10:00				
	Belg (Autumn)	SEP					10:00-11:00				
		OCT					11:00-12:00				
		NOV					Afternoon				
	Bega (Summer)	DEC					12:00-1:00	52		21	
		JAN	11				1:00-2:00		34		
		FEB		22	36		2:00-3:00				9
	Tseday (Fall)	MAR					3:00-4:00				
		APR	49	8			4:00-5:00				
		MAY					5:00-6:00				

In identifying the overheated months, the following percentages were claimed by respondents: January and February by 8.7%, February and March by 28.6%, April and May by 38.9%, April by 6.3%, and February by 17.5%. 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 12:00 p.m. to 4:00 p.m. was claimed to be thermally uncomfortable by 46% of respondents.

4.4 Environmental variables measurement analysis and discussion.

Field measurement was carried out in a south-facing room with and without a shading device on a similar floor, as I tried to explain in Chapter 3 Methods and material.

4.4.1 Temperature

Chart 4:3 shows the highest and lowest outdoor temperatures recorded in April and May. The maximum temperature, which was 33.6 °C, was recorded in April, while the minimum temperature, which was 25.4 °C, was recorded in May. The lowest temperature, which was 24 °C, was recorded between 3:00 am and 4:00 am in the morning, while the highest temperature, which was 33.6 °C, was recorded between 6:00 am and 7:00 am.

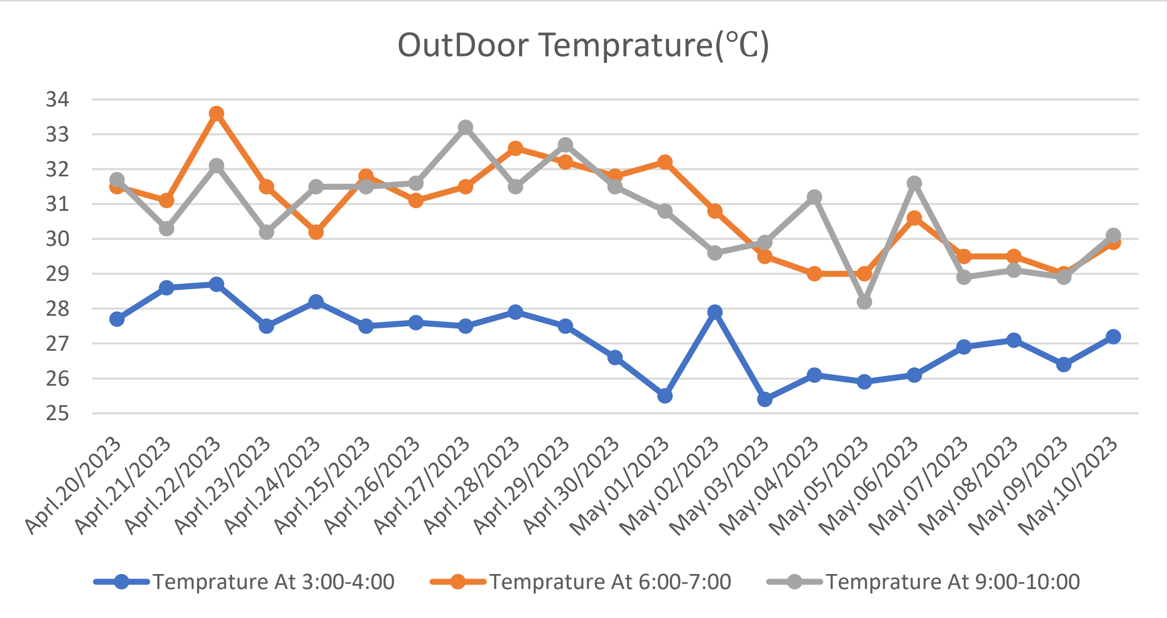


Chart 4:3: Outdoor Temperature (Source: Field Measurement)

4.4.1.1 Indoor temperature of south facing room window with shading device

According to Chart 4:4 the highest indoor temperature of the living room was recorded at 31.9 °C, the minimum indoor temperature was recorded at 24 °C, and the outdoor temperature ranges from 25.4 °C to 33.6 °C. The lowest indoor temperature recorded in the morning between 3:00 am and 4:00 am is 24 °C, and the highest temperature recorded is between 6:00 am and 7:00 am at 31.9 °C.

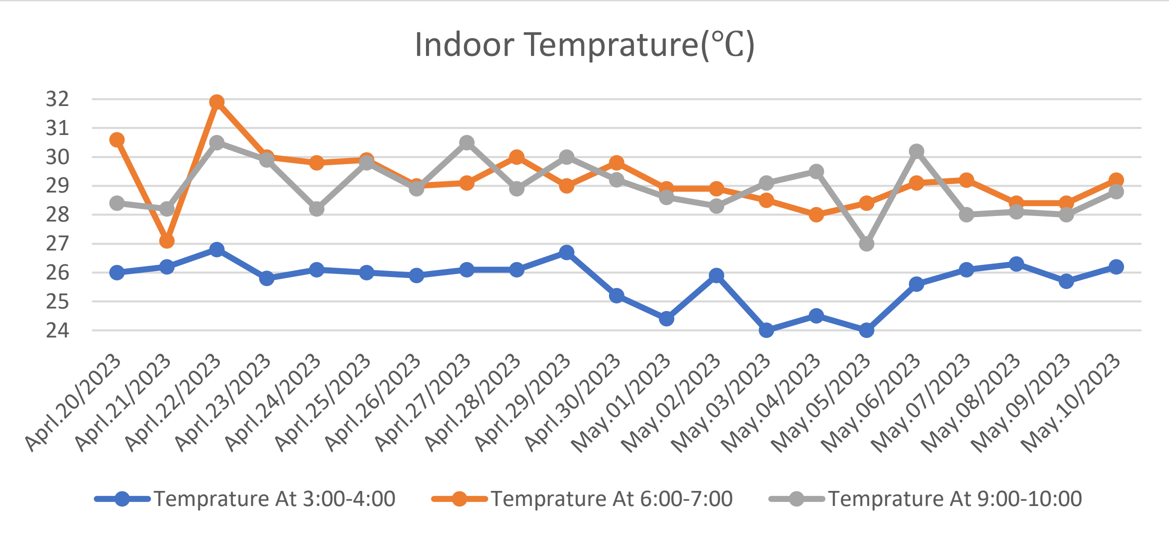


Chart 4:4: Indoor Temperature of living room with shading device (Source: Field Measurement)

4.4.1.2 Indoor temperature of south facing room window without shading device

Chart 4:5 presents an insightful analysis of the indoor temperature recordings. The living room's maximum indoor temperature was observed to be 31.9 °C, while the minimum indoor temperature was recorded at 24 °C. The outdoor temperature, on the other hand, ranged from 25.4 °C to 33.6 °C, as seen in the chart. The temperature analysis of the indoor space indicated that the lowest temperature was recorded early in the morning, between 3:00 am and 4:00 am, at 24 °C. Concurrently, in the morning hours of 6:00 a.m.–7:00 a.m., peaking at 31.9 °C is the highest temperature.

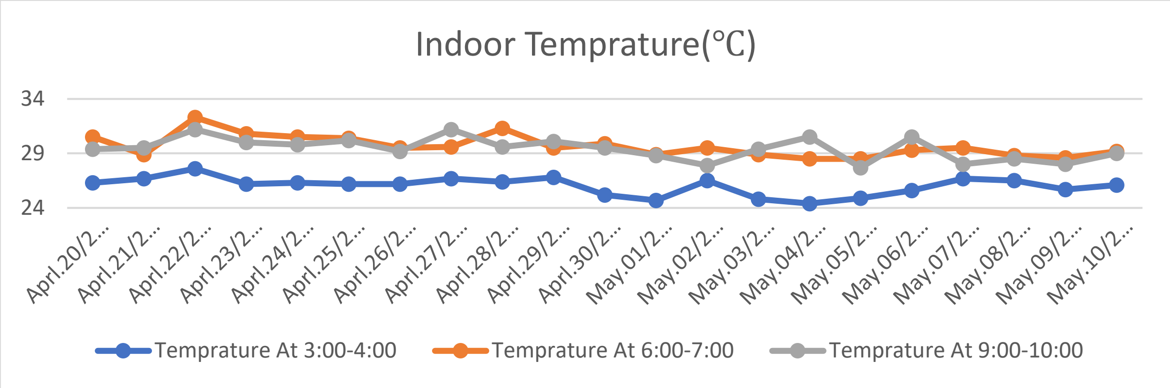


Chart 4:5: Indoor Temperature of living room with shading device (Source: Field Measurement)

4.4.1.3 Discussion on air temperature

The temperature of a south-facing room with a shading device has been recorded in Chart 4:6,with a maximum of 31.9 °C and 25.4 °C is the minimum temperature. These readings were taken during the overheated months of April and May, when outdoor temperatures recorded a maximum of 33.6 °C and 25.4 °C is the minimum temperature. While the existing shading device in the south-facing room also showed readings of maximum 31.9 °C and minimum 25.4 °C, the ASHRAE standard states that the ideal comfort level falls between 21 °C and 27 °C. Any temperature outside this range may lead to discomfort. A recent study found that a south-facing room with an existing shading device falls outside the standard comfort zone.

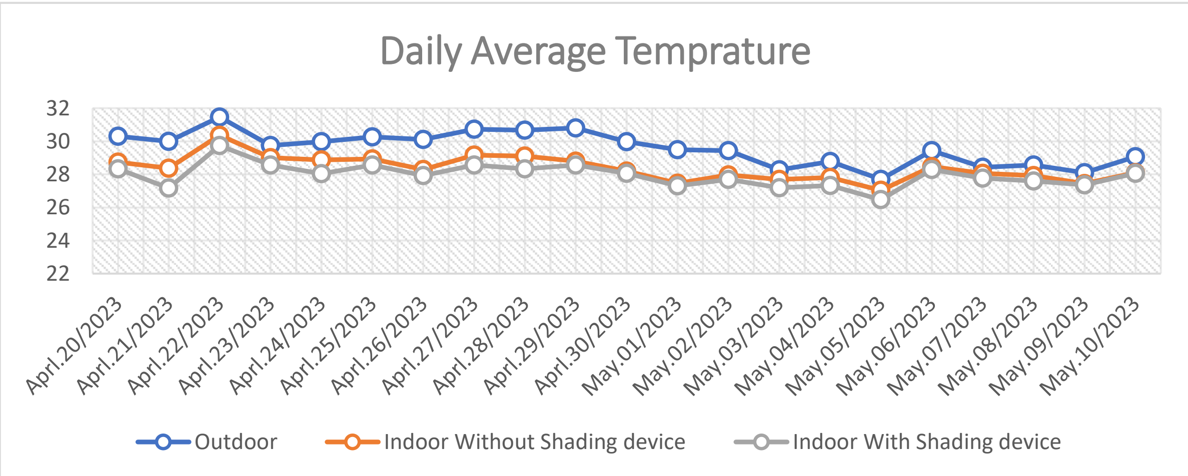


Chart 4:6: Daily Average Temperature (Source: Field Measurement)

4.4.2 Relative Humidity

As per the field measurement conducted for the outdoor environment, Chart 4:7 reveals that the south-facing room recorded a maximum relative humidity of 33%, while the minimum was at 25%. Both April and May recorded the highest levels of humidity.

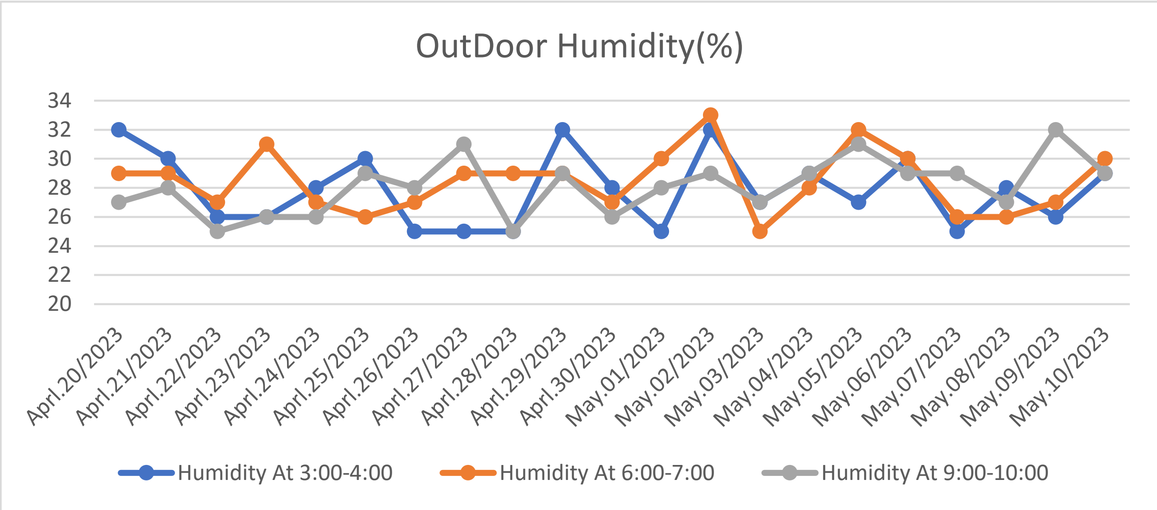


Chart 4:7: Outdoor Relative Humidity (Source: Field Measurement)

4.4.2.1 Indoor Relative Humidity of south facing room window with shading device

As per, Chart 4:8 the south-facing window living room with a shade device exhibited a maximum relative humidity of 34%, and 25% is the minimum. Concurrently, the outdoor humidity showed a range between 33% and 25%.

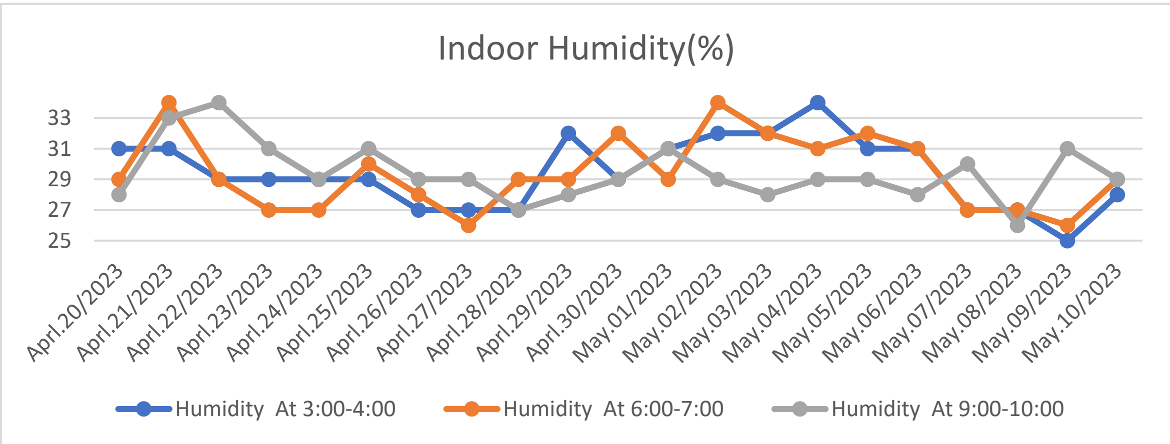


Chart 4:8: Indoor Relative Humidity of a Living Room with a Shaded Device (Source: Field Measurement)

4.4.2.2 Indoor Relative Humidity of south facing room window without shading device

Based on the field measurement provided in Chart 4:9, It can be observed that the living room, located in the south direction and without any shading device, had a maximum relative humidity of 32% and 24% minimum. On the other hand, the outdoor humidity during this time period ranged from 33% to 25%.

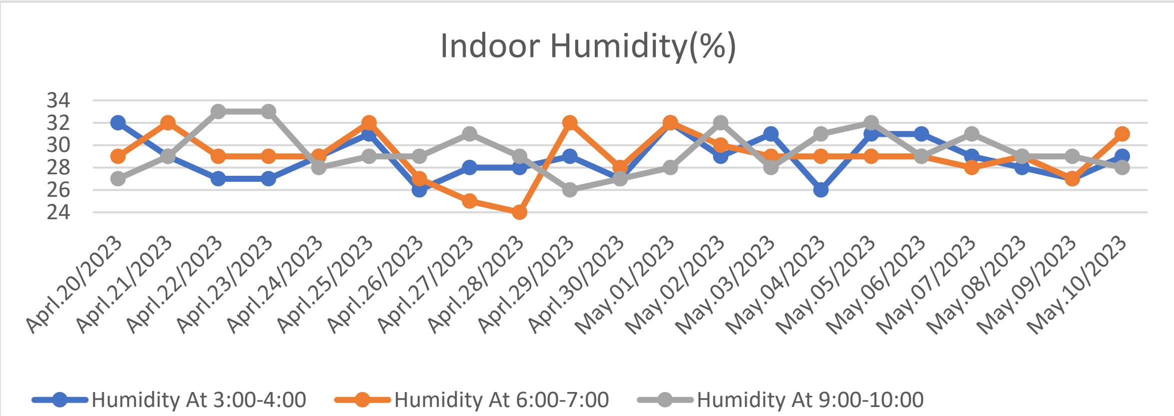


Chart 4:9: Indoor Relative Humidity of living room without shading device (Source: Field Measurement)

4.4.2.3 Discussion on relative humidity

According to Chart 4:10, the south facing room with an existing shading device had superior humidity levels compared to room without a shading device. In the month of April, the maximum and minimum humidity levels recorded for the room with a shading device were 34% and 26% respectively. While in May, the maximum and minimum humidity levels recorded were 34% and 25%, respectively. It is show that the relative humidity of the south facing room with an existing shading device is better than room without a shading device.

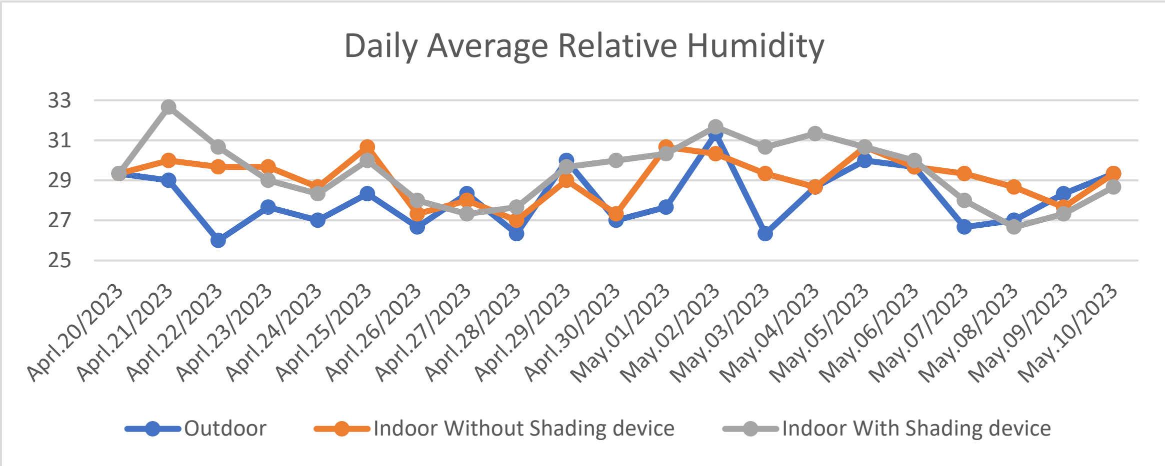


Chart 4:10: Daily Average Relative Humidity (Source: Field Measurement)

The south-facing room with a shading device had an average humidity level of 29.3%. The humidity data recorded imply that the existing shading device is, on average, out of the comfort zone. The amount of moisture in the air significantly decreased as the temperature rose, as was to be expected. Residents of the room responds similar results on a thermal sensation scale to those found in the data recorded.

4.4.3 Air velocity

According to a field measurement conducted for the outdoor environment, the data presented in Chart 4:11, indicates that the maximum air speed recorded in a south-facing room was 4.5 m/s, while the lowest was 0.45 m/s. A two-month measurement revealed that the highest air speed occurred during the month of May, specifically during the time frame of 3:00–4:00 a.m. in the morning.

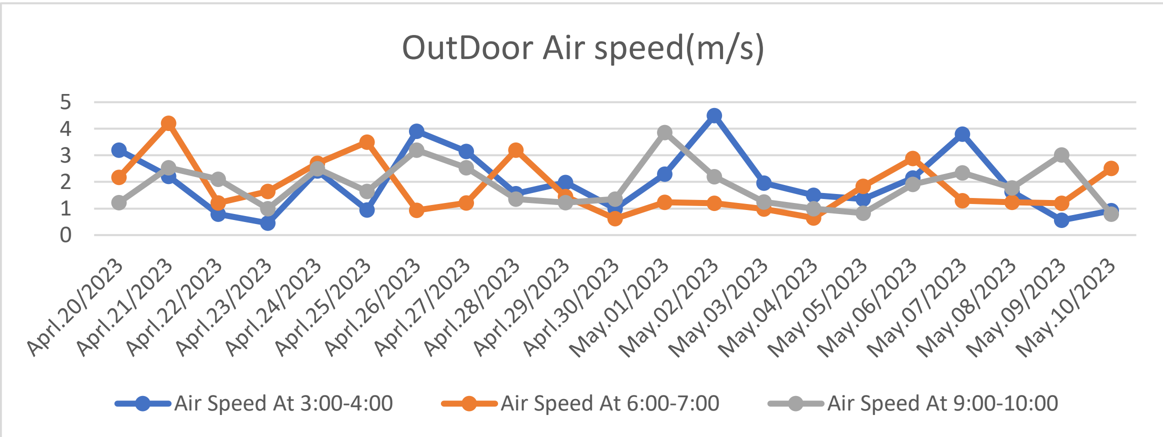


Chart 4:11: Outdoor Air Velocity (Source: Field Measurement)

4.4.3.1 Indoor Air velocity of south facing room window with shading device

In April and May, according to Chart 4:12, the velocity of indoor air in south-facing rooms with shading devices ranges from 0.00 m/s to 0.96 m/s, while outdoor air speed ranges from 0.45 m/s to 4.5 m/s. These findings suggest that indoor air movement is significantly weaker than outdoor air movement.

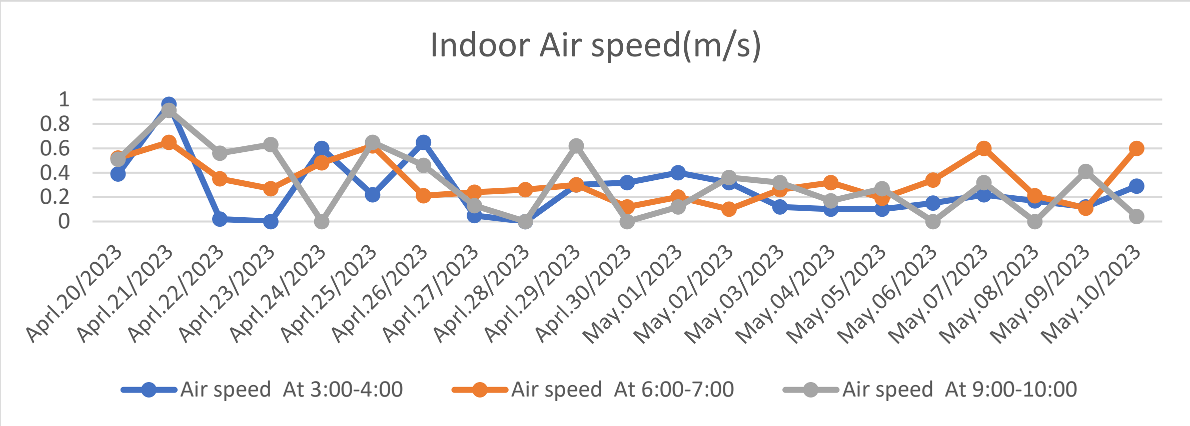


Chart 4:12: Indoor air velocity of a south-facing room window with a shading device (Source: Field Measurement)

4.4.3.2 Indoor Air velocity of south facing room window without shading device

As per Chart 4:13, the analysis conducted in April and May reveals that the airflow velocity indoors in south-facing rooms without any shading devices varies from 0.00 m/s to 0.98 m/s. However, outdoor airspeed ranges from 0.45 m/s to 4.5 m/s. These outcomes indicate that the movement of indoor air is far less intense compared to outdoor air movement.

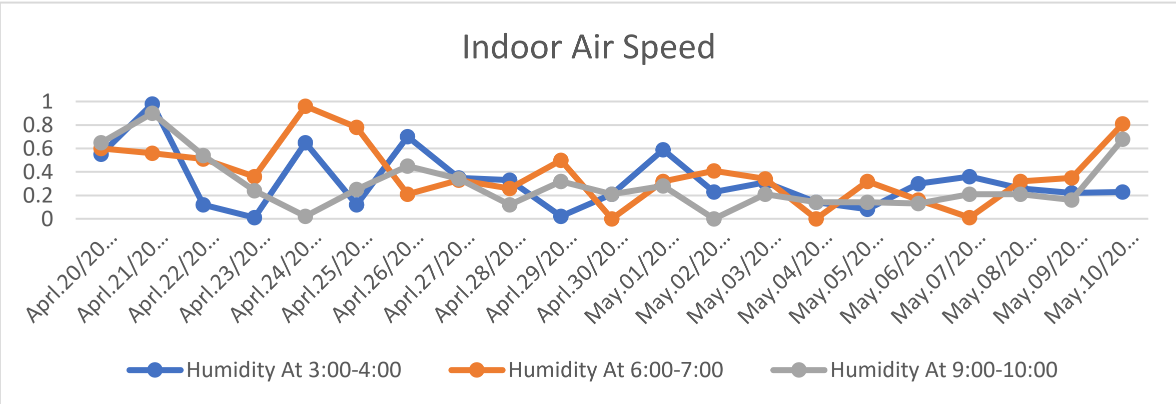


Chart 4:13: Indoor air velocity of a south-facing room window without a shading device (Source: Field Measurement)

4.4.3.3 Discussion on air velocity

The Average maximum air speed for operating temperatures exceeding 25.5°C is 0.8 m/s, and the maximum air speed for operating temperatures below 25.5°C is 0.3 m/s, according to ASHRAE 55. Based on Chart 4:14 the airspeed within a room with a shade device and without a shading device was low when comparing to the airspeed outside, which is high (4.5 m/s).

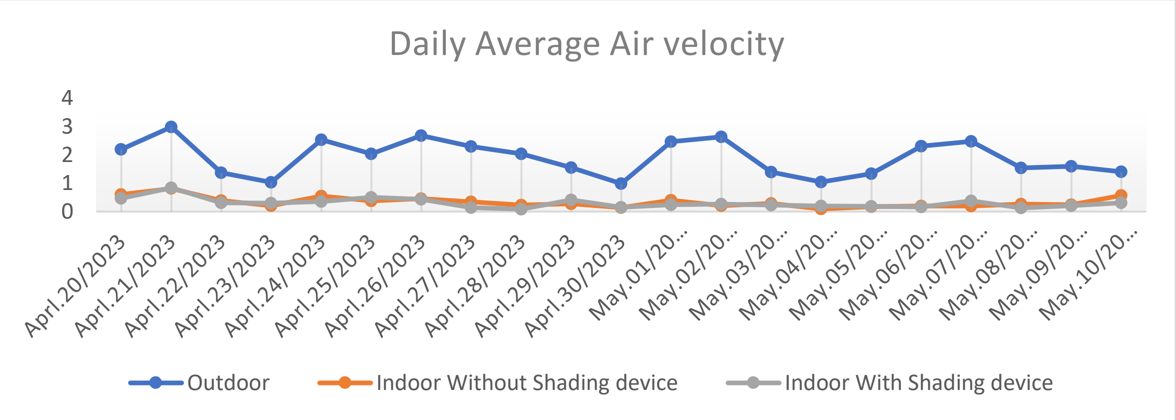


Chart 4:14: Daily Average Air velocity (Source: Field Measurement)

Without a shade device the average interior airspeed in a living room 0.49 m/s is less than what is considered comfortable with range of 0.00 to 0.96 m/s indoors and 4.5 m/s outside The building's aperture is closed to prevent unwanted sunlight from coming in and preventing desired air from entering This suggests the structure needs a suitable passive method to reduce the amount of outside air in the interior space The airspeed measured from April 10 to May 20/23 is According to Chart 4:14 the outside air velocity varies from 0.45 m/s to 4.45 m/s Air flow through the space ranged from 0.00 to 0.98 meters per second.

4.4.4 Daylight illuminance

Based on the results of the analysis conducted in May and April as outlined in Chart 4:15, it was found that the highest recorded indoor daylight illuminance was 1987lux, while the lowest was 520lux throughout the day. The intensity of indoor daylight illuminance typically ranges from 250lux to 665lux. These findings imply that the indoor lighting levels can vary significantly depending on the time of day.

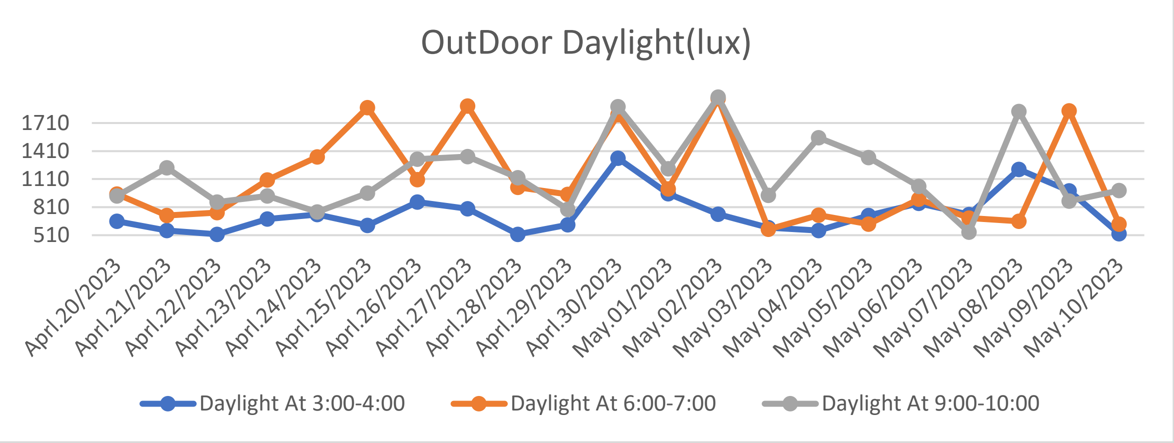


Chart 4:15: Outdoor Daylight illuminance (Source: Field Measurement)

4.4.4.1 Indoor Daylight illuminance of south facing room window with shading device

As per Chart 4:16, the analysis conducted in April and May reveals that the daylight illuminance indoors in south-facing rooms with shading devices ranges from 250 lux to 665 lux. However, outdoor daylight illuminance ranges from 520 lux to 1987 lux.

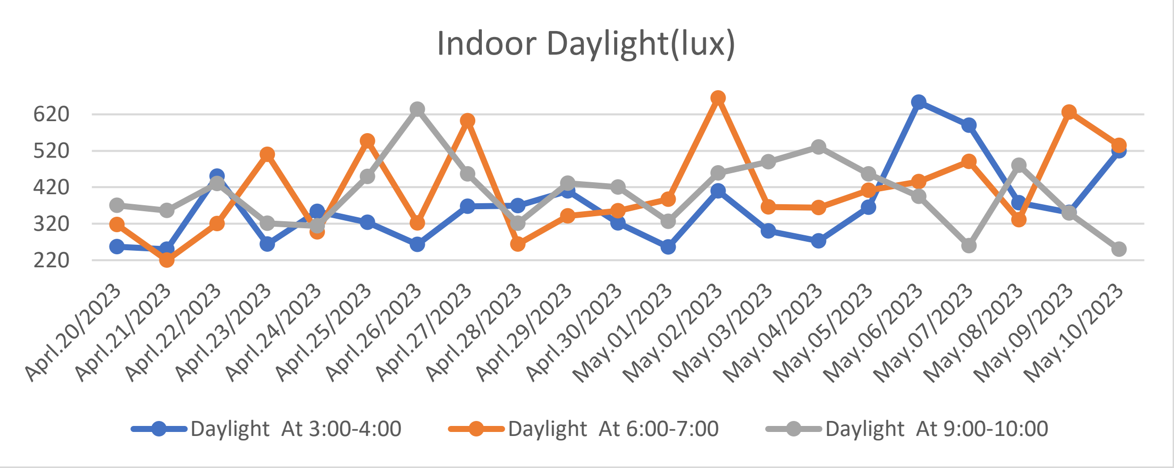


Chart 4:16: Indoor daylight illuminance of a south-facing room with a shading device (source: field measurement)

4.4.4.2 Indoor Daylight illuminance of south facing window out with shading device

In April and May, according to Chart 4:17, the indoor daylight illuminance in south-facing rooms without shading devices ranges from 263 lux to 670 lux, while outdoor daylight illuminance ranges from 520 lux to 1987 lux.

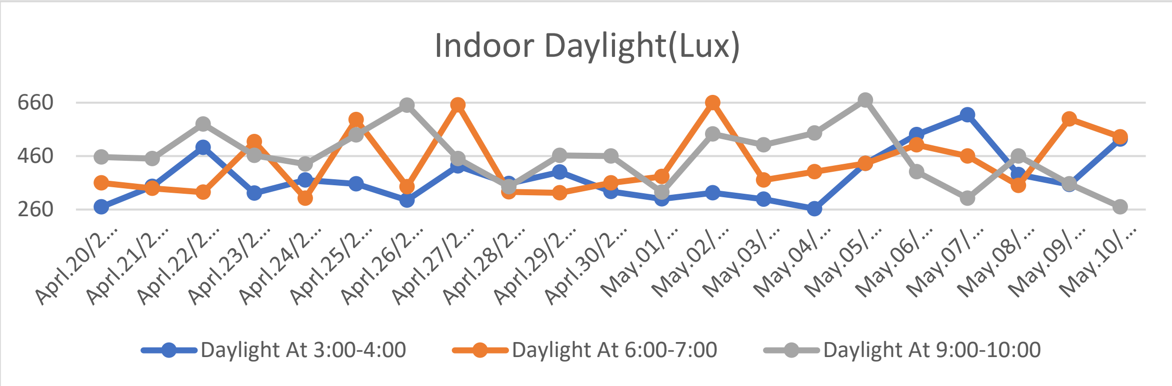


Chart 4:17: Indoor daylight illuminance of a south-facing room without a shading device (Source: Field Measurement)

4.4.4.3 Discussion on daylight illuminance

The recommended range of daylight lighting for the living room by standard (ASHRAE 55) is 150-200 lux. However, statistical data reveals considerable fluctuations in the observed amount of daylight at elevated indoor temperatures. Evidently, when daylight illumination & indoor temperatures are both low, it adversely affects thermal comfort levels.

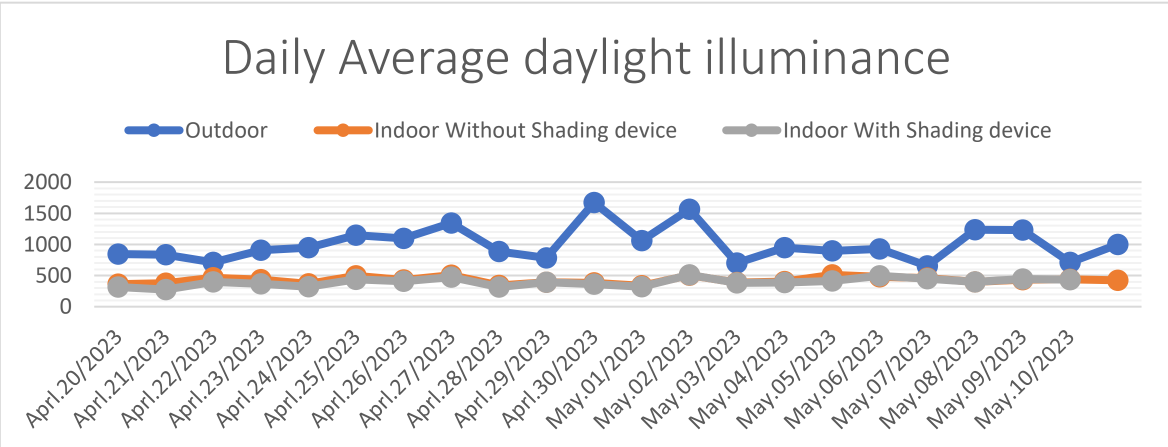


Chart 4:18: Daily Average Illuminance (Source: Field Measurement)

According to Chart 4:18, the daylight illumination average level in the without a shading device exceeds 200 lux. The indoor spaces receive an illumination level above the required average of 200 lux, and approximately 23% of the outdoor illumination is transmitted indoors, meeting the relevant standards. However, usage of a shading device leads to a decrease in received light, though still maintaining levels above the prescribed requirement. As per the illuminance measurement, the primary living room of the residents experiences a significantly high light level at clear sky conditions.

4.5 Thermal comfort chart with environmental variable

Using ASHRAE 55 standard in Figure 4:1 Air temperature, relative humidity, ratio radiant temperature and air bulb temperature enthalpy are used in psychometrics. In terms of the availability of measuring instruments is used the relative humidity and air temperature ratio to identify comfort level. In the south facing room with a shading device range of Temperature from 24°C to 31.6°C and range from outdoor 25.4°C to 33.6°C, air velocity from 0.00 m/s to 0 96 m/s while outdoor from 0.45 m/s to 4.5 m/s, relative humidity ranges from 25% to 33%, outdoor ranges from 25% to 33%, daylight illuminance ranges from 250 lux to 665 lux and outdoor from 520 lux to 1987 lux, South facing room without shading device Range of Temperature from 24°C to 31.6°C and outdoor 25.4°C to 33.6°C air velocity from 0.00 m/s to 0.98 m/s while outdoor ranges from 0.45 m/s to 4.5 m/s, range of relative humidity from 24% to 32% and outdoor from 25% to 33% , range of daylight illumination from 250 lux to 665 lux and outdoor from 520 lux to 1987 lux.

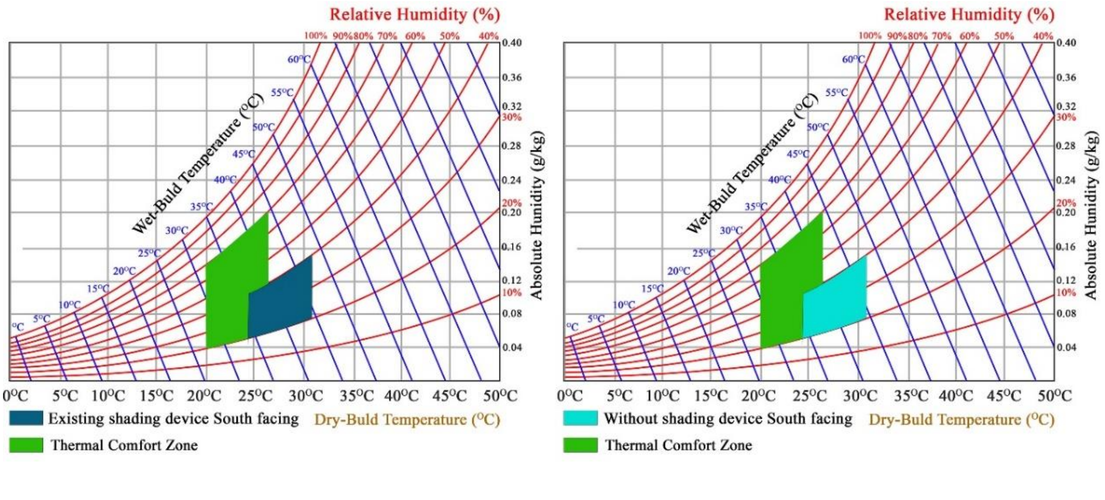
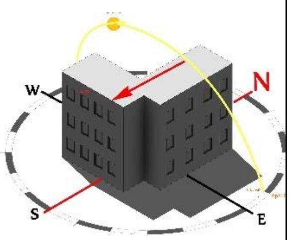
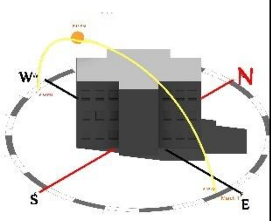
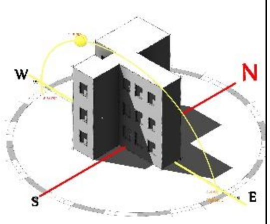
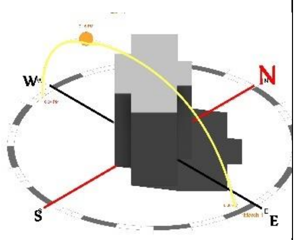
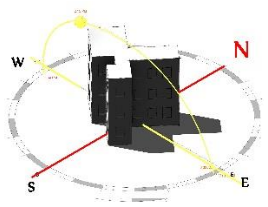


Figure 4:1: Psychometric chart for without and with shading device (Source: Author)

4.6 Sun paths and Building orientation of condominium sites in Adama

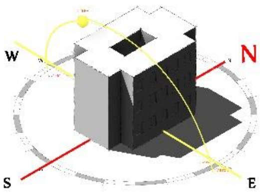
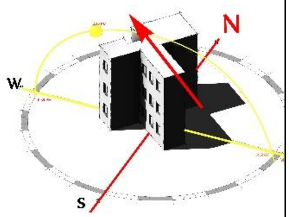
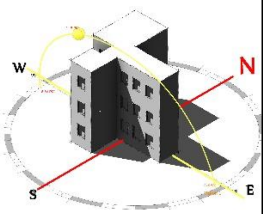
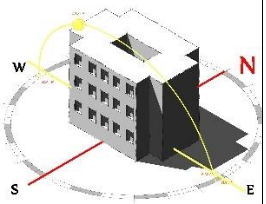
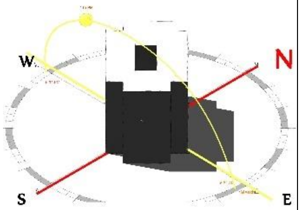
All 122 Blocks in Adama Condominium Building listed are in four orientation 0°N, 45°E, 90°E and 315° N. Adama Condominium Site located at 8 different locations with four kebeles (kebele 01,04,05,09) Atenatera condominium site, Goro condominium site, Silase condominium site, Gandagara condominium site, Cherkacherk condominium site, Moenko condominium site, Duket condominium site and Sodober condominium site

Table 4:4: Atenatera Condominium Site

Site: Atenatera Condominium Site			
Orientation			
S – N axis (Azimuth angle-0°N)	NE – SW axis Azimuth angle-45°E	E – W axis (Azimuth angle-90°E)	NW – SE axis Azimuth angle- 315° N
2 Blocks 	1 Blocks 	2 Blocks 	1 Blocks  3 Blocks 

There are 9 blocks in Atenatera condominium site from those blocks 2 blocks are oriented S-N axis with azimuth angle 0°N,1 block are oriented NE – SW axis Azimuth angle-45°,2 blocks are oriented E – W axis (Azimuth angle-90°E) and 3 blocks are oriented NW – SE axis Azimuth angle- 315° N.

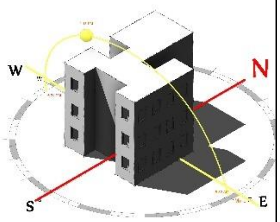
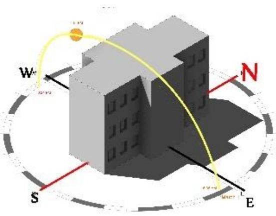
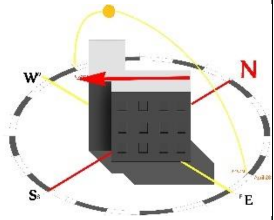
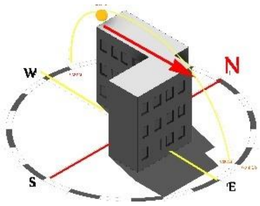
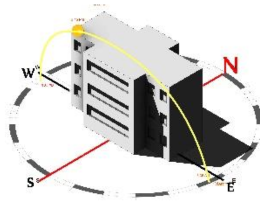
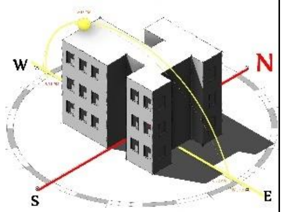
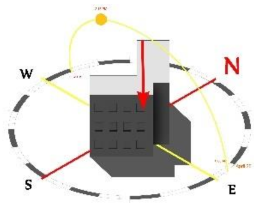
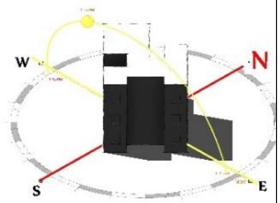
Table 4:5: Duket Condominium Site

Site: Duket Condominium site			
Orientation			
S – N axis (Azimuth angle-0°N)	**NE – SW axis Azimuth angle-45°E**	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle- 315° N**
5 Blocks 	2 Blocks 	10 Blocks  15 Blocks 	1 Blocks 

At Duket condominium site 32 blocks are listed with 4 orientations from these blocks 5 blocks are oriented S – N axis (Azimuth angle-0°N), 2 blocks are oriented NE – SW axis Azimuth angle-45°E, 25 blocks are oriented E – W axis (Azimuth angle-90°E), 1 block oriented NW – SE axis Azimuth angle- 315° N.

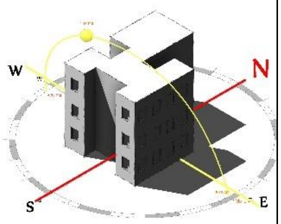
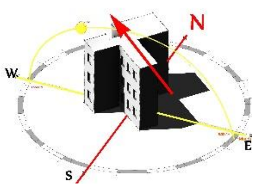
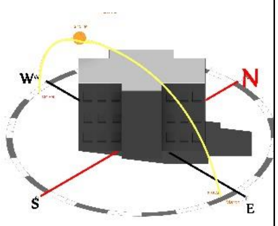
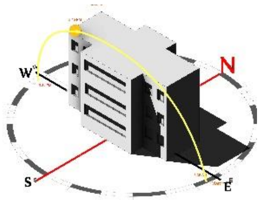
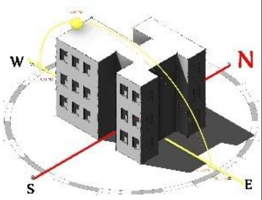
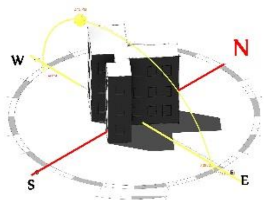
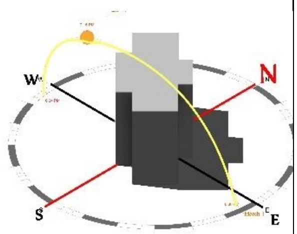
Figure 4:2: Duket condominium site (Source: google earth)

Table 4:6: Ganda Gara Condominium site

Site: Ganda Gara Condominium Site			
Orientation			
S – N axis (Azimuth angle-0°N)	**NE – SW axis Azimuth angle-45°E**	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle-315° N**
3 Blocks  1 Block  	1 Block  	2 Blocks  4 Blocks  2 Blocks  	1 Block  2 Blocks 

At Ganda Gara Condominium site from 16 blocks 4 blocks are Oriented S – N axis (Azimuth angle-0°N), 1 block oriented NE – SW axis Azimuth angle-45°E, 8 blocks are oriented E – W axis (Azimuth angle-90°E), 3 blocks are oriented NW – SE axis Azimuth angle- 315° N.

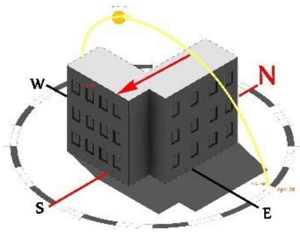
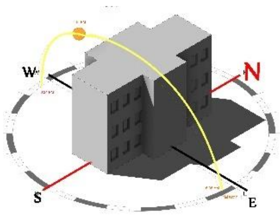
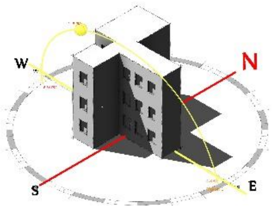
Table 4:7: Goro condominium site

Site: Goro Condominium site			
Orientation			
S – N axis (Azimuth angle-0°N)	**NE – SW axis Azimuth angle-45°E**	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle- 315° N**
3 Blocks 	3 Blocks  2 Blocks 	5 Blocks  3 Blocks 	3 Blocks  3 Blocks 

At Goro Condominium site from 21 blocks 3 blocks are Oriented S – N axis (Azimuth angle-0°N), 5 blocks are oriented NE – SW axis Azimuth angle-45°E, 8 blocks are oriented E – W axis (Azimuth angle-90°E), 6 blocks NW – SE axis Azimuth angle- 315° N.

Figure 4:3: Goro Condominium site

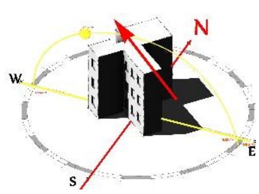
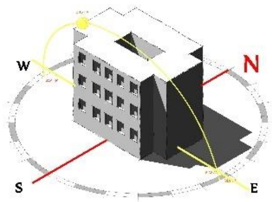
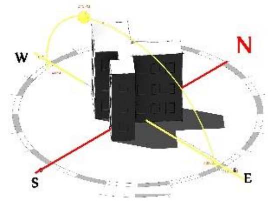
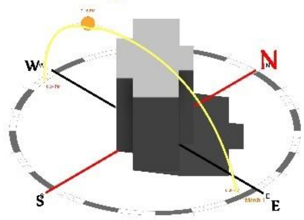
Table 4:8: Cherkacherk Condominium Site

Site: Cherkacherk Condominium Site			
Orientation			
S – N axis (Azimuth angle-0°N)	**NE – SW axis Azimuth angle-45°E**	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle-315° N**
1 Block  2 Blocks 	No	4 Blocks 	No

At Cherkacherk Condominium site from 7 blocks 3 blocks Oriented S – N axis (Azimuth angle-0°N) and 4 blocks-oriented E – W axis (Azimuth angle-90°E).

Figure 4:4: Cherkacherk Condominium site

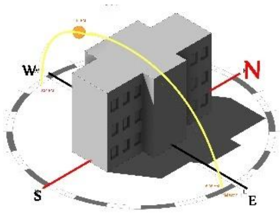
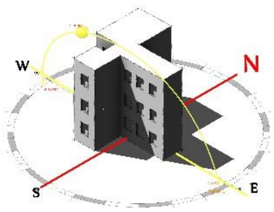
Table 4:9: Silase Condominium site

Site: Silase Condominium site			
Orientation			
S – N axis (Azimuth angle-0°N)	**NE – SW axis Azimuth angle-45°E**	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle- 315° N**
No	3 Blocks 	2 Blocks 	5 Blocks  2 Blocks 

At Silase Condominium site from 12 blocks no blocks are Oriented S – N axis (Azimuth angle-0°N), 3 block oriented NE – SW axis Azimuth angle-45°E, 2 blocks-oriented E – W axis (Azimuth angle-90°E), 7 blocks NW – SE axis Azimuth angle- 315° N.

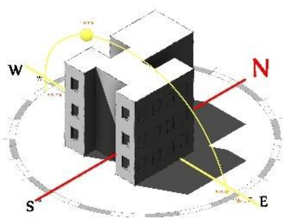
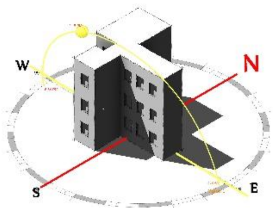
Figure 4:5: Silase Condominium site (source: Google earth)

Table 4:10: Moenko Condominium Site

Site: Moenko Condominium Site			
Orientation			
S – N axis (Azimuth angle-0°N)	**NE – SW axis Azimuth angle-45°E**	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle-315° N**
2 Blocks 	No Blocks	2 Blocks 	No Blocks

At Moenko Condominium site from 4 blocks 2 blocks are Oriented S – N axis (Azimuth angle-0°N), no blocks are oriented NE – SW axis Azimuth angle-45°E, 2 blocks are oriented E – W axis (Azimuth angle-90°E), no blocks are NW – SE axis Azimuth angle- 315° N.

Table 4:11: Sodober Condominium site

Site: Sodober Condominium site			
Orientation			
S – N axis (Azimuth angle-0°N)	**NE – SW axis Azimuth angle-45°E**	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle-315° N**
2 Blocks 	No Blocks	3 Blocks 	No Blocks

At Sodober Condominium site from 5 blocks 2 blocks are Oriented S – N axis (Azimuth angle-0°N), no blocks are oriented NE – SW axis Azimuth angle-45°E, 3 blocks are oriented E – W axis (Azimuth angle-90°E), no blocks are NW – SE axis Azimuth angle- 315° N.

4.7 Shading device Information

From 122 blocks found in Adama city 21 blocks used shading device, this shading device is often used in south, southwest and west facing building.

Figure 4:6: Adama Condominium building Shading device (Source: Site Observation Author 2023)

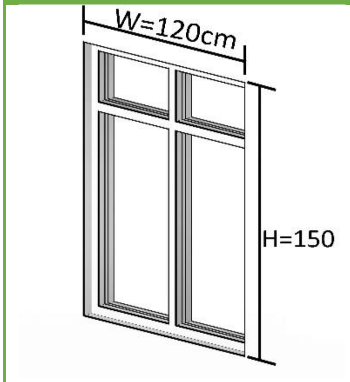
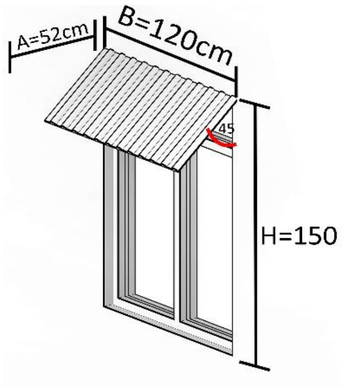
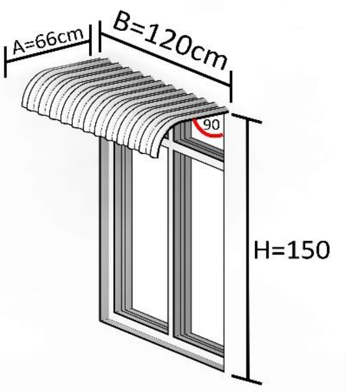
Window size Description	Shading device information	
		
Width =120cm Height =150cm **Material= clear glass**	Layout (A = 52cm, B = 120cm Angel= 45 degree Material= Metal Sheet Type = Horizontal/Overhang Location= south, west & south west No of block = 12	Layout (A= 66cm, B = 120cm Angel= 90 degree Material= Metal Sheet Type = Horizontal/Overhang Location= south, west & south west No of block = 9

Table 4:12: Shading device information

There are different shading devices size used by residents. Information regarding their location, orientation, height, shading type, shading material, and layout is explained. Occupant used external and internal shading devices from those as try to explain in Table 4:12. Adama condominium resident used blinds and fixed shading device with different layout and size.

4.8 Shading design

To ensure effective window shading, it is Important to take into account three key shadow angles: the horizontal shadow angle (HSA), the vertical shadow angle (VSA), and the end profile angle (EPA). These angles serve to indicate the position of the sun in relation to a building's facade at a specific orientation and may be utilized to determine the efficacy of a given shading device based on the extent of shade it provides.

The horizontal shadow angle (HAS) the vertical shadow angle (VSA) and the end profile angle (EPA) must be considered in order to achieve appropriate window shading. Indicating the sun's position in reference to a building's facade at a particular orientation these angles can be helps to assess the effectiveness of a particular shading device depending on the amount of shade it casts

4.8.1 Identifying sun position of Adama and when shading is required

Depending on the season and latitude, the earth's rotation around the sun causes multiple solar trajectories with varying heights and lengths. Sun path diagrams are a useful tool for displaying the sun's shifting position in the sky throughout the course of a year. These images are projected on a horizontal plane and show the four cardinal directions (North, South, West, and East). The plane has a base with concentric circles and radial lines Figure 4:7. Adama city lat:8.5263823 and Lon:39.2695925.

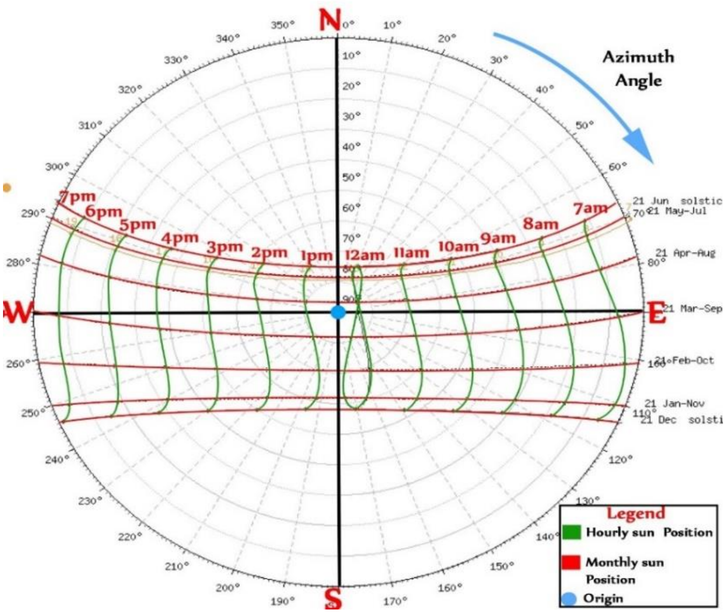


Figure 4:7 Adama Sun path (Source: Sunearthtools.com)

The stereographic projection is the most popular and often used alternative, as tried to explain on literature chapter two from different 5 (five) ways the sun's location from these basic. Figure 4:7 shows Adama City in the globe's geographic center. The red horizontal lines depict the path of the sun, while the veiled vertical lines reveal the hours of the day.

4.8.2 Identifying When Shading Is Necessary

Depending on Location, different regions experience various weather conditions. Therefore, the overheated periods vary from location to location. Now a days, a location's weather information is easily available Different websites. On this paper overheated periods is identifying using occupant satisfaction, field measurement and online weather stations. On weather stations, various weather conditions are recorded and updated on a regular basis. The US Department of Energy is the latest and most trustworthy providers of local meteorological data (DOE). It’s critical to properly analyse and interpretation such data to determine a region's times of comfort and discomfort. From Several applications supports in interpreting weather data from DOE, Climate Consultant software is used. It is most popular and user-friendly program that aids in interpreting weather information by offering four comfort model choices.

In this instance, a Time-Table Plot chart displaying weather information from Adama city was employed. It is a graph showing the average daily temperature and monthly temperature information from Energy Plus. Information is shown in three colour zones: Red (Hot/Overheated), Turquoise (Comfortable), and Blue (Cold/Underheated) depending on the Adaptive Comfort Model that was selected. Figure 4:8 shows Adama monthly average temperatures.

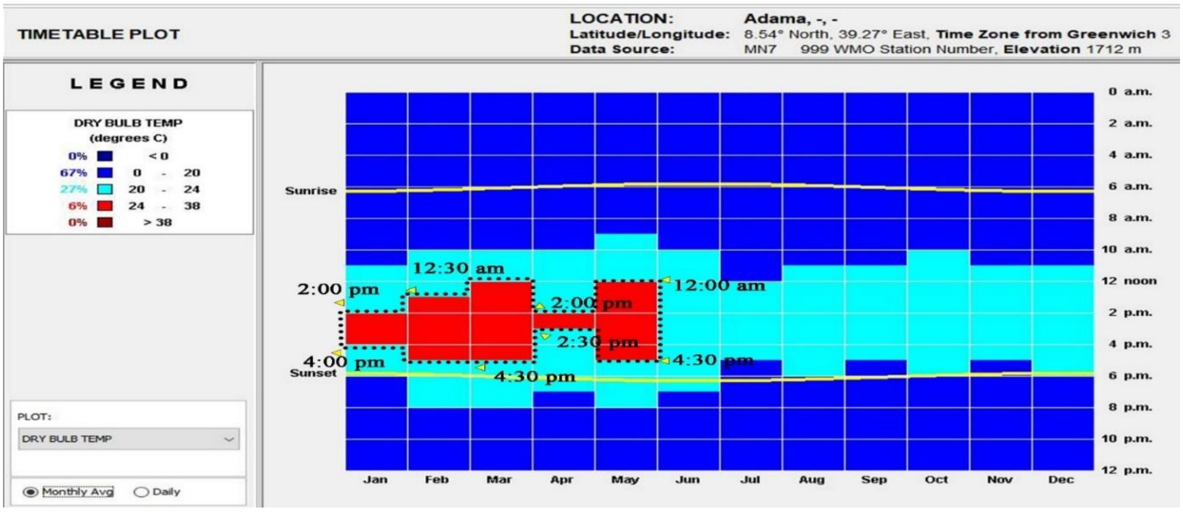


Figure 4:8 Adama City Time Table plot chart average monthly temperature

On above Figure 4:8 shows that, January month from 2pm-4pm, February from 12:30 noon -4:30pm, March from 12:00 noon -4:30pm, Aprill 2:00pm-2:00pm, and May from 12:00 noon -4:30pm are hottest months of Adama city.

Based on the data from Figure 4:8 overheated periods showed in red colour. Periods of overheated are registered in the months of January through May. Repetitive hot times are mapped by taking into account the periods of recurrence for each month. The sun's trajectory and hour lines should be carefully taken into account when mapping the data on the Time-Table Plot to the stereographic diagram. One-month elapses between each subsequent sun trajectory. Mapped first are times of comfort, followed by times of discomfort Figure 4:9.

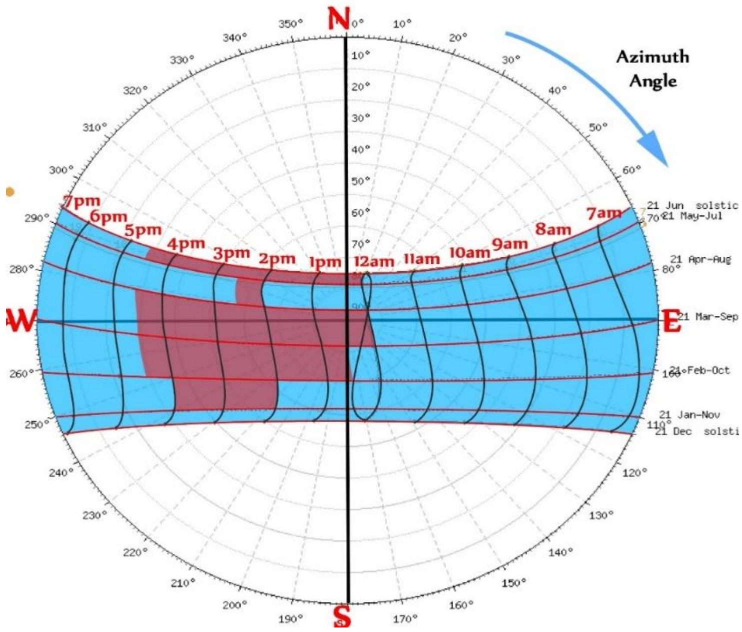


Figure 4:9.Stereographic diagram mapped overheating month of Adama City

4.8.3 Identifying Proportion and Dimension of Shading Device for overheated Period

The azimuth and elevation of the sun will change throughout the day, from sun rise to sun set. Different exposure angles will be created on surfaces that are vulnerable by this sun track. Given that we are taking the entire day into account, from sundown to sunrise, the azimuth and elevation of the sun will change. Figure 4:10 shows the sun's potential effects on shadow angles.

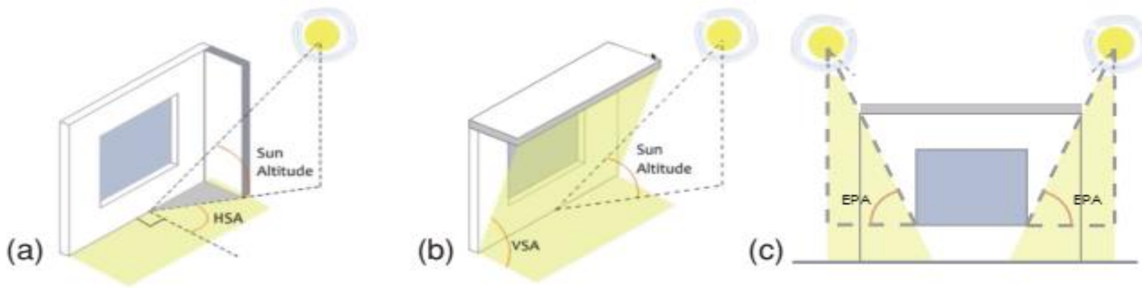


Figure 4:10.Sun Movements create the shading angle (a) HSV(Horizontal shadow angle), (b) VSA(vertical shadow angle), (c) EPA(End profile shading angle) (source:University of oregon)

4.8.3.1 The shading angle protractor

The solar shading protractor shown in Figure 4:11 is helpful for analyzing a building's fins, overhangs, and sunshades. It can be put on the polar diagram to show how shading affects it because it has the same proportions. The shading mask of a solar shading device is produced by lining up a specific viewpoint with the center of the chart. This is created by vertical and horizontal overhangs. This perspective must fit a particular perspective.

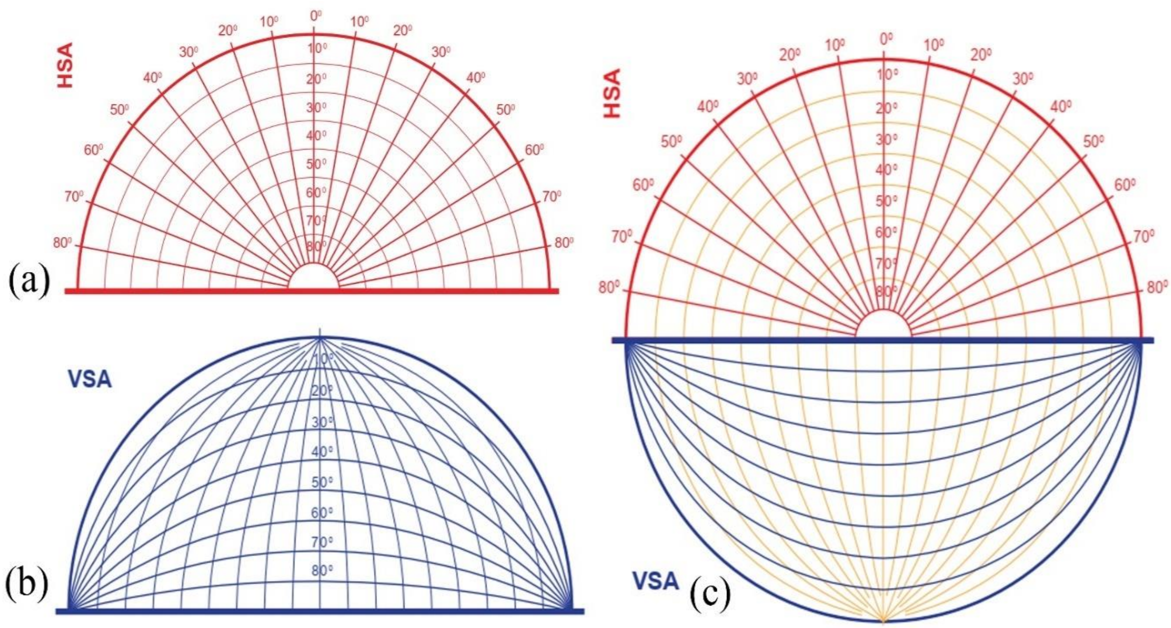


Figure 4:11 Shading protractor (a) HSA-Horizontal shadow angle (b) VSA-Vertical shadow angle (c) EPA-End profile shading angle protractor (source:University of oregon)

4.8.3.2 Shading protractor reading

By using a semi-circular protractor two sets of lines are Shows in Figure 4:12.

- ✓ Radial lines with the number 0 in the center and the numbers -90 to the left and +90 to the right are used to calculate the HSA. device with vertical fins.
- ✓ Arcual lines that cross the centerline and align with the altitude circles, but diverge and converge at the protractor's two corners, will provide a reading of the VSA. To use an overhang device

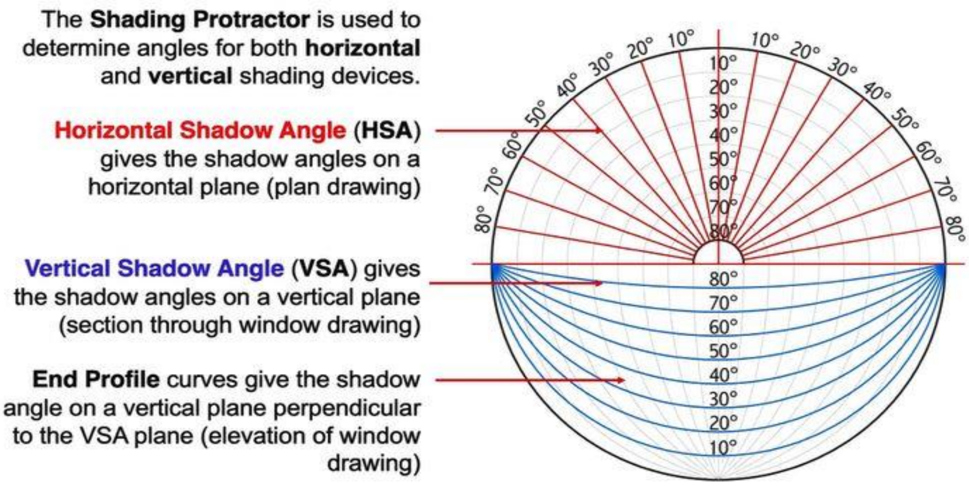


Figure 4:12.Shading protractor (source:(UN Habitat, 2018))

4.8.3.3 South Orientation Horizontal shadow angle (HSA), Vertical shadow angle (VSA) and End profile angle (EPA) Identification

A) **South Orientation Vertical shadow angle (VSA) Identification**

VSA (Vertical shadow angle) for South facing Window, by placing the protractor’s center on stereographic diagram by facing south direction.Figure 4:13 the purple colour line help for reading angle and steps is shown.

Step-1. Using stereographic sun path diagram mapped with overheated hours and month. Overlaying sun protractor.

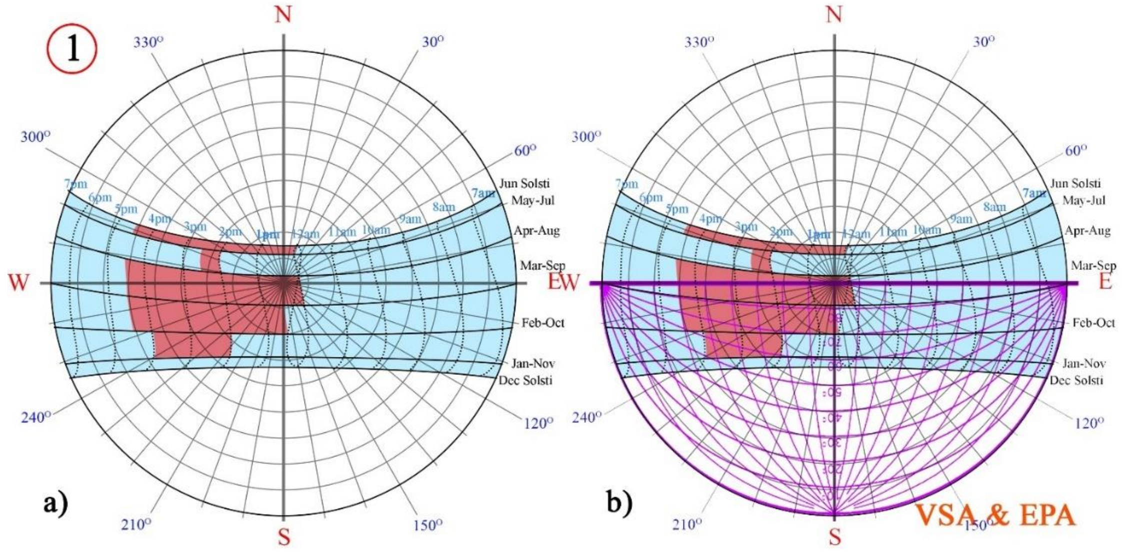


Figure 4:13.a)Sun path with mapped overheated months and hours; b) VSA measuring sun protractor place south facing (Source: Sunearthtools.com and Author)

Step-2. After placing VSA Measuring sun protractor by facing south orientation reading and identifying end angle of overheating month and hour.

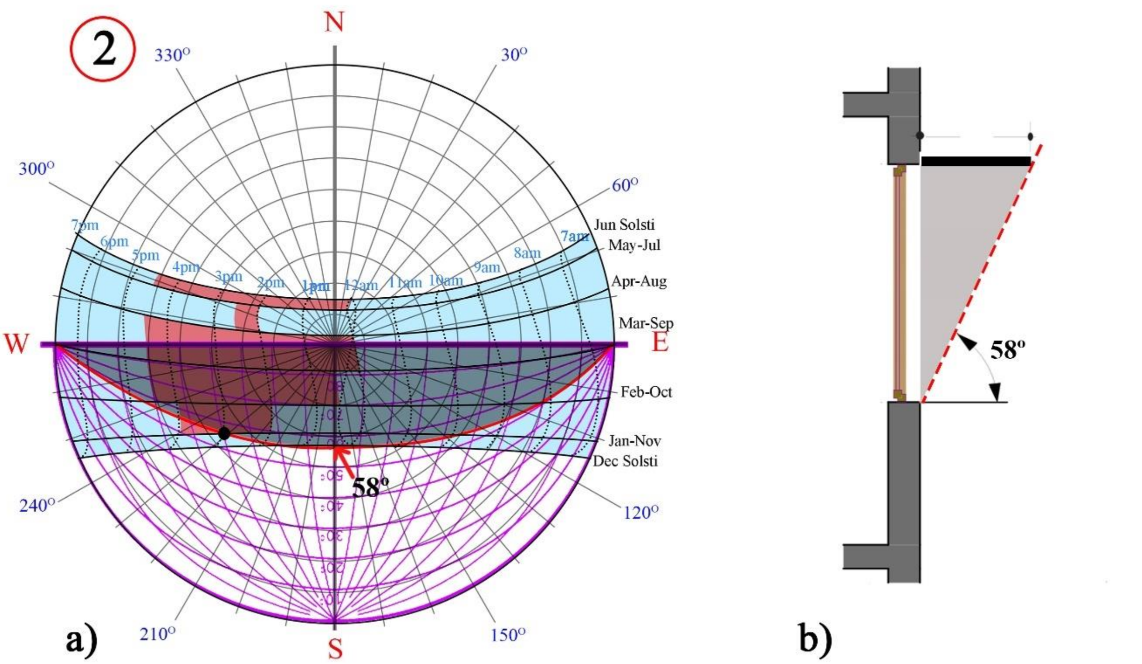


Figure 4:14.a)VSA recorded shadow angle; b) plan view with horizontal overhang and angle (source: sunearthtools.com and author)

As try to show in Figure 4:14 the VSA protractor show the mapped overheated period around 58°. A 58° angle is chosen to shade periods because, at this angle, horizontal shading devices have performance by blocking overheated sun incidents. Figure 4:14 b) shows a Section view of window. The projection line of the VSA Figure 4:14.(a) is drawn a perpendicular line to the Window and Projected 58° creates the line towards by Extending another line perpendicular from the window till it creates the diagonal line and the depth to the Horizontal overhang.

B) South Orientation End profile angle (EPA) Identification

EPA (End profile angle) for South facing Window, by placing the protractor's center on stereographic diagram by facing south direction. Figure 4:15 the brown colour lines help to reading angle and step are shown.

Step-1. By Using stereographic sun path diagram with mapped overheated hours and month. Overlaying sun protractor.

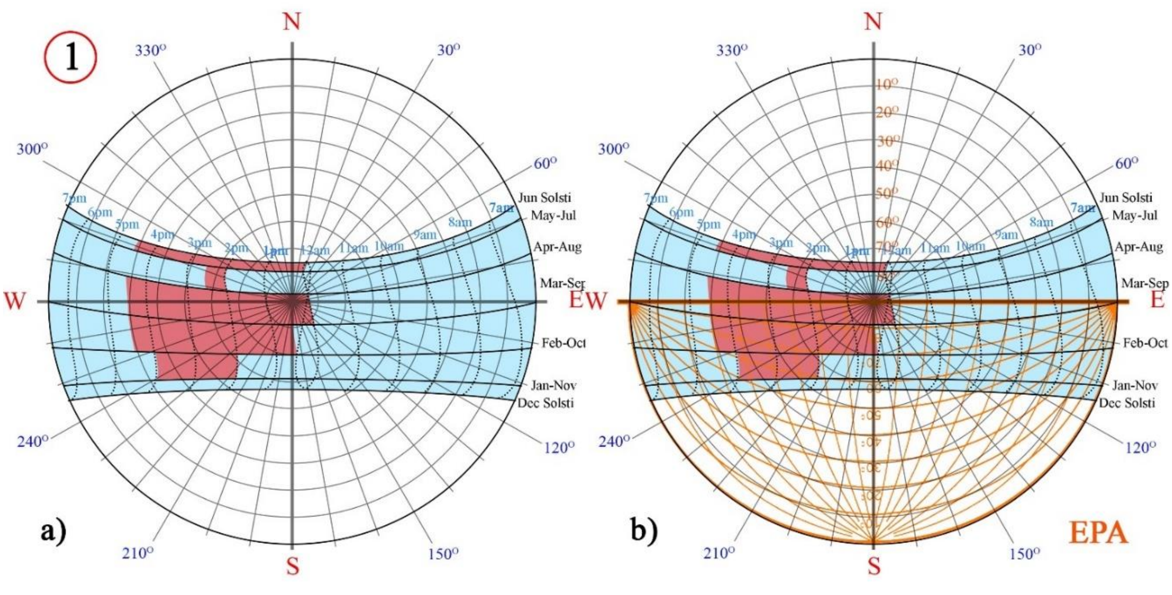


Figure 4:15.a)Sun path with mapped overheated month and hours b) EPA by measuring using Sun protractor place south facing (Source: Sunearthtools.com and Author)

Step-2. After placing EPA Measuring sun protractor by facing south orientation reading and identifying end angle of overheating month and hour.

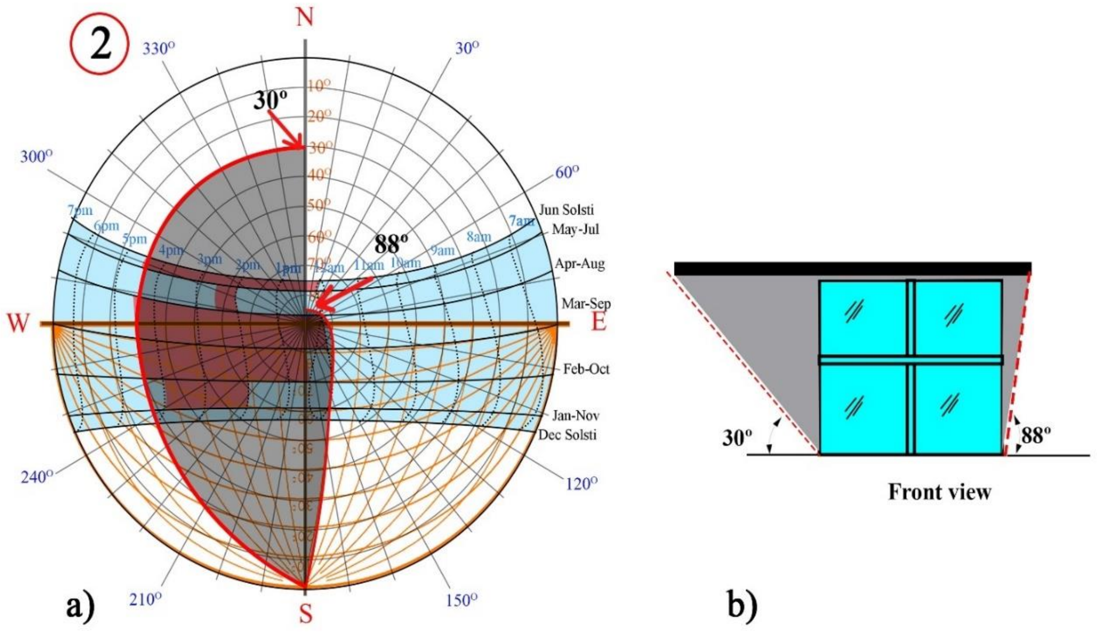


Figure 4:16.a)EPA recorded shadow angle, b) Front view with horizontal overhang and end angle (Source: Sunearthtools.com and Author)

In Figure 4:16 a) and b) end profile angle for horizontal shading device or overhang the angel is recorded 30 degrees to the west and 88 degrees to east side create desired shading for mapped overheated month and hour by extending shading device.

C) South Orientation (Horizontal shadow angle (HSA) Identification)

For South facing Window HSA (horizontal shadow angle), by placing the protractor's center on stereographic diagram by facing south direction.Figure 4:17 reading angle and step are shown below.

Step-1. By Using stereographic sun path diagram with mapped overheated hours and month. Overlaying sun protractor.

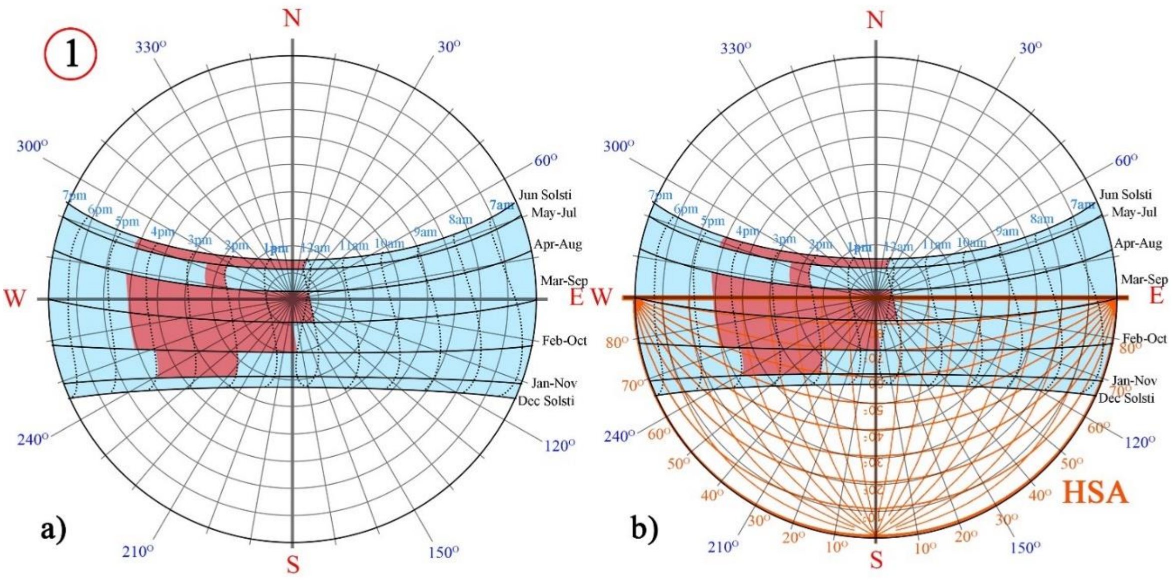


Figure 4:17.a)Sun path with mapped overheated month and hours b) HSA measuring Sun protractor placed toward south facing direction (Source: Sunearthtools.com and Author)

Step-2. After placing HSA Measuring sun protractor by facing south orientation reading and identifying end angle of overheating month and hour.

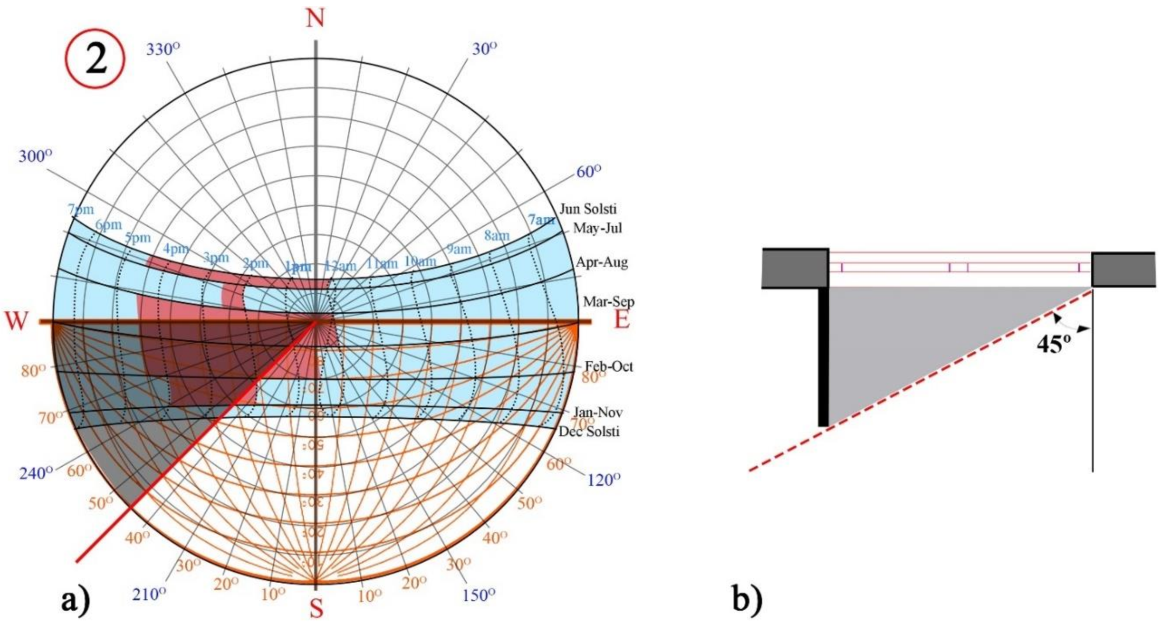


Figure 4:18.a)HSA recorded shadow angle, b) plan view with vertical fin and angle

(Source: Sunearthtools.com and Author)

As try to show in Figure 4:18.a) the HSA protractor show the mapped overheated period around 45°. A 45° angle is chosen to shade periods.Figure 4:18.(b) shows a plan of windows. The projection line of the HSA Figure 4:18.(a) is drawn a perpendicular line to the window and Projected 45° creates the line towards by Extending another line perpendicular from the window till it creates the diagonal line and the depth to the Vertical fine.

4.8.3.4 South-west Orientation Horizontal shadow angle (HSA), Vertical shadow angle (VSA) and End profile angle (EPA) Identification.

A) **South -west Orientation Vertical shadow angle (VSA) Identification**

VSA (Vertical shadow angle) for South-West facing Window, by placing the protractor's center on stereographic diagram by facing south direction. Figure 4:19 the purple colour line help for reading angle and steps is shown.

Step-1. Using stereographic sun path diagram mapped with overheated hours and month. Overlaying sun protractor.

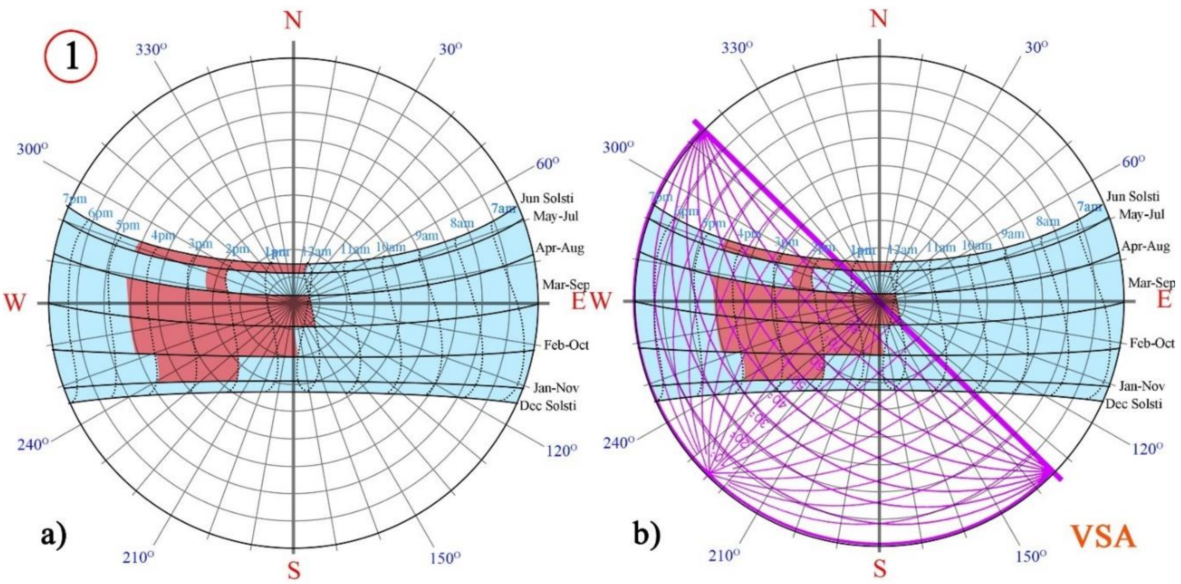


Figure 4:19.a)Sun path with mapped overheated month and hours b) VSA measuring Sun protractor place south west facing (Source: Sunearthtools.com and Author)

Step-2. After placing VSA Measuring sun protractor by facing south-west orientation reading and identifying angle of overheating month and hour

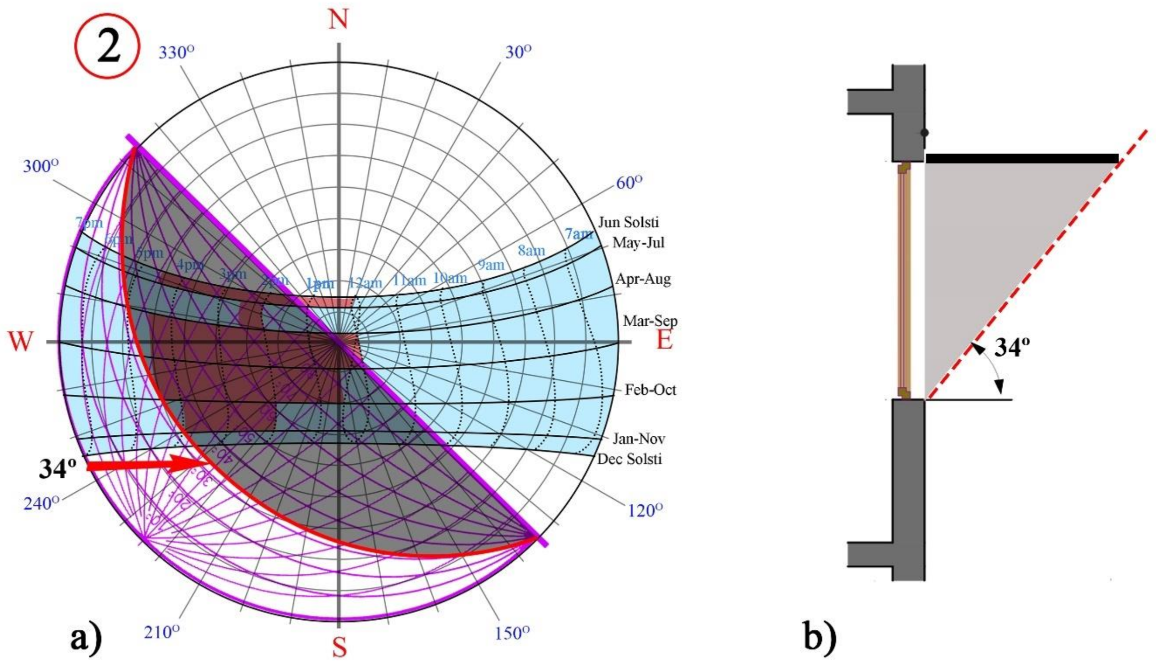


Figure 4:20.a)VSA recorded shadow angle, b) plan view with horizontal overhang and angle (Source: Sunearthtools.com and Author)

As try to show in Figure 4:20 the VSA protractor show the mapped overheated period around 34°. A 34° angle is chosen to shade periods because, at this angle, horizontal shading devices have performance by blocking overheated sun incidents.Figure 4:20.(b) shows a Section view of window. The projection line of the VSA Figure 4:20.(a) is drawn a perpendicular line to the Window and Projected 34° creates the line towards by Extending another line perpendicular from the window till it creates the diagonal line and the depth to the Horizontal overhang.

B) South West Orientation End profile angle (EPA) Identification)

EPA (End profile angle) for South west facing Window, by placing the protractor's center on stereographic diagram by facing south direction.Figure 4:21 the brown colour lines help to reading angle and step are shown.

Step-1. Using stereographic sun path diagram mapped with overheated hours and month. Overlaying sun protractor.

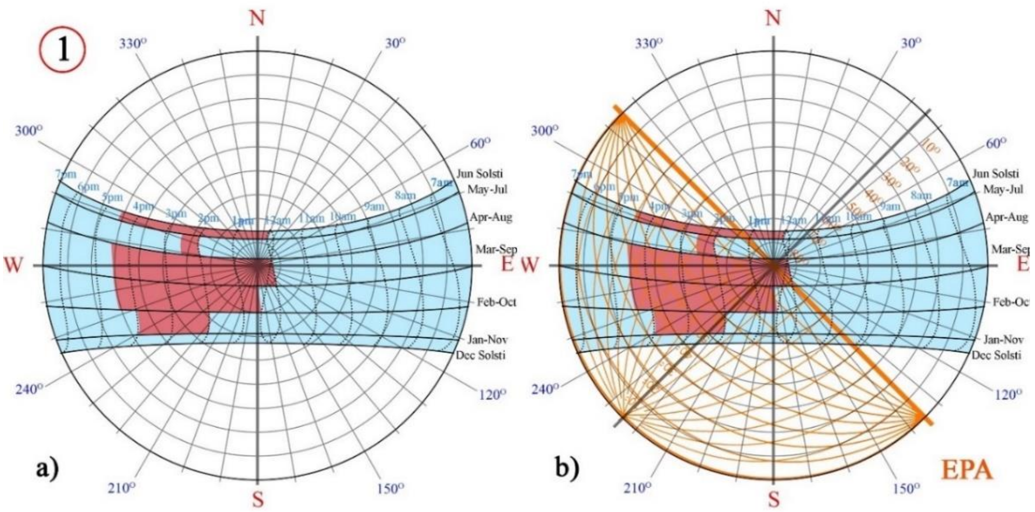


Figure 4:21.a)Sun path with mapped overheated month and hours b) EPA measuring Sun protractor place south-west facing (Source: Sunearthtools.com and Author)

Step-2. After placing EPA Measuring sun protractor by facing south west orientation reading and identifying end angle of overheating month and hour.

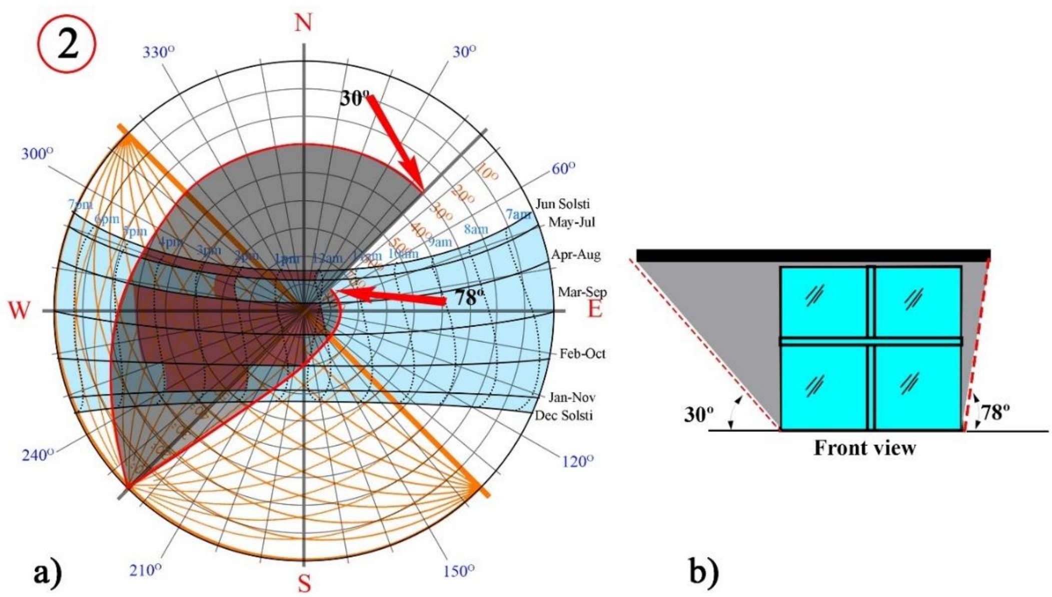


Figure 4:22.a)EPA recorded shadow angle, b) Front view with horizontal overhang and end angle (Source: Sunearthtools.com and Author)

Figure 4:22 a) and b) end profile angle for horizontal shading device or overhang the angel is recorded 30° to the North west side and 78° to South east side create desired shading for mapped overheated month and hour by extending shading device.

C) South west Orientation (Horizontal shadow angle (HSA) Identification)

HSA (horizontal shadow angle) for South west facing Window, by placing the protractor's center on stereographic diagram by facing south west direction. Figure 4:23 the brown colour helps to identify angle and step are shown.

Step-1. Using stereographic sun path diagram mapped with overheated hours and month. Overlaying sun protractor.

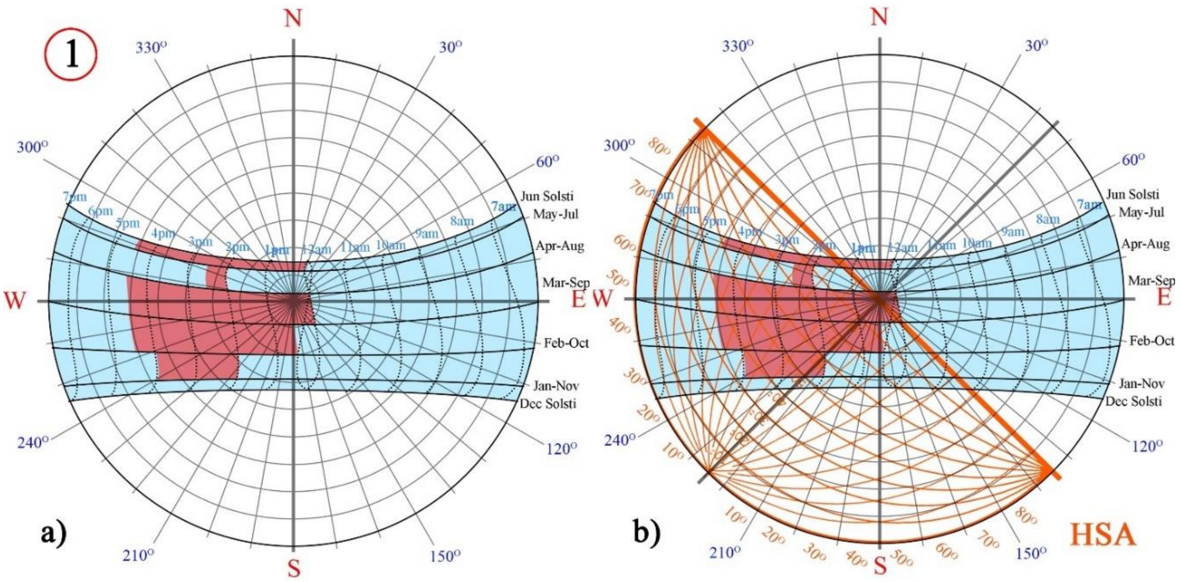


Figure 4:23.a)Sun path with mapped overheated month and hours b) HSA measuring Sun protractor place south west facing (Source: Sunearthtools.com and Author)

Step-2. After placing HSA Measuring sun protractor by facing south west orientation reading and identifying end angle of overheating month and hour.

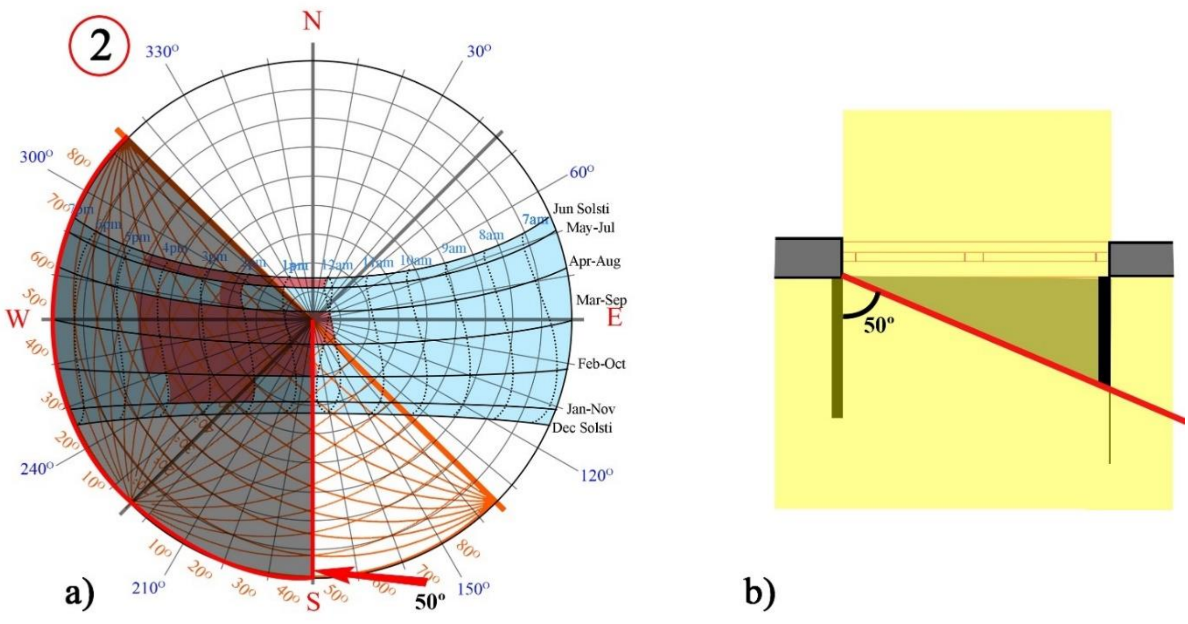


Figure 4:24.a)HSA recorded shadow angle, b) plan view with vertical fin and angle (Source: Sunearthtools.com and Author)

As try to show in Figure 4:24 the HSA protractor show the mapped overheated period around no angle to the north awest side and 50° to south east side. A 50° angle is chosen to shade periods only to south west side because vertical fine cannot create shade at any angle on overheated hours and month. Figure 4:24.(b) shows a plan of windows. The projection line of the HSA Figure 4:24.(a) is drawn a perpendicular line to the window and Projected 50° creates the line towards by Extending another line perpendicular from the window till it creates the diagonal line and the depth to the Vertical fine.

4.8.3.5 West Orientation Horizontal shadow angle (HSA), Vertical shadow angle (VSA) and End profile angle (EPA) Identification.

A) **West Orientation Vertical shadow angle (VSA) Identification**

VSA (Vertical shadow angle) for west facing Window, by placing the protractor’s center on stereographic diagram by facing west direction. Figure 4:25 the purple colour line help for reading angle and steps are shown.

Step-1. Using stereographic sun path diagram mapped with overheated hours and month. Overlaying sun protractor.

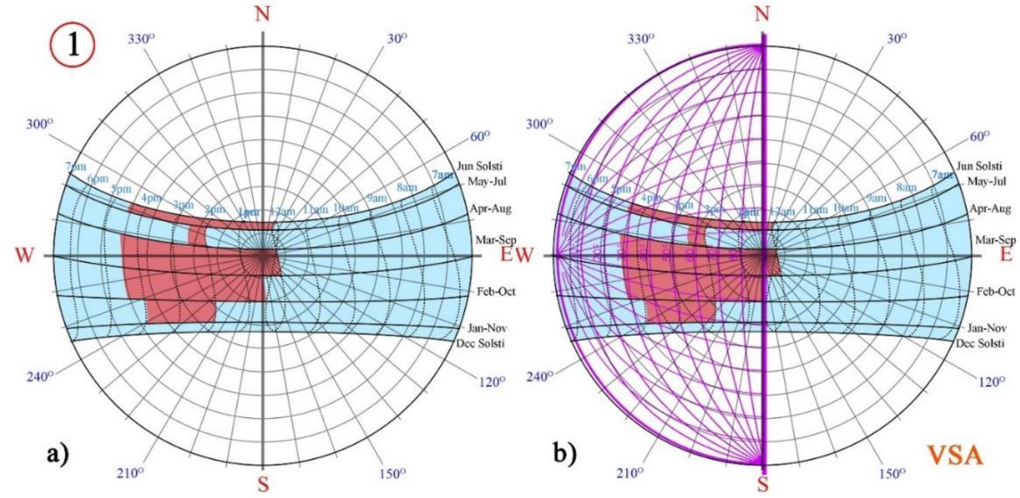


Figure 4:25 a) Sun path with mapped overheated month and hours b) VSA measuring Sun protractor place south facing (Source: Sunearthtools.com and Author)

Step-2. After placing VSA Measuring sun protractor by facing west orientation reading and identifying end angle of overheating month and hour

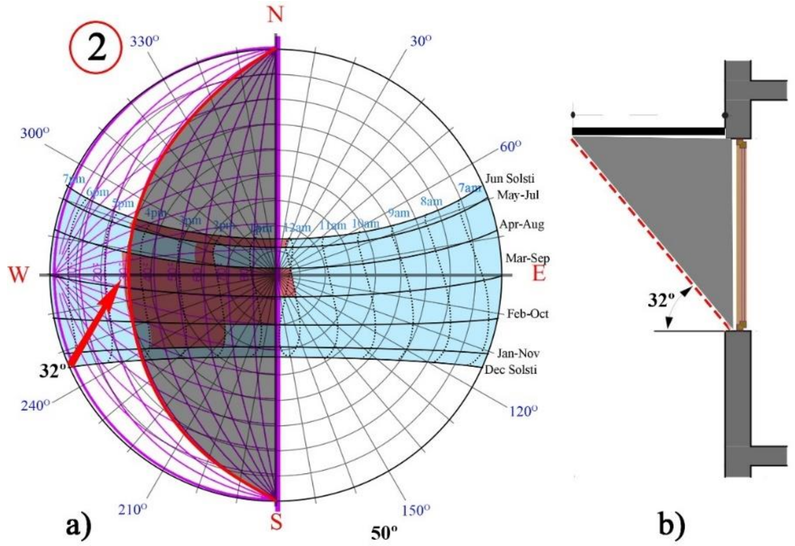


Figure 4:26.a)VSA recorded shadow angle, b) plan view with horizontal overhang and angle (Source: Sunearthtools.com and Author)

As try to show in Figure 4:26 the VSA protractor show the mapped overheated period around periods around 32°. A 32° angle is chosen to shade periods because, at this angle, horizontal shading devices have performance by blocking overheated sun incidents. Figure 4:26.(b) shows a Section view of windows. The projection line of the VSA Figure 4:26.(a) is drawn a perpendicular line to the Window and Projected 32° creates the line towards by Extending another line perpendicular from the window till it creates the diagonal line and the depth to the Horizontal overhang.

B) West Orientation End profile angle (EPA) Identification)

EPA (End profile angle) for west facing Window, by placing the protractor's center on stereographic diagram by facing south direction. Figure 4:27 brown colour line help to identify angle and step are shown.

Step-1. Using stereographic sun path diagram mapped with overheated hours and month. Overlaying sun protractor.

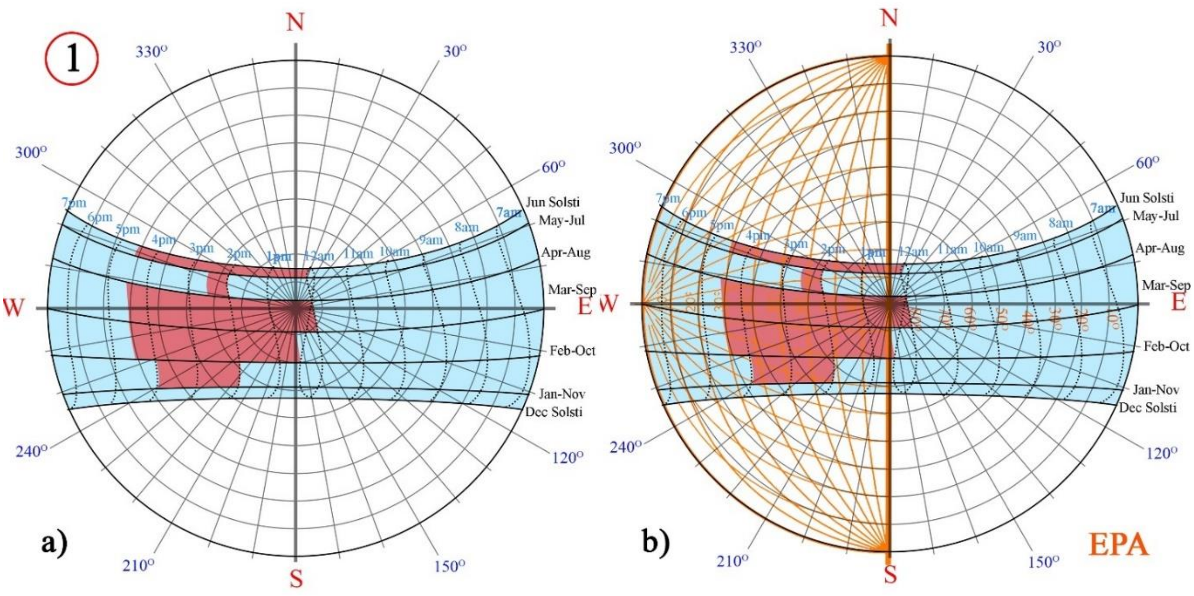


Figure 4:27.a)Sun path with mapped overheated month and hours b) EPA measuring Sun protractor place west facing (Source: Sunearthtools.com and Author)

Step-2. After placing EPA Measuring sun protractor by facing west orientation reading and identifying end angle of overheating month and hour.

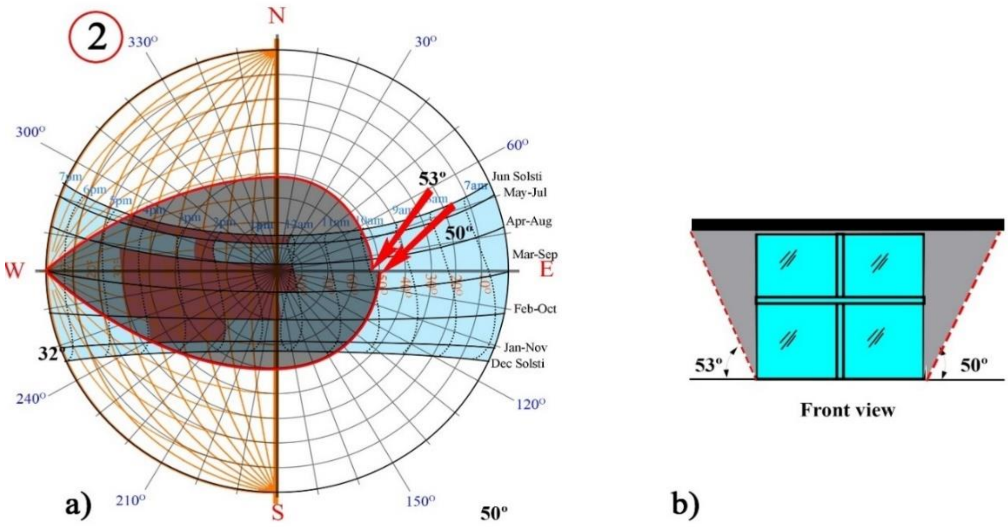


Figure 4:28.a)EPA recorded shadow angle, b) Front view with horizontal overhang and end angle (Source: Sunearthtools.com and Author)

Figure 4:28 a) and b) end profile angle for horizontal shading device or overhang the angel is recorded 50° to South side and 53° to the North side create desired shading for mapped overheated month and hour by extending shading device

C) West Orientation (Horizontal shadow angle (HSA) Identification)

HSA (horizontal shadow angle) for west facing Window, by placing the protractor's center on stereographic diagram by facing West direction. Figure 4:29 brown colour identify by reading angle and step are shown.

Step-1. Using stereographic sun path diagram mapped with overheated hours and month. Overlaying sun protractor.

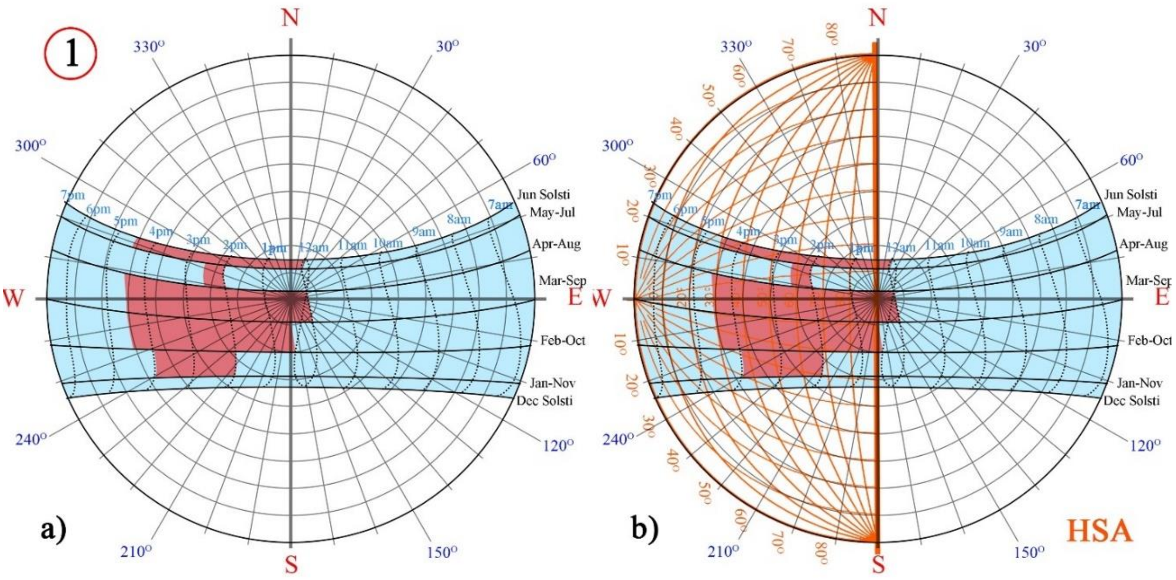


Figure 4:29.a)Sun path with mapped overheated month and hours b) HSA measuring Sun protractor place south facing (Source: Sunearthtools.com and Author)

Step-2. After placing HSA Measuring sun protractor by facing west orientation reading and identifying end angle of overheating month and hour.

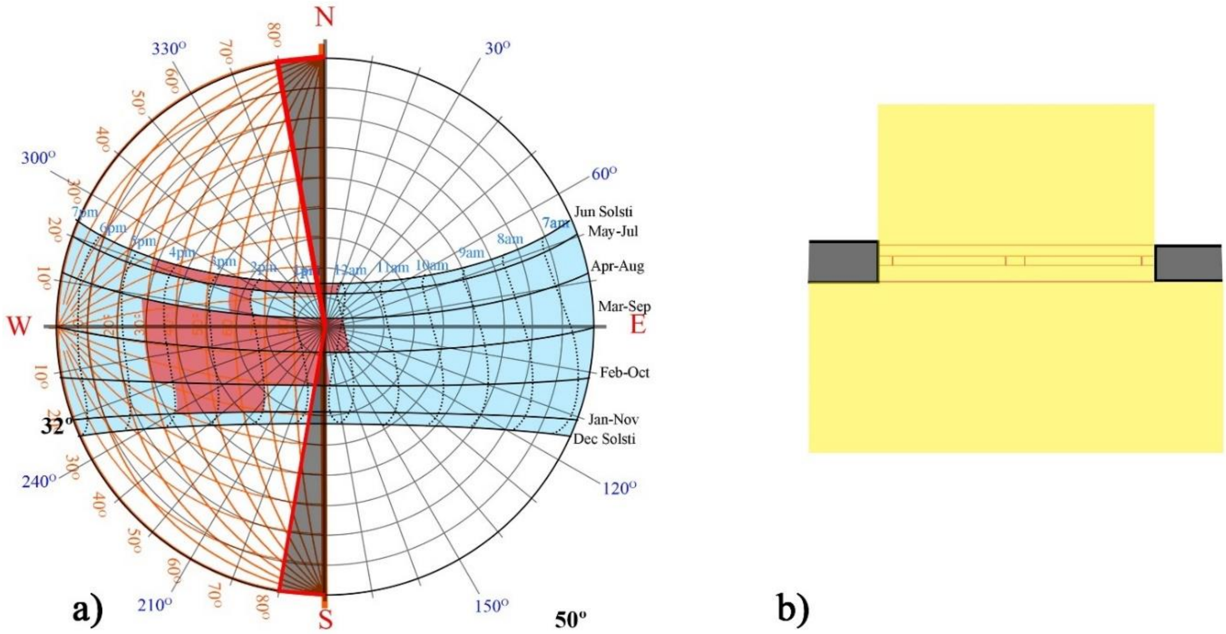


Figure 4:30.a)HSA recorded shadow angle, b) plan view with vertical fin and angle (Source: Sunearthtools.com and Author)

As try to show in Figure 4:30 the HSA protractor show overheated hours and month between 90° to 80° angle to the south side and between 90° to 80° angle to the north. This means Figure 4:30 b) shows that solar exposed plan and 0° angle projection are aligned parallel because of extension this vertical fin will not block incoming solar radiation this orientation. For this reason, vertical shading is not recommended. for this orientation. For three South, Southwest and west orientation Table 4:13 summarized helps to design shading device.

Table 4:13 Adama city shading angle using sun protractor

Adama city lat:8.5263823 and Lon:39.2695925			
Orientation	VSA Overhang	HSA Vertical fine	EPA Overhang
South	58°	45°	30° and 88°
South west	34°	-	30° and 78°
West	32°	-	53° and 58°

(Source: Sunearthtools.com and Author,2023)

4.9 Calculation for overhang and fins sizes

4.9.1 Horizontal Shadow angle (HSA)

The Horizontal Shadow Angle (HSA) pertains to the effectiveness of vertical shading systems. Calculated as the variance in azimuth between the sun's current location and the facade orientation, HSA is a crucial metric for architects and designers seeking to optimize building performance and energy efficiency.

Equation 4:1 Horizontal Shadow angle Formula

HSA = AZI – ORI (Szokolay, 2007)…….Equation 4:1

HSA = Horizontal Shadow Angle

AZI = Azimuth Angle

ORI = Orientation of building Façade

4.9.2 Vertical shadow angle (VSA)

The measuring of the vertical shadow angle (VSA) is a requisite for horizontal shading devices. It pertains to the angle formed between the horizontal plane of the building exterior being examined and an inclined plane populated by the sun or shading device edge. One can determine VSA by utilizing the following equation.

Equation 4:2: Vertical Shadow angle Formula

$$\text{VSA} = \arctan\left(\frac{\tan(Altitude)}{Cos(HSA)}\right)$$ (UN Habitat, 2018)……Equation 4:2

VSA=Vertical Shadow Angle

HSA=Horizontal Shadow Angle

4.9.3 Shading device Dimensions

According to (UN Habitat, 2018), To determine the size of a shading device required for a window, one must utilize the HSA and VSA angles. The equations to calculate the overhang depth, its width (extra projection from the side of the window), and the fins are as follows:

Equation 4:3: Overhang and Fin size calculating Formula

$$\text{Overhang Depth} = \frac{Height}{Tan(VSA)} \qquad \text{Overhang Width} = \frac{Depth}{Tan(HSA)}$$

$$\text{Fin Depth} = \frac{Width}{Tan(HSA)}$$ ……. Equation 4:3

Depending on the Table 4:13 the VSA and HSA as determined using sun protractor for overheated month and hour, shading device overhang and fins are designed using the Equation 4:3 as follow.

4.9.3.1 Shading device dimension for South facing room window

Table 4:13 and Figure 4:31 show that angles to block excessive solar incident to the building using sun protractor for specific area with overheated month and hour for south facing room window with VSA = 58°, HSA 45° and EPA with 30° to west side and 88° to east side.

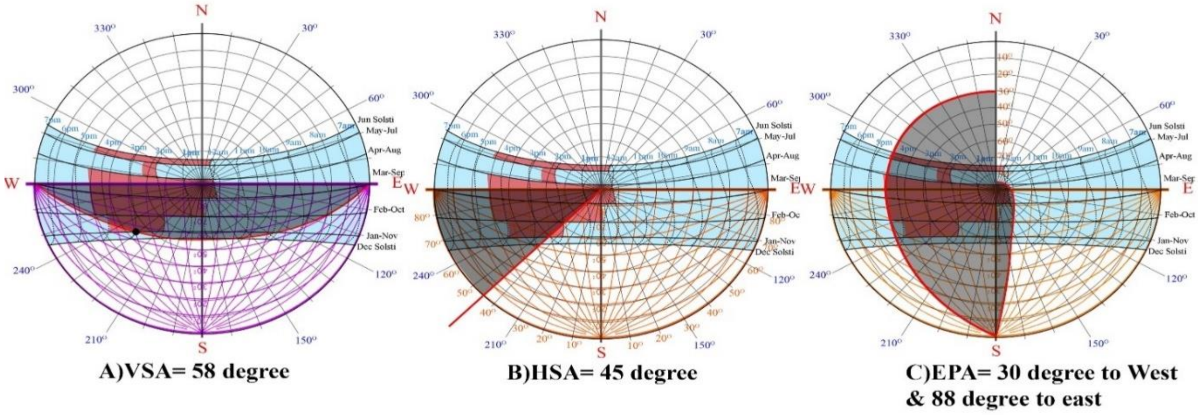


Figure 4:31: VSA, HSA and EPA angle for south-facing room window (Source: Sunearthtools.com and Author)

With the window size of 1.20m width and 1.50m height, calculating the overhang size and vertical becomes crucial for effectively regulating the amount of sunlight that enters the building. Equation (3) is a valuable tool in calculating the overhang depth, width, and fin depth.

Overhang Depth = $\frac{Height}{Tan(VSA)}$ Overhang Width = $\frac{Depth}{Tan(HSA)}$ Fin Depth = $\frac{Width}{Tan(HSA)}$

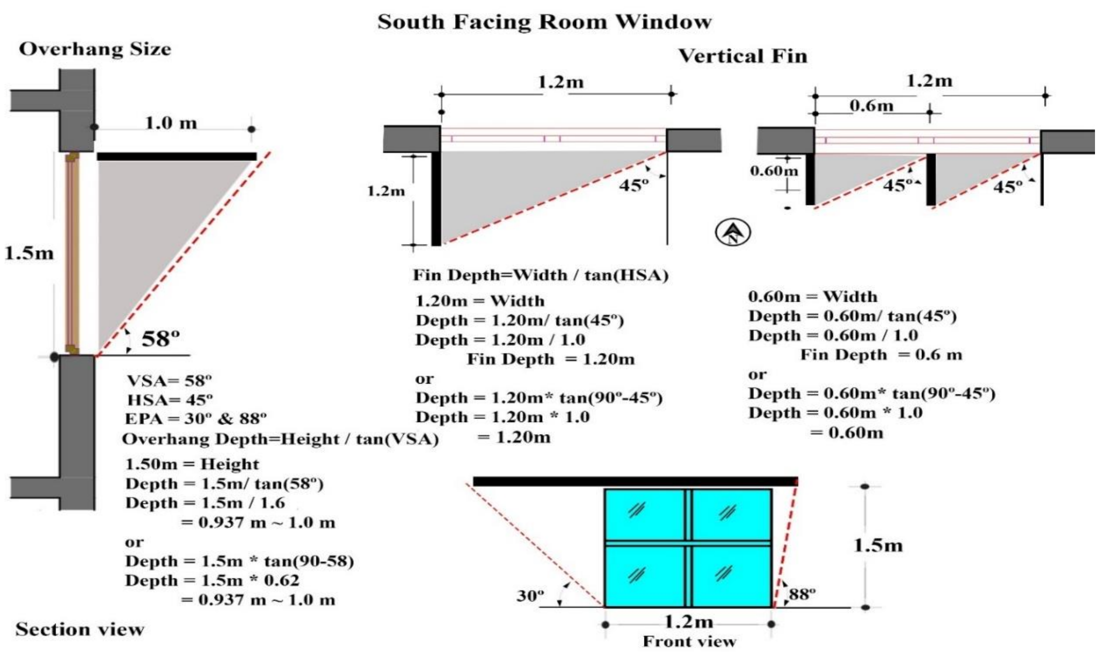


Figure 4:32: Calculation of south facing window overhang and fin size (Source: Author)

According to Figure 4:32 An overhang with a 58-degree cutoff angle (or a depth equal to 0.62 times the window's 1.5-meter height) and a 1.0-meter depth will provide effective shading. The overhang's end profile is 30 degrees to the west and 88 degrees to the east. In addition to the overhang, a vertical fin will offer total shading. 45 degrees should be the cut-off angle for the vertical fin (depth should equivalent to 1.0 times the window width 1.2m). The size of the fine will be 0.6m in order to reduce the fin depth two vertical fine by dividing the with in to have 0.6m times 1.0.

4.9.3.2 Shading device dimension for Southwest facing room window

Figure 4:33 illustrates the utilization of a sun protractor to obstruct excessive solar radiation from entering a building. This is accomplished by specifying the overheated month and hour for a south west facing room window with a VSA of 32 degrees. The vertical fin is deemed ineffective in this scenario no HSA, while an EPA of 30 degrees to the west side and 78 degrees to the east side is recommended.

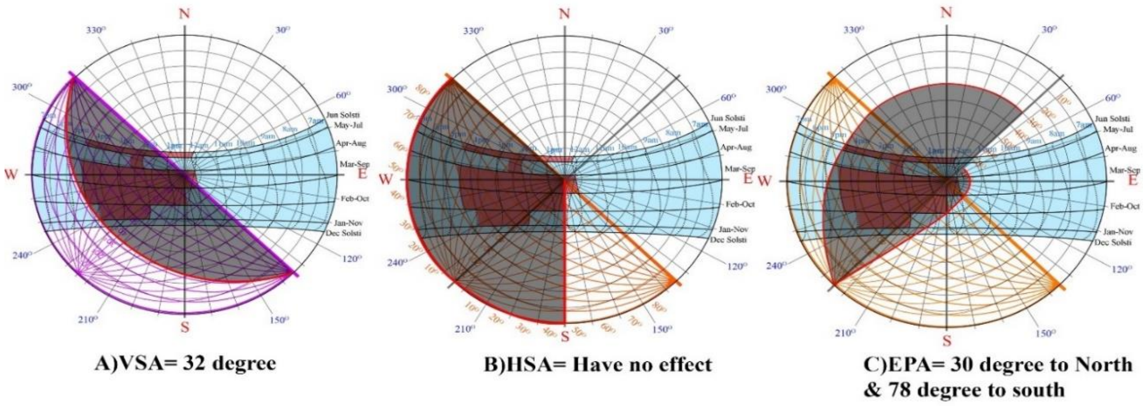


Figure 4:33: VSA, HSA and EPA angle for southwest facing room window (Source: Sunearthtools.com and Author)

Precise calculation of the overhang size and vertical shading device in controlling the incidence of sunlight in a building, particularly considering the window dimensions of 1.20m in width and 1.50m in height. Equation (1-3) is an invaluable aid in determining the overhang depth, width, and fin depth of the shading device.

Overhang Depth = $\frac{Height}{Tan(VSA)}$ Overhang Width = $\frac{Depth}{Tan(HSA)}$ Fin Depth = $\frac{Width}{Tan(HSA)}$

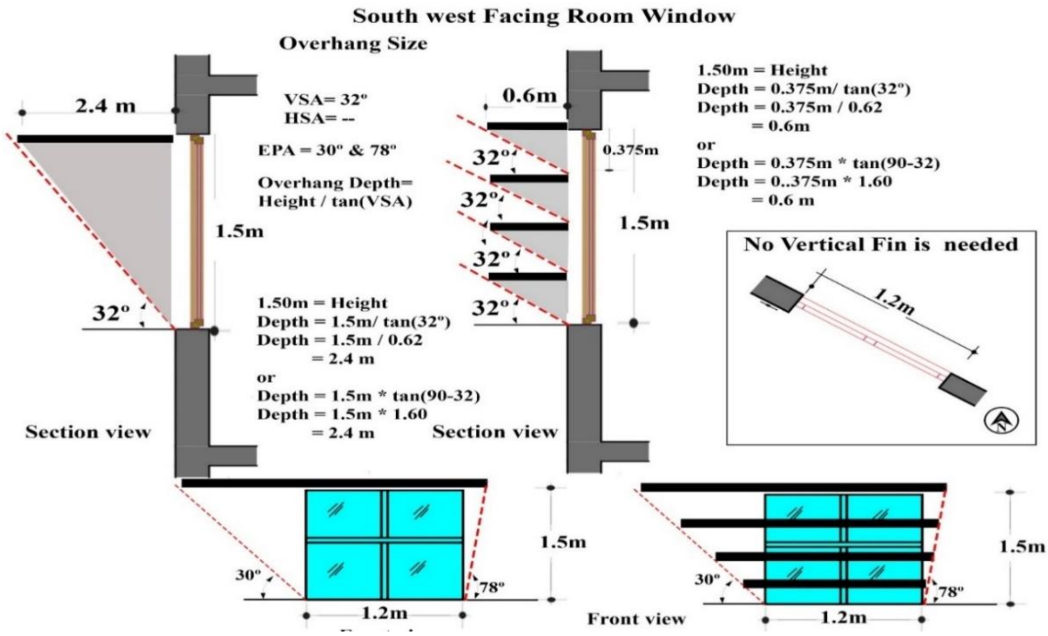


Figure 4:34: Calculation of southwest facing window overhang and fin size (Source: Author)

According to Figure 4:33, a south west oriented room cannot be adequately shaded using only Vertical shading devices due to the absence of HSA for the masked overheated period. However, the VSA reading suggests that a shade can be created using a horizontal shading device, as the EPA measures 30 degrees to the north west side and 78 degrees to the south east side. In order to determine the appropriate size of shading device relative to the window size, calculations were carried out as presented in Figure 4:34. The resulting overhang depth was found to be 2.4 meters, which is quite lengthy. For this reason, by dividing the size into four sections using the same VSA, the overhang width can be reduced to 0.6 meters, providing sufficient shading.

4.9.3.3 Shading device dimension for West facing room window

According Figure 4:35 illustrates the utilization of a sun protractor to obstruct excessive solar radiation from entering a building. This is accomplished by specifying the overheated month and hour for a west facing room window with a VSA of 32 degrees. The vertical fin is deemed ineffective in this scenario no HSA, while an EPA of 53 degrees to the west side and 58 degrees to the east side is recommended.

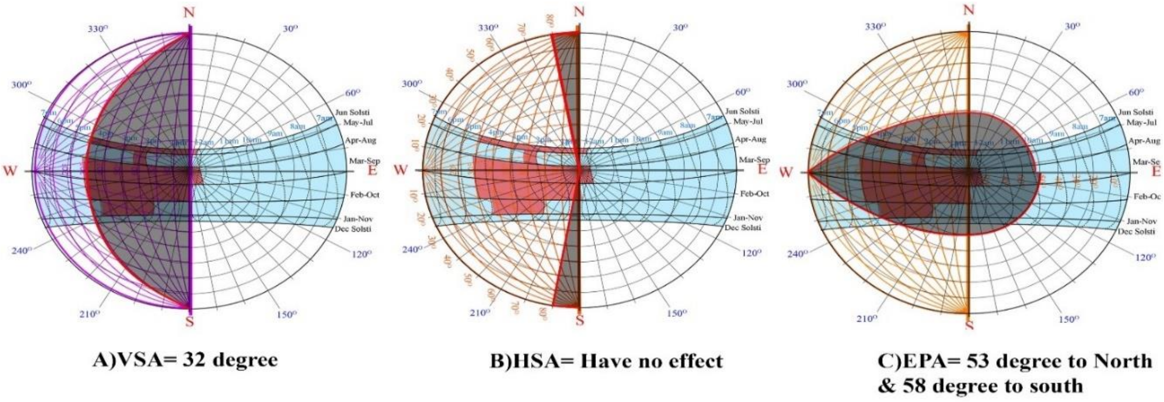


Figure 4:35: VSA, HSA and EPA angle for West facing room window (Source: Sunearthtools.com and Author)

Precise calculation of the overhang size and vertical shading device in controlling the incidence of sunlight in a building, particularly considering the window dimensions of 1.20m in width and 1.50m in height. Equation (1-3) is an invaluable aid in determining the overhang depth, width, and fin depth of the shading device.

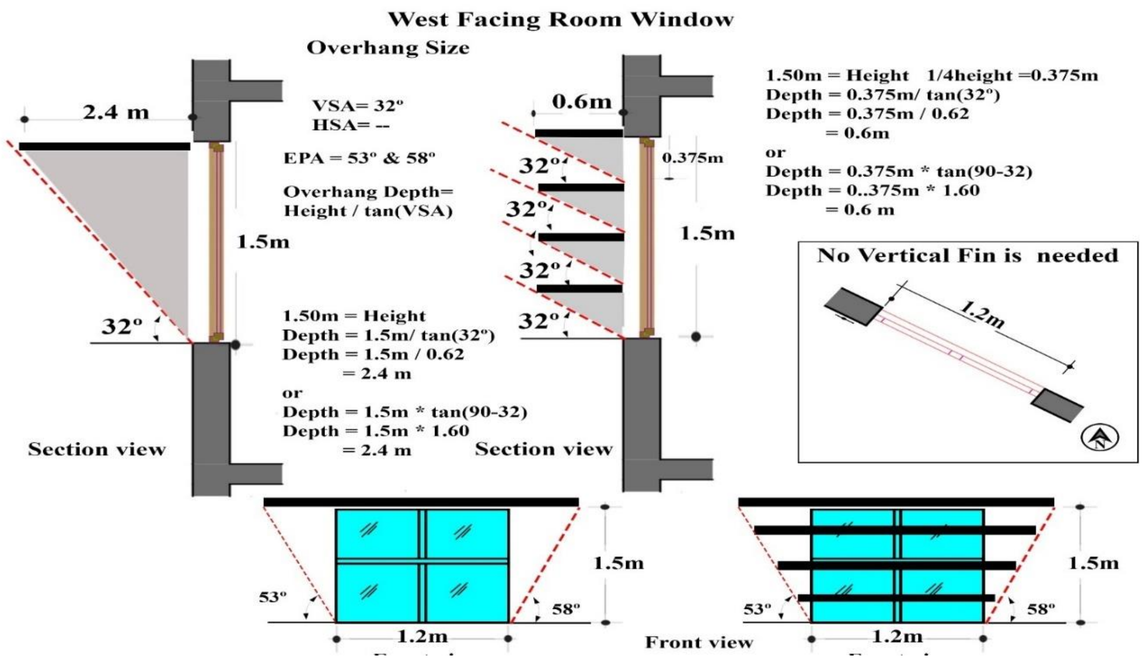


Figure 4:36: Calculation of west facing window overhang and fin size (Source: Author)

According to Figure 4:35, a west oriented room cannot be adequately shaded using only Vertical shading devices due to the absence of HSA for the masked overheated period. However, the VSA reading suggests that a shade can be created using a horizontal shading device, as the EPA measures 53 degrees to the northern side and 58 degrees to the south side. In order to determine the appropriate size of shading device relative to the window size, calculations were carried out as presented in Figure 4:36. The resulting overhang depth was found to be 2.4 meters, which is quite lengthy. For this reason, by dividing the size into four sections using the same VSA, the overhang width can be reduced to 0.6 meters, providing sufficient shading.

4.10 Computer Simulation

Computer simulation performed on rooms with and with-out shading device by selecting similar building block, typology, adjacent floors and orientation. Computer simulations support provide objective data in accessing the performance of exterior shading devices by blocking penetration of undesired solar radiation as well as optimizing indoor thermal comfort. Ecotect software used to simulate temperature distribution and hourly temperature profile on a model utilizing an Adama weather dataset.

4.10.1 Simulation on south facing room

The simulation conducted in the south facing room encompassed the distribution of temperature under three distinct scenarios. The first scenario involved the south facing room without any shading device, the second encompassed the room with its existing shading device, while the third scenario implemented a newly designed shading device. The simulation was performed on a consistent room size and window dimensions, as illustrated in the corresponding Figure 4:37.

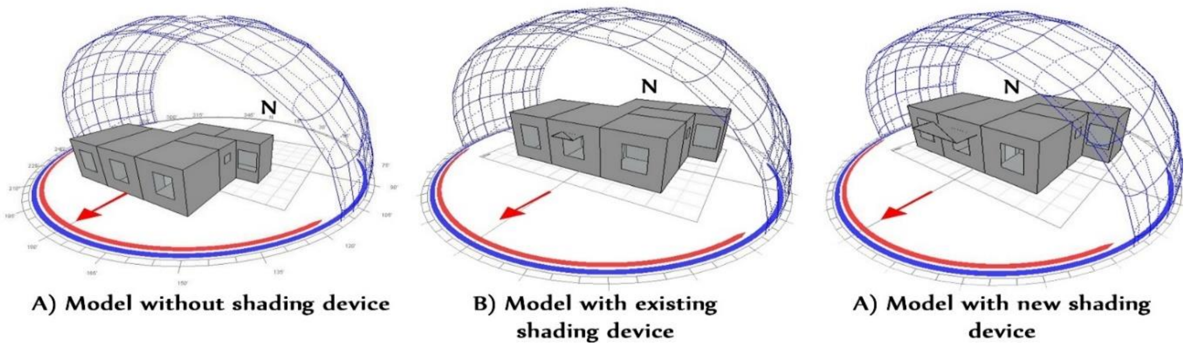


Figure 4:37: Model south-facing room with and without shading device (Source: Ecotect)

Based on a site survey, it was determined that an existing shading device with a depth of 1.2m and width of 0.6m was modeled for simulation purposes. A new shading device design was developed based on the harsh hour and month data from a time plot table using climate consultant software and the sun protector VSA angle of 58°, HSA angle of 45°, EPA angle of 30° to the west side, and 88° to the east side. The overhang dimension is 1m in depth, and the vertical panel consists of two panels with a spacing of 0.6m and depth of 0.6m.

4.10.1.1 Simulation on South facing room outside and inside temperature on existing shading device

Chart 4:19 shows the results of south facing room a simulation for the inside with existing shading and outdoor temperature degrees Celsius for the date April 10 average hottest day where the maximum temperature is 19 0°C and minimum is 16 2°C While the greatest temperature outside was 28 0°C and the lowest was 14 6°C the average temperature inside was 19 0°C making the average outside temperature 21 55°C

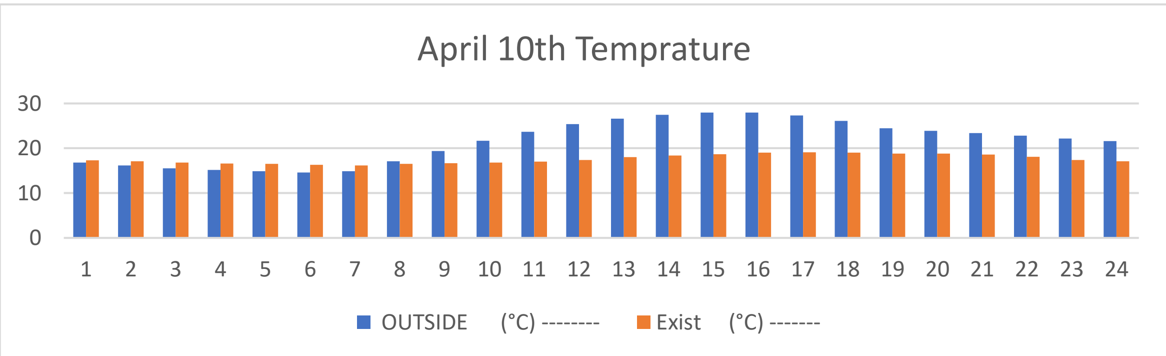


Chart 4:19: Simulation outside and inside room with existing shading device (Source: Ecotect)

4.10.1.2 Simulation on South facing room inside temperature with existing shading and new shading device

The maximum temperature for the inside is 19.0°C and minimum is 17.4°C as shown in Chart 4:20, Simulation result of inside temperature degree Celsius with existing shading and new shading device date of 10th April hottest day average The existing shading device predicted a maximum temperature of 19.0°C and a low temperature of 16.2°C however the new overhang and fin recorded maximum temperatures of 18.4°C and 18.0°C and minimum temperatures of 15.6°C and 16°C respectively However average temperature inside a room with existing shading was 17.59°C while the maximum temperature inside a room with new overhang shading was 18.40°C and the minimum temperature outside was 17.4°C while the minimum temperature inside a room with new overhang shading was 15.6°C.

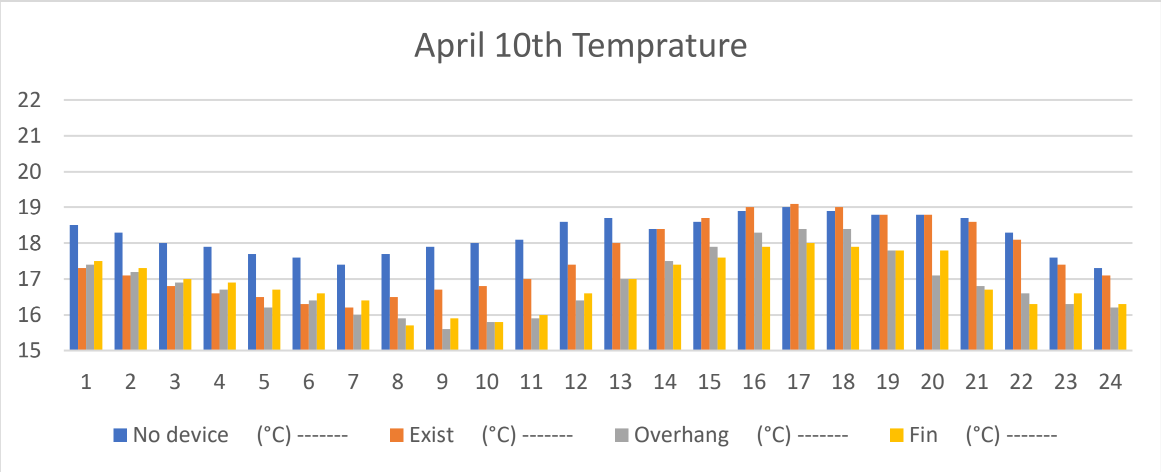


Chart 4:20: Simulation outside and inside south facing room with existing shading device (Source: Ecotect)

4.10.2 Simulation on southwest facing room

The south west facing room was subjected to a simulation that aimed to analyze the temperature distribution under three specific scenarios. The initial scenario involved the room without any shading device facing the south-west. The second involved the room with its existing shading device, while the third implemented a recently designed shading device. The simulation was conducted on a constant-sized room and window dimensions as depicted in Figure 4:38.

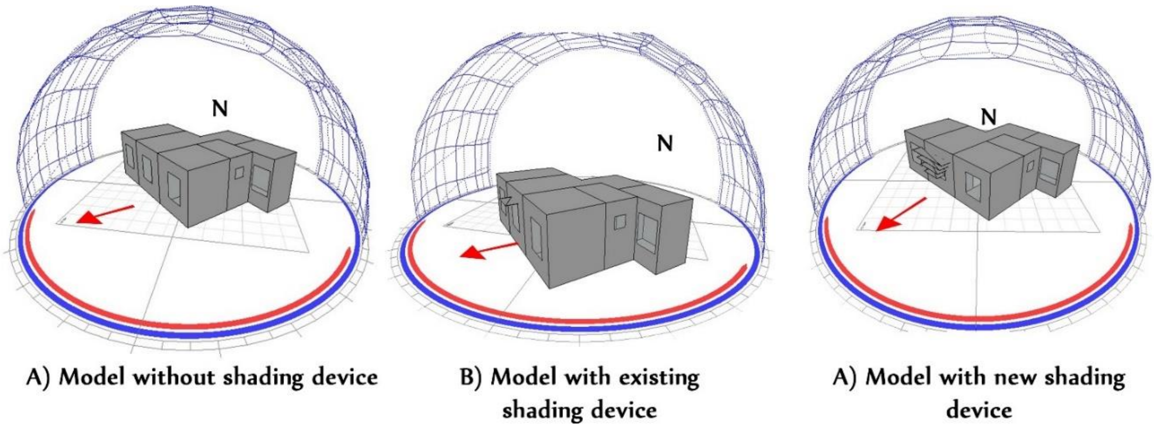


Figure 4:38: Model south-west-facing room with and without shading device (Source: Ecotect)

After a thorough site survey, it was discovered that an existing shading device, measuring 1.2 meters in depth and 0.6 meters in width, used as the basis for simulation purposes. Through the utilization of climate consultant software, a new shading design was developed that relied on harsh hour and month data from a time plot table. Specifically, the design was configured to consider the sun protector VSA angle of 32°, EPA angle of 30° towards the North west side, and 78° to the South east side. Through an efficient overhang dimensioning approach, the size was divided into four sections, with the resultant overhang width being reduced to 0.6 meters whilst ensuring adequate shading.

4.10.2.1 Simulation on Southwest facing room outside and inside temperature on existing shading device

Chart 4:21 illustrates the southwest simulation result for indoors with existing shade and outdoor temperature in degrees Celsius; for the date of April 10th, the hottest day on average with shading elements, 23.2°C indicates maximum temperature and minimum is 20.5°C for the indoors. However, the interior temperature was 17.5°C on average, while the outside temperature was 28.0°C on average and 14.6°C on lowest, making the outdoor temperature on average 21.55°C.

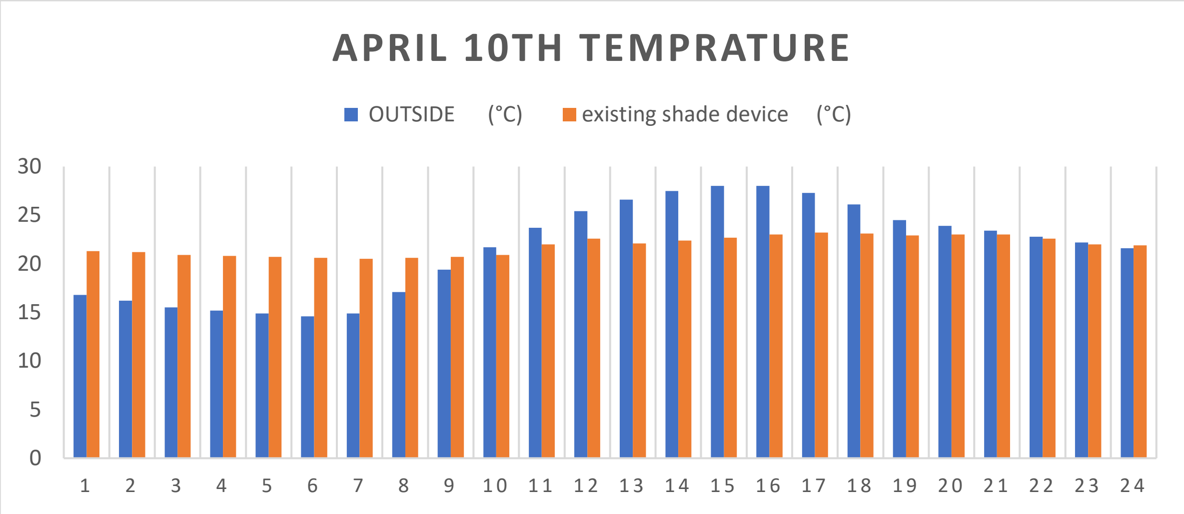


Chart 4:21: Simulation outside and inside south west facing room with existing shading device (Source: Ecotect)

4.10.2.2 Simulation on Southwest facing room inside temperature with existing shading and new shading device

Simulation result for inside temperature (degree Celsius) in a southwest-facing room with existing shading and a new shading device: the date of April 10th, average hottest day without a shading device, shows in Chart 4:22, 24.1 °C is the maximum, and the minimum temperature is 21.5 °C for the inside. Existing shading devices simulated maximum 23.2 °C and minimum 20.5 °C, whereas the new overhang is 22.8 °C with maximum temperature and 18.6 °C inside minimum temperature.

However, for indoor the average temperature with existing shading being 21.86°C while the 22.8°C was the maximum obtained for new overhang shading device and minimum being 20.5°C for exiting, when 19.6°C is minimum temperature for room with new overhang shading device.

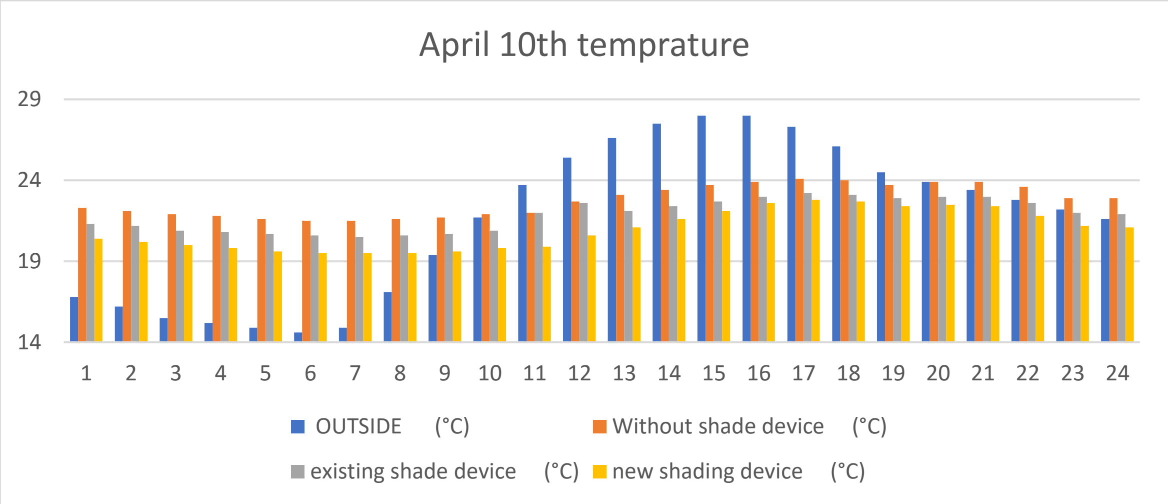


Chart 4:22: Simulation outside and inside southwest facing room with existing shading device (Source: Ecotect)

4.10.3 Simulation on west facing room

The west facing room simulation involved examining temperature distribution under three distinct scenarios. The first scenario studied the south facing room in its natural state without the use of any shading devices. The second scenario analyzed the room with an existing shading device in place. In contrast, the third scenario tested a newly designed shading device. The simulation was carried out using the same room size and window dimensions, which are displayed in Figure 4:39.

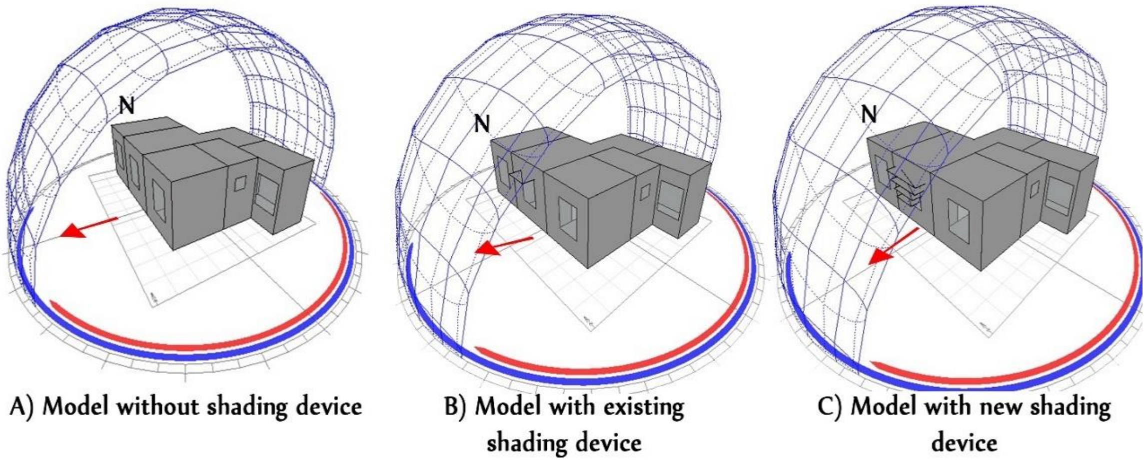


Figure 4:39: Model West-facing room with and without shading device (Source: Ecotect)

Based on site survey, it was discovered that an existing shading device, measuring 1.2 meters in depth and 0.6 meters in width, used as the basis for simulation purposes. Through the utilization of climate consultant software, a new shading design was developed that relied on harsh hour and month data from a time plot table. Specifically, the design was configured to consider the sun protector VSA angle of 32°, EPA angle of 53° towards the North side, and 58° to the South side. Through an efficient overhang dimensioning approach, the size was divided into four sections, with the resultant overhang width being reduced to 0.6 meters whilst ensuring adequate shading.

4.10.3.1 Simulation on West facing room outside and inside temperature on existing shading device

Chart 4:23 shows for the date 10th April, the hottest day on average, with shading elements, 23.6°C displays maximum temperature and minimum is 20.5°C for the inside of a west-facing room with current shading and external temperature degree Celsius. However, the average temperature inside was 22.07°C, while the minimum and highest temperatures outside were 14.6°C and 28.0°C, respectively. As a result, the average temperature outside is 21.55°C.

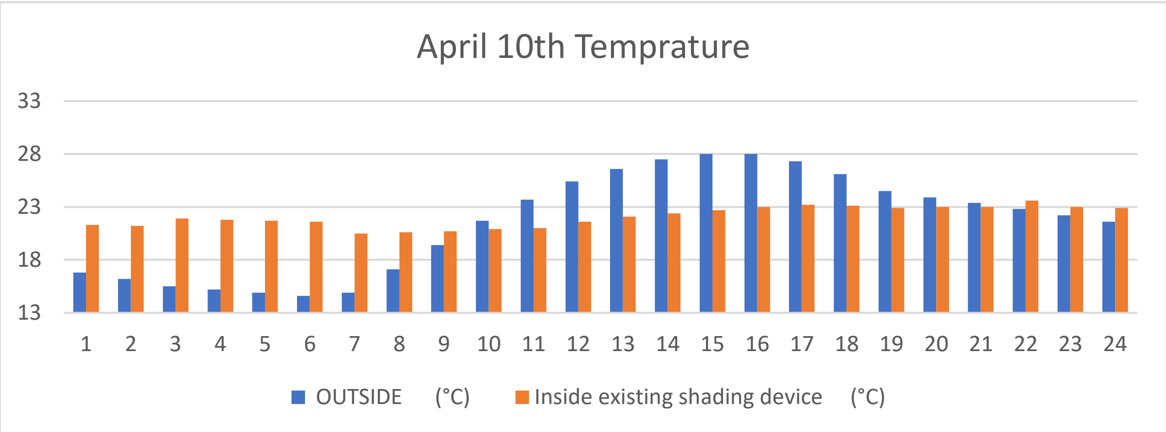


Chart 4:23: Simulation outside and inside west facing room with existing shading device (Source: Ecotect)

4.10.3.2 Simulation on west facing room inside temperature with existing shading and new shading device

Simulation result for inside temperature (degree Celsius) in a southwest-facing room with existing shading and a new shading device: the date of April 10th, average hottest day without a shading device, shows in Chart 4:24, 24.5°C is the maximum, and the minimum temperature is 21.5°C for the inside. Existing shading device simulated maximum 23.6°C and minimum 20.5°C. whereas new overhang 23°C with maximum temperature, 21.5°C inside minimum temperature. However, for indoor the average temperature with existing shading being 22.07°C while the 23°C was the maximum obtained for new overhang shading device and minimum being 20.5°C for exiting, when 19.5°C is minimum temperature for room with new overhang shading device.

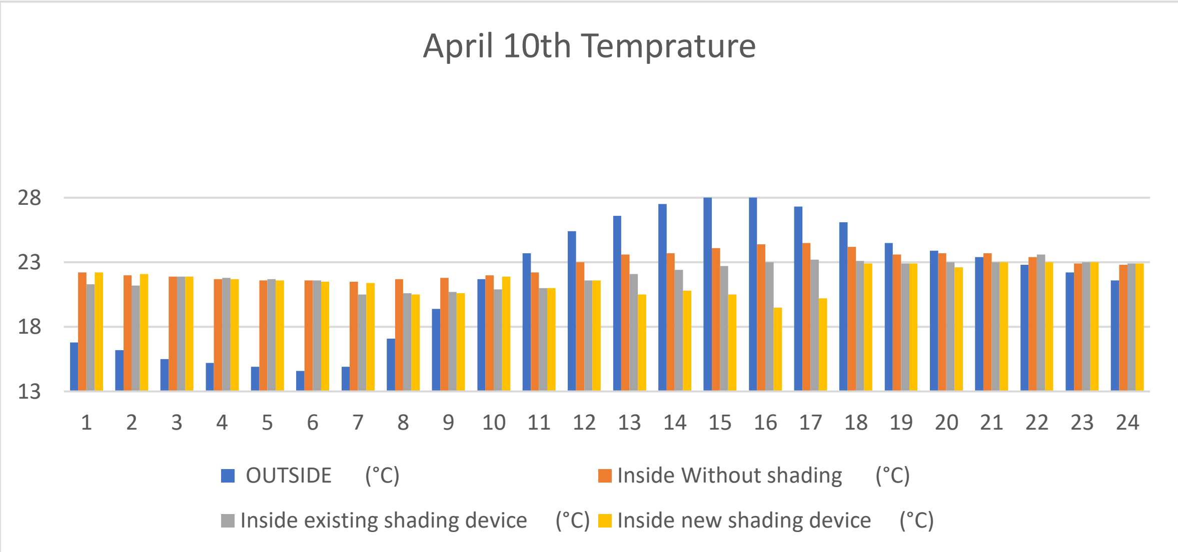
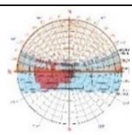
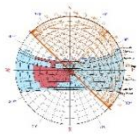
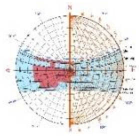
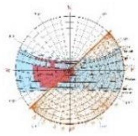
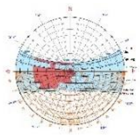
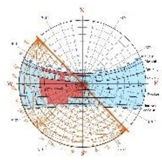
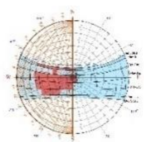
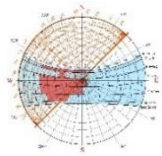


Chart 4:24: Simulation outside and inside west facing room with existing shading device (Source: Ecotect)

4.11 Determination for shading Device Design HSA, VSA and projection factor

Table 4:14 shows that horizontal shadow angle. vertical shadow angle, End profile Angle and projection factor for North, Northeast, East, Southeast, South, Southwest, West and northwest orientation

Table 4:14: HSA, VSA, EPA and projection factor for different orientation

Orientation	Vertical fine		Overhang		EPA		Sun Protractor Placement
	HSA (degree)	Projection factor	VSA (degree)	Projection factor	Left Side	Right side	
North	30°	1.7	55°	0.7	30° W-side	85° E side	
North East	25°	2.1	80°	0.1	85° S-side	70° N-Side	
East	40°	1.2	80°	0.1	80° S-side	75° W-side	
South East	-	-	85°	0.09	65° NE-side	85° SW-side	
South	45°	1	58°	0.6	88° E-side	30° W-side	
South West	-	-	32°	1.6	78° NW-side	30° SE-side	
West	-	-	32°	1.6	58° S-side	53° N-side	
North West	32°	1.6	10°	5.7	33° SW-side	-	

4.12 Summary of Discussion

For understanding the level of thermal satisfaction occupant total of 126 occupants were involved in the survey, of which 55 were male, accounting for 44%, and 71 were female, accounting for 56% because of females are less satisfied with room temperatures than males and feel both uncomfortably cold and uncomfortably hot more often. The respondent range is from 15 to over 61 years old. A total of 122 building blocks from 21 in were surveyed. Shading device is used in three orientations south, west and south west. The thermal comfort response of occupant over south west, south and west facing 7:00pm-8:00pm shows the highest thermal preference about 65=51.6% and 53 = 42.1% were uncomfortable, 42 = 33.3% were slightly uncomfortable. The thermal comfort response of a building with shading device has the weakest performance. Table 4:3 demonstrates that from January to May, from 6:00 to 10:00 pm is the most thermally unpleasant hour in all buildings, while April and May are the most excessively hot month. Overall, the time from 12:00 p.m. to 4:00 p.m. was claimed to be thermally uncomfortable by 46% of respondents. Field measurement of Environmental variable take placing in two south facing room with shading and without shading device. The existing shading device in the south-facing room showed readings of maximum 31.9 °C and minimum 25.4 °C, the ASHRAE standard states that the ideal comfort level falls between 21 °C and 27 °C any temperature outside this range may lead to discomfort. This finding implies the existing shading device are thermally discomfort. As well as daylight illuminance, relative humidity and air velocity of room with shading device are discomfort and not giving required solution. Identifying sun position of Adama and when shading is required show that January month from 2pm-4pm, February from 12:30 noon -4:30pm, March from 12:00 noon-4:30pm, Aprill 2:00pm-2:00pm, and May from 12:00 noon -4:30pm are hottest months of Adama city required shading. Proportion and Dimension of Shading Device for overheated Period identifying using sun protractor and time plot table from these three-orientation used shading device the optimal dimension is stated for south orientation VSA 58°, HSA 45° and EPA 30° and 88°, Overhang at a cut-off angle of 58 degrees (or depth equivalent to 0.62 times the window height 1.5m) the overhang depth is

1.0m will give good shading, overhang depth was found to be 2.4 meters, which is quite lengthy. For this reason, by dividing the size into four sections using the same VSA, the overhang width can be reduced to 0.6 meters, providing sufficient shading. For south west VSA 34°, HSA no and EPA 30° and 78°.The resulting overhang depth was found to be 2.4 meters, which is quite lengthy. For this reason, by dividing the size into four sections using the same VSA, the overhang width can be reduced to 0.6 meters, providing sufficient shading. For west facing VSA 32°, HSA no and EPA 53° and 58° The vertical fin should have a cut-off angle of 45 degrees (depth should equivalent to 1.0 times the window width 1.2m). To minimize the fin depth two vertical fine by dividing the with in to have 0.6m times 1.0 the size of fine will be 0.6m. The effects of shading device were examined by using software simulation for hottest month 10 April. Software simulation for April hottest month shows that the new designed shading device have good performance than the existing shading device.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this paper, the effects of shading devices on thermal comfort are examined in an Adama City condominium building. The study was carried out using both objective and subjective evaluation techniques, including questionnaires, and environmental variable measurements (daylight illumination, temperature, airspeed, and humidity) were recorded for two of the warmest months for 20 days using an instrument, including ASHRAE 55's 7-point sensational scale. The questionnaires were given to 126 samples, and software simulations were run on two sample living rooms with a similar layout. From the 122 blocks in Adama, 21 blocks used shading devices. The occupant's response to thermal satisfaction implies discomfort and warmer weather conditions. When comparing the room with a shading device to the room without a shading device, both rooms have almost similar discomfort, but the room with a shading device shows little improvement over the other. Most of the blocks used for shading devices are oriented in south-facing rooms with a maximum long shading span of 0.6 m and window Height of 1.5 m and Width 1.2 m. In the south-facing room with shading device, temperature range from 24 °C to 31.6 °C and air velocity 0.00 m/s to 0.96 m/s, outdoor 25.4 °C to 33.6 °C, while outdoor ranges from 0.45 m/s to 4.5 m/s; relative humidity ranges from 25% to 33%; outdoor ranges from 25% to 33%; daylight illumination from 250 lux to 665 lux; and outdoor from 520 lux to 1987 lux. South-facing room without shading device Temperature ranges from 24 °C to 31.6 °C; air velocity 0.00 m/s to 0.98 m/s; relative humidity from 24% to 32%; and daylight illumination from 250 lux to 665 lux. Ecotect software for the simulation of a south-facing room with a shading device and a new shading device using a sun protractor for overheated months and hours shows that the new shading device had good performance on temperature distribution. On thermal comfort, shading devices have an impact. Buildings with appropriate shading devices increase thermal comfort. In conclusion, the existing shading devices have low performance on residents' thermal comfort, and the new shading design approaches for south orientation VSA 58°, HSA 45° and EPA 30° and 88°, Overhang at a cut-off angle of 58 degrees, for west facing VSA 32°, HSA no and EPA 53° and 58° The vertical fin should have a cut-off angle of 45 degrees, For south west VSA 34°, HSA no and EPA 30° and 78°. understanding the sun path, window size, and overheated period in considering HSA, VSA, and EPA have better performance.

5.2 Recommendation

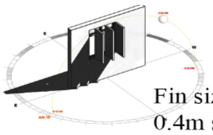
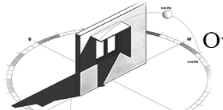
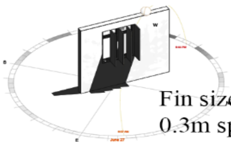
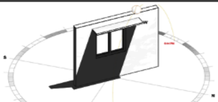
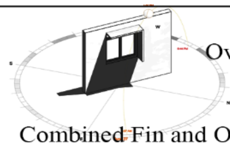
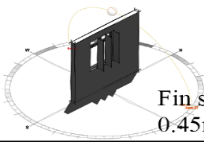
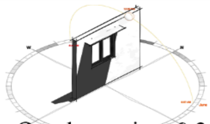
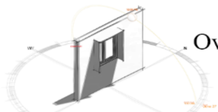
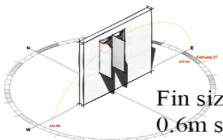
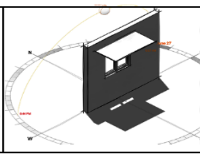
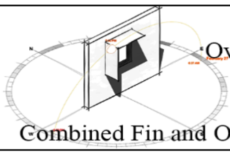
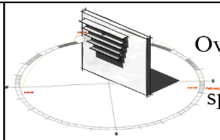
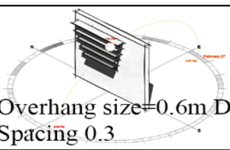
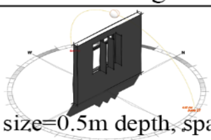
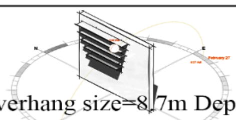
I recommend that to achieve thermal performance and solar shading, it is advisable to consider a shading device. In order to successfully implement such shading strategies,

- ✓ It is crucial to have a comprehensive understanding of the local climate and the periods when the building is most prone to excessive heat. By considering these factors, we can develop innovative shading solutions that not only enhance the aesthetic appeal of the building but also ensure the comfort and well-being of its occupants.
- ✓ Shading devices can range from simple overhangs and awnings to more complex systems that utilize automated louvers or dynamic shading panels, all designed to adapt to changing weather conditions. By carefully selecting and integrating these shading devices into the glazed facade, a harmonious balance can be achieved between energy efficiency, visual appeal, and thermal comfort.
- ✓ It is crucial to take into consideration various factors such as orientation, location, and the sun path diagram of the specific site and opening size, including the azimuth angle, horizontal shadow angle, vertical shadow angle, and end profile angle.
- ✓ Software simulations enable evaluation of the impact of the shading device on the building's thermal performance and energy consumption. By analysing data such as solar incident, heat gain, and cooling load reduction, we can make informed decisions to enhance the building's energy efficiency and reduce reliance on mechanical cooling systems.

5.2.1 Design recommendation

For effective shading as tried to show in Table 4:14 the angle and profile factor helps to determine the optimum shading device design for 8 cardinal direction using overhang width and fin depth calculation formula Equation 4:3 as follow in Table 5:1 create effective shading for Adama condominium building.

Table 5:1 Effective shading device recommended for Adama condominium building

North facing		
 Fin size=0.6m Depth, 0.4m spacing	 Overhang size=1.07m Depth	 Fin=0.6m Overhang=1.0m Combined Fin and Overhang
North east facing		
 Fin size=0.6m Depth, 0.3m spacing	 Overhang size=0.3m Depth	 Fin=0.6m Overhang=0.3m Combined Fin and Overhang
East facing		
 Fin size=0.5m Depth, 0.45m spacing	 Overhang size=0.3m Depth	 Fin=0.5m Overhang=0.3m Combined Fin and Overhang
South facing		
 Fin size=0.6m Depth, 0.6m spacing	 Overhang size= 1.0m Depth Overhang size= 0.5m Depth spacing 0.75m	 Fin=0.6m Overhang=1.0m Combined Fin and Overhang
South West facing		
Fin size=not effective	 Overhang size= 0.6 Depth spacing 0.3m	Combined Fin and Overhang
West facing		
Fin size=not effective	 Overhang size=0.6m Depth Spacing 0.3	Fin=0.6m Overhang=1.0m Combined Fin and Overhang
Northwest facing		
 Fin size=0.5m depth, spacing 0.3m	 Overhang size=8.7m Depth /0.7m depth spacing 0.2m	Combined Fin and Overhang Egg crate shading device Fin=0.5m Overhang=0.9m

5.3 Implication for further Research

I recommend Additional research and experimentation are necessary to thoroughly explore the potential of implementing passive solar control systems to ensure thermal comfort for building occupants. Utilizing these techniques has the ability to significantly diminish the daytime energy demands of radiation-vulnerable glazed buildings and the climate conditions in Adama. The overheated period shading design approaches can offer significant value to the condominium building design guidelines. It is important to explore the various shading techniques that can be employed for glazed surfaces. These structures receive abundant sunlight, during which the heat gains are desirable in the morning but not so much in the afternoon. Achieving optimal thermal shading throughout the day without exterior shading components is still an arduous task. Overheated time-based shading design approaches can provide useful insights that can improve condominium building design guidelines. This, in turn, presents an opportunity for professionals in the construction sector to devise innovative design solutions that integrate the findings of relevant literature. The ultimate goal is to optimize the thermal and visual performance of the vulnerable glazed window.

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REFERANCE

Adama Weather & Climate | Temperature & Weather By Month - Climate-Data.org. (n.d.).

Baniyounes, A. M., Liu, G., Rasul, M. G., & Khan, M. M. K. (2012). Analysis of solar desiccant cooling system for an institutional building in subtropical Queensland, Australia. Renewable and Sustainable Energy Reviews, 16(8), 6423–6431.

Barka, R. A., & Dr. C. Senthil Kumar. (2020). CRITICAL ANALYSIS ON SUPPLY AND AFFORDABLITY OF CONDOMINIUM HOUSING IN ADAMA CITY. International Research Journal of Human Resource and Social Sciences, 7(02), 137–153.

Charles G.Ramser AND, & Sleeper, H. R. (1970). Architectural Graphics standards.

Cuce, E., & Cuce, P. M. (2019). Performance Assessment of Solar Chimneys: Part 2 – Impacts of Slenderness Value and Collector Slope on Power Output. Energy Research Journal, 10(1), 20–26.

Datta, G. (2001). Effect of fixed horizontal louver shading devices on thermal perfomance of building by TRNSYS simulation. Renewable Energy, 23(3–4), 497–507.

De Dear, R. J., & Brager, G. S. (2002). Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. Energy and Buildings, 34(6), 549–561.

Edition, S. I., Erbe, D. H., Lane, M. D., Anderson, S. I., Baselici, P. A., Hanson, S., Heinisch, R., Humble, J., Taylor, S., & Kurtz, R. D. (2013). Energy standard for buildings except low-rise residential buildings. ASHRAE Standard, 2013(90.1-2013 (I-P)), 404–636.

EnergyPlus. (n.d.). from https://energyplus.net/

Eskandari, H., Saedvandi, M., & Mahdavinejad, M. (2017). The impact of Iwan as a traditional shading device on the building energy consumption. Buildings, 8(1).

Hailu, H., Gelan, E., & Girma, Y. (2021). Indoor Thermal Comfort Analysis: A Case Study of Modern and Traditional Buildings in Hot-Arid Climatic Region of Ethiopia. Urban Science, 5(3), 53.

Havenith, G. (2001). Temperature regulation and technology. Gerontechnology, 1(1).

Hoof, J. Van, & Hensen, J. L. M. (2006). Thermal comfort and older adults.

Gerontechnology, 4(4), 223–228.

Ishaq, M. S., & Alibaba, H. Z. (2017). Effects Of Shading Device On Thermal Comfort Of Residential Building In Northern Nigeria. December.

Jessel, S., Sawyer, S., & Hernández, D. (2019). Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature. Frontiers in Public Health,

Karjalainen, S. (2007). Gender differences in thermal comfort and use of thermostats in everyday thermal environments. Building and Environment, 42(4), 1594–1603.

Kirimtat, A., Koyunbaba, B. K., Chatzikonstantinou, I., & Sariyildiz, S. (2016). Review of simulation modeling for shading devices in buildings. Renewable and Sustainable Energy Reviews, 53, 23–49.

Liddament, M. W. (2000). A review of ventilation and the quality of ventilation air. Indoor Air, 10(3), 193–199.

Mateus, T., & Oliveira, A. C. (2009). Energy and economic analysis of an integrated solar absorption cooling and heating system in different building types and climates. Applied Energy, 86(6), 949–957.

Mehrotra, M. (2005). Solar control devices ; balance between thermal performance and daylight. International Conference "Passive and Low Energy Cooling for the Built Environment," May, 991–996.

Norbert Lechner. (2015). HEATING, COOLING, LIGHTING.

Nugent, A., & Russell, S. (n.d.). Chapter 4: Water Vapor.

Pawar, B., & Kanade, P. (2018). Energy Optimization of Building Using Design Builder Software. International Journal of New Technology and Research, 4(1), 263152.

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. Energy and Buildings, 40(3), 394–398.

Petros A. Lapithis. (2002). Solar Architecture in Cyprus (Issue May).

Potential, E. S. (2022). A Review of Thermal Comfort in Residential Buildings : Comfort.

Revit Add-Ons: Introducing Autodesk InSight 360. (n.d.).

Sealey, A. (1979). (1979). Introduction to Building Climatology. Design of shading devices.

Shewa, E. (2020). Seasonal And Annual Climate Profile of Adama. 7(2), 65–74.

Szokolay. (2007). Solar Geometry.

Tang, C., & Wu, L. (2011). Research on the application of building energysaving measures in wall. 2011 2nd International Conference on Artificial Intelligence, Management Science and Electronic Commerce, AIMSEC 2011 - Proceedings, 6361–6364.

Turner, S. C., Paliaga, G., Lynch, B. M., Arens, E. A., Aynsley, R. M., Brager, G. S., Deringer, J. J., Ferguson, J. M., Filler, J. M., Hogeling, J. J., Int-hout, D., Kwok, A. G., Levy, H. F., Sterling, E. M., Stoops, J. L., Taylor, S. T., Tinsley, R. W., Cooper, K. W., Dean, K. W., … Peterson, J. C. (1979). American society of heating, refrigerating and air-conditioning engineers. International Journal of Refrigeration, 2(1), 56–57.

Tzempelikos, A., & Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. Solar Energy, 81(3), 369–382.

UN Habitat. (2018). Sun Shading Catalogue (Adequate Shading: Sizing Overhangs and Fins). Promoting Energy Efficiency in Buildings in East Africa, 1(1), 1–76.

APPENDIX

Appendix 1: Questionary

Questionary

Department of Architecture
MSc In Environmental Architecture
School of civil engineering & Architecture

First of all, thanks for voluntariness to accepting my research fulfilment questionnaires'. Please kindly respond to each question with the appropriate response, and participate in my study paper. Dear Respondents, the goal of these questions is to help research on **Effect of Shading Devices on Thermal Comfort in Condominium Buildings: In the Case of Adama City**.

Thank you

Sheet Number: ___	**Site name: _______________**	**Block no: ________**
Story number: ________	**Time: ______________**	**Date: ___________**

Note: Answer the following Questions by putting √ or X for the boxes and fill the blank spaces with your idea.

A. Personal information		
Sex: ☐ **Male** ☐ **Female**		**Age:** ☐ **>15** ☐ **16-30** ☐ **31- 45** ☐ **46-60** ☐ **61<**
Body Weight: ☐ **> 30kg** ☐ **31-60kg** ☐ **61-90kg** ☐ **90kg <**		
Clothing type:	**Upper: __-------------------------**	
	Lower: __-------------------------	
	Shoe; -------------------------	
	Other:	
Activity:	☐ **Standing** ☐ **Sitting** ☐**Relaxing** ☐**Working** **Other: _-----------------------------** **_________________________________**	
How many years you are living in this house?		☐ **>1year** ☐ **1-3year** ☐ **3-5year** ☐ **5 above**

B. Background Information

1. In which direction of the building is your Room located?

☐South(S) ☐ North(N) ☐ West(W) ☐ East(E) ☐ Southwest Corner

☐ Southeast (SE) ☐ Northwest(NW) ☐ Northeast(NE)

2.Which of the following do you do while regulating or adjusting room temperature?

☐ Room air-conditioning unit ☐ Portable heater ☐ Thermostat ☐ blinds

☐ Ceiling fan ☐ Portable fan ☐ Windows Other____________

C. Thermal Comfort Level

Fill the following table, Actual temperature of room ($_{o}$C)_______ R. Humidity (%)____

Daylight illumination (lux)_________

1. Thermal Preference scale

ASHRAE 55 thermal Preference scale (Humphreys, 2007)

PMV Value	**Thermal Preference**	**Time**		
		3:00am-4:00am	**7:00pm-8:00pm**	**10:00pm-11:00pm**
3	**Hot**			
2	**Warm**			
1	**Slightly warm**			
0	**Neutral**			
-1	**Slightly cool**			
-2	**Cool**			
-3	**Cold**			

2. Sensational scale

ASHRAE 55 Sensational scale (Series & Science, 2018)

Level of Scale	**Thermal Sensational**	**Time**		
		3:00am-4:00am	**7:00pm-8:00pm**	**10:00pm-11:00pm**
3	**Very Uncomfortable**			
2	**Uncomfortable**			
1	**Slightly Uncomfortable**			
0	**Comfort**			
-1	**Slightly comfortable**			
-2	**comfortable**			
-3	**Very comfortable**			

3. The questions that follow are about your overall perception of hot times/overheated indoor.

3.1. Which season of year do you find to be the warmest?

☐ Kiremt -Winter (December, January, February) ☐ Tseday-Spring (March, April, May)

☐ Bega-Summer (June, July, August) ☐ Belg -Autumn (September, October, November)

3.2. Which month do you think is the warmest this year?

☐ September	☐ October	☐ November
☐ December	☐ January	☐ February
☐ March	☐ April	☐ May
☐ June	☐ July	☐ August

3.3 Which time period of the day do you start to feel overheated? (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

3.4. In which time period of the day do you experience the hottest 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

Appendix 2: Measuring instrument

HOLDPEAK Digital Anemometer Heat Stress Meter, Handheld Wind Speed Meter HVAC, HP-881W CFM Anemometer and

PRODUCT SPECIFICATION

Hazard level	WBGT
Caution	26.7~29.4℃ / (80~84.9℉)
Extreme caution	29.4~31℃ / (85~87.9℉)
Danger	31~32.2℃ / (88~89.9℉)
Extreme Danger	>32.2℃ / (>90℉)

unit	Range	Resolution	Accuracy
M/s	0~30	0.1	±5%
Ft/min	0~5860	19	
Knots	0~55	0.2	
Km/h	0~90	0.3	
Mph	0~65	0.2	

Temp.range	0~50℃
Temp.resolution	0.1℃/℉
Temp.accuracy	+/-0.6℃
Humidity.range	0.1%~99.9%RH
Humidity.resolution	0.1%RH
Humidity accuracy	10.0%~90.0%@25℃: Typical 5%. Others 7%
WBGT temp.range	0~50℃
WBGT Alarm Range	20~50℃
Stabilization time	15~25minutes typical
Operation temp.	0~50℃
Operation RH%	Humidity<80%

Appendix 3: Field Measurement

A) Temperature

Temperature				
Room type = Three bed room, Orientation by = South facing room				
Date	**Time**	**Outdoor**	**With shading Device**	**Without shading device**
Apr. 20/2023	3:00-4:00am	27.7	26.0	26.3
	6:00-7:00am	31.5	30.6	30.5
	9:00-10:00am	31.7	28.4	29.4
Apr. 21/2023	3:00-4:00am	28.6	26.5	27.1
	6:00-7:00am	31.1	27.1	28.9
	9:00-10:00am	30.3	28.2	29.5
Apr. 22/2023	3:00-4:00am	28.7	26.8	27.6
	6:00-7:00am	33.6	31.9	32.3
	9:00-10:00am	32.1	30.5	31.2
Apr. 23/2023	3:00-4:00am	27.5	25.8	26.2
	6:00-7:00am	31.5	30.0	30.8
	9:00-10:00am	30.2	29.9	30.0
Apr. 24/2023	3:00-4:00am	28.2	26.1	26.3
	6:00-7:00am	30.2	29.8	30.5
	9:00-10:00am	31.5	28.2	29.8
Apr. 25/2023	3:00-4:00am	27.5	26.0	26.2
	6:00-7:00am	31.8	29.9	30.4
	9:00-10:00am	31.5	29.8.	30.2
Apr. 26/2023	3:00-4:00am	27.6	25.9	26.2
	6:00-7:00am	31.1	29.0	29.5
	9:00-10:00am	31.6	28.9	29.2
Apr. 27/2023	3:00-4:00am	27.5	26.1	26.7
	6:00-7:00am	31.5	29.1	29.6
	9:00-10:00am	33.2	30.5	31.2
Apr. 28/2023	3:00-4:00am	27.9	26.1	26.4
	6:00-7:00am	32.6	30.0	31.3
	9:00-10:00am	31.5	28.9	29.6
Apr. 29/2023	3:00-4:00am	27.5	26.7	26.8
	6:00-7:00am	32.2	29.0	29.5
	9:00-10:00am	32.7	30.0	30.1

Apr. 30/2023	3:00-4:00am	26.6	25.2	25.2
	6:00-7:00am	31.8	29.8	29.9
	9:00-10:00am	31.5	29.21	29.5
May01/2023	3:00-4:00am	25.5	24.4	24.7
	6:00-7:00am	32.2	28.9	28.9
	9:00-10:00am	30.8	28.6	28.8
May02/2023	3:00-4:00am	27.9	25.9	26.5
	6:00-7:00am	30.8	28.9	29.5
	9:00-10:00am	29.6	28.3	27.9
May03/2023	3:00-4:00am	25.4	24.0	24.8
	6:00-7:00am	29.5	28.5	28.9
	9:00-10:00am	29.9	29.1	29.4
May04/2023	3:00-4:00am	26.1	24.5	24.4
	6:00-7:00am	29.0	28.0	28.5
	9:00-10:00am	31.2	29.5	30.5
May05/2023	3:00-4:00am	25.9	24.0	24.9
	6:00-7:00am	29.0	28.4	28.5
	9:00-10:00am	28.2	27.0	27.7
May06/2023	3:00-4:00am	26.1	25.6	25.6
	6:00-7:00am	30.6	29.1	29.3
	9:00-10:00am	31.6	30.2	30.5
May07/2023	3:00-4:00am	26.9	26.1	26.7
	6:00-7:00am	29.5.	29.2	29.5
	9:00-10:00am	28.9	28.0	28.0
May08/2023	3:00-4:00am	27.1	26.3	26.5
	6:00-7:00am	29.5	28.4	28.8
	9:00-10:00am	29.1	28.1	28.5
May09/2023	3:00-4:00am	26.4	25.7	25.7
	6:00-7:00am	29.0	28.4	28.6
	9:00-10:00am	28.9	28.0	28.0
May10/2023	3:00-4:00am	27.2	26.2	26.1
	6:00-7:00am	29.9	29.2	29.2
	9:00-10:00am	30.1	28.8	29.0

B) = Relative Humidity

Relative Humidity (%)				
Room type = Three bed room, Orientation by = South facing room				
Date	**Time**	**Outdoor**	**With shading Device**	**Without shading device**
Apr. 20/2023	3:00-4:00am	32	31	32
	6:00-7:00am	29	29	29
	9:00-10:00am	27	28	27
Apr. 21/2023	3:00-4:00am	30	31	29
	6:00-7:00am	29	34	32
	9:00-10:00am	28	33	29
Apr. 22/2023	3:00-4:00am	26	29	27
	6:00-7:00am	27	29	29
	9:00-10:00am	25	34	33
Apr. 23/2023	3:00-4:00am	26	28	29
	6:00-7:00am	31	27	29
	9:00-10:00am	26	31	33
Apr. 24/2023	3:00-4:00am	28	29	29
	6:00-7:00am	27	27	29
	9:00-10:00am	26	29	28
Apr. 25/2023	3:00-4:00am	30	29	31
	6:00-7:00am	26	30	32
	9:00-10:00am	29	31	29
Apr. 26/2023	3:00-4:00am	25	27	26
	6:00-7:00am	27	28	27
	9:00-10:00am	28	29	29
Apr. 27/2023	3:00-4:00am	25	27	28
	6:00-7:00am	29	26	25
	9:00-10:00am	31	29	31
Apr. 28/2023	3:00-4:00am	25	26	29
	6:00-7:00am	29	29	24
	9:00-10:00am	25	27	29
Apr. 29/2023	3:00-4:00am	32	32	29
	6:00-7:00am	29	29	32
	9:00-10:00am	29	28	26
Apr. 30/2023	3:00-4:00am	28	29	27

	6:00-7:00am	27	32	28
	9:00-10:00am	26	29	27
May01/2023	3:00-4:00am	25	31	32
	6:00-7:00am	30	29	32
	9:00-10:00am	28	31	28
May02/2023	3:00-4:00am	32	32	29
	6:00-7:00am	33	34	30
	9:00-10:00am	29	29	32
May03/2023	3:00-4:00am	27	32	31
	6:00-7:00am	25	32	29
	9:00-10:00am	27	28	28
May04/2023	3:00-4:00am	29	34	26
	6:00-7:00am	28	31	29
	9:00-10:00am	29	29	31
May05/2023	3:00-4:00am	27	31	31
	6:00-7:00am	32	32	29
	9:00-10:00am	31	29	32
May06/2023	3:00-4:00am	30	31	31
	6:00-7:00am	30	31	29
	9:00-10:00am	29	28	29
May07/2023	3:00-4:00am	25	27	29
	6:00-7:00am	26	27	28
	9:00-10:00am	29	30	31
May08/2023	3:00-4:00am	28	27	28
	6:00-7:00am	26	27	29
	9:00-10:00am	27	26	29
May09/2023	3:00-4:00am	26	25	27
	6:00-7:00am	27	26	27
	9:00-10:00am	32	31	29
May10/2023	3:00-4:00am	29	28	29
	6:00-7:00am	30	29	31
	9:00-10:00am	29	29	28

C) = Air Velocity

Air Velocity (M/s)				
Room type = Three bed room, Orientation by = South facing room				
Date	**Time**	**Outdoor**	**With shading Device**	**Without shading device**
Apr. 20/2023	3:00-4:00am	3.20	0.39	0.55
	6:00-7:00am	2.17	0.52	0.60
	9:00-10:00am	1.22	0.51	0.65
Apr. 21/2023	3:00-4:00am	2.21	0.96	0.96
	6:00-7:00am	4.21	0.65	0.56
	9:00-10:00am	2.54	0.91	0.90
Apr. 22/2023	3:00-4:00am	0.79	0.02	0.12
	6:00-7:00am	1.21	0.35	0.51
	9:00-10:00am	2.10	0.56	0.54
Apr. 23/2023	3:00-4:00am	0.45	0.00	0.01
	6:00-7:00am	1.65	0.27	0.36
	9:00-10:00am	1.00	0.63	0.24
Apr. 24/2023	3:00-4:00am	2.41	0.60	0.65
	6:00-7:00am	2.70	0.48	0.96
	9:00-10:00am	2.5	0.00	0.02
Apr. 25/2023	3:00-4:00am	0.95	0.22	0.12
	6:00-7:00am	3.5	0.62	0.78
	9:00-10:00am	1.65	0.65	0.25
Apr. 26/2023	3:00-4:00am	3.91	0.65	0.70
	6:00-7:00am	0.93	0.21	0.21
	9:00-10:00am	3.2	0.46	0.45
Apr. 27/2023	3:00-4:00am	3.15	0.05	0.35
	6:00-7:00am	1.21	0.24	0.33
	9:00-10:00am	2.53	0.13	0.34
Apr. 28/2023	3:00-4:00am	1.56	0.00	0.33
	6:00-7:00am	3.2	0.26	0.26
	9:00-10:00am	1.36	0.00	0.12
Apr. 29/2023	3:00-4:00am	1.98	0.30	0.02
	6:00-7:00am	1.45	0.3	0.50
	9:00-10:00am	1.22	0.62	0.32
Apr. 30/2023	3:00-4:00am	0.99	0.32	0.21

	6:00-7:00am	0.62	0.12	0.00
	9:00-10:00am	1.35	0.00	0.21
May01/2023	3:00-4:00am	2.30	0.40	0.59
	6:00-7:00am	1.23	0.20	0.32
	9:00-10:00am	3.86	0.12	0.28
May02/2023	3:00-4:00am	4.50	0.32	0.23
	6:00-7:00am	1.20	0.10	0.41
	9:00-10:00am	2.20	0.36	0.00
May03/2023	3:00-4:00am	1.96	0.12	0.31
	6:00-7:00am	0.98	0.26	0.34
	9:00-10:00am	1.25	0.32	0.21
May04/2023	3:00-4:00am	1.50	0.10	0.14
	6:00-7:00am	0.65	0.32	0.00
	9:00-10:00am	0.99	0.17	0.14
May05/2023	3:00-4:00am	1.35	0.10	0.08
	6:00-7:00am	1.84	0.19	0.32
	9:00-10:00am	0.83	0.27	0.14
May06/2023	3:00-4:00am	2.15	0.15	0.30
	6:00-7:00am	2.88	0.34	0.16
	9:00-10:00am	1.91	0.00	0.13
May07/2023	3:00-4:00am	3.8	0.22	0.36
	6:00-7:00am	1.3	0.60	0.01
	9:00-10:00am	2.34	0.32	0.21
May08/2023	3:00-4:00am	1.63	0.17	0.26
	6:00-7:00am	1.23	0.21	0.32
	9:00-10:00am	1.78	0.00	0.21
May09/2023	3:00-4:00am	0.56	0.12	0.22
	6:00-7:00am	1.20	0.11	0.35
	9:00-10:00am	3.02	0.41	0.16
May10/2023	3:00-4:00am	0.92	0.12	0.23
	6:00-7:00am	2.51	0..6	0.81
	9:00-10:00am	0.79	0.04	0.68

D) Daylight

Day light (lux)				
Room type = Three bed room, Orientation by = South facing room				
Date	**Time**	**Outdoor**	**With shading Device**	**Without shading device**
Apr. 20/2023	3:00-4:00am	660	257	270
	6:00-7:00am	950	318	360
	9:00-10:00am	930	370	456
Apr. 21/2023	3:00-4:00am	561	250	347
	6:00-7:00am	720	220	339
	9:00-10:00am	1230	356	450
Apr. 22/2023	3:00-4:00am	520	450	493
	6:00-7:00am	753	320	325
	9:00-10:00am	865	430	580
Apr. 23/2023	3:00-4:00am	683	264	321
	6:00-7:00am	1101	510	514
	9:00-10:00am	930	321	462
Apr. 24/2023	3:00-4:00am	730	354	370
	6:00-7:00am	1346	297	302
	9:00-10:00am	760	314	430
Apr. 25/2023	3:00-4:00am	614	324	356
	6:00-7:00am	1876	547	596
	9:00-10:00am	960	449	539
Apr. 26/2023	3:00-4:00am	863	263	295
	6:00-7:00am	1106	322	345
	9:00-10:00am	1325	634	650
Apr. 27/2023	3:00-4:00am	794	368	423
	6:00-7:00am	1891	602	652
	9:00-10:00am	1351	456	450
Apr. 28/2023	3:00-4:00am	520	369	357
	6:00-7:00am	1021	264	326
	9:00-10:00am	1124	321	345
Apr. 29/2023	3:00-4:00am	620	410	400
	6:00-7:00am	946	341	322
	9:00-10:00am	786	431	463
Apr. 30/2023	3:00-4:00am	1332	322	327

	6:00-7:00am	1800	355	360
	9:00-10:00am	1884	420	460
May01/2023	3:00-4:00am	954	256	300
	6:00-7:00am	1005	387	384
	9:00-10:00am	1221	326	325
May02/2023	3:00-4:00am	736	410	322
	6:00-7:00am	1970	665	660
	9:00-10:00am	1987	459	543
May03/2023	3:00-4:00am	590	300	298
	6:00-7:00am	572	366	370
	9:00-10:00am	935	490	502
May04/2023	3:00-4:00am	560	273	263
	6:00-7:00am	724	364	402
	9:00-10:00am	1554	530	546
May05/2023	3:00-4:00am	720	365	432
	6:00-7:00am	630	412	432
	9:00-10:00am	1340	456	670
May06/2023	3:00-4:00am	852	653	540
	6:00-7:00am	895	435	502
	9:00-10:00am	1031	395	401
May07/2023	3:00-4:00am	730	590	615
	6:00-7:00am	695	491	460
	9:00-10:00am	542	260	302
May08/2023	3:00-4:00am	1214	377	391
	6:00-7:00am	658	331	350
	9:00-10:00am	1835	480	460
May09/2023	3:00-4:00am	984	351	354
	6:00-7:00am	1841	626	599
	9:00-10:00am	874	349	356
May10/2023	3:00-4:00am	526	520	523
	6:00-7:00am	629	535	532
	9:00-10:00am	987	250	270

Appendix 4: Simulation Result

HOUR	Outside	No device	Exist device	New Overhang	New Fin
	(°C)	(°C)	(°C)	(°C)	(°C)
0	16.8	18.5	17.3	17.4	17.5
1	16.2	18.3	17.1	17.2	17.3
2	15.5	18	16.8	16.9	17
3	15.2	17.9	16.6	16.7	16.9
4	14.9	17.7	16.5	16.2	16.7
5	14.6	17.6	16.3	16.4	16.6
6	14.9	17.4	16.2	16	16.4
7	17.1	17.7	16.5	15.9	15.7
8	19.4	17.9	16.7	15.6	15.9
9	21.7	18	16.8	15.8	15.8
10	23.7	18.1	17	15.9	16
11	25.4	18.6	17.4	16.4	16.6
12	26.6	18.7	18	17	17
13	27.5	18.4	18.4	17.5	17.4
14	28	18.6	18.7	17.9	17.6
15	28	18.9	19	18.3	17.9
16	27.3	19	19.1	18.4	18
17	26.1	18.9	19	18.4	17.9
18	24.5	18.8	18.8	17.8	17.8
19	23.9	18.8	18.8	17.1	17.8
20	23.4	18.7	18.6	16.8	16.7
21	22.8	18.3	18.1	16.6	16.3
22	22.2	17.6	17.4	16.3	16.6
23	21.6	17.3	17.1	16.2	16.3