The Impact of Orientation on Indoor Thermal Performance in Curtain-Walled Office Rooms : In The Case Of Adama, Ethiopia

Maedot Berhanu Shitark

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
Masters of Science in Environmental Architecture

Office of Graduate Studies
Adama Science and Technology University

June, 2025

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Declaration

I hereby declare that this Master Thesis entitled **“The Impact of Orientation on Indoor Thermal Performance in Curtain-Walled Office Rooms : In The Case Of Adama, Ethiopia”** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

Maedot Berhanu Shitark	________________________	________________
Name of student	Signature	Date

Recommendation of Advisors

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **“The Impact of Orientation on Indoor Thermal Performance in Curtain-Walled Office Rooms : In The Case Of Adama, Ethiopia”** prepared under my guidance by Maedot Berhanu. submitted in partial fulfillment of the requirements for the degree of Master’s of Science in Environmental Architecture. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr Yared Girma	______________________	______________
Major Advisor	Signature	Date

Approval of Board of Reviewers

We, the advisors of the thesis entitled **"The Impact of Orientation on Indoor Thermal Performance in Curtain-Walled Office Rooms : In The Case Of Adama, Ethiopia"** and developed by Maedot Berhanu, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

____________________	______________________	____________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Maedot Berhanu have read and evaluated the thesis entitled **"The Impact of Orientation on Indoor Thermal Performance in Curtain-Walled Office Rooms : In The Case Of Adama, Ethiopia"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Environmental Architecture.

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ACRONYMS AND ABBREVIATIONS

AC	Air Conditioning
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CBE	Center for the Built Environment
CFD	Computational Fluid Dynamics
CLO	Clothing Insulation Unit
EPW	EnergyPlus Weather File
HVAC	Heating, Ventilation, and Air Conditioning
ISO	International Organization for Standardization
IEA	International Energy Agency
MET	Metabolic Equivalent Task
NW	Northwest
PPD	Predicted Percentage of Dissatisfied
PMV	Predicted Mean Vote
RH	Relative Humidity
SE	Southeast
SET	Standard Effective Temperature
TMY	Typical Meteorological Year
WFR	Window-to-Floor Ratio
WWR	Window-to-Wall Ratio

ABSTRACT

The trend of constructing a curtain-facade buildings is increasingly common in modern days due to their modern aesthetic and ability to maximize natural daylight. This makes maintaining indoor thermal comfort become even more challenging for cities like Adama which have a hot climates. These buildings have high solar heat gain because of the low insulation and high solar transmittance behaviour of the materials this makes their thermal performance affected by room orientation difference. However, there have been limited studies conducted in Ethiopia to explore how room orientation affects thermal performance. This study investigated the impact of room orientation on indoor thermal performance of selected curtain-walled office buildings in Adama, by analyzing 24 orientation (0^0 and 360^0 have same value) and then giving more focus on the Northwest (NW) and Southeast (SE) orientation based on optimum chart. It uses a mixed-method approach combining physical measurement, occupant survey and computer simulation. Field measurements were carried out during working hours from April to May 2025 twice a day. The results shows that specially in afternoon period SE-facing rooms has a higher air temperature and relative humidity value when compared to NW-facing room. The simulation analysis also confirmed that NW-facing rooms have a higher comfort hours the SE-facing rooms. Also the respondents of the occupant thermal comfort survey revealed that they prefer a cooler condition and they don't feel comfortable especially in the afternoon. Based on the obtained results, it can be concluded that Northwest (NW)-facing rooms provide better thermal performance and longer comfort hours compared to Southeast (SE)-facing rooms. Therefore, to optimize indoor thermal comfort in curtain-walled office buildings in Adama, it is recommended that future office buildings should be oriented along South-north axis (curtain-wall should be in the north side), while for existing buildings southeast-facing facades should use a proper external shading devices and low emission glass, and adapting an orientation-based design strategies can improve the thermal comfort in this climate context.

Keywords : *Thermal performance, Curtain-walled buildings, Room orientation, Thermal comfort, Solar heat gain, Adama, Mixed-method approach*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

According to International Energy Agency [IEA] (2022), Buildings operation accounts 30% of global final energy consumption and 26% of global energy-related emissions which the 8% is attributed to direct emissions in buildings and the rest 18% is indirect emissions from the generation of electricity and heat used in buildings. And it mainly uses this energies to maintain indoor thermal comfort which is a condition where occupants feel neither too hot nor too cold. This is particularly critical in office buildings where individuals spend a significant portion of their day and maintaining it is essential for their productivity and well-being (Salonen et al., 2013). Keeping its levels balance can prevent pain, illnesses linked to heat stress, and even thermal shock (Sun ,2023).

In now days energy efficiency and thermal comfort have become main priorities in modern buildings design. ISO (2005) defined thermal comfort as the condition where the occupants feel satisfied with their thermal environment. It depends on factors like air temperature, humidity, air velocity, and personal factors. Balancing these factors reduces reliance on mechanical cooling and heating, especially in regions with hot climates.

Orientation of buildings plays a critical role in determining indoor thermal conditions. This is because of the variation of the amount of solar radiation that is received by the building. A well-oriented building can significantly reduce energy use, which is used to maintain indoor thermal comfort, by minimizing unwanted solar radiation in hot seasons and maximizing it during cooler periods. While poor-orientation can cause overheating or overcooling which will lead to excessive reliance on HVAC systems. Based on Khedari et al (2001), east-facing rooms are exposed to direct sunlight in the morning, while west-facing rooms are in the afternoon. This will be contributing to thermal discomfort for both. On the other hand, north- and south-facing rooms generally experience more stable thermal conditions, though they are still affected by the local climate and the building's specific design.

Curtain-walled facades buildings are featured by their large glass windows and a metal frames. And because of this they are increasingly in number due to their aesthetic appeal and ability to maximize natural light. However, these facades can cause a thermal issues due to low insulation and high solar transmittance behaviour. They allow a significant solar heat gain through the windows which will cause the temperature variations inside a building (Givoni, 1994; Salonen et al., 2013).

Adama has a hot climates where there is a high temperatures and direct solar radiation . As the trend of constructing a glass-facade buildings in the city continued maintaining indoor thermal comfort becomes even more challenging. Rooms facing different directions within the same building can experience significant differences in thermal conditions.

Despite the growing number of curtain-façade buildings and the importance of understanding these dynamics, limited studies have been conducted in Ethiopia to explore how room orientation affects thermal performance. Existing research in the country focuses on residential buildings or broader climatic adaptation strategies without addressing orientation-specific design considerations for office spaces. This gap is greatly significant for buildings with curtain-walled facades, as these designs present unique challenges in terms of solar heat gain and thermal comfort. This study aims to address this gap by investigating the indoor thermal conditions of rooms with opposite orientation in office buildings with curtain-walled facades in Adama. By examining the influence of room orientation on indoor thermal Performance, this research seeks to provide valuable insights into improving the thermal comfort of office buildings occupants in hot climates like that of Adama.

1.2 Statement of the problem

Curtain-walled office buildings are becoming increasingly common in modern days due to their modern aesthetic and ability to maximize natural daylight. As the trend of constructing a curtain-facade buildings grows, maintaining indoor thermal comfort becomes even more challenging for cities like Adama which have a hot climates where there is a high temperatures and direct solar radiation. This is due to that orientation of many buildings are often determined by the site and its surrounding road network. Peoples prioritize having the large side as a building front and aligning the building's front with street to increase visibilty and aesthetics, rather than considering optimal solar orientation at the first place. Beside that most of this buildings often have a curtain-wall facades on both front and rear sides or they are fully glazed without any external shading devices. This will increase exposure to solar heat gain making it harder to maintain comfortable indoor environment due to their higher solar heat gain and lower insulation properties. And according to Herrera (2007), if there is no shading this facades allow more than 80% of heat to enter to the building through them.

One of the key factors influencing indoor thermal performance in buildings is room orientation, as different orientations receive varying amounts of solar radiation throughout the day (Khedari et al, 2001). According to optimum orientation charts, certain directions are determine as the worst orientation. This orientations receives the highest direct solar radiation during hot periods or they faces the longest sun exposure during the hottest hours of the day. This study focuses on this orientation from the chart and compares it with its opposite direction to better understand thermal performance due to orientation.

Although there are some international studies that focus on this their findings cannot be used in the local context because the quality of glass facades in Ethiopia is significantly influenced by issues related to material selection and system specification, often linked to limited technical knowledge and a lack of comprehensive regulations. When architects select and specify glass for building facades, the primary criteria are often product availability, experience, cost, and aesthetical values whereas performance characteristics and properties of glass aren't mentioned (Mulatu, B, 2019). And also there is difference in occupant behaviour. There are also research that has been conducted in Ethiopia, Such as studies by Getachew and Gabore (2020) and by Yadeta et al. (2021) this studies examined thermal comfort in naturally ventilated sub-city office buildings in Addis Ababa and evaluating thermal comfort levels in naturally ventilated residential buildings in Jimma. These studies do not specifically investigate orientation-based thermal variations in office environments with curtain-walled facades. Moreover, thermal comfort is adaptive and influenced by clothing behavior and daily activity patterns which vary across regions (de Dear & Brager, 1998). Therefore, localized research is needed.

This research aims to fill that gap by focusing on the influence of room orientation on the thermal performance of curtain-façade office rooms in Adama. Addressing this is essential for developing sustainable office building designs that enhance occupant comfort while reducing energy demand. By analyzing the indoor thermal conditions of different room orientations in curtain-walled office, this study seeks to identify worst-case orientation (poor thermal performance) and compares it with its opposite direction to better understand and propose passive design strategies to mitigate their impact.

1.3 Objectives of the study

1.3.1 General objective

The general objective of this study is to investigate the impact of orientation on indoor thermal performance in curtain-walled office rooms in Adama, Ethiopia.

1.3.2 Specific objectives

- ✓ To measure and compare indoor thermal parameters of selected rooms in curtain-walled office buildings.
- ✓ To identify optimum azmitual angle for curtain-walled office buildings in Adama.
- ✓ To assess occupant thermal perception and comfort levels based on room orientation.

1.4 Research questions

- ✓ How do indoor thermal parameters vary between selected rooms in curtain-walled office buildings with different orientations?
- ✓ What is the optimum azimuthal orientation for curtain-walled office buildings in Adama in terms of thermal comfort performance?
- ✓ How does room orientation affect occupant thermal perception and comfort levels?

1.5 Scope of the study

This study focuses on analyzing the influence of orientation on indoor thermal performance in curtain-walled facade office rooms in Adama, Ethiopia. As the number of curtain-walled buildings are increasing in the city. This research is geographically centered on the center of Adama, a city known for its hot climate, high daytime temperatures, and significant solar radiation. It is geographically located in 8°26 ′15″N to 8°37 ′00″N latitude and 39°12′15″E to 39°19′45″E longitude.

The research includes examining and comparing selected rooms which receive higher solar radiation with its opposite orientations based on optimum orientation charts and limits its assessment to indoor thermal comfort parameters (air temperature, air velocity, and humidity) along with occupant thermal satisfaction using ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) models. Measurements is conducted during regular office hours to reflect the thermal environment experienced by building occupants throughout the workday and to isolate orientation as the primary variable affecting indoor thermal performance it uses rooms which have similar range of WFR(window to floor ratio). Other factors such as lighting, noise, or other factors are beyond the study's scope. And at last the research aims to provide recommendations for improving indoor thermal comfort by optimizing design strategies for future office rooms in Adama.

1.6 Limitation of the study

The study has certain limitations. First, the research is limited to a few selected office buildings in Adama due to constraints in time and resources constraints, which may restrict the generalizability of the findings. Second, the study focuses only on curtain-walled facade buildings, which means the results may not be applicable to other types of office buildings with different architectural styles or materials. Third, the study relies on occupant feedback for thermal comfort perception, which is subjective and can vary based on personal preferences, clothing, and metabolic rate. And also it isolates room orientation as a primary variables, excluding the influence of factors such as shading devices, glazing types, or mechanical ventilation systems. Despite these limitations, the research provides valuable insights into how orientation affects indoor thermal conditions and recommend design solution to improve the thermal comfort of office rooms with curtain-walled facades in Adama.

1.7 Significance of the research

This research aims to provide a more in depth understanding of the impact of orientation on indoor thermal performance within curtain-walled office rooms in Adama, Ethiopia. By analyzing indoor thermal parameters variation and their relationship with orientation. This will help architects and engineers to design energy-efficient office rooms that reduce overheating and minimize reliance on mechanical cooling systems. The results of this study can assist building professionals, policymakers, and developers in making informed decisions that enhance indoor thermal comfort, improve occupant well-being.

1.8 Operational definition of the study

- ✓ **Room Orientation** - refers to the directional placement of a room within a building, typically categorized as north-facing, south-facing, east-facing, or west-facing (Szokolay, 2014).
- ✓ **Curtain-Walled Facade** - is a non-load-bearing exterior wall system composed mainly of glass and metal framing, designed to provide daylighting and aesthetic appeal (Givoni, 1994).
- ✓ **Thermal Comfort** – is the state in which a person feels neither too hot nor too cold, typically determined by air temperature, humidity, mean radiant temperature, air velocity, clothing insulation, and metabolic rate (ASHRAE, 2020).
- ✓ **Window-to-Floor Ratio (WFR)** - is the proportion of a room's total window area to its total floor area (Szokolay, 2014).
- ✓ **Occupant Thermal Perception** - is the subjective evaluation of indoor thermal conditions by building occupants, often assessed through surveys and comfort indices (Fanger, 1970).
- ✓ **Solar Heat Gain** - is the increase in indoor temperature due to solar radiation entering a building through transparent or translucent materials, such as glass windows (Givoni, 1994).

1.9 Organization of the thesis

This thesis is composed of five main chapters. Chapter one: Introduction, provides an overview of the study, including the background, statement of the problem, research objectives, research questions, significance of the study, and scope and limitations. Chapter Two: Literature Review, it reviews relevant literature on thermal comfort, room orientation, and energy performance in office buildings. Chapter Three: Research Methodology, it includes the research design, study area, data collection methods, and analytical techniques used in the study. Chapter Four: Results and Discussion, includes the findings of the study, data analysis, comparisons of thermal conditions across different room orientations, and occupant comfort levels. And finally Chapter Five: Conclusion and Recommendations, summarizes the key findings of the research and discusses their practical implications then provide a recommendations and design solutions.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Theoretical literature review

2.1.1 Thermal comfort

According to (Turner, 2011), “Thermal comfort is a mental condition defined by contentment with one's thermal surroundings. It is a subjective feeling that differs from one individual to the next. It is maintained when the heat created by human metabolism is allowed to escape at a rate that keeps the body at a constant temperature.”

For a comfortable indoor atmosphere indoor thermal comfort is needed. Inhabitants' poor health and operating efficiency can be caused by environmental factors like heat from daylight, insufficient ventilation, excessive humidity, and solar radiation (Givoni, 1992).

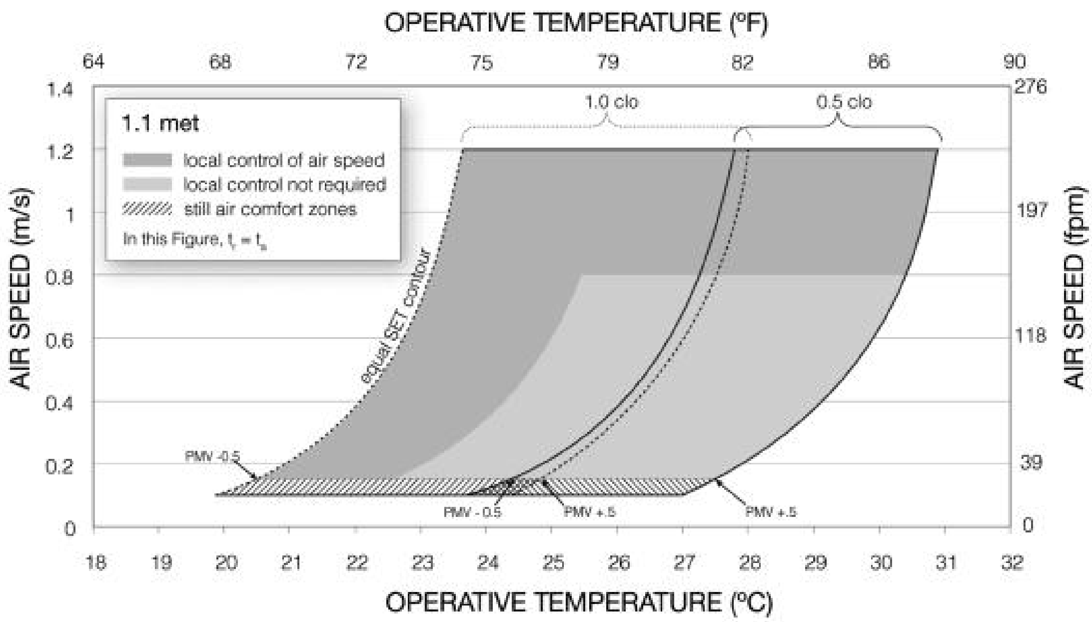


Figure 2.1: Thermal comfort chart using ASHRAE 55 parameters (Humidity ratio = 0.010); Source: ASHRAE 55, Basic of thermal comfort (2024)

Factors affecting thermal comfort and room temperature are divided in to two:
(Vellei, 2022)

- Environmental factors - it contains
    - ✓ Air temperature
    - ✓ Humidity
    - ✓ Radiant temperature
    - ✓ Air velocity
- Personal factors - consists of
    - ✓ Clothing insulation
    - ✓ Metabolic heat
    - ✓ Gender Consideration

A. Environmental factors

It refer to the external conditions that influence how comfortable a person feels in a given thermal environment.

i. Air temperature

According to Health and Safety Executive (HSE), "Air temperature is the temperature surrounding the body and is measured by degree Celsius or Fahrenheit." It is most known environmental factors by human being because they are very sensitive to it (Hanqing et al., 2006). Based on ASHRAE guidelines it is recommended that in winter it should be 68 F to 74 F whereas in summer 72 F to 80 F for internal environment of a building.

ii. Humidity

According to ISO-7730 (2005), humidity is defined as a water vapour pressure in the air. If water is heated and evaporated in a place, it will increase the percentage of humidity at the air. "Relative humidity is the percentage between the current amount of evaporative water and the actual amount of water that the air can hold at a given air temperature" (Liu et al., 2014).

Humidity is connected to air temperature and air speed of an environment. However, when the relative humidity is between 40-70% it is generalized as comfortable (Liu et al., 2014). However, ASHRAE 44 doesn't have a standard for lower humidity value for thermal comfort. This is because only humidity can not determine the state of the occupants there should be other aspects to be taken as a factor (ASHRAE-55, 2004).

iii. Radiant temperature

It is the heat that radiates from a heated object in the environment. In some cases it may have a greater influence than air temperature. The most radiant object is the sun however there are objects like cookers, dryers, hot surfaces and ovens which can create it (HSE, 2012). Heating the wall, on the other hand, increases the quantity of heat produced into the structure by boosting direct solar radiation. If the structure is designed from the outset to regulate solar radiation, the use of radiation can be natural and pure. According to (Hui, 2009), the average radiant temperature has an impact on external thermal comfort and energy flow through the walls of buildings, the more internal thermal comfort is maintained. In terms of the ceiling, there were no noticeable differences between the cooling and warming, but there was a clear difference in the case of the wall.

iv. Air velocity

It has been defined as "It is the speed of an air moving in the environment" (Liu et al., 2014). It is a major factor as people are very sensitive to it. It can cool down or heat up indoor space. Air temperature, relative humidity and air speed have the most effect on indoor human thermal comfort(Hall, 2010). And it influences the convective heat exchange between a person and the environment which will entirely affect the heat loss process (ISO-7730, 2005).

B. Personal factors

It refer to individual characteristics and preferences that influence how comfortable a person feels in a given thermal environment.

i. Activity (metabolic rate)

Activity is a factors which affects the thermal comfort of a person. There are many types of level activities that is done in different buildings. As a result, the activity of people in one space is different from the other which makes the thermal sensation different. It can be defined as "a heat inside our bodies that is a result of physical activity " (Mustapa et al., 2016). The more active we do the more heat we produce.

Based on ISO-7730 (2005), the difference of 0.1met might result production of a thermal sensation equals to that produced by 1°C in air temperature. Wheras a difference of 0.4met could lead to 2.5 to 3°C in air temperature. This indicates that different type of activities can create different value of thermal sensation value.

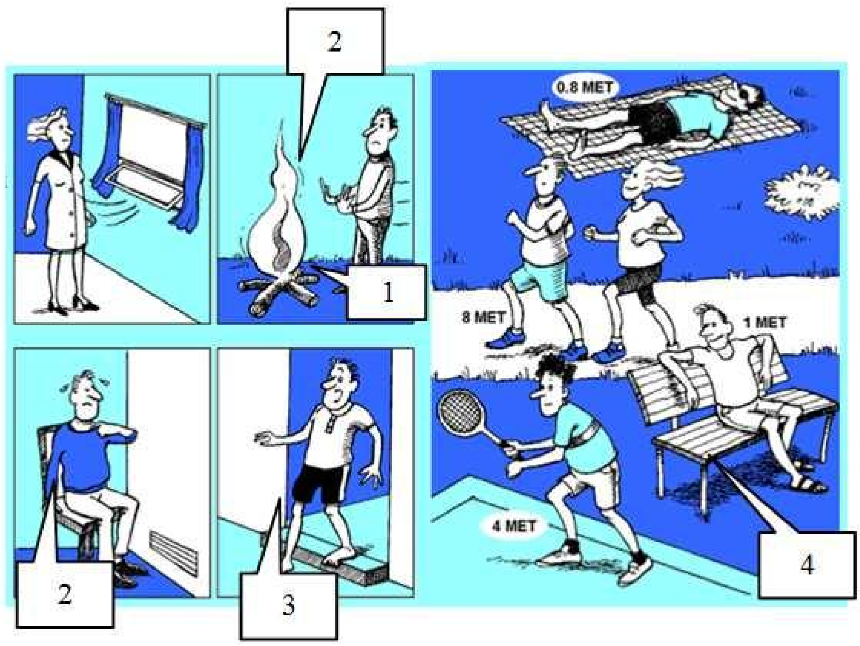
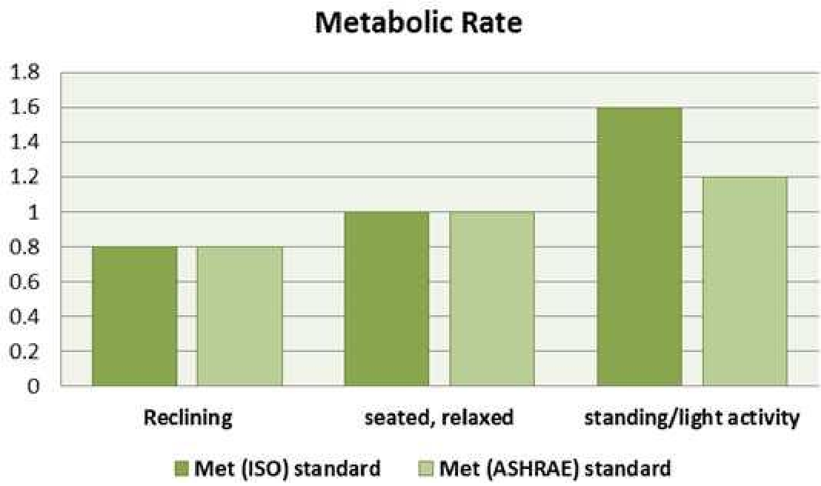


Figure 2.2: Local thermal discomfort caused by radiation;Source: ANNOVA thermal comfort(1997).



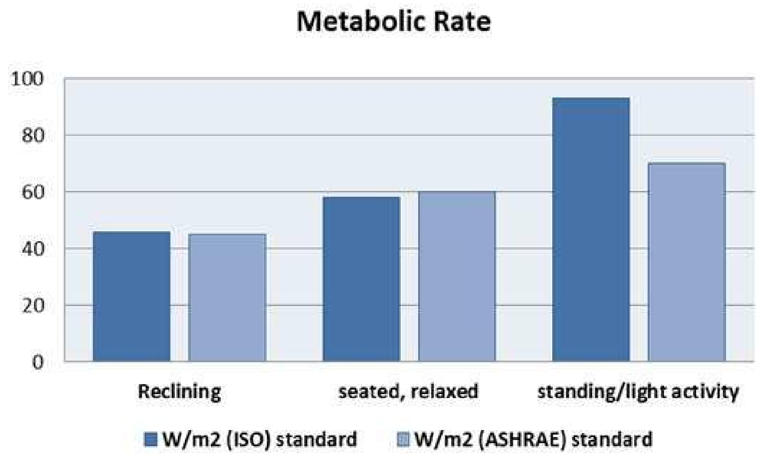


Figure 2.3: Metabolic rate of common activities ; Source: Alwetaishi, M. S. (2016)

ii. Clothing Insulation

Man uses different clothing to protect him self from cold and other effects. For example in the prehistoric time they use animal's furs (Caril et al., 2007). Body insulation's such as clothing and skin protects it from the environment. Oliveira et al. (2011) has indicated that the assessment of the thermal insulation of clothing is important. Because it provide a thermal resistance for the body and also it keepps it in a comfortable state whether it cold or hot.

iii. Gender Consideration

It is quite common that male and female has to work or be at the same place with the same condition. This could be uncomfortable for one or both of them. Many researchers agree that females are comfortable at a higher temperature compared to males (Mamdooh, 2016).

Karjalainen (2007) and Parsons (2002) study indicated that woman prefer higher temperature than male, especially, in office buildings where the internal environment considerably high. Wang (2006) also specified that the thermal comfort value difference between them is 1°C (20.9 for males and 21.9 for female) which is because of conditions and type of building. This view also has been supported by a study done by Choi et al. (2010). it states that female are more dissatisfied in summer time rather than males with their thermal environment . In contrast, Parsons (2002) believes that there is no thermal satisfaction differences between male and female rather than this he believed that female are more sensitive to temperature compared to males (Sakka et al., 2012).

2.1.2 Adaptive thermal approaches

Human body try to maintain a comfortable environment by physiological process such as sweating or shivering (MACQUARIE, 2004). Moreover, they always wanted to achieve thermal comfort in their environment (HSE, 2012) and also uses many methods to obtain it (Liu and Humphecys, 2002). Adaptive principle can be defined as "If a change happened and produced a thermal discomfort, people will try to restore their comfort" (Liu and Humphecys, 2002; Liu et al., 2012; Sing et al., 2011; MACQUARIE, 2004).

Adaptive thermal comfort is classified into three main categories:

1. Physiological adaptation
2. Psychological adaptation and
3. Behavioural adaptation.

Physiological adaptation can be considered as a controller of thermal human body. It doesn’t have a clear defination which makes it more complicated (Choi et al., 2010).

Whereas behavioural adaptation have three major elements which are personal level which involve changing clothes and others, technological level which include usage of windows and cultural adjustment (Sing et al., 2011; Choi et al., 2010).

Researchers have pointed out several elements. Such as climate, building design and time (seasons) and also clothing (Mui and Chan, (2003), MACQUARIE, (2004)). This elements will ensure that thermal comfortablity for people (Sing et al., 2011). One more point that has to be highlighted is natural ventilation which has the ability to change thermal comfort level indoors with steady indoor temperature (ASHRAE-55, 2004; Schweiker et al., 2012).

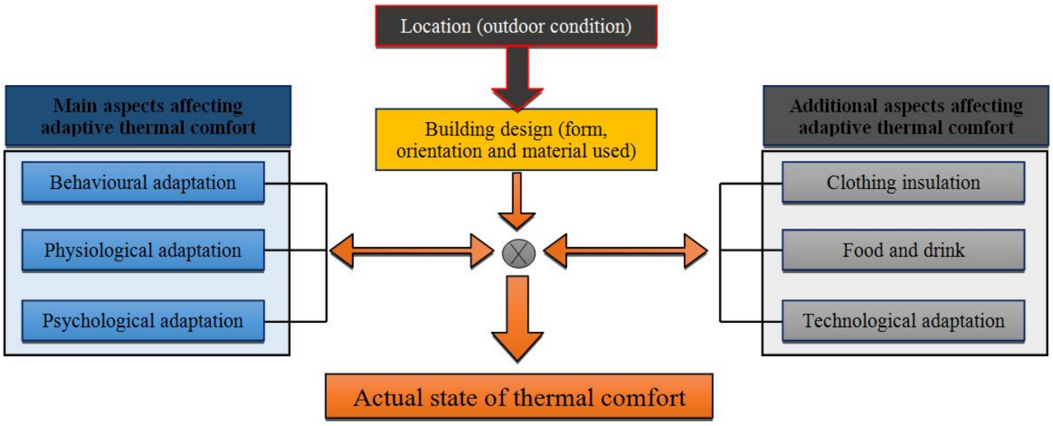


Figure 2.4: The main aspects effecting thermal comfort and other additional common aspects that leading to the actual state of thermal comfort; Source: Alwetaishi, M. S. (2016)

2.1.2.1 Effect of building function on adaptive thermal comfort - for office buildings

Deep plan in office buildings started to appear since 1960s with fully glazed façade that would increase the need for artificial lights. Then personal computers started to be used in 1980s which added extra heat to the indoor. Natural ventilation can not remove these loads especially in moderate climates (Djongyang et al., 2012). As a result, to maintain the indoor thermal comfort in office buildings energy consumption is mainly used (Ghisi and Massignani, 2007).

There are several active approaches that may result a massive reduction in energy consumption in office buildings:

- ✓ Temporal and spatial control which is changing time based on their activity.
- ✓ Changing cloths based on the climate condition
- ✓ Solar shading control
- ✓ Switching off the lights which it is not needed
- ✓ Natural ventilation control by using windows (Barlow and Fiala, 2007).

2.1.3 Thermal comfort estimation approaches

According to Fanger's study there are two main approaches to estimate human thermal comfort Predicted Mean Vote (PMV) and the Percentage of Dissatisfied (PPD). They are affected by environmental elements such as dry bulb temperature, humidity, air velocity and mean radiant temperature, thermal resistance and metabolic rate (Mamdooh, 2016). Thermal balance is when the internal heat production of a body is equal to the heat loss to the surrounding environment (ISO-7730, 2005).

i. Predicted Mean Vote (PMV)

PMV is an index that predicts the mean value of votes of a large group of persons on the 7-point thermal sensation scale" (ISO-7730, 2005) . It ranges as +3 is too hot, +2 is warm, +1 is slightly warm, 0 is neutral, -1 is slightly cool, -2 is cool and -3 is cold.

$$PMV = f(Ta, Tmr, RH, Va, M, Icl)$$

where

- ✓ Ta is indoor air temperature (◦C),
- ✓ Tmr is mean radiant temperature (◦C),
- ✓ RH is relative humidity (%),
- ✓ Va is air velocity (m/s),
- ✓ M is metabolism (met) and
- ✓ Icl is clothing (clo).

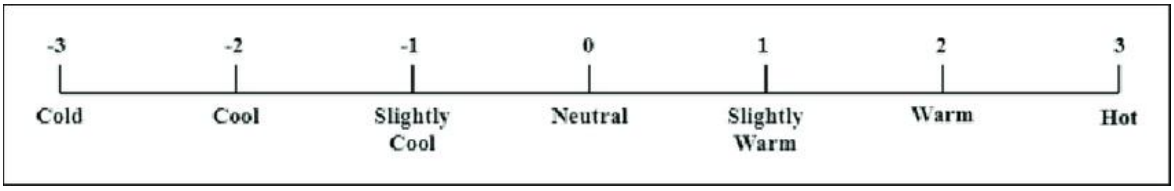


Figure 2.5: ASHRAE seven point thermal sensation scale; Source: Jin, Y., Wang, F., Payne, S. R., & Weller, R. B. (2021)

Scale value	Thermal comfort descriptor	Thermal sensation descriptor
+3	Much too warm	Hot
+2	Too warm	Warm
+1	Comfortably warm	Slightly warm
0	Comfortable	Neutral
-1	Comfortably cool	Slightly cool
-2	Too cool	Cool
-3	Much too cool	Cold

Table 2.1: Thermal comfort scale vs. thermal sensation scale; Source: Arendt, K. (2013).

ii. Predicted Percentage of Dissatisfaction (PPD)

The PPD predicts the mean value of the thermal of a large number of people (ISO-7730, 2005). It is related to the PMV model but it is expressed by those who feel discomfort (+2 and +3 or -3 and -2) (ASHRAE-55, 2004). It has been established to determine the percentage of thermally dissatisfied people who is feeling too hot or too cool.

- ✓ When PMV = 0, about 5% of occupants will feel discomfort (PPD = 5%).
- ✓ As PMV moves away from 0 (either positive or negative), the PPD increases, meaning more people feel discomfort.

Typical PMV ranges with their corresponding PPD values:

- ✓ PMV = 0: PPD ≅ 5%
- ✓ PMV = ±0.5: PPD ≅ 10%
- ✓ PMV = ±1.0: PPD ≅ 25%
- ✓ PMV = ±2.0: PPD ≅ 75%

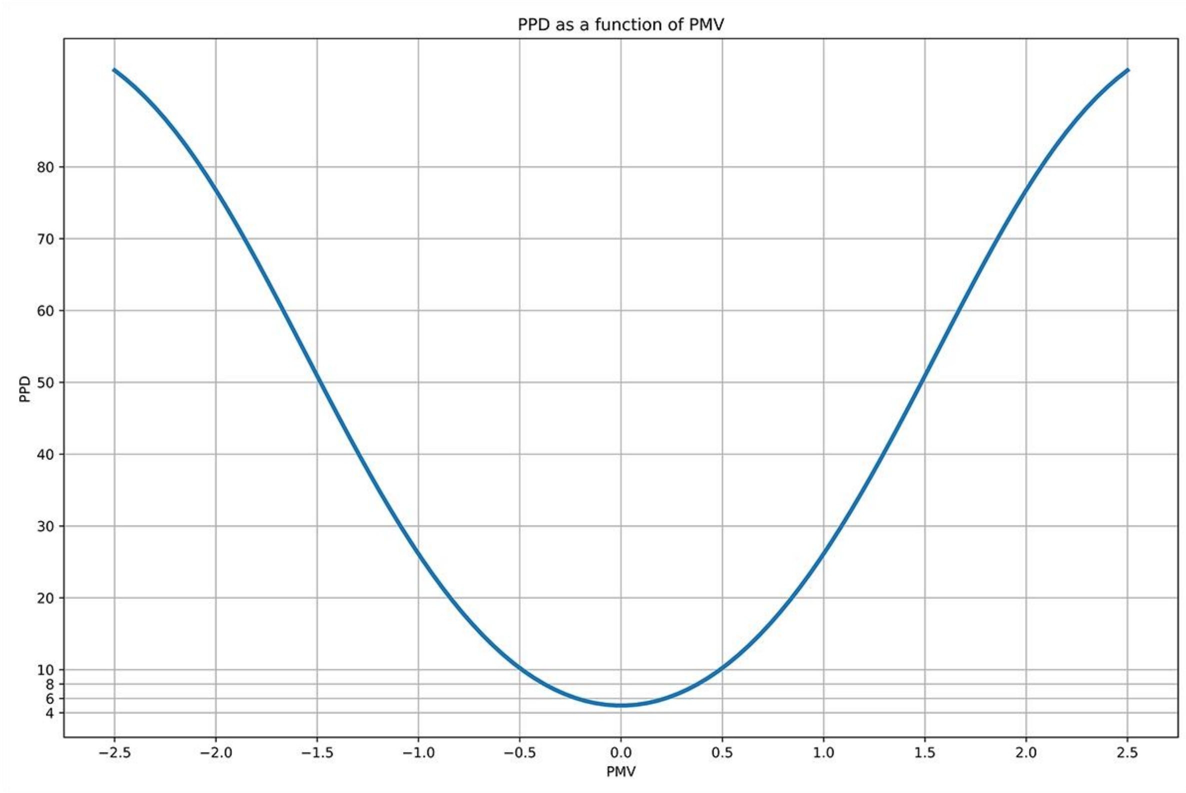


Figure 2.6: Percentage People Dissatifsfied (PPD) as a function of Predicted Mean Vote (PMV); Source: Yau, Y. H., Chuah, Y. K., Chuah, K. H., & Rajput, U. (2023)

2.1.3.1 Recommended thermal comfort requirements

It is recommended as acceptable that the PPD to be lower than 10%. This corresponds to the following PMV criteria: (Quadco Engineering, 2025)

$$-0.5 < \text{PMV} < +0.5$$

✧ **Light, mainly sedentary, activity during summer conditions (cooling period)**

This are the conditions that should be followed: (Quadco Engineering, 2025)

a. Operative temperature = 23 °C and 26 °C.
b. Relative humidity = 30 % and 70 %.

✧ **Typical values for Met and Clo**

Tables summarizing typical Met (Metabolic Rate) and Clo (Clothing Insulation) values (Quadco Engineering, 2025)

Activity	Metabolic Rate (Met)
Resting (seated quietly)	0.8
Reading or Writing	1.0
Seated, light office work	1.2
Standing, light activity	1.4
Standing, medium activity	1.8
Walking (3 km/h)	2.0
House cleaning	2.5
Walking (5 km/h)	2.8
Heavy work (lifting, etc.)	3.5
Running (8 km/h)	8.0

Table 2.2: Typical Met (Metabolic Rate) values

Clothing Type	Clothing Insulation (Clo)
Nude	0.0
Summer, light clothing	0.5
Typical indoor clothing	0.6
Long-sleeve shirt, trousers	0.7
Light business suit	0.9
Business suit with sweater	1.0
Winter clothing	1.3
Winter clothing with coat	1.5
Heavy winter coat, thermal gear	2.0

Table 2.3: Typical Clo (Clothing Insulation) values

- ✓ Met values increase with activity level.
- ✓ Clo values represent the insulation provided by clothing.

2.2 Empirical literature review

2.2.1 Global studies

A study by Solomon, A. S., & Kibert, C. J. (2018) examines the effect of building shape, zones, orientation and window to wall ratio (WWR) on the lighting energy requirement and the thermal comfort in the naturally ventilated houses in tropical climate. They were 300 different models of two-storey houses that is obtained using Design Builder simulation software. This models have three different shapes (square, rectangle and L-shaped) and their orientation were changed for 24 orientations and four window to wall ratios. This study found that building orientation can affect thermal discomfort. When the simulated building models were rotated 90° and 270° compared to the best orientation (the one with the lowest discomfort hours), the thermal discomfort generally increased. However, the magnitude of this effect depended on the building shape. This study used simulated residential models to analyze orientation effects in a tropical climate which makes it different with this one in building type & function, climate context, and analysis methods (it uses computer simulation mainly with out incorporating real-life buildings).

Other study by Abass, F (2021) studied the user's perception of thermal comfort and air conditioning in office buildings in Batu Pahat, Johor area. 3 specific, air-conditioned office buildings were selected based on their similarities in design, shading, facade materials, and structure. The methodology involved field measurements of indoor environmental parameters, specifically air temperature, relative humidity, and air velocity and also it included the calculation of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices and the use of Post Occupancy Evaluation (POE) surveys to gauge user perception of thermal conditions. The study found that thermal comfort zone temperature ranges between 21.6-23.6°C, with relative humidity playing a significant role while PMV calculation may align with standards, PPD and user perception can vary, suggesting that international standards may require consideration of local climate adaptation, with low air velocity being a notable factor affecting comfort.

A study by Jose (2024) investigated that how different architectural parameters have an impact on both operational and embodied energy in buildings, with a special focus on the Window-to-Floor Ratio (WFR). It found that increasing WFR tends to result in higher operational energy consumption and carbon emissions, particularly due to greater solar heat gain and reduced insulation performance through glazed areas. Also it states that small WWR or WFR differences (around 5%) are often considered marginal, especially when both rooms are in the same climate, building type, and use similar glazing/materials.

2.2.2 Ethiopian context

Although limited, some Ethiopian research has touched on building performance in relation to climate. For example, a study by Getachew, S. G., & Gabore, N. Y.(2020) assessed thermal comfort in five naturally ventilated sub-city administration office buildings in Addis Ababa. By using occupant surveys and field measurements as a data collection method in May. The research found that most occupants (70%) preferred a cooler environment. And thermal discomfort was most prevalent in the afternoon, particularly between 2:00 pm and 4:00 pm, accounting for over 81% of reported discomfort time. And also it revealed that building which was oriented towards North West, demonstrated better thermal performance.

Another research by Yadeta, C., Tucho, G. T., Tadesse, E., & Alemayehu, E. (2021) focused on evaluating thermal comfort levels in naturally ventilated residential buildings in Jimma, Ethiopia. It used both field measurements and computational simulations to assess indoor environmental conditions. The result was that low air speed aggravated issues with temperature and humidity also by using Computational Fluid Dynamics (CFD) simulations the study demonstrated that increasing the speed of fresh air by opening windows and doors has significant potential to regulate thermal variables and improve comfort for the occupants. At last the study recommended that buildings should have particular attention on window and door size, type, and orientation, to achieve better thermal comfort.

2.2.3 Gaps in existing literature

The relationship between room orientation and indoor thermal conditions has been widely studied globally, but there is a noticeable lack of research focusing on Ethiopia, particularly in Adama. Most existing studies are concentrated on regions with different climatic conditions, which may not align with the semi-arid climate of Adama. This regional gap leaves a significant opportunity to explore how building design, particularly room orientation, interacts with the local environment to influence thermal conditions.

Additionally, while much of the existing literature emphasizes residential buildings .The limited attention to office building type, especially in the Ethiopian context, restricts our understanding of how spatial design and orientation impact the comfort and productivity of occupants.

Another issue is that people have not given enough attention to how office workers personally feel and experience about their work spaces. While it’s helpful to measure things like temperature, humidity or other things, these don’t tell the whole story about how people actually experience their environment.

CHAPTER THREE

3. METHODS AND MATERIALS

This sections presents the materials and methods which is used to investigate the impact of room orientation on indoor thermal conditions in curtain-walled facade office buildings in Adama, Ethiopia.

3.1 Study area and population

The study is conducted in Adama, Ethiopia. This city is found at latitude 8°26 ′15″N to 8°37 ′00″N and longitude 39°12′15″E to 39°19′45″E and has an elevation that ranges from 1500 m to 1900 m above sea level. It located in East Shoa zone of Oromia regional about 100 km south east of Addis Ababa.

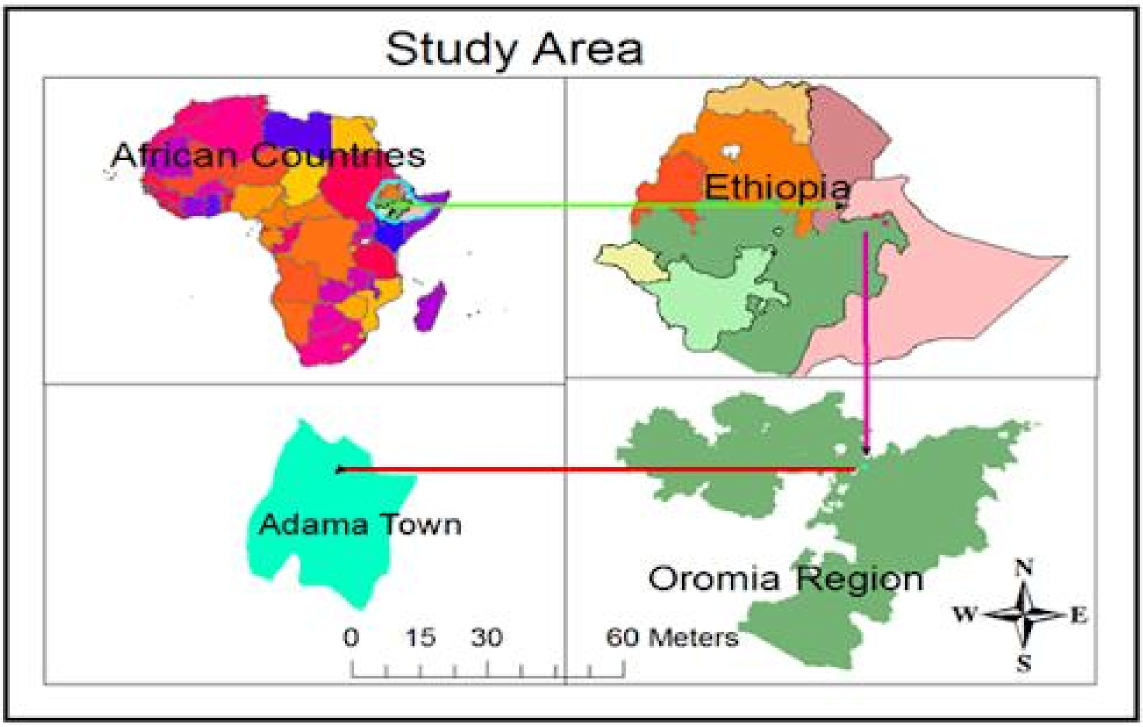


Figure 3.1: Location map of the study area

Adama is a reformed city in the region, with a city administration made up of 14 urban and four rural kebeles.

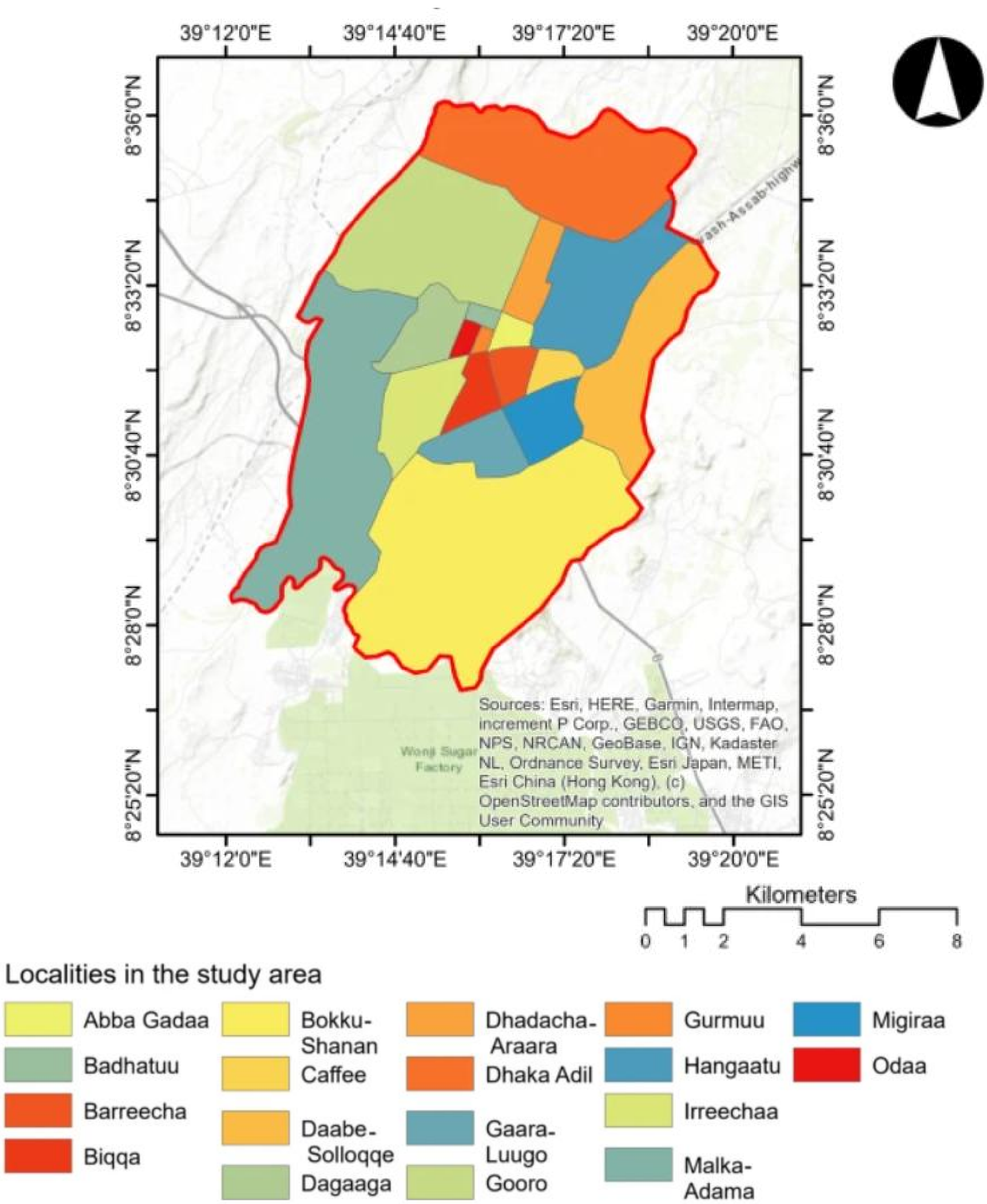


Figure 3.2: Adama city map

From all this kebeles based on the land use map only the central part of the city has the capacity to hold buildings that are up to G+6 to G+10. And it is mainly used for commercial business use.

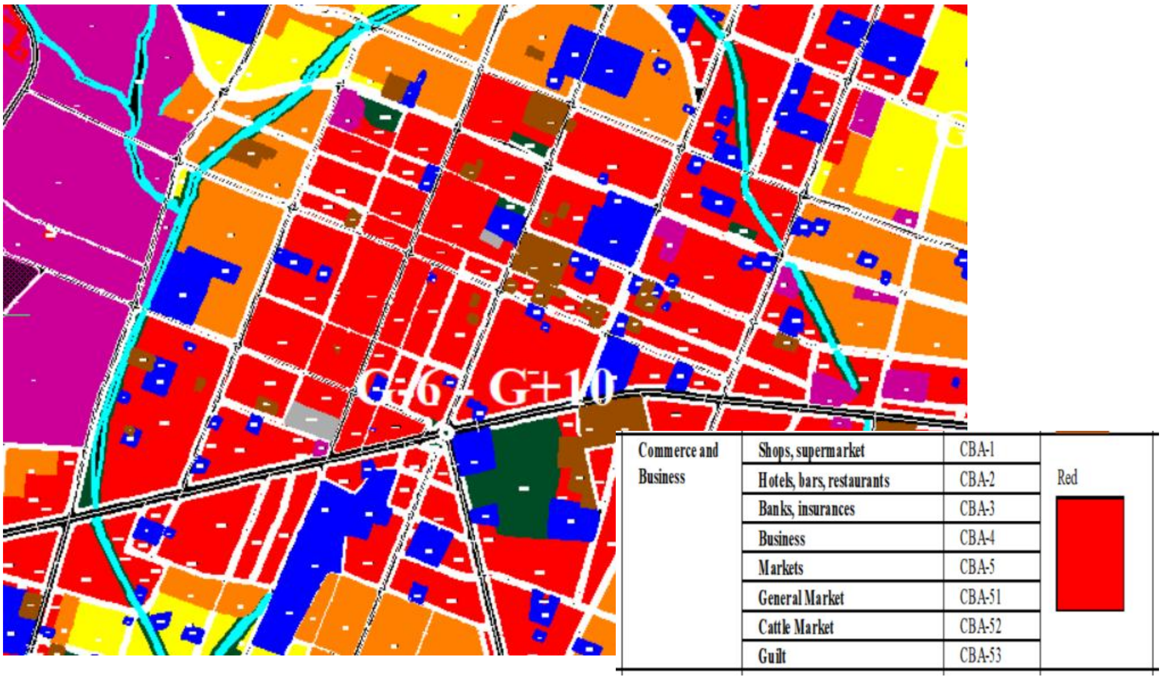


Figure 3.3: Land use map of central part of Adama

According to the National Meteorological Agency, Adama has a semi-arid to sub-humid climate features distinct rainy and dry seasons. Summer lasts from December to June, whereas winter lasts from June to September. Summer is hot and humid, with plenty of sunshine.

Throughout the year, precipitation is scarce in Adama and average annual temperature is 20.7 °C | 69.3 °F. Annually, approximately 371 mm | 14.6 inch of precipitation descends. The months April and May have the highest average temperature, with a recorded maximum of 22.5 °C | 72.5 °F and 22.7 °C | 72.8 °F. (Climate-Data.org., 2021).

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

Table 3.1: Weather data of Adama by month (source: Climate-Data.org)

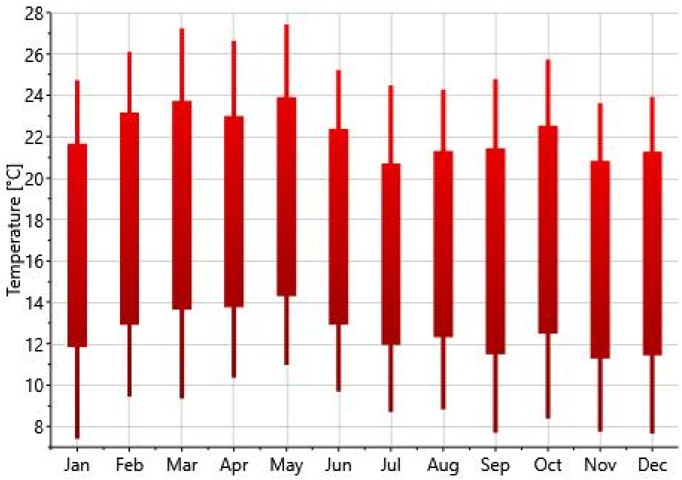
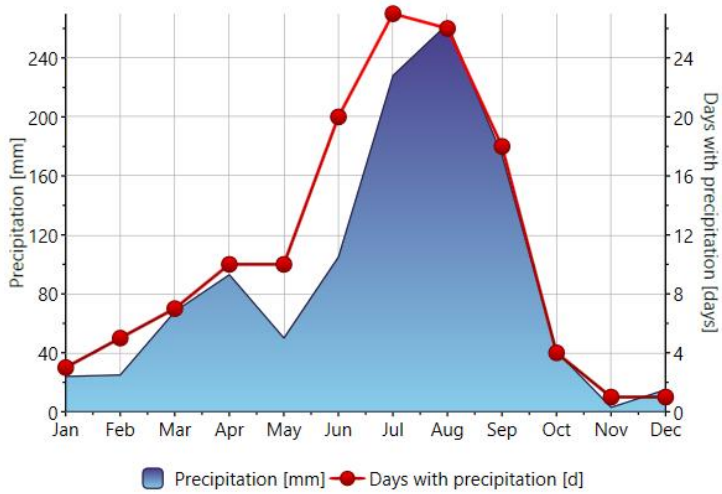


Figure 3.4: Weather data of Adama (temperature and precipitations)
Source: Climate-data.org/Meteonorm 7



According to this psychometric chart on figure 3.5, Adama's climate falls into the hot/dry region, and most of the hours throughout the year fall outside the thermal comfort zone. And this chart presents several design strategies such as Internal heat gains and Passive solar direct gain to improve this situation. As a result, 22.8% of the total hours (1994 hours) are within the comfort zone, while the remaining 77.2% (6766 hours) are in the discomfort zone throughout the year.

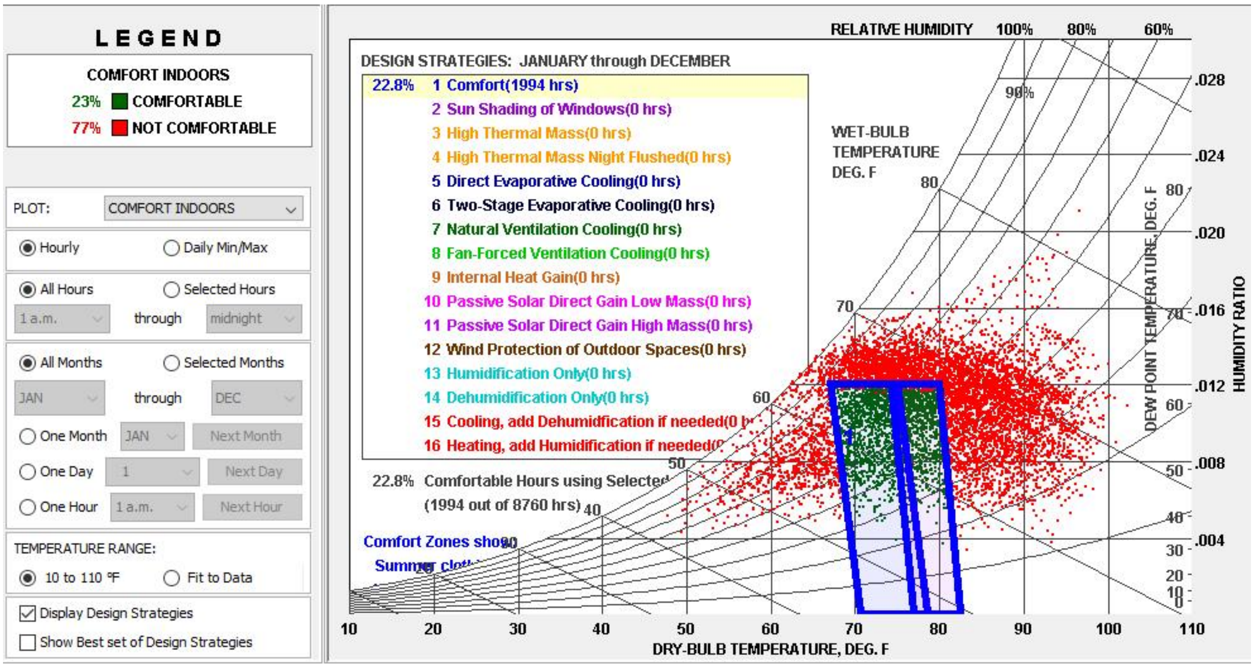


Figure 3.5: Psychometric chart of Adama city (source: Climate consultant)

Based on the wind frequency chart in below, it shows that the wind speed ranges from 10 km/h to 50 km/h, with increments of 10 km/h. it shows the prevailing wind frequencies in different directions, with the highest frequencies (the most common) shown in the north and northwest directions which ranges from 10-20 km/h. Winds in the 30-40 km/h range are also relatively frequent, again primarily in the north and northwest directions. While winds above 40 km/h are less common, they are still present in these predominant wind directions.

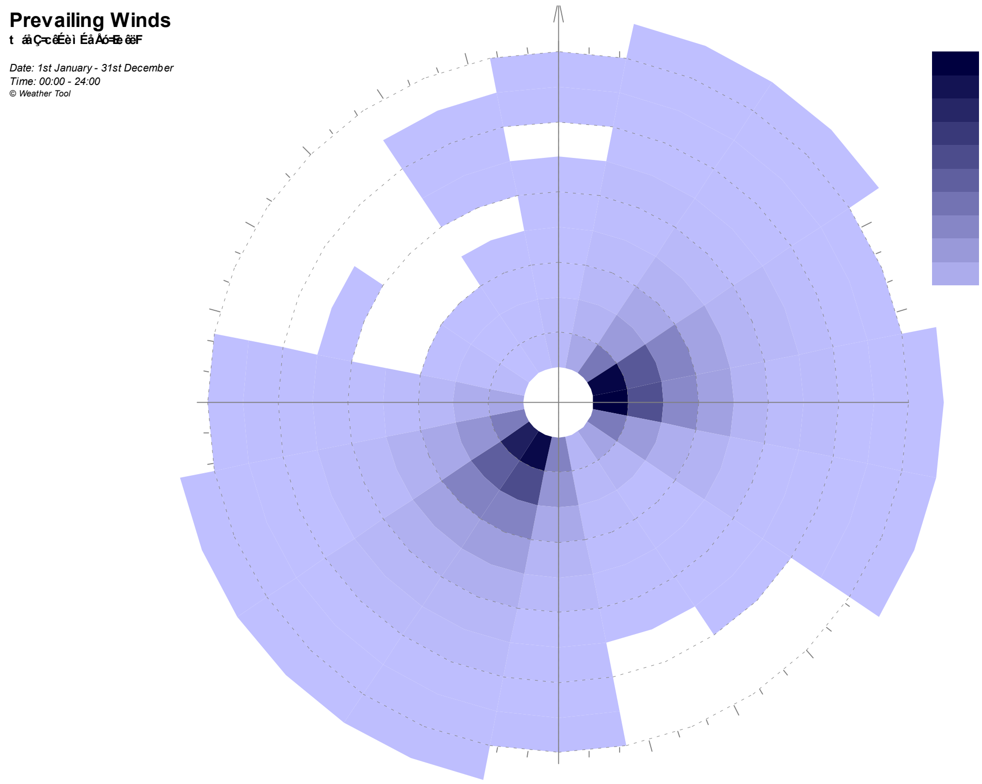


Figure 3.6: Prevailing winds of Adama (source: Autodesk Ecotect Analysis)

3.2 Research design

This research uses a mixed-method, field-based comparative design. It integrates quantitative physical measurements, qualitative occupant survey data and computer simulation and also it compares indoor thermal comfort of rooms with different orientation.

The research begins by reviewing theoretical frameworks and existing literature related to thermal comfort and building orientation. Then it proceeds to a field-based empirical investigation involving both physical measurements and occupant surveys. It combines quantitative and qualitative data collected from selected office rooms with similar features but opposite orientations to reflect thermal contrasts driven by sun exposure.

In this research design, there are two core elements that are interdependent: room orientation and indoor thermal comfort. Indoor thermal comfort is guided by standards such as ASHRAE 55 and ISO 7730. Then it shows that if this variables are affected by the building's orientation with respect to the sun's path, prevailing wind direction, and local climate conditions. And at last by measuring thermal conditions of opposite facing rooms, which have comparable design features, and comparing them against occupant thermal perceptions, the study seeks to identify which orientation provides more thermally stable and comfortable indoor conditions throughout typical working hours. The final outcome aims to recommend the optimal orientation for curtain-walled office spaces in Adama and offer practical guidance for architects, engineers, and policymakers.

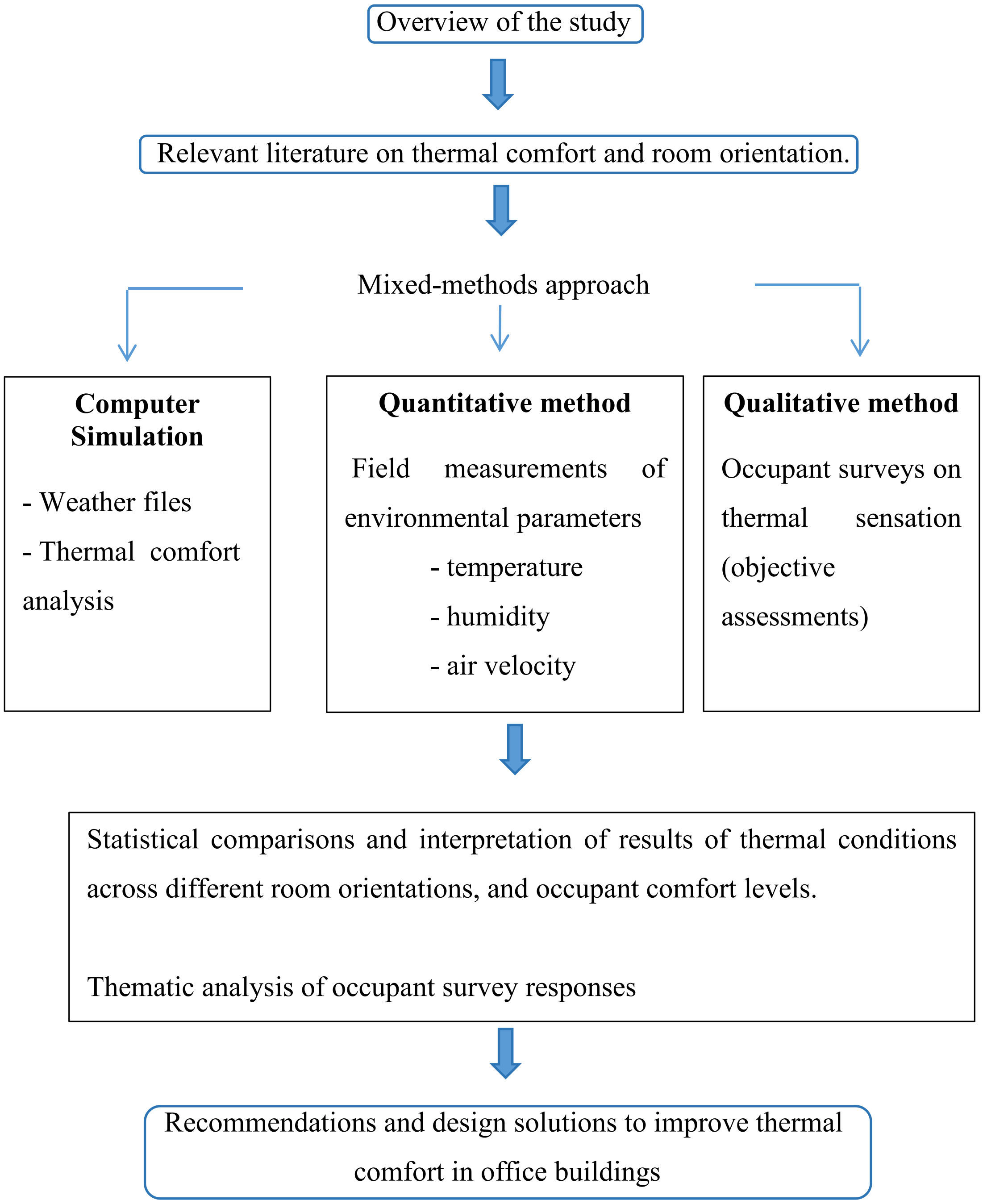


Figure 3.7: Research outline and hierarchy of study

3.2.1 Identification of parameters

Identifying both constant and variable parameters is a fundamental step for conducting accurate field measurements and thermal comfort surveys. It will determine the internal thermal environment and allow for a controlled comparison between differently oriented office rooms. Through literature review and preliminary observation, key parameters were selected to isolate the effects of orientation on indoor thermal environment. And they are classified into three categories: constant parameters, variable parameters, and confounding factors and they are summarized in Table below.

Constant Parameters	Variable parameters	Confounding factors
✓ Weather data and location ✓ Room height ✓ Time of measurement ✓ Curtain-wall glazing system (material and type) ✓ Office Furniture and equipment ✓ Working hours and User behavior (e.g., clothing level, activity)	✓ Room orientation (NW vs SE)	✓ Outdoor temperature, humidity and air speed ✓ Personal thermal sensitivity ✓ Psychological state

Table 3.2: Parameters in the study: (Source: Author, 2025)

- **Constant parameters**

i. **Weather Data and Location:** The study is conducted in Adama, Ethiopia, using standardized EPW weather data files and climate statistics specific to the city. These data sets represent typical meteorological conditions and are crucial for comparing thermal responses between orientations under similar environmental input.

ii. **Room height of the building:** the height of the room were kept constant, hence change in room height would affect all the volume and other values of the study.

iii. **Time of measurement:** Temperature, humidity, and air velocity are recorded at the morning and afternoon on same time interval and on the same day on the selected rooms.

iv. **Curtain-Wall Glazing System:** the selected office rooms utilize similar curtain-walled facades with consistent material properties.

v. **Working hours and User behavior (clothing level, activity):** the occupants have same working hours and there is a dress code for all the employees which is long sleeve shirt, trousers or skirts. And the activities they do most of the time is typing (computer work).

- **Variable parameters**

i. **Room orientation** : the identification and selection of rooms were based on both theoretical understanding and orientation simulations conducted using Autodesk Ecotect Analysis.

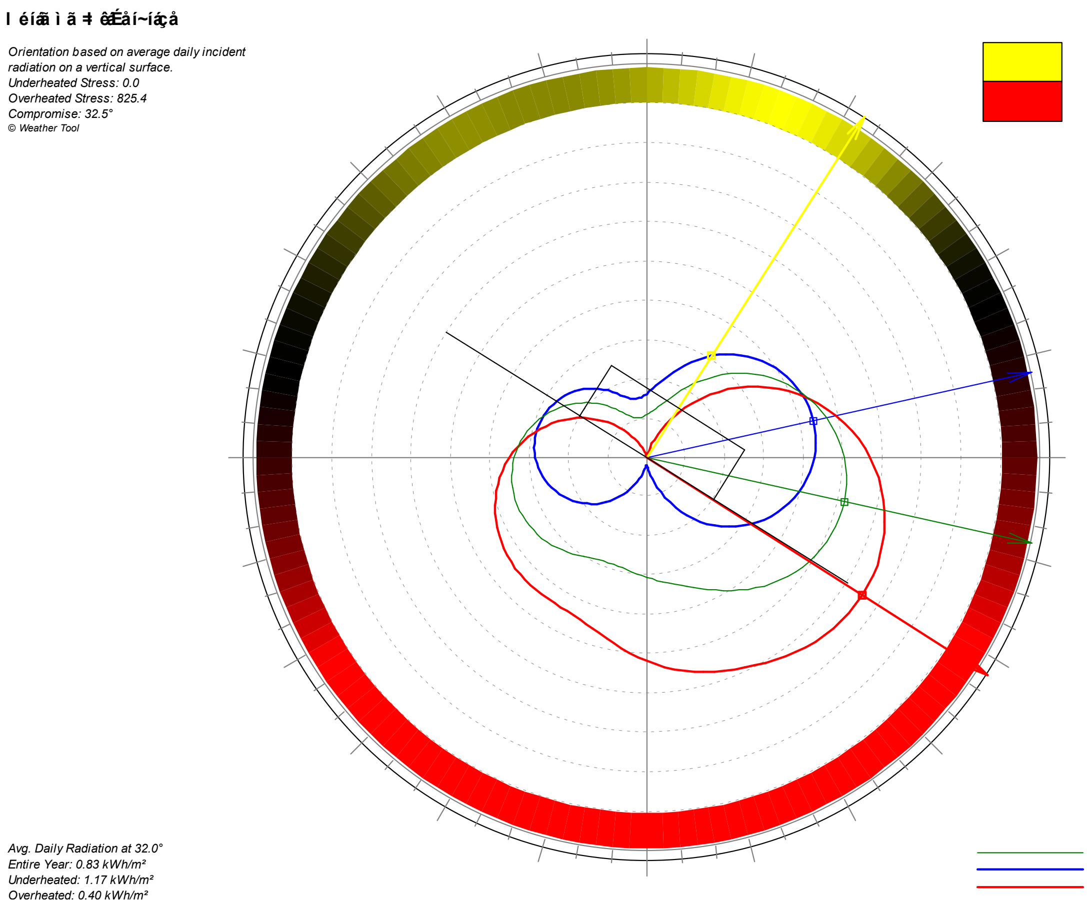


Figure 3.8: Optimum orientation of Adama (Source: Autodesk Ecotect Analysis).

According to the simulation, the optimum orientation is found to be at a compromise of approximately 32.5° North, with a favorable range between 328°N and 40°E. In contrast, orientations between 45°E and 315°N are exposed to excessive solar radiation. Among these, the worst thermal orientation was identified as 122.5° Southeast (SE), which experiences the highest solar exposure and corresponding thermal stress.

Based on this analysis, two room orientations were selected.Southeast (SE), the worst-case orientation, representing a high solar gain scenario. And Northwest (NW), the room on more thermally favorable orientation and which is opposite in direction.

- **Confounding factors**

i. **Outdoor thermal conditions:** is considered as a confounding factor because it isn't the main focus in this research but it influences the indoor air temperature. For example on a hotter day even a favorable room orientation might show higher indoor temperature.

ii. **Personal thermal sensitivity:** this variability to temperature can be due to age, gender, or health status.

iii. Psychological state:

3.3 Case buildings selection and characteristics

The specific site area of the study will be in the center of the city because the highest concentration of curtain walled office buildings are located there and the capacity of the land to hold the highest floor level. With prospective sampling, three offices buildings were selected in this area and were labeled as Building 1, Building 2 and Building 3.

The selection of this buildings are based on a preliminary observation that there are fewer than ten buildings in Adama which are both used as office spaces and have more than 6 stories (mid-rise buildings). Therefore, this selected buildings represent a significant portion of the available population of curtain-walled, mid-rise office buildings in the city.

3.3.1 Criteria for selection

- ✧ **Location:** The buildings must be located in the center of Adama.
- ✧ **Building Type:** The buildings should be Curtain walled office buildings .
- ✧ **Floor level of selected rooms :** should be in same floor level, should have opposite orientation.
- ✧ **Room orientation:** The selected rooms are in the NW and SE direction.
- ✧ **Similar WFR values:** WFR value of the selected rooms should be within ±5% variation for comparison and to minimize the influence of glazing area differences.

Figure 3.9: . Survey building Sites of central business area; Google image On April 10, 2019. Source: Google map (8°32′ N latitude / 39°16′E longitude)

A. Building 1 : ODA building

This building is 11 story mixed building with 3 basements, which include commercial and office uses. It has a rectangular shape and curtain facade in the front and back of the building. The building is facing the main road. It has a base and a tower. The base of the building is used as a commercial center and faces SW to NE whereas the tower part of the building is used as office faces SE to NW.

Figure 3.10: Exterior views of Oda building

For this study the 6th floor is selected because of they are in opposite orientation and have the same range of WFR. The floors from 5th to the 7th is used by Ethio-telecom. The selected rooms in this floor are HR and Finance office. The first room faces NW whereas the latter room faces SE.

(a) (b)

Figure 3.11: Interior view of the selected rooms (a) Room 1 in NW direction, (b) Room 2 in SE direction

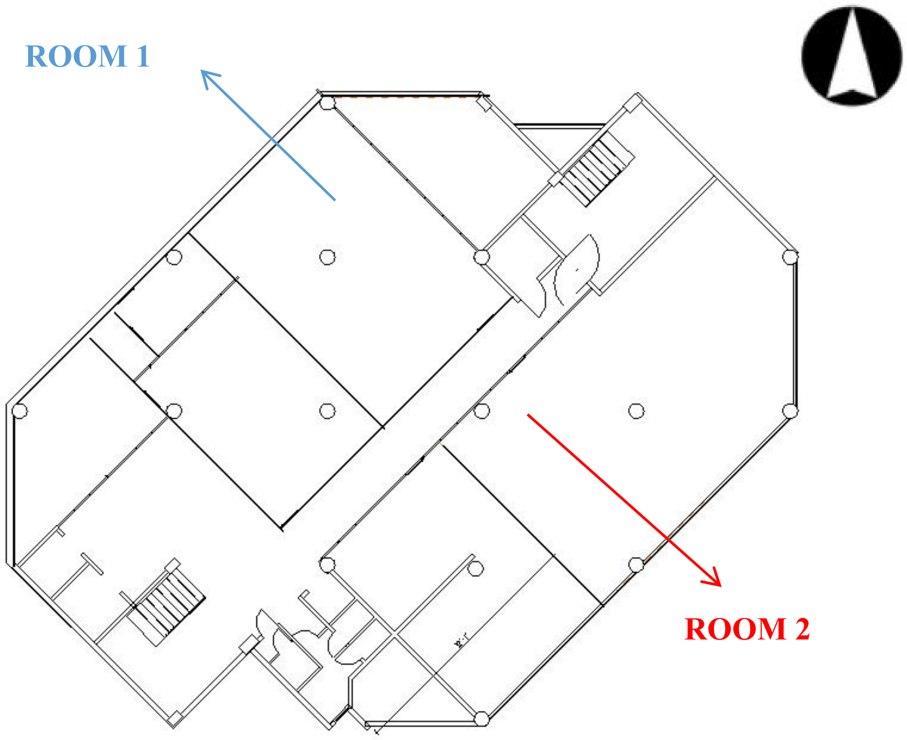


Figure 3.12: Floor plan of the selected rooms: (Source: Author, 2025)

These rooms were selected for their comparable design features and opposite orientations (NW and SE). The variation in WFR is considered acceptable for comparative purposes and aligns with findings from literature indicating that small WWR or WFR differences (around 5%) are often considered marginal both rooms are in the same climate, building type, and use similar glazing/materials Jose (2024).

B. Building 2 : Awash bank

This building is 8 story mixed building. It has a rectangular shaped base and circular shaped tower. The ground floor is used as bank and on the first floor most of the rooms are office and there is one internet cafe. The other remaining floors are used as offices and conference halls. For the some part of the base and tower of the building has different entrance. The tower part of the building has a curtain facade which faces NE and SW orientation in which it faces the main road in both direction.

Figure 3.13: Exterior views of Awash bank

The selected rooms are on the 7th floor. This rooms are HR office and Engineering department office. The HR room faces NW while the Engineering department office faces SE direction.

Figure 3.14: Interior view of the selected rooms (a) Room 1 in NW direction, (b) Room 2 in SE direction

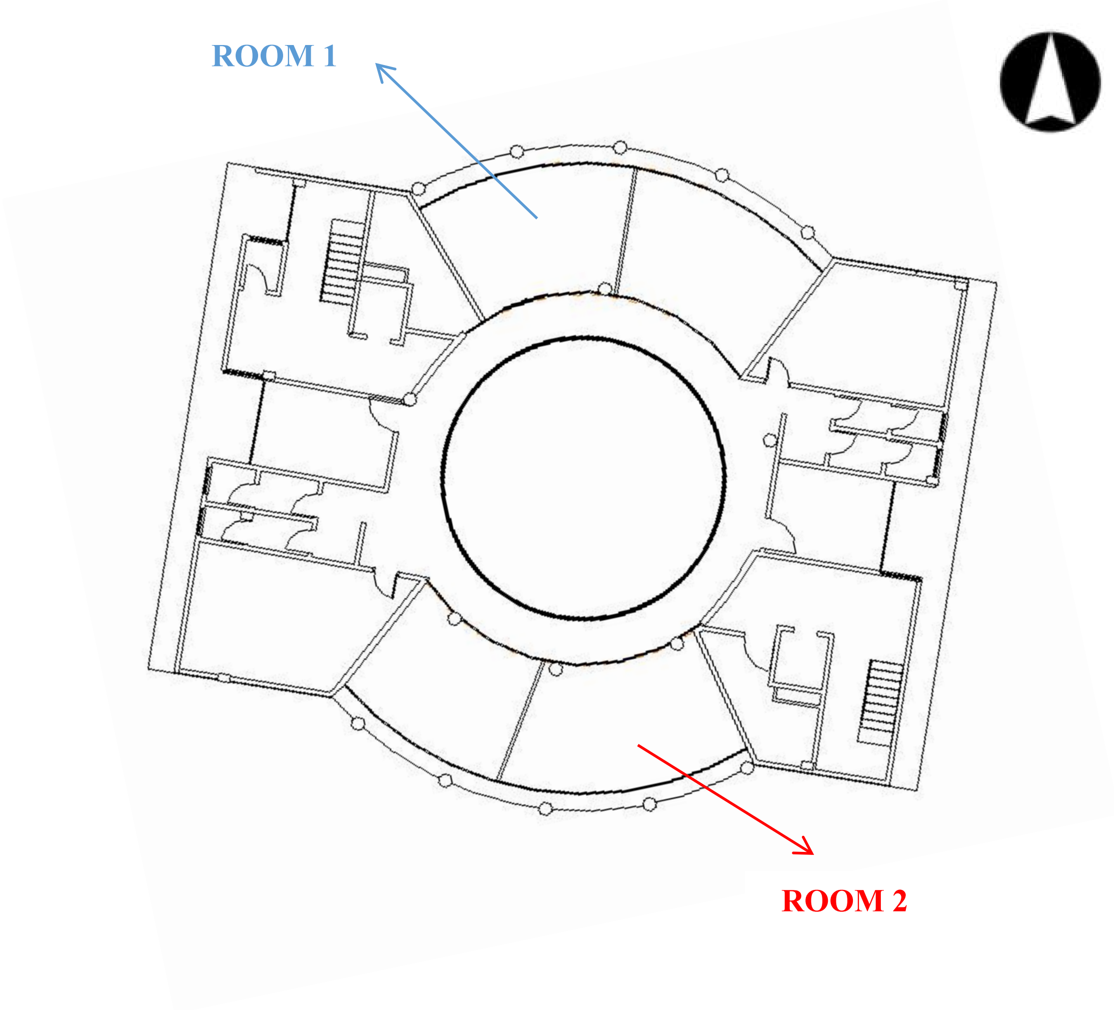


Figure 3.15: Floor plan of the selected rooms: (Source: Author, 2025)

C. Building 3 : Dashen bank

This building is 6 story mixed building. It is a rectangular shaped with some sides are slanted . The ground floor is used as bank while the rest of the other floors are office. It has a curtain facade in the front and back part of the building which faces SW to NE.

Figure 3.16: Exterior views of Dashen bank

The selected rooms are on the 2nd floor. This rooms are used as Finance offices. The first room that is on the rear side of the building faces NW while the second room faces SE direction .

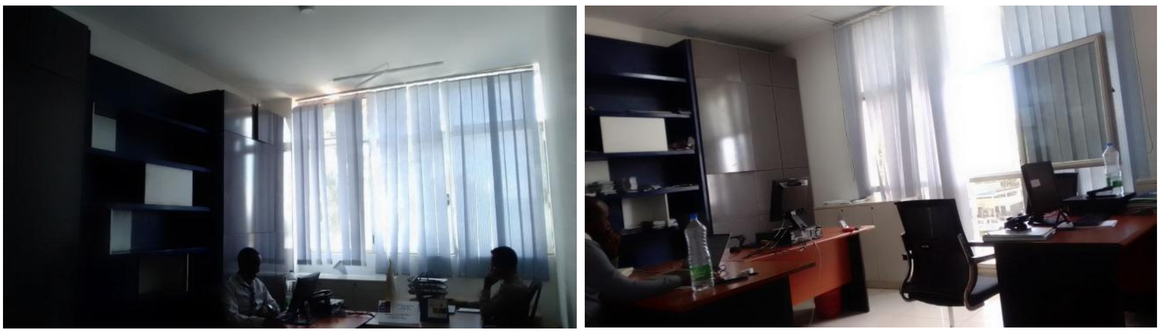


Figure 3.17: Interior view of the selected rooms (a) Room 1 in NW direction, (b) Room 2 in SE direction

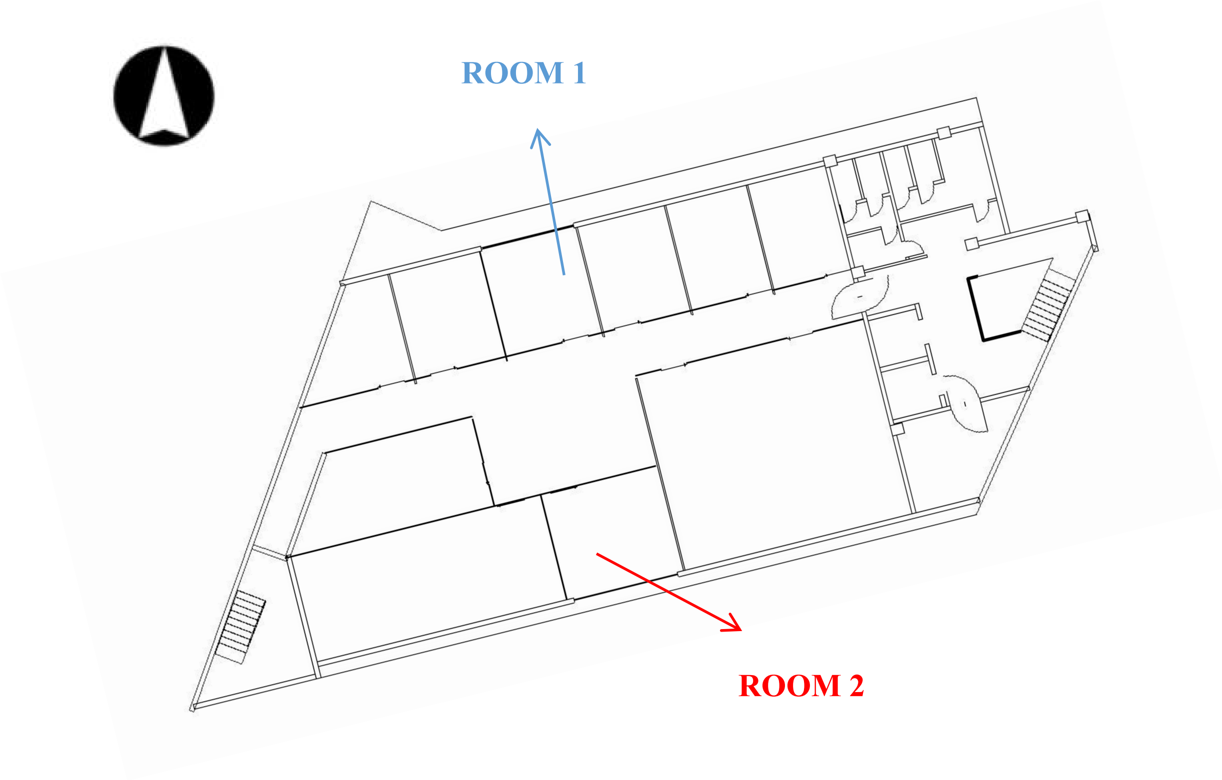


Figure 3.18: Floor plan of the selected rooms: (Source: Author, 2025)

3.3.1 Characteristic of the selected rooms

Parameters	Building 1		Building 2		Building 3	
	Room 1	**Room 2**	**Room 1**	**Room 2**	**Room 1**	**Room 2**
Orientation	NW	SE	NW	SE	NW	SE
Floor level	6th	6th	7th	7th	2nd	2nd
Window-to-Floor Ratio (WFR)	30-35%	30-35%	60-65%	60-65%	55-60%	55-60%
Glass curtain type	Full curtain	Full curtain	Half curtain	Half curtain	Full curtain	Full curtain
Ceiling height	3.00m	3.00m	3.00m	3.00m	3.00m	3.00m

Table 3.3: Selected room characteristics

Note:

- ✓ The selected rooms have 3–11 occupants.
- ✓ Building 3 uses AC and windows during work hours while others rely solely on windows.
- ✓ While the WFR (Window to floor ratio) vary between 5–6% within each building, the rooms were selected for their comparable design features and opposite orientations (NW and SE). The variation is considered acceptable for comparative purposes and aligns with findings from literature indicating that small WWR or WFR differences (around 5%) are often considered marginal both rooms are in the same climate, building type, and use similar glazing/materials Jose (2024).

3.3.2 Sample design /participants

There are 36 employees in the selected rooms of the buildings. According to Daryle W. Morgan methods, using formula for determining sample size. This method is used because the research has known population and it is based on survey.

Formula:
$$\boxed{s = \frac{X^2NP(1-P)}{d^2(N-1)+X^2P(1-P)}}$$

Where:

- ✓ X^2= 3.841 (Chi-square value for 1 degree of freedom at 95% confidence)
- ✓ N = 36 (Population size)
- ✓ P=0.5P = 0.5 (Population proportion for maximum variability)
- ✓ d=0.05d = 0.05 (degree of accuracy)

$s=\{3.841\times36\times0.5\times(1-0.5)\}/\{(0.05)^2\times(36-1)+3.841\times0.5\times(1-0.5)\}$

$s= 34.569/(0.0875+0.96025)$

$s= 34.569/1.04775$

$s= 32.994 \approx 33$

So, the recommended sample size for a occupants of 36 in three buildings, a confidence level of 99%, and a margin of error (degree of accuracy) of 3.5% would be 33 (Krejcie 1970). According to this the survey sample of 33 occupants on three buildings was selected to participate in this three-week field study starting from mid-April to first week of May 2025. This approach is used to ensure statistical reliability while minimizing redundancy in responses. Instead of the full population this makes it more efficient and helps avoid unnecessary workload during data collection and analysis, especially when the difference between the sample and the total population is minimal. Also it strengthens the scientific credibility of the study by ensuring that the data collected is both representative and manageable within the study's time and resource constraints.

3.3.3 Selections and justifications of research methods

The methodological objective of this research is to correlate subjective occupant responses with actual environmental measurements in order to evaluate indoor thermal comfort conditions of curtain-walled facade office rooms. This means it needs both physical measurement and subjective assessment. Because of this the study adopts a mixed-methods approach by selecting three complementary techniques.

- ✓ **Field Measurements (Experimental Method):** Environmental parameters such as air temperature, relative humidity, and air velocity were measured using data logger and anemometer in selected office rooms oriented to the Northwest (NW) and Southeast (SE) in both morning and afternoon time.
- ✓ **Questionnaire Survey (Subjective Assessment):** structured questionnaires was used to gather subjective responses of the employees on thermal comfort, clothing level, activity type, and perceived satisfaction. This helps compare measured data with user experience.
- ✓ **Computer Simulation (Analytical Method):** Using Autodesk Ecotect, Meteonorm and climate consultant the thermal impact of room orientation was analyzed by simulating solar radiation and thermal gain based on Adama's climatic data.

3.3.4 Procedures

For this study, detailed climatic data for Adama city was collected from the National Meteorological Agency (NMA) of Ethiopia and supplemented with TMY (Typical Meteorological Year) weather files. This included key parameters such as dry bulb temperature, relative humidity, wind speed, and solar radiation, including their daily maximum, minimum, and monthly averages. Then the data was interpreted by using Climate Consultant and Ecotect software.

The research is conducted in rooms located on the Northwest (NW) and Southeast (SE) curtain-walled facades were purposively selected for their contrasting orientation in terms of solar exposure. These rooms were chosen based on prior Ecotect simulations, which identified SE as the least optimal orientation (approximately 122.5° SE) in terms of solar heat gain, while NW lies outside the critical solar exposure range (45°E to 315°N), representing a more moderate orientation.

To isolate the effect of orientation several parameters were kept constant across samples rooms like Room height, Window-to-Floor Ratio (WFR), furniture type, Curtain-wall material layers and thickness and also occupancy level.

Field measurements were conducted during the hottest season in Adama, from April 21 to May 6, 2025, this represents the overheating seasonal of the year. The measurements were taken for 7 days with one-day intervals of work days, two times the day which is in the morning (10:00 - 11:00am) and afternoon (3:00 -4:00 pm). During field measurement digital data logger and Anemometer were are set at same height at 0.80 meter above the floor level and in center of the selected rooms. During this time windows closed, and internal heat-generating equipment was turned off.

3.4 Data collection

A. Questionnaire

Is the main thing that helps to understand and estimate the level of thermal sensation and satisfaction scale of respondent at a specific data collection time. The ASHRAE 55 thermal preference and thermal satisfaction scale of occupants is used.

Scale value	Thermal comfort descriptor	Thermal sensation descriptor
+3	Much too warm	Hot
+2	Too warm	Warm
+1	Comfortably warm	Slightly warm
0	Comfortable	Neutral
-1	Comfortably cool	Slightly cool
-2	Too cool	Cool
-3	Much too cool	Cold

Figure 3.19: Thermal comfort scale vs. thermal sensation scale

This survey questionnaire consists of demographics, general working environment thermal assessment and also clothing and activity level. And it is listed on Appendix.

B.Physical data Measurements: Environmental parameters such as air temperature, relative humidity, and air velocity were measured using data logger and anemometer in selected office rooms

Figure 3.20: Digtal data logger and Anemometer

C.Simulation tools: Using Autodesk Ecotect the least optimum orientation was determined based on the local weather data. And this tools are used in this study because of their ease of operation and better accuracy in terms of data analysis and interpretation.

3.5 Data analysis method

The qualitative and quantitative data that has been collected from the field measurement and survey is analyzed using tools such as Microsoft Excel whereas environmental simulations and solar studies were conducted using Ecotect software and weather data for Adama.

3.5.1 Simulation analysis

Weather data was imported from Meteonorm and then entered to Ecotect Analysis software to validate solar exposure, sun path, and orientation behavior in Adama's climate. This helped to theoretical assume and select which orientation have high and low solar exposure.

The study also included the actual 3D modeling of selected rooms in there floor layouts and rotated them across 24 different azimuth angles (at 15° intervals) to simulate thermal comfort performance under various orientations throughout the year. It is used to estimate the number of annual comfort hours inside the modeled rooms for each orientation, based on ASHRAE 55 adaptive thermal comfort standards. The results helped to identify the optimum and least favorable orientations for curtain-walled office buildings in Adama.

3.5.2 Qualitative analysis

The qualitative data of this study involves questionnaire survey which includes demographics, general working environment thermal assessment of office employees. This data is analyzed thematically, using statements and paragraphs it also is shown by pictures to show the real-time situation.

3.5.3 Quantitative analysis

The quantitative data of this study involves collecting and analyzing environmental measurements (air temperature, humidity and air speed) during work hours using calibrated instruments. The results is shown in the form of graphs, tables, pie charts and bar graph.

The table below shows the overall data collection and analysis method of the research.

Specific Objective	Data Used	Collection Method	Analysis Technique
To measure and compare indoor thermal parameters of rooms in opposite orientations.	Field measurements	Using digital data logger and anemometer	Graphs, and charts
To identify optimum azmitual angle for curtain-walled office buildings.	Simulation data	Using Ecotect Analysis software with Meteonorm weather file	Orientation-based thermal simulation, annual comfort hour comparison
To assess occupant thermal perception and comfort levels in NW and SE orientation.	Survey data	Using a questionnaires	Descriptive statistics, cross-tabulation and scatter plot

Table 3.4: Overall summary of data collection and analysis method: (Source: Author, 2025)

3.6 Data quality assurance

The study uses calibrated instruments to measure indoor thermal conditions. And data were consistently collected across all sampled rooms, ensuring measurements are taken at the same time of day and under similar conditions.

3.7 Validation of Simulation

The simulation was configured to reflect actual building conditions, including operational hours (Monday to Saturday, 8:00 AM to 5:00 PM), typical occupant clothing, and activity levels. The setup aimed to represent real-world usage as closely as possible to ensure realistic comfort hour predictions.

3.8 Ethical considerations

The research ensured the privacy and confidentiality of all participants involved. Participants was fully informed about the purpose, scope, and methods of the study, and their voluntary consent was obtained prior to their involvement. And all resources that are utilized in the research were credited.

CHAPTER FOUR

4. RESULT AND DISCUSSION

This chapter discusses the results obtained from field measurements and occupant surveys. The results include measured indoor environmental parameters (temperature, humidity, and air velocity), and subjective responses from building occupants based on thermal comfort surveys.

4.1 Measuring and comparing indoor thermal parameters

Comparing the actual temperature, humidity, and air speed in selected rooms facing different directions to show that orientation changes the thermal conditions inside.

4.1.1 Sun's paths of adama

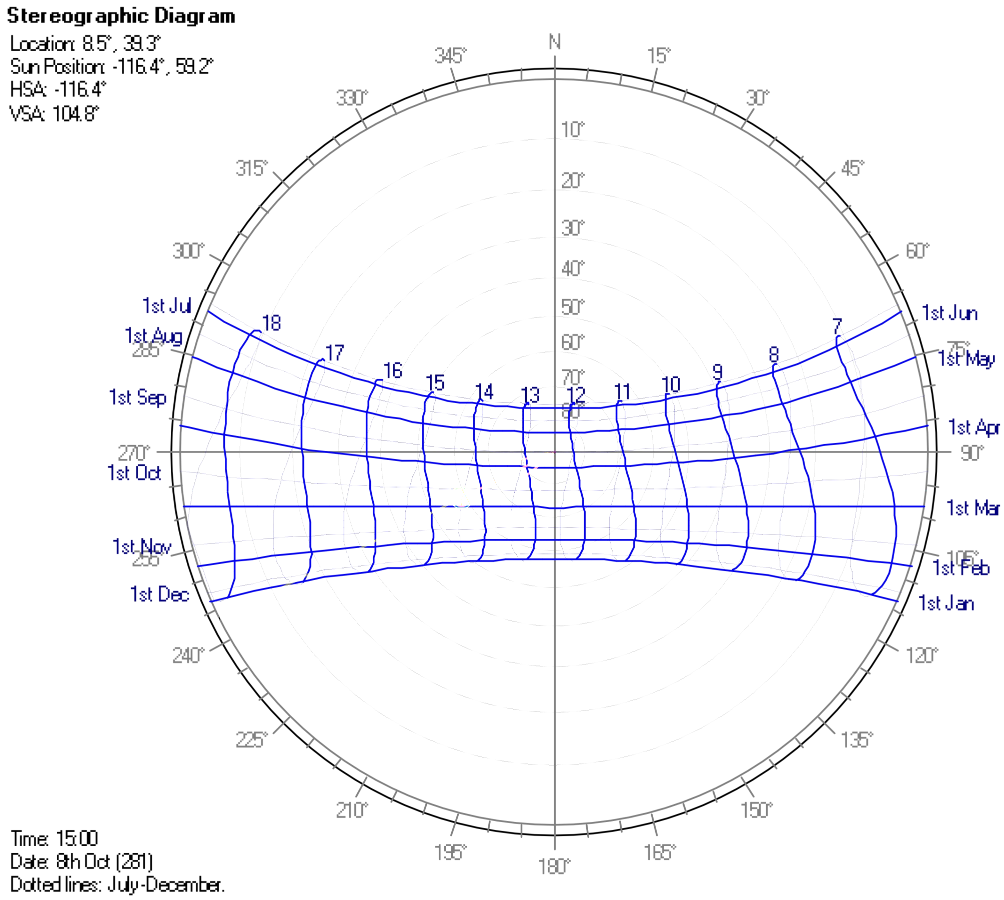


Figure 4.1: Stereographic sun-path diagram of Adama city: (Source: Autodesk Ecotect Analysis)

Stereographic diagram shows the sun's apparent path across the sky for different times of the year. According to Figure 4.1, In Adama the sun follows a high-altitude path during equinoxes and summer months, contributing to elevated solar radiation on exposed surfaces. The diagram shows the months March, April, and May and also September and October, indicate periods of potential overheating due to high solar altitude and longer sun exposure. The diagram shows that the maximum sun altitude during sunset is approximately 292.5°NW and during sunrise it is around 62.5°NE. The minimum sun altitude occurs near 242°SW and 122°SE during winter solstice.

4.1.2 Simulation analysis

The simulation analysis was conducted using Autodesk Ecotect to access the thermal performance of the rooms by rotating the floor model in 24 orientations (0^0 and 360^0 have the same value) by incrementing 15° azimuth angle in curtain-walled office buildings. It was set to reflect the actual operational schedule of the buildings which is workdays (Monday to Saturday) from 8:00AM to 5:00PM excluding Sunday and public holidays. Corresponding to this the occupant number, type of clothing and activity type was set to the buildings accordingly. The results focus on the how many indoor thermal comfort hours the building experience on an entire year (during work hours) in different orientation. The existing orientation is highlighted in the table.

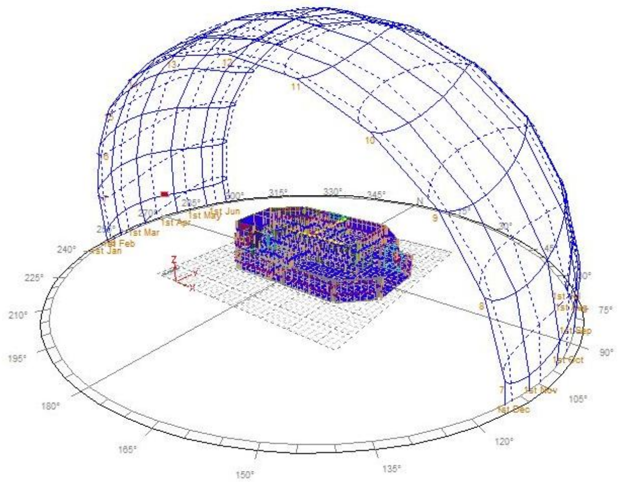
Selected building	Angle	Comfort hrs	Percentage	Angle	Comfort hrs	Percentage
 Building 1	Azimuth 0/360	2287	44.8%	Azimuth 180	2204	43.2%
	Azimuth 15	2265	44.4%	Azimuth 195	2169	42.5%
	Azimuth 30	2238	43.8%	Azimuth 210	2154	42.2%
	Azimuth 45	2243	43.9%	Azimuth 225	2138	41.9%
	Azimuth 60	2248	44.0%	Azimuth 240	2128	41.7%
	Azimuth 75	2273	45.5%	Azimuth 255	2102	41.2%
	Azimuth 90	2406	47.1%	Azimuth 270	2122	41.6%
	Azimuth 105	2008	39.3%	Azimuth 285	2147	42.1%
	Azimuth 120	2019	39.5%	Azimuth 300	2163	42.4%
	Azimuth 135	2040	39.9%	Azimuth 315	2184	42.8%
	Azimuth 150	2051	40.1%	Azimuth 330	2199	43.1%
	Azimuth 165	2059	40.3%	Azimuth 345	2229	43.7%

Table 4.1: Simulation analysis (Annual comfort hour and percentage)for building 1: (Source: Author, 2025)

The above model represent the 6th floor of Building 1 and the room in the SE direction was selected to do the simulation. This model is set to have a full single-glazed curtain wall with gypsum internal partition, 3m ceiling height, 35% WFR, natural ventilation system, used by 8 occupants which are doing computer work (typing). The operational schedule of the buildings is set as, workdays (Monday to Saturday) from 8:00AM to 5:00PM excluding Sunday and public holidays.

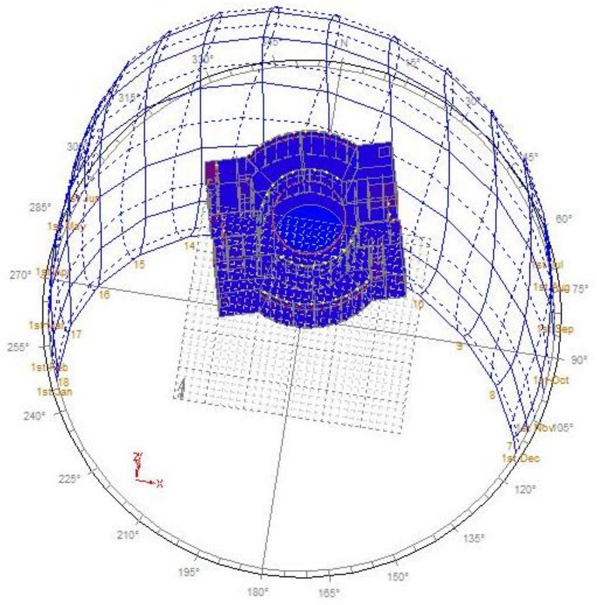
Selected building	Angle	Comfort hrs	Percentage	Angle	Comfort hrs	Percentage
	Azimuth 0/360	418	7.80%	Azimuth 180	389	7.2%
	Azimuth 15	401	7.50%	Azimuth 195	391	7.30%
	Azimuth 30	395	7.40%	Azimuth 210	310	7.30%
	Azimuth 45	389	7.20%	Azimuth 225	335	7.9%
	Azimuth 60	375	7.0%	Azimuth 240	450	8.4%
	Azimuth 75	365	6.80%	Azimuth 255	504	9.4%
	Azimuth 90	352	6.60%	Azimuth 270	565	10.5%
	Azimuth 105	340	6.30%	Azimuth 285	594	11%
	Azimuth 120	344	6.40%	Azimuth 300	629	11.70%
	Azimuth 135	359	6.7%	Azimuth 315	610	11.40%
	Azimuth 150	372	6.90%	Azimuth 330	578	10.80%
Building 2	Azimuth 165	380	7.10%	Azimuth 345	485	9.0%

Table 4.2: Simulation analysis (Annual comfort hour and percentage)for building 2: (Source: Author, 2025)

The above model represent the 7th floor of Building 2 and the room in the SE direction was selected to do the simulation. This model is set to have a half single-glazed curtain wall with gypsum internal partition, 3m ceiling height, 62% WFR, natural ventilation system, used by 6 occupants which are doing computer work (typing). The operational schedule of the buildings is set as, workdays (Monday to Saturday) from 8:00AM to 5:00PM excluding Sunday and public holidays.

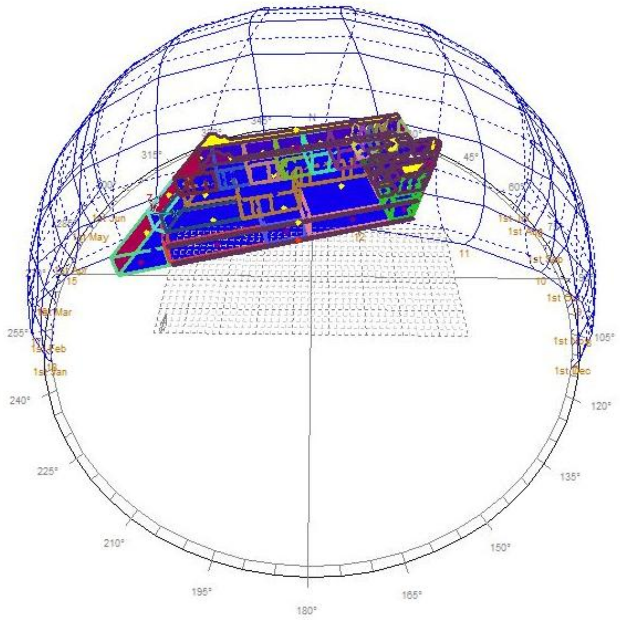
Selected building	Angle	Comfort hrs	Percentage	Angle	Comfort hrs	Percentage
	Azimuth 0/360	2769	51.6%	Azimuth 180	2300	42.90%
	Azimuth 15	2740	51.10%	Azimuth 195	2453	45.70%
	Azimuth 30	2299	42.80%	Azimuth 210	2424	45.20%
	Azimuth 45	2348	41.90%	Azimuth 225	2397	44.70%
	Azimuth 60	2092	39%	Azimuth 240	2355	43.90%
	Azimuth 75	2027	37.80%	Azimuth 255	2264	42.20%
	Azimuth 90	1969	36.70%	Azimuth 270	2270	42.70%
	Azimuth 105	1971	36.70%	Azimuth 285	2291	43.10%
	Azimuth 120	2003	37.30%	Azimuth 300	2355	43.90%
	Azimuth 135	1732	32.30%	Azimuth 315	2387	44.50%
	Azimuth 150	2177	40.60%	Azimuth 330	2423	45.1%
Building 3	Azimuth 165	2261	42.10%	Azimuth 345	2453	45.70%

Table 4.3: Simulation analysis (Annual comfort hour and percentage)for building 3: (Source: Author, 2025)

The above model represent the 2nd floor of Building 3 and the room in the SE direction was selected to do the simulation. This model is set to have a full single-glazed curtain with gypsum internal partition, 3m ceiling height, 56% WFR, natural ventilation system, used by 3 occupants which are doing computer work (typing). The operational schedule of the buildings is set as, workdays (Monday to Saturday) from 8:00AM to 5:00PM excluding Sunday and public holidays.

The result from the simulation of the three buildings is shown that North facing rooms have a better annual comfort hours and percentage relative to the South facing rooms. It also showes that Southeast orientation is the least optimum orientation for Adama.

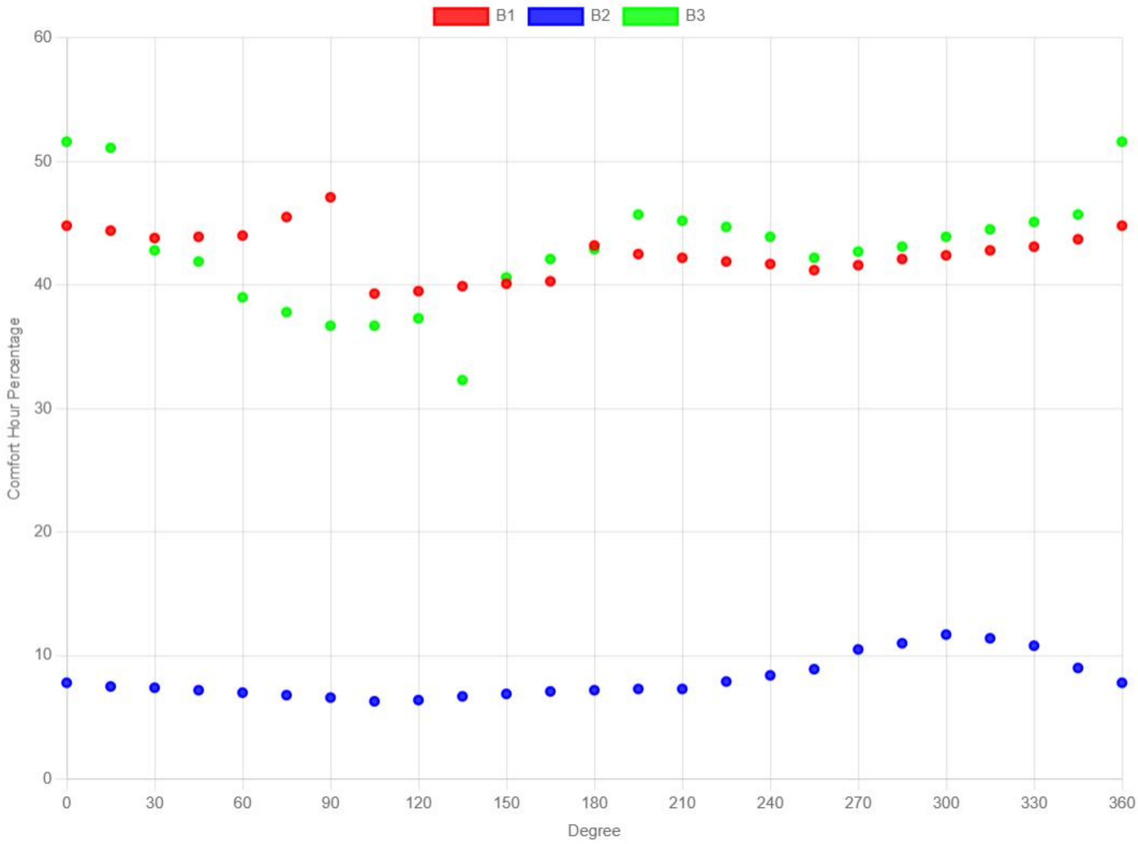


Figure 4.2: Comfort hours of the three selected buildings on 24 orientation

4.1.3 Indoor environmental measurments

According to the occupancy schedule based on observation, Most occupants follow a typical workday routine from 8:00 AM to 12:00 PM in the morning and resume work after a lunch break from 2:00 PM to 5:00 PM in the afternoon. This defines in what time window should all field measurements of temperature, humidity, and air velocity should be conducted.

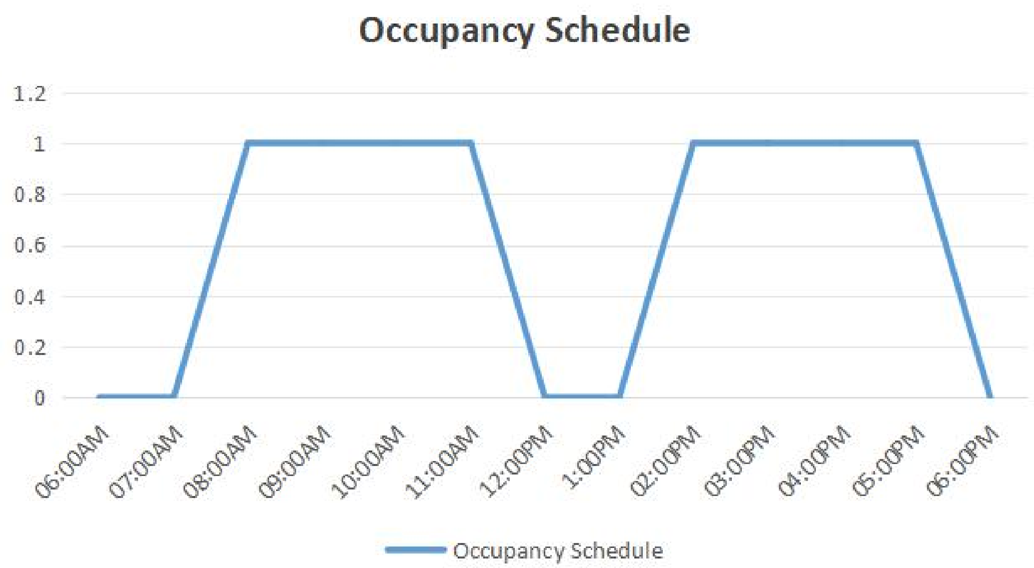


Figure 4.3: Occupancy Schedule of respondants: (Source: Author, 2025)

Based on the graph, measurements were taken from 10:00-11:00AM in the morning and from 3:00-4:00PM in the afternoon period. This is to reflect the real environment that the occupants experienced during regular working hours. Also this time gap can represent average thermal parameters in both time interval of a day.

4.1.3.1 Indoor air temperature

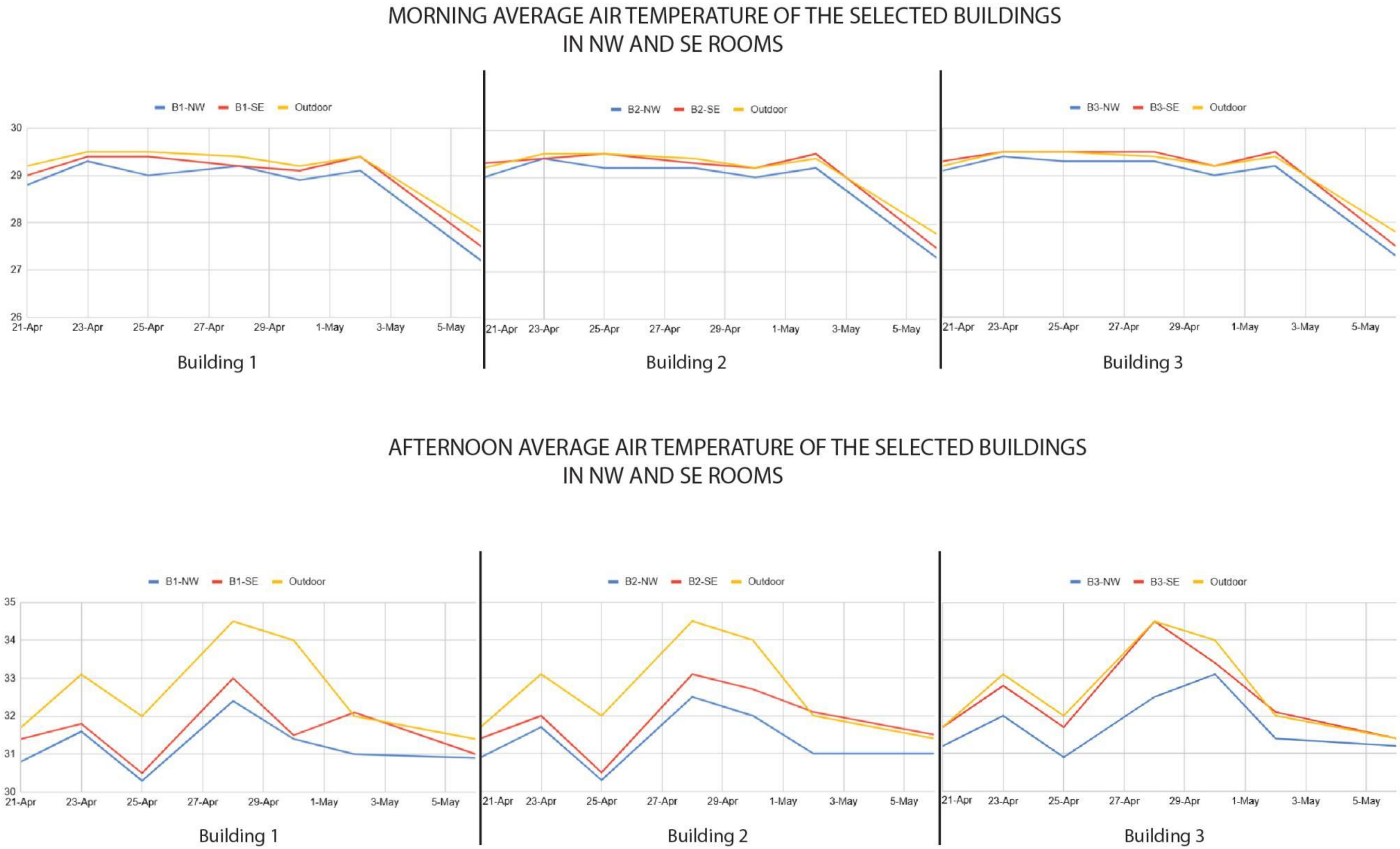


Figure 4.4: Morning and Afternoon Avg.Temperature of selected buildings room: (Source: Author, 2025)

The above figure represents the graph of morning and afternoon average indoor air temperature of NW and SE oriented selected rooms in the three building with the outdoor temperature which has been measured from April 21 to May 6 twice a day. The measurements are taken at equal time between rooms which have same range of WFR, same type of curtain type, same furniture, equipment type, equal occupants number, equipment's which can create heat are off and windows & AC are closed. On this graph all SE-facing rooms are the red line, NW-facing rooms are blue line while the outdoor temperature is expressed in yellow lines.

During the morning time (10:00-11:00AM) the SE-oriented rooms have a slightly higher air temperature than their NW counter parts across all three buildings. They have a range between 27^0C and 30^0C. The noticeable drop in May 6 was due to cold weather (rain) in that day. While in the afternoon time (3:00-4:00PM) the SE and NW-facing rooms shows a clear difference from 0.5^0C to 1.2^0C while it ranges between 30^0C to 35^0C. In April 28 the temperature of the buildings reached it's peak. Whereas the outdoor has been recorded to show that orientation has an impact on the indoor thermal performance of a building. It was in between 27^0C to 30^0C in the morning and 30^0C to 35^0C in the afternoon.

4.1.3.2 Relative humidity

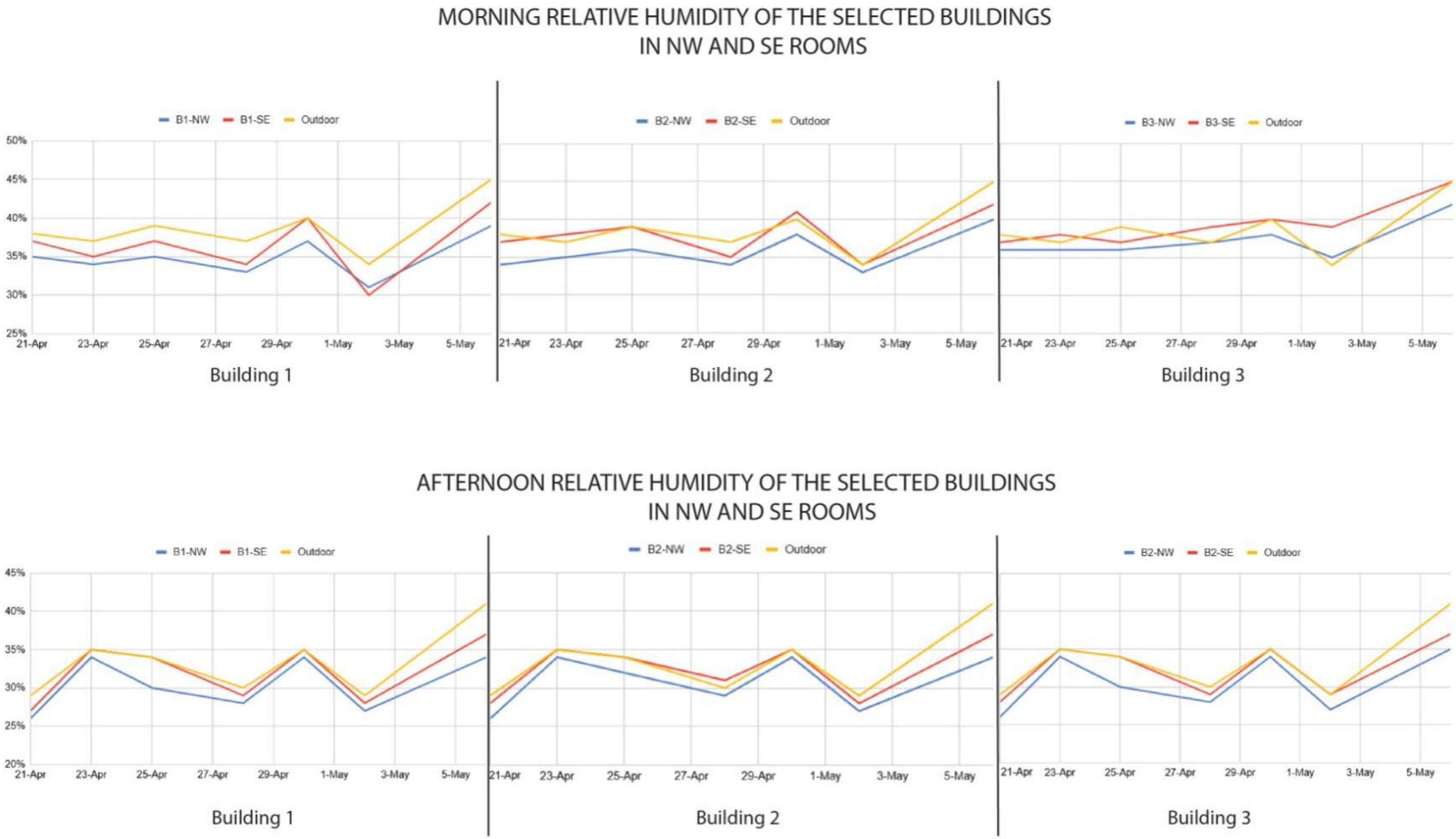


Figure 3.5: Morning and Afternoon Relative Humidity of selected buildings room: (Source: Author, 2025)

The above graphs shows the morning and afternoon relative humidity of the NW and SE facing rooms in the three buildings along with the corresponding outdoor relative humidity value which has been measured from April 21 to May 6 twice a day. In this graphs SE-facing rooms are the red line, NW-facing rooms are blue line while the outdoor RH value is expressed in yellow lines. The measurements are taken at equal time between rooms which have same range of WFR, same type of curtain type, same furniture, equipment type, equal occupants number, equipment's which can create heat are off and windows & AC are closed.

In the morning period (10:00-11:00AM) the SE rooms shows a slightly higher RH value than NW counter rooms in of 1-3% value. They have a range between 30-45%. And in the afternoon period (3:00-4:00PM) also the same the SE rooms shows a slightly high (1-4%) RH value than the NW facing counter rooms. The RH value at this time ranges between 25-40%. Whereas the outdoor RH values ranges 30-40% in the morning with a peak value of 45% in May 06 and 29-41% in the afternoon with a peak value of 41% in May 06. The increase in RH value in May 06 due to the rain in that day.

4.1.3.3 Air velocity

All selected rooms (NW and SE) in the three buildings have an indoor air velocity of 0 m/s during the monitoring periods. This is because windows were closed to have a fair comparison between the selected rooms during the measurement, to eliminate the impact of natural ventilation.

4.2 Occupant subjective responses for thermal comfort assessment

By linking comfort levels of the occupants to room orientation. It shows how orientation affects real occupants.

According to the demographic response of employees, all respondents in selected rooms fell within the age group of 26–35 years. Table 4.1 shows that most participants had significant experience working in their respective office environments. The mean duration of time spent in Building 1 is 2.72 years, for Building 2 is 2.5 years and for Building 3 is 2.33 years. They also have a standard deviations of 1.13, 1.09, and 1.21 respectively. This shows that the majority of participants had more than one year of experience in their current workplace which allowed them to provide informed feedback on indoor thermal comfort.

	Response Key 1=<6mo 2=6mo–1yr 3=1–3yrs 4=>3yrs		
Building Number	**Count**	**Mean**	**Std. Dev.**
Building 1	18	2.722222222	1.127493605
Building 2	12	2.5	1.087114613
Building 3	6	2.333333333	1.211060142

Table 4.4: Survey participant year of work experience: (Source: Author, 2025)

4.2.1 Occupants perception

All respondents wears typical office uniform during the survey period, consisting mainly of short or long sleeve shirts paired with skirts or trousers. It corresponds to a moderate clothing insulation level, generally estimated at around 0.6 clo. The consistency in clothing type among occupants minimizes variability in personal thermal insulation on perceived thermal comfort.

Whereas their primary activity during the hour prior to and during the thermal comfort measurement period was typing or computer-based office work. It corresponds to a low metabolic rate, typically around 1.1 met. Since all participants engaged in similar light sedentary activities, variation in metabolic heat generation among respondents was minimal.

4.2.1.1 Thermal sensational scale

This was collected from April 21 to May 6, 2025, in one working-day intervals, at the same times as field measurements (10:00–11:00 AM and 3:00–4:00 PM) in each selected room to align with real-time thermal conditions. This minimized the effect of day-to-day weather variability and ensured that responses reflected the actual indoor comfort conditions experienced during those specific time windows.

MORNING THERMAL SENSATION SCALE RESPONSES OF EMPLOYEES

Building	Orientation	-3	-2	-1	0	1	2	3
Building 1	NW	0%	0%	0%	33.33%	66.67%	0%	0%
	SE	0%	0%	0%	0%	66.67%	33.33%	0%
Building 2	NW	0%	0%	0%	0%	50.00%	25.00%	25.00%
	SE	0%	0%	0%	0%	0%	33.33%	66.67%
Building 3	NW	0%	0%	0%	25.00%	50.00%	25.00%	0%
	SE	0%	0%	0%	0%	66.67%	33.33%	0%

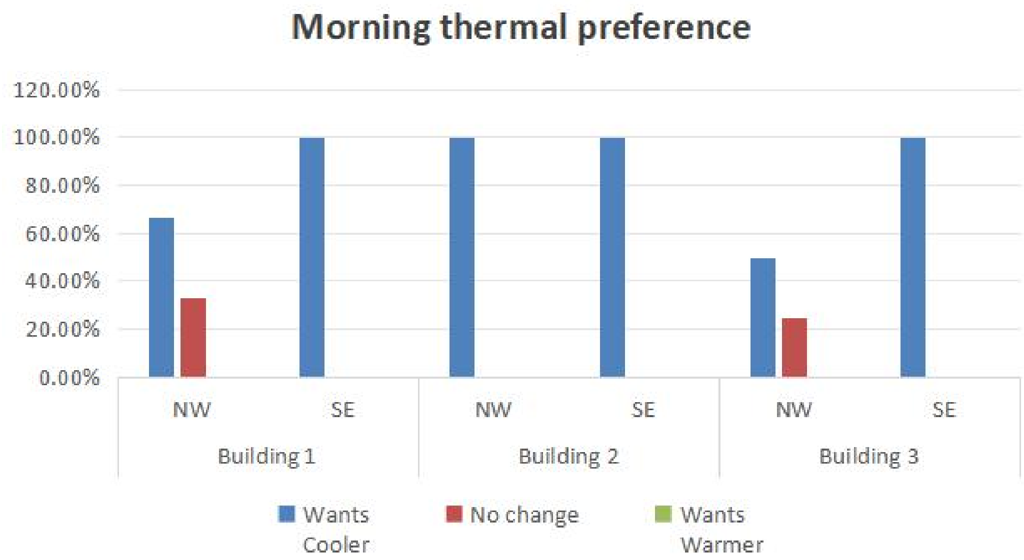
AFTERNOON THERMAL SENSATION SCALE RESPONSES OF EMPLOYEES

Building	Orientation	-3	-2	-1	0	1	2	3
Building 1	NW	0%	0%	0%	0%	50.00%	50.00%	0%
	SE	0%	0%	0%	0%	0.00%	50.00%	50.00%
Building 2	NW	0%	0%	0%	0%	25.00%	50.00%	25.00%
	SE	0%	0%	0%	0%	0%	50.00%	50.00%
Building 3	NW	0%	0%	0%	0.00%	50.00%	50.00%	0%
	SE	0%	0%	0%	0%	33.33%	33.33%	33.33%

Table 4.5: Morning and Afternoon thermal sensation scale responses of employees: (Source: Author, 2025)

The above tables presents the thermal sensation scale responses of the employees in the selected rooms of the three buildings. It was collected using the ASHREA 55 seven point scale. In the morning (10:00-11:00AM) most occupants feels slightly warm (+1) and hot (+3). The SE rooms have a higher percentage of warm (+2) and hot (+3) compared to NW facing rooms. The NW oriented rooms leaned to neutral (0) and slightly warm (+1). For example, 25% of the occupants reported hot (+3) in the NW rooms and 66.67% of them reported hot (+3) in the SE facing rooms in building 2. While in the afternoon (4:00-5:00PM) most occupants feels warm (+2). The SE rooms show a higher percentage of hot (+3) compared to NW rooms. The NW rooms shows a higher percentage toward slightly warm (+1). For example, 50% of the occupants responded hot (+3) in SE orientation while 0% responded hot (+3) in the NW orientation.

4.2.1.2 Thermal preference scale



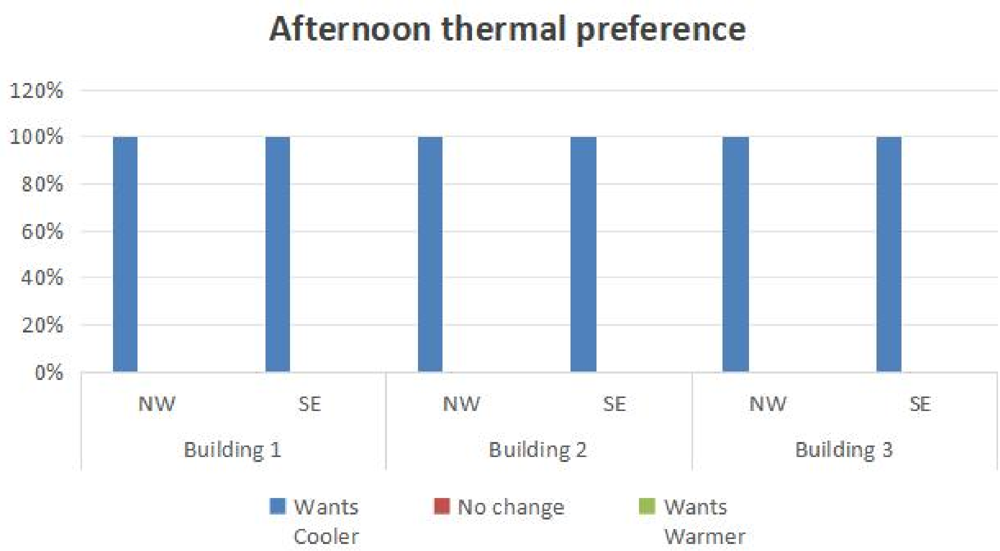


Figure 4.6: Morning and Afternoon thermal preference of occupants: (Source: Author, 2025)

The above graphs shows the thermal preferences of occupants during the morning and afternoon period in the three buildings. The responses were divided into three which are wants cooler, neutral and wants warmer. In the morning (10:00-11:00AM) period most occupants wants cooler condition in both orientation which ranges from 50% to 100% and some occupants (25% to 33.33%) in the NW orientation suggested no change. Whereas in the afternoon (03:00-04:00) period all occupants (100%) wants a cooler condition in both orientation.

4.2.1.3 Thermal adjustment strategies of selected buildings

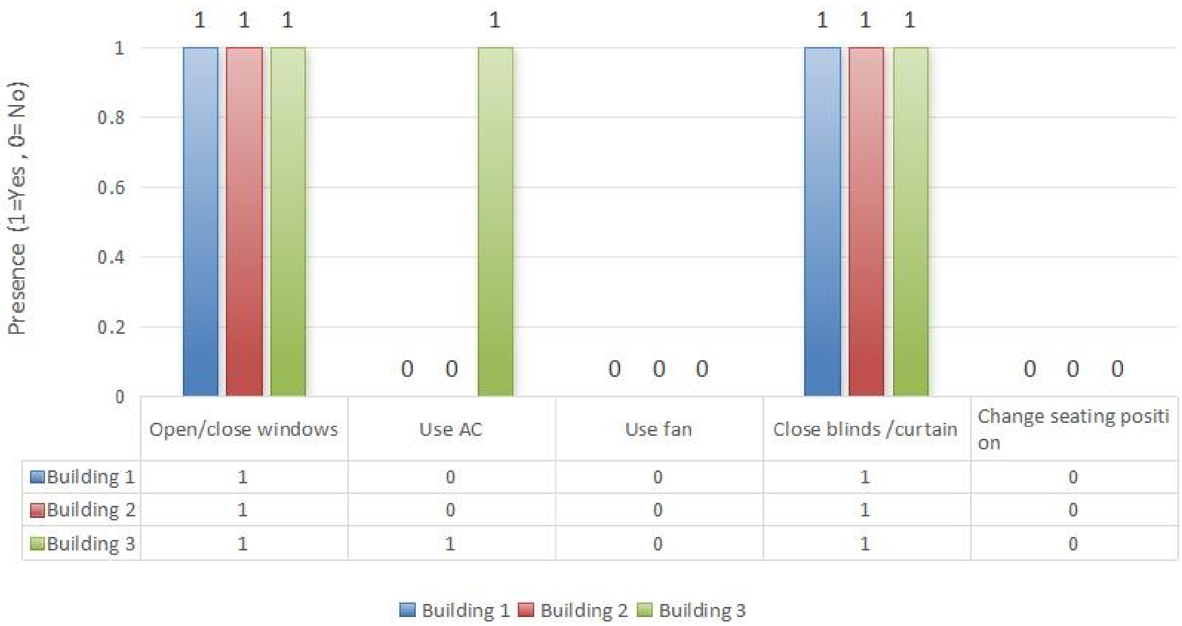


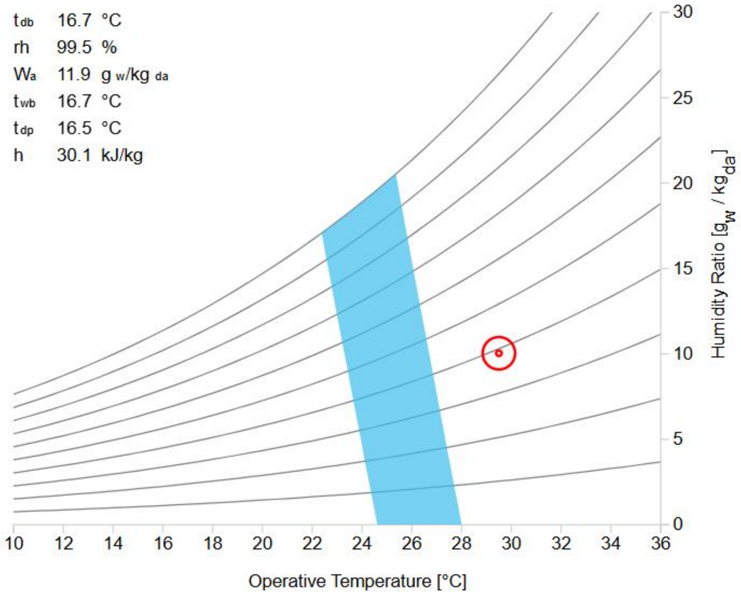
Figure 4.7: Thermal adjustments strategies of selected buildings: (Source: Author, 2025)

As the above graph indicates the selected buildings used a thermal adjustment methods to keep the indoor thermally comfortable. From these strategies all the three buildings uses opening/closing windows and blinds/curtain where as Building 3 uses air conditioning (AC) additionally. Strategies like using fan or changing seat position are not used in this buildings.

4.2.1.3 Thermal comfort for naturally ventilated spaces

- ✓ **ASHREA 55: Psychrometric chart**

To do this psychrometric chart Building 3 was selected because it shows the highest air temperature difference in a day (in April 28) of SE facing, in the morning it have 29.5^{0}C and in afternoon 34.5^{0}C. Compared to other buildings 34.5^{0}C is the highest measured value of all. This two charts can show



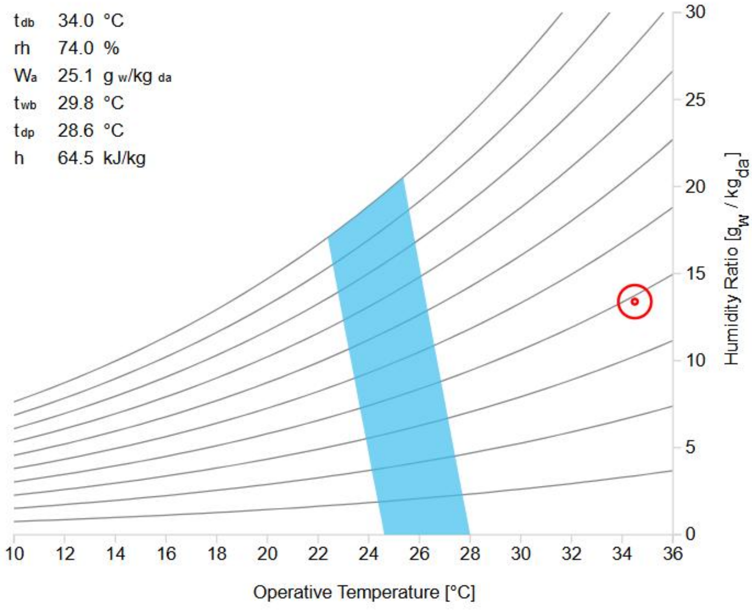
PMV = 1.33

PPD = 42 %

Sensation = Slightly Warm

SET = 28.9 °C

(a) Using morning measured value of average temperature (29.5^{0}C) and relative humidity (39%) of building SE room of Building 1



PMV = 2.97

PPD = 99%

Sensation = Hot

SET = 33.3 °C

(b) Using afternoon measured value of average temperature (34.5^{0}C) and relative humidity (39%) of building SE room of Building 1

Figure 4.8: Psychrometric chart for Building 1 (source, CBE thermal comfort)

In this psychrometric chart the operative temperature and for each point dry-bulb temperature equals mean radiant temperature (DBT = MRT). The comfort zone represents the combination of conditions with the same DBT and MRT for which the PMV is between -0.5 and +0.5, according to the standard. And clothing is 0.6clo (long sleeve shirts paired with skirts or trousers) when the metabolic activity is 1.1met (computer work/typing). This resulted the PMV (predicted mean vote) value of 1.33 and 2.97, PPD (predicted percentage of dissastisfied) value of 42% and 99%, and a SET (standard effective temperature) value of 28.9^{0}C and 33.3^{0}C during peak discomfort period. This means it is in the slightly warm category inn the morning and hot category in the afternoon which exceeded the optimal comfort levels based on the ASHRAE 55 standard for a naturally ventilated area.

4.3 Discussion

Results from the sun path diagram, simulation analysis and field measurements shows that indoor thermal performance is affected by building orientation in Adama's curtain-walled office buildings. The stereographic sun-path diagram of Adama revealed that March to May and September to October have a high sun altitude which resulted high solar exposure and indoor overheating in the Southeast rooms.

The simulation of the selected buildings also shows that Northwest rooms have a high value of annual comfort hours and percentage relative to the Southeast room. Field measurement shows similar result with the others that SE rooms have a higher indoor temperature (difference of 0.5-1.2^{0}C) in contrast with the NW rooms. The SE rooms have reached 30-35^{0}C in the afternoon time. However in case of relative humidity all rooms have 30-60% which is in the ASHRAE's comfort range. Also SE rooms have a slightly higher value (difference of 1-4%) than the NW rooms. Mean while air velocity was kept 0 m/s (windows were closed) during measurement time this was to ensure that only orientation difference was the variable affecting the thermal performance.

The demographic data of occupants in the three selected buildings fell within the age range of 26-35 years and they had over one year of work experience in their office rooms. This will make their feedback more consistence and reliable. During the questionnaire, ASHRAE 55 seven-point scale was used to record the responses of occupants on their thermal sensation. To mininize the personal thermal variability between occupants they have the same clothing insulation of 0.6 clo from short or long sleeve shirts paired with skirts or trousers and a metabolic rate of 1.1 met from computer work. The thermal sensation scale table shows that both in the morning and afternoon that the SE-oriented have a higher thermal sensation rating (warm & hot) compared to the NW-oriented room (neutral & slightly warm). In contrast the thermal preference graph indicates that most of the occupants in SE and NW preferred a cooler indoor environment in the morning period however in the afternoon all respondents (100%) prefer a cooler environment. This suggested that SE-oriented rooms have a higher solar heat gain during the afternoon relative to NW-oriented rooms it resulted less percentage of neutral thermal preference in the morning period relative to it. This was supported by the stereographic sun-path of Adama which shows that SE orientation have a higher solar heat gain orientation.

In the ASHRAE 55 psychrometric chart the average indoor condition during the survey falls in the slightly warm zone, which exceeded optimal indoor comfort level. This result aligns with the thermal sensation response of the occupants which was rated slightly warm to hot. During this discomfort working hours all buildings uses thermal adjustment strategies like natural ventilation by opening/closing windows and using blinds/curtain. While Building 3 uses AC (air conditioning) additionally.

All of these results shows that room orientation has an impact on thermal comfort. And emphasizes that there is a need for orientation-based design decisions to enhance energy efficiency and occupant well-being in curtain-walled office buildings in Adama.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study investigated the impact of room orientation in indoor thermal performance of curtain-walled office buildings in Adama, Ethiopia. It uses a mixed-method approach which included field measurement of indoor thermal parameters along with occupants surveys to determine how does orientation influence thermal comfort of office employees.

The results from field measurements and computer simulation clearly shows that orientation has a significant effect on indoor thermal conditions. Southeast (SE) facing rooms (the worst-case orientation based on solar exposure simulations in Autodesk Ecotect) have a higher indoor air temperature and a relative humidity value compared with their Northwest (NW) counterparts. These difference was mostly seen in the afternoon period when solar heat gain is at peak, even if the rooms were same in WFR (Window to floor ratio) range, curtain type, occupant clothing & activity type, and operational schedule, the SE-oriented rooms are warmer and less comfortable than NW-oriented rooms.

Also the results from the occupants survey further supported the field measurement and simulation. Most occupants in SE-oriented rooms responses were they feel uncomfortably warm during work time. And nearly all occupants from both orientations express the need for cooler conditions in the afternoon. According to the thermal comfort indices which is PMV value of 1.35 and PPD value of 43% indicated that most people were dissatisfied. To improve this the buildings used natural ventilation while some of them uses a mechanical cooling (AC) as their adjustment strategy.

This study confirms that solar exposure due to orientation can lead to indoor thermal discomfort. The findings can be help to reduce the use of mechanical cooling system in buildings.

5.2 Recommendations

Based on the results obtained from the research, that indoor thermal performance of curtain-walled office buildings in Adama are greatly affected by orientation, it is clearly showed that southeast facing rooms have a greater indoor thermal discomfort because of the high exposition of solar radiation compared to northwest facing rooms. Therefore, it is recommended that

- ✓ Architects & engineers should integrate orientation-based design strategies when designing and building curtain-walled buildings, especially in cities which have a hot climate like Adama.
- ✓ Future office buildings in Adama should be oriented along South-north axis (curtain-wall should be in the north side) to reduce the area of solar radiation exposure and use of mechanical cooling system during peak hours.
- ✓ While for existing buildings southeast-facing facades should use a proper external shading devices and low emission glass to control solar radiation and internal heat gain. This strategies will help to improve the indoor thermal comfort for occupants.
- ✓ Also by encouraging natural ventilation and optimizing window-to-floor ratio (WFR) within an acceptable range across office spaces will help ensure comparative thermal performance.

Overall, adapting orientation-based design principle not only improve the indoor thermal comfort but also enhances energy efficiency of curtain-walled buildings.

For further study there are several opportunities to expand the research like

- ✓ Can investigate how different glazing types, thermal insulation materials, and external shading strategies interact with orientation to influence indoor comfort.
- ✓ Can investigate the role of psychological and cultural factors in occupants' thermal perception.
- ✓ Can include open-window conditions to analyze natural ventilation's effect on thermal performance.

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APPENDIX- I

THERMAL COMFORT SURVEY QUESTIONNAIRE

Participant Code (Optional): ___________

Date: ___________

Time: ___________

Building Name/Code: ___________

Room Orientation: ______________

Room Floor Level: ___________

A. General Information (Demographics & Room Use)

1. **What is your age group?**

   1. ☐ 18-25
   2. ☐ 26-35
   3. ☐ 36-45
   4. ☐ 46-55
   5. ☐ 56+

2. **How long have you been working in this office?**

   1. ☐ Less than 6 months
   2. ☐ 6 months – 1 year
   3. ☐ 1–3 years
   4. ☐ More than 3 years

Q1. How would you describe the current temperature in this room?

Thermal Sensation Level	Mark (✓)
+3 Hot	
+2 Warm	
+1 Slightly Warm	
0 Neutral	
-1 Slightly Cool	
-2 Cool	
-3 Cold	

A. **Does the temperature in your office change significantly throughout the day?**

1. ☐ Yes, a lot
2. ☐ Yes, a little
3. ☐ No, it stays the same

B. **At what time do you feel the most thermal discomfort?**

1. ☐ Morning (8:00 AM - 10:00 AM)
2. ☐ Midday (12:00 PM - 2:00 PM)
3. ☐ Afternoon (3:00 PM - 5:00 PM)
4. ☐ Evening (6:00 PM - 8:00 PM)

C. **How do you usually adjust to uncomfortable temperatures?**

1. ☐ Open windows
2. ☐ Use air conditioning
3. ☐ Use a fan
4. ☐ Close blinds/curtains
5. ☐ Change seating position

Q2. Are you satisfied with the thermal conditions in this room?

☐ Yes ☐ No If **No**, please briefly explain:________________________

Q3. What are you currently wearing? (Check all that apply)

☐ Short sleeves shirt ☐ Long sleeves shirt ☐ Sweater/jacket

☐ Skirt ☐ Trousers ☐ Shoes ☐ Sandals ☐ Hat

Q4. What are you currently doing?

☐ Sitting at desk ☐ Typing/computer work ☐ Standing

☐ Walking ☐ Talking ☐ Other: ___________

Q5. What were you doing an hour before?

☐ Sitting at desk ☐ Typing/computer work ☐ Standing

☐ Walking ☐ Talking ☐ Other: ___________

Q6. How would you describe the air movement in the room?

☐ No air flow ☐ Slight air movement ☐ Noticeable airflow ☐ Drafty

APPENDIX- II

የቴርማል ምቾት ዳሰሳ ጥያቄ

የአሳታፊ ኮድ (ከተፈለገ): __________
ቀን: ___________
ሰዓት: ___________
የሕንፃ ስም/ ኮድ: ___________
የክፍል አቀማመጥ: ___________________
የክፍል ወለል ደረጃ ፡ ___________

ሀ. አጠቃላይ መረጃ (ሥነሕዝብ እና የክፍል አጠቃቀም)

1. የዕድሜ ምድብዎ ስንት ነው?

1.☐ 18-25
2.☐ 26-35
3.☐ 36-45
4.☐ 46-55
5.☐ 56+

2. በዚህ ቢሮ ውስጥ ምን ያህል ጊዜ እየሰሩ ነው?

1. ☐ ከ6 ወር በታች
2. ☐ 6 ወር - 1 ዓመት
3. ☐ 1-3 ዓመታት
4. ☐ ከ 3 ዓመት በላይ

ጥ1. በዚህ ክፍል ውስጥ ያለውን የሙቀት መጠን እንዴት ይገልጹታል?

የሙቀት ስሜት ደረጃ	ምልክት ያድርጉ (✓)
+3 ትኩስ	
+2 ሙቅ	
+1 ትንሽ ሙቅ	
0 ገለልተኛ	
-1 ትንሽ አሪፍ	
-2 አሪፍ	
- 3 ቀዝቃዛ	

1. በቀን ውስጥ በቢሮዎ ውስጥ ያለው የሙቀት መጠን በከፍተኛ ሁኔታ ይለወጣል?

    1. ☐ አዎ ብዙ
    2. ☐ አዎ ትንሽ
    3. ☐ አይ፣ እንደዛው ይቆያል

2. በጣም ሞቃት ምቾት የሚሰማዎት በየትኛው ሰዓት ላይ ነው?

    1. ☐ ጥዋት (8:00 AM - 10:00 AM)
    2. ☐ እኩለ ቀን (12:00 PM - 2:00 PM)
    3. ☐ ከሰአት (ከምሽቱ 3:00 - 5:00 ፒኤም)
    4. ☐ ምሽት (6:00 PM - 8:00 PM)

3. ብዙውን ጊዜ የማይመች የሙቀት መጠንን እንዴት ማስተካከል ይቻላል?

    1. ☐ መስኮቶችን ይክፈቱ
    2. ☐ የአየር ማቀዝቀዣ ይጠቀሙ
    3. ☐ ደጋፊ ይጠቀሙ
    4. ☐ ዓይነ ስውሮችን/መጋረጃዎችን ዝጋ
    5. ☐ የመቀመጫ ቦታን ይቀይሩ

ጥ 2. በዚህ ክፍል ውስጥ ባለው የሙቀት ሁኔታ ረክተዋል?
☐ አዎ ☐ አይ
አይደለም ከሆነ ፣ እባክዎን ባጭሩ ያብራሩ፡ ________________________________

ጥ3. አሁን ምን ለብሰቸኋል? (የሚመለከተውን ሁሉ ያረጋግጡ)
☐ አጭር እጅጌዎች ☐ ረጅም እጅጌዎች ☐ ሹራብ/ጃኬት
☐ ቀሚስ ☐ ሱሪ ☐ ጫማ ☐ ክፍት ጫማ ☐ ኮፍያ

ጥ 4. አሁን ምን እየሰራህ ነው?
☐ ዴስክ ላይ መቀመጥ ☐ የኮምፒውተር ስራ ☐ መቆም
☐ መራመድ ☐ ማውራት ☐ ሌላ፡ __________

ጥ 5. ከአንድ ሰአት በፊት ምን ታደርግ ነበር ?

☐ ዴስክ ላይ መቀመጥ ☐ የኮምፒውተር ስራ ☐ መቆም
☐ መራመድ ☐ ማውራት ☐ ሌላ፡ __________

ጥ 6 . በክፍሉ ውስጥ ያለውን የአየር እንቅስቃሴ እንዴት ይገልጹታል?
☐ ምንምየአየር ፍሰት የለም ☐ ትንሽ የአየር እንቅስቃሴ ☐ የሚታይ የአየር ፍሰት ☐ ረቂቅ

APPENDIX-III

1. Measurement values of selected buildings air temperature along with outdoor temperature

Morning Average Indoor Temperature of Selected rooms

Building name	Room name	Date						
		21-Apr	23-Apr	25-Apr	28-Apr	30-Apr	2-May	6-May
B1	B1-NW	28.8	29.3	29	29.2	28.9	29.1	27.2
	B1-SE	29	29.4	29.4	29.2	29.1	29.4	27.5
B2	B2-NW	29	29.4	29.2	29.2	29	29.2	27.3
	B2-SE	29.3	29.4	29.5	29.3	29.2	29.5	27.5
B3	B3-NW	29.1	29.4	29.3	29.3	29	29.2	27.3
	B3-SE	29.3	29.5	29.5	29.5	29.2	29.5	27.5
Outdoor		29.2	29.5	29.5	29.4	29.2	29.4	27.8

Afternoon Average Indoor Temperature of Selected rooms

Building name	Room name	Date						
		21-Apr	23-Apr	25-Apr	28-Apr	30-Apr	2-May	6-May
B1	B1-NW	30.8	31.6	30.3	32.4	31.4	31	30.9
	B1-SE	31.4	31.8	30.5	33	31.5	32.1	31
B2	B2-NW	30.9	31.7	30.3	32.5	32	31	31
	B2-SE	31.4	32	30.5	33.1	32.7	32.1	31.5
B3	B3-NW	31.2	32	30.9	32.5	33.1	31.4	31.2
	B3-SE	31.7	32.8	31.7	34.5	33.4	32.1	31.4
Outdoor		31.7	33.1	32	34.5	34	32	31.4

APPENDIX-IV

2. Measurement values of selected buildings relative humidity along with outdoor relative humidity.

Morning Relative Humidity of Selected rooms

Building name	Room name	Date						
		21-Apr	23-Apr	25-Apr	28-Apr	30-Apr	2-May	6-May
B1	B1-NW	35%	34%	35%	33%	37%	31%	39%
	B1-SE	37%	35%	37%	34%	40%	30%	42%
B2	B2-NW	34%	35%	36%	34%	38%	33%	40%
	B2-SE	37%	38%	39%	35%	41%	34%	42%
B3	B3-NW	36%	36%	36%	37%	38%	35%	42%
	B3-SE	37%	38%	37%	39%	40%	39%	45%
Outdoor		38%	37%	39%	37%	40%	34%	45%

Afternoon Relative Humidity of Selected rooms

Building name	Room name	Date						
		21-Apr	23-Apr	25-Apr	28-Apr	30-Apr	2-May	6-May
B1	B1-NW	35%	34%	35%	33%	37%	31%	39%
	B1-SE	37%	35%	37%	34%	40%	30%	42%
B2	B2-NW	34%	35%	36%	34%	38%	33%	40%
	B2-SE	37%	38%	39%	35%	41%	34%	42%
B3	B3-NW	36%	36%	36%	37%	38%	35%	42%
	B3-SE	37%	38%	37%	39%	40%	39%	45%
Outdoor		38%	37%	39%	37%	40%	34%	45%