EFFECT OF BUILDING ENVELOPE ON INDOOR THERMAL QUALITY OF OFFICE BUILDINGS: THE CASE OF ADDIS ABABA

Daniel Kidane Wakene

A Thesis submitted to the Department of Architecture

College 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

November, 2024

Adama, Ethiopia

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Advisor: Belay Zeleke (PhD)

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DECLARATION

I declare that this thesis entitled **“Effect of Building Envelope on indoor Thermal Quality of Office Buildings: The Case of Addis Ababa.”** is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

_Daniel Kidane Wakene ____ ________________________ ____________________

Name of student Signature Date

RECOMMENDATION OF ADVISOR

I, the major advisor of this research proposal, hereby certify that I have closely advised the student while developing this proposal and read the draft thesis proposal entitled **"Effect of Building Envelope on indoor Thermal Quality of Office Buildings: Addis Ababa."** prepared under my guidance by Musa Daniel Kidane Wakene, ID No PGR 24455/14. Therefore, I recommend the submission of the proposal to the department for further review and evaluation.

Belay Zeleke (PhD)	______________________	______________________
Major Advisor	Signature	Date
______________________	______________________	______________________
Co-advisor	Signature	Date

APPROVAL PAGE FOR THESIS PROPOSAL

I hereby certify that the recommendation and suggestion given by the proposal review committee are appropriately incorporated into the final thesis proposal entitled **"Effect of Building Envelope on indoor Thermal Quality of Office Buildings: The Case of Addis Ababa."** by Daniel Kidane Wakene, ID No; PGR 24455/14.

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Major Advisor	Signature	Date
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Co-advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the Board of Reviewers of the proposal open defense by Daniel Kidane Wakene have read and evaluated the thesis proposal entitled **"Effect of Building Envelop on indoor Thermal Quality of Office Buildings: The Case of Addis Ababa."** and assessed the understanding of the candidate about the proposed research. This is, therefore, to certify that the thesis proposal is accepted and we recommend the implementation of the thesis .---

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Reviewer 1	Signature	Date
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Finally, approval and acceptance of the thesis/dissertation proposal is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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School Dean	Signature	Date
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Office of Postgraduate Studies, Dean	Signature	Date

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ABBREVIATIONS

ITQ – Indoor Thermal Quality

ITC – Indoor Thermal Comfort

ITE – Indoor thermal environment

IAQ – Indoor Air quality

HVAC - Heating ventilation air conditioning

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

PMV - Predicted mean vote

PPD - Predicted people dissatisfied

TA - Air temperature and mean radiant temperature

TRV - Relative air velocity

RH - Relative humidity

MR - Metabolic Rate

IAQ - Indoor air quality

ZEN - Zenith angle

AZI - Azimuth

SHI - Surface Heat Island

UHI - Urban Heat Island

(WBT) -wet blub temperature

(RH)- Relative Humidity

(GT)- Globe temperature

(BIM)- Building Information Modeling

VSA- Vertical Shadow Angle

HSA- Horizontal Shadow Angle

ABSTRACT

Office spaces are where individuals spend 7 to 9 hours of their time daily, and it should be comfortable under all circumstances. Comfortability or uncomfortable work behavior of workplace have significant influence on the productivity of worker and health of employee. Most offices in Ethiopia are built with similar and repetitive envelope; the similar office-building envelope can affects the thermal and visual comfort as well as productivity of occupants. One effective strategy for creating a friendly atmosphere is through the utilization of building envelope. This study is going to assess the thermal comfort level of selected Addis Ababa office curtain wall glass facade. The study selected three different site with similar orientation to check the urban heat effect and two building, which have the same orientations and has different envelope treatment for comparison. Therefore, the aim of this paper is to evaluate the indoor thermal quality of selected office building in terms of room temperature, relative humidity and solar radiation. In either case, an important indoor quality factor in office buildings is measured. The study is based on field survey measurement of twenty sequent days from April 20 to May 10 which I use 10 days from both months in the warmest month of 2024 according to the Questionnaires done from the three site on 56 respondents. 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. It includes the literature review and use of secondary data. The occupants asked about the thermal level, their preference through the primary data collection. The major indoor thermal comfort variables air temperature and relative humidity in each case offices is be measured in these twenty days to compare and analyze with the standard office operational temperature. The data is obtained and analyzed by the BIM and simulation software like Ecotect or design builder, climate consultant, sunearth tool, Archi CAD, Revit and excel.

Keywords: Office buildings, thermal comfort variables, Occupants, relative humidity, building envelope, simulation, Thermal Comfort.

CHAPTER ONE

Introduction

Addis Ababa has been undergoing rapid growth and change in the construction industry. These changes include the construction of highly glazed buildings intended for office buildings. Highly glazed building envelops greatly contribute to the energy demand for occupants comfort. Among the various technological advancements in building skins, large windows and highly glazed envelope elements have been increasingly used allowing access to daylight, and external view. However, this has been constantly challenged by the existence of solar radiation especially in tropical climates thus causing high solar heat gain. To tackle this challenge, different sustainable approaches have been developed. Among these, the use of exterior shading devices is preferred to block incident solar radiation first hand. Such devices block about 80 percent of the solar gain through clear windows as compared to internal shadings which are only about 20 percent efficient. (Lechner, 2015). Sustainable architecture is very important in all aspects. Sustainable architecture is a movement that meets the architectural needs of the present without affecting the capabilities of future generations.(Bachrun, Ming, and Cinthya, 2019). So, fixed exterior shading devices remain a valid choice, aside from first hand solar protection, due to their ease of construction, maintenance and are cost effective solutions by design. (Lechner, 2015) However, not all fixed exterior shading devices work in the same effectiveness. It is questionable which ones are preferable to others. I used a mixed methods study that combines and integrates qualitative and quantitative research methods into one study. It involves collecting and analyzing qualitative and quantitative data to better understand phenomena and answer research questions. The main premise of using mixed methods studies is that the strengths of each data type are exploited while the weaknesses are offset. Researchers combine qualitative and quantitative methods to expand evidence to increase the reliability of research findings and interpret them by comparing the results of one method with the results of another method.(Ul and Ce, 2010). A lack of thermal comfort makes us feel stressed, annoyed and distracted if it is too cold and it can make us feel sleepy, tired and lacking concentration if it is too hot. In turn, thermal comfort inevitably has an impact on well-being, productivity, the ability to think clearly specially in office building. I used to in node interior design in 22 during that time the building is too cold and I can't concentrate on working I always wait for the time I leave the building and the work I have to do is going to stay for tomorrow this happen because of the lack of thermal comfort in the building. And a lot of office building exists in Addis Ababa because it is the central city and a lot of office works more than 7 hours that’s why I choose to work on thermal comfort of building office and specifically I choose the envelope because it is the main factor that influences the thermal comfort of a given building.

In this study, the thermal comfort parameter is an important parameter that significantly influences the perception of building occupants and the overall indoor environment. This study aims to evaluate indoor thermal comfort in office buildings and determine user perceptions and satisfaction with office buildings through surveys of field-measured NPs and parametric models of comfort conditions. Increase.(Abass etal. 2021)

1.1Background of the study

The term energy efficiency means reducing the amount of energy needed to create a comfortable indoor space. Depending on the buildings energy certification it may be environmentally friendly or energy efficient if it uses less external energy for building maintenance but it is not sustainable.(Kumar and Raheja 2016). The role of building envelopes in performing energy management functions is important as the development of energy concepts is discussed in many studies. Many papers focus on discussing the building envelope by changing the material orientation and color of the building layout. This is only for energy efficiency and thermal comfort in the indoor environment (Bachrun, Ming, and Cinthya 2019). Thermal comfort is related to physical environmental factors in naturally ventilated and air-conditioned environments. It has been described as a state of mind that is content with the thermal environment.” (ASHRAE, 2013). There is a strong correlation between energy consumption and international standards for thermal comfort for buildings. There are several thermal comfort indices based on the Fanger comfort equation such as predicted mean volume (PMV) and predicted percent dissatisfaction (PPD). These indicators are used to evaluate existing buildings to determine thermal comfort values. In the long run. (Zuhaib et al, 2018a).

The rational use of building materials should consider the comfort of indoor buildings. The thermal comfort is close to the optimum comfort temperature of 22.8˚C-25.8˚C and humidity of 70% (applicable to hot and humid areas).According to Lipsmeyer (1994) the comfort zone for equatorial conditions is a temperature of 22.5˚C-29˚C with a humidity of 20 -50% (Carera & Prianto, 2016; Syah & Nugroho, 2013). It also explains that the comfort value should be considered as a possible combination of humidity air temperature radiant heat and wind speed. This sufficient temperature is obtained through experiments that measure air temperature humidity and wind speed.(Bachrun, Ming, and Cinthya 2019).The design of Building envelope has evolved from our ancestors to today. People in traditional cultures know how to build the buildings they need. Building culture has evolved over the years through trial and error reflection and new experimentation to integrate material climates other physical constraints and cultural practices into forms that meet the needs of individuals or groups. Envelope design develops when traditional building knowledge is passed from generation to generation. So in the end the building envelope roof walls and floors became conceptually independent elements that have remained to this day with little change in use and materials. (Kumar and Raheja 2016).

The larger the area of the building the higher the energy cycle. The building envelope is also an important component of the control hardware (Bachrun, Ming, and Cinthya 2019). The building envelope refers to the envelope of the built environment that consists of walls doors windows roofs air vents and other openings for light and ventilation. The building envelope is the set of elements (the building) made up of parts that separate the buildings internal environment from its external environment. The inner envelope of the building and its occupants are protected from the weather and other external factors. The distinctive envelope design has a significant impact on the buildings energy consumption as well as the visual and thermal comfort of the buildings occupants. The skin (materials used) determines the appearance of the building envelope design of the building model and the shape or volume of the building. The design of building skins usually takes into account various determinants such as environmental technology socio-cultural function and aesthetics.(Kumar and Raheja 2016).

Building envelope components can be divided into clear and transparent parts. Opaque parts include wall panels ceiling base walls and opaque doors. Elements of the transparent building envelope (envelope system) include glazed windows glass-walled ventilation doors and glass blocks. Common measures of building envelope efficiency components include physical protection from weather and climate (comfort) air quality (sanitation and hygiene) sustainable energy efficiency. It must also satisfy the users psychology and environment.(Kumar and Raheja 2016). Technological innovation in glass will allow window systems to respond according to environmental conditions to achieve sustainability in built form.(Kumar and Raheja 2016).Indoor IEQ is a concept used by architectural scientists to determine optimal indoor conditions for buildings based on multiple criteria such as indoor air quality visual quality acoustic quality and thermal comfort. The exact level of these parameters determines the ideal office environment.

The design of the building envelope has an impact on the energy load of the building and by designing the building envelope with better thermal performance external heat gain can be reduced. The purpose of building envelope engineering is to increase energy efficiency by using shading devices to increase the shaded area. It also reduces the buildings energy load by reducing the heat gain of the building from solar radiation.(Bachrun, Ming, and Cinthya 2019)

Addis Ababa's rapidly expanding building area has contributed significantly to indoor and outdoor temperature changes in recent years. Structural solutions are insufficient and ineffective to improve the design and condition of most buildings. Additionally situations where office buildings operate for more than 8 hours should not be taken into account. This causes high or low temperature in the room which affects the comfort and productivity of the occupants.

This research paper mainly examines the characteristics of selected buildings in terms of their internal thermal comfort and how modifying the building envelope and reducing heat transfer through the building envelope can reduce peak heating and cooling demand. It is important to reduce the final consumption of energy in office buildings.

1.2 Statement of the problem

Most office buildings envelope form and material today are built exclusively in a repetitive manner which creates radiation vulnerable full-glazed and lack of overheated period based design of building envelope limits their efficiency in responding to undesired solar heat gain periods. This results in high solar heat gains and rise in indoor temperature. The occupants are not comfortable especially those near the building envelope. It is the result of design and construction regardless of weather conditions and orientation. Nothing is done to address extreme temperatures (cold or hot). Buildings are responsible for more than one third of the total energy use and associated greenhouse gas emissions, both in developed and developing countries.(Ascione et al. 2016). The envelope protects the interior of a building and its occupants from the weather and other external elements. Most places with open spaces facing the direction of strong sun suffer from various spatial quality issues. This condition directly affects the comfort and productivity of the occupants of the untreated building envelope.The design features of the building envelope strongly influence occupant visual and thermal comfort(Kumar and Raheja 2016).

Airflow is directly linked to energy control, since controlling air movement may account for 10 to 20% of heat loss within the building. On the other hand, airflow also dictates indoor air quality, and condensation, which both contribute to comfort (or discomfort) of inhabitants in a building.

This study investigates the thermal comfort performance of office buildings envelop and suggest possible solutions to improve thermal comfort in office building in Addis Ababa, Ethiopia.

1.3 Study gap

In Ethiopia there are no regulations and monitoring system regarding improvement of thermal comfort and building envelope integration in a building design and its approval based on building orientation and the sun path diagram and without finding When Shading Is Necessary. In addition there are limited studies that contributed to regulations and monitoring system in modification of buildings thermal comfort in Addis Ababa.

Some studies in thermal comfort areas are limited to studying problem of building envelope based on the shadow angle created because of the sun path and the building orientation. They do not consider envelope as a main device that solves the problem of thermal comfort. Building envelope elements provide climate control for how air, heat, light, and other environmental elements move in and out of the house, which affects the thermal comfort. In addition, there are no guidelines and principles for evaluation and assessment regarding integration of building envelope and thermal comfort.

1.4 Research Questions

1) To what extent does the selected office buildings fulfill the indoor thermal comfort conditions?
2) What are the relationships of selected office buildings towards indoor thermal quality and building envelop types?
3) What type of building envelope can fulfill the indoor thermal comfort quality and regulate indoor temperature in Ethiopia/ A.A?

1.5 Objective

1.5.1 General Objective

The General objective of the study is to investigate the effect of building envelopes on Indoor thermal quality in selected office buildings in AA.

1.5.2 Specific Objective

- ✓ To evaluate the thermal comfort level of selected buildings according to three environmental factors affecting indoor thermal quality.
- ✓ To examine the relationships of the Offices towards indoor thermal comfort and building envelop.
- ✓ To recommend possible remedial solutions based on building envelope, to indoor thermal comfort.

1.5 Significance of the study

This research work is important for its academic contribution to energy efficiency and technology development. Research findings are based on facts obtained from current sources and real-life situations. Many buildings in Addis Ababa are not constructed with adequate building envelopes to maintain internal thermal properties. As a result there is a lack of research or presentations using the building envelope as a keyword. This research is important to improve building envelope needed to reduce solar radiation due to climate change and urban heat islands or for people to retrofit their buildings for thermal comfort. Since then architects and engineers have had to consider the impact of the building envelope from the outset. The findings of this research will help reduce the growing disease suffered by cities as well as private construction users.

Research can bridge the gap and balance human comfort with thermal comfort. Building envelopes should be adopted and used in the design of office buildings where people work longer because, it separate the buildings internal environment from its external environment. This study is important in providing a superior product for the thermal quality of indoor thermal quality. It also contributes significantly to building health and well-being.

1.6 Scope of the study

Spatial Scope

This paper focused on solar radiation-exposed office buildings in Addis Ababa City that have used building envelope shading elements to achieve passive solar control and indoor thermal comfort and not used any building envelope treatment. An analysis was conducted to evaluate the effectiveness of building envelope mechanisms in minimizing the amount of solar heat absorbed by sun-exposed buildings throughout the day.

Thematic scope

The scope of this investigation is restricted to the evaluation of solar energy inputs and their corresponding gains. However, this analysis does take into account other variables, such as building envelope elements, 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 lowest performed building envelope by using simulation software for office buildings to determine the effect of thermal quality and solar radiation reduction.

1.7 Operational definition of the study

Indoor Thermal Quality (ITQ): The thermal quality of the indoor environment is also known as indoor thermal comfort (ITC). Ambient humidity and air currents and surface temperature affect ITQ. Good indoor air is characterized by cleanliness and freshness with the right room temperature and humidity.

Indoor thermal comfort: Thermal comfort is a state of mind that describes satisfaction with a thermal environment. It is evaluated by subjective evaluation according to ANSI/ASHRAE Standard 55. One of the important goals of the HVAC design engineer is to maintain this level of thermal comfort for the occupants of a building or other location..(Raatikainen 2016).

Thermal comfort zone: The combination of average radiant temperature and humidity of air temperature should be considered an acceptable thermal environment at specified values of wind speed and metabolic rate and thermal insulation of clothing.

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° or360°); 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).

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)

Indoor air quality (IAQ): Indoor air quality (IAQ) represents a significant part of indoor climate quality (IEQ) and indoor climate quality (ICQ). It refers to the quality of air in and around buildings and structures especially for the health and comfort of occupants..(Raatikainen 2016)

Relative Humidity: Relative humidity is the ratio of the partial pressure of water vapor to the equilibrium pressure of water vapor at the same temperature which affects the indoor thermal comfort .(Raatikainen 2016)

Air Speed/velocity: Wind speed is defined as the speed at a point independent of wind direction. 55 is the average velocity of open air in a body relative to space and time according to ANSI/ASHRAE standards.(Raatikainen 2016)

Radiant temperature: Radiant temperature is related to the radiant heat transferred from a surface which is the building envelope to the office space which alters the indoor thermal comfort of the office buildings.(Raatikainen 2016)

operative temperature: The operating temperature is an approximate average of the ambient room surface temperature and the room air temperature.(Raatikainen 2016)

Air temperature: Air temperature is the spatial and temporal average temperature of the air around the occupant (spatial and temporal averages per ASHRAE 55).(Raatikainen 2016)

PMV (Predicted Mean Vote): An index that estimates the average vote of a group of voters for a particular areas comfort level.

PPD (percentage of dissatisfied people): This is the function of PMV.

ASHRAE Scale: The ASHRAE seven-point scale has seven options available to refer to perceived thermal comfort for a specific environment (cold, cold moderate, neutral, hot warm, warm and hot)

1.8 Organization of the Study

This thesis is categorized into five 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 this thesis is categorized into five chapters. Every chapter systematically and successfully examines the content material and statistics of the content and data of the study. The fundamental chapters within the thesis are in addition 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 important issues related to indoor thermal comfort, building envelope and thermal comfort, solar control, and research data.

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 Theoretical Literature Review

2.1 Indoor Thermal Quality (IEQ)

A key factor in achieving a healthy environment in buildings is to provide a high level of Indoor Environmental Quality (IEQ). IEQ refers to acceptable indoor air quality (IAQ) and visual and acoustic thermal comfort.(Zuhaib et al. 2018b). The European multi-annual roadmap for energy efficient buildings until 2020 identifies IEQ as a key area of research. (EC, 2013). Environmental factors such as acoustics visual comfort thermal comfort and IAQ determine the quality of the indoor environment. The following subsections discuss each of these in light of current standards and research.(Zuhaib et al. 2018b).

2.1.2 Indoor Thermal Quality (IEQ)

The two main methods used to evaluate human thermal comfort today are Default Average Rating (PMV) and Percent Dissatisfaction (PPD). This approach is based on the results of Fangers work, which takes into account several aspects of the environment such as dry bulb temperature humidity wind velocity and average radiation temperature. (Fig. 1 and 2) as well as human factors such as heat resistance and metabolic rate. Heat balance occurs when the internal production of heat in the body equals the loss of heat to the surrounding environment. Many published papers examine this method and validate it as a universally applicable standard. Although there are many results that conflict with it, it still contributes well to becoming the most widely used approach in thermal comfort calculation as Jung et al. They have been shown to be convenient methods that have the ability to explain user feedback on their features.(Alwetaishi 2016).

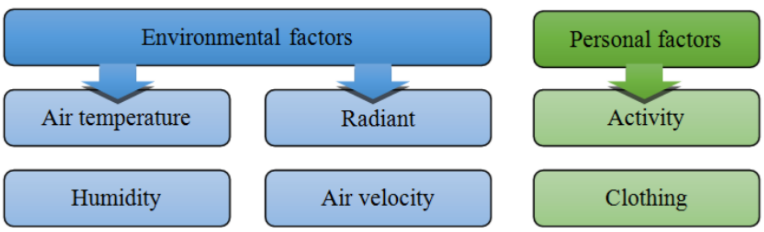


Figure 1The most important environmental factors affecting indoor thermal comfort(source: Alwetaishi 2016).

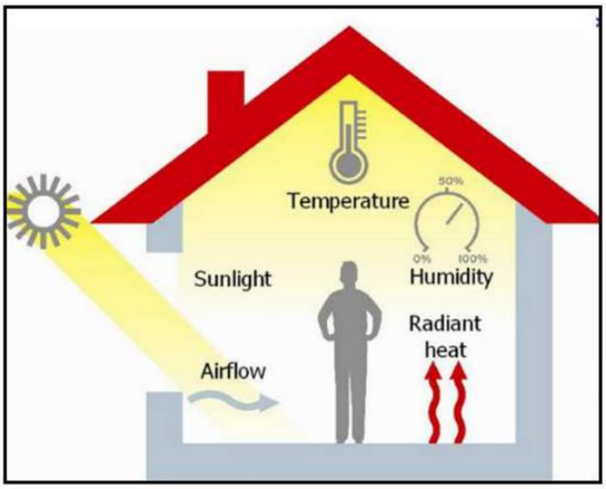


Figure 2Aspects affecting thermal comfort perceptions in both methods (PMV and PPD). (source: Alwetaishi 2016).

In terms of PMV, it can be defined as mentioned. PMV is an indicator that evaluates the average rating value of a large group of people on a 7-point thermos sensory scale. The scale ranges from: 3 very hot 2 hot 1 moderately warm 0 neutral -1 moderately cold -2 cold and -3 cold. In addition, the PMV model uses a mixed thermal balance method with six factors to calculate the users thermal comfort level. (Alwetaishi 2016)

For PPD ISO-7730 (2005) states that PPD predicts the average temperature value of a large population and is related to the PMV model (Ricardo et al. 2016) but is defined by these populations. Suffer (2 and 3 or -3 and -2). Temperature was established to determine the percentage of dissatisfied subjects who felt too hot or too cold.(Alwetaishi 2016)

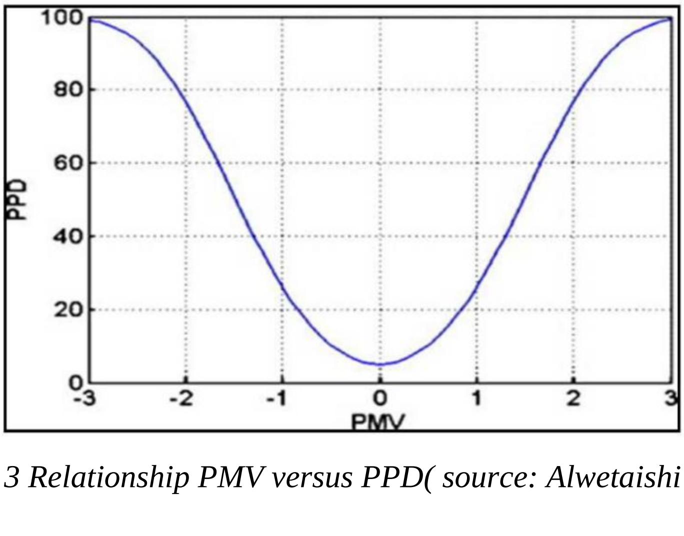


Figure 3 Relationship PMV versus PPD(source: Alwetaishi 2016).

2.1.3 Psychometric

Psychometrics helps in choosing the right air conditioning equipment and in determining the factors influencing human thermal comfort in the environment. It is also used to better understand the geographic environment and location of buildings as well as human habitation and use and architectural aspects. Humidity graphs help define specific comfort zones by factoring in thermal comfort variables such as air temperature relative humidity radiant temperature lethally wind speed and metabolic rate. According to much literature, temperature and relative humidity are of particular importance in defining comfort zones on psychometric graphs.

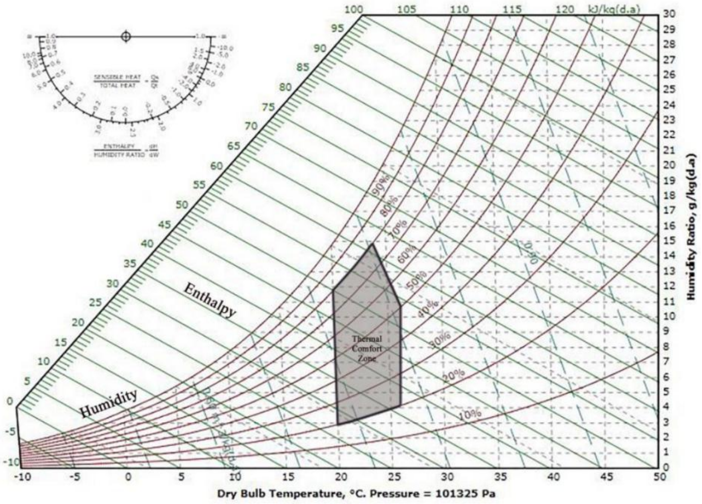


Figure 4psychometric thermal comfort zone, (source: ASHRAE standard 55-2010)

2.2 Factors Affecting Thermal Comfort

In addition to individual factors having a relative impact on thermal comfort some factors have a significant impact on occupant satisfaction or dissatisfaction. The factors that most influence the thermal comfort of the human body are environmental factors that cover many aspects and need to be taken into account. However, some attention is paid to everyone's considerations. (ASHRAE-55, 2004) and (Parsons, 2002) When considering thermal comfort air temperature humidity radiation and air movement as environmental factors it is more important to determine the following factors. Due to physical activity and body insulation (i.e. clothing) there is also metabolic rate. However some sources express other factors that support the group format. Gadi in Hole (2010) directs this. Gadi divided the reasons into two different groups. The first group includes metabolic rate average radiation temperature wind speed clothing air temperature resistance and vapor pressure and the second group includes sweat rate skin-reflective clothing and skin-friendly thermal clothing. Tactile and cloth surface.(Alwetaishi 2016)

2.2.1 Air Temperature

According to the Health and Safety Executive (HSE) air, temperature is the temperature around the body, which can be in degrees Celsius or Fahrenheit. Talking about air temperature is the most influential of all environmental factors. Because people are very sensitive to heat. Regarding the optimum core temperature Fanger suggested that the optimum core temperature for human thermal comfort in the northern temperate zone is 256°C Celsius. On the other hand, some have suggested 27°C (80%) RH and 0.4 msec-1 wind speed. (Jang et al., 2007). In fact, these two proposed figures are related to air diversity using humidity and speed, which play an important role in determining the optimal temperature of the roof. In addition, people considering a wider range of temperatures may overestimate the average air temperature to a greater degree. A study by Wang et al. (2010) Passengers rate the comfort level of a occupants. The 80 occupant received air temperatures ranging from 21.5 to 31.0 °C with an air temperature of 23.7°C and a clothing insulation of 0.54 °C, which is significantly lower and higher than the world average set. Indications The average temperature in international standards is 24°C to 28°C degrees Celsius.(Alwetaishi 2016).

2.2.2 Radiant Temperature

Hot objects in the environment give off heat. In some cases, this can have a greater impact than temperature itself. The sun is probably the most important radiator to consider. However, there are some examples such as stoves and hot surface drying ovens. If a building is designed from, the beginning to control solar radiation the use of radiation will be natural and clean. A study conducted by (Memon et al. 2008) concluded that thermal comfort can be achieved for most of the year. However, for hot countries the solar radiation produced by the sun or other radiation sources should be controlled and blocked according to the local climatic conditions. No doubt this leads to thermal discomfort.(Alwetaishi 2016).

2.2.3 Relative Humidity

According to ISO-7730 (2005) humidity is absolute humidity expressed as the water vapor pressure in the air due to evaporative heat loss by humans. If the water warms up and evaporates around the area, it will increase the percentage of humidity in the air. Relative humidity is the percentage between the current amount of water vapor and the actual amount of water that the air can hold at a given air temperature. Another effect of humidity is closely related to the prevailing air temperature and wind velocity in the environment, which causes heat loss to the skin. But when the relative humidity is between 40-70% it does not affect human comfort much.(Alwetaishi 2016)
High humidity is a big problem in hot countries because sweat prevents the skin from cooling. Parsons (2002) expressed the importance of sweating when body temperature rises sweating is the main and most effective technique for cooling the skin when evaporation occurs (Sakka et al. 2012). ISO 7730 ranges indicate allowable humidity. High or even moderate humidity at moderate temperatures (26°C and above) and moderate activity (about 2 gallons) can cause discomfort to the

occupant. In addition, heat sensitivity humidity skin dryness and eye irritation are added to the number of variables that equally affect sweat. ISO-7730 (2005).(Alwetaishi 2016)

2.2.4 Air Velocity

It is defined as the movement of air over a worker which can help cool the worker if it is cooler than the ambient temperature (Liu et al. 2014). Wind speed is a very important factor because people are very sensitive to it. Therefore it can cool or heat a space according to given indoor conditions such as indoor temperature and relative humidity. These two factors along with air movement have the greatest impact on human thermal comfort indoors (Hall 2010). An important issue with wind speed is that it affects heat exchange between people and the environment resulting in ISO-7730 (2005) normal heat losses. This relationship is highly dependent on the temperature and relative humidity of the surrounding environment. According to ASHRAE 44 there are no indoor air velocity limits established to improve the relationship between air velocity and comfort. However changing the air velocity in a room can make the temperature more acceptable under certain conditions. The standard does not give a fixed figure for the limit but recommends a maximum indoor air velocity of 0.2 m sec-1. Based on experience being indoors exceeding 02 m s 1 can cause discomfort even though the indoor air temperature is high and the need for convective skin with a high environment (ASHRAE-55 2004). Additionally ISO 7730 takes into account that there is no fixed minimum indoor wind speed because it will depend so much on other variables that the wind speed is sometimes zero or very close to it and Occupants can be satisfied.(Alwetaishi 2016)

2.2.5 Activity

Activity is one of the main factors affecting thermal comfort. There are many types of buildings each with their own purpose and required activity level. Therefore, school activities are different from office activities, which makes a big difference in the sensation of heat. It can be defined as the heat generated in the body when performing physical activity (Mustapa et al., 2016). The more active we are the more heat we produce. As a result we have to remove more heat from our body so that we don’t feel uncomfortable. ISO-7730 (2005) 01 indicates that the calculated difference in air temperature can produce a sensation of heat produced by 1 °C. Similarly, the air temperature is 25 to 3 degrees Celsius due to 04 mathematical differences. Therefore, it clearly shows how efficient it is to perform various household tasks that may result in heating or cooling under different conditions. In addition, Rowes (2001) study found that when the air temperature and radiation environment were the same at 24°C and the air speed was 041 m/s the relative humidity was 43% and the body temperature was 07. Fabric. Average production volume (PMV) can be expected to be natural with an active index of 1.2. However PMV at a metabolic rate of 16 is far from the recommended resting limit; Figure 2.4 shows the differences in metabolic rate for some types of activation criteria (ASHRAE-55 2004; ISO-7730 2005). Somewhat known.(Alwetaishi 2016).

2.2.6 Clothing Insulation

In prehistoric times, humans used animal fur to protect themselves from the cold (Carill et al.2007). Both clothing and skin can be seen as the body's defense against the environment. Oliveira and others. (2011) indicated that the evaluation of the thermal insulation of clothing is very important for human thermal research. The layer of clothing provides thermal insulation between the body and the environment. It also maintains the body at an acceptable temperature for various weather conditions.(Alwetaishi 2016)

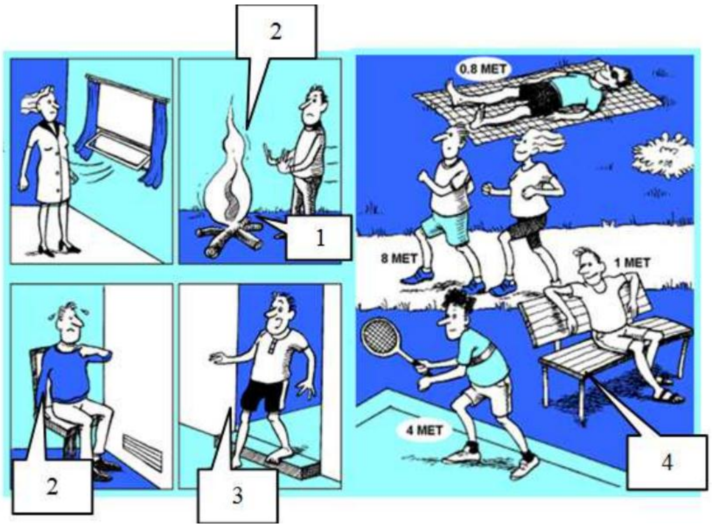


Figure 5local thermal discomfort; 1. Cooling or heating parts of the body through radiation (source: Alwetaishi 2016).

This is the so-called radiation asymmetry problem; 2. The vertical temperature difference is large cold feet and warm head; 3. Uncomfortable floor temperature and hot or cold feet; 4. Estimation of metabolic rate; Source: ANOVA Thermal Comfort (n.a)

2.3 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 Sun-path diagrams

1. 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)

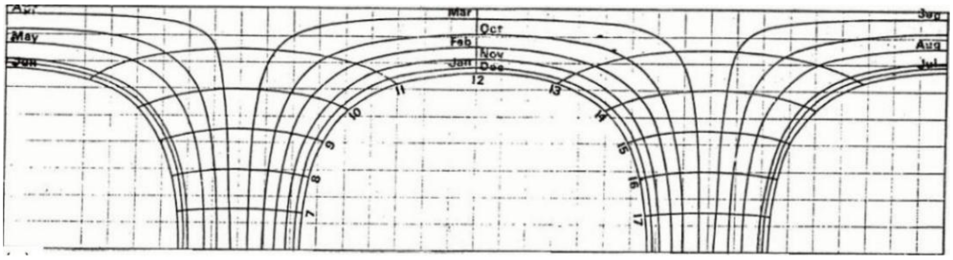


Figure 6 Orthogonal Projection (Sealey, 1979)

2. 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).

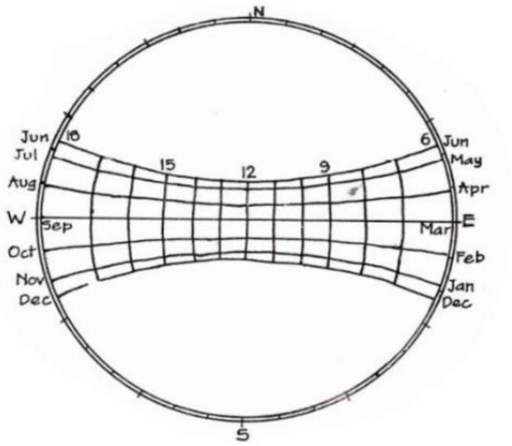


Figure 7 Stereographic Projection(Sealey, 1979)

2.3.2 The Use of Sun Path Diagram

Understanding and determining the position of the sun where building envelope is required and 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

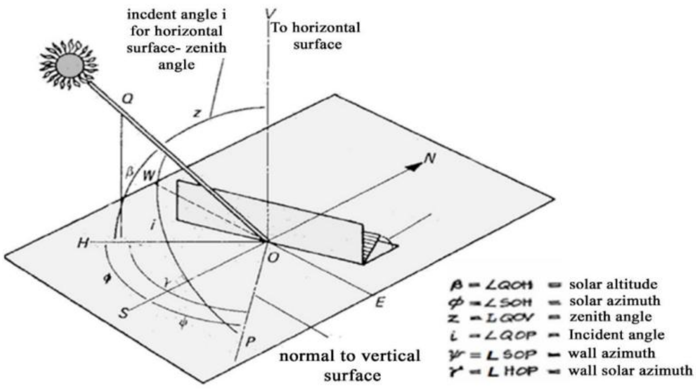


Figure 8 Solar For Vertical, Sloping and Horizontal surfaces (Sealey, 1979)

2.3.3 Effect of Building Function on Adaptive Thermal Comfort

Articles can be categorized according to different building types and functions (Peters et al. 2009). The function and use of a building makes a huge difference in terms of the adaptive heating potential of a dwelling. Four main aspects of construction are considered:

- Residential buildings
- Office building
- Health buildings
- Education buildings

Each of these buildings has different activity uses and types of areas that have a certain influence on the possibility of adaptation. This may be due to the amount of time people spend at home. Moreover Djongyang et al. (2010) noted that residential buildings consist of several types of spaces such as living rooms bedrooms and kitchens each of which requires its own level of thermal comfort.(Alwetaishi 2016)

Zhongyang et al. (2010) pointed out that residential buildings have different types of spaces such as living rooms bedrooms and kitchens and each of them requires its own level of thermal comfort. In a study conducted by Peters et al. (2009) who stated that thermal comfort in residential buildings is highly dependent on local weather conditions. There are three explanations for this. The first reason is that most people in developing countries live in rural areas. (Alwetaishi 2016)

The second reason is that many people live in detached houses where all the exterior walls and ceilings are exposed to weather fluctuations. Third, considered by (Ghisi and Massignani 2007) it shows the importance of apartment thermal performance leading to increased energy consumption. Therefore, it should be emphasized that the energy consumption of residential buildings should be reduced especially with the rapid growth of residential buildings. In the work done by Peeters et al.

(2009) he divided residential facilities into three main areas; each with different thermal comfort needs these needs are as follows: bathroom bedroom and other rooms such as kitchen living room study etc. Furthermore, Peeters has shown the reason for this classification based on physical activity level, etc. Individual factors will be discussed later in this article. For example in a bathroom, there is the air temperature of the bath water the air temperature of the bathtub, and the humidity of the air (Zingano 2001).

Peters et al. (2009) observed that bathing water has a very important lower temperature limit due to body condition (naked condition) and humidity (humidity). (21 to 305 °C) range is declared for bathroom comfort. More articles on bathrooms have been published considering different areas of residential architecture. So we will pay more attention.(Alwetaishi 2016)

2.3.4 Theoretical Review of Building envelope

The building envelope project aims to achieve building energy efficiency and increase the shading area using shading devices. It also reduces the buildings energy load because it reduces the buildings heating from solar radiation. In summary, it is finally clear that the passive design principles of the building envelope have a significant impact on the comfort of the building. (Bachrun, Ming, and Cinthya 2019).

2.3.5 Benefits of Building envelope

As the most important architectural element of a building the building envelope has a significant impact on the energy consumption of the building.(Bachrun, Ming, and Cinthya 2019)

2.3.6. Environmental Benefits of Building envelope

The selection of building skin components has a significant impact on all phases of the building life cycle from an environmental and energy point of view and plays an important role in sustainable building design.(Žigart et al. 2018). The main concern in the modern arena is to achieve a comfortable indoor environment in terms of visual thermal and psychological comfort. Further innovation in the design and construction of modern buildings and their components is likely to develop rapidly. The design of the building and envelope places great emphasis on making the building sustainable reducing energy consumption without compromising user comfort. This creates a challenge for designers and engineers to study and control the effects of built-model design parameters on performance.(Kumar and Raheja 2016)

2.4 Tools for Shading Systems Analysis

Due to changing environmental conditions, the manual calculation of temperature and Visibility parameters for many zones or homes have grown to be more complicated. These consist of modifications in outdoor air temperature and solar radiation over time, shading from Neighboring homes, self-shading and the thermal capability of the building. 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. This tool can estimate the overall performance of various building designs for a particular environmental situation. Popular and validated building energy simulation tools can be found listed on the U.S Department of Energy's (DOE) Building

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. 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 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: 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.

2.5 The interactions and connections between sustainable building envelope design and building sustainability

To analyze the impact of envelope design on the sustainability of buildings it is important to note the fundamental role of the concept of sustainable development in the sustainability of buildings. The building envelope is an important component of construction responsible for the function of protecting the internal environment from external environmental influences. It is the interface between the external environment and the internal environment. Building envelopes regulate energy consumption resource consumption and environmental degradation by protecting the interior environment and comfort levels from negative environmental influences (Erin and Robert 2007). In addition to protecting and regulating the building envelope controls the flow of solar and heat and the flow of moisture into and out of the building. It also controls indoor air quality and noise impact on non-fire buildings.(Iwaro and Mwasha 2013).

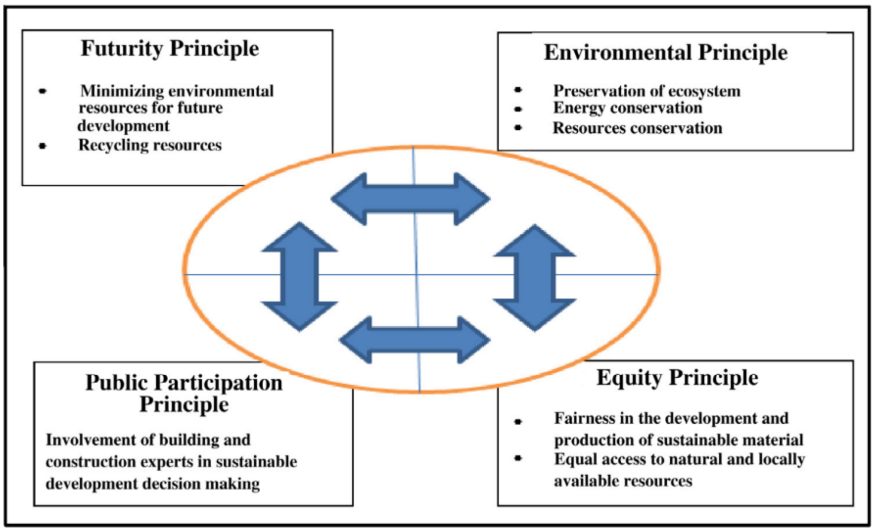


Figure 9 A modified sustainable development model for building envelopes.

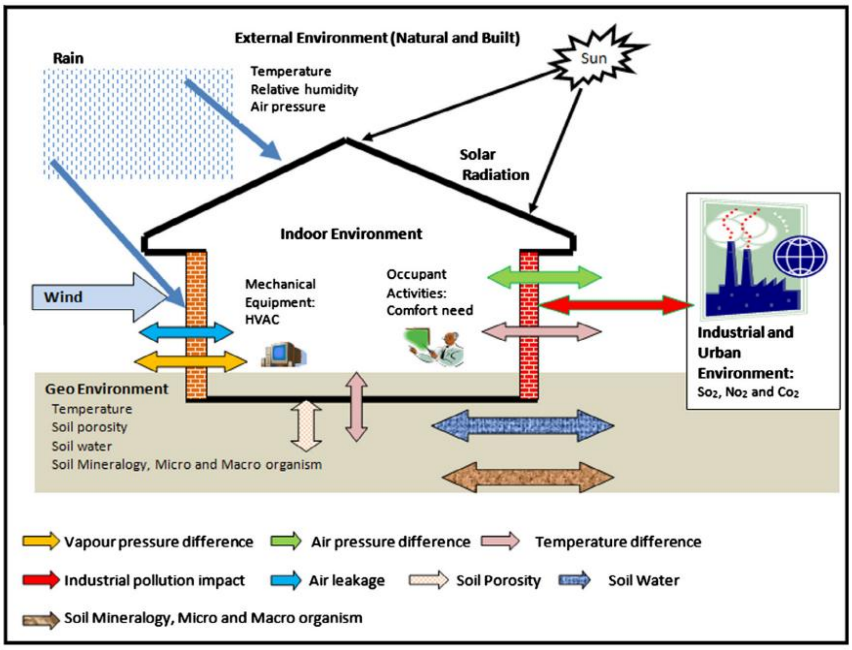


Figure 10 Building Envelope Environmental Load

2.6 Determinants Role in Building Envelope

The design of building envelope components must consider both external and internal thermal loads and solar gains. Components of the building envelope are always designed with the objective of realizing the functional aesthetic technical socio-cultural environmental determinants of the project for their maximum efficiency and duration. These design decisions include studies on aspects such as maximizing daylight gain controlling direct sunlight minimizing heat gain during overheating controlling glare and views of the outdoor environment. Designing a building envelope for a space that determines the properties and parameters of the components will help understand the physical processes of heat air humidity and light in the building envelope (Figure 1). The most important factor in the field of comfort is thermal comfort, which is determined by variables like dry bulb temperature (DBT) wet bulb temperature (WBT) relative humidity (RH) soil temperature (GT) fabric exchange value thermal etc. Big wind speed etc. Different models.(Kumar and Raheja 2016)

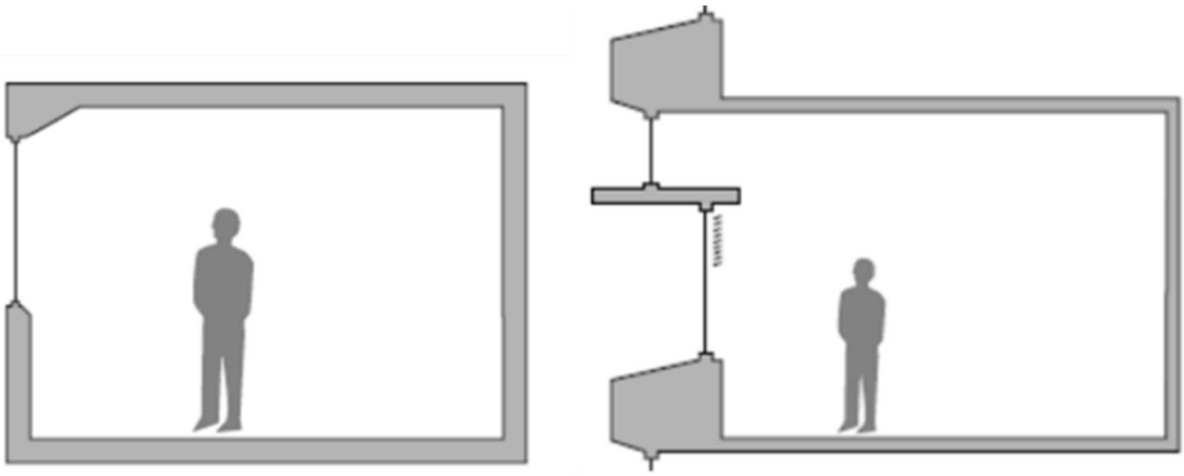


Figure 11 Part of the facade (a) Curved surface in the opening to soften the light; (b) Inner wall area to shade oneself (Source: Krishan Baker et al. 1999)

2.7 Typologies of Building Envelope

Understanding the behavior of building envelope components requires classification of different types of building envelopes to determine appropriate combinations of site and climate. Generally, the building envelope is divided into two parts:

- Single skin façade building envelope

- Double or many skin façade building envelope

As discussed thus far architectural elements from the past have evolved into current architectural styles and are now used in multiple materials or skins on the facades of modern buildings known as double-skinned facades. The benefit of using the double building envelope concept in buildings is to encourage sustainable building design and energy savings to build thermal and visual comfort. In modern times designers and researchers in the architectural field have integrated the concept of sustainable design, which can improve the overall design results by saving building energy improving indoor air quality and thermal and visual comfort. The double-layer façade concept is an architectural element integrated into the building that allows for multiple views thus improving the performance of the building.(Kumar and Raheja 2016).

Another type of building envelope can be defined as a completely enclosed envelope a good example of this type is the Mont Senis Training Center in Herne-Sodingen Germany. It is a perfect example of a fully enclosed building envelope that incorporates multiple green strategies and promotes a microclimate framework that accommodates the expansive microcosm of urban life. They are located in two rows of buildings around a terraced central road in a 123000-square-foot glass building.(Kumar and Raheja 2016).

2.7.1 Box Window Façade:

The first façade typology was introduced in the construction industry. The facade of the building is divided horizontally by vertical sections. Such facades are divided into independent window boxes. Good for high-level heat and sound insulation. The only architectural firm provides these functions for facades with simple rectangular openings. This system can be used to renovate buildings to increase efficiency and facilitate the use of double skin facades in older buildings.(Kumar and Raheja 2016)

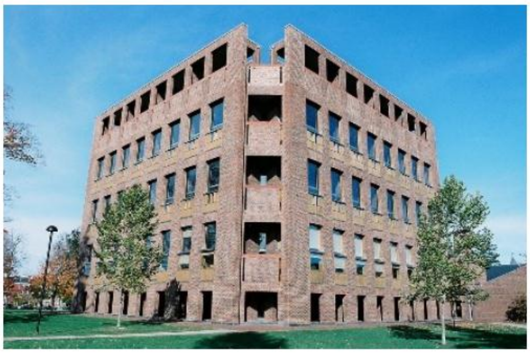


Figure 12 Example: Phillips Library Exeter Academy New Hampshire USA

2.7.2 Shaft Box Type Façade:

This system is based on the grid type window. It consists of an independent element of a horizontal grid window with vertical axis adjustment. Benefit from chimney ventilation while maintaining high levels of solar radiation and acoustic insulation. Columns can be used for airflow systems (natural or mechanical). Since in practice the pile height is limited this form of construction is more suitable for buildings with basement floors.(Kumar and Raheja 2016)

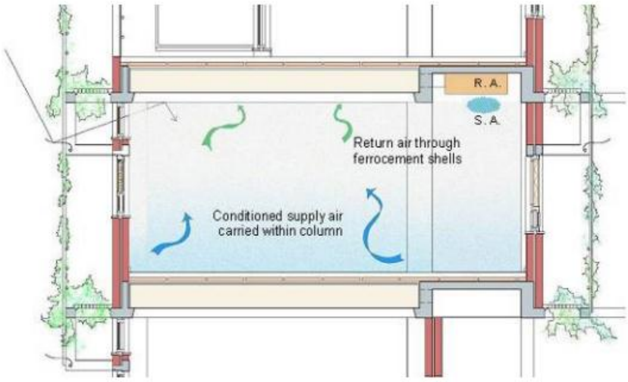


Figure 13 Example: Suzlon One Earth, Pune, India

2.7.3 Corridor Façade:

The cavity space or open space between the exterior and interior facades is divided horizontally in each floor. It is accessible and broad enough to be used as a service platform. Ventilation can be natural or mechanical. Air inlets and exhaust holes on the outer layer of the facade located near the floor and ceiling. The advantage of corridor facades is that they do not limit the height of the building.(Kumar and Raheja 2016)

2.7.4 Multi Storey Double Skin Façade:

There is no horizontal or vertical separation between the two skins instead; air space is transferred through large openings close to the base of the building and the roof. It combines corridor façade and the shaft box types. It acts as a supply air front in winter and an exhaust air front in summer. Suitable for locations where external noise levels are very high and there is no need to spread gaps at high altitudes. Multi-layered facades can be used as ordinary air ducts.(Kumar and Raheja 2016)

Figure 14 Example: Torrent Research Center Ahmedabad India

2.8 Tools for Shading Systems Analysis

Due to the change in environmental conditions, the manual calculation of temperature and other parameters for many zones or buildings has become more complex. 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. Computerbased simulation tools are now available to quickly and accurately assess a building's thermal and daylighting performance. These tools can evaluate the performance of different building designs for a specific environmental condition.

2.8.1 Simulation Tool

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.

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.

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.

2.9 EMPIRICAL REVIEW

As research conducted (Abraham Seno Bachrun1, 2019) in building envelope component to control thermal indoor environment in sustainable building, the building envelope can have a substantial impact on total energy usage as it can significantly affect the cooling loads, primarily due to the control of the acquisition of heat radiation through openings, and the utilization of sun light. A combination of passive design strategies has the potential for energy savings of about 31% in office buildings. The combination can be accomplished through the design of building envelopes that include shading. The extent of Window to Wall Ratio (WWR),window ratios, the selection of glass with low shading coefficient and the utilization of natural light for indoor illumination (Abraham Seno Bachrun1, 2019).

Building orientation can be the most crucial step in providing the building with passive thermal and visual comfort oriented to the north and south (ValladaresRendóna, Schmid & Lo, 2016). The condition allows the window to get natural light from the dome of the sky while still minimizing the heat gain from solar radiation directly. Service spaces and stairs with massive walls can be placed on the West and East side so that they can function as thermal buffer zones. To avoid overheating of excessive solar radiation, the main surface of the building's envelope with windows is as far as possible oriented to the north and south (Abraham Seno Bachrun1, 2019).

Orientation must be decided along with curing in the initial design process since both cannot be utterly optimized without the other (Abraham Seno Bachrun1, 2019).Even the process has to be thought of since the idea (holistic design). Orientation is merely a form of a compass facing a building. The orientation should be optimized early on, along with the mass, and can be the most crucial step for passive design. (Abraham Seno Bachrun1, 2019)

As stated in Investigating the effectiveness of the Building's envelope materials in hot and arid climates to achieve indoor thermal comfort by Khaled Mansouri it shows the impact of building envelope on indoor thermal comfort which is evaluated by ambient and surface radiant temperature with different envelope building materials in a hot and dry climatic context of the city of Biskra .the study demonstrates the essential results of an empirical study that have been done using in situ measurements as well as numerical simulations, also it reveals the importance of the building wall configuration. To achieve a better thermal performance of the envelope, it is desirable to have a multi-layered envelope comprising materials of different thermo-physical properties which allow regulating heat exchanges between the building and its environment, a double red brick wall with isolation is efficient to ensure thermal comfort due to his thermo-physical properties, thus A bad choice of the material constituting the building envelope can result in a long-term additional cost to ensure thermal comfort. In general, the study has shown that choosing a multilayered isolated envelope will likely affect positively the level of the indoor thermal comfort. (Mansouri, 2023).

2.9.1 Shading Device

2.9.1.1 Internal Shading Device

The internal shade (curtain) retains solar radiation after passing through the glass window and prevents the occurrence of direct solar radiation concerning the occupants and the deeper interior (Gago et al., 2015). However, internal shading is not as effective as external shade in reducing cooling loads. (Abraham Seno Bachrun1, 2019)

2.9.1.2 External Shading Device

The external shade is more effective, reducing solar thermal gain than the internal shade because it can block solar radiation before it reaches the building envelope. The external shade needs to be carefully designed not only to reduce the cooling load but also to create an aesthetic architecture while taking into account the natural lighting performance (Huang, Niu, & Chung, 2103).

The geometry of the shading device should be designed according to the path of the sun movement, which led to the design of different shapes and sizes for different orientations. In general, horizontal shading devices are more suitable for windows with south and north orientation, where the angle of sunlight arrives relatively high. Example of the vertical and horizontal shading as shown in Fig. below

Figure 15 Example of the Vertical Fins Application (Mansouri, 2023)

In this study, a quantitative method was conducted to evaluate indoor thermal conditions using in situ measurements and numerical simulations.

Light Shelf

Light Shelf is a horizontal element that divides the window into two parts. Upper window for natural lighting and lower window for vision In addition to functioning as a lower window shade, the reflector of light also serves to reflect sunlight coming from the top of the window to help penetrate natural light into the room away from the window. (Abraham Seno Bachrun1, 2019)

This will optimize light penetration without causing excessive heat. To obtain better natural lighting distribution, the reflector's top surface, as well as the ceiling, should have a high reflectance. (Abraham Seno Bachrun1, 2019)

This study shows the impact of building envelope on indoor thermal comfort which is evaluated by ambient and surface radiant temperature with different envelope building materials in a hot and dry climatic context of the city of Biskra .the study demonstrates the essential results of an empirical study that have been done using in situ measurements as well as numerical simulations, also it reveals the importance of the building wall configuration. (Mansouri, 2023)

To understand the thermal performance of the building envelope on the indoor environment, he points out that most studies have found that time lag and decrement factor are the most critical performance measures of a building envelope that influence heat transfer and the indoor temperature. Envelope design characteristics affect the thermal comfort of the occupants, as well as energy consumption in the building. (Mansouri, 2023)

In order to evaluate the thermal comfort, a numerical simulation was conducted with "Design Builder 5.5" software. Design Builder is a tool for dynamic thermal simulation and energy consumption analysis of buildings. The model of the studied Buildings and envelope compositions simulated with Design Builder based on actual weather conditions (climatic weather data file). (Mansouri, 2023)

2.10 Summary of literature and research gaps

As different research tried to assess on related thermal comfort and building envelope, In research entitle building envelope component to control thermal indoor environment in sustainable building by Abraham Seno Bachrun1,2, Ting Zhen Ming1 , Anastasia Cinthya3 focuses on the deepening of technology of building envelope elements, and how the building envelope can control the thermal comfort as part of the indoor environment in a building that carries sustainability architecture. In conclusion, finally, reveal that the principles of passive design on building envelope have a great influence on the comfort level in the building. It is not possible to create a design that meets the thermal comfort requirements by emphasizing the design of building envelopes. The goal to be achieved in sustainable design is to minimize the use of the current design that takes much energy (almost14% world energy consumption) to address the issue of energy crisis lately. (Abraham Seno Bachrun1, 2019)

In research entitle Investigating the effectiveness of the Building's envelope materials in hot and arid climates to achieve indoor thermal comfort To achieve a better thermal performance of the envelope, it is desirable to have a multi-layered envelope comprising materials of different thermo-physical properties which allow regulating heat exchanges between the building and its environment, a double red brick wall with isolation is efficient to ensure thermal comfort due to his thermo-physical properties, thus A bad choice of the material constituting the building envelope can result in a long-term additional cost to ensure thermal comfort. In general, the study has shown that choosing a multilayered isolated envelope will likely affect positively the level of the indoor thermal comfort. (Mansouri, 2023)

To perform a thermal and energy analysis, the results show that choosing a multilayered isolated envelope such as double red brick isolated wall will likely affect positively the level of the indoor thermal comfort. (Mansouri, 2023)

CHAPTER THREE

Methods and Materials

3.1 Description of study Area

This research was conduct in Addis Ababa city which is the Ethiopia's capital, located in the geographic epicenter of the country, and surrounded by the regional state of Oromia. It is the largest city in the country and plays a central political, economic and symbolic role in Ethiopia. Addis Ababa lies at an elevation of 2,355 meters (7,726 ft) and is a grassland biome, located at 9° 1′ 48″ N 38° 44′ 24″ E.

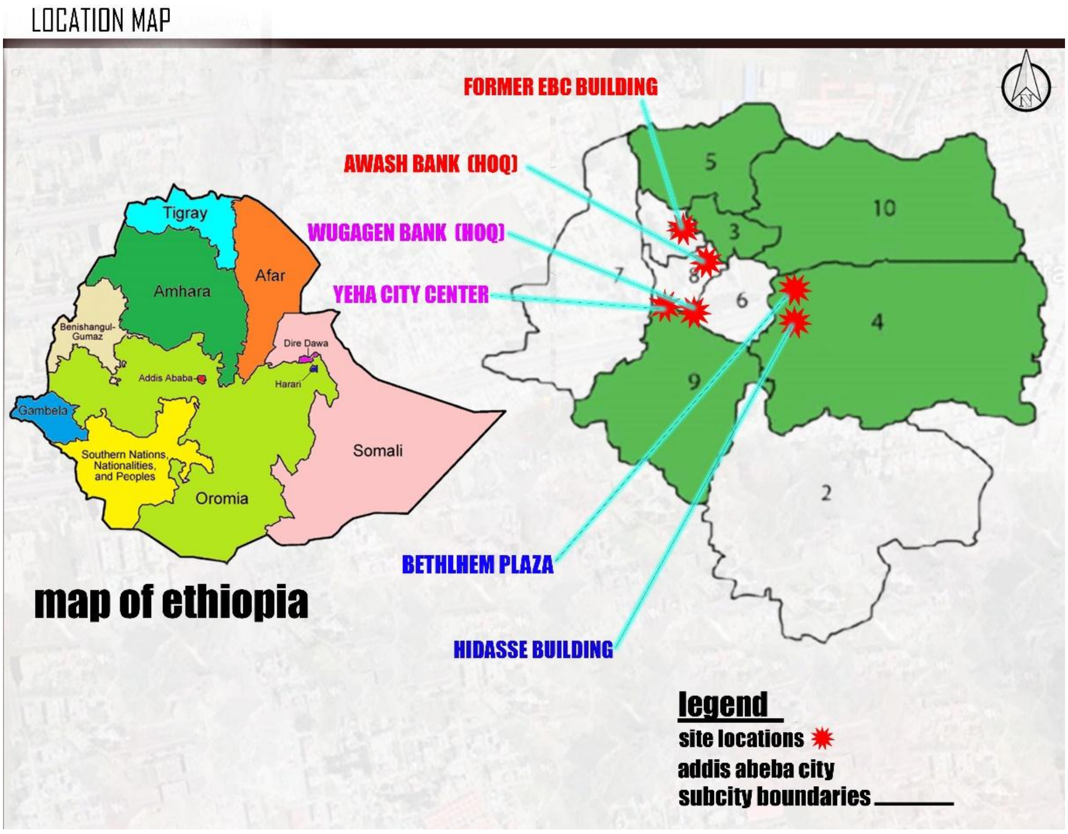


Figure 16 Location Map of Addis Ababa city (Source: author, (2024)

3.2 Research Design

The purpose of this study is to develop a descriptive model that describes the relationship between flexible office buildings. There are 4 types of variables in this study.

Dependent variables

(i) Indoor thermal comfort

Independent variables

(ii) Building envelop systems

(iii) orientation of the buildings

(iv) Relationship of the buildings

The work flow of this paper is as shown in Chart 2 Thermal comfort and building envelope are inter-reliant. Building envelope with consideration of sun path, envelope material, 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.

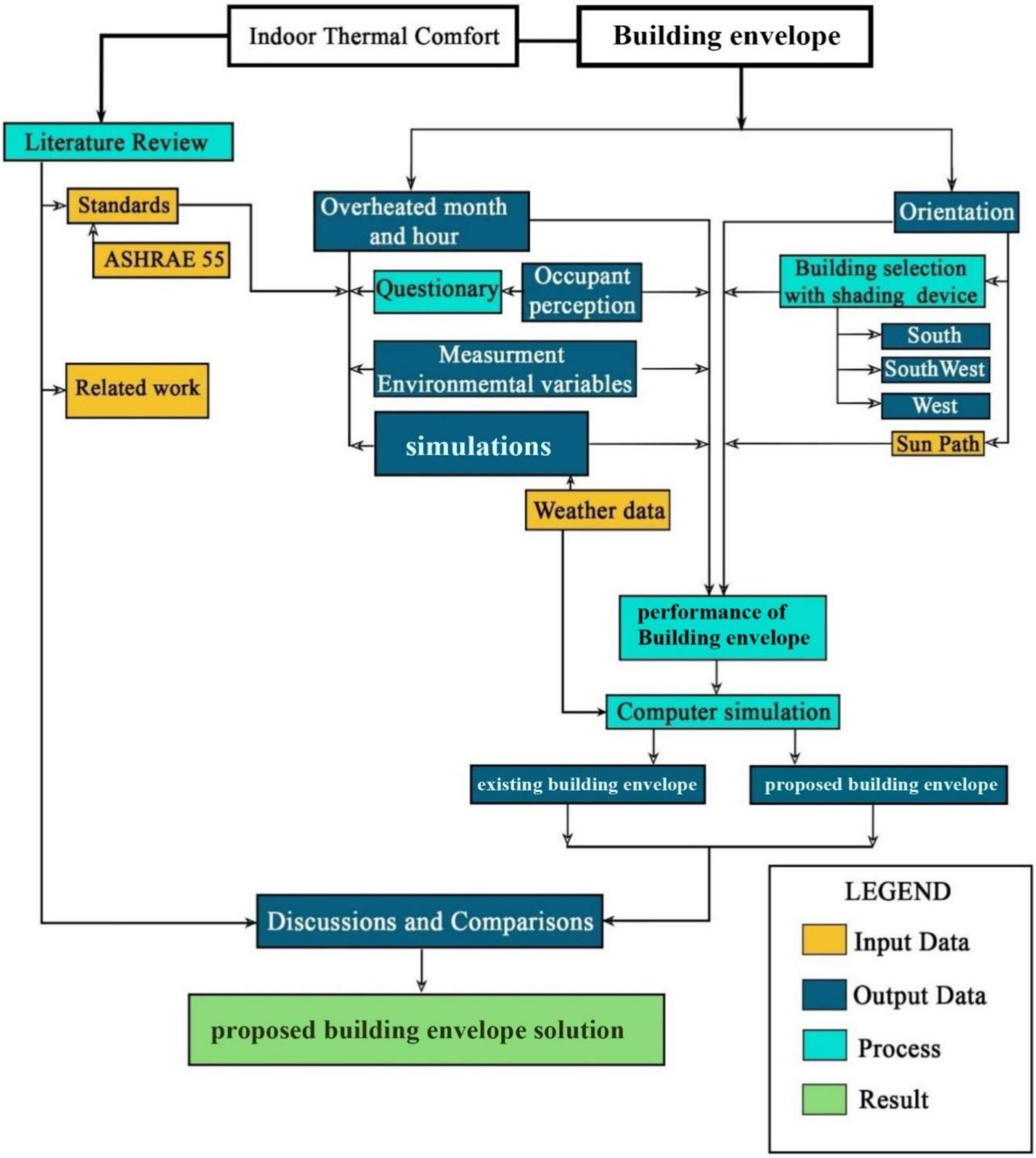


Figure 17 Research design framework chart (Source: Author: 2024)

3.3 DATA TYPE AND SOURCES

A, sampling technique

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

B, Methods for Assessing Perceived Thermal Comfort in Office Buildings

Primary data

Primary data is collected through semi-structured interviews including focus group interviews key informant interviews and distribution of questionnaires (with paper and web links) to communities and relevant organizations. Key issues raised by all forms of data collection include: Identify the causes and effects of head office thermal problems Challenges and problems. Health and productivity of individual work behavior in relation to temperature and nature.

a. Interview

An interview is a data collection method that involves asking respondents face-to-face either individually or in groups. This data collection method is used to collect data from employees in this study. 56 respondents may be employees and executives. Most of the time who spent in the office. All respondents wanted information about suggested solutions to problems and useful information about nature and comfort.

b. Questionnaire

A written questionnaire (also referred to as self-administered questionnaire) is a data collection tool in which written questions are presented that are to be answered by the respondents in written form. (Chaleunvong, 2009). This questionnaire is paper based and web link based. Now a day's web link based question nary reach many people and enable researchers to obtain many information. In this research in order to prepare the questionnaires, the first step is identifying the actors of the case area. In this questionnaire, the respondents would be asked about the availability of well-designed and health working space, connection with nature, level of comfort in office and the experience about building envelop systems.

C Standardized questionnaire

There are several types of standardized questionnaires in the literature, such as the Royal Society of Health (RSH) questionnaire developed by the British Building Research Establishment, which focuses on office buildings (Rohdin et al., 2012), the standardized questionnaires described in ANSI/ASHRAE Standard 55 and in NS/EN 15251 (Berge & Matisen, 2016), and Miljö Medicinsk (MM) questionnaire (The MM Questionnaires, 2014). The MM questionnaire for offices (MM 040

NA Office) was applied in this study since it is well established and often used in Nordic countries in studies focused on investigating perceptions and experiences related to indoor climate.

D MM questionnaire

The first version of the MM-questionnaire for non-industrial workplaces was released in 1989 by the Department of Occupational and Environmental Medicine at Örebro University Hospital in Sweden (Andersson et al. 1993) after three years of being intensely tested regarding its validity, reliability and its practical application (Andersson 1998. Several versions exist for different environments such as schools, day care centers, offices, hospitals and residential buildings (Andersson 1998). The 47 MM-questionnaire for offices (MM 040 NA Office) included a total of ten categories of questions about:

(1) Background factors such as the location of the workplace, the position of the staff, working hours, etc.

(2) Disturbing factors in the work environment such as draught, too high room temperature, etc. ADVANCES IN BUILDING ENERGY RESEARCH 223

(3) Work conditions such as workload, support from fellow-workers, etc.

(4) Present symptoms in the work environment such as fatigue, headache, etc.

(5) Physical and psychological work environment such as being on sick leave, etc.

(6) Temperature conditions such as too cold in winter, too warm in summer, etc.

(7) Cleaning situation in the work environment

(8) Noise in the work environment such as disturbing noise from ventilation, noise from outside, etc. (9) Air quality like problems such as odors, problems in different periods of the day, etc.

(10) Other background factors such as date of birth, gender, education level, etc

E Observation

Data collected from 6 Building blocks in 3 sites based on factors including building mass, orientation, climate, and building envelope, among others. Because the field measurement is time consuming two similar building used from each site by sampling out the building envelope and orientation Measuring Equipment used to measure the room's environmental variable. This Data's was automatically recorded every 10 to 20 minutes.

The equipment is as follows:

- Air temperature and relative humidity: two digital thermometers Testo, with automatic data recording, at 10 minutes interval.
- Globe thermometer, with a sensor inside, for measurements of globe temperature and calculation of mean radiant temperature.
- Thermoanemoter Testo, for measurement of air speed.

- Surface temperatures of the walls through a probe fastened in the wall, for evaluation of the influence of vegetation on the wall surfaces.

Then the study will be continued with data collection from site observations of all these buildings. Then a comparative study will conducted to put together all the findings to indicate suitable envelope systems appropriate for regulating office room temperature. However, the case study nature of the study, the time constraint as well as the restricted length of this paper set the limitations of the study.

Site Survey

This method will be applied to observe the existing situation of the selected building under study and was made by visiting the selected buildings to independently assess the current condition based on thermal comfort and envelope infrastructure principles.

✓ 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 building envelope type. Compared the existing building with that of building envelope integration principles, a standard checklist for thermal comfort created, which was defined building envelope 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

figure18 Measuring equipment that can be used in evaluation analysis and assessment of thermal comfort 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 1 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.

3.3 .2 Secondary Data collection

Totally, literatures such as journals and guidebooks will be used to relate the situation of the area with different researchers used also help to figure out what kind of approach help.

Journals and Web

In this research the web and journals will be used to find updated and research based data about the case of envelope, building orientation and thermal comfort, location, climate and topography, room temperature. In addition, different kinds of literature, case studies will be used.

3.4 Data quality assurance

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

3.5 Sampling

The sampling technique of the research is purposive as it takes the samples on technical and aiming in order to achieve the specific goal. As the research method is case study method it takes several cases to investigate detail information and data from the specific study area. Although there are many office buildings in Addis Ababa that are related to a topic in research, this study only looked at 3 different buildings sites. The choice of a building was based on the following determining variables. Numerous issues, such as to analyze different urban heat locations, solar radiation, and glazed building envelope orientation. In each, site 3 different site 2 buildings on medium and high height, envelope difference to examine the effect of the height and orientation of the building. The building sampling depends on the following.

- **Material and Building envelope**: weather they are Glass, special façade treatment, HCB wall,
- **Building form**:- cube/prism of box like, cylindrical, circular, mixed form adjustment
- **Size/height:-** high-rise, low rise or medium height building, or sky scraper
- **Site/location**: whether or not it influenced by the location regarding the activity, mobility and traffic, CBD, or peripheral of the city.
- **Orientation:** towards the sun direction in harsh and different time of the day.

Megengna Site

The first site is Bole sub-city woreda known with local name Megenagna. In Megenagna two different buildings selected. The function of both buildings are office. The site is one of highly commercial activity and the place is connecting all corners of the city. This high mobility and traffic play in thermal comfort and in comfort Buildings in this site have different envelope, building character, building form and similar orientation.

Figure19 Megenagna google map location

Hidase CBE building

Hidase building is commercial Bank of Ethiopia with B+G+M+13 floors. The function of the building is Gymnasium and parking at basement, banking service a mezzanine and ground floor. Building is treated with special façade treatment of metal perforated elements in front of the buildings. HCB

Figure20 3d exterior of Hidase building site & author

Betelhem Plaza

The second building at Megenagna is betelhem plaza. Its B+G+7 floors. Its medium floor building unlike the Hidase building. The function is commercial at lower level and office compartments at higher levels. The material is glazed façade. HCB at the South West direction or at the back of the building.

Figure 21 Exterior 3D of Bethlehem plaza author

Biherawi Site

The second site is around Biherawi. In this site two buildings with the same orientation selected Awash Bank HQ tower and EBC/ETV HQ with different material. This place is selected as it is city center (CBD) of Addis Ababa to be high in temperature increase because of a lot of skyscrapers and glazing facades glowing the place. Selecting this place is

Awash Bank HQ

Awash Bank is located at Kirkos Subscity known local name Biherawi, found at back of National Theater around national Bank of Ethiopia. Its glazed façade, partially HCB the building is selected for its curved glazed and cylindrical form. Its 2B+G+18 floors high rise building. The function is totally office, HQ offices, branch bank at the ground, and parking and storage at the basement.

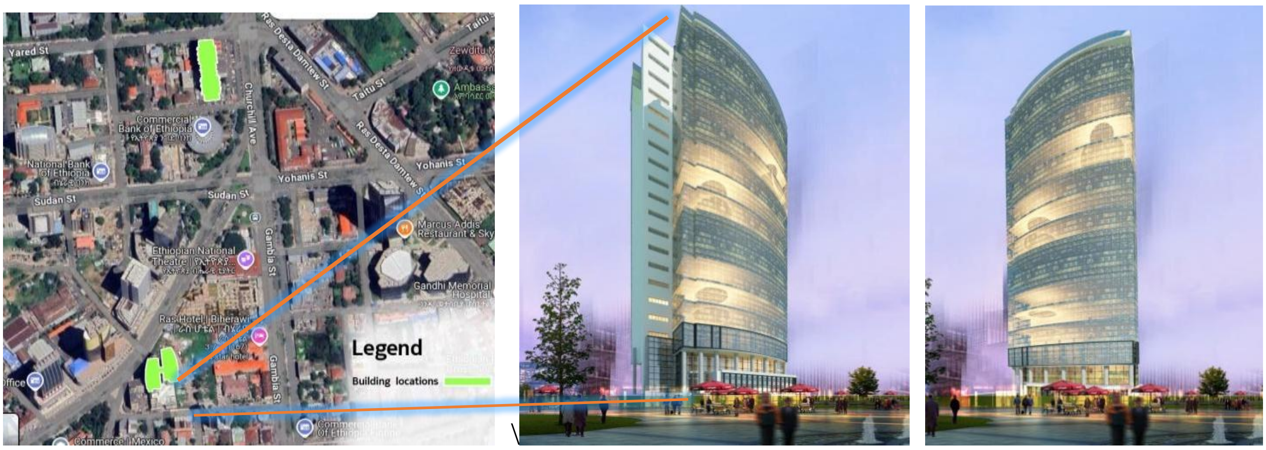


Figure 22 Awash bank Exterior 3D location map and Image (author)

EBC HQ building

It found around Biherawi in the same site with Awash Bank HQ in Kirkos subcity local known as Biherawi, next to CBE old HQ building. The building is medium floor height. The material is total of HCB. The opening is half glazed half fixed while other places are kind of glass block. It characterize by the small and medium window size, old age.

Figure 23 Exterior 3D of EBC headquarter (author)

Stadium Site

The next site in the city center Kirkos subcity know locally stadium area. The first building is Yeha city center and the second building is Wegagen Bank HQ. Both building have similar orientation to the north. The place is known in high traffic activity as it is city center and incoming high-rise buildings.

Wegagen Bank HQ building

The building is function of office building. The façade treatment is special in both west and east side. That cover all the glazed parts, the corners materials are HCB and other building material. The building is B+G+23.

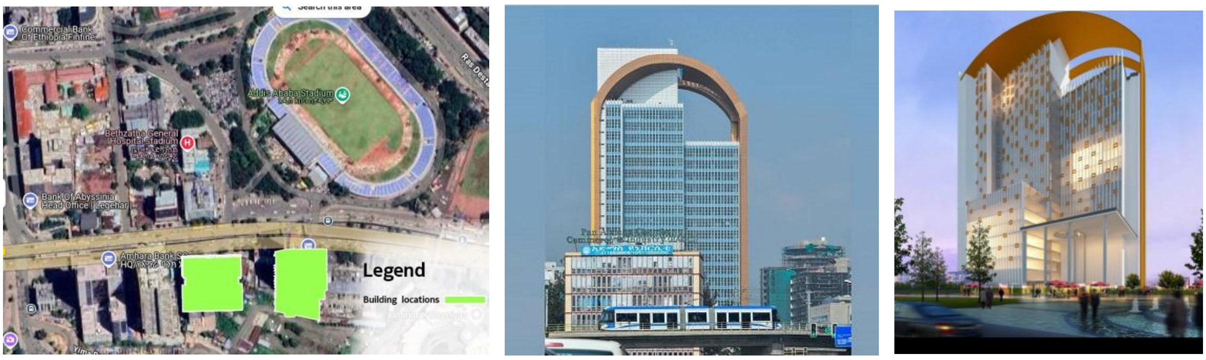


Figure 24 Exterior 3D of Wegagen bank location image (author)

Yeha City Center

The building found in around stadium with medium floor level and HCB wall and regular opening s with few glazing at front. Its cubic form with cladding. The floor number is B+G+M+13. It oriented to the North. Building function is commercial at the lower levels and office at higher levels.

Figure 25 Exterior 3D of yeha city center(author)

3.6 Floor Sampling and measurement techniques

After selecting buildings with in each building 2-3 floors selected as a sample. The upper lower and intermediate floor is selected because addressing the whole floor is time taking and it decrease the quality of measurement data and also the floor factor in between the last floor and the ground is the same. In case covering 3 floors is difficult the intermediate floor was selected. 2 different pool offices from the floor were selected. The employee in different corners like North, east, west and south, southwest were selected for interview at the moment of data collection using thermometer. This interview was about their feeling about the moments their feeling of thermal comfort and indoor quality. The hygrometer was placed in the room, while the infrared instrument used to measure all sidewalls temperature to compare their difference with each other and with other buildings.

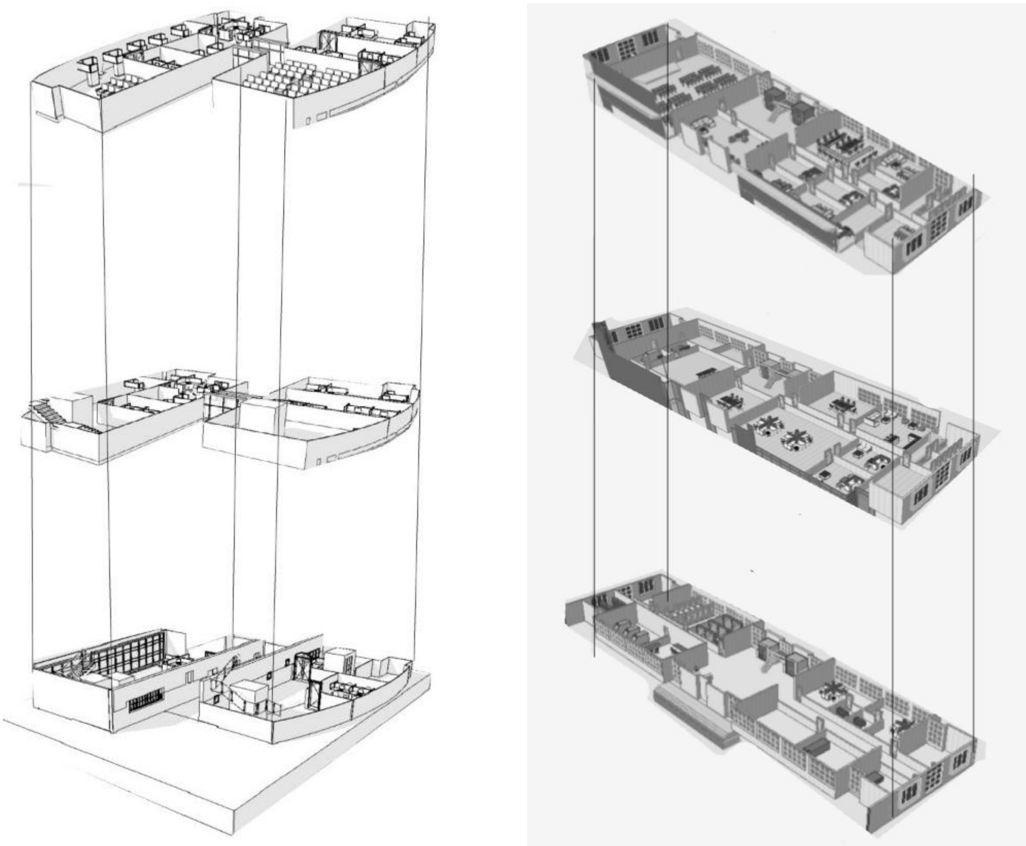


Figure 26 Awash and former EBC buildings 3 floors buildings 3 selected floors

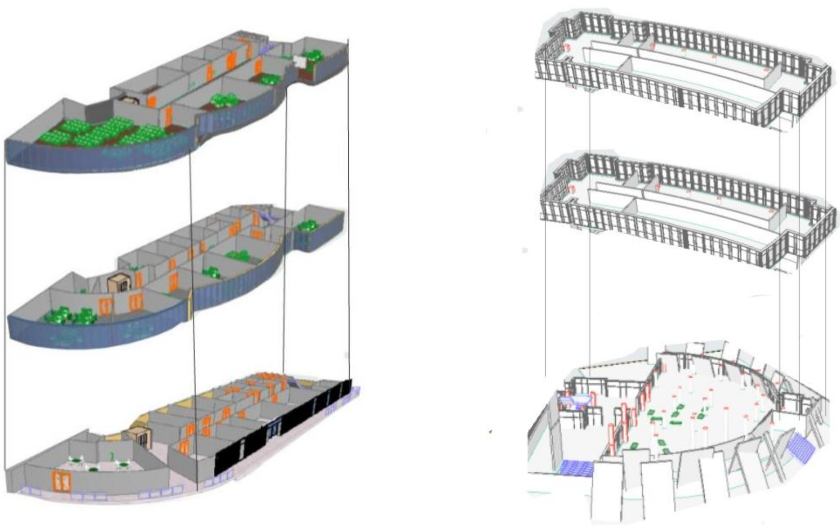


Figure 27 Bethlehem plaza and hidasse buildings 3 selected floors

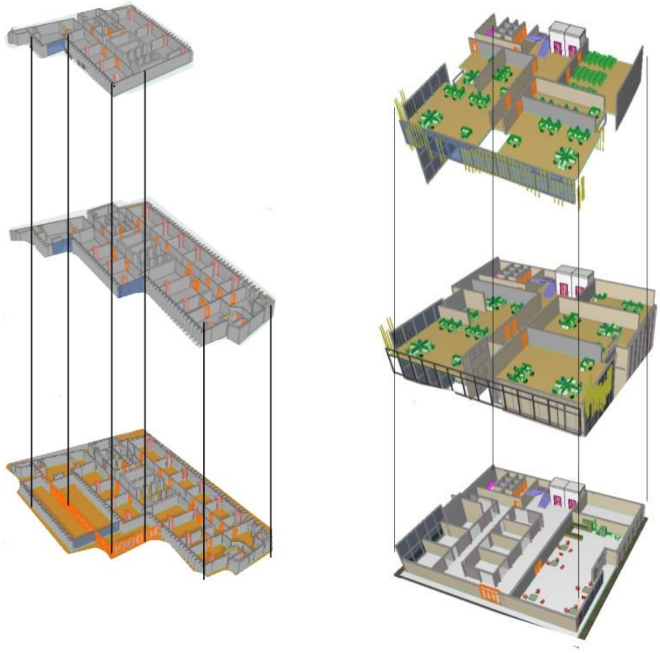


Figure 28 wegagen and yeha city center buildings 3 selected floors

3.5 Sampling method

Two buildings with proximate envelope will be analyzed each. Each two buildings differ depend on parameters like, building mass size, room height, paint, occupant’s type, passive and active shading devices etc. but the same in orientation. In single building of intermediate floor, it will be divided into four places or zones for zones.

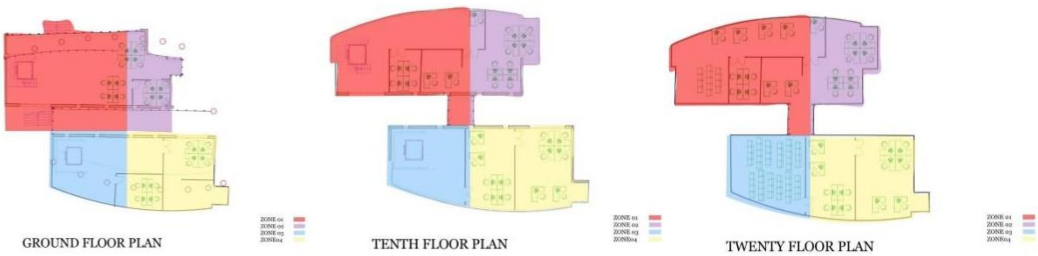


Figure 29 Awash bank Sample Building plan divided into four zones per floor.

Figure 30 EBC Sample Building plan divided into four zones per floor.

Figure 31 Bethlehem plaza Sample Building plan divided into four zones per floor.

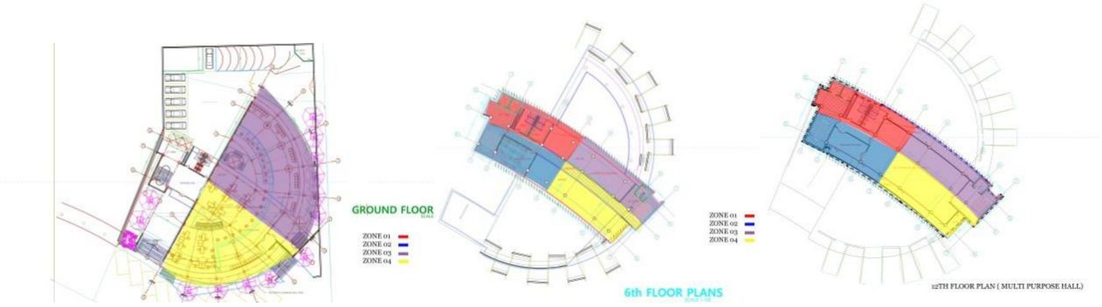


Figure 32 Hidasse Sample Building plan divided into four zones per floor.

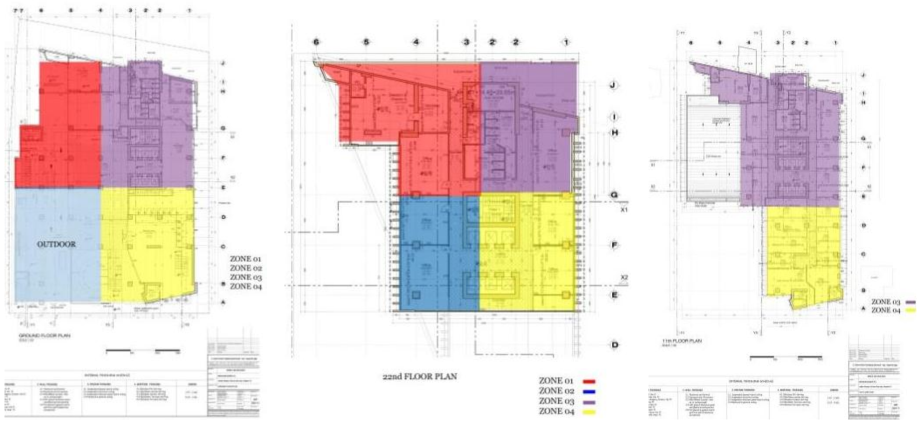


Figure 33 wegagen Sample Building plan divided into four zones per floor.

Figure 34 Yeha city center Sample Building plan divided into four zones per floor.

Method of Data Collection on Selected Case Buildings

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

Questionnaires. Questionnaires are prepared for users of the selected case buildings. They relate to thermal comfort and follow ASHRAE standards for thermal comfort survey. They include questions categorized in two sections.

3.6 Data analysis and interpretation

This research allowed a deeper understanding of the building envelope. An exploratory case study explored many phenomenon's. Exploratory studies examine data at the surface and take steps to explain phenomena in the data(Symonds and Symonds, 2016). 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 45°C or less than 18.056°C 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 graphs maps, 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 2 Data analysis tools and their 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 building envelope
- The procedure for analyzing the data

Identification of Parameters

While analyzing sample sizes in research, Working with all the variables throughout a scientific inquiry is difficult. It's crucial to determine the dependent and independent 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. Material and Building envelope, building form, Size/height, Orientation and Site/location
- Constant. Room size, construction materials, indoor colors and opening sizes.

3.7 Approaches and Tools for Sustainable Intervention Measures

3.7.1 Identifying sun position of Addis Ababa city and when shading is required

Depending on the season and latitude, the earth rotating around the sun causing multiple solar trajectories with varying heights and lengths. Sun path diagrams very useful tool for showing 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. Addis Ababa city lat: 9.005401 and Lon: 38.763611.

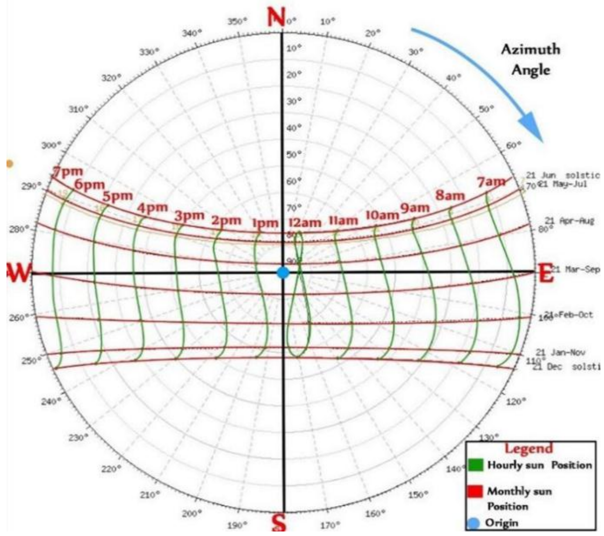


Figure 35 Addis Ababa Sun path (Source: Sunearthtools.com)

The stereographic projection is the most well-known and frequently used option, as tried to explain on literature chapter two from different 5 (five) ways the sun's location from these basic. Figure 47 shows Addis Ababa City in the globe's geographic center. The red horizontal lines depict the sun path, while the veiled vertical lines reveal the time of the day.

3.7.2 Identifying Proportion and Dimension of Shading Device for overheated Period

Azimuth and elevation of the sun will change throughout the day the month and year, from sun rise to sun set. Different exposure angles will be created on different surfaces that are vulnerable by this sun ray.

Given that we are taking the entire day into account, from sundown to sunrise, the azimuth and elevation of the sun will change. Figure 50 shows the sun's potential effects on creating shadow angles.

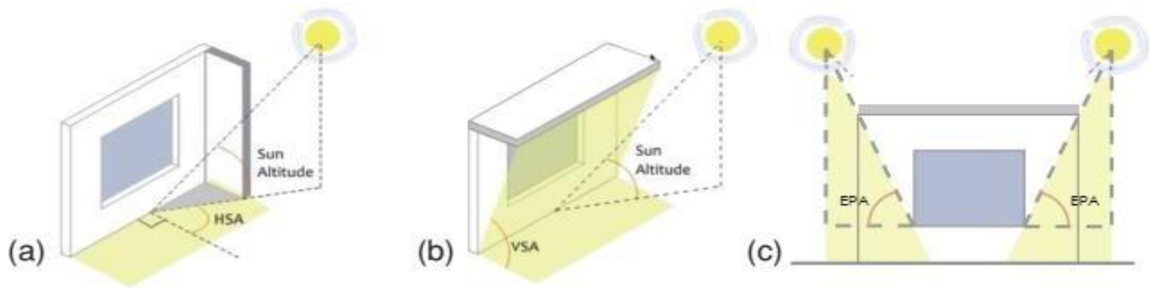


Figure 36 Sun rotation create the shading angle (a) (Horizontal shadow angle) HSV,

(b) (vertical shadow angle) VSA, (c) (End profile shading angle) EPA (source: University of oregon)

3.7.3 The shading angle protractor

The solar shading protractor shown in Figure 51 is useful in analyzing the building envelope. It can be set on the polar diagram to show how envelope affects it because it has the same proportions. The shading mask of a building envelope 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.

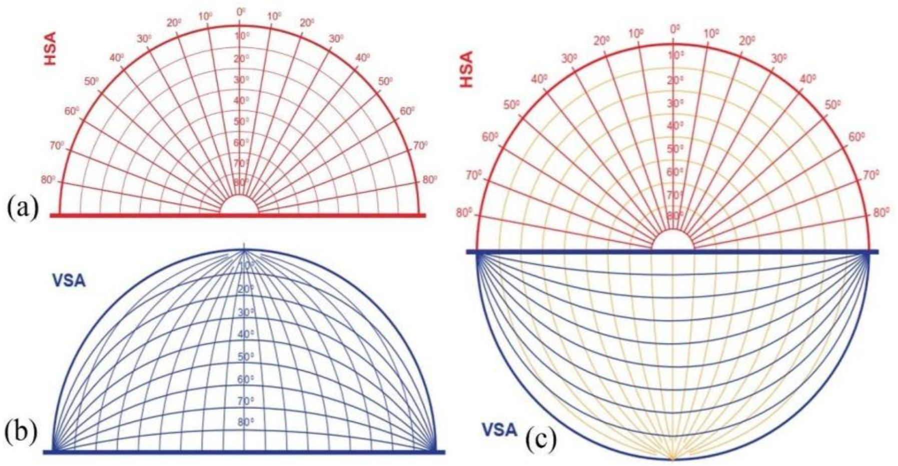
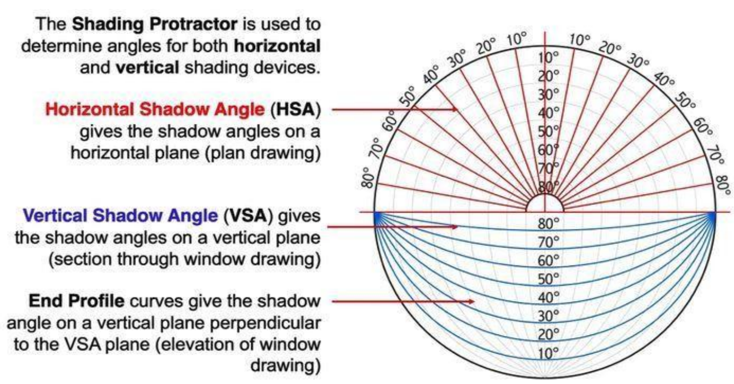


Figure 37 Shading protractor (a) Horizontal shadow angle - HSA (b) Vertical shadow angle - VSA (c) End profile shading angle protractor - EPA (source:University of oregon)

3.7.4 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 right and -90 to the left are used to calculate the HSA. Building envelope with vertical elements or fins.
- Curved lines that cross the centerline and aligned 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.



3.7.5 Vertical shadow angle (VSA)

The measuring of the vertical shadow angle (VSA) is a requisite for horizontal shading elements. It relate 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. (UN Habitat, 2018)

$$\text{VSA} = \arctan\left(\frac{\tan\,(Altitude)}{Cos(HSA)}\right) \quad \text{......Equation 4:2}$$

Equation 4:2: Vertical Shadow angle Formula

VSA=Vertical Shadow Angle

HSA=Horizontal Shadow Angle

3.7.6 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 (horizontal element) and Fin (vertical element) size calculating Formula

$$VSA = \arctan\left(\frac{\tan\,(altitude)}{\cos\,(HSA)}\right) \qquad (eq.\,2)$$

Equation 4:3: Vertical Shadow angle Formula

VSA=Vertical Shadow Angle
HSA=Horizontal Shadow Angle

Equation 4;4 overhang and fin size calculating formula

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

$$Fin\ Depth = \frac{Width}{\tan(HSA)} \qquad (eq.\,3)$$

Depending on the Table 4.3 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.

Building energy simulation software

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

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.

The methodology for generating data on shading devices

Computer Simulations

There is different existing building envelope 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 the building envelope 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.

At the same time, a comprehensive graphical user interface – ArchiCad and Revit – has been developed for the whole building modeling to export to Design builder.

The study conducted using a qualitative method based on onsite observations and resourcing data from the literature that provide a thorough understanding of the concept of the building envelop system and the benefits for the occupants and surrounding buildings. Both a literature study and an interview study were conducted in order to answer the research questions and aim of this paper.

Procedures

1. Creating models of the determined fixed exterior building envelope type for usage in samples.
2. Simulating a sample model for initial results. The simulations are temperature distribution of hottest month.
3. Simulating for building envelope for building orientations on the sample.
4. Comparing and discussing about the results of orientation.
5. Recommending the best building envelope strategy based on meteorological data from Addis Ababa and testing on a sample for orientations.
6. Results of the suggested building envelope and the currently used building envelope are compared.

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.

I. Case Building Thermal Comfort Assessment and Analysis

This study investigates the thermal performance of building envelope systems in hot and humid climates. Experimental procedures will used to measure room temperature and humidity.

Experiments to obtain data on temperature relative humidity and air velocity will be conducted using a HOBO U12-011 globe thermometer and humidity-measuring instrument. Daily room temperature wind speed and indoor moisture content temperature are recorded at different times of the day. Data will be taken three times a day at 4:00 am, 7:00 am and 11:00 am.

Another method of obtaining an analysis of the thermal comfort of a building is to use a questionnaire. This questionnaire contains questions about people's comfort what makes them uncomfortable or comfortable what time is difficult and what time is convenient. They will be asked.

II. Evaluation of the building envelope

The experiment was performed using HOBO U12-011 devices to obtain data of temperature, relative humidity and air velocity. It investigated the contribution of thermal behavior of the envelop for the building indoor. The temperature of room, the room air velocity and humidity, temperature of material for each day with in different time of day recorded similar with assessment of selected building. The data was taken three times a day. The data was from some selected buildings envelop in Addis Ababa.

The other method is like assessing and analyzing the questionnaire and observation. In this method the researchers and the occupants of the buildings experience and feeling will be obtained.

The other method in Building Envelope integration obtaining is using simulation software. After identifying appropriate Envelope design by analyzing the data and reviewing literatures the modeling of the design will be followed. The model will be taken to another software's to be evaluated level of comfort.

3.8 Ethical Considerations

the research is a preliminary understanding to create research goals and objectives to produce quality. Consent was obtained from each study participant prior to data collection. Consent from each study participants have obtained, before data collection Anonymous and confidential information is protected. A legal permit will be issued for the office building of Addis Ababa. All materials in the study are known. The measuring device is kept at space without disturbance.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Introduction

In this chapter, the results of the study are presented and discussed with reference to the aim of the study, which was to determine the Effect of Building Envelope on indoor Thermal Quality of Office Buildings in Addis Ababa. The data collected during the study are presented, analyzed and interpreted based on field measurement, case studies, computer simulation and the responses of 56 respondents. The presented data is analyzed to verify the relevant conclusions.

4.2. Respondents' information

4.2.1. Gender of the respondents'

According to Chart 4:1, 6 buildings in Addis Ababa were surveyed to collect data. A total of 56 occupants were involved in the survey, of which 27 were male, accounting for 48.3%, and 29 were female, accounting for 51.7%. The objective of this survey was to determine and evaluate the occupants' overall perceptions of indoor thermal comfort in their living areas.

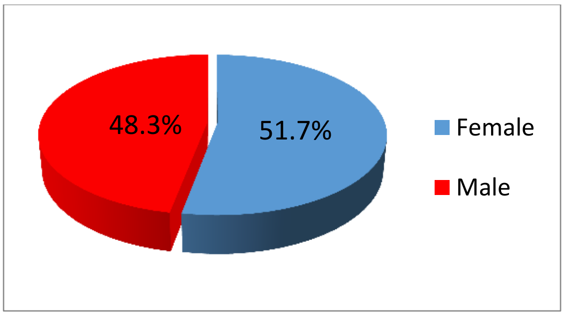


chart 1 Gender of respondent (Source: Data Survey)

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 women tend to be more sensitive to cold and hot temperatures in the room.

4.2.2 Age of respondents

According to the data collected, as shown in Chart 3, the respondent range is from 15 to over 61 years old. From a total of 56 people, most of them were between the ages of 15 and 30 (64.2% = 36 people), 31–45 (21.4%) = 12 people, and 46–60 (14.2% = 8people).

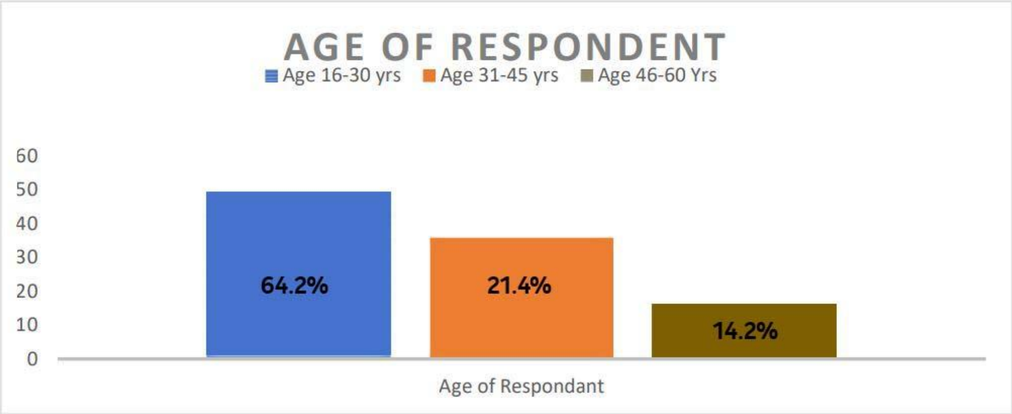


chart 2 Age of respondents (Source: Data Survey)

4.3 Occupant's perception
Personal Perceptions to thermal comfort and envelope Infrastructure

Regarding factors affecting thermal comfort the following table shows the average and the most frequent answer from all office collectively. The data shows how the temperature variables affected by personal perceptions and preferences. It is according to the data collected by questionnaire by identifying the variable and personal factors are dependent significantly, insignificant slight significance. This data is identified by SPSS quantification method and significance and non-significance is identified according to the data of two variables impact on each other. All the input of this data is the questionnaire collected from the questionnaire of all 6 offices of total 56 respondents.

4. 3.1 Predicted Mean vote PMV analysis

The other thing to get it level of thermal comfort and room temperature is predicted mean vote in which respondents react to the environment they feel, and they lean toward. This depends on the standard given to the number of levels of temperature concurring to ASHRAE. In like manner the survey data of the respondents are displayed underneath. The survey questions aimed to identify and assess the general perceptions of occupants regarding indoor thermal comfort in their respective working environments. it shows the number of respondents and their responses during overheated periods.

Table: vote in each office are the taking after in average thermal Sensation votes in each building

Table 3 PMV Thermal Preference of Hidasse building

PMV Thermal Preference of Hidasse building		Time		
Value		3:00am-5:00am	7:00am-9:00am	9:00am-11:00am
3	Hot	0.0%	0%	0 %
2	Warm	0.0%	3%	2 %
1	Slightly warm	13%	20%	21.4 %
0	Neutral	77%	64%	64 %
-1	Slightly cool	10%	13%	10%
-2	Cool	0.0%	0.0%	2.6%
-3	Cold	0.0%	0.0%	0.0%

According to Table 3 the thermal comfort response over Hidasse building shows the highest thermal preference about 0%, 3%, 20%, 64%, 13%, 0.0% and 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.

Table 4 PMV Thermal Preference of Bethlhem plaza building

PMV Thermal Preference of Bethlhem plaza building		Time		
Value		3:00am-5:00am	7:00am-9:00am	9:00am-11:00am
3	Hot	0.0%	0%	0 %
2	Warm	15%	15%	6%
1	Slightly warm	25%	25%	29 %
0	Neutral	50%	60%	55 %
-1	Slightly cool	10%	0%	10%
-2	Cool	0.0%	0.0%	0%
-3	Cold	0.0%	0.0%	0%

According to Table 4 the thermal comfort response over bethlhem plaza building shows the highest thermal preference about 15%, 25%, 60%, 0%, 0%, 0% and 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.

According to Table 4:1 the thermal comfort response over Bethlhem plaza building shows the highest thermal preference about 0%, 3%, 20%, 64%, 13%, 0.0% and 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 The weakest performance than hidasse building.

Table 5 PMV Thermal Preference of Wegagen bank building

PMV Thermal Preference of Wegagen bank building		Time		
Value		3:00am-5:00am	7:00am-9:00am	9:00am-11:00am
3	Hot	0.0%	0%	0 %
2	Warm	0.0%	2%	3 %
1	Slightly warm	12%	20%	20.4 %
0	Neutral	75%	67%	65 %
-1	Slightly cool	13%	11%	9%
-2	Cool	0.0%	0.0%	2.6%
-3	Cold	0.0%	0.0%	0.0%

According to 5 the thermal comfort response over wegagen bank building shows the highest thermal preference about 0%, 3%, 20%, 64%, 13%, 0.0% and 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.

Table 6 PMV Thermal Preference of yeha city center building

PMV Thermal Preference of yeha city center building		Time		
Value		3:00am-5:00am	7:00am-9:00am	9:00am-11:00am
3	Hot	0.0%	0%	0 %
2	Warm	0.0%	4%	3 %
1	Slightly warm	26%	30%	29.4 %
0	Neutral	63%	55%	57 %
-1	Slightly cool	11%	11%	9%
-2	Cool	0.0%	0.0%	2.6%
-3	Cold	0.0%	0.0%	0.0%

According to Table 6 the thermal comfort response over Yeha city center building shows the highest thermal preference about 0%, 3%, 20%, 64%, 13%, 0% and 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 than wegagen bank.

Table 7 PMV Thermal Preference of EBC building

PMV Thermal Preference of EBC building		Time		
Value		3:00am-5:00am	7:00am-9:00am	9:00am-11:00am
3	Hot	0.0%	0%	0 %
2	Warm	0.0%	3%	2 %
1	Slightly warm	15%	19%	21.4 %
0	Neutral	73%	64%	66 %
-1	Slightly cool	12%	14%	8%
-2	Cool	0.0%	0.0%	2.6%
-3	Cold	0.0%	0.0%	0.0%

According to Table 7 the thermal comfort response over EBC building shows the highest thermal preference about 0%, 3%, 20%, 64%, 13%, 0.0% and 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.

Table 8 PMV Thermal Preference of Awash bank building

PMV Thermal Preference of Awash bank building		Time		
Value		3:00am-5:00am	7:00am-9:00am	9:00am-11:00am
3	Hot	0.0%	0%	0 %
2	Warm	0.0%	3%	2 %
1	Slightly warm	15%	19%	21.4 %
0	Neutral	73%	64%	66 %
-1	Slightly cool	12%	14%	8%
-2	Cool	0.0%	0.0%	2.6%
-3	Cold	0.0%	0.0%	0.0%

According to Table 8 the thermal comfort response over awash bank building shows the highest thermal preference about 0%, 3%, 20%, 64%, 13%, 0% and 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 than EBC building.

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 9 -14

Table 9 Thermal Sensational of hidasse building

Thermal Sensational of hidasse building		**Time**		
Level of Scale	Thermal Sensational	3:00am-4:00am	7:00pm-8:00pm	10:00pm-11:00pm
-3	Very Uncomfortable	0.0%	0.0%	0.0%
-2	Uncomfortable	6.6%	3.6%	7.6%
-1	Slightly Uncomfortable	11.90%	11.90%	8.90%
0	Comfort	58.5%	61.5%	60.5%
1	Slightly comfortable	17.6%	18.6%	16.6%
2	comfortable	5.3%	4.3%	6.3%
3	Very comfortable	0.0%	0.0%	0.0%

Table 10 Thermal Sensational of Bethlehem plaza building

Thermal Sensational of bethlhem plaza building		**Time**		
Level of Scale	Thermal Sensational	3:00am-4:00am	7:00pm-8:00pm	10:00pm-11:00pm
-3	Very Uncomfortable	0.0%	0.0%	0.0%
-2	Uncomfortable	19.6%	17.6%	18.6%
-1	Slightly Uncomfortable	8.90%	11.90%	11.90%
0	Comfort	51.5%	47.5%	46.5%
1	Slightly comfortable	13.6%	17.6%	15.6%
2	comfortable	6.3%	5.3%	7.3%
3	Very comfortable	0.0%	0.0%	0.0%

Accordingly, the occupants of the bethlhem plaza building and hidasse building bethlhem plaza are not comfortable, as the result shows that the respondents highly answered uncomfortably than comfort.

Table 11 Thermal Sensational of wegagen bank building

Thermal Sensational of wegagen bank building		**Time**		
Level of Scale	Thermal Sensational	3:00am-4:00am	7:00pm-8:00pm	10:00pm-11:00pm
-3	Very Uncomfortable	0.0%	0.0%	0.0%
-2	Uncomfortable	5.6%	8.6%	6.6%
-1	Slightly Uncomfortable	8.90%	9.90%	10.90%
0	Comfort	62.5%	58.5%	9.5%
1	Slightly comfortable	16.6%	16.6%	13.6%
2	comfortable	6.3%	6.3%	9.3%
3	Very comfortable	0.0%	0.0%	0.0%

Table 12 Thermal Sensational of yeha city center building

Thermal Sensational of yeha city center building		**Time**		
Level of Scale	Thermal Sensational	3:00am-4:00am	7:00pm-8:00pm	10:00pm-11:00pm
-3	Very Uncomfortable	0.0%	0.0%	0.0%
-2	Uncomfortable	5.6%	8.6%	6.6%
-1	Slightly Uncomfortable	8.90%	9.90%	10.90%
0	Comfort	62.5%	58.5%	9.5%
1	Slightly comfortable	16.6%	16.6%	13.6%
2	comfortable	6.3%	6.3%	9.3%
3	Very comfortable	0.0%	0.0%	0.0%

Accordingly, the occupants of the wegagen bank building and yeha city center building Bethlehem plaza are not comfortable, as the result shows that the respondents highly answered uncomfortably than comfort.

Table 13 Thermal Sensational of EBC building

Thermal Sensational of EBC building		**Time**		
Level of Scale	Thermal Sensational	3:00am-4:00am	7:00pm-8:00pm	10:00pm-11:00pm
-3	Very Uncomfortable	0.0%	0.0%	0.0%
-2	Uncomfortable	5.6%	2.6%	7.6%
-1	Slightly Uncomfortable	11.90%	8.90%	5.90%
0	Comfort	59.5%	65.5%	65.5%
1	Slightly comfortable	18.6%	19.6%	18.6%
2	comfortable	4.3%	3.3%	6.3%
3	Very comfortable	0.0%	0.0%	0.0%

Table 14 Thermal Sensational of Awash bank building

Thermal Sensational of Awash bank building		**Time**		
Level of Scale	**Thermal Sensational**	3:00am-4:00am	7:00pm-8:00pm	10:00pm-11:00pm
-3	Very Uncomfortable	0.0%	0.0%	0.0%
-2	Uncomfortable	5.6%	11.6%	9.6%
-1	Slightly Uncomfortable	18.90%	22.90%	7.90%
0	Comfort	52.5%	48.5%	9.5%
1	Slightly comfortable	16.6%	16.6%	13.6%
2	comfortable	6.3%	6.3%	9.3%
3	Very comfortable	0.0%	0.0%	0.0%

Accordingly, the occupants of the EBC building and awash bank building awash bank building are not comfortable, as the result shows that the respondents highly answered uncomfortably than comfort. Awash bank building is the most uncomfortable from all 6 building from different site.

4.3.3 Thermal discomfort hours and overheated month

Table 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 15 Overheated hours and month result

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	9			
		OCT					11:00-12:00				
		NOV					Afternoon				
	Bega (Summer)	DEC					12:00-1:00	15			
		JAN	12				1:00-2:00				
		FEB			8		2:00-3:00		25	7	
	Tseday (Fall)	MAR					3:00-4:00				
		APR	26	46			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 21.4%, February and March by 14.2%, April and May by 46.4%, April by 7.14%, and may by 10.7%. Overall, the month of May was claimed to be the hottest by 10.7% of the respondents. In identifying overheated time ranges, the following percentages were claimed: 12:00pm-5:00pm by 26.7%, 2:00pm-3:00pm by 12.5%, 2:00pm-4:00pm by 26.7%, 10:00pm-12:00pm 16% overall, the time from 12:00 p.m. to 5:00 p.m. and the time from 2:00-4:00 was claimed to be thermally uncomfortable by 26.7 % of respondents respectively.

4.4.4 Environmental variables measurement analysis and discussion

Field measurement was carried out at megenagna site on hidasse building and Bethlhem plaza as I tried to explain in Chapter 3 Methods and material.

4.4.4.1 Temperature

Chart 4.1 shows the highest and lowest outdoor temperatures recorded in April and May on Megenagna site. The maximum temperature,which was 29.2 °C, was recorded in April, while the minimum temperature, which was 24.4 °C, was recorded in May. The lowest temperature, which was 24.4 °C, was recorded between 3:00 am and 4:00 am in the morning, while the highest temperature, which was 29.2 °C, was recorded between 9:00 am and 10:00 am.

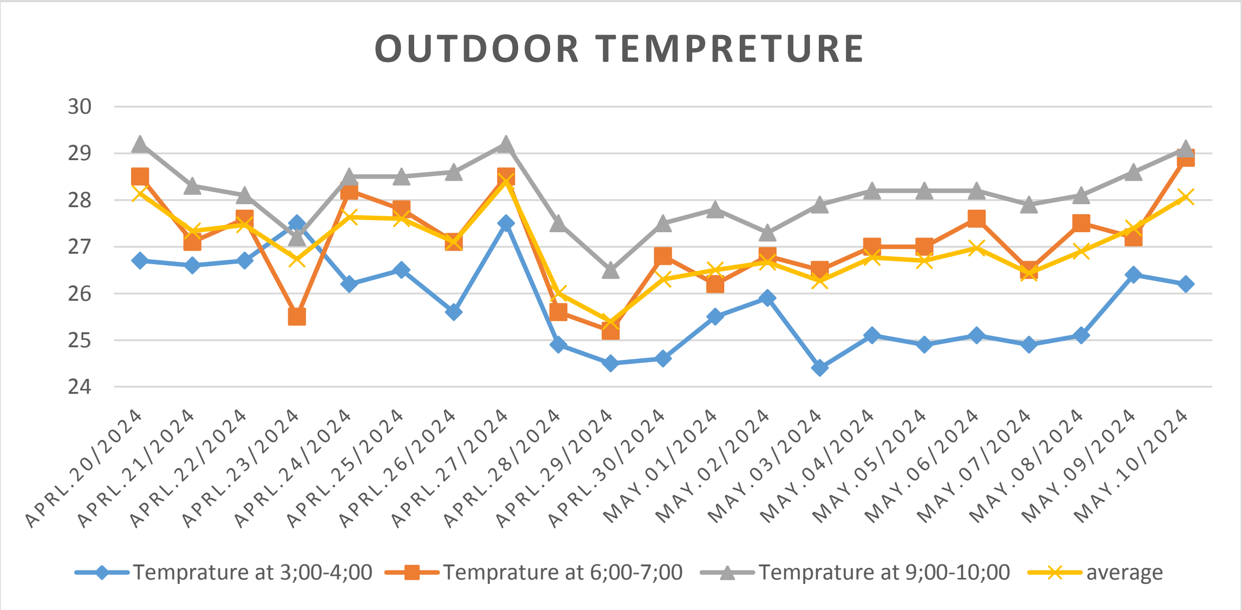


chart 3 Outdoor tempreture of megenagna

4.4.4.2 Indoor temperature of hidasse building

According to Chart 5 the highest indoor temperature of the Hidasse building was recorded at 27.7 °C, the minimum indoor temperature was recorded at 22°C, and the outdoor temperature ranges from 24.4°C to 29.2°C. The lowest indoor temperature recorded in the morning between 6:00 am and 7:00 am is 22°C on may 04 and 05, and the highest temperature recorded is between 9:00 am and 10:00 am at 27.7°C on april 20.

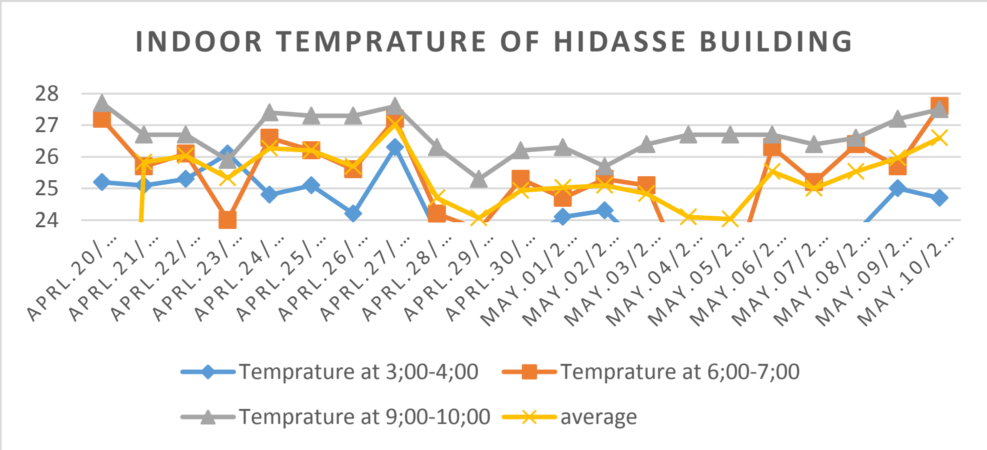


chart 4 indoor tempreture of hidasse building

4.4.4.3 Indoor temperature of bethlhem plaza

Chart 6 presents an insightful analysis of the indoor temperature recordings. the highest indoor temperature of the Bethlhem plaza building was recorded 28.9 °C, while the minimum indoor temperature was recorded at 23 °C. The outdoor temperature, on the other hand, ranged from 24.4°C to 29.2°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 6:00 am and 7:00 am on my 04, at. and the highest temperature recorded is between 9:00 am and 10:00 am at 27.7°C on april 20.

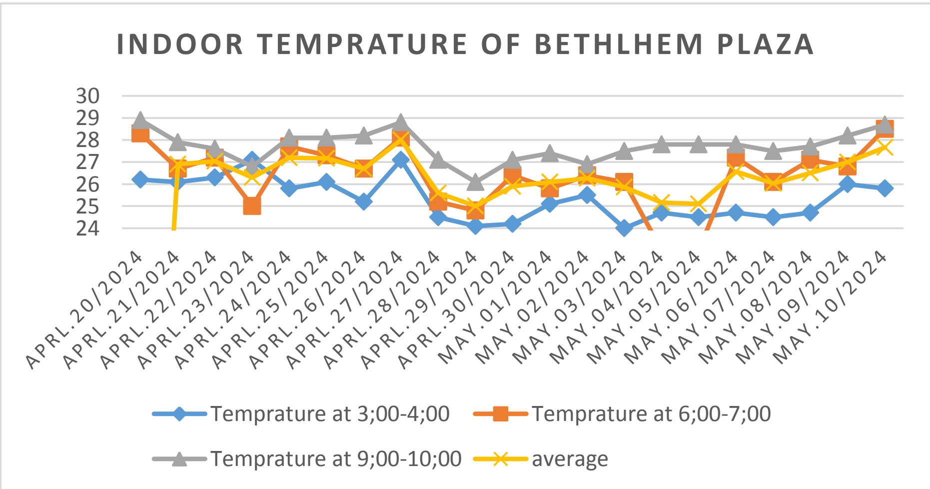


chart 5 indoor tempreture of bethlhem plaza building

4.4.4.4 Outdoor Temperature of Stedium site

Chart 7 shows the highest and lowest outdoor temperatures recorded in April and May on Stedium site. The maximum temperature, which was 29.3 °C, was recorded in April 20, while the minimum temperature, which was 24.1 °C, was recorded in april 28. The lowest temperature, which was 24.1 °C, was recorded between 3:00 am and 4:00 am in the morning, while the highest temperature, which was 29.3 °C, was recorded between 9:00 am and 10:00 am.

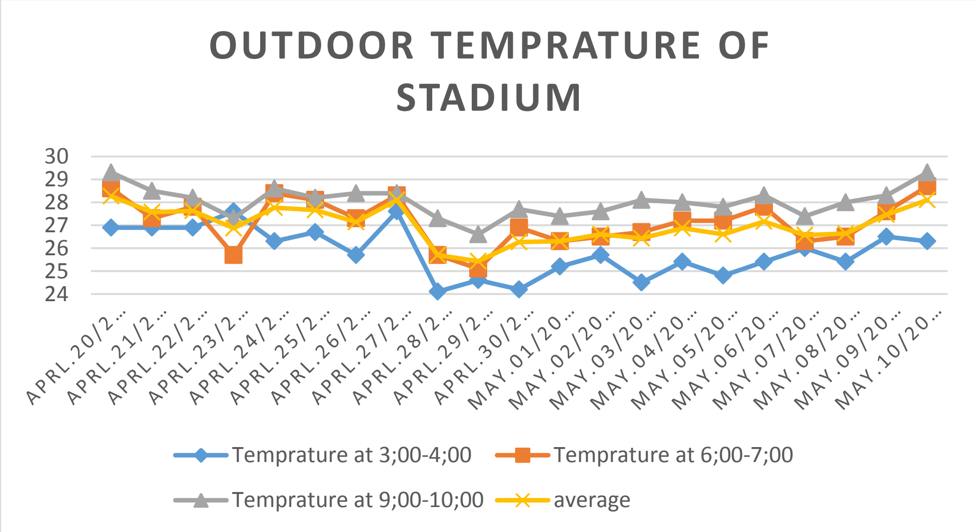


chart 6 outdoor tempreture of stadium

4.4.4.5 Indoor temperature of wegagen

Chart 8 presents an insightful analysis of the indoor temperature records. The wegagens maximum indoor temperature was observed to be 26.9 °C, while the minimum indoor temperature was recorded at 23.1 °C. The outdoor temperature, on the other hand, ranged from 24.1 °C to 29.3 °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 may 03.and the highest temperature recorded is between 9:00 am and 10:00 am at 27.7°C on april 20.

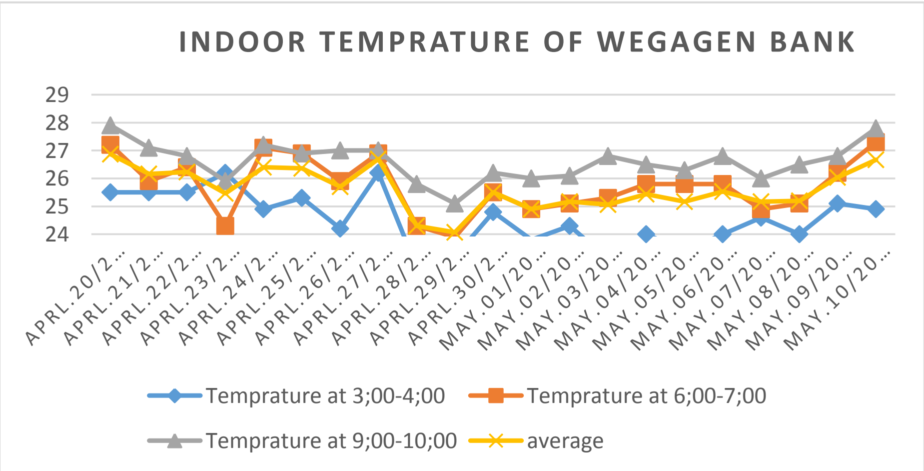


chart 7 indoor tempreture of wegagen bank building

4.4.4.6 Indoor temperature of Yeha city

Chart 9 presents an insightful analysis of the indoor temperature records. The yeha citys maximum indoor temperature was observed to be 28.9 °C, while the minimum indoor temperature was recorded at 24.2 °C. The outdoor temperature, on the other hand, ranged from 24.1 °C to 29.3 °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 April 29.and the highest temperature recorded is between 9:00 am and 10:00 am at 27.7°C on April 20.

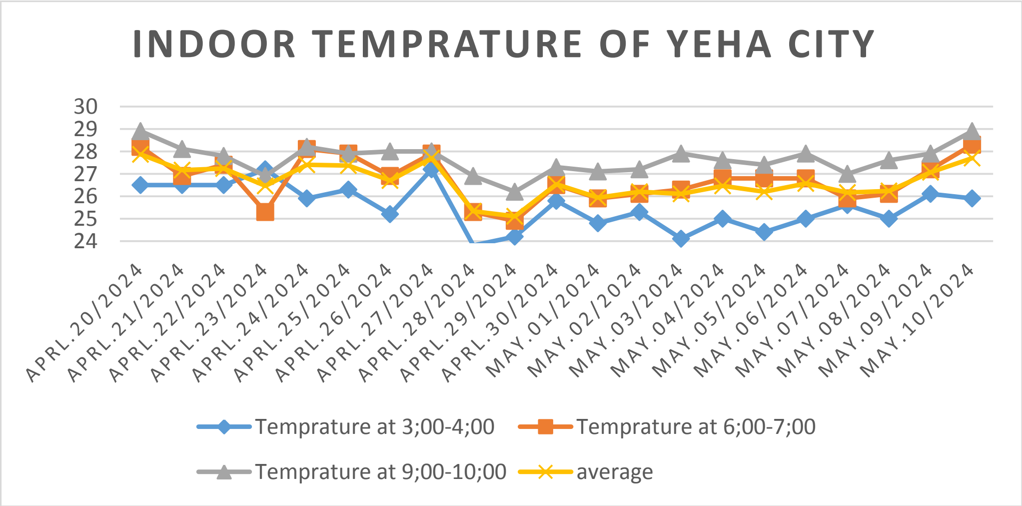


Chart 8 indoor temperature of yeha city centre building

4.4.4.7 Outdoor Temperature of Berhawi Site

Chart 10 shows the highest and lowest outdoor temperatures of berhawi site. The maximum temperature, which was 29.3 °C, was recorded in April 20, and April 29. While the minimum temperature, which was 24.2 °C, was recorded in April 29. The lowest temperature, which was 24.1 °C, was recorded between 3:00 am and 4:00 am in the morning, while the highest temperature, which was 29.3 °C, was recorded between 9:00 am and 10:00 am.

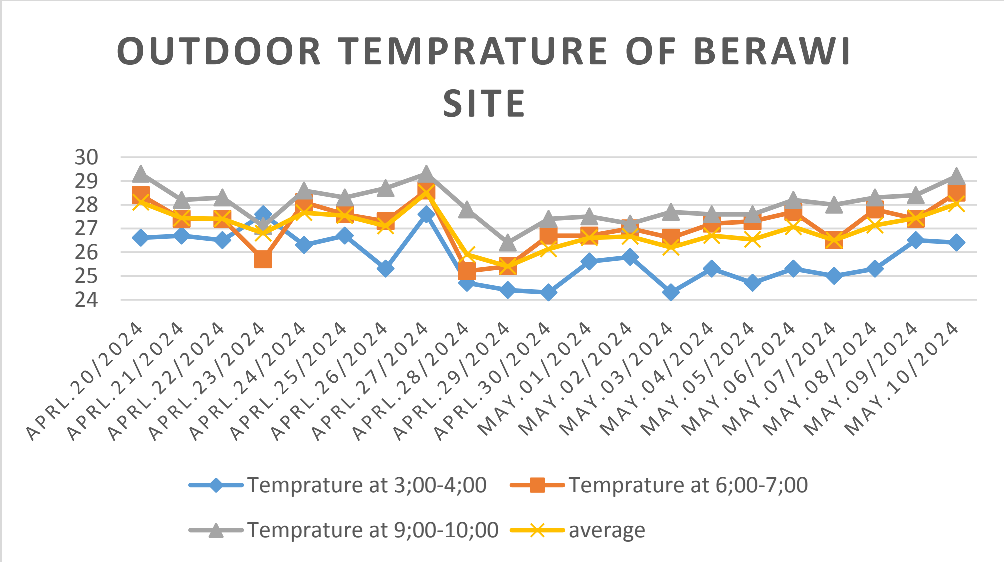


chart 9 outdoor tempreture of berhawi site

4.4.4.8 Indoor temperature of EBC building

Chart 11 presents an insightful analysis of the indoor temperature records. The EBC's maximum indoor temperature was observed to be 27.8 °C, while the minimum indoor temperature was recorded at 22.7 °C. The outdoor temperature, on the other hand, ranged from 24.2 °C to 29.3 °C °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 may 05. and the highest temperature recorded is between 9:00 am and 10:00 am at 27.8°C on April 20.

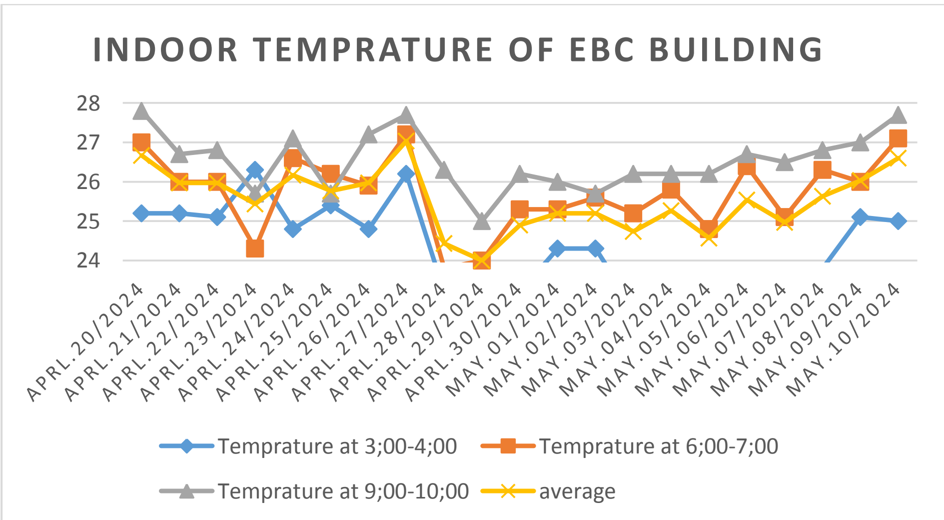


chart 10 Indoor tempreture of EBC building

4.4.4.9 Indoor temperature of awash bank building

Chart 12 presents an insightful analysis of the indoor temperature records. The EBC's maximum indoor temperature was observed to be 28.9°C, while the minimum indoor temperature was recorded at 23.9 °C. The outdoor temperature, on the other hand, ranged from 24.2 °C to 29.3 °C °C, as seen in the chart. The temperature analysis of the indoor space indicated that the lowest temperature 23.9 °C was recorded early in the morning, between 3:00 am and 4:00 am, at may 03. and the highest temperature recorded is between 9:00 am and 10:00 am at 28.9°C on April 20.

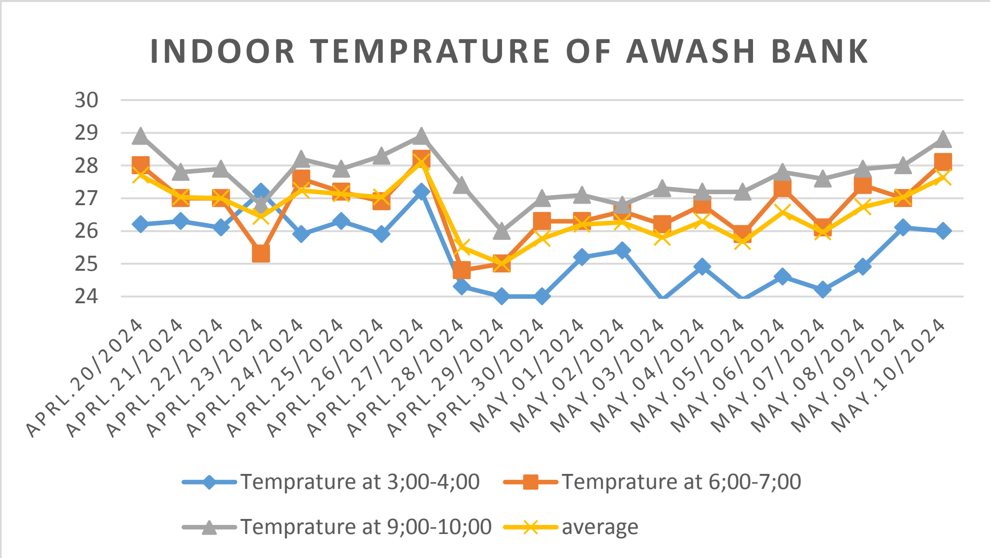


Chart 11 Indoor tempreture of awash bank

4.4.4.10 Discussion on air temperature of megenagna site (bethlhem plaza and hidasse building)

The temperature of a hidasse building has been recorded in Chart 13,with a maximum of 27.7 °C and 22 °C is the minimum temperature. These readings were taken during the overheated months of April and May, when outdoor temperatures recorded a maximum of29.2 °C and 24.4 °C is the minimum temperature. While the bethlhem plaza also showed readings of maximum 28.9 °C and minimum 23 °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 bethlhem plaza falls outside the standard comfort zone.

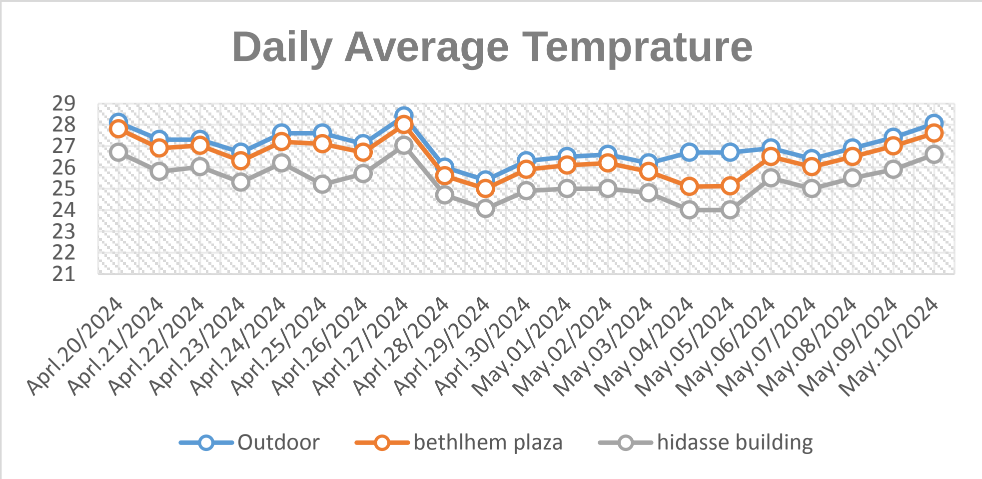


Chart 12 Daily average tempreture of megenagna site

4.4.4.11 Discussion on air temperature of Stedium site (yeha city center and wegagen bank building)

The temperature of a wegagen has been recorded in Chart 14 with a maximum of 26.9 °C and 22 °C is the minimum temperature. These readings were taken during the overheated months of April and May, when outdoor temperatures recorded a maximum of 29.3 °C and 24.1 °C is the minimum temperature. While the yeha city also showed readings of maximum 28.9 °C and minimum 24.2 °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 yeha city falls outside the standard comfort zone.

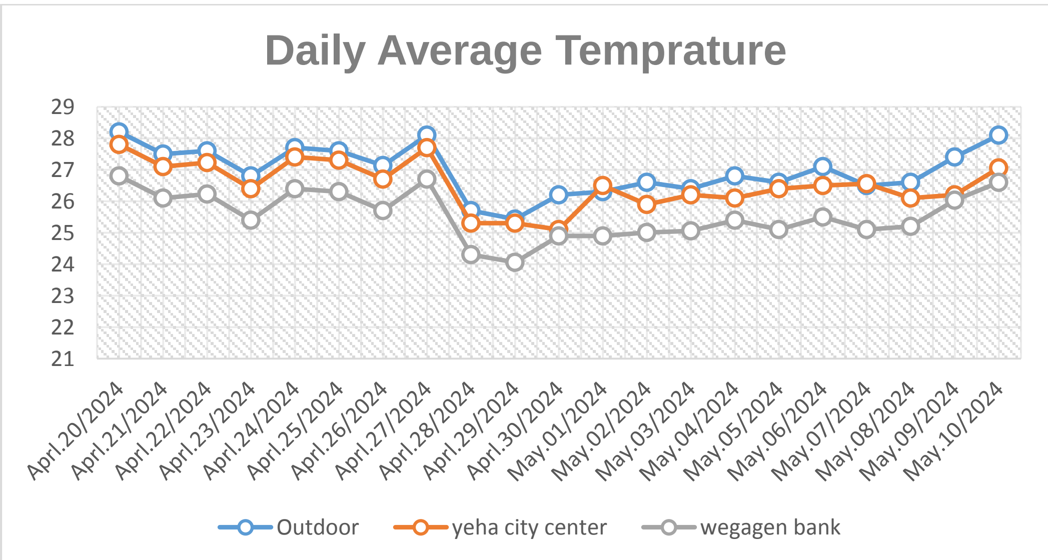


Chart 13 Daily average temperature of stadium site

4.4.4.12 Discussion on air temperature of berhawi site (awash bank and EBC building)

The temperature of a EBC has been recorded in Chart 15, with a maximum of 27.8 °C and 22.7 °C is the minimum temperature. These readings were taken during the overheated months of April and May, when outdoor temperatures recorded a maximum of 29.3 °C and 24.1 °C is the minimum temperature. While the Awash bank also showed readings of maximum 28.9 °C and minimum 23.9 °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 awash bank falls outside of the standard comfort zone.

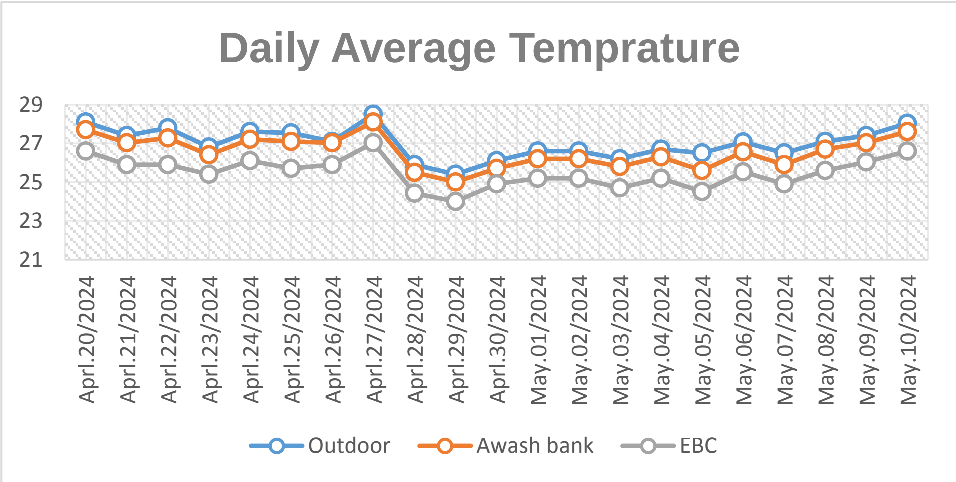


Chart 14 Daily average temperature of berhawi site

4.4.4.13 Relative Humidity

As per the field measurement conducted for the outdoor environment, Chart 16 reveals that Megenagna site records a maximum relative humidity of 38%, while the minimum was at 24%. Both April and May recorded the highest levels of humidity.

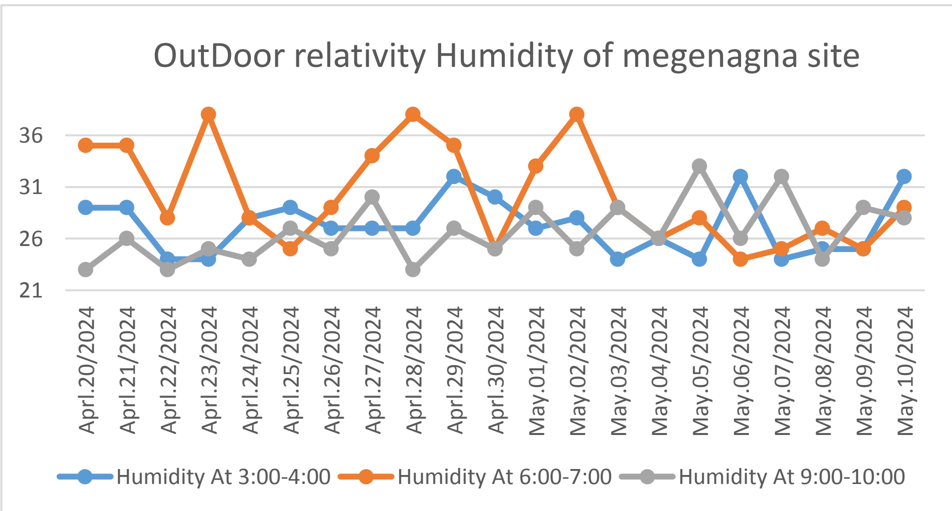


Chart 15 Relative humidity of megenagna site

4.4.4.14 Indoor Relative Humidity of hidasse building

As per, Chart 17 the hidasse building exhibited a maximum relative humidity of 37%, and 22% is the minimum. Concurrently, the outdoor humidity showed a range between 38% and 25%.

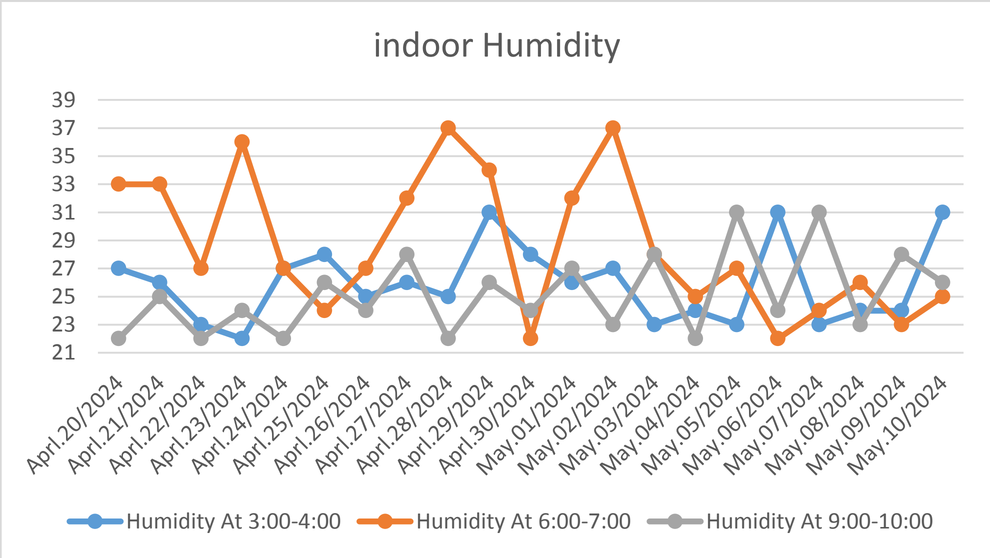


Chart 16 Relative humidity of hidasse building

4.4.4.15 Indoor Relative Humidity of bethlhem plaza

As per, Chart 18 the bethlhem building exhibited a maximum relative humidity of 37%, and 21% is the minimum. Concurrently, the outdoor humidity showed a range between 38% and 25%.

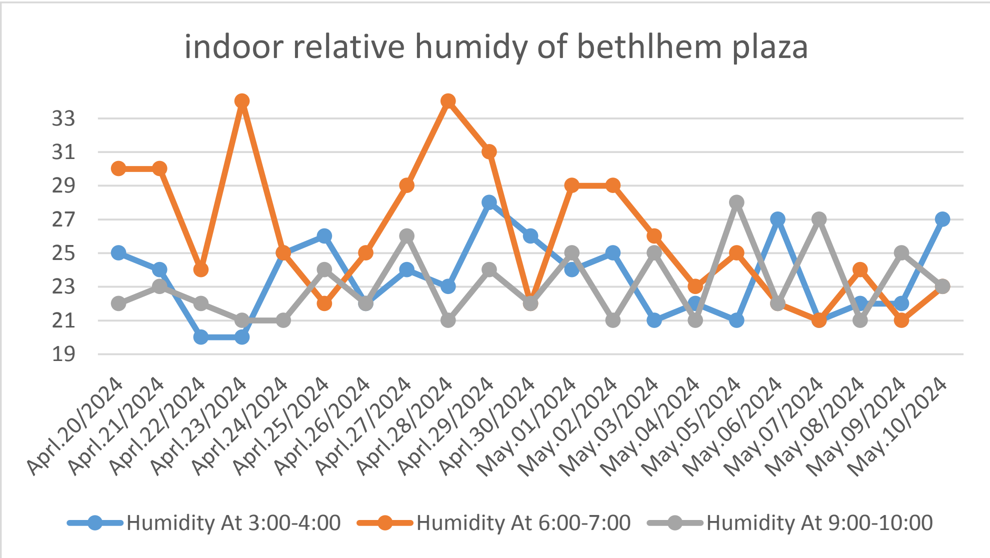


Chart 17 Relative humidity of bethlhem plaza building

4.4.4.16 Relative humidity of stadium site

As per the field measurement conducted for the outdoor environment, Chart 19 reveals that stedium site records a maximum relative humidity of 38%, while the minimum was at 22%. Both April and May recorded the highest levels of humidity.

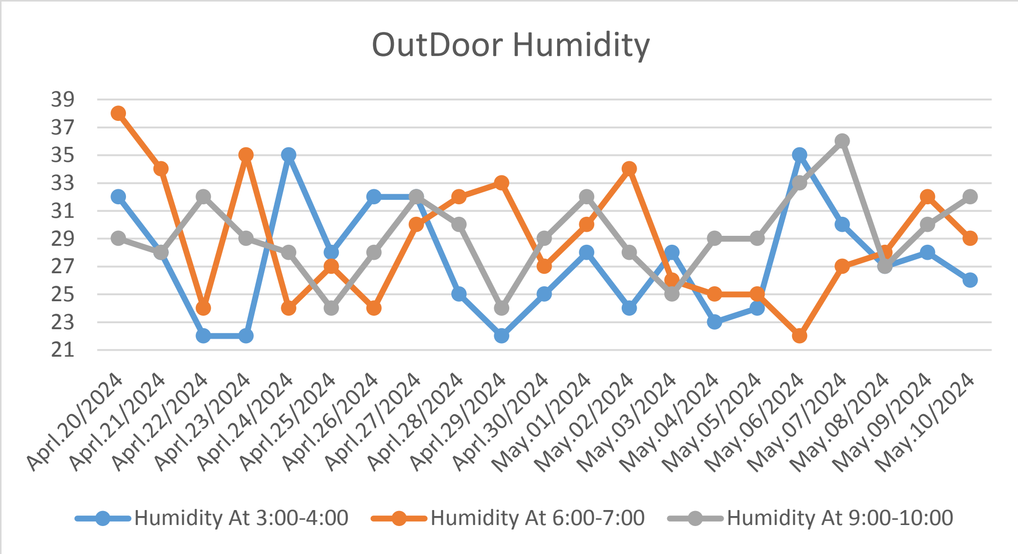


Chart 18 Relative humidity of stedium site

4.4.4.16 Indoor Relative Humidity of wegagen bank

As per, Chart 20 the wegagen bank building exhibited a maximum relative humidity of 32%, and 21% is the minimum. Concurrently, the outdoor humidity showed a range between 38% and 22%.

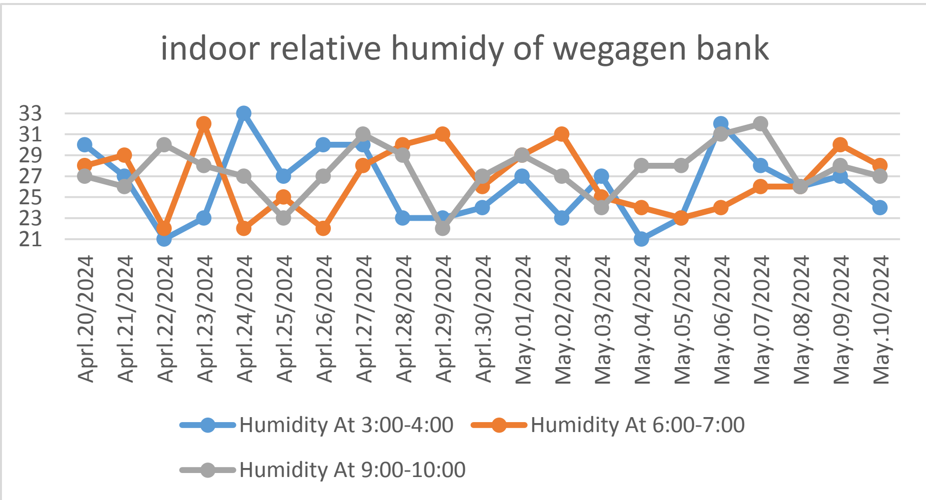


chart 19 Relative humidity of wegagen bank

4.4.4.17 Indoor Relative Humidity of yeha city center

As per, Chart 21 the yeha city center building exhibited a maximum relative humidity of 32%, and 20% is the minimum. Concurrently, the outdoor humidity showed a range between 38% and 22%.

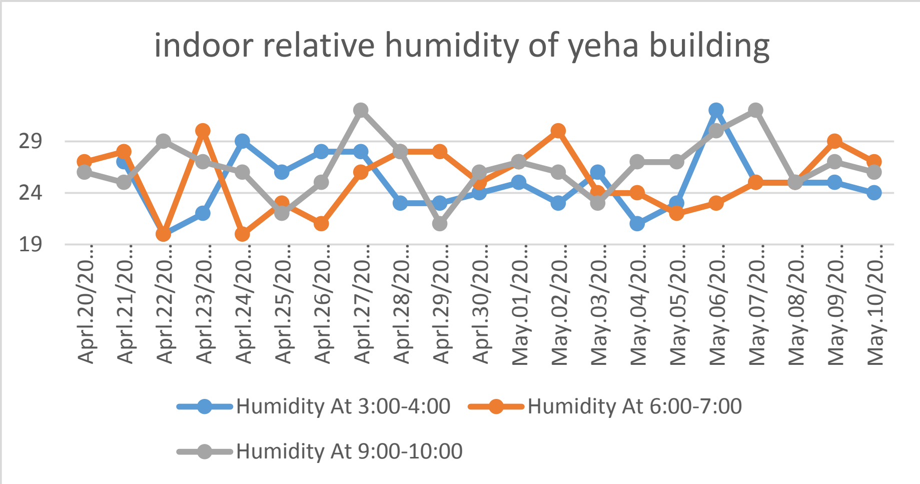


chart 20 Relative humidity of yeha city center

4.4.4.18 Relative Humidity of berhawi site

As per the field measurement conducted for the outdoor environment, Chart 22 reveals that berhawi site records a maximum relative humidity of 35%, while the minimum was at 25%. Both April and May recorded the highest levels of humidity.

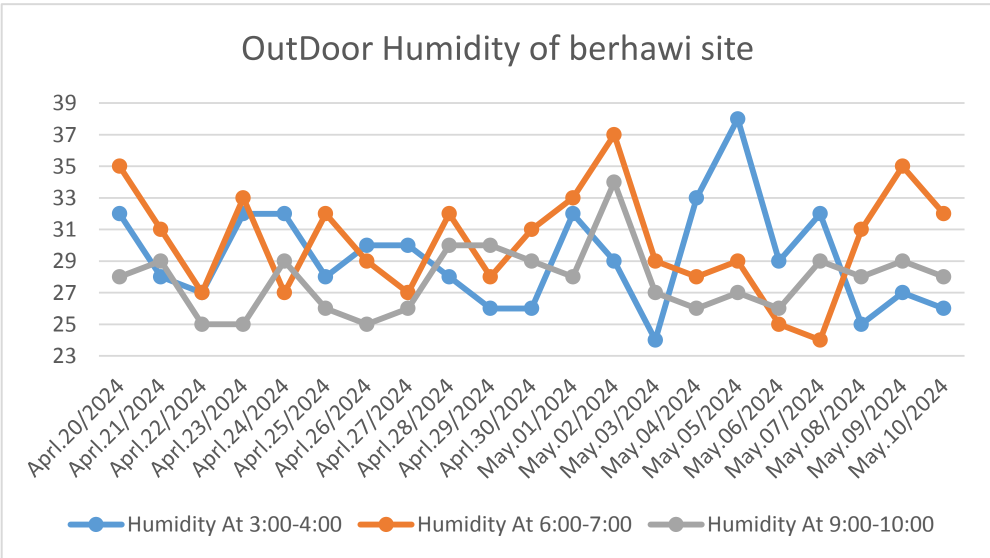


Chart 21 Relative humidity of berhawi site

4.4.4.19 Indoor Relative Humidity of EBC building

As per, Chart 23 theEBC center building exhibited a maximum relative humidity of 33%, and 23% is the minimum. Concurrently, the outdoor humidity showed a range between 35% and 25%.

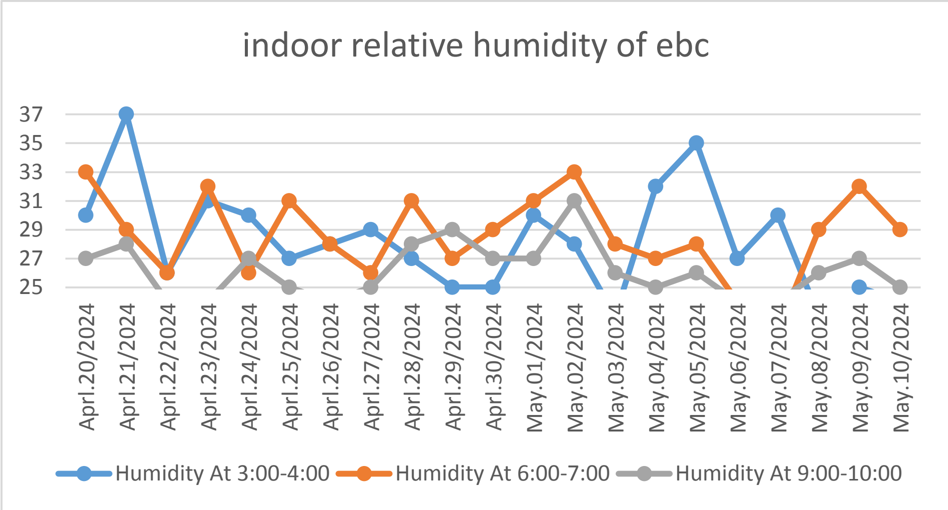


chart 22 Relative humidity of EBC building

4.4.4.20 Indoor Relative Humidity of Awash bank building

As per, Chart 24 the Awash bank center building exhibited a maximum relative humidity of 31%, and 21% is the minimum. Concurrently, the outdoor humidity showed a range between 35% and 25%.

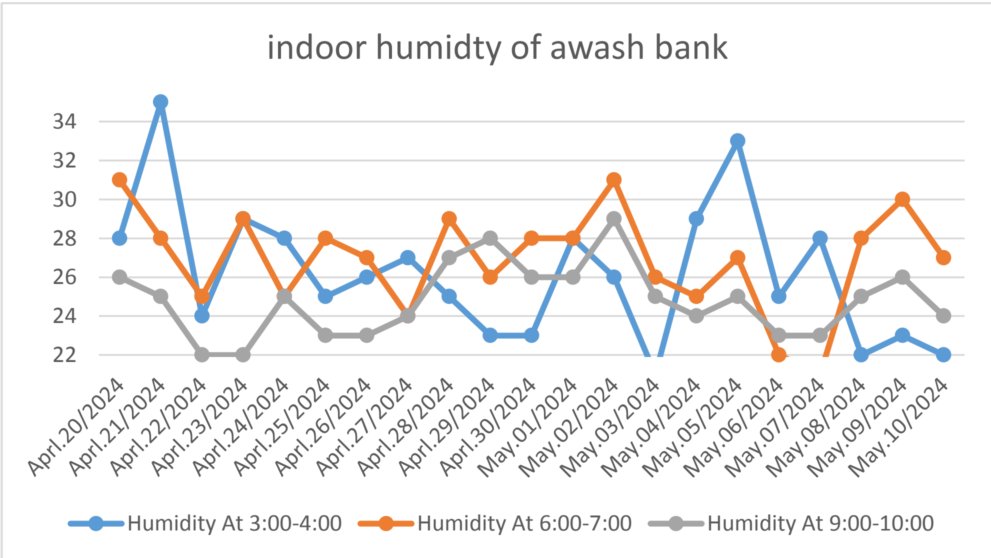


chart 23 Relative humidity of awash bank

4.4.4.21 Discussion on relative humidity of megenagna site

According to Chart 25, the hidasse building envelope had superior humidity levels compared to bethlhem plaza building envelope. In the month of April, the maximum and minimum humidity levels recorded for the hidasse building were 37% and 22% respectively. While in May, the maximum and minimum humidity levels recorded on bethlhem building were 32% and 20%, respectively. It is show that the relative humidity of the the hidasse building envelope is better than bethlhem plaza's building envelope.

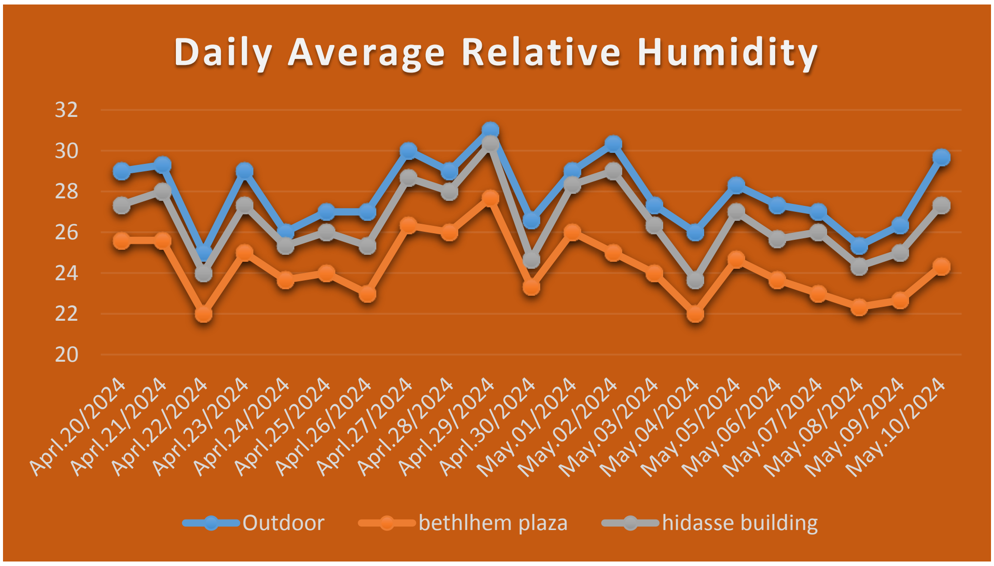


chart 24 Daily Relative humidity of megenagna site

4.4.4.22 Discussion on relative humidity of stedium site

According to Chart 26, the wugagen building envelope had superior humidity levels compared to yeha city center building envelope. In the month of April, the maximum and minimum humidity levels recorded for the wugagen bank building were 32% and 21% respectively. While in May, the maximum and minimum humidity levels recorded on yeha city center building were 32% and 20%, respectively. It is show that the relative humidity of the the hidasse building envelope is better than bethlhem plaza's building envelope.

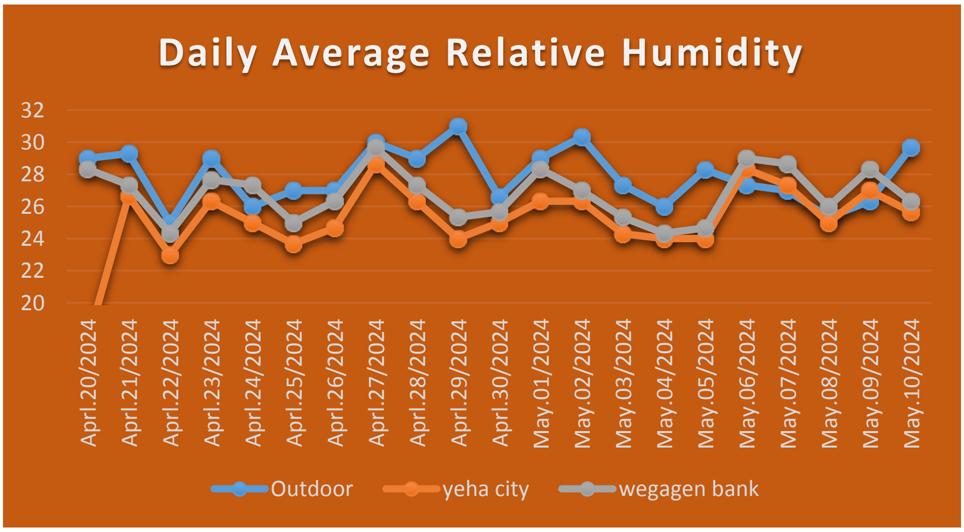


chart 25 Daily Relative humidity of stedium site

4.4.4.23 Discussion on relative humidity of berhawi site

According to Chart 27, the EBC building envelope had superior humidity levels compared to Awash bank building envelope. In the month of April, the maximum and minimum humidity levels recorded for the EBC building were 33% and 23% respectively. While in May, the maximum and minimum humidity levels recorded on awash bank building were 31% and 21%, respectively. It is show that the relative humidity of the the hidasse building envelope is better than bethlhem plaza's building envelope.

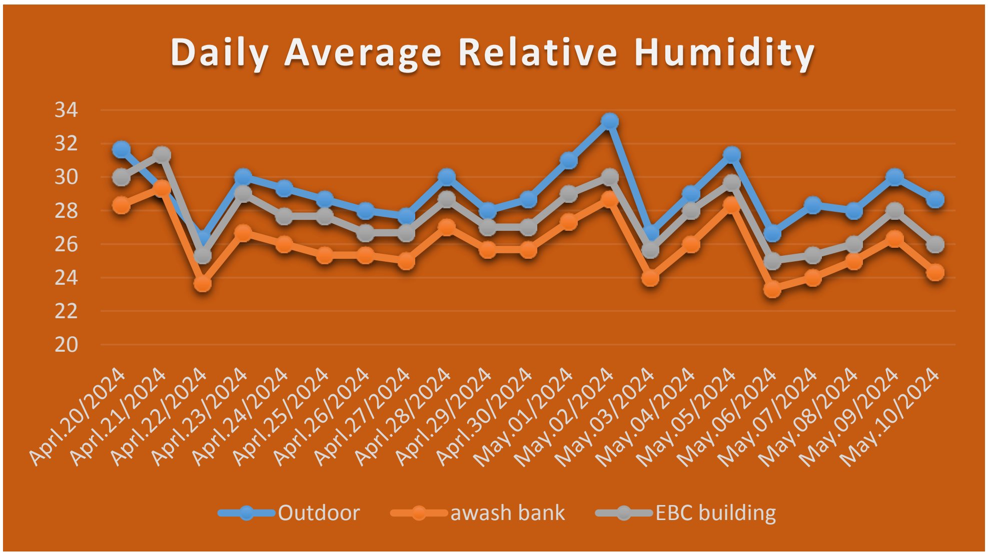


chart 26 Daily Relative humidity of berhawi site

4.4.4.24 Air velocity

According to a field measurement conducted for the Megenagna, the data presented in Chart 28, indicates that the maximum air speed recorded in a south-facing room was 2.41 m/s, while the lowest was 0.53 m/s. A two-month measurement revealed that the highest air speed occurred during the month of April, specifically during the time frame of 3:00–4:00 a.m. in the morning.

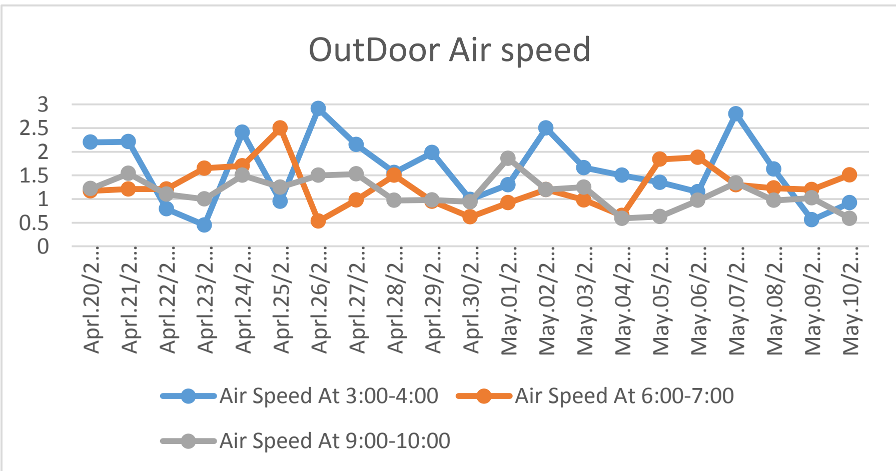


chart 27 Outdoor Air velocity of megenagna site

4.4.4.25 Indoor Air velocity of hidasse building envelope

In April and May, according to Chart 29, the velocity of indoor air in hidasse building envelope from 0.00 m/s to 0.98 m/s, while outdoor air speed ranges from 0.35 m/s to 3.5 m/s. These findings suggest that indoor air movement is significantly weaker than outdoor air movement.

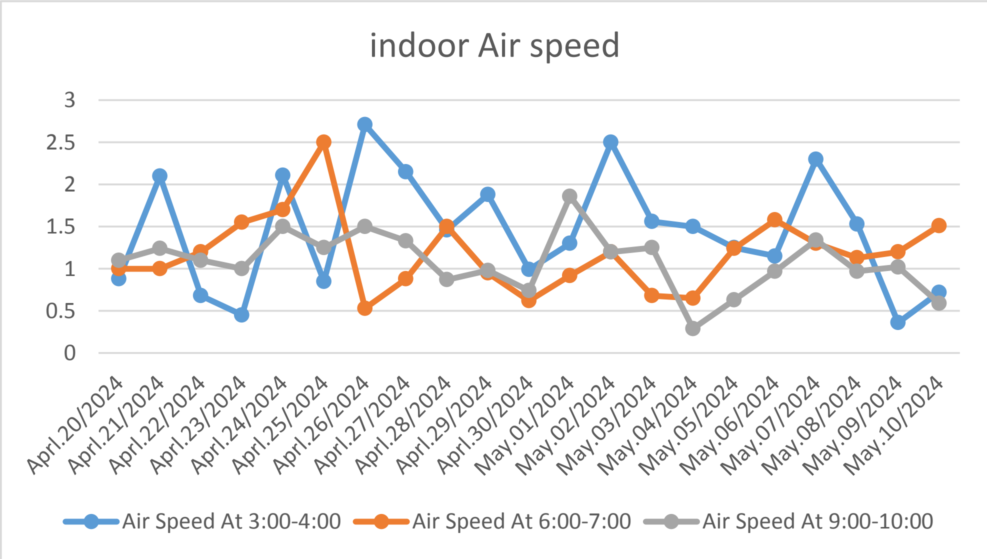


chart 28 Air velocity of hidasse building

4.4.4.26 Indoor Air velocity of Bethlhem plaza building envelope

In April and May, according to Chart 30, the velocity of indoor air in bethlhem plaza building envelope from 0.00 m/s to 0.97 m/s, while outdoor air speed ranges from 0.35 m/s to 3.5 m/s. These findings suggest that indoor air movement is significantly weaker than outdoor air movement.

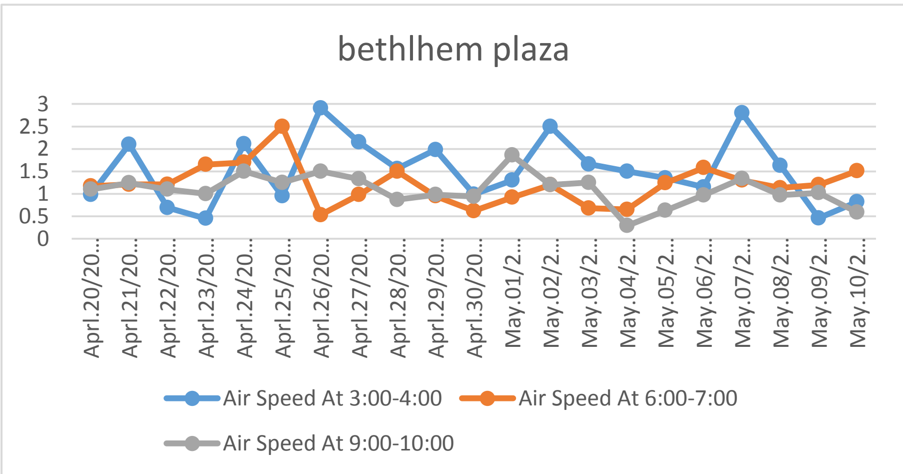


chart 29 Air velocity of bethlhem plaza

4.4.4.27 Air velocity of stedium site

According to a field measurement conducted for the stedium site, the data presented in

Chart 31, indicates that the maximum air speed recorded in a south-facing room was 2.41 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 April, specifically during the time frame of 3:00–4:00 a.m. in the morning.

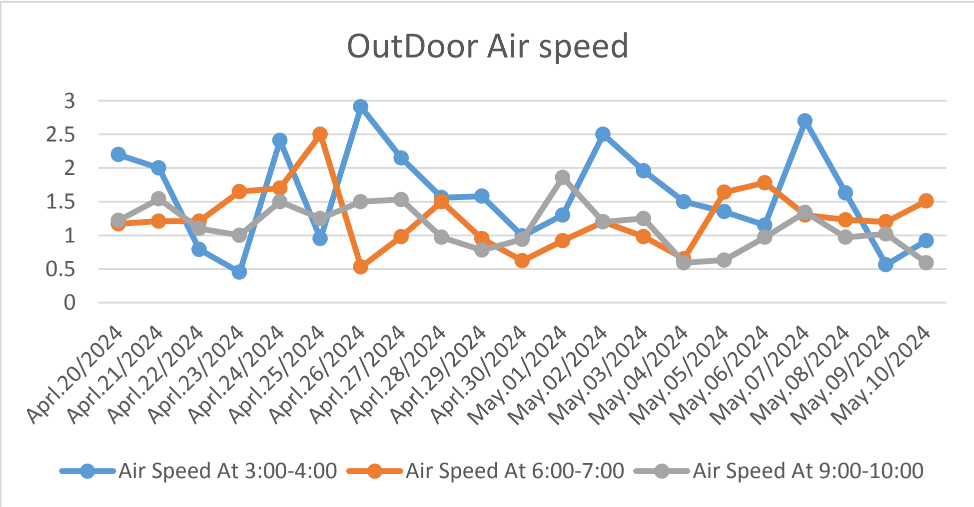


Chart 30 Outdoor Air velocity of stadium site

4.4.4.28 Indoor Air velocity of wegagen building envelope

In April and May, according to Chart 32, the velocity of indoor air in hidasse building envelope from 0.00 m/s to 0.97 m/s, while outdoor air speed ranges from 0.3 m/s to 2.7 m/s. These findings suggest that indoor air movement is significantly weaker than outdoor air movement.

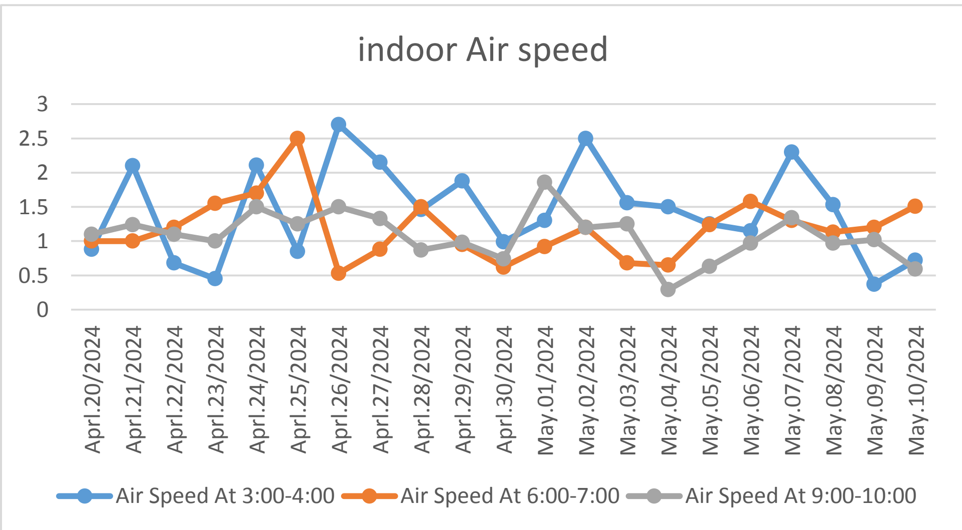


chart 31 Air velocity of wegagen bank

4.4.4.29 Indoor Air velocity of yeha city building envelope

In April and May, according to Chart 33, the velocity of indoor air in hidasse building envelope from 0.00 m/s to 0.99 m/s, while outdoor air speed ranges from 0.3 m/s to 2.7 m/s. These findings suggest that indoor air movement is significantly weaker than outdoor air movement.

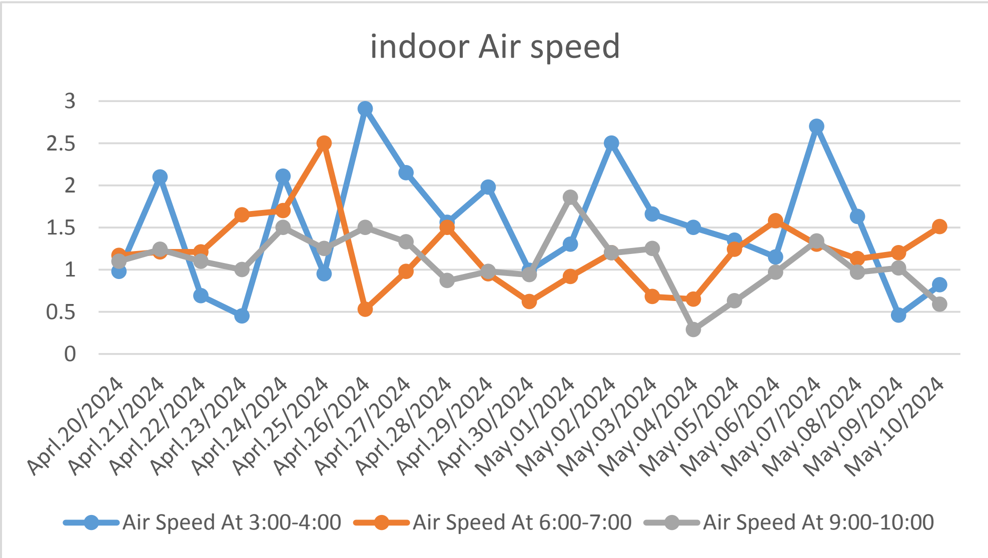


chart 32 Air velocity of yeha city center

4.4.4.30 Air velocity of berhawi site

According to a field measurement conducted for the stedium site, the data presented in Chart 34, indicates that the maximum air speed recorded in a south-facing room was 2.41 m/s, while the lowest was 0.53 m/s. A two-month measurement revealed that the highest air speed occurred during the month of April, specifically during the time frame of 3:00–4:00 a.m. in the morning.

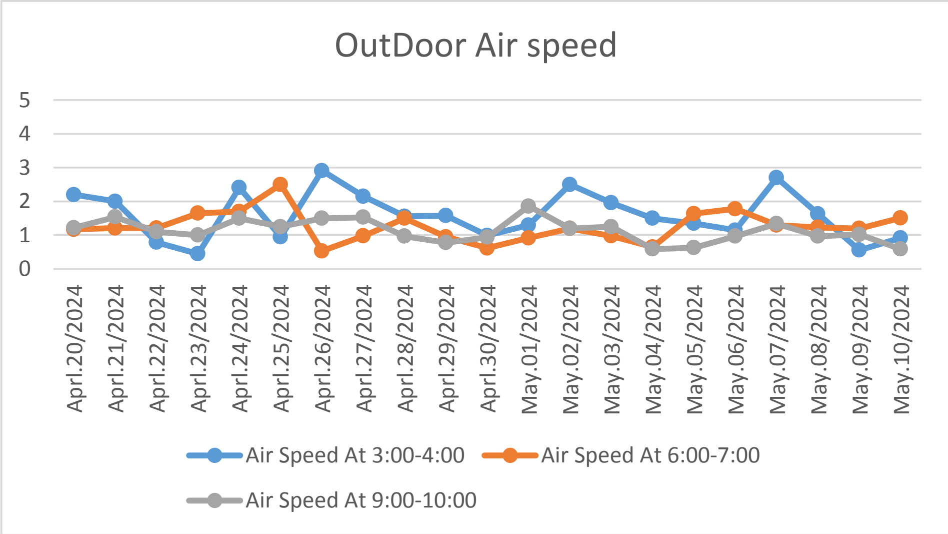


chart 33 Outdoor Air velocity of berhawi site

4.4.4.31 Indoor Air velocity of EBC building envelope

In April and May, according to Chart 35, the velocity of indoor air in EBC building envelope from 0.00 m/s to 0.97 m/s, while outdoor air speed ranges from 0.3 m/s to 2.7 m/s. These findings suggest that indoor air movement is significantly weaker than outdoor air movement.

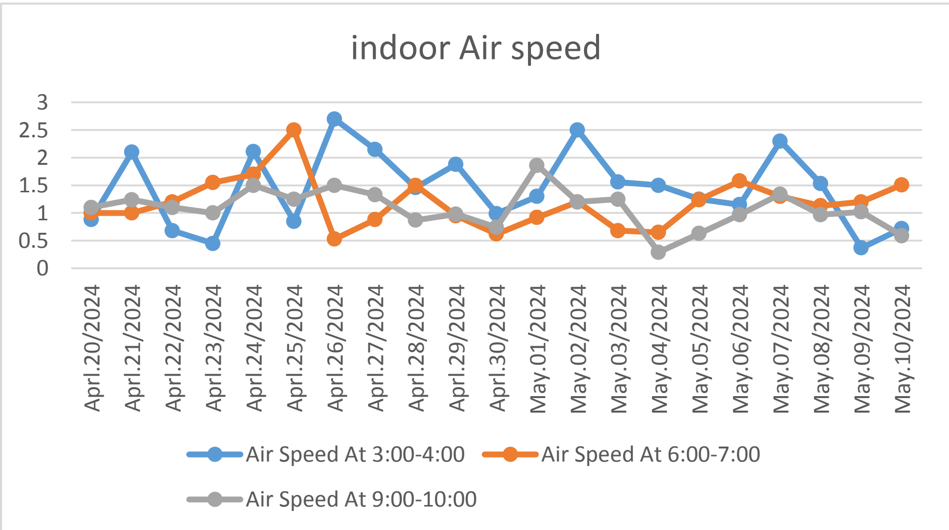


chart 34 Air velocity of EBC building envelope

4.4.4.32 Indoor Air velocity of awash bank building envelope

In April and May, according to Chart 36, the velocity of indoor air in awash bank building envelope from 0.00 m/s to 0.98 m/s, while outdoor air speed ranges from 0.3 m/s to 2.7 m/s. These findings suggest that indoor air movement is significantly weaker than outdoor air movement.

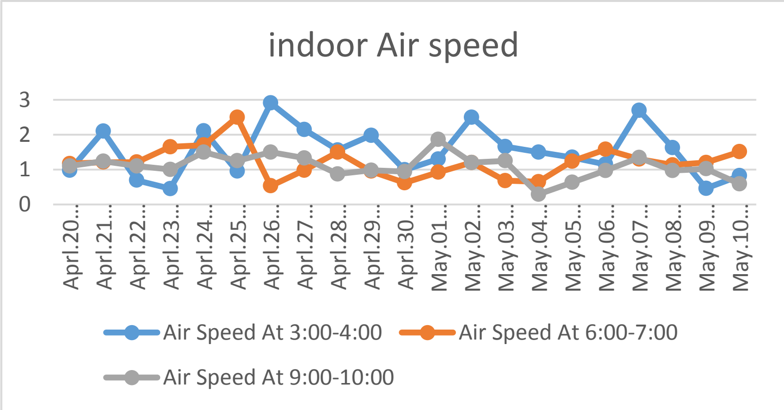


chart 35 Air velocity of awash bank

4.4.4.33 Discussion on megenagna

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 37 the airspeed within Hidasse building Envelope and Bethlhem plaza envelope was low when comparing to the airspeed outside, which is high (2.41 m/s).

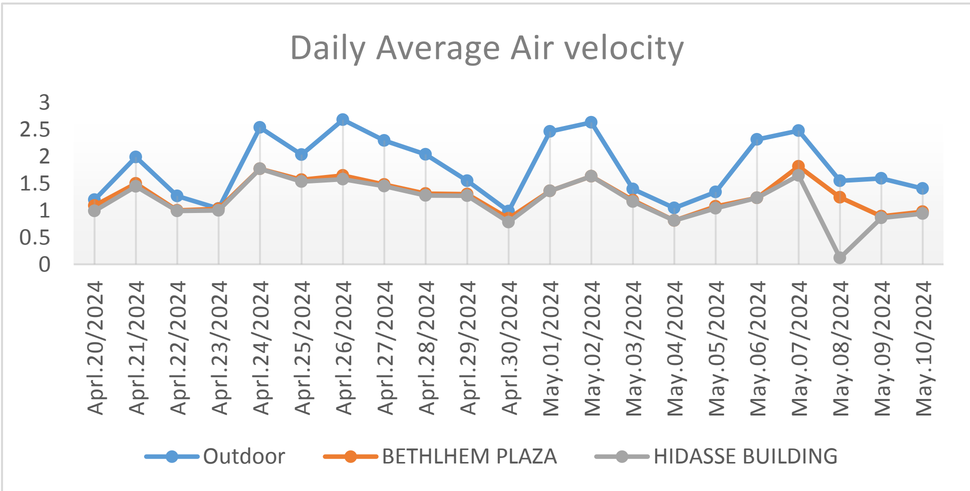


chart 36 Daily average Air velocity of megenagna site

4.4.4.34 Discussion on stedium site

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 38 the airspeed within wegagen bank building Envelope and yeha building envelope was low when comparing to the airspeed outside, which is high (2.41 m/s).

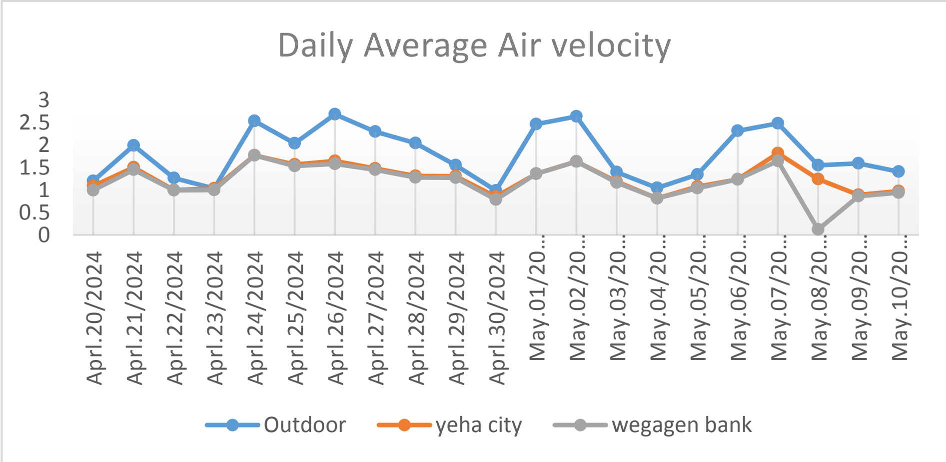


chart 37 Daily average Air velocity of stadium site

4.4.4.35 Discussion on berhawi site

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 39 the airspeed within EBC building Envelope and Awash bank building envelope was low when comparing to the airspeed outside, which is high (2.42 m/s).

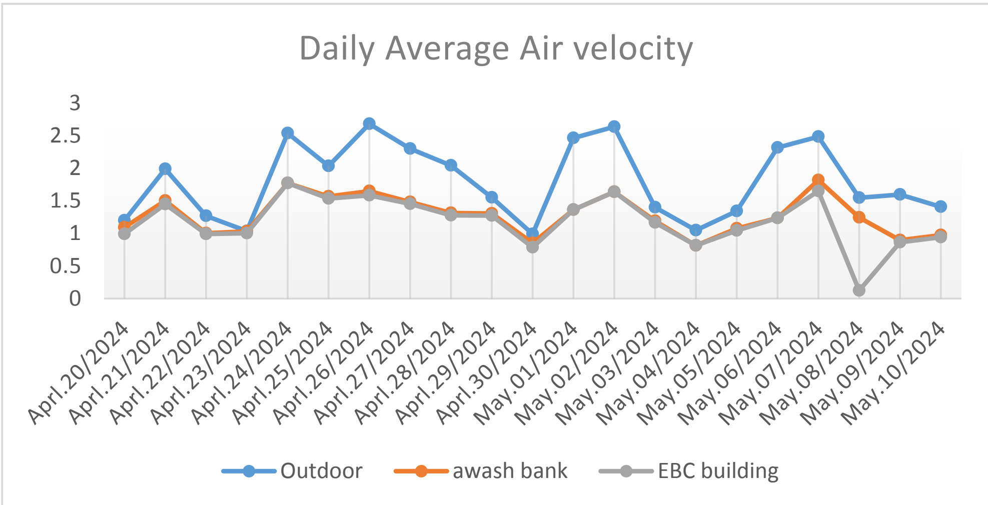


chart 38 Daily average Air velocity of berhawi site

Awash building envelope average interior airspeed 0.41 m/s is less than what is considered comfortable with range of 0.00 to 0.96 m/s indoors and 2.5 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 to the interior space The airspeed measured from April 10 to May 20/24 is According to Chart 4:14 the outside air velocity varies from 0.41 m/s to 2.45 m/s Air flow through the space ranged from 0.00 to 0.97 meters per second.

4.4.4.36 Daylight illuminance

Based on the results of the analysis conducted in May and April as outlined in Chart 40, it was found that the highest recorded indoor daylight illuminance was 1787 lux, while the lowest was 320lux throughout the day. The intensity of indoor daylight illuminance typically ranges from 150lux to 565lux. These findings imply that the indoor lighting levels can vary significantly depending on the time of day.

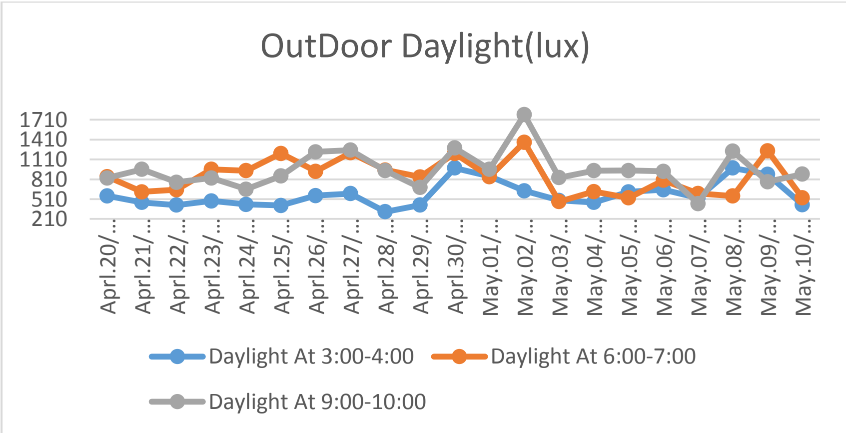


chart 39 Outdoor daylight illuminance of berhawi site

4.4.4.37 Indoor Daylight illuminance of hidasse building envelope

In April and May, according to Chart 41, the indoor daylight illuminance hidasse building envelope Ranges from 150 lux to 575 lux, while outdoor daylight illuminance ranges from 320 lux to 1787 lux.

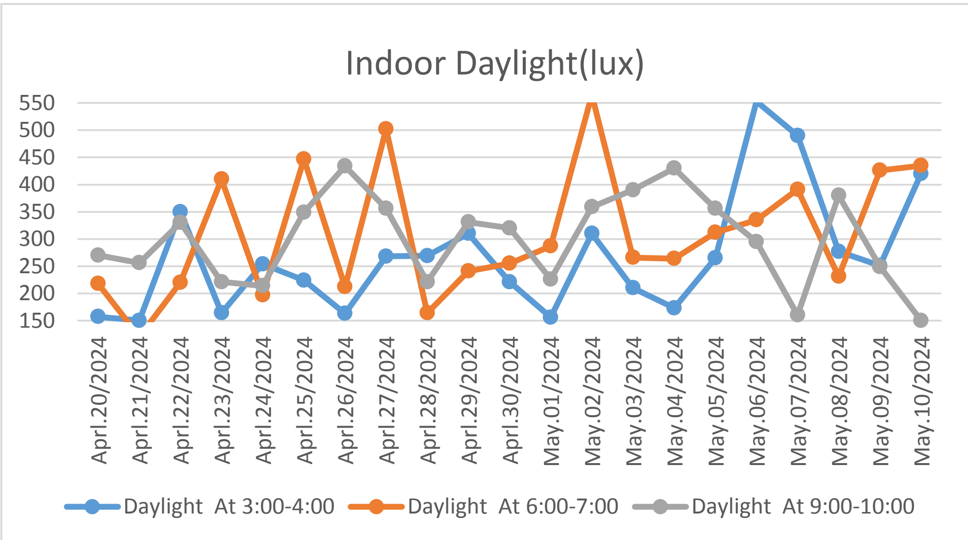


Chart 40 daylight illuminance of hidasse building

4.4.4.38 Indoor Daylight illuminance of Bethlehem plaza building envelope

In April and May, according to Chart 42, the indoor daylight illuminance in Bethlehem plaza building envelope ranges from 570 lux to 163 lux, while outdoor daylight illuminance ranges from 320 lux to 1787 lux.

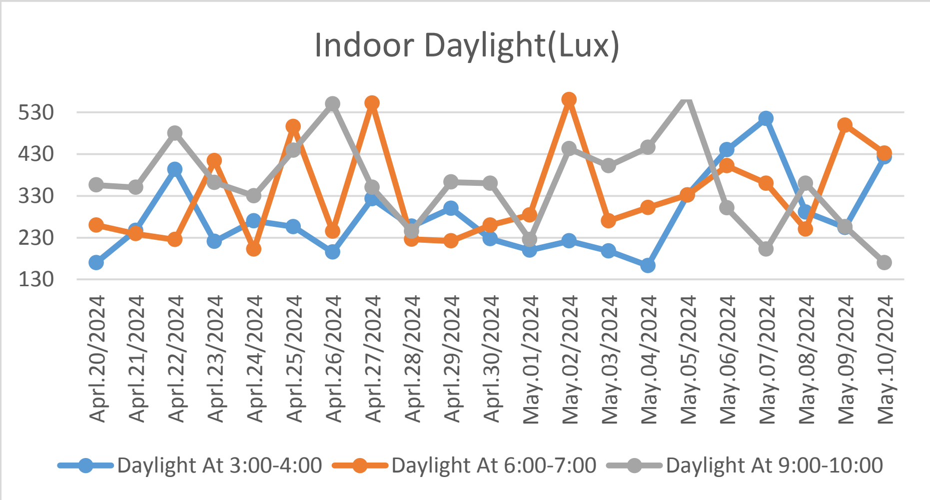


chart 41 daylight illuminance of bethlhem plaza building

4.4.4.39 Outdoor Daylight illuminance of stadium site

Based on the results of the analysis conducted in May and April as outlined in Chart 43, it was found that the highest recorded indoor daylight illuminance was 1788 lux, while the lowest was 321lux throughout the day. The intensity of indoor daylight illuminance typically ranges from 152lux to 563lux. These findings imply that the indoor lighting levels can vary significantly depending on the time of day.

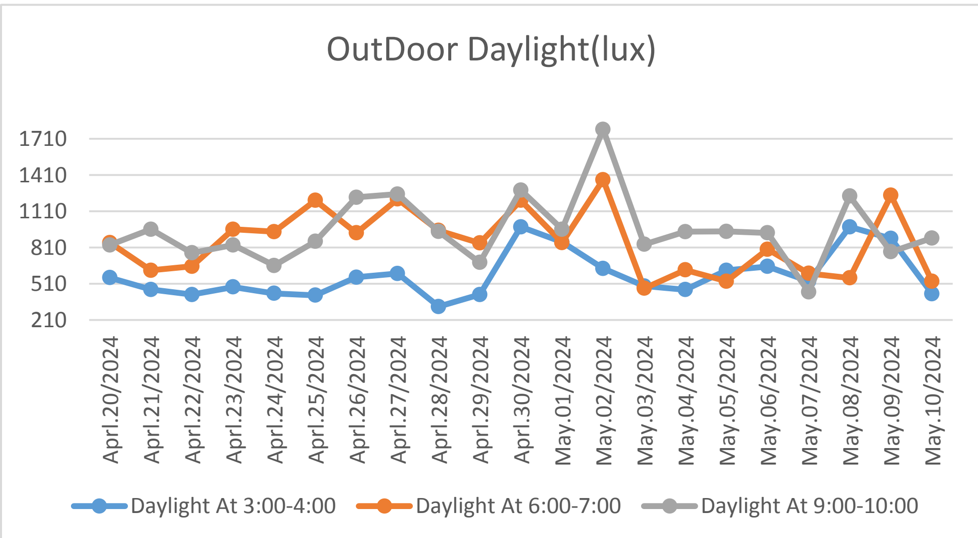


Chart 42 Outdoor daylight illuminance of stadium site

4.4.4.40 Indoor Daylight illuminance of wegagen bank building envelope

In April and May, according to Chart 44, the indoor daylight illuminance wegagen bank building envelope ranges from 151 lux to 576 lux, while outdoor daylight illuminance ranges from 321 lux to 1788 lux.

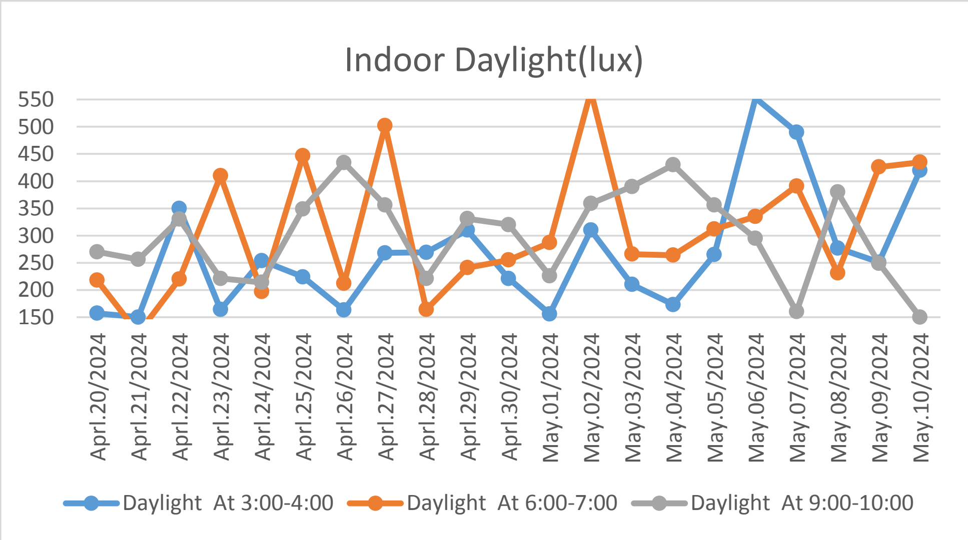


chart 43 daylight illuminance of wegagen bank building

4.4.4.41 Indoor Daylight illuminance of yeha city building envelope

In April and May, according to Chart 45, the indoor daylight illuminance in yeha city building envelope ranges from 569 lux to 162 lux, while outdoor daylight illuminance ranges from 319 lux to 1786 lux.

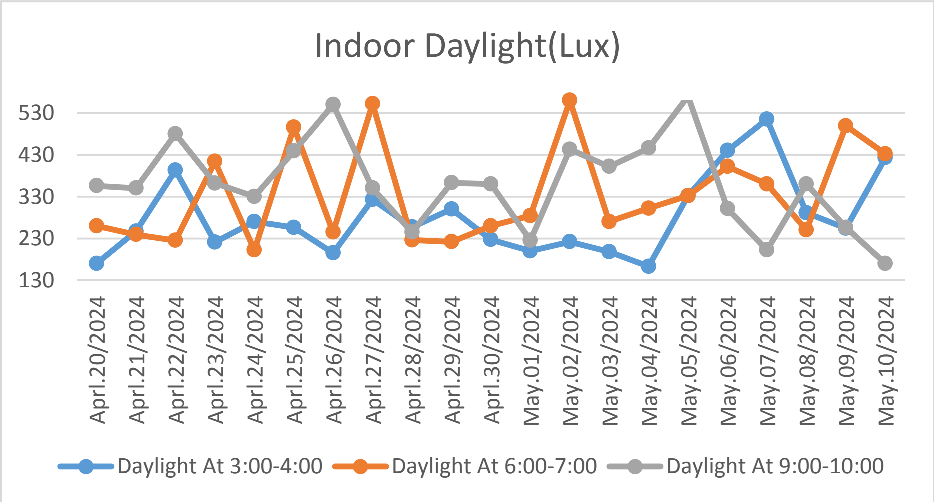


Chart 44 daylight illuminance of yeha city center

Based on the results of the analysis conducted in May and April as outlined in Chart 45, it was found that the highest recorded indoor daylight illuminance was 1787 lux, while the lowest was 320lux throughout the day. The intensity of indoor daylight illuminance typically ranges from 150lux to

564lux. These findings imply that the indoor lighting levels can vary significantly depending on the time of day.

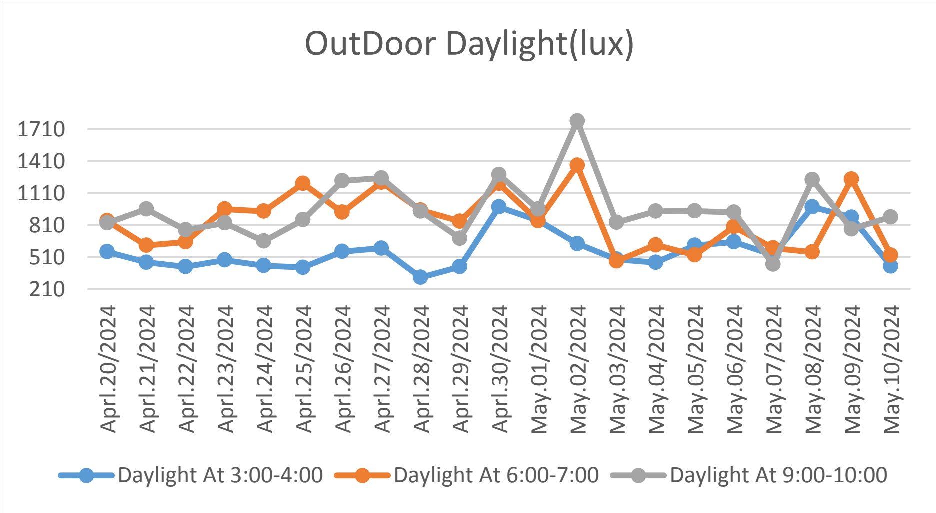


chart 45 Outdoor daylight illuminance of berhawi site

4.4.4.42 Indoor Daylight illuminance of EBC building envelope

In April and May, according to Chart 47, the indoor daylight illuminance EBC building envelope ranges from 152 lux to 575 lux, while outdoor daylight illuminance ranges from 320 lux to 1787 lux.

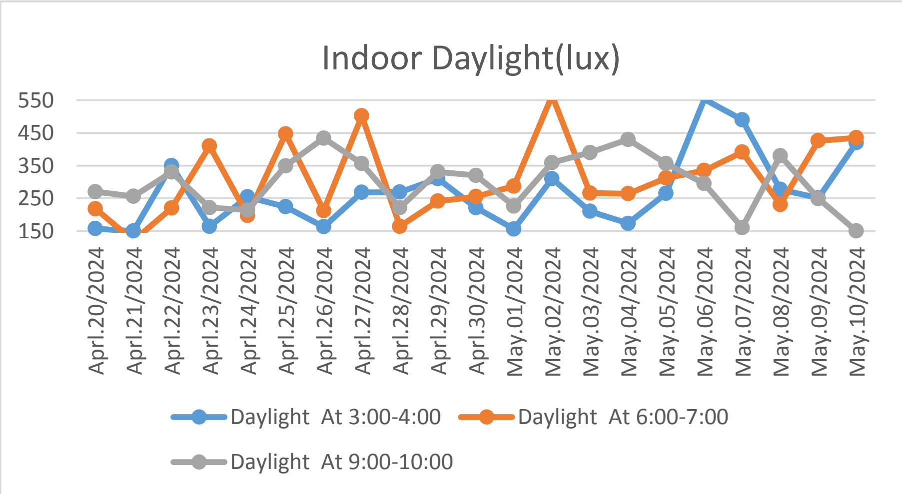


chart 46 Daylight illuminance of EBC building

4.4.4.43 Indoor Daylight illuminance of awash bank building envelope

In April and May, according to Chart 48, the indoor daylight illuminance in awash bank building envelope ranges from 568 lux to 163 lux, while outdoor daylight illuminance ranges from 320 lux to 1787 lux.

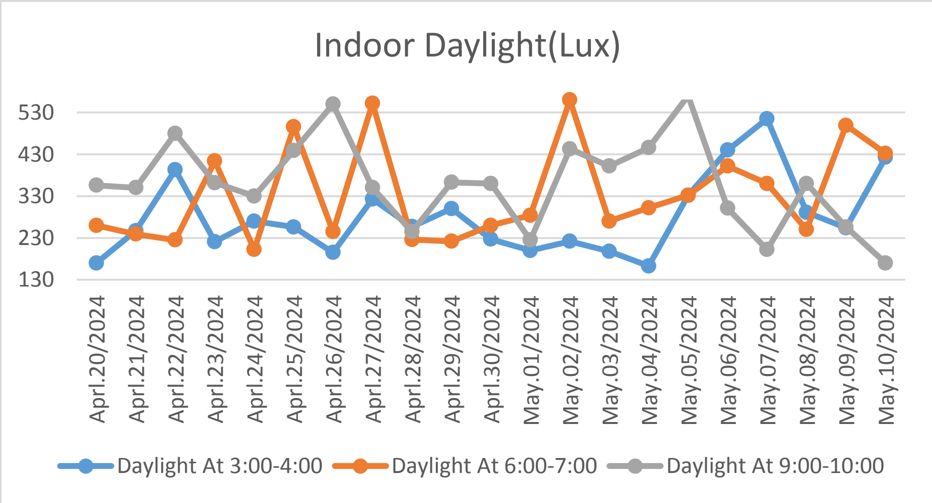


chart 47 Daylight illuminance of awash bank building

4.4.4.44 Discussion on daylight illuminance of megenagna site

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.

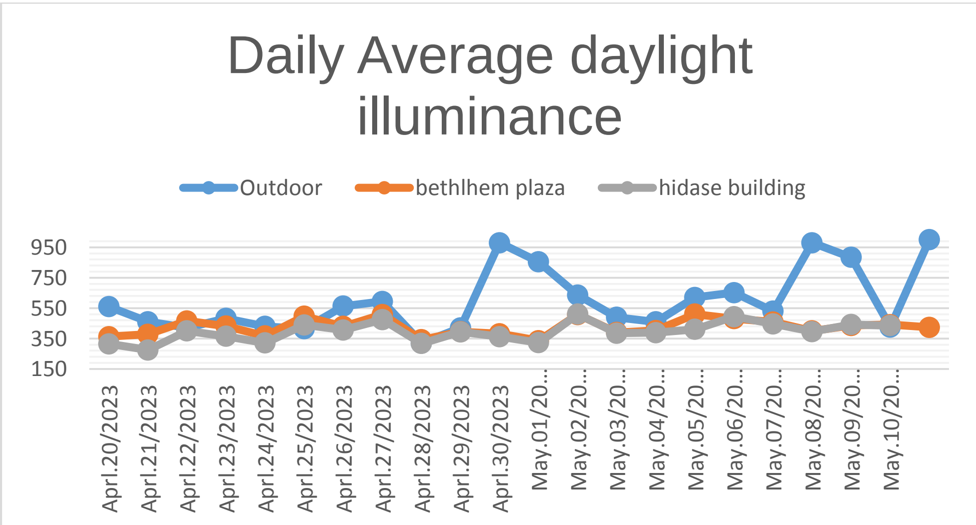


chart 48 Daily average Daylight illuminance of megenagna site

4.4.4.45 Discussion on daylight illuminance of stedium site

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.

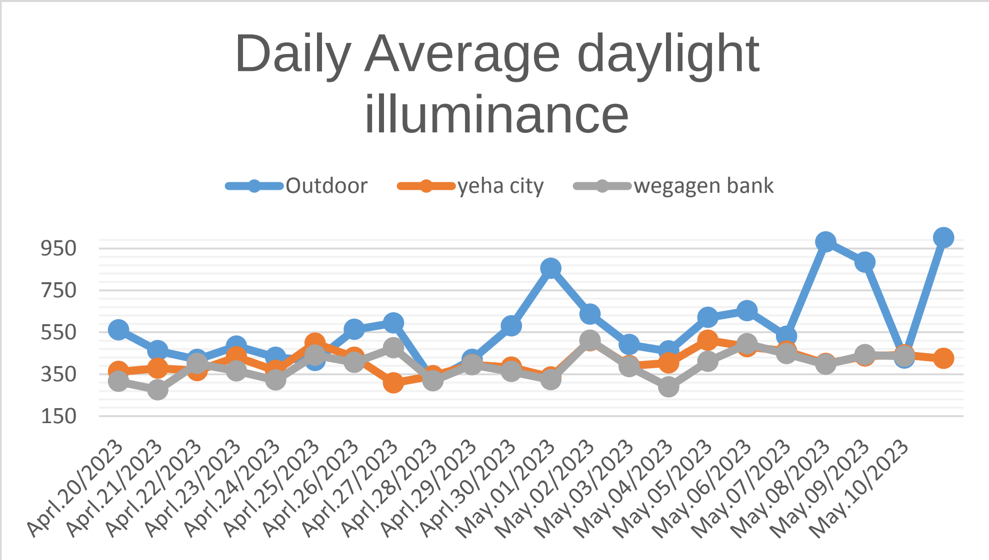


Chart 49 Daily average Daylight illuminance of stadium site

4.4.4.46 Discussion on daylight illuminance of behrawi site

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.

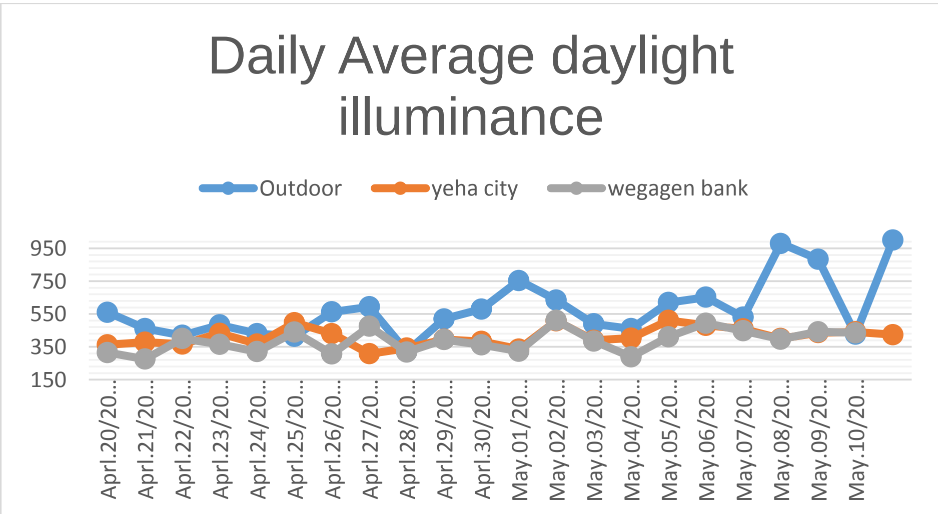


Chart 50 Daily average Daylight illuminance of berhawi site

According to Chart 52, the daylight illumination average level in the bethlhem plaza yeha city and awash bank exceeds 200 lux. The indoor spaces receive an illumination level above the required average of 200 lux, and approximately 25% of the outdoor illumination is transmitted indoors, meeting the relevant standards. However, usage of a building leads to a decrease in received light, though still maintaining levels above the prescribed requirement. As per the illuminance measurement, the primary bethlhem plaza yeha city and awash bank of the occupants experiences a significantly high light level at clear sky conditions.

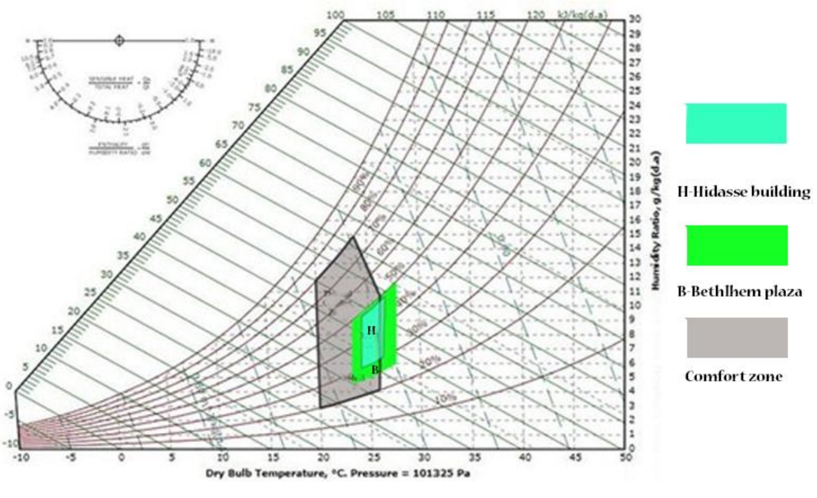
4.5 Thermal comfort chart with environmental variable in megenagna site

The temperature of a hidasse building has been recorded in Chart 25,with a maximum of 27.7 °C and 22 °C is the minimum temperature. These readings were taken during the overheated months of April and May, when outdoor temperatures recorded a maximum of29.2 °C and 24.4 °C is the minimum temperature. While the bethlhem plaza also showed readings of maximum 28.9 °C and minimum 23 °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 bethlhem plaza falls outside the standard comfort zone.

According to Chart 25, the hidasse building envelope had superior humidity levels compared to bethlhem plaza building envelope. In the month of April, the maximum and minimum humidity levels recorded for the hidasse building were 37% and 22% respectively. While in May, the maximum and minimum humidity levels recorded on bethlhem building were 32% and 20%, respectively. It is show that the relative humidity of the the hidasse building envelope is better than bethlhem plaza’s building envelope.

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 41 the airspeed within Hidasse building Envelope and Bethlhem plaza envelope was low when comparing to the airspeed outside, which is high (2.41 m/s).

According to Chart 51, the daylight illumination average level in the bethlhem plaza yeha city and awash bank exceeds 200 lux. The indoor spaces receive an illumination level above the required average of 200 lux, and approximately 25% of the outdoor illumination is transmitted indoors, meeting the relevant standards. However, usage of a building leads to a decrease in received light, though still maintaining levels above the prescribed requirement. As per the illuminance measurement, the primary bethlhem plaza yeha city and awash bank of the occupants experiences a significantly high light level at clear sky conditions.



4.6 Thermal comfort chart with environmental variable in stedium site

The temperature of a wegagen has been recorded in Chart 36 with a maximum of 26.9 °C and 22 °C is the minimum temperature. These readings were taken during the overheated months of April and May, when outdoor temperatures recorded a maximum of 29.3 °C and 24.1 °C is the minimum temperature. While the yeha city also showed readings of maximum 28.9 °C and minimum 24.2 °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 yeha city falls outside the standard comfort zone.

According to Chart 4:10, the wugagen building envelope had superior humidity levels compared to yeha city center building envelope. In the month of April, the maximum and minimum humidity levels recor

Figure 39 Psychometric chart for bethlhem plaza and hidasse building (Source: Author)

ı May, the maximum and minimum humidity levels recorded on yeha city center building were 32% and 20%, respectively. It is show that the relative humidity of the the hidasse building envelope is better than bethlhem plaza's building envelope.

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 wegagen bank building Envelope and yeha building envelope was low when comparing to the airspeed outside, which is high (2.41 m/s).

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.

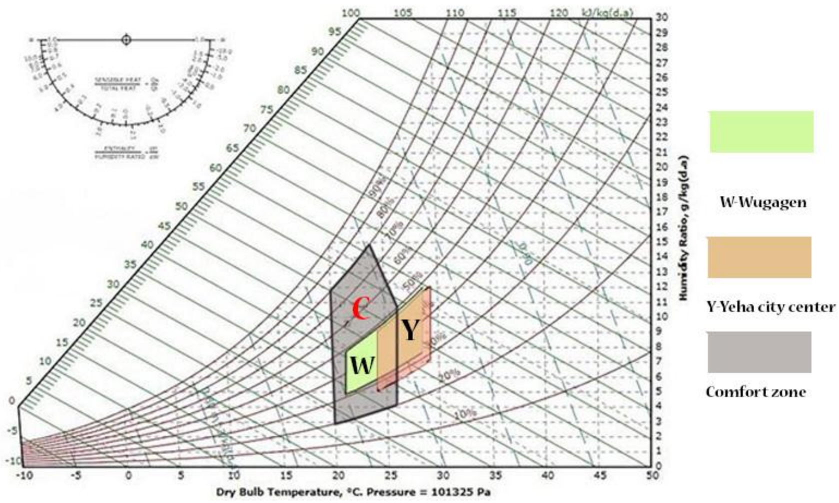


Figure 40 Psychometric chart for yeha city center and wegagen building (Source: Author)

4.7 Thermal comfort chart with environmental variable in behrawi site

The temperature of a EBC has been recorded in Chart 37 with a maximum of 27.8 °C and 22.7 °C is the minimum temperature. These readings were taken during the overheated months of April and May, when outdoor temperatures recorded a maximum of 29.3 °C and 24.1 °C is the minimum temperature. While the Awash bank also showed readings of maximum 28.9 °C and minimum 23.9 °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 awash bank falls outside of the standard comfort zone.

According to Chart 4:10, the EBC building envelope had superior humidity levels compared to awash bank building envelope. In the month of April, the maximum and minimum humidity levels recorded for the EBC building were 33% and 23% respectively. While in May, the maximum and minimum humidity levels recorded on awash bank building were 31% and 21%, respectively. It is show that the relative humidity of the the hidasse building envelope is better than bethlhem plaza's building envelope.

According to a field measurement conducted for the stedium site, the data presented in Chart 4:11, indicates that the maximum air speed recorded in a south-facing room was 2.41 m/s, while the lowest was 0.53 m/s. A two-month measurement revealed that the highest air speed occurred during the month of April, specifically during the time frame of 3:00–4:00 a.m. in the morning.

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 high or low & indoor temperatures are low, it adversely affects thermal comfort levels.

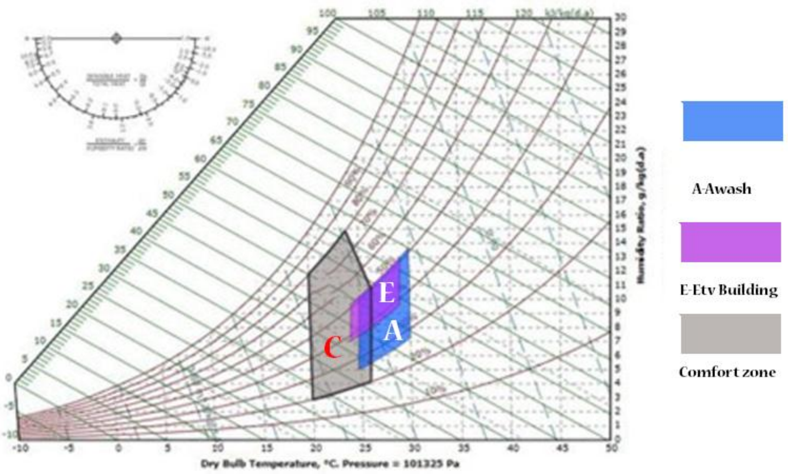
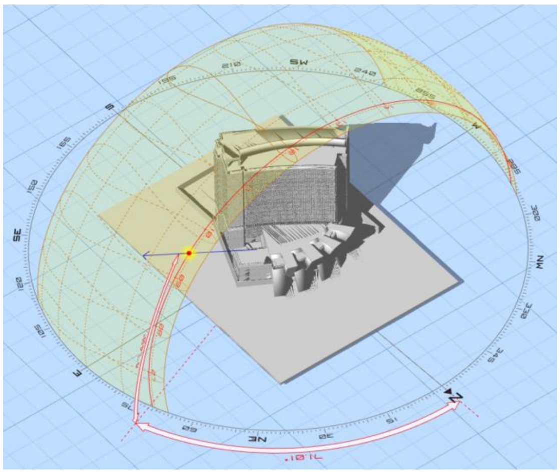
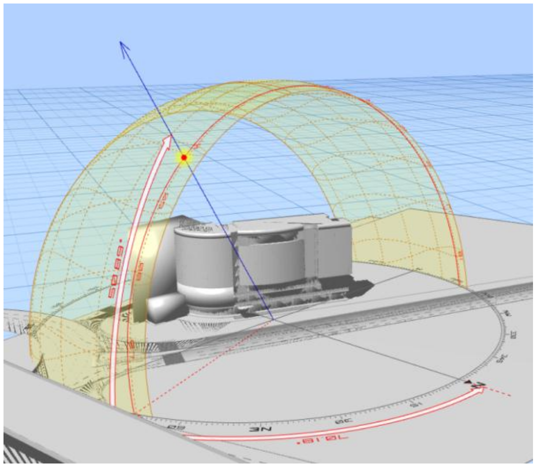


Figure 41 Psychometric chart for awash bank and EBC building (Source: Author)

4.8 Sun paths and Building orientation of selected office buildings in addis abeba

All 6 office buildings in addis abeba listed are in four orientation 90°N, 15°N, 45°E,0°N and 30° N. the office buildings Site located at 3 different locations with megenagna site, stedium site and berhawi site.

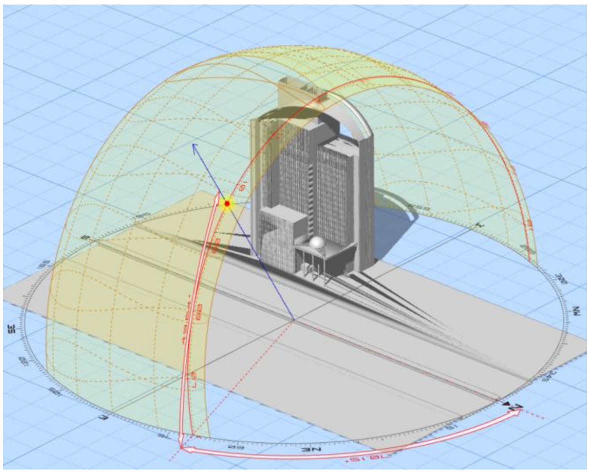
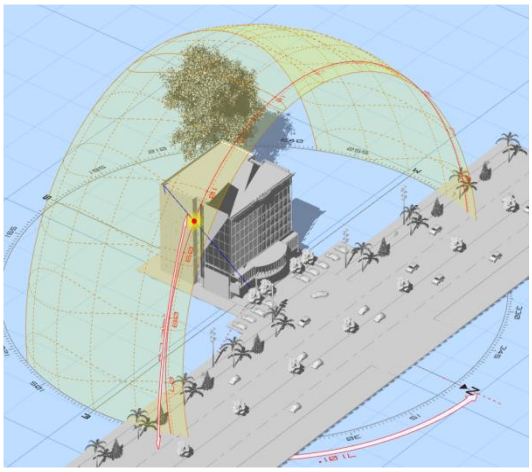
Table 16 megenagna Site

Site: Megenagna Site	
Orientation	
N – E axis (Azimuth angle-71°N)	N – E axis (Azimuth angle-70°N)
1 Blocks (Hidasse building) 	1 Blocks (Bethlehem plaza building) 

There are 2 blocks in Megenagna site from those blocks 1 blocks are oriented N-E axis with azimuth angle 71°N And the other block is oriented N – E axis Azimuth angle 70°.

Figure 42 megenagna site (Source: google earth)

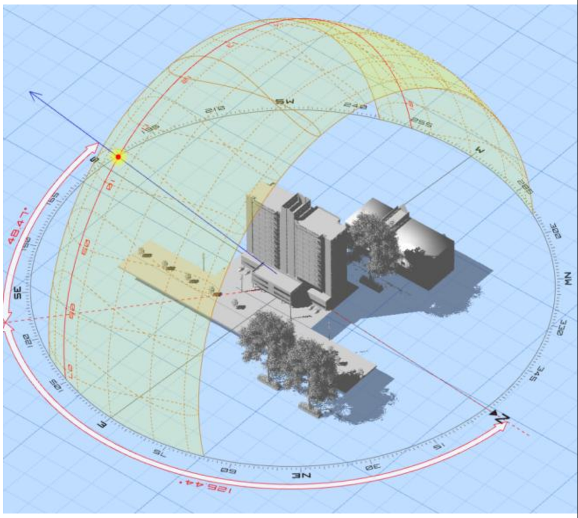
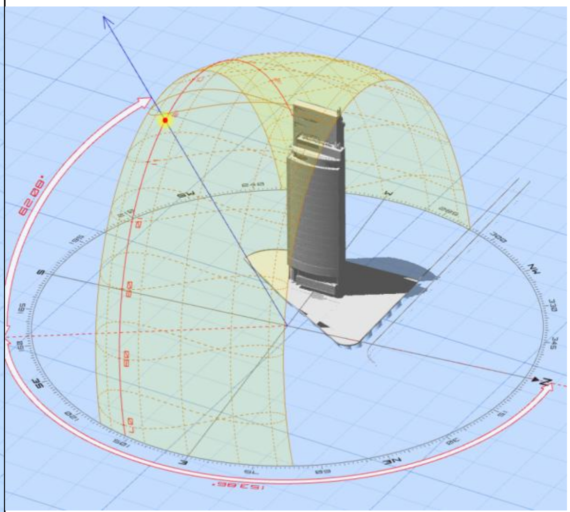
Table 17 stedium Site

Site: stedium Site	
Orientation	
E axis (Azimuth angle-70.15°N)	N axis (Azimuth angle-71.01°N)
1 Blocks(wegagen bank building) 	1 Blocks(yeha city center building) 

There are 2 blocks in stedium site from those blocks 1 block are oriented E axis with azimuth angle 70.15°N And the other block is oriented N axis Azimuth angle 71.01°.

Figure 43 stedium site (Source: google earth)

Table 18 Berhawi site

Site: Berhawi site	
Orientation	
E axis (Azimuth angle-126.43°N)	N axis (Azimuth angle-71.01°N)
1 Blocks(EBC building)	1 Blocks(Awash bank building)
	

There are 2 blocks in Berhawi site from those blocks 1 block are oriented E axis with azimuth angle 126.43°N and the other block is oriented N axis Azimuth angle 153.6°.

Figure 44 berhawi site (Source: google earth)

4.9 building envelope Information

From 6 building selected in Addis Ababa city 2 building used building envelope, those are hidasse building from megenagna site and wegagen building from stedium site.

Envelope treatment Assessment of Hidase Building

Hidase Building front facade have almost infrastructure integrated particularly on the north east and south west direction.

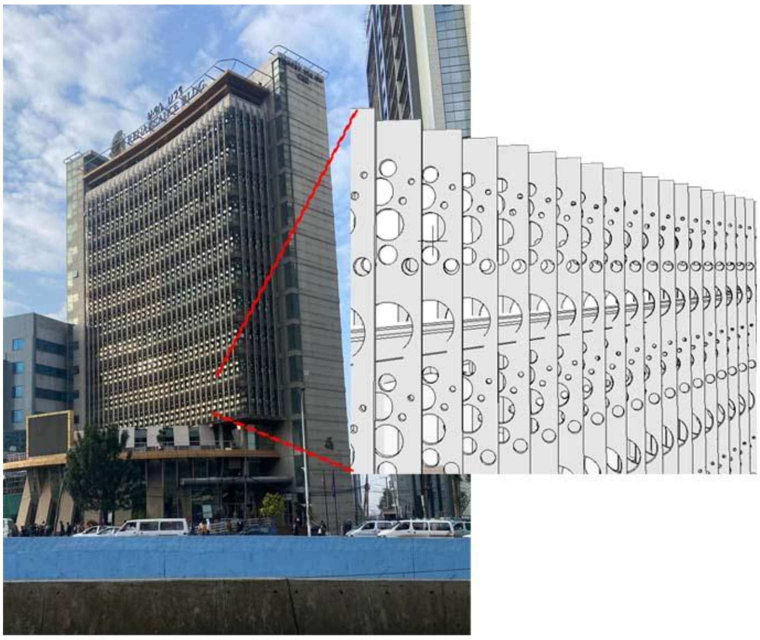
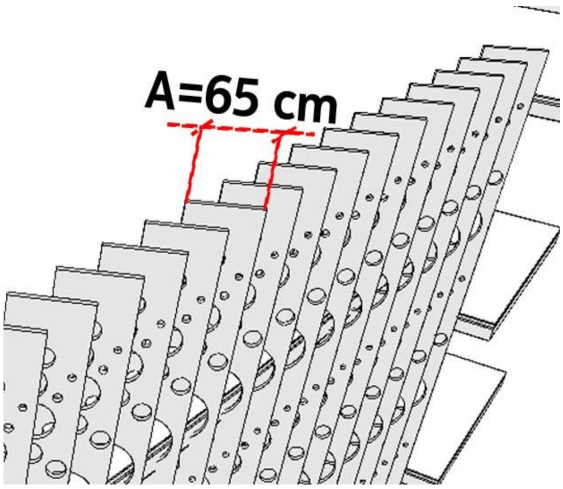


Figure 45 hidasse building envelope (Source: Site Observation Author 2024)



(A = 65cm, thickness=8 cm Angel= 45 degree Material= Metal Sheet Type=vertical Location= north east and south west. Cover 26 meter length north east and south west each.

Envelope treatment Assessment of bethlhem plaza Building

Bethlhem plaza building envelope is a single skin curtain wall facade on north west,north, north east and south west and south east covered by HCB wall.

Figure 46 Bethlehem plaza building envelope (Source: Site Observation Author 2024)

Envelope treatment Assessment of wegagen bank

Wegagen bank building facades have building envelope integrated particularly on the north east, and west direction.

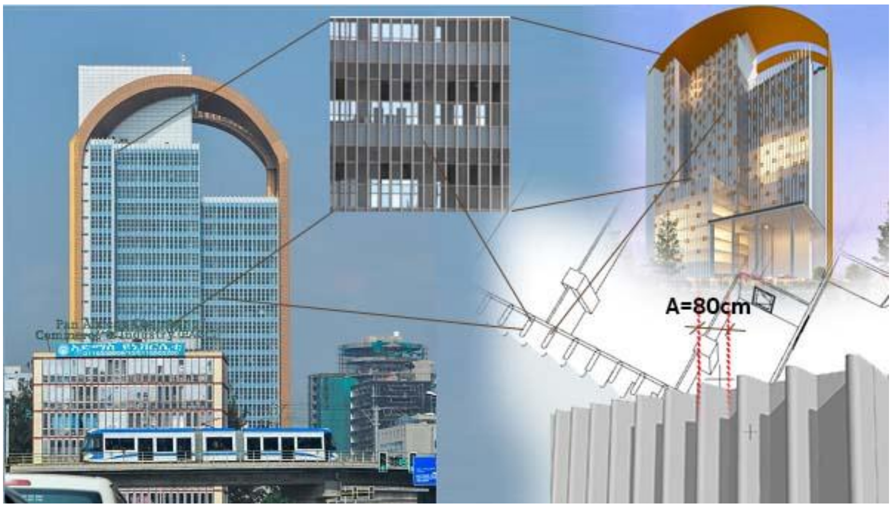


Figure 47 wegagen bank building envelope (Source: Site Observation Author 2024)

(A = 80cm, thickness=15cm Angel= 90 degree Material= aluminum Type=vertical Location= east and west. Cover 41 meter and 38 meter length east and west respectively.

Envelope treatment Assessment of yeha city center Building

yeha city center building envelope is a single skin curtain wall facade on north covered with cirtain wall glass, north east,south east covered by aluminium panels and onsouth covered by HCB wall.

Figure 48 yeha city center building envelope (Source: Site Observation Author 2024)

Envelope treatment Assessment of EBC

EBC building facades have no envelope integrated particularly on all direction covered by HCB wall and window opening.

Figure 49 EBC building envelope (Source: Site Observation Author 2024)

Envelope treatment Assessment of awash bank Building

Awash bank Building envelope is a single skin curtain wall facade covered with shear wall on north, south and east west covered by curtain wall panel.

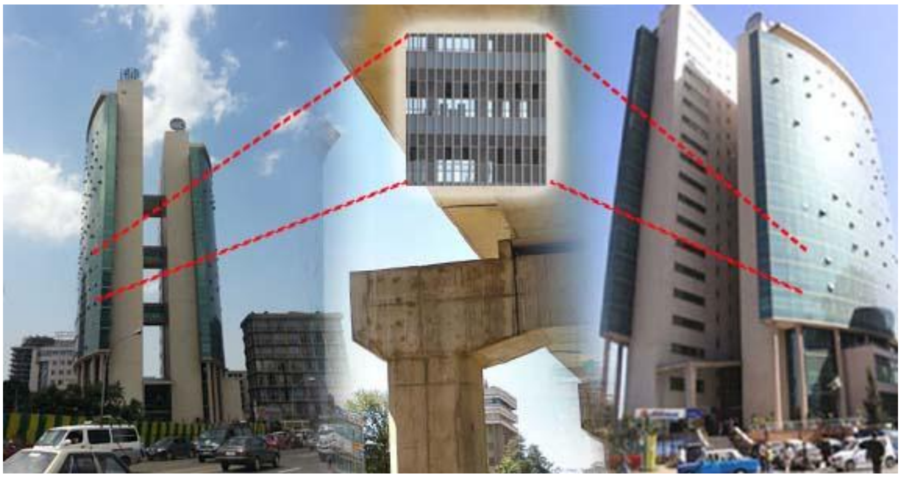


Figure 50 Awash bank building envelope (Source: Site Observation Author 2024)

4.10 Shading design

To guarantee effective building envelope, it is good to consider three important key points: the flat shadow point/ horizontal shadow angle (HSA), the upward shadow point vertical shadow angle (VSA), and the end profile point (EPA). These points effectively shows the place of the sun concerning a building envelope in a particular direction and might be used to decide the viability of a given concealing gadget given the degree of shade it gives and amount of shade it casts.

4.10.2 Identifying When Shading Is Necessary

Depending on Location, different regions get different weather conditions. Therefore, the overheated period's different from location to location. Now a days, a location's weather information is easily available on different websites. On this research overheated periods is identified 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 analyze and interpret 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 helps in interpreting weather information by offering four comfort model choices.

In this instance, a Time-Table Plot chart displaying weather information from Addis abeba city was employed. The graph showing the average daily temperature and monthly temperature data information from Energy Plus. Information is shown in three different colour zones: Red (Hot/Overheated), Turquoise (Comfortable), and Blue (Cold/Under heated) depending on the

Adaptive Comfort Model data that was selected. Figure 4:8 shows Addis Ababa monthly average temperatures.

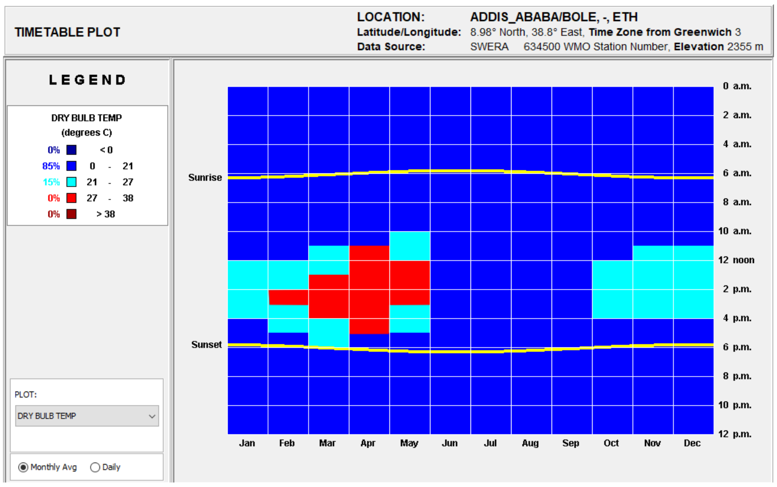


Figure 51 Addis Ababa City Time Table plot chart average monthly temperature

On above Figure 4:8 shows that, February month from 2pm-9pm, march from 7:00 noon-4:00pm, April from 11:00 noon -11:00pm, and May from 12:00 noon -9:30pm are hottest months of Addis Ababa city.

Based on the data from Figure 4:8 overheated periods showed in red colour. Periods of overheated are registered in the months of February 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 49

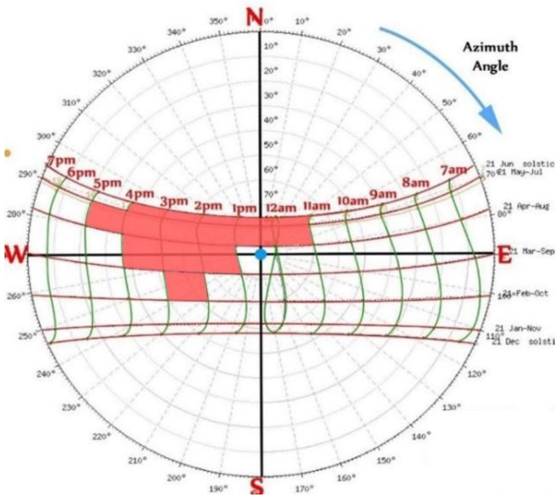


Figure 52 Stereographic diagram mapped overheating month of Addis Ababa City

4.10.6 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 53 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.

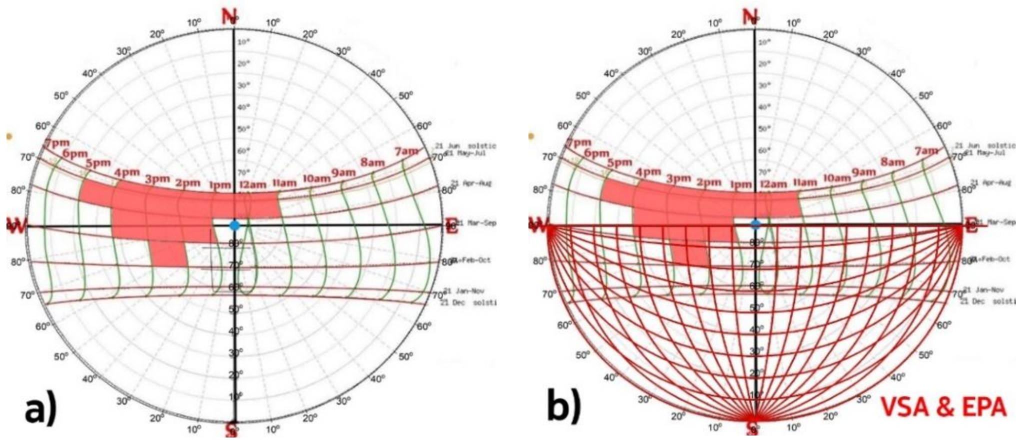


Figure 53 Sun path with mapped overheated months and hours; b) VSA measuring sun protractor place south facing (Source: Sunearthtools.com and Author)

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

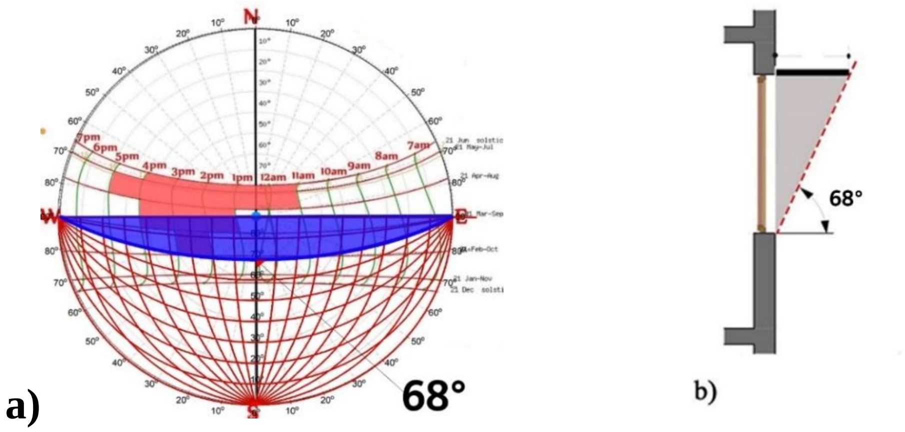


Figure 54 VSA recorded shadow angle; b) section view with horizontal overhang and angle (source: sunearthtools.com, climate consultant and author)

As tried to show in Figure 54 the VSA protractor show the mapped overheated period around 68°. A 68° angle is chosen to shade periods because, at this angle, horizontal building envelope elements / the overhang will block overheated sun rays. Figure 54 b) shows a Section view of window. The projection line of the VSA Figure 54.(a) is drawn a perpendicular line to the opening and Projected 68° creates the line towards by Extending another line perpendicular from the opening till it creates the diagonal line and the depth to the Horizontal overhang.

South Orientation (Horizontal shadow angle Identification)HAS

For South facing envelope HSA (horizontal shadow angle), by Extending a radial line in the upper half of the protractor so that it becomes like the diameter of the protractor which means by placing the protractor's center on stereographic diagram by facing south direction .Figure 55 reading angle and step are shown below.

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

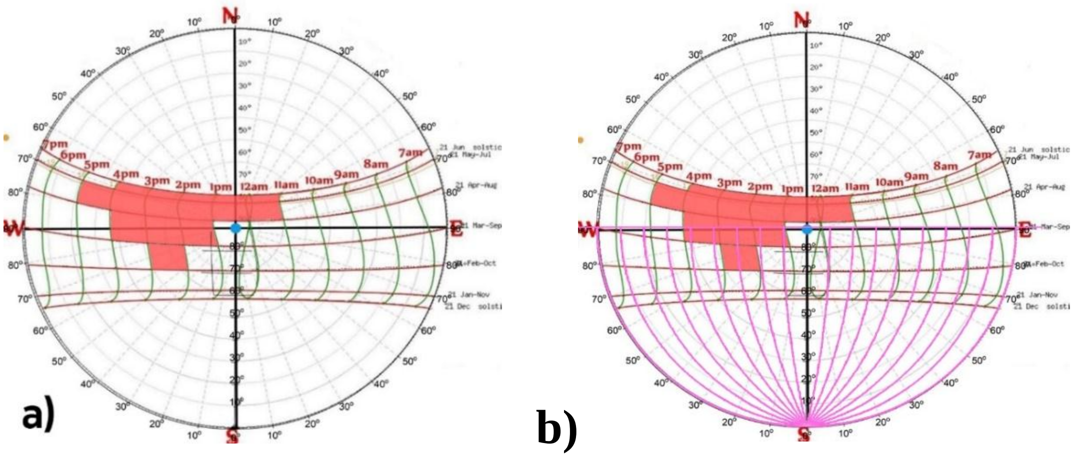


Figure 55 a) Sun path with mapped overheated month and hours b) HSA measuring Sun protractor placed toward south facing direction (Source: Sunearthtools.com climate consultant and Author)

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

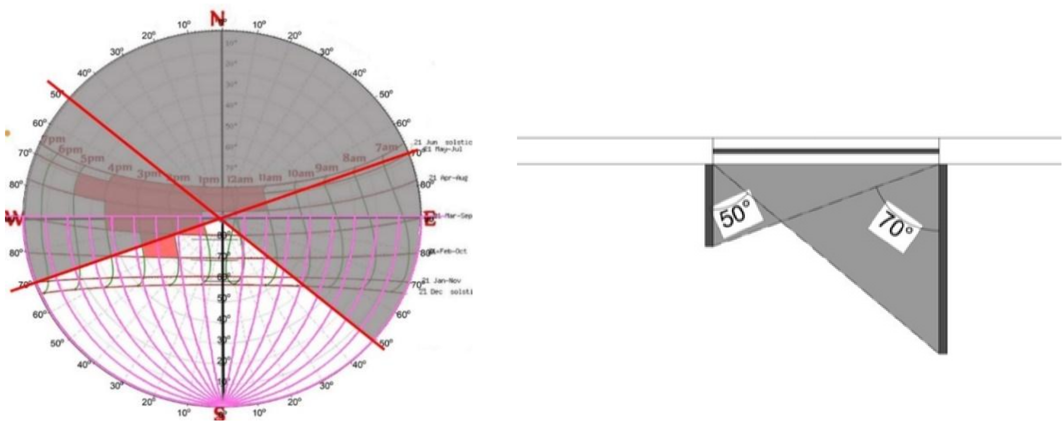


Figure 56 a) HSA recorded shadow angle, b) plan view with vertical fin and angle (Source: Sunearthtools.com and Author)

This means whenever the sun’s azimuth angle is greater than 70^{o} measured from due south clockwise, the vertical fin on the west side will obstruct it. Whenever the sun’s azimuth angle is greater than 50^{o} measured from due south counter-clockwise, the vertical fin on the east side will obstruct it. as shown on above figure

B) South Orientation End profile angle (EPA) Identification

EPA (End profile angle) for South facing building envelope, by putting the protractor’s center on stereographic diagram by facing south direction. Figure 57 the cyan 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.

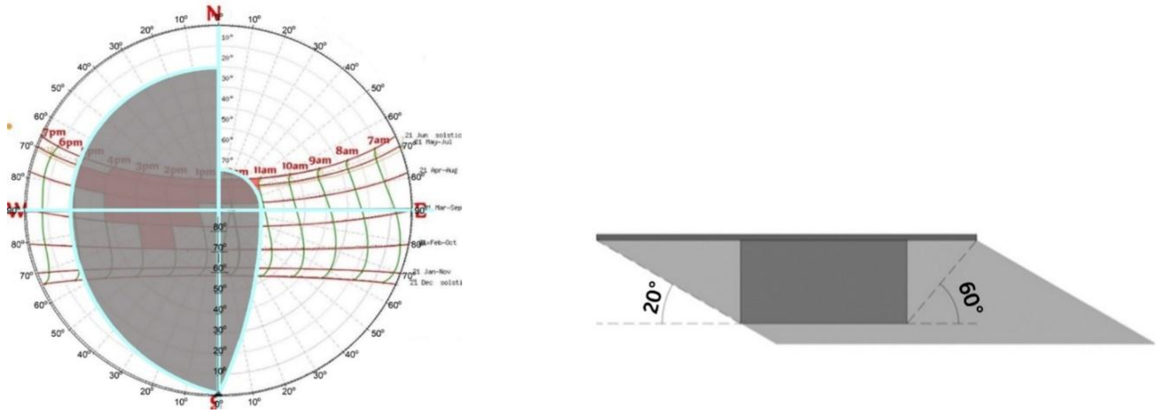


Figure 57 a)EPA recorded shadow angle, b) Front view with horizontal overhang and end angle (Source: Sunearthtools.com, climate consultant and Author)

In Figure 57 a) and b) end profile angle for horizontal shading device or overhang the angel is recorded 20 degrees to the west and 60 degrees to east side create desired shading for mapped overheated month and hour by extending shading element.

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

A) South -west Orientation (VSA) Vertical shadow angle 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.

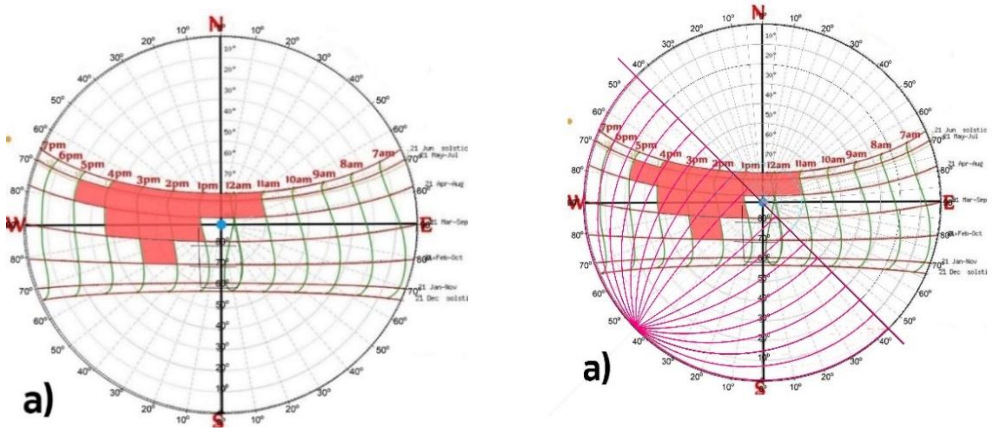


Figure 58 a) Sun path with mapped overheated month and hours b) VSA measuring Sun protractor place south west facing (Source: Sunearthtools.com and Author)

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

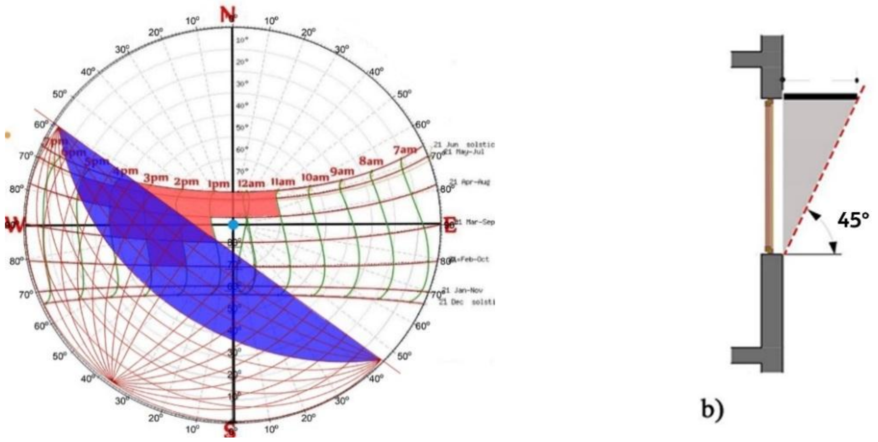


Figure 59 a)VSA recorded shadow angle, b) plan view with horizontal overhang and angle (Source: Sunearthtools.com and Author)

As try to show in Figure 59 the VSA protractor show the mapped overheated period around 45°. A 45° angle is chosen to shade periods because, at this angle, horizontal shading devices have performance by blocking overheated sun incidents. Figure 59. (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.

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

HSA (horizontal shadow angle) for South west facing building envelope, by placing the protractor's center on stereographic diagram by facing south west direction. Figure 60 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.

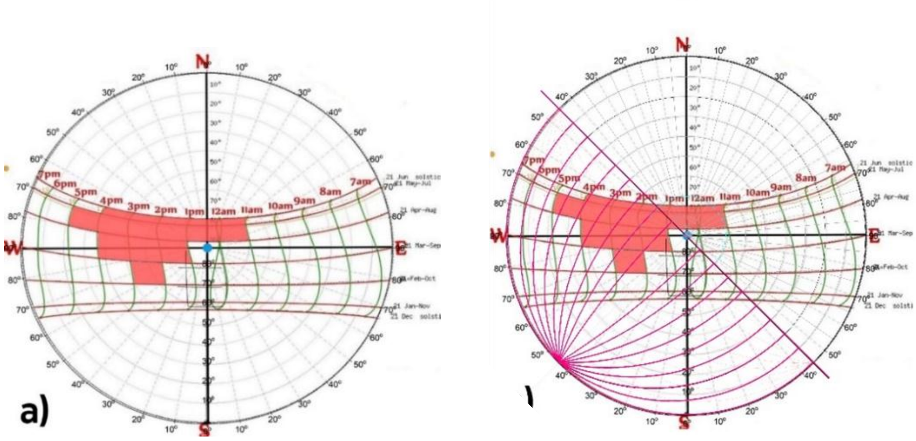


Figure 60 a)Sun path with mapped overheated month and hours b) HSA measuring Sun protractor place south west facing (Source: Sunearthtools.com and Author)

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

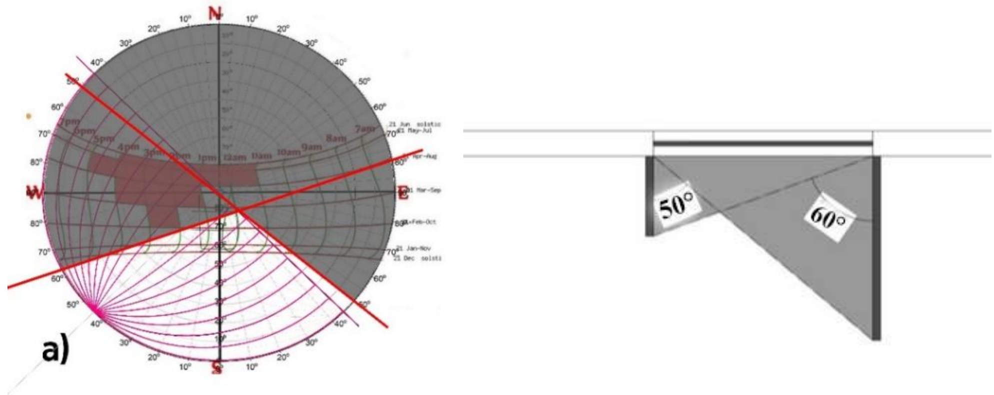


Figure 61 identifying end angle of overheating month and hour.

This means whenever the sun's azimuth angle is greater than 60^o measured from due south clockwise, the vertical fin on the west side will obstruct it. Whenever the sun's azimuth angle is greater than 50^o measured from due south counter-clockwise, the vertical fin on the east side will obstruct it. as shown on above figure

F)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 62 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.

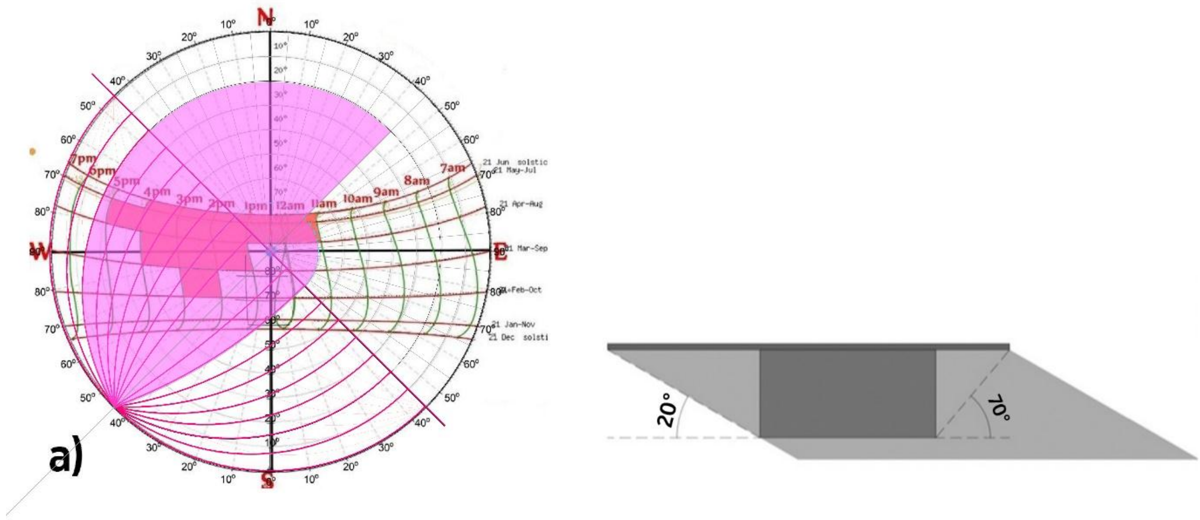


Figure 62 EPA recorded shadow angle, b) Front view with horizontal overhang and end angle (Source: Sunearthtools.com and Author)

Figure 62 a) and b) end profile angle for horizontal shading device or overhang the angel is recorded 20° to the North west side and 70° to South east side create desired shading for mapped overheated month and hour by extending building envelope shading elements.

Table 19 Addis Ababa shading angle using sun protractor (Source: Sunearthtools.com and Author, 2024)

Addis Ababa city lat: 8.514477and Lon: 39.269257			
Orientation	Orientation	HSA Vertical fine	EPA Overhang
South	South	50°	20° and 70°
South west	South west	-	30° and 78°

4.11 Calculation for horizontal building envelope elements (overhang) and vertical building envelope elements (fins) sizes

4.11.1 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

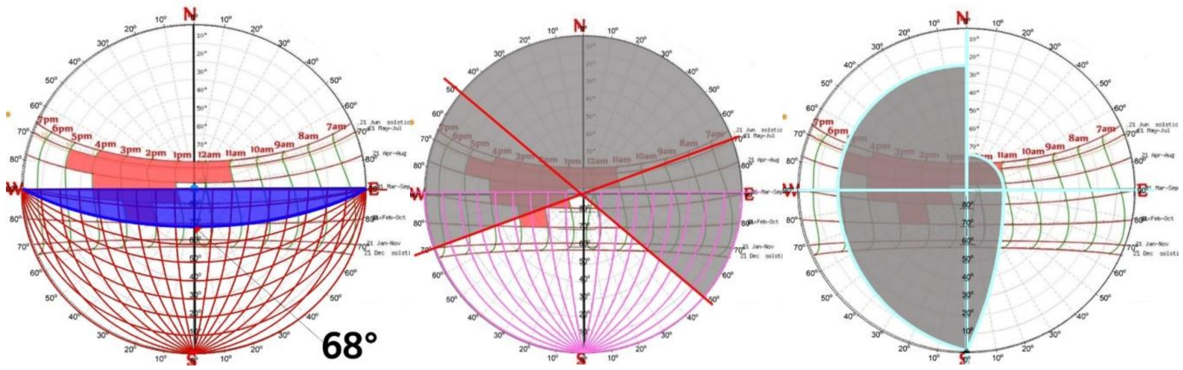
HSA = Horizontal Shadow

Angle AZI = Azimuth Angle

ORI = Orientation of building Facade

4.11.3.1 Shading device dimension for South facing room windows

Figure 63 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 = 68°, HSA 50^{o} **EAST** 70^{o} **WEST** with 20° to west side and 60° to east side.



VSA =68 **°** HSA = 50^{o} **EAST** 70^{o} **WEST** EPA =20^{o} EAST & 60^{o} **WEST**

Figure 63 VSA, HSA and EPA angle for south-facing room window (Source: Sunearthtools.com and Author)

With the window size of 1.20m width and 3.50m 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.

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

$$Fin\ Depth = \frac{Width}{\tan(HSA)} \qquad (eq.3)$$

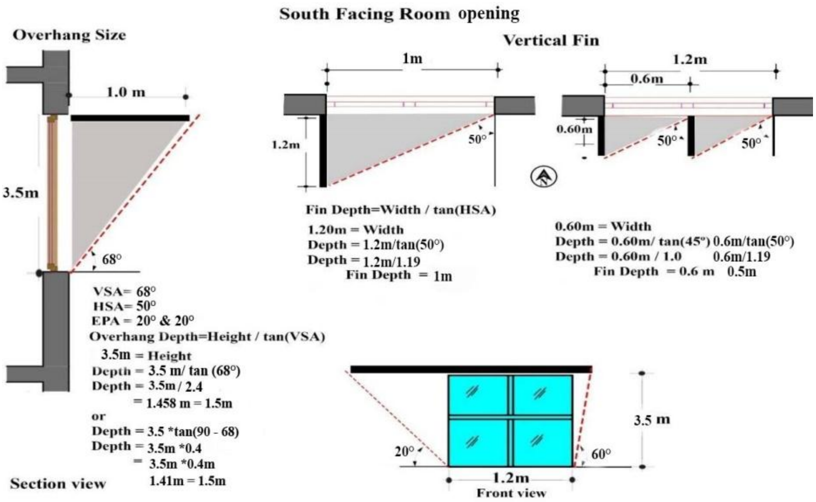
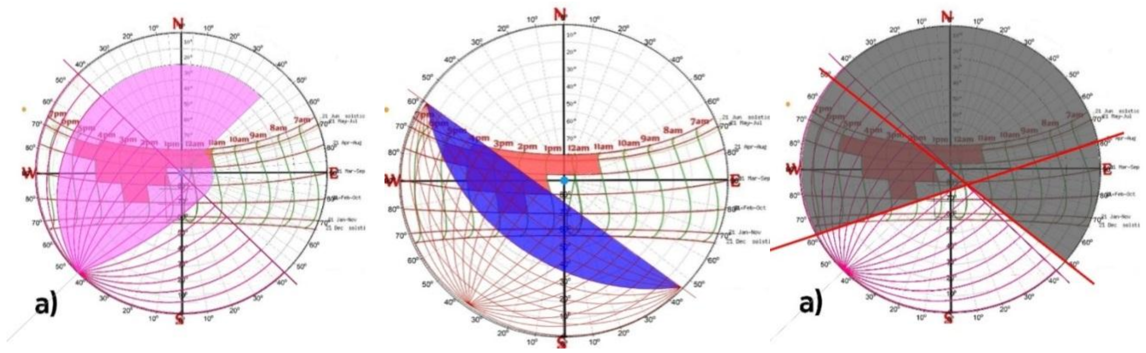


Figure 64 Calculation of south facing window overhang and fin size (Source: Author)

According to Figure 4:32 an overhang with a 68-degree cutoff angle (or a depth equal to 0.62 times the window's 1.2-meter height) and a 1.0-meter depth will provide effective shading. The overhang's end profile is 20 degrees to the west and 60 degrees to the east. In addition to the overhang, a vertical fin will offer total shading. 50 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 0.5m in order to reduce the fin depth two vertical fine by dividing the with in to have 0.5m times 1.0.

4.11.3.2 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.



VSA =45 ° HSA = 60^{o} **EAST** 50^{o} **WEST** EPA =20^{o} EAST & 70^{o} **WEST**

Figure 65 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.

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

$$Fin\ Depth = \frac{Width}{\tan(HSA)} \qquad (eq. 3)$$

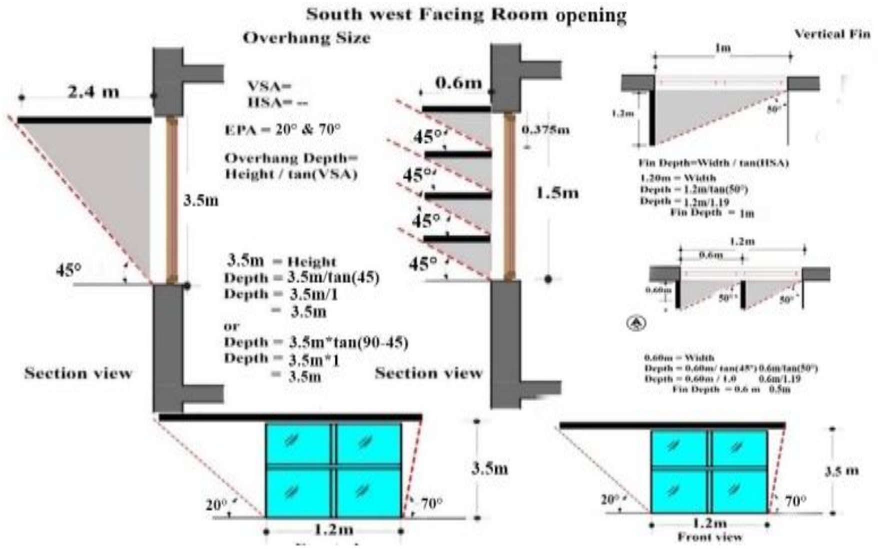


Figure 66 VSA, HSA and EPA angle for southwest facing room opening (Source: Sunearthtools.com and Author)

Figure 66: Calculation of southwest facing window overhang and fin size (Source: Author) According to Figure 66, 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 20 degrees to the north west side and 70 degrees to the south east side. In order to determine the appropriate size of shading device relative to the opening size, calculations were carried out as presented in Figure 4:34. The resulting overhang depth was found to be 3.5 meters, which is quite extended. 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.

4.12 Computer Simulation

Computer simulation performed on rooms existing building and proposed building envelope of awash building which have low performance from all selected office building envelopes. Computer simulations support provide objective data in accessing the performance of exterior building envelope 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 Addis Ababa weather dataset.

Figure 67 3D model of existing awash bank HOQ

Figure 68 3D model of proposed building envelope of awash bank HOQ

4.12.1 Simulation on south facing room

The simulation conducted in the south facing room in three different floor encompassed the distribution of temperature under two distinct scenarios. The first scenario involved the south facing room without building envelope, the second encompassed the room with proposed building envelope. The simulation was performed on a consistent space and opening dimensions, as illustrated in the corresponding Figure 67.

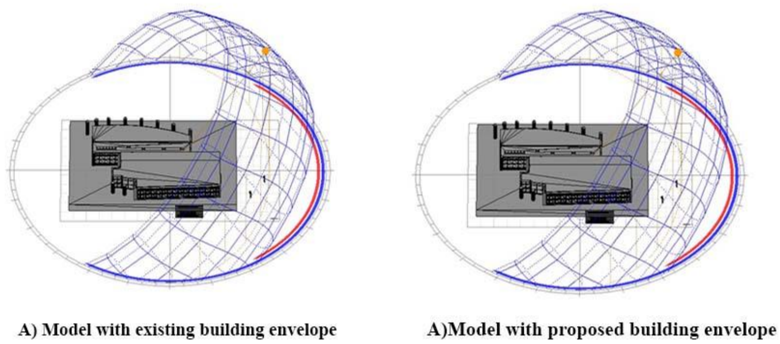


Figure 69 Model south-facing room with existing and with proposed building envelope (Source: Ecotect)

Based on a site survey, it was determined that an existing shading device with a depth of 1.2m and width of 0.5m 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 68°, HSA angle of 50°, EPA angle of 20° to the west side, and 60° to the east side. The overhang dimension is 1m in depth, and the vertical panel consists of two panels with a spacing of 0.5m and depth of 0.5m.

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

Chart 53 shows the results of south facing room a simulation for the inside with existing building envelope and outdoor temperature degrees Celsius for the date April 10 average hottest day where the maximum temperature is 23 0°C and minimum is 16 °C While the greatest temperature outside was 27 0°C and the lowest was 14°C the average temperature inside was 19 0°C making the average outside temperature 22 °C

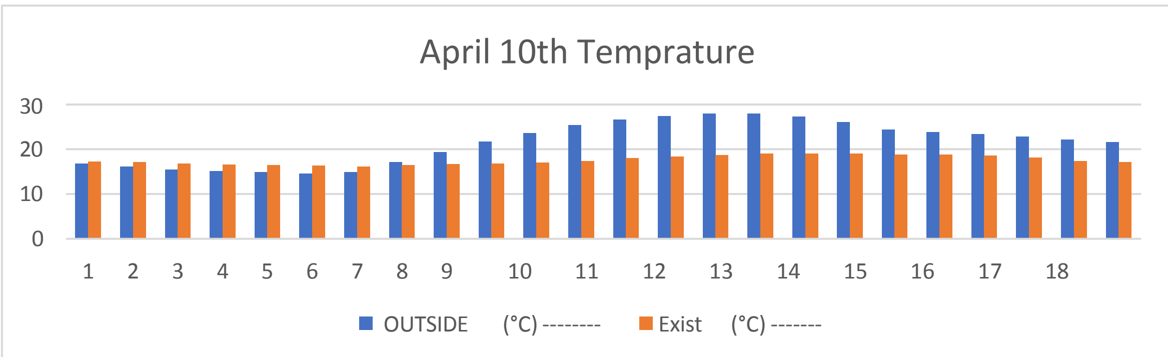
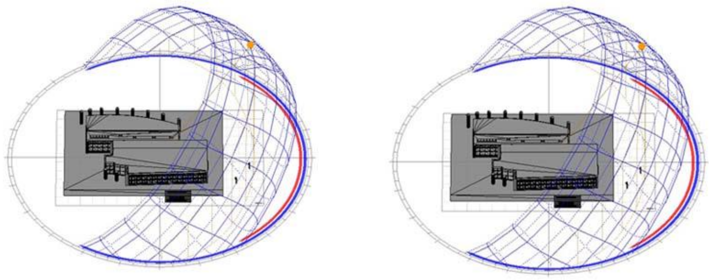


chart 51 Simulation outside and inside room with existing shading device (Source: Ecotect)

4.12.1.2 Simulation on South facing room inside temperature with existing and new building envelope of the ground floor



A) Model with existing building envelope A)Model with proposed building envelope

Figure 70 Simulation on South facing room inside temperature with existing and new building envelope of the ground floor

The maximum temperature for the inside is 18.0°C and minimum is 16.4°C as shown in Chart 4:20, Simulation result of inside temperature degree Celsius with existing building envelope and new building envelope on the date of 10th April hottest day average The building envelope predicted a maximum temperature of 18.0°C and a low temperature of 16.4°C however the new building envelope recorded maximum temperatures of 17.4°C and 17.0°C and minimum temperatures of 14.6°C and 15°C respectively However average temperature inside a room with existing building envelope was 16.59°C while the maximum temperature inside a room with new building envelope was 17.40°C and the minimum temperature outside was 16.4°C while the minimum temperature inside a room with new overhang shading was 14.6°C.

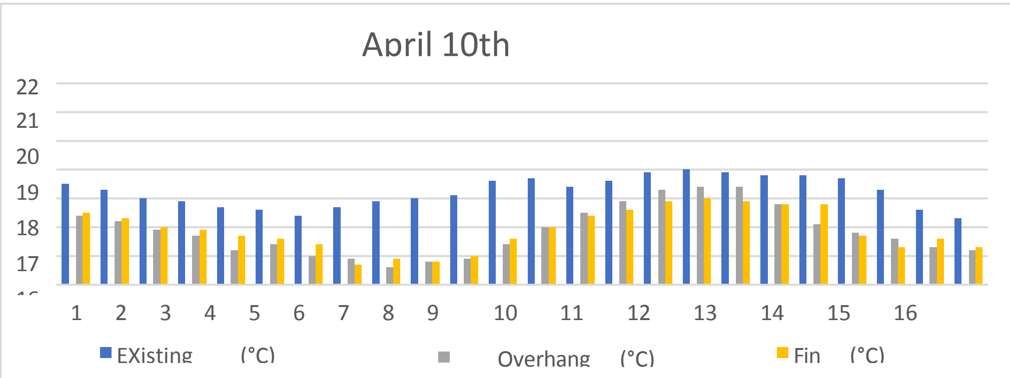


chart 52 Simulation on South facing room inside temperature with existing and new building envelope of the ground floor

4.12.1.2 Simulation on South facing room inside temperature with existing and new building envelope of the middle floor

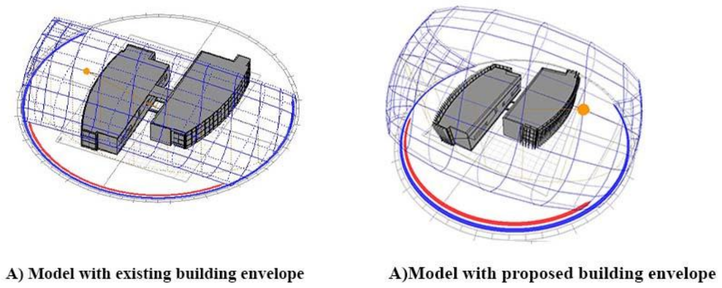


Figure 71 Simulation on South facing room inside temperature with existing and new building envelope of the middle floor (Source: Ecotect)

The maximum temperature for the inside is 17.3°C and minimum is 16.1°C as shown in Chart 4:20, Simulation result of inside temperature degree Celsius with existing building envelope and new building envelope on the date of 10th April hottest day average The building envelope predicted a maximum temperature of 17.4°C and a low temperature of 16.3°C however the new building envelope recorded maximum temperatures of 17 °C and 17.1°C and minimum temperatures of 14.5°C and 15°C respectively However average temperature inside a room with existing building envelope was 16.59°C while the maximum temperature inside a room with new building envelope was 17.30°C and the minimum temperature outside was 16.3°C while the minimum temperature inside a room with new overhang shading was 14.5°C.

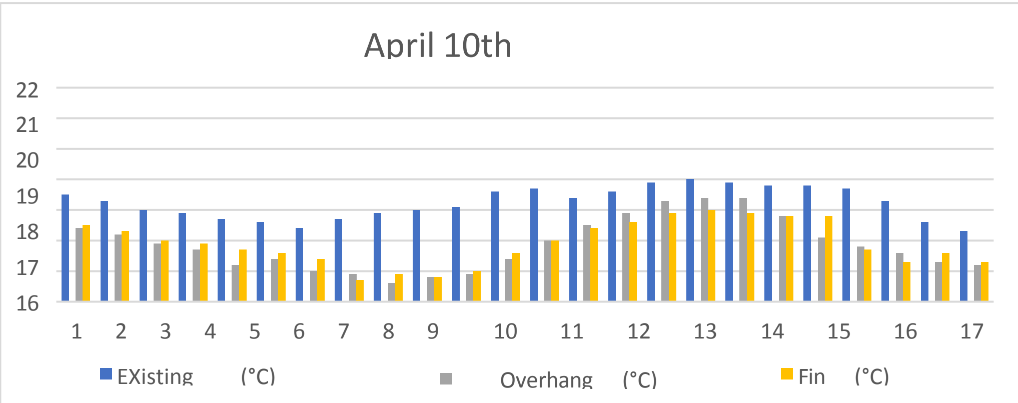
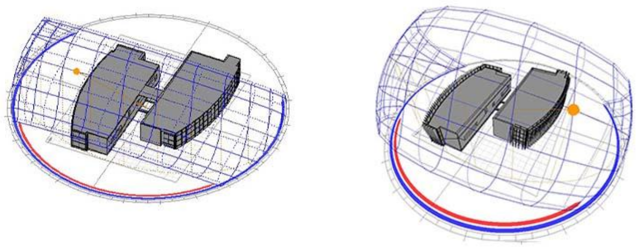


Chart 53 Simulation on South facing room inside temperature with existing and new building envelope of the middle floor (Source: Ecotect)

4.12.1.2 Simulation on South facing room inside temperature with existing and new building envelope of the upper floor



A) Model with existing building envelope A)Model with proposed building envelope

Figure 72 Simulation on South facing room inside temperature with existing and new building envelope of the upper floor

Figure 73 Simulation on South facing room inside temperature with existing and new building envelope of the upper floor (Source: Ecotect)

The maximum temperature for the inside is 17.7°C and minimum is 16.1°C as shown in Chart 4:20, Simulation result of inside temperature degree Celsius with existing building envelope and new building envelope on the date of 10th April hottest day average The building envelope predicted a maximum temperature of 17.2°C and a low temperature of 16.1°C however the new building envelope recorded maximum temperatures of 17.3°C and 17 °C and minimum temperatures of 14.4°C and 15°C respectively However average temperature inside a room with existing building envelope was 16.57°C while the

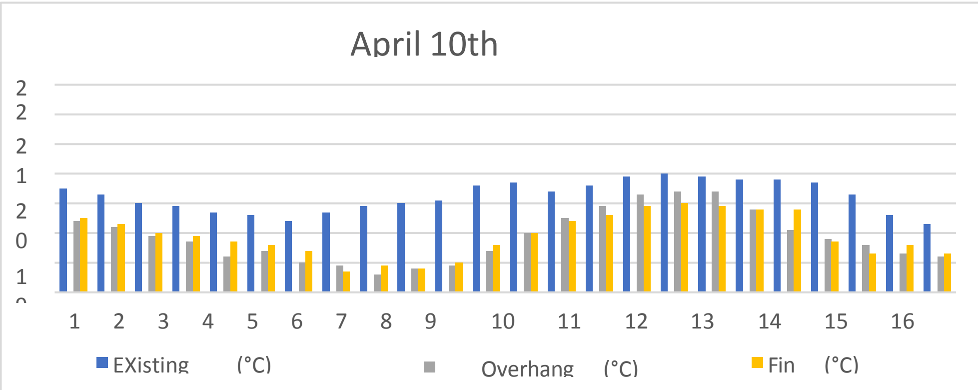


chart 54 Simulation on South facing room inside temperature with existing and new building envelope of the upper floor (Source: Ecotect)

maximum temperature inside a room with new building envelope was 17.30°C and the minimum temperature outside was 16.1°C while the minimum temperature inside a room with new overhang shading was 14.4°C.

4.12.2 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. 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.

4.12.2.1 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, 22.2°C indicates maximum temperature and minimum is 19.5°C for the indoors. However, the interior temperature was 16.5°C on average, while the outside temperature was 27.0°C on average and 13.6°C on lowest, making the outdoor temperature on average 20.55°C.

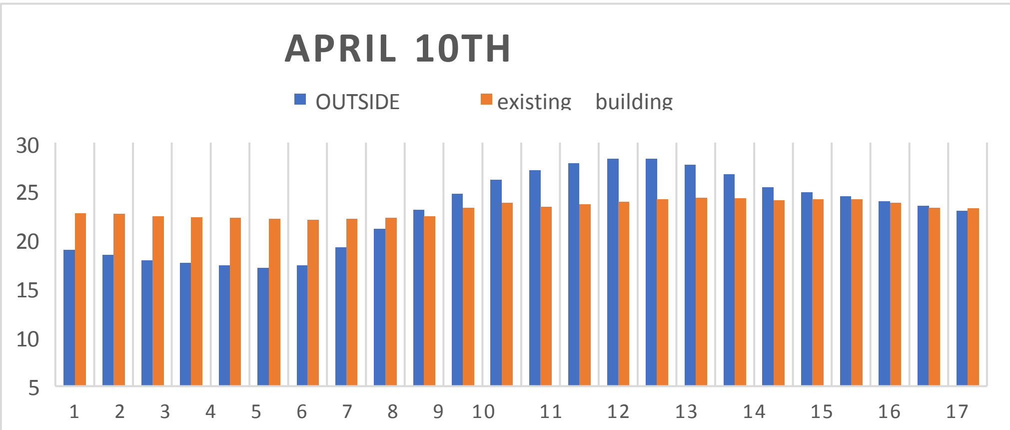


chart 55 Simulation outside and inside south west facing room with existing building envelope (Source: Ecotect)

4.12.2.2 Simulation on Southwest facing room inside temperature with existing and new building envelope on the ground floor

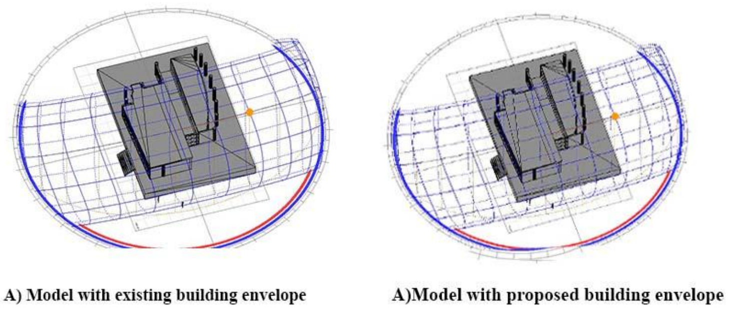


chart 56 Simulation on Southwest facing room inside temperature with existing and new building envelope on the ground floor(Source: Ecotect)

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 20.5 °C for the inside. Existing shading devices simulated maximum 22.2 °C and minimum 19.5 °C, whereas the new overhang is 21.8 °C with maximum temperature and 17.6 °C inside minimum temperature. However, for indoor the average temperature with existing shading being 20.86°C while the 21.8°C was the maximum obtained for new overhang shading device and minimum being 19.5°C for exiting, when 18.6°C is minimum temperature for room with new overhang shading device.

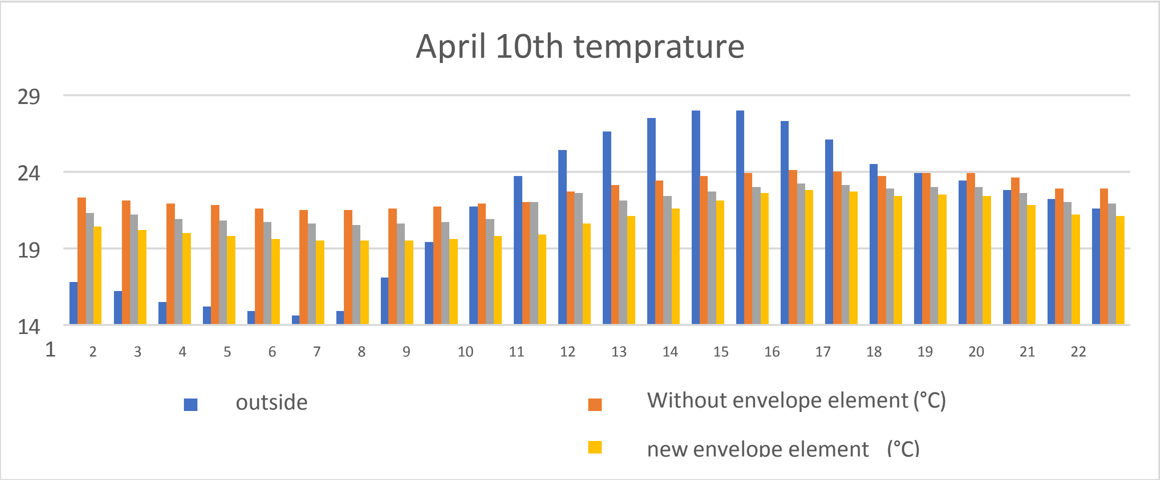
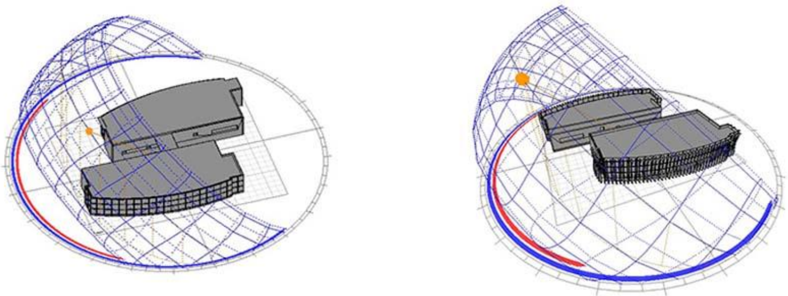


chart 57 Simulation on Southwest facing room inside temperature with existing and new building envelope on the ground floor (Source: Ecotect)

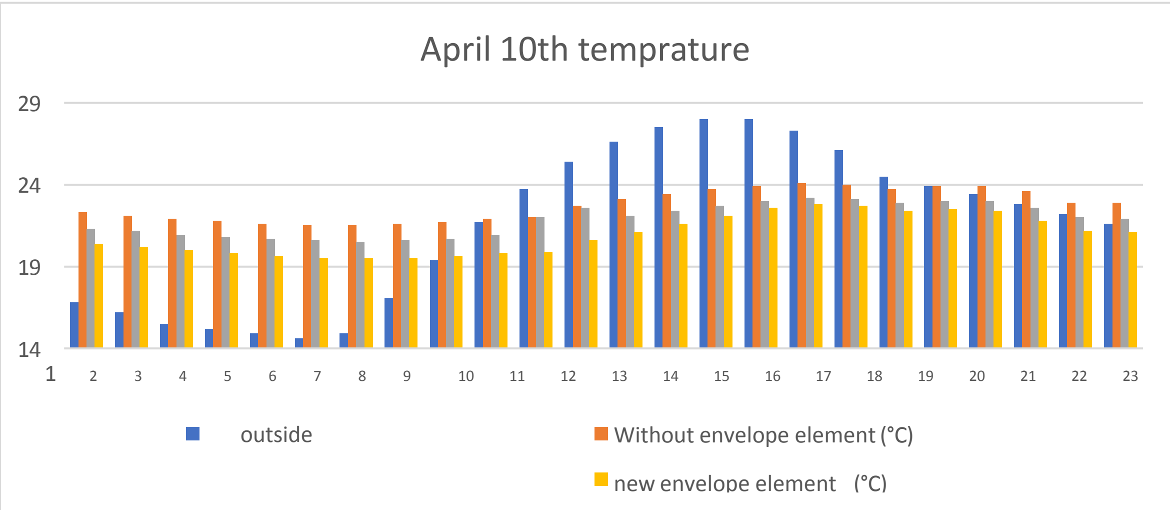
4.12.2.2 Simulation on Southwest facing room inside temperature with existing and new building envelope on the middle floor.



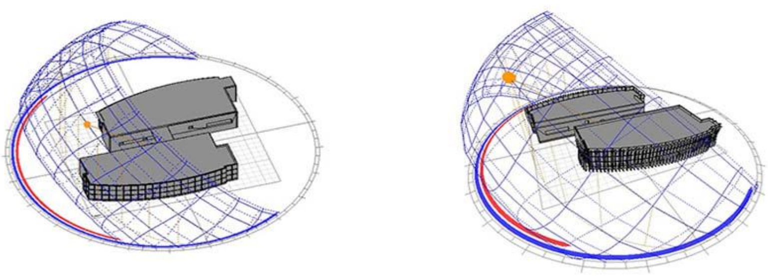
A) Model with existing building envelope A)Model with proposed building envelope

Figure 74 shows for the date 10th April, the hottest day on average, with shading elements,

22.6°C displays maximum temperature and minimum is 19.5°C for the inside of a west- facing room with current shading and external temperature degree Celsius. However, the average temperature inside was 21.07°C, while the minimum and highest temperatures outside were 13.6°C and 28.0°C, respectively. As a result, the average temperature outside is 20.55°C.



4.12.2.2 Simulation on Southwest facing room inside temperature with existing and new building envelope on the upper floor.



A) Model with existing building envelope A)Model with proposed building envelope

Figure 75shows for the date 10th April, the hottest day on average, with shading elements,

22.3°C displays maximum temperature and minimum is 19.2°C for the inside of a west- facing room with current shading and external temperature degree Celsius. However, the average temperature inside was 21.02°C, while the minimum and highest temperatures outside were 13.2°C and 27.5 °C, respectively. As a result, the average temperature outside is19.5°C.

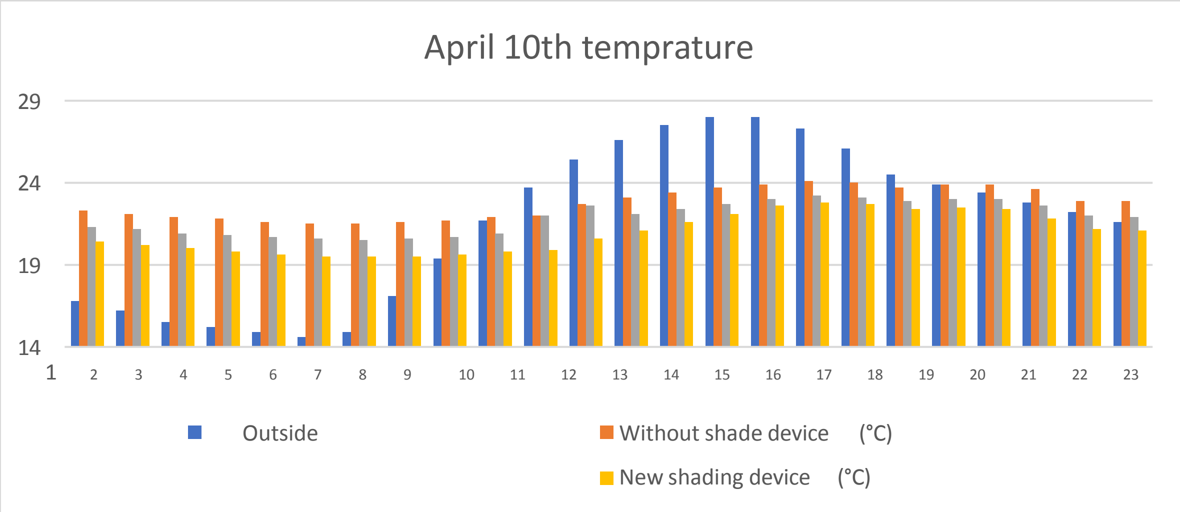


chart 58 shows for the date 10th April, the hottest day on average, with shading elements,

4.13 Summary of Discussion

For understanding the level of thermal satisfaction occupant total of 56 occupants were involved in the survey, of which 27 were male, accounting for 48.3%, and 29 were female, accounting for 51.7% 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 16 to over 60 years old. A total of 6 building blocks from 3 sites were surveyed. Building envelope is in two different buildings. The thermal comfort response of occupant over awash bank building 7:00pm-8:00pm shows the highest thermal preference about 51.6% and 8.6% were uncomfortable, 11.9% were slightly uncomfortable. The thermal comfort response of awash bank building has the weakest performance from the entire three sites. Table 43 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 52% of respondents. Field measurement of Environmental variable took place in three sites by comparing two buildings in one site. From megenagna site the bethlhem plaza building envelope showed readings of maximum 28.9 °C and minimum 23 °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. From stedium site the yeha city center building envelope showed readings of maximum 28.9 °C and minimum 24.2 °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. From berhawi site the awash building envelope showed readings of maximum 29.3 °C and minimum 24.6 °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 building envelope of Bethlehem yeha and awash bank are thermally discomfort. As well as daylight illuminance, relative humidity and air velocity of room with building are discomfort and not giving required solution. Identifying sun position of Addis ababa 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, April 2:00pm-2:00pm, and May from 12:00 noon-4:30pm are hottest months of Addis Ababa city required a good building envelope. Proportion and Dimension of building envelope elements for overheated Period identifying using sun protractor and time plot table from these two-orientation used building envelope the optimal dimension is stated for south orientation VSA 68°, HSA 50° and EPA 20° and 70°, Overhang at a cut-off angle of 58 degrees (or depth equivalent to 0.6 times the window height 3.5m) the overhang depth 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°, and EPA 20° and 70°.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 45°, HSA no and EPA 20° and 70° The vertical element 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 them into have 0.6m times 1.0 the size of fine will be 0.6m.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this paper, the effects of building envelope on indoor thermal comfort are examined in an Addis ababa City office buildings. The study was carried out using both objective and subjective evaluation techniques, including questionnaires, and variable measurements (temperature, airspeed, daylight illumination, and humidity) were recorded for two warmest months for 20 days using different measuring tools, including ASHRAE 55's 7-point sensational scale. The questionnaires were given to 59 samples, and software simulations were run on 2 sample buildings on 3 different floors with a similar layout. From the 6 sample buildings, 2 buildings used building envelope treatment. The occupant's response to thermal satisfaction implies discomfort and warmer weather conditions. When comparing the room with a building envelope to the room without a building envelope, both rooms have almost similar discomfort, but the room with a building envelope shows some improvement over the other. Hidasse building one of the building that used building envelope are oriented in north east and south-west facing rooms with a maximum long shading span of 0.65 m and wegagen bank building envelope are oriented in north east with a maximum long shading span of 0.8 m and wall Height of 3.5 m.

The temperature of a Hidasse building has been recorded a maximum of 27.7 °C and 22 °C is the minimum temperature. When outdoor temperatures recorded a maximum of 29.2 °C and 24.4 °C is the minimum temperature. Air velocity of hidasse rages from 0.00 m/s to 0.98 m/s While outdoor 2.41 m/s, while the lowest was 0.53 m/s. Relative humidity ranges from 37% and 22% daylight illumination from 150 lux to 575 lux, while outdoor ranges from 320 lux to 1787 lux.

The temperature of a Bethlehem plaza building has been recorded a maximum of 28.9 °C and 23 °C is the minimum temperature. When outdoor temperatures recorded a maximum of 29.2 °C and 24.4 °C is the minimum temperature. Air velocity of Bethlehem rages from 0.00 m/s to 0.97 m/ss while outdoor 2.41 m/s, while the lowest was 0.53 m/s. Relative humidity ranges from 37%, and 21% daylight illumination from 570 lux to 163 lux, while outdoor ranges from 320 lux to 1787 lux.

The temperature of a wegagen bank building has been recorded a maximum of 26.9 °C, and 23.1 °C is the minimum temperature. When outdoor temperatures recorded a maximum of 29.3 °C and 24.1°C is the minimum temperature. Air velocity of wegagen rages from 0.00 m/s to 0.97 m/s While outdoor 2.7 m/s, while the lowest was 0.3 m/s. Relative humidity ranges from 32% and

21% daylight illumination from 151 lux to 576 lux, while outdoor ranges from 321 lux to 1788 lux.

The temperature of a yeha city center building has been recorded a maximum of 28.9 °C, and 24.2 °C is the minimum temperature. When outdoor temperatures recorded a maximum of 29.3 °C and 24.1°C is the minimum temperature. Air velocity of yeha city center rages from 0.00 m/s to 0.99 m/s m/s While outdoor 2.7 m/s, while the lowest was 0.3 m/s. Relative humidity ranges from 32% and 20% daylight illumination from 569 lux to 162 lux, while outdoor ranges from 321 lux to 1788 lux.

The temperature of an EBC building has been recorded a maximum of 27.8°C, and 22.7 °C is the minimum temperature. While outdoor temperatures recorded a maximum of 24.2 °C to 29.3 °Cis the minimum temperature. Air velocity of EBC rages from 0.00 m/s to 0.97 m/s While outdoor ranges from 0.3 m/s to 2.7 m/s. Relative humidity ranges from 33% and 23% and outdoor Relative humidity ranges from 35% and 25% daylight illumination from 152 lux to 575 lux, while outdoor ranges from 320 lux to 1787 lux.

The temperature of an awash bank building has been recorded a maximum of 28.9 °C a, and 23.9 °C a °C is the minimum temperature. While outdoor temperatures recorded a maximum of 24.2 °C to 29.3 °Cis the minimum temperature. Air velocity of awash bank rages from 0.00 m/s to 0.98 m/s While outdoor ranges from 0.3 m/s to 2.7 m/s. Relative humidity ranges from 31% and 21% and outdoor Relative humidity ranges from 35% and 25% daylight illumination from 568 lux to 163 lux, while outdoor ranges from 320 lux to 1787 lux.

Ecotect software for the simulation of a south-facing room with existing building envelope and a new building envelope using a sun protractor for overheated months and hours shows that the new building envelope had good performance on temperature distribution. On thermal comfort, building envelope have an impact. Buildings with appropriate building envelope increase thermal comfort. In conclusion, the existing building envelope have low performance on occupants thermal comfort, and the new building envelope design approaches for south orientation VSA 68°, HSA 50° and EPA 30° and 88°, Overhang at a cut-off angle of 58 degrees, for west facing VSA 32°, HSA no and EPA 20° and 60° The vertical fin should have a cut-off angle of 50 degrees, For south west VSA 34°, EPA 30° and 78°. Understanding the sun path, opening size, and overheated period in considering HSA, VSA, and EPA have better performance.

5.2 Recommendation

I recommend that to achieve good thermal performance, it is advisable to consider the building envelope. In order to successfully implement such strategies,

- It is crucial to have a comprehensive understanding of the local climate and the periods when the building is most exposed to excessive solar heat. By considering those factors, we can develop innovative building envelope solutions that not only enhance the aesthetic appeal of the building but also ensure the comfort, performance and well-being of its occupants.
- Building envelope can range from simple elements and awnings to more complex systems that utilize dynamic building envelope panels, all designed to adapt to the changing weather conditions. By carefully selecting and integrating these building envelope elements into the glazed building 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 specially 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 the evaluation of the impact of the building envelope on the building's thermal performance and energy consumption. By analyzing 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 which affects the energy consumption of buildings.

5.3 Design recommendation

For effective building envelope element the angle and profile factor helps to determine the optimum building envelope element design for 8 cardinal direction using overhang width and fin depth calculation formula Equation 4:3 as follow in Table 5:1 to create effective building envelope for Addis Ababa office buildings.

Table 20 Table 5:1 Effective shading device recommended for Ababa office buildings

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
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
West facing		
Fin size=not effective	Overhang size=0.6m Depth Spacing 0.3	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	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=0.6m Depth, 0.6m spacing	Overhang size= 0.6 Depth spacing 0.3m	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

5.3 Implication for further Research

I recommend Additional research and experimentation are necessary to explore the potential of implementing effective building envelope to ensure thermal comfort for building occupants. Utilizing those techniques has the ability to enhance the daylight energy demands of radiation-vulnerable glazed buildings and the climate conditions in Addis Ababa. The overheated period shading design approaches can offer very important value to the office building design guidelines. It is important to explore the various building envelope techniques that can be employed for glazed surfaces. These structures receive direct sunlight, during the heat gains are needed in the morning but not so much in the afternoon. Achieving optimal thermal comfort throughout the day without exterior building envelope elements or components is very hard. Overheated time-based building envelope design approaches can provide useful insights that can improve office building design guidelines. This, in turn, presents an opportunity for professionals to come forward with innovative design solutions that integrate the findings of relevant literature. The ultimate goal is to optimize the thermal and visual performance of the vulnerable space because of glazed opening.

5. Reference

Abass, F, L H Ismail, I A Wahab, W A Mabrouk, and H Kabrein. 2021. "Indoor Thermal Comfort Assessment in Office Buildings in Hot-Humid Climate." *IOP Conference Series: Materials Science and Engineering* 1144 (1): 012029. https://doi.org/10.1088/ 1757-899x/ 1144/1/012029.

Alwetaishi, Mamdooh S. 2016. "Impact of Building Function on Thermal Comfort: A Review Paper." *American Journal of Engineering and Applied Sciences* 9 (4): 928–45. https://doi.org/10.3844/ajeassp.2016.928.945.

Ascione, Fabrizio, Rosa Francesca De Masi, Filippo de Rossi, Silvia Ruggiero, and Giuseppe Peter Vanoli. 2016. "Optimization of Building Envelope Design for NZEBs in Mediterranean Climate: Performance Analysis of Residential Case Study." *Applied Energy* 183: 938–57. https://doi.org/10.1016/j.apenergy.2016.09.027.

Bachrun, Abraham Seno, Ting Zhen Ming, and Anastasia Cinthya. 2019. "Building Envelope Component To Control Thermal Indoor Environment in Sustainable Building: A Review." *Sinergi* 23 (2): 79. https://doi.org/10.22441/sinergi.2019.2.001.

Haileleul, Teaka. 2015. "Evaluation of Selected Addis Ababa Buildings with Respect to the Green Building Features Title of Thesis : Evaluation of Selected Addis Ababa Buildings with Respect to the Green Building Features," 167.

Hydro, Manitoba. 2020. "Manitoba Hydro Place, Winnipeg, Canada." *The Tall Buildings Reference Book,* 398–405. https://doi.org/10.4324/9780203106464-51.

Iwaro, Joseph, and Abrahams Mwasha. 2013. "The Impact of Sustainable Building Envelope Design on Building Sustainability Using Integrated Performance Model." *International Journal of Sustainable Built Environment* 2 (2): 153–71. https://doi.org/10.1016/ j.ijsbe.2014.03.002.

Kumar, Gireendra, and Gaurav Raheja. 2016. "Design Determinants of Building Envelope for Sustainable Built Environment: A Review." *International Journal of Built Environment and Sustainability* 3 (2). https://doi.org/10.11113/ijbes.v3.n2.127.

Raatikainen, Mika. 2016. *Intelligent Knowledge Discovery on Building Energy and Indoor Climate Data*.

Symonds, Percival, and Percival M. Symonds. 2016. "The Case Study as a Research Method." *Case Studies,* no. January: 15–15. https://doi.org/10.4135/9781473915480.n2.

Ul, C Q C, and T U V Ce. 2010. "电容 ，电容的作用详细介绍 - 电子电路图 ，电子技术资料

网 站 Page 1 of 4 ;," 3–6.

Žigart, Maja, Rebeka Kovačič Lukman, Miroslav Premrov, and Vesna Žegarac Leskovar. 2018. "Environmental Impact Assessment of Building Envelope Components for Low-Rise Buildings." *Energy* 163: 501–12. https://doi.org/10.1016/j.energy.2018.08.149.

Zuhaib, Sheikh, Richard Manton, Corey Griffin, Magdalena Hajdukiewicz, Marcus M. Keane, and Jamie Goggins. 2018a. "An Indoor Environmental Quality (IEQ) Assessment of a Partially-Retrofitted University Building." *Building and Environment* 139 (May): 69–85. https://doi.org/10.1016/j.buildenv.2018.05.001.

———. 2018b. "An Indoor Environmental Quality (IEQ) Assessment of a Partially-Retrofitted University Building." *Building and Environment* 139: 69–85. https://doi.org/10.1016/j.buildenv.2018.05.001.

Ali, A., & Abdel-Rhman, H. I. (2003). Determination of the solar motion from radial velocity. https://www.researchgate.net/publication/261027451

Liu, L. (2023). Simulation Optimization of Energy-saving Techniques for Gymnasiums in Jiangxi Province Based on DesignBuilder. E3S Web of Conferences, 439. https://doi.org/10.1051/e3sconf/202343901005

Abraham Seno Bachrun1, 2. T. (2019). BUILDING ENVELOPE COMPONENT TO CONTROL THERMAL. SINERGI.

Mansouri, K. (2023). Investigating the effectiveness of the Building's envelope materials in hot. IJANSER.

APPENDIX

Questioner

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

First of all, thanks for your voluntariness to accept 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 building envelope on indoor thermal quality of office buildings: the case of Addis Ababa**.

Sheet Number: _____	**Site name: _______________**	**building: _________**
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:	□**Working** **Other activities :** ------------------------------------	
How many years you are working in this building?		□>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 technique is used to regulating or adjust 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 (oC) ______________ 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**			

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

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)

1.1. 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…5:00p

m

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…5:00m

Morning ☐ Noon ☐ After Noon ☐