THE RELATIONSHIP OF BUILDING ORIENTATION TO INDOOR THERMAL COMFORT AND DAYLIGHTING: THE CASE OF CONDOMINIUM BUILDING IN ADAMA CITY, ETHIOPIA

Olyad Gudeta Dabesa

A Thesis Submitted to the School of Civil Engineering and Architecture

Department of 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, 2022

Adama, Ethiopia

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APPROVAL SHEET

I, the advisors of the thesis entitled **"The Relationship of Building Orientation to Indoor Thermal Comfort and Daylighting: The case of Condominium Building in Adama city, Ethiopia"** and developed by Olyad Gudeta Dabesa, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Belay Zeleke (PhD)	______________________	______________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Olyad Gudeta have read and evaluated the thesis entitled **"The Relationship of Building Orientation to Indoor Thermal Comfort and Daylighting: The case of Condominium Building in Adama city, 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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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Department Head	Signature	Date
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Office of Postgraduate Studies,Dean.	Signature	Date

DECLARATION

I hereby declare that this Master Thesis entitled **"The Relationship of Building Orientation to Indoor Thermal Comfort and Daylighting: The case of Condominium Building in Adama city, Ethiopia"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Olyad Gudeta Dabesa	________________________	__________________
Name of the student	Signature	Date

RECOMMENDATION

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

Belay Zeleke (PhD)	____________________	____________________
Major Advisor	Signature	Date

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ACRONYMS AND ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
ALT	Altitude
AR	Aspect Ratio
AZI	Azimuth
Clo	Cloth insulation [m²·K/W]
E	East
EBCS	Ethiopian Building Code Standards
HVAC	Heating ventilation air-conditioning
IAQ	Indoor Air quality
IEQ	Indoor Environmental Quality
IHDP	The Integrated Housing Development Programme
ITC	Indoor Thermal Comfort
ITQ	Indoor Thermal Quality
ISO	The International Organization for Standardization
L/W	Length to Width Ratio
Max	Maximum
Min	Minimum
Met	Unit of metabolic activity [W/m2]
MR	Metabolic Rate
NMA	National Meteorological agency
N	North
NE	North East
PMV	Predicted mean vote
PPD	Predicted people dissatisfied
R^2	The Square of the correlation coefficient
RH	Relative humidity
S	South
SW	South West
TS	Thermal sensation
TP	Thermal preference
W	West
WWR	Window Wall Ratio

LOCAL TERMS

Bega- Also known as Ethiopia's winter, represents the hottest and dry season. It begins on December 22nd and ends on June 21st.

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

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

Tsedey- Also known as Ethiopia's spring, represents the slightly warmest season. It begins on December 22nd and ends on June 21st. In this season.

Atana tera (Solee) condominium site located in (kebele 01) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Cherkacherk (Adodee) condominium site (located in kebele 04) -The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Duket (Jallisi) condominium site (located in kebele 09) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Ganda gara (Lujoo) condominium site (located in kebele 01) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Goro condominium site (located in kebele 01) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Moenco (Diko) condominium site, (located in kebele 05) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Silase condominium site (located in kebele 01) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Sodober (Wenji road) condominium site (located in kebele 09) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Kebele - The smallest administrative unit in Adama.

ABSTRACT

The orientation of the building is one of the sustainable passive techniques for minimizing energy consumption and maintaining a building's indoor thermal comfort in terms of indoor temperature, solar radiation, aspect ratio, and window to wall ratio. The study focused on the effect of poorly oriented buildings and did not consider the climate condition, sun's path of location, wind direction, and window to wall ratio (WWR) to investigate the impact of orientation as a design variable on indoor thermal comfort and daylight illumination. Buildings are not designed to reduce solar gain and enhance indoor thermal comfort in generally hot and dry places like Adama City, which receives intensive sunlight all year. Duket condominium was chosen to investigate the thermal comfort of naturally ventilated at a specific condominium location in Adama city in various orientations on a distinct solar axis (i.e., S–N, E–W, NW–SE, and NE–SW) with window to wall ratios (i.e., South: 52.7%, East: 35.5%, West: 41.6%, North: 25.3%) and 57.2% aspect ratio using a field survey, and data collected during the hottest months of the year, *April and May 2022. First, a data logger was used to take measurements of indoor air temperature, relative humidity, airspeed, and daylight illuminance for different building orientations. In addition, using a standard questionnaire, the residents were asked about their thermal perceptions in their households. Secondly, the collected data was processed using Excel and Ecotect software was used for simulation and sun paths of location. According to the data gathering and analysis, the result demonstrates that more than half of those respondents (64.8%) on the E-W axis (south oriented) are uncomfortable. The E-W axis was about 30C to 40C and 300lux to 500lux higher than that of the building-oriented S-N axis. Finally, based on the adaptive model of ASHRAE-55 and ISO-7730, the results showed that the east-west orientation affects indoor thermal comfort when compared to the south-north orientation. In this regard, the study concludes that a south-north orientation is the best optimum orientation and provides good thermal comfort.*

Keywords: Building Orientation, Climate, Condominium building, Environmental variables, Sun path, Thermal comfort, Window to wall ratio

CHAPTER ONE

INTRODUCTION

This paper is written for a study conducted in the administrative city of Adama, Ethiopia. In partial fulfillment of a Degree of Masters in Environmental Architecture at Adama Science and Technology University. The study aimed to analyzing the effect of building orientation on indoor thermal comfort and daylighting in condominium buildings. Understanding that the sun's paths and wind's directions are different for every location is critical for designing building orientation that allows for passive solar gain while reducing solar radiation and ventilating the indoors. The indoor thermal comfort and daylight illumination of buildings also change depending on building orientation and climate conditions. Around 70% of condominium buildings in the city are south-oriented, allowing solar radiation to reach all exterior faces throughout the year. Therefore, building design should consider different climatic conditions, sun paths, and wind directions of a location to provide the best indoor thermal comfort. Because the first design requirement for a building design is orientation, which reduces the impact of natural climatic elements including daylight illumination, temperature, and airspeed. This chapter discusses the background of the study; the statement of the problem; the objective; research questions; the significance of conducting the study; the scope of the study; and limitations.

1.1 Background of the study

Climate plays a major role in the day-to-day and overall life of occupants in residential buildings (Kisan et al., 2010). Orientation is a key design parameter in climate-responsive design since it plays a major role in the achievement of indoor thermal comfort in the built environment. Because the effect of orientation on indoor thermal comfort is also one of the most critical design variables. The absence of thermal comfort in residential buildings is primarily attributable to improper orientation and climate (Woods, 2021).

In Ethiopia, the sun's path and wind directions are different from location to location. Additionally, the climatic conditions also vary significantly. As a result, for each location condominium design should consider climate condition. Orientation, sun path, and wind are all essential variables that influence a building's indoor thermal performance (Hailu et al., 2021).

Creating a thermally comfortable environment for condominium houses is one of the most important when designing residential buildings (Rilatupa, 2019). Because one of the most essential considerations for designers is building orientation.

Passive building strategies like building orientation, window to wall ratio, and aspect ratio have a significant impact on people’s daily life and indoor thermal comfort. Because building orientation is one of the most sustainable passive strategies for reducing energy consumption and maintaining a building's indoor thermal comfort (Rodrigues & Landin, 2019). When a building's orientation is not aligned with its surroundings and climate conditions, it causes intense overheating due to solar radiation in buildings in hot climates (Sedki et al., 2013).

In Adama, the majority of buildings poorly designed in terms of orientation, ventilation and solar path. Because designs are duplicated and repetitive the same orientation and types of design in different parts of the country for different climate conditions and sun paths. As a result, the study focused on how orientated buildings are affect indoor thermal comfort and daylight illumination.

1.2 Statement of the problem

Most condominium house designs are built repetitively, duplicating the same orientation and types of design in different parts of the country for different climate conditions, without regard to orientation, sun path, wind direction, window to wall ratio, and aspect ratio. The result of designing a building without consideration of the sun's paths, wind directions, and the orientation in different climate conditions has an impact on the occupants' indoor thermal comfort. There is no use for any sun shading systems or any measures taken to solve the problem of daylight illumination and to attain thermal comfort in Adama city, where the climate is hot and receives sunlight all year. In Adama, approximately 70% of condominiums were oriented south (east-west axis) so that solar radiation could reach all external facades of buildings all year. The intention of designing condominium houses by the government for the federal and different regions in mass is not consider the climate condition of the location. Currently, the majority of condominium houses use the same orientation, material, and fenestration. In Ethiopia, there are no regulations and monitoring systems regarding building orientation to improve the thermal comfort of condominium houses by considering orientation, sun path, and climatic conditions. As a result, most condominium houses in Adama City are not optimally positioned, based on standard and stereotype diagram. And many buildings' indoor thermal comfort is compromised, and the energy required to cool and ventilate.

In addition, there are no recommendations or principles for designing condominium houses in various climates to address the issues of indoor thermal comfort and daylighting. The fact demonstrates that the IHDP of the federal government is only concerned with duplicating buildings and solving the housing problem for poor and middle-income individuals. These modular condominiums are designed at the federal level before being dispersed to ten regions and two federal cities without consideration for climate, sun path, and natural ventilation. Furthermore, no research has been done in Adama on the effect of orientation on the internal thermal comfort of residential buildings. Hence, this study is intended to fill up the gaps that should be considered before duplicating and repeating condominium houses.

1.3 Objective

General Objective

To understand the effect of building orientation on the indoor thermal comfort and daylighting on condominium building in Adama city, Ethiopia.

Specific Objectives

1) To measure indoor temperature, relative humidity, airspeed, and daylight illuminance of selected orientation that affect thermal comfort.
2) To identify residents' thermal perception in the selected building orientation
3) To compare and find the optimum orientation of the selected condominium site in Adama based on sun paths, wind direction and WWR, for indoor thermal comfort.

1.4 Research Questions

Main question

How does the building orientation affect the indoor thermal comfort and daylighting?

Specific questions

1) What is the magnitude of the indoor temperature, relative humidity, airspeed, and daylight illumination levels in a selected orientation?
2) What is the thermal perceptions of residents towards thermal comfort in the case of selected orientation?
3) Which orientation is the best optimum orientation for Adama city?

1.5 Significance of the study

The study will be important for designers as it gives a chance to orientated buildings to the best optimum orientation. This will be useful for IHDP to determining the importance of thermal comfort in design decisions and to consider building orientation with climate conditions and sun paths. It can also be used to guide climate-responsive building design, which evaluates the local climatic condition and quantifies the building's passive performance in a way that is sensitive and precise enough to represent the impact of building orientation on indoor thermal comfort. It is hoped that the findings of this study, benefit and create more awareness among condominium housing designers, government, Adama municipality, and other organizations dealing with indoor thermal comfort of condominium houses by considering the climate, orientation, and environments. And, ideally, it will encourage researchers to do additional research in the field.

1.6 Scope of the study

The study is conducted with in the current boundary of Adama city lies in the geographical location of 8°26 ′15″N to 8°37 ′00″N latitude and 39°12′15″E to 39°19′45″E longitude. It focused on the building's orientation, climate, sun paths, aspect ratio, and window to wall ratio in the site were studied to represent the other building typologies to compare and determine the best orientation for the buildings on the chosen location.

1.7 Limitations of the study

The study has faced many problems. It was challenging to measure every environmental variable hourly and minutely during the measurement time. The constraint of time and resources, Covide19 pandemic, and the political situation in Ethiopia was the big limitation to collect detailed survey and the occupant’s response. Furthermore, throughout the data gathering stage, certain informants' willingness was difficult.

1.8 Organization of the report

The paper consists of five chapters. Chapter one - Introducing the study. This chapter gives a brief introduction to building orientation and indoor thermal comfort. Chapter two deals about A literature review. This chapter describes the theoretical review of thermal comfort and contextual review of the sun path, orientation, WWR, and Climate condition of the study area.

Chapter three - Methods and materials. The research methodologies and materials were addressed in the chapter. The research design, size of the sample, data source and method, and the material used are specified. Chapter four- Result and Discussion. It also includes the results of field data collection, case study building orientation, analysis of WWR and aspect ratio. It analyzes the data from results to determine the orientation's thermal comfort and comparisons of both orientations. Chapter five- Conclusion and recommendation. Based on the result and discussion study's recommendations and conclusions are presented in the last chapter. Finally, Reference, thermal checklist, questionnaires, and comparative graph between south orientated and north orientated rooms are given in the Appendixes I to VI.

1.9 Operational definition of the study

Aspect ratio: The length and width of a building's footprint (x:y) enables for surface area comparison between different building designs. Increases in relation to the east-west or north-south axis for orthogonal building designs (Tajuddeen & Ango, 2017).

Azimuth (AZI) - the sun's position in the horizontal plane measured clockwise from north (so east = 90^{o}, south = 180^{o}, and west = 270^{o}, although north might be 0 ^{o} or 360^{o}) (Steven, 2007).

Building Orientation: The position of a building in respect to its exposure to sunlight is referred to as its orientation. As previously stated, the structure can be oriented north, east, south-north, west, and east-west (M. Al-Tamimi et al., 2011).

Building Site: a site where a building or residence is being built or situated.

Condominium Housing: "Condominium housing is a kind of housing tenure in which each resident household owns their apartment but shares ownership and responsibility for the building's shared facilities and amenities (UN-Habitat, 2011).

Housing: The number of dwelling units in existence (a noun) as well as the process of keeping that number up to date (E-mail, 2006).

Thermal preference: Thermal preference is the desired body temperature in the absence of biological limitations, and it's often used to figure out how climate change affects extinction vulnerability and activity variations (ASHRAE 55, 2020).

Thermal sensation: is a standard parameter in most thermal experiments. It is uniformly defined in ISO 7730 and ASHRAE 55 standard with five or seven scale from -3 (cold) to +3 (hot). (ASHRAE 55, 2020) and (ISO 7730, 2005).

Window to wall ratio: WWR is the percentage of the above-grade wall area covered by fenestration, computed as the ratio of the wall fenestration area to the above-grade wall area, according to ASHRAE 90.1 (ASHRAE 90.1, 2004).

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Thermal comfort

Thermal conditions play a critical role in influencing dwellers comfort and well-being. Thermal comfort is a mental condition defined by contentment with one's thermal surroundings. Thermal comfort 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 (Turner, 2011).

In the home, thermal comfort is a mental state that expresses happiness with the temperature Council, 2019. Figure 2.1 depicts that indoor thermal comfort is essential for a comfortable indoor atmosphere. These environmental factors, such as heat from daylight, insufficient ventilation, excessive humidity, and solar radiation, can all contribute to inhabitants' poor health and operating efficiency (Givoni, 1992).

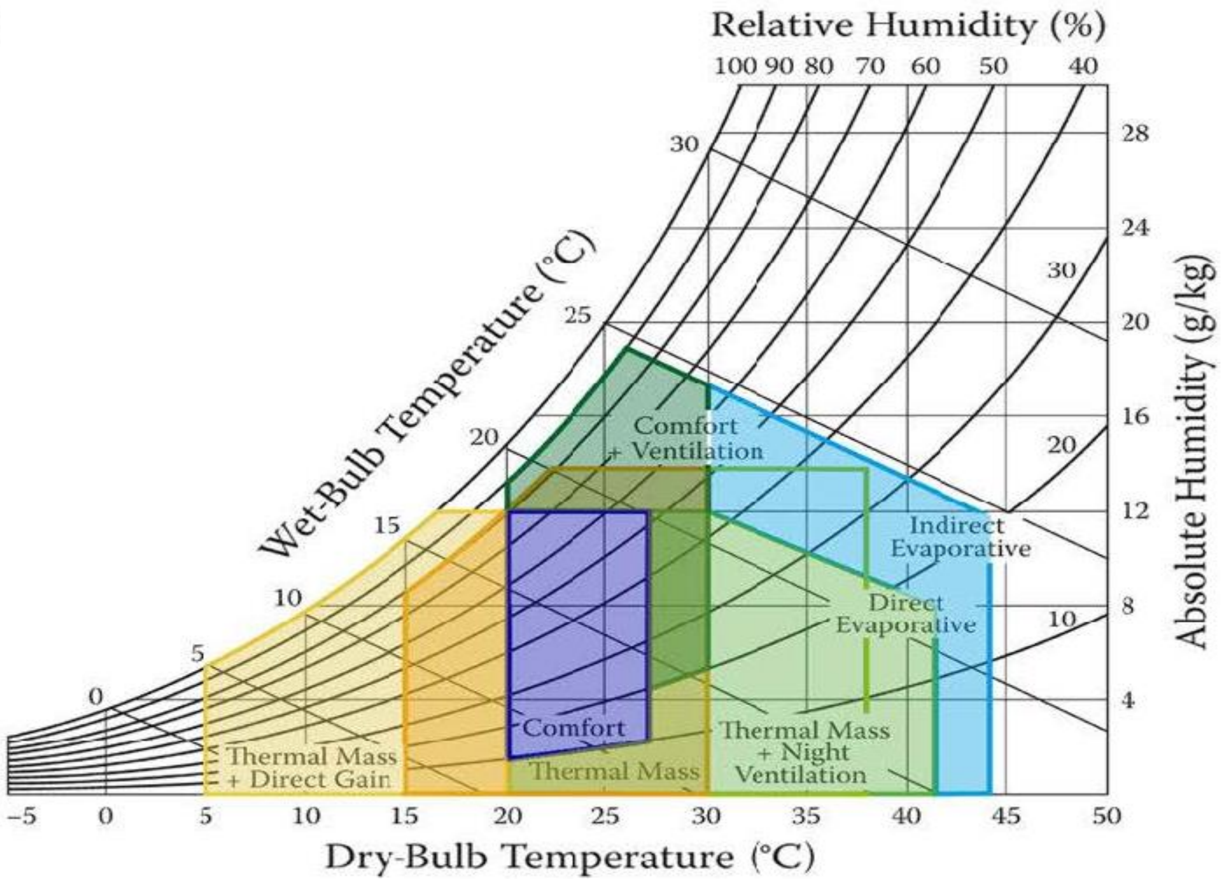


Figure 2.1: Comfort area on Psychometric chart (Source: Schiavon, 2014)

The amount of radiation received by the building is determined by its orientation, according to (Givoni, 1992). According to figure 2.2, the cooling load is affected by direction. It's critical to align the building with the prevailing winds in places where air circulation is the primary source of comfort. In areas where the ambient temperature has a larger impact on comfort than ventilation, sun orientation is critical. The major facades should be oriented north-south because the summer sun only penetrates the facades and openings marginally in these directions, however in the winter, when the sun's path is lower, there is the possibility of solar access (Rosenlund, 2000).

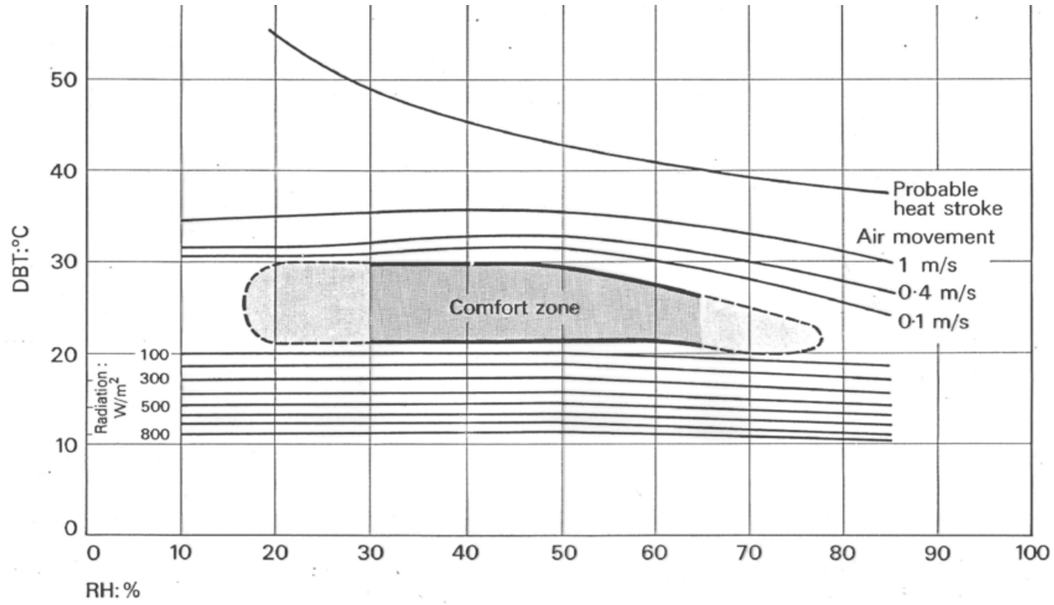


Figure 2.2: The Olgyay bioclimatic (Source: Schiavon, 2014)

2.1.2 Factors Affecting Thermal Comfort

Regarding the factors affecting thermal comfort and room temperature regulation literatures and studies classified into two that some of them takes the six parameters as a variables of thermal comfort as well as the rest use these as a factor affecting thermal comfort. Even though both may work we have to decide on general standards in which in this study ISO and ASHRAE standards (Council, 2019).

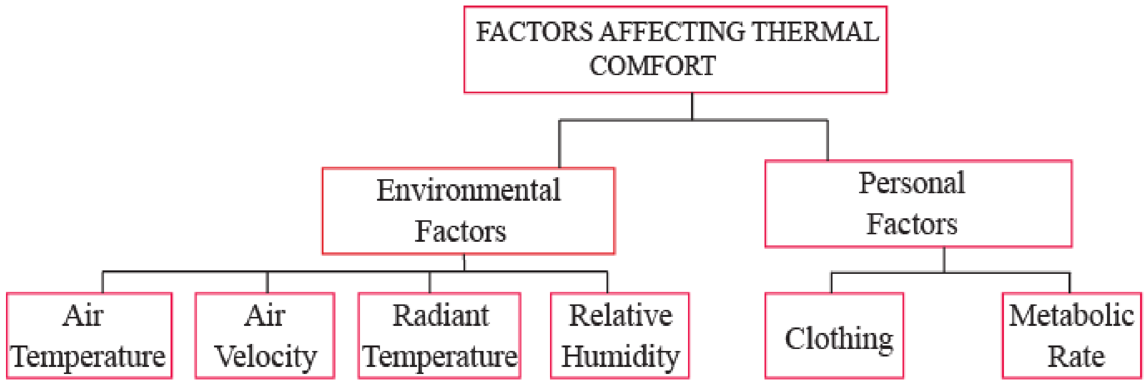


Figure 2.3: Factor affecting indoor thermal comfort (Source: Turner, 2011)

A. Environmental factors

(Body, 2021), Any further heat gain or loss produces severe pain, according to the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). The quantity of heat created must equal the amount of heat lost to sustain thermal comfort. It has long been recognized that elements other than air temperature impact the sense of hot or cold. Thermal comfort is influenced by six primary components and variables (Mora, 2021).

i) air temperature (ambient temperature)

ii) Relative Humidity (water vapor measurement in an air-water mixture)

iii) Radiant temperature (the temperature of the surfaces surrounding us)

iv) Air motion/velocity (the rate at which air moves around and touches skin)

i. Air Temperature

Regarding to (Council, 2019), The temperature around the body, often known as room temperature or air temperature, is measured in degrees Celsius or Fahrenheit. The most expressive of all environmental elements is air temperature. Because people are particularly temperature sensitive, this is the case. A thermometer is used to measure this. The comfortable range for most people (80%) is 20°C to 23°C and 23°C to 26°C in winter and summer respectively. The air temperature is one of the most important aspects of thermal comfort.

ii. Radiant Temperature

The heat radiated by a hot element in the medium is referred to as radiant temperature. In some circumstances, this factor might have a greater impact than air temperature. The sun is perhaps the most important radiating object to consider (Body, 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.

iii. Relative Humidity

Humidity is defined as the percentage of absolute humidity in the air represented as water vapor pressure, which influences a person's evaporative heat loss (Standard, 2005). When water is heated and evaporates in the surrounding region, the percentage of humidity in the air rises.

However, when relative humidity levels are between 30% and 70%, there is little impact on human comfort (Lai, 2019). There is no defined lower humidity threshold for thermal comfort, according to ASHRAE 55 (Liaison, 2004). (Parsons, 2002) underlines the importance of sweating as the body temperature rises; perspiration is the primary and most efficient technique of cooling the skin when evaporation occurs. ISO 7730 has underlined the allowable humidity range. High or even moderate humidity might make occupants uncomfortable at a moderate temperature (26°C or greater) with moderate exercise (around 2 met) (Kisan, 1987).

iv. Air Velocity

Airspeed has a crucial influence since people are so sensitive to it. As a consequence, it may cool or heat a room based on indoor factors such as temperature and relative humidity. These two elements, together with airspeed, have the biggest impact on passengers' thermal comfort (Schiavon, 2014). The most important aspect of airspeed is that it influences the convective heat exchange between man and the environment, which impacts overall heat loss ISO7730 (2005). This relationship is influenced by the ambient temperature and relative humidity. Even when interior air temperatures are high and the requirement for environmental convection skin is vital, having more than 0.2m/s indoors might cause turbulence (Turner, 2011).

B. Personal factors

i. Activity (metabolic rate)

One of the most important aspects impacting thermal comfort is activity. There are various types of structures, each with its own function and activity level. As a result, people's activity at school differs from that in-home settings, resulting in significant disparities in thermal experience. It is described as "heat produced within our bodies as a result of physical exercise." (Havenith, 2018). We emit more heat the more active we are. As a result, more heat must be shed from our bodies in order to avoid pain. According to ISO-7730 (2005), a temperature differential of 0.1 met can induce a thermal feeling equivalent to 1°C in ambient temperature. Similarly, a difference of 0.4 met might result in an increase of 2.5 to 3°C in air temperature (Standard, 2005). This demonstrates how having a range of activities indoors may prevent overheating or cooling in different situations. Furthermore, when the air and mean radiant temperatures are both 24°C, the air velocity is 0.41 m/s, the relative humidity is 43%, and the body insulation is 0.7 clo, according to (Background, 2005) (Body, 2012).

ii. Clothing Insulation

Clothing and skin protect the body from the elements by providing insulation. (Oliveira, 2011) pointed out that it is quite important to evaluate the insulation ability of clothing provided that there is a study of human warmth. When it comes to insulation, clothing provides heat resistance between the body and the environment (Timplalexis, 2018).

C. Design factors

The architectural design of the house is one of the variables that affects the thermal comfort of a room. The orientation of a building is important in terms of climatic factors (such as temperature, humidity, air speed, and day lighting) (Woods, 2014). The building's insulation level, form and orientation, window to wall ratio, glazing type, and Aspect ratio all influence solar radiation levels. Heating may be required in north-facing areas, while cooling may be required in south-facing areas of the same structure. Rooms with a west-facing orientation may need to be heated in the morning and cooled in the afternoon (Majewski, 2020).

2.1.3 Indoor Thermal Comfort Estimation Approaches

The Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) are the two most used approaches for determining human thermal comfort. According to Fanger's study (Ekici, 2016)), these two techniques take into account environmental elements, human features such as heat resistance and metabolic rate, air temperature, relative humidity, air velocity, and mean radiant temperature are all factors to consider. When the amount of heat produced by the body equals the amount of heat lost to the environment, thermal equilibrium is reached (Standard, 2005). These are also useful for determining the thermal level, occupant comfort level, and room temperature. Let we list them collectively and see each.

a) Predicted mean vote (PMV)
b) Predicted Percentage of dissatisfied (PPD)
c) Adaptive thermal comfort

a) Predicted Mean Vote (PMV)

"A model and an index that assesses the mean value of a large number of people's votes on a 7-point thermal feeling scale," according to the PMV (Ekici, 2016), with the following range of the scale in a chart: +3 is too hot, +2 is warm, +1 slightly warm, 0 is neutral, -1 slightly cool, -2 is cool, and -3 cold. According to ASHRAE-55, 2020, PMV employs heat balancing methods to integrate the six parameters and assess the users' level of thermal comfort.

According to table 2.1 and 2.2, conclusion the variation of PMV index can be approximated by an analytic expression. The PMV index's variability may be approximated by an analytical equation corresponding to a curve shaped like the inverse Gaussian distribution in the picture below, according to Fanger's work (Standard, 2005). The Predicted Percentage Dissatisfied People Index, or PPD index, can be calculated using the PMV index. These two index and analyses is shown in figure 2:4.

Table 2.1: ASHRAE 55 thermal sensational scale (Humphreys, 2007)

PMV Value	3	2	1	0	-1	-2	-3
Comfort feeling	Hot	Warm	Slight Warm	Neutral	Slight Cold	Cool	Cold
Bedford level	Much too warm	Too warm	Comfortable warm	Neutral	Comfortable cool	Too cool	Much too cool

Table 2.2: ASHRAE 55 Thermal satisfaction scale (Series and Science, 2018)

Level of Scale	3	2	1	0	-1	-2	-3
Satisfaction Scale	Very satisfied	Satisfied	Slightly satisfied	Neutral	Slightly dissatisfied	Dissatisfied	Very dissatisfied
Bedford level	Very Comfort able	Comfort able	Slightly Comfort able	Neutral	Slightly Dis comfortable	Dis Comfort able	Very Discomfort able

b) Predicted Percentage of Dissatisfaction (PPD)

PPD is defined by (Ekici, 2016) ISO7730 because it predicts the mean heat values of a large population, it is associated with the PMV model. However, it is voiced by people who are happy (+3 very satisfied to +1 slightly satisfied) and unhappy (-1 slightly dissatisfied to -3 very dissatisfied). It was created to assess the percentage of persons who are both too hot and too cold because of the heat.

c) Calculating PMV and PPD

According to figure 2.4, PMV is from the vote of the occupants toward the temperature (while PPD is calculated from the PMV). The PPD index is a numerical assessment of a group's reaction to a certain circumstance and is frequently used to determine thermal comfort in thermal settings. The PPD index is a scale that ranges from 5% to 75%.

The index should only be used for PMV values between +3 and -3, according to ISO 7730. The 5% of dissatisfaction always exists because of the different perceptions on the comfort.

Thus: $PPD = 100 - 95 \cdot e^{-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)}$ *Equation 2:1 PPD Evaluation (Standard, 2005)*

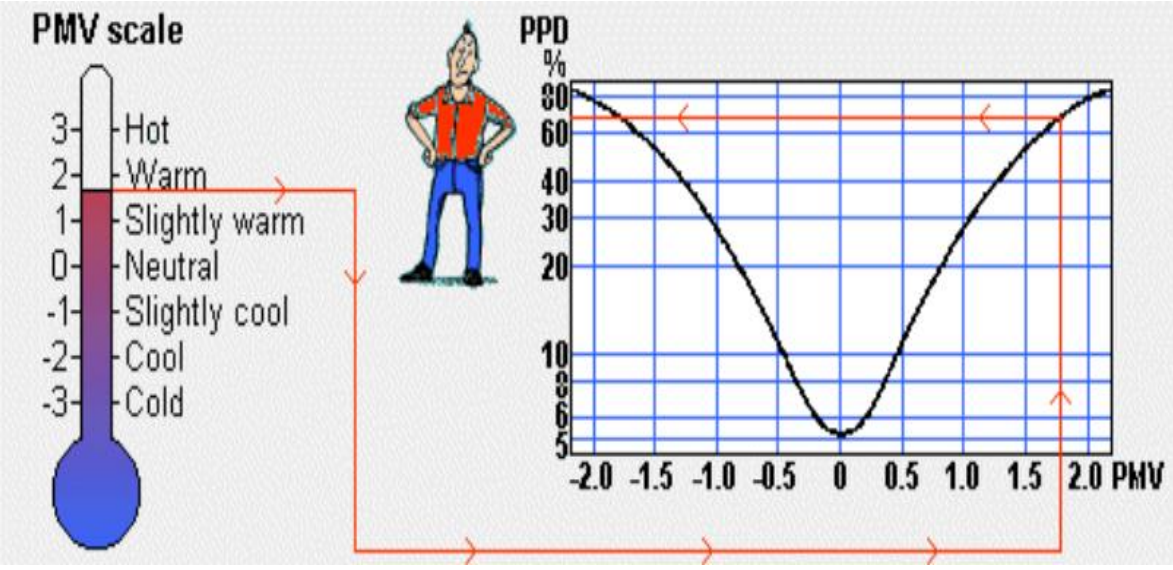


Figure 2.4: Index PPD and PMV variation (Profile, 2014)

2.1.4 Adaptive thermal comfort

According to one of the key assumptions supporting adaptive thermal comfort, thermally stable persons behave in ways that have a natural inclination to recover their thermal comfort and adapt to changing environmental situations. The outcomes of field research that collected data on people's instantaneous thermal responses to the thermal environment in real-life scenarios informed the adaptive approach to thermal comfort (Nicol, 2012).

The adaptive thermal comfort technique is based on field research that gathered data on people's immediate thermal reactions to the thermal environment in real-world situations. Without resorting to significant mechanical heating and cooling energy, occupants adjust their thermal environment by changing garments, activating windows, personal warmers or fans, water, and the use of sun shades (Dear, 2018). Humans react to variations in indoor and outdoor temperature in a number of ways. The occupant's thermal expectations and preferences will be affected by contextual conditions and historical thermal experience, according to adaptive thermal comfort theory. Warmer interior temperatures are preferred by those who live in hot climate zones over those who live in cold climate zones. Because people adapt to varying temperatures at different times of the year, the adaptive model indicates that the outside environment impacts inside comfort. According to the adaption hypothesis, contextual variables such as having access to environmental controls and past thermal history may impact building occupants' thermal expectations and preferences (Albatayneh, 2016).

90% acceptability limits = Tc ± 2.5°C, 80% acceptability limits = Tc ± 3.5°C

When the outside temperature is 23°C, the adaptive thermal comfort temperature climbs above the outside temperature and can reach 30°C, as illustrated in the figure below.

According to the adaptive technique in the ASHRAE 55-2010 Standard, the dark blue and light blue zones represent the 90 percent and 80 percent acceptable levels, respectively (Turner, 2011).

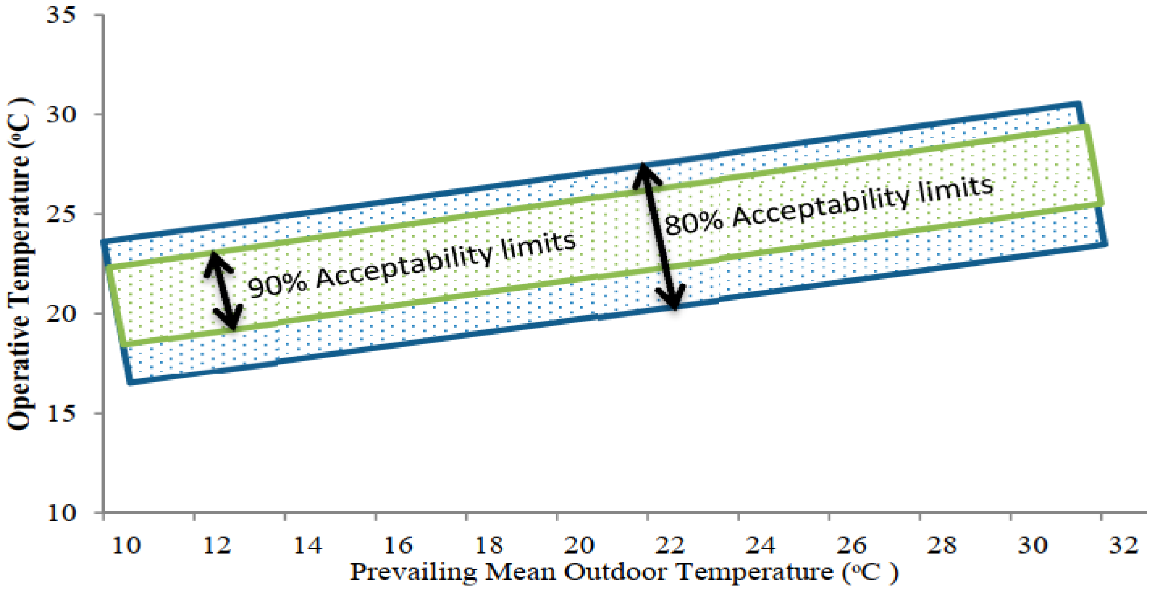


Figure 2.5: The 80% and 90% acceptability limits (Albatayneh, 2016)

a) HVAC systems

Adapting to the environment was the first challenge, in which humans came up with simple but sophisticated systems. Heating, ventilation, and air conditioning (HVAC) systems are intended to provide interior comfort while also ensuring appropriate indoor air quality. Rather than creating controlling the heating and cooling process, the HVAC systems that create this excessive heating or cooling are also generating significantly higher carbon emissions than necessary (Bayram, 2021).

b) Daylight illumination

Daylight, or the intensity of the sun, is one of the most important elements that affects thermal comfort/quality inside. Daylight lighting is the radiant energy collected from the sun. Lux is a measurement unit for the quantity of light falling on a surface per unit area. The amount of illumination on a surface varies depending on its geographic location (latitude and longitude), direction, season, time of day, and climatic conditions. The recommended illuminance values for residential building is less than 200lux (Dilaura, 2017).

2.2 Contextual Review

2.2.1 Condominium Housing in Ethiopia

Condominium housing is a relatively recent concept in Ethiopia. It's the same age as the IHDP. Condominium Housing in Ethiopia covers the Ethiopian government's ambitious intentions and efforts since 2005 G.C. to build housing for low- and middle-income people, create considerable employment, and stimulate small businesses (Planning. 2010).

2.2.2 Condominium Housing in Adama city

Adama, like most other cities in the country, has a severe housing crisis. Following the condominium proclamation approved by the Ethiopian government, the Adama city municipality has built several condominiums in different parts of the city between 2005 and 2006 G.C to solve this problem. According to figure 2.6, there is eight (8) condominiums site in Adama city, and they are Duket and Sodober site (located in kebele 09), Silase, Atana tera and Goro site (located in kebele 01), Ganda gara (lujoo), and Cherkacherk (adodee) site (located in kebele 04), Moenco site, (located in kebele 05). Then, building selection is depending on the following determinant factors. Most of the time the condominium buildings are built repetitively with the same design and the same orientation in different places. Unregulated room temperature, sun radiation, and other orientation constraints are all issues that repetitive buildings encounter in many areas.

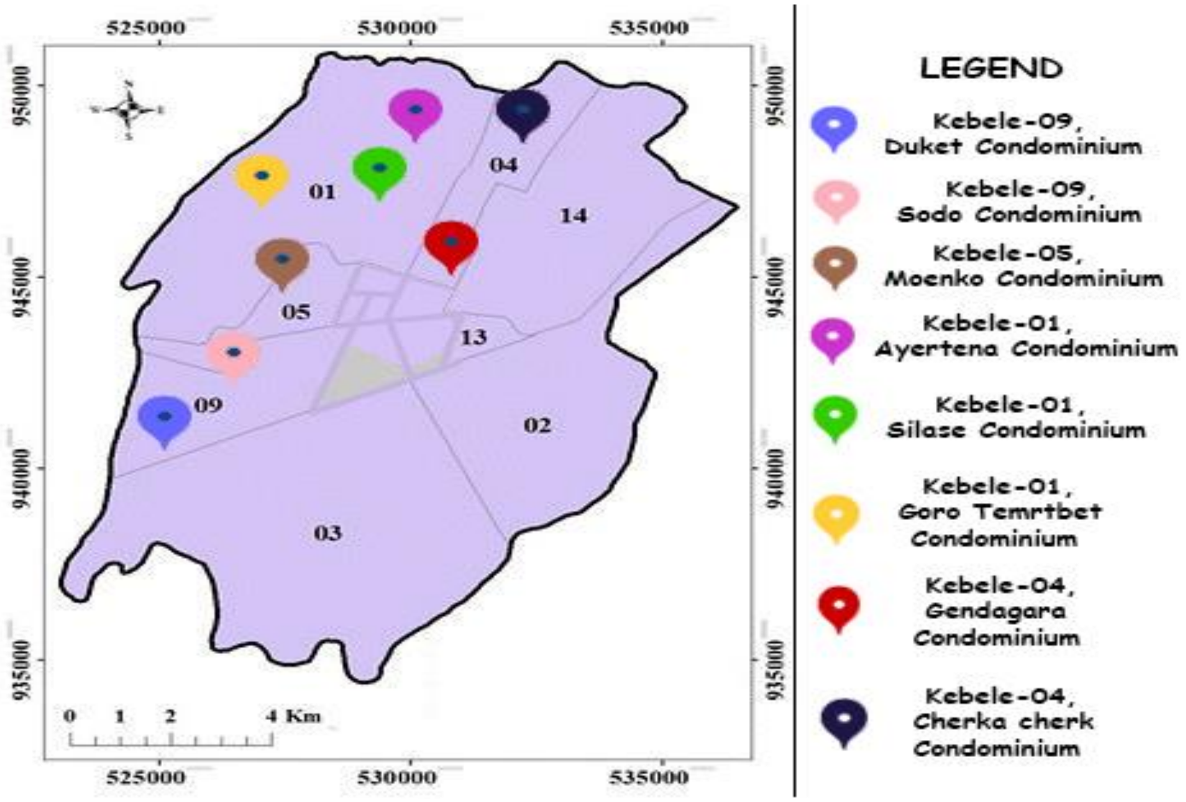


Figure 2.6: Location of Condominium site found in Adama city

2.2.3 Ethiopian building codes and standard

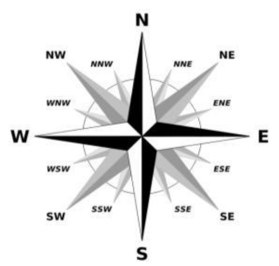
Every space designed for human occupation must be provided with natural light through outside glass openings, according to the Ethiopian Building Code and Standard (EBCS) amended in 2014. If one-half of the shared wall is open and unobstructed, any room should be regarded a section of a neighboring room for daylight illumination, should provide an opening of not less than l/l0th of the inner room's floor area of 2.5 m^2. A space designed for human occupation must have a minimum net glazed area of 15% of the total floor area of the room served. In other circumstances (such as the nature of the operation or physiological reasons) necessitate different values, a minimum rated illuminance of 200.0lux must be given for indoor workplaces that are manned full-time.

2.2.4 Condominium orientation in Adama

Around 70% of buildings in Adama city are oriented on an east-west axis or south orientation, and all exterior faces of buildings get solar radiation throughout the year. As a result, the interior temperatures in these surroundings are high, affecting thermal comfort.

Building orientation should be examined concerning the sun to decrease facades facing east and west and to accept local prevailing winds, as a result of the combination between building orientation and natural ventilation. Therefore, building orientation should place a premium on decreasing solar gain while boosting natural ventilation.

Table 2.3: All of the orientations existing in this study

Cardinal Direction	Azimuth angle	Cardinal Direction	Azimuth angle	
North- south	0^0-180^0	East	90^0	
East- west	90^0-270^0	west	270^0	
North	0^0	south east - Northwest	135^0-315^0	
South	180^0	Northeast- southwest	450-225^0	

2.2.5 Building layout

As a result of the variability of sun radiation at different angles, building orientation has an effect on heat uptake (Givoni, 2002). According to figure 2.7, Adama condominium buildings in various directions from 0° to 360°, the eight primary orientations (N, NW, W, SW, S, SE, E, and NE) were undertaken to examine the influence of orientation on the internal environment. The majority of the condominium buildings in Adama are oriented east-west and northwest-southeast.

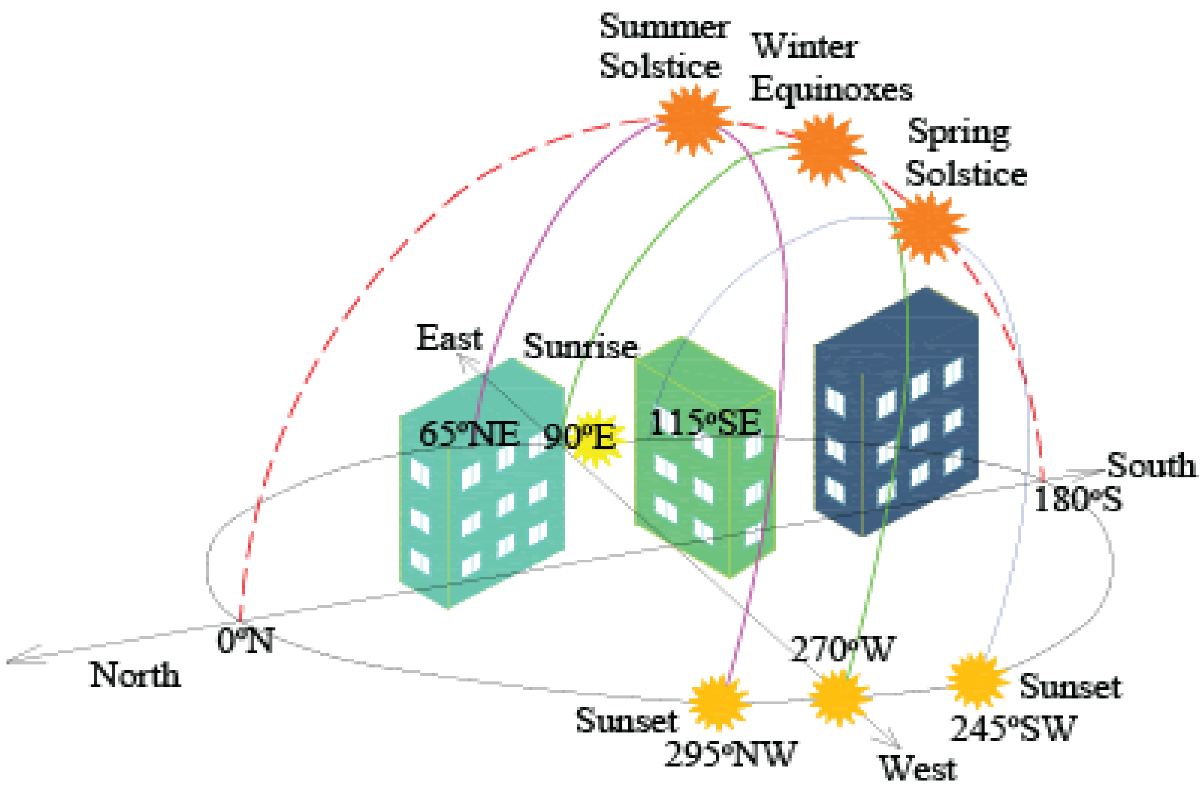


Figure 2.7: Sun's apparent path

2.2.6 Climatic Condition of the study area

Table 2.4 shows that the climatic condition of Adama city has been described as a hot zone with a warm dry season and a pleasant rainy season, according to the National Meteorological Agency. Adama is located in the Great Rift Valley of East Africa. Summer lasts from December to June, whereas winter lasts from June to September. Summer is hot and humid, with plenty of sunshine. The temperature is consistently high (average 27^{o}C lowest and 33^{o}C maximum) during this season, with less diurnal amplitude. The humidity level is really low (average about 22 percent). The winter is hot and humid. The temperature is somewhat low (average 19^{o}C lowest and 27^{o}C maximum) and the humidity is considerable throughout this season (average about 40 percent). Throughout the year, the wind is mostly from the north and south. The mean monthly wind speed is from 1m/s to 5m/s in the winter and 0.5m/s to 4m/s in the summer (NMA, 2021).

Adama climate is characterized as a desert environment with severe heat during the day and a sharp decrease in temperature at night (Climate-Data.org," 2021). The building business utilizes the most energy of all other industries due to the intense heat. The climate data of Adama during the study time showed the prominent wind direction was east-west.

Location: Adama, Latitude: 8.54^{o} North, Longitude:39.27^{o} East, Elevation: 5616 ft.

Time zone from Greenwich 3, Dara source: MN7 999 WMO Station number

Table 2.4: The climate condition of Adama (source: Adama Weather climate)

Environmental Indicators		Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (^{0}C)	Max.	28	30	33	35	34	31	25	25	26	29	28	27
	Min.	21	22	24	25	24	22	15	16	19	23	22	20
	Ann.	24	26	28	29	29	27	20	21	23	26	25	24
humidity (%)	Average	50	48	37	24	25	56	62	60	44	39	36	45
Wind Speed (m/s)	Max.	3	3	2	4	4	5	4	2	4	4	3	2
daylight (mph)	Average	11	11	12	12	12	12	12	12	12	11	11	11

Monthly overheating

According to figure 2.8, climate consultant of Time Table plot, January, February, March, Aparil, and May are overheatinh months of adama city.

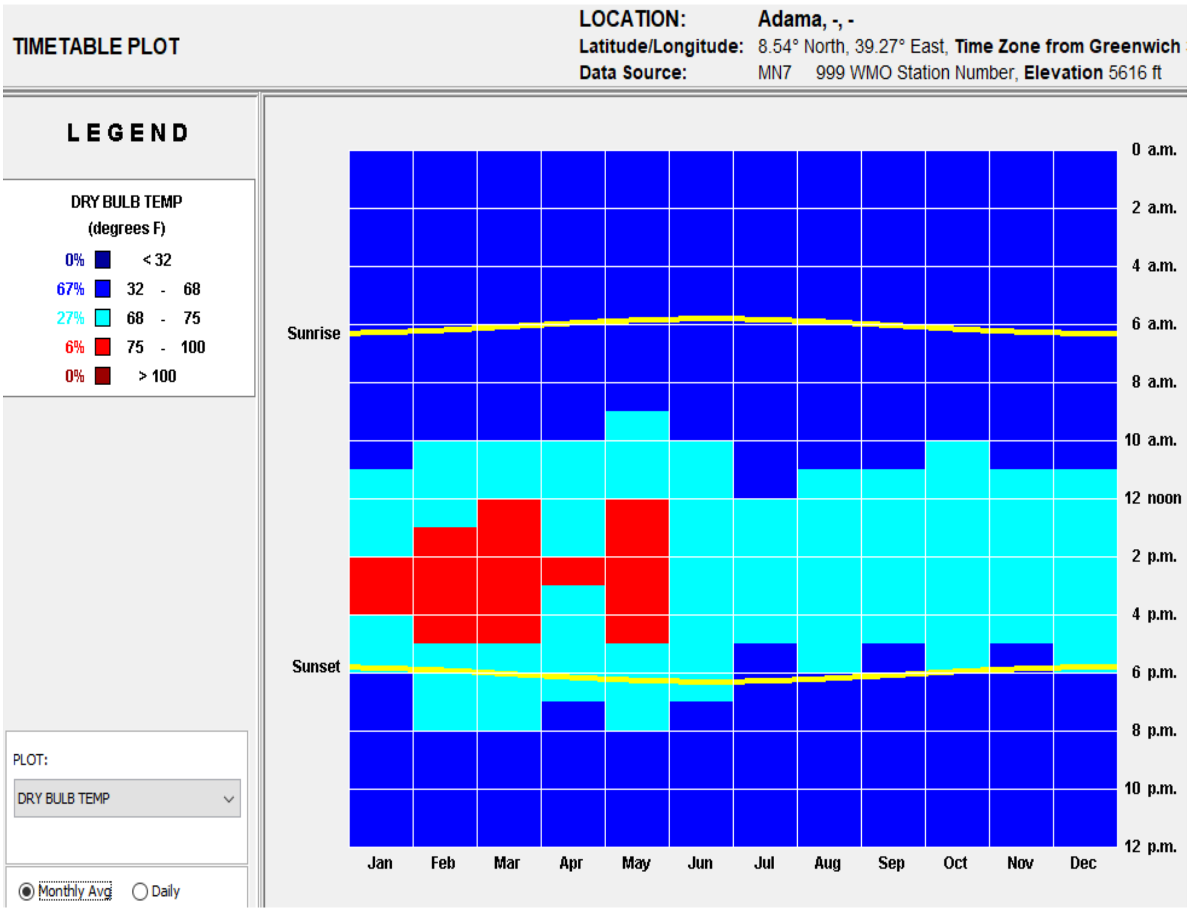


Figure 2.8: Overheating months of Adama (source, Climate consultant)

Maximium, Minimium and Annual Temperature: The maximum mean and minimum mean temperature variations are shown in figure 2.9. March, April and May were the highest recorded temperature ranges between 32^{0}C and 33^{0}C.

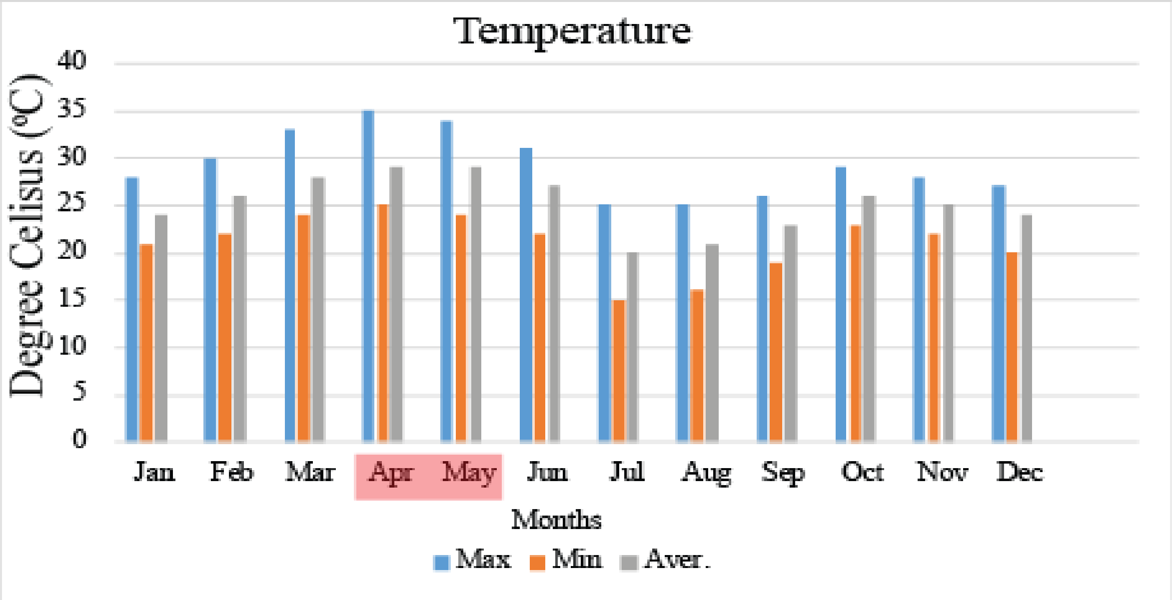


Figure 2.9: Maximum and minimum temperature of Adama

Seasonal Overheating: In Ethiopia, Kiremt or Meher (Summer) - June, July and August are the summer season. Bega (Winter) – February, March, April, and May are the winter season with frost in morning specially in January. Belg (Autumn) - September, October and November are the spring season sometime known as the harvest season. Tseday (Spring) - December, January, February, March, and April are the spring season. April and May is the hottest month in Adama. Overheating months were April and May. As the result, Winter is the overheating season.

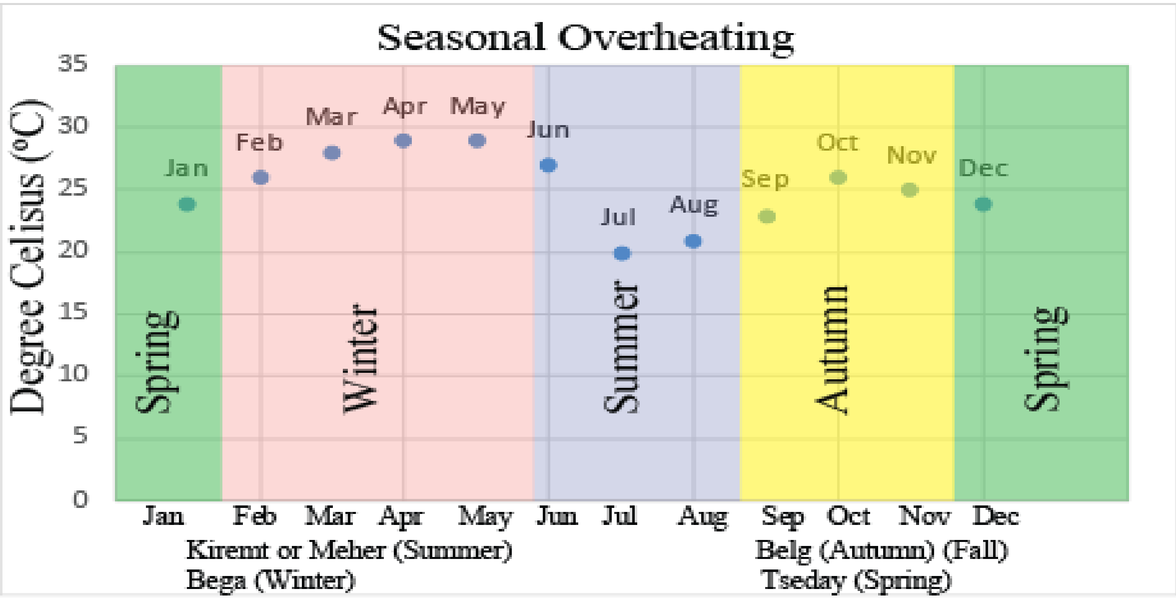


Figure 2.10: Seasonal Overheating

Daily Overheating: Depend on figure 2.11, When comparing the afternoon (12pm-2pm) and morning (8am-10am) temperatures, the morning temperatures in Adama are low. According to Adama's daily overheating, temperature is higher in the midday (12pm-2pm) and decline in the late afternoon (4pm-6pm). As a result, the hourly overheating is at midday (12pm-2pm).

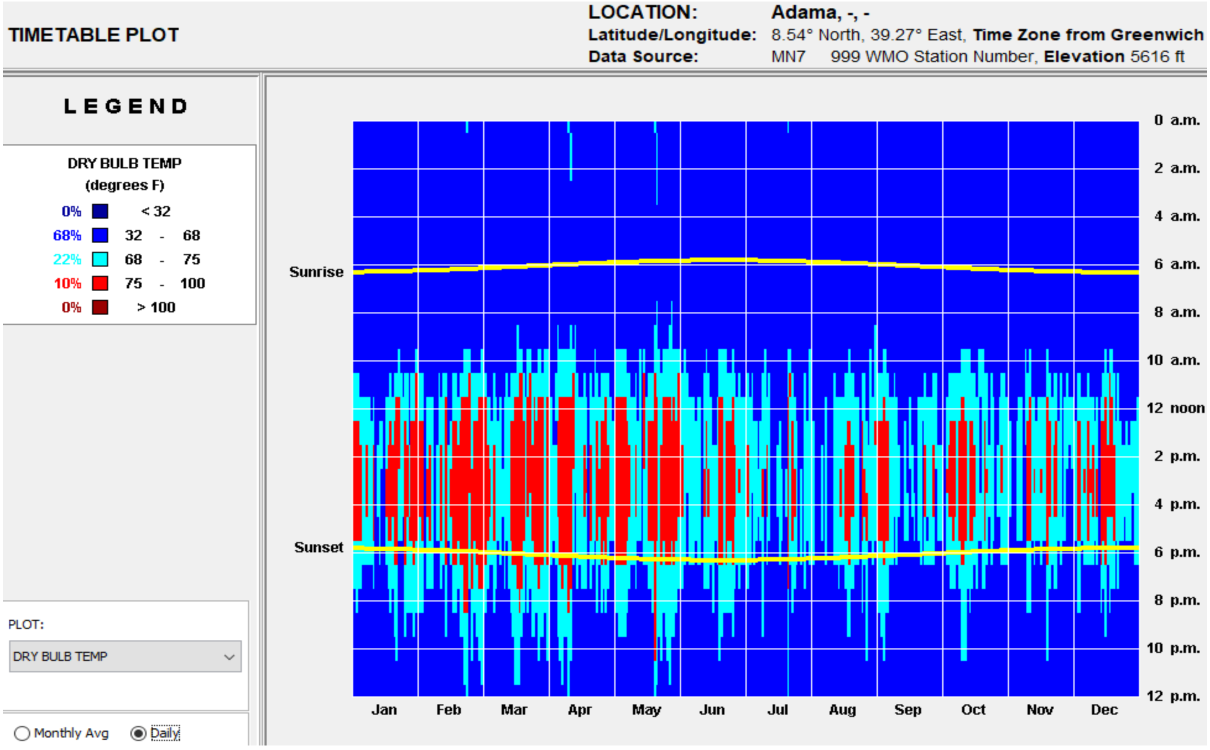


Figure 2.11: Daily overheating of Adama city (source: Climate consultant)

Annual Temperature: (For both the winter and summer seasons, the typical comfort zone is 20^0°C - 26^0°C).

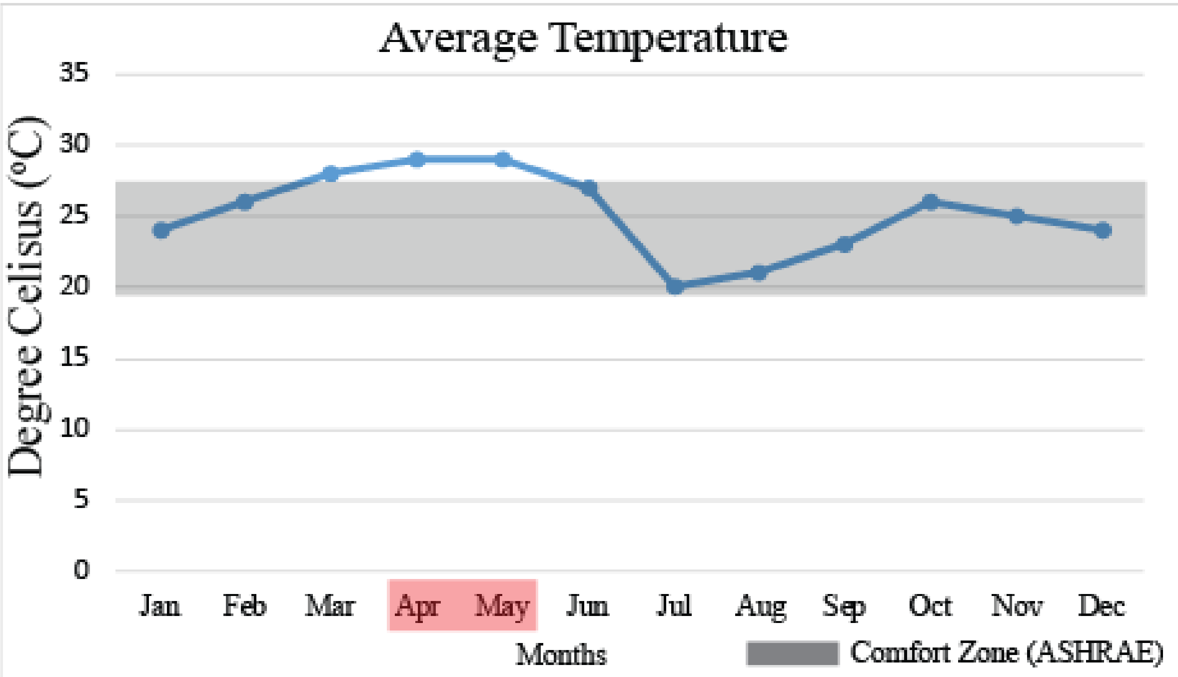


Figure 2.12: Annual temperature of Adama city

Average Humidity: (For both the winter and summer seasons, the typical comfort zone is 30%–70%)

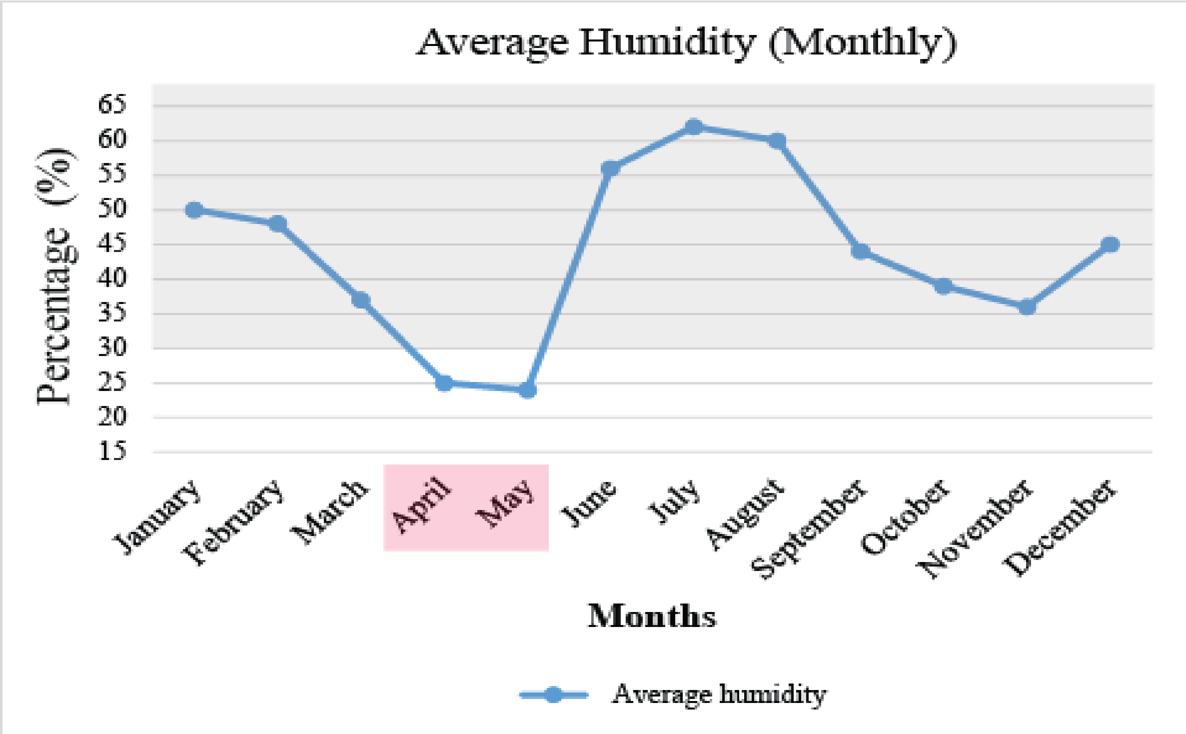


Figure 2.13: Average relative humidity of Adama city

Bioclimatic chart: March, April, and May are out of comfort zone of human according to Adama's bioclimatic chart on figure 2.14.

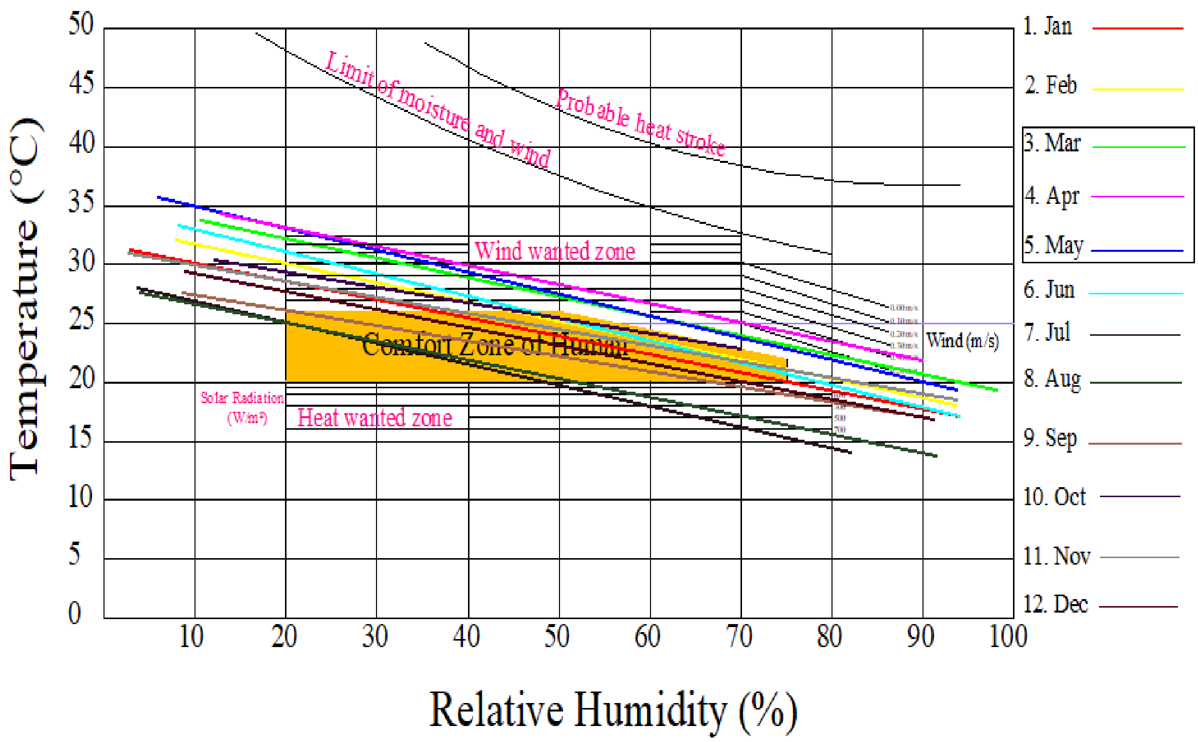


Figure 2.14: Bioclimatic chart of Adama city

Psychometric chart: According to this psychometric chart on figure 2.15, the Adama climate is falling into the hot/dry region, and most of the hours fall outside the thermal comfort to get it back into the comfort zone, the psychometric presents a strategy for designing a building that is thermally comfortable for the inhabitants while also lowering the energy consumption of the facility. (Based on this, 22.8% is comfort zone (1994hrs) and 77% (8760hrs) is discomfort throughout the year).

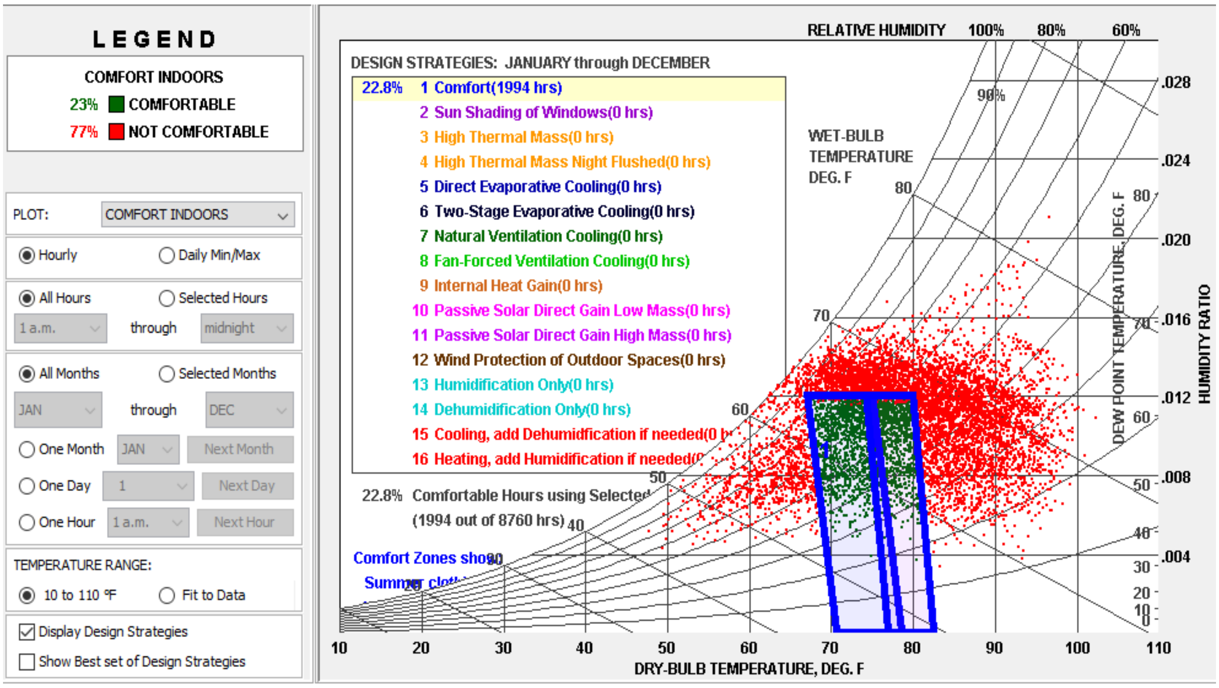


Figure 2.15: Psychometric chart of Adama city (source: Climate consultant)

Wind speed: Depend on figure 2.16, Annual Average wind speed 3.5 m/s. The wind blows from east to west during the winter and northeast to northwest in Summer. The minimum wind speed occurs during September (1.65m/s), while the wind with high velocity occurs during December, January, and February (3.05-3.2 m/s).

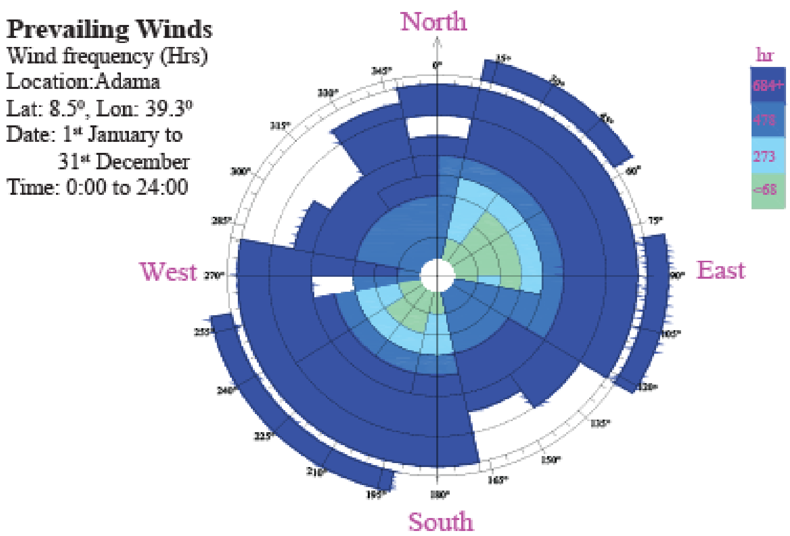


Figure 2.16: Prevailing winds of Adama (source: Ecotect analysis)

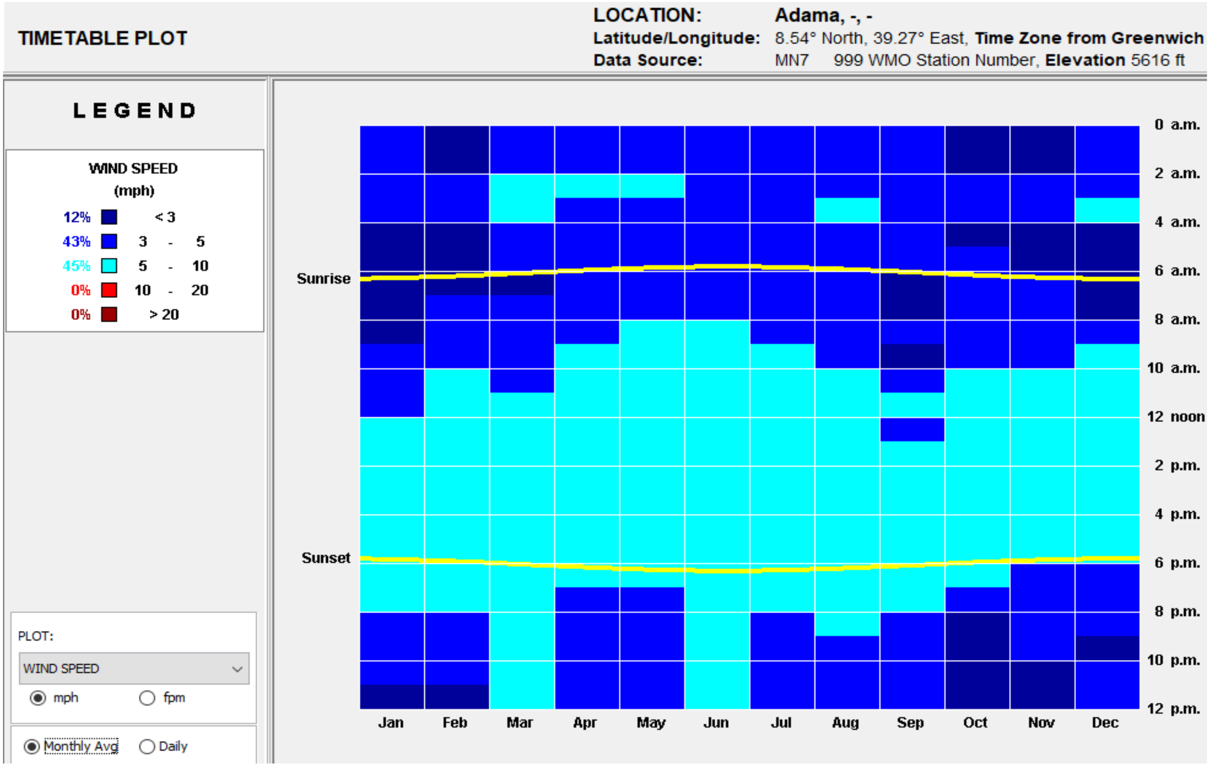


Figure 2.17: Monthly average of wind speed in Adama (source, Ecotect analysis)

Discomfort degree hours

According to figure 2.18, discomfort Degree Hours represents the total discomfort degree hours throughout the year. Too cool represents in blue and reach to the maximum in July and too hot represents in red and reach to the maximum in March, April and May.

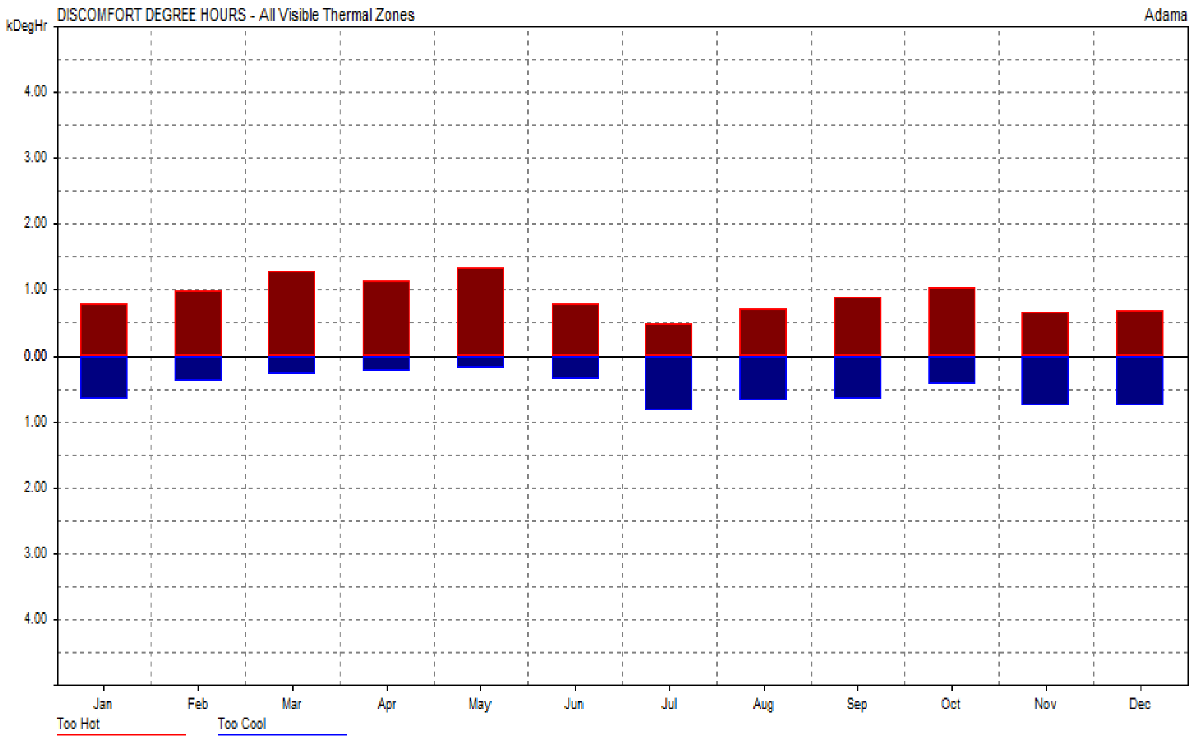


Figure 2.18: Discomfort degree hours of Adama (source, Climate consultant)

2.2.8 Contextual literature

Thermal comfort standards depend upon different literature done in Ethiopia.

During this investigation, two local instances relating to the reliability and validity of thermal comfort were considered. One was a study done by Amanuel Hailu and Nebyou Yonas (2022) in the study, 120 participants were involved around 78.33% of respondents were dissatisfied with the thermal environment. Furthermore, environmental factors measurements of selected case buildings showed the months of March, April, and May to be the hottest periods of the year. Similarly, another study was done by Samuel Getachew (2020), 117 participants were involved around 68.5% of respondents were dissatisfied with the thermal environment. The purpose of this research is to investigate and evaluate the thermal comfort of naturally ventilated administrative buildings. The research looked at five distinct sub-city administration offices in Addis Ababa. The study was conducted through field measurements, occupant survey, secondary data, and analysis. During the study, necessary field and survey measurements were taken during April and May as it is considered to be the warmest month. At this time, the buildings oriented towards North-West showed a better thermal environment for occupants than the other building orientations. Melaku (2019), Fitsum Gebreyohannes, and Ingo Helmedag (2021) were among the local literatures referred.

CHAPTER THREE

METHODS AND MATERIALS

3.1 Description of study Area

Adama is a city found in Ethiopia at latitude 8°26 ′15″N to 8°37 ′00″N and longitude 39°12′15″E to 39°19′45″E. it has an elevation that ranges from1500 m to 1900 m above sea level. It located in East Shoa zone of Oromia regional about 100 km south east of Addis Ababa along the main road to Harar. After the Addis Ababa-Djibouti railway line opened in 1916, the city was established. The Great Rift Valley is to the east, and the foot of an escarpment is to the west. Adama is a reformed city in the region, with a city administration made up of 14 urban and four rural kebeles.

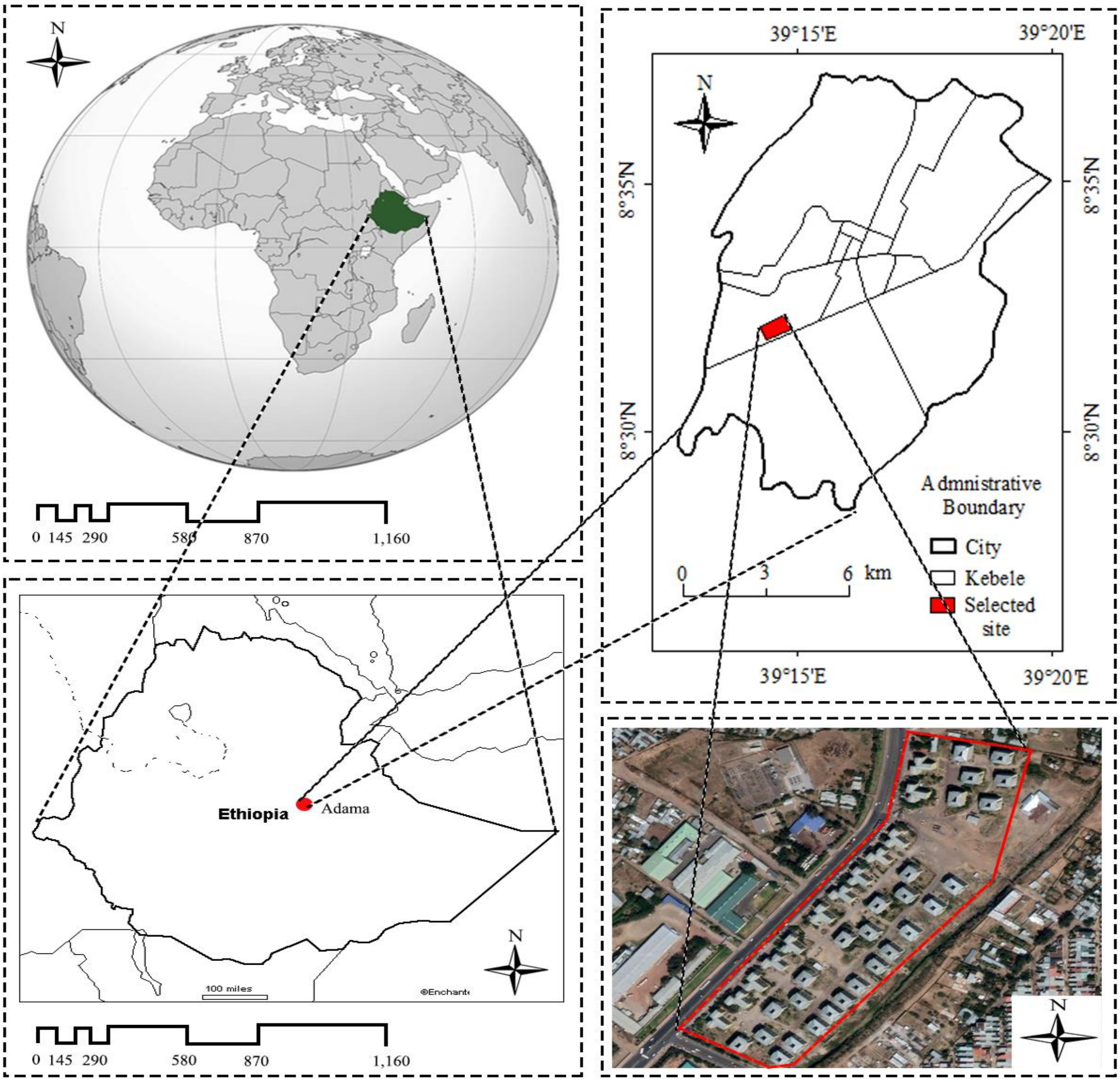


Figure 3.19: The Study Area

3.2 Research Design

Figure 3.20 depicts the whole work flow for this research. In this research design, there are two terminators that are interdependent: orientation and indoor thermal comfort. The indoor thermal comfort of the building, which is controlled by ASHRAE and ISO standards, will be affected if it is not oriented in line with weather conditions, sun's paths, and wind direction. finally, the best orientation for the selected location in the city is found by comparing all four of the axis.

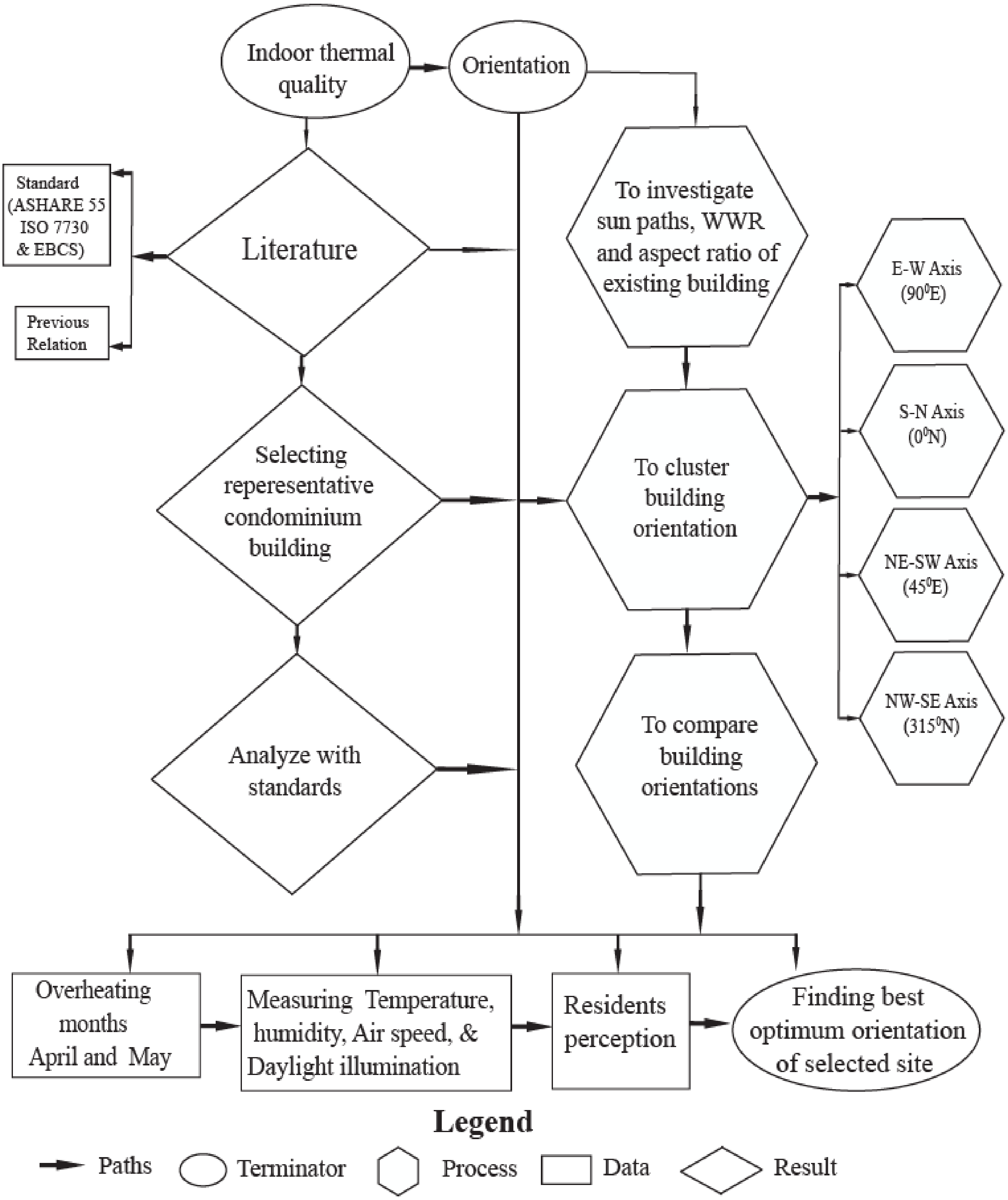


Figure 3.20: Research design

3.3 Method

For this study, weather data of the Adama city has been collected and the research was carried out. All necessary information regarding the dry bulb temperature, relative humidity, daylight hours, and wind speed with their maximum, minimum, and average for all months of the year was imported from weather data and the NMA of Adama. This can also be observed in the interpreted data of the weather file by Climate Consultant and Ecotect software.

Open plan condominiums were chosen as their design is very critical in terms of orientation, and how the orientation is affect temperature, humidity, airspeed, and solar radiation due to perimeter, WWR, Aspect Ratio, and sun path location. The height of the room was kept constant, hence the change in room height would affect the volume of the space which in turn is directly related to thermal comfort. The number of equipment found in the condominium and the floor area and volume of the room space was kept constant. The length, width, and height of the designated space were all kept constant. Properties and layers of materials (HCB with plaster) were identified and kept constant throughout the measurements. The inner and external characteristics of buildings in different orientations are quite similar. The floor plan layout, the paint, and the color used in interior spaces are similar.

All furniture located in the sample condominium model was set to be similar to the real residential material properties and color, to avoid significant differences. The buildings have four stories. The second story was chosen due to the structure's conduction and convection. During the measurement, the building form is not changed. The major parameter that impacts the thermal comfort of condominium houses are Building orientation and openings on the facade. Before measuring, the rooms were split into several equal small sections that should be square, and the centers of each square were marked with a dot on the map figure 3:21.

The measured data has been taken three times a day at 3:00AM, 7:00PM, and 10:00PM local time from April 15 to May 7, 2022. The data loggers were placed in the center of each chamber, around 1.20 meters above the ground level.

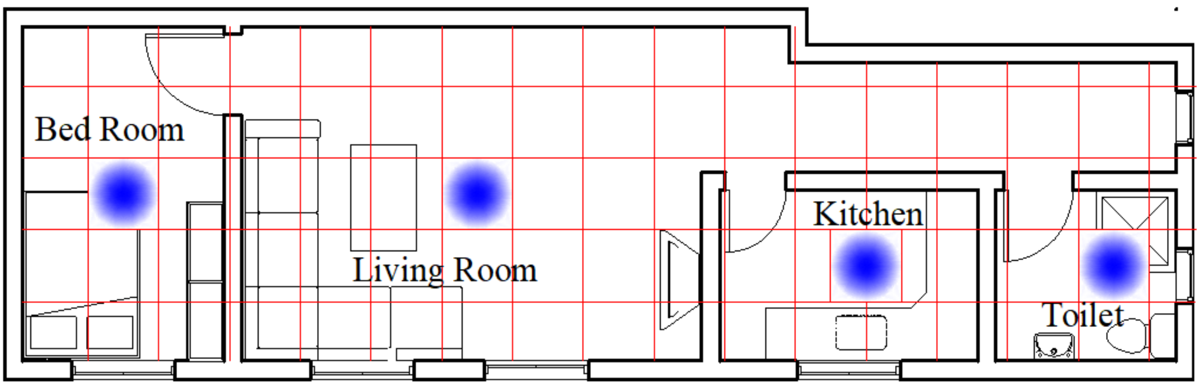


Figure 3.21: Showing position of the data logger

During measurement, Care was taken to avoid impacts on the measurements Based on consideration of sky condition, temperature, and airspeed, air vents, doors, and windows are closed and internal heat sources such as incandescent lamps, refrigerators, and television offed. (Window closed, artificial light dimmed by sun radiation) Before installing the equipment, the researcher evaluated each residence and determined the best place to collect uniform measurements. Designing condominium buildings with many windows on the south face can be considered an "environmental crime" in hot and dry environments. In this research, different window-to-wall ratios were to be examined to understand their exact impact on indoor thermal comfort. WWR (South: 52.7%, East: 35.5%, West: 41.6%, North: 25.3%) and 57.2% aspect ratio (L/W) were chosen.

The orientation of the building is the first decision a designer takes throughout the design process. As a consequence, it was picked as the first variable to be examined. Condominium houses with various orientations were to be investigated. To conduct the measurements, a purposeful selection procedure was employed to choose sample residential dwellings of eight condominium sites Duket condominium site located in kebele 09 was selected, based on observation of the building orientation, the building envelope, location, and the massive of blocks in the site are considered which qualify the criteria and can represent the other building typologies. The building was tested from two orientations (east-west and south-north orientation) to investigate how temperature, relative humidity, airspeed, and daylight illumination affect indoor thermal comfort.

Temperature, humidity, airspeed and daylight illumination were recorded from April 15 to May 7,2022 and both months were the hottest months of the year and in the typical winter season. Winter was defined as the months of December 22nd to June 21st. The overheating seasonal of the year, according to climate condition of Adama, are April, and May. As the result, the measurements were conducted during the hottest months and overheating season of the year, from April 15 to May 7, to better understand the impact of orientation on thermal comfort. Temperature, humidity, airspeed, and daylight illumination were all recorded by the data recorder. The measurements were taken for twelve days with one-day intervals from morning to late afternoon, diurnal overheating (3:00 am, 7:00 pm and 10:00 pm). During field measurement Thermo-hygrometer, Anemometer, and lux meter are set in different rooms of the house.

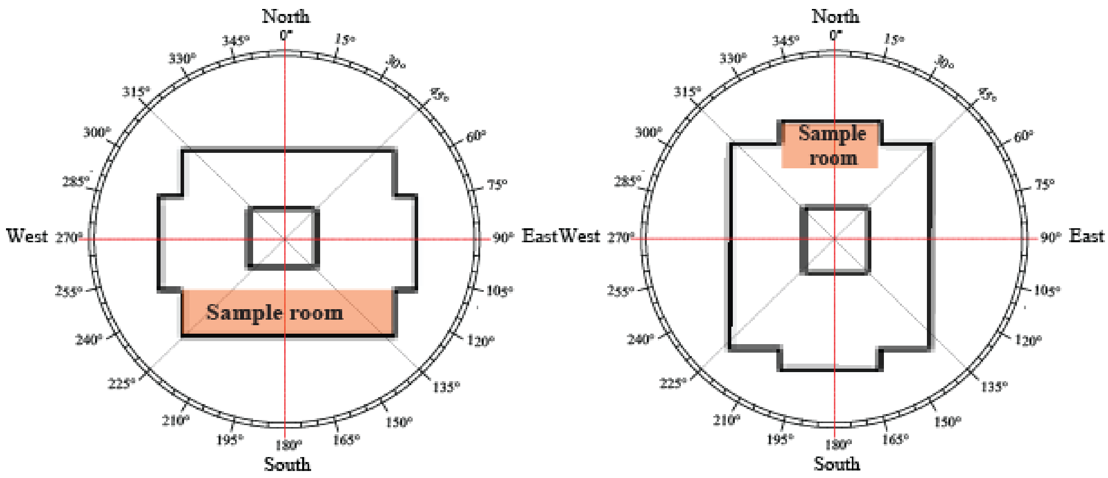


Figure 3.22: Sample room face and orientation angle for measurements.

3.4 Sample Floor plan

The three-bedroom has 57.9 square meters. Figure 3.23, the characteristics of the floor plan are almost similar to other sampled of other condominium sites but it has a partition with simple wall material for different activities and stores. This does not influence room temperature levels when compared to those sampled condominium buildings with other condominium buildings. Layout, utility, and service rooms and materials (except those modified) are similar to other rooms. In most cases, these should be located towards the south and north side of the sun path. For the lengthy facades, the building should be oriented south-north. However, it could be slightly rotated in either direction to allow the dominant East-west wind of Adama to improve natural ventilation without compromising the optimal orientation advantages.

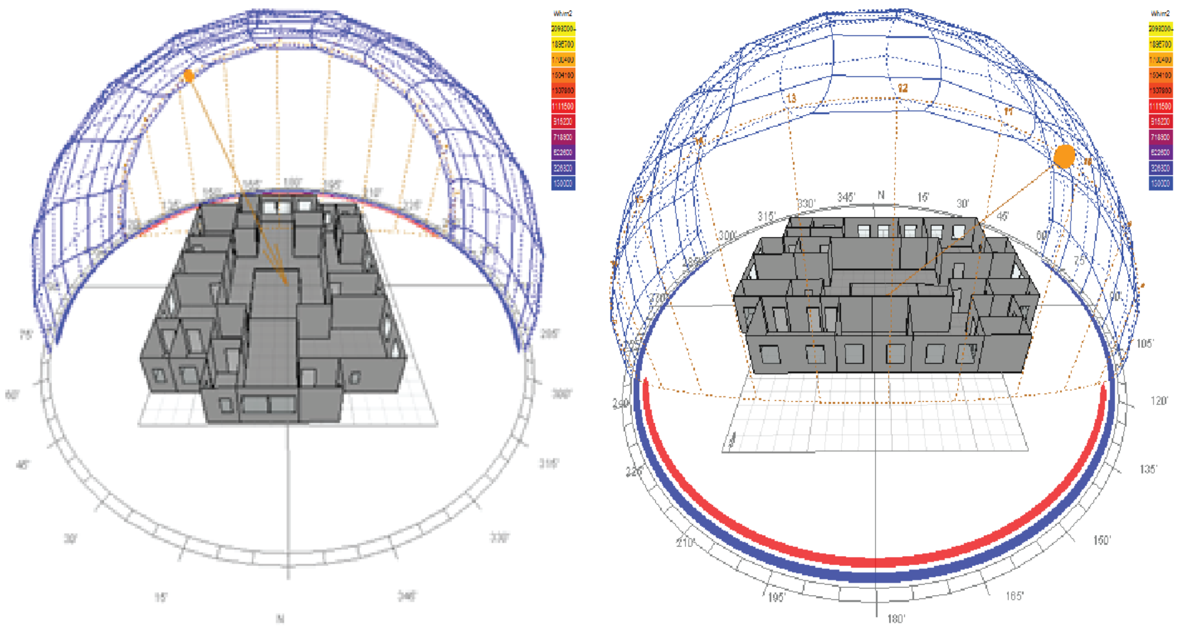


Figure 3.23: Orientation sample room a) E-W axis B) S-N axis (source: Ecotect analysis)

Table 3.5: Physical Characteristics of sample spaces

Zone (E-W axis: three bed room, S-N axis: three bed room)	Length (m)	Width (m)	Area(m^2)	Building material
Living room	E-W: 6.5m S-N: 5m	E-W: 4m S-N: 4m	E-W: $26m^2$ S-N: $20m^2$	HCB wall with cement plaster
Bed room	E-W: 2.5m S-N: 3m	E-W: 4m S-N: 3m	E-W: $10m^2$ S-N: $9m^2$	HCB wall with cement plaster
Kitchen	E-W: 3.5m S-N: 3.5m	E-W: 2m S-N: 2m	E-W: $7m^2$ S-N: $7m^2$	HCB wall with cement plaster
Toilet	E-W: 2m S-N: 2.5	E-W: 1.5m S-N: 1m	E-W: $3m^2$ S-N: $2.5m^2$	HCB wall with ceramics

Roof: The roof is covered in CIS, with the rest portion finished with cement and porcelain tiles. Gypsum board ceilings are utilized throughout the interior. The pitch of the roof is 12.5%.

Walls: Fine quartz painted HCB walls cover the majority of the building's south and north facades. The most common type of inside wall is HCB, however, Gypsum can also be found. The walls are plastered and painted yellow and gray on the interior and outside.

Floor: Terrazzo tiles cover the whole interior floor, however, carpets are also typical in most flats.

Opening: Doors and single glass windows, aligned E-W, are framed by timber framework and transparent glass.

3.5 Field measurements

A field measurement was carried out in two residential units to measure the thermal comfort of orientation in the condominium house of Adama. In phase one**,** the East-West axis (south faced room) condominium building located (Latitude: at (8° 31' 59" N, Longitude: 39° 15' 00" E) and 1611m above sea level, in Duket on the second floor of four stories was selected. The measurement room is the living room, bedroom, kitchen, toilet, and outdoor respectively as shown in figure 4:46. The temperature, humidity, airspeed, and daylight illumination in the room were all measured. For 12 internal days from April 15 to May 7/2022. In phase two**,** South- north axis (north faced room) condominium building located (Latitude: 8° 30' 54" N, Longitude: 39° 14' 56" E) and 1610m above sea level, in Duket on the second floor of four stories was selected.

The measurement room is the living room, bedroom, kitchen, toilet, and outdoor respectively as shown in figure 3.24. The temperature, humidity, airspeed, and daylight illumination in the room were all measured. For 12 internal days from April 15 to May 7/2022. Field experiment was carried out in two residential units to measure the thermal comfort of orientation in condominium house of Adama.

Figure 3.24: Typical sample of North facing room

The identical typologies, building materials, location, climate conditions, and floor level were evaluated in multiple orientations, facing south and north. Depend on figure 3.25, In each residence, three data loggers were used to capture data from the living room, bedroom, kitchen, and toilet, which are where the tenants spend the majority of their time.

Figure 3.25: Field survey photo during data collection (Source, field survey)

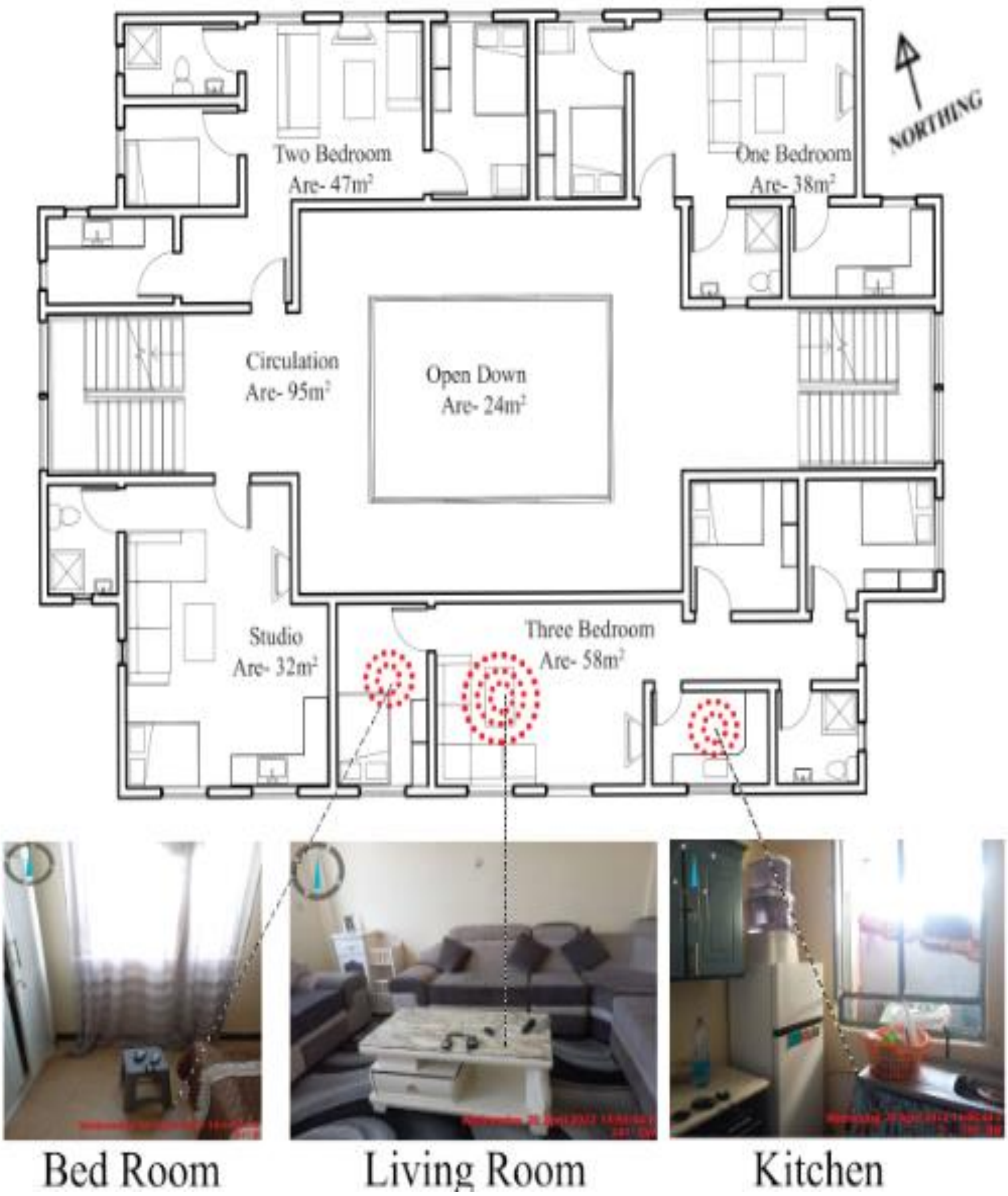


Figure 3.26: Typical sample of South facing room

3.6 Sample Size of household

The sample size is determined according to Singh & Masuku, 2014 (as cited in Gosaye B, 2007), and (Kotari, 2014). The sample size is computed using the method below when the intended research population (N) is less than 10,000. (Total number of households is 2,279)

Formula 1: N_t =n/1+n/N (1)………. Estimated household size (Singh & Masuku, 2014).

Where: n= the desired sample of household, (when the population is less than 10,000)

N = total households of condominium, is (2,279)

Nt= Estimated household size.

Formula 2: n = (Z^2* p*q)/d^2 (2)…..The desired sample of households (Singh & Masuku, 2014)

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

p= estimated characteristics of target population that is 0.50,

d= level of statistical significance (i.e. 10%),

q= maximum standard deviation.

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

$$q=1-0.5=0.5,$$

$$n= ((1.96)^2 *0.5*0.5) / (0.1)^2 =96.04,$$

$$N_t=96/1+2,279/96$$

$$=96+23.73$$

$$=119.7\approx120 \text{ (household sample size)}$$

A sample of 120 households (n=120) is selected from a total household of N=2,279, within the condominium housing. The sample households are chosen using a stratified random sampling method. A stratified random sampling method is used to select the sample houses.

Formula 4: S=n.Pi, Pi=ni/Nt (4) ……Sample size for each building (per floor) (Kotari, 2004)

Where S is the sample size for each condominium building,

n is the total sample size,

Nt is the total households and

ni is the household of each building.

That is, if Pi represents the proportion of households included in different stratum i, and n represents the total sample size, the number of elements selected from the stratum is n. Pi. Based on this, purposive sampling technique was used for questionnaires distribution based on i) to collect data from selected buildings (E-W axis), ii) who would have been the experience of living in condominium house, respondents to fill the questionnaires will have drawn, iii) for the need to reach the targeted issues of specific objectives.

Table 3.6: Sample size per building

Sample frame	Total Number of residents in each building (households)	Sample size
Condominium house	ni=25 households in each building and (5 households in each floor)	n=12 households from each building (3 households from each floor)

3.7 Data Sources

The research relied on the data collected from Related literature reviews, site visits and observations, and sample surveys.

3.8 Data Collection

i) Questionnaire

In the questionnaire, the main thing that helps to understand and estimate the level of thermal sensation and satisfaction scale is asking the questionnaire respondent at a specific data collection time, what they perceive about the thermal environment at that specific time. The ASHRAE 55 thermal preference and thermal satisfaction scale of occupants, which focuses on thermal comfort inside, is one sort of standardized questionnaire in the literature. Survey sample questionnaires were distributed to 120 households. According to table3.7, each respondent's questionnaire was evaluated using the ASHRAE thermal sensory scale. Cold (-3), Cool (-2), slightly cool (-1) neutral (0), slightly warm (1) warm (2), and hot (3) were utilized on a seven-point thermal sensation vote (TSV) scale (7). The questionnaires were distributed three a day to the residents to evaluate their thermal perception, while measurements were taken. (See Appendix II).

Table 3.7: Thermal perception scale (Series and Science, 2018)

PMV Value	3	2	1	0	-1	-2	-3
Thermal preference	Much too warm	Too warm	Slightly warm	Neutral	Slightly cool	Too cool	Much too cool
Thermal Sensation	Very Comfort able	Comfort able	Slightly Comfort able	Neutral	Slightly Dis comfortable	Dis Comfort able	Very Discomfort able
Thermal satisfaction	Very satisfied	Satisfied	Slightly satisfied	Neutral	Slightly dissatisfied	Dis satisfied	Very Dissatisfied

ii) Observation

The data were taken from East-West Axis (south facing rooms) and the South-North axis (north facing rooms) in Duket condominium site depending on parameters like orientation, Sun paths, wind direction, WWR, and aspect ratio.

iii) Site Survey

This approach was used to examine the present state of the selected building under consideration by visiting the chosen orientation and independently assessing the current state based on thermal comfort (See Appendix III).

Table 3.8: Instruments used to measure Environmental variables

Environmental indicator	**Test instrument**	**Specific objective**	**Accuracy**	**Image**
Indoor Temperature and Relative humidity	**Thermometer**	To measures air temperature of room. Hot-Cold (°C). And relative humidity (water vapor in air) of room. Percentage.	Accuracy ±0.2 °C T-98% 10%-99% and 10°C -70°C (14°F -15°F). **Accuracy** ±3% RH - **98%** Range=0–100%	
Air Speed	**Anemometer**	To measure the speed or volume of air movement of room.	**Accuracy**±0.05 m/s ± 0.25% of FSR from 50 mV to FSV Range=0.05–9.99 m/s	
Daylight illumination	**Lux meter**	To measuring the level of daylight illuminance) which is affect indoor thermal comfort.	**Range**- 02,000 /2,000-19,99/ 20,000-50,000 Lux **Accuracy**=23 ± 5^{0}C: ±5% of reading ±10+2d	

3.9 Data Analysis methods

The comfort zone described in ASHARE 55 and ISO 7730 standard was compared to the indoor thermal comfort parameters (temperature, airspeed, and humidity) and (daylight illumination) discovered in the locations. Different soft-wares such as Ecotect Analysis, and Excel were used to analyze the data in the form of descriptive statistics analysis. Triangulation is a technique used for cross-checking the analysis result. And compare the result of environmental variables. To investigate the sun paths, optimum orientation and wind direction of a location, Ecotect with weather data of Adama were used.

Table 3:9: Summary of methods

No	Specific objective	Data used	Collection method	Analysis
1	To determine indoor temperature, relative humidity, airspeed, and daylight illuminance of selected orientation.	Field measurement of temperature, humidity, airspeed, and daylight illumination.	By using a thermometer, anemometer, and lux meter.	By using an Excel graph.
2	To identify residents' thermal perception in the selected building orientation.	ASHRAE 55 Standard questionnaires, PMV values	By distributing Questioner and formal interview	By using a scatter plot graph.
3	To compare and find the optimum orientation for selected condominium site in Adama.	Field measurement of temperature, humidity, airspeed, and daylight illumination. Too hot and too cool of discomfort hours of each Azimuth angle.	By using a thermometer, anemometer, and lux meter. Discomfort degree hours by incrementing the azimuth angle of East-West and South-North Axis	Comparing the measured data and heating and loading load incrementing azimuth angle by using an Excel chart, graph, and table

3.9.1 Simulation analysis

These assessments were evaluated using the Ecotect simulation program's outputs, which were derived from data such as direction (Azimuth angle), and weather data. The model has a four stories with a 57.2 aspect ratio, a window-to-wall ratio of 52.7 percent in the south, 35.5 percent in the east, 41.6 percent in the west, and 25.3 percent in the north, and a flat pitched roof. The building has Single-glazed windows and HCB walls with cement plaster on the inside and outside. On a model with a length of 28 meters and a width of 16 meters, the study looked at several building orientations. The simulation was carried out in the model for various building orientations. Between 0^0N to 90^0E and 90°E to 180°S azimuth angle, a 10° angle increment was used to run 19 distinct simulations. As a consequence of these simulations, the ideal orientation is the one with the lowest yearly too hot and too cool hours need.

3.10 Data quality assurance

The accuracy of the instruments was checked. The value of measurements has been cross checked with the standard like ASHRAE 55, ISO 7730 and EBCS. To identify the respondent thermal perception and identifying the preference scale, the questionnaires were prepared in English and translated into both Afaan Oromo and Amharic (See Appendix II).

3.11 Ethical Considerations

The research data remained confidential throughout the study to obtained participants' permission to participate in the study voluntarily. The respondents' dignity and well-being were safeguarded. All resources utilized in the research were credited. The measuring equipment were located in a way that doesn't disturb households. The results were analyzed the data relative to standards without manipulation.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This chapter discusses the result of the data and presents the analyzed data, which is collected during the study to ensure the objectives of the research. Subjective and objective approaches were used, according to ASHRAE 55 and ISO 7730. The temperature, relative humidity, airspeed, and daylight illumination level of condominium buildings are presented according to the collection of one-month survey in the hottest month and overheating season of April, and May, 2022.

4.2 Sun's paths of Adama city

Sun paths is critical in thermal gaining or losing from solar radiation. According to figure 4.27, the sun path chart of Adama, the Dry Bulb temperature exceeds the comfort zone, March, April, and May indicate overheating. In Adama, windows should be fully exposed for passive heating, and windows should be shaded where there are red or yellow dots to avoid overheating. Because south orientation is the bear high angel of solar radiation. The exposed surfaces gain more heat from solar radiation other parts lose heat due to the same reason of orientation.

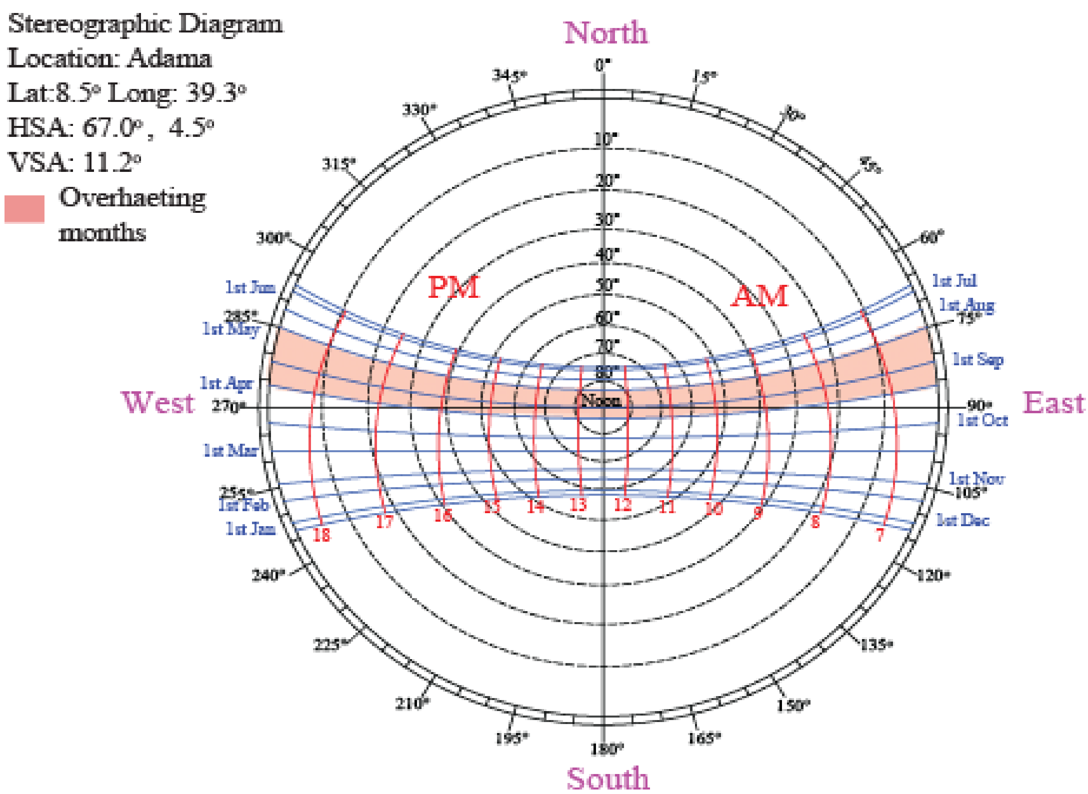


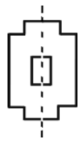
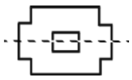
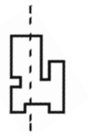
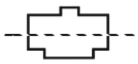
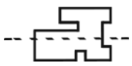
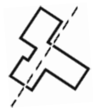
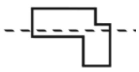
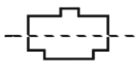
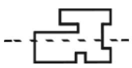
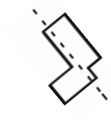
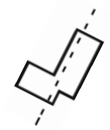
Figure 4.27: A stereographic sun-path diagram of Adama city

The Maximum sun altitude at sunset is (292.5^{0}NW) and the minimum altitude is (242^{0}SW). The maximum sun altitude at sunrise is (62.5^{0}NE) and the minimum altitude is (122^{0}SE) solstice. The maximum Azimuth angle observed at sun rise and sunset time is shown below figure 4:27.

4.3 Building orientation and sun paths of condominium sites in Adama

In Adama, proper orientation of most Condominiums is not given due consideration. Buildings that are properly positioned take advantage of the temperature, airspeed, solar radiation, and prevailing wind. During the winter season, overheating from sun radiation is a major issue in Adama.

Table 4.10: Building orientation of condominium house in Adama

No	Condominium site	Orientation			
		S – N axis (Azimuth angle-O^{0}N**)**	**E – W axis (**Azimuth angle-90^{0}E**)**	**NW – SE axis (**Azimuth angle-315^{0}N**)**	**NE – SW axis (**Azimuth angle-45^{0}E**)**
1	Duket condominium site	 5 blocks	 15 blocks  12 blocks	 6 blocks	 2 blocks
2	Goro condominium site	 3 blocks	 5 blocks  3 blocks	 3 blocks  3blocks	 3 blocks  2 blocks
3	Ganda gara condominium site	 3 blocks  1 block	 1 block  4 blocks  2 blocks	 1 block  2 blocks	 1 block

4	Moenko condominium site	2 blocks	7 blocks	--	--
5	Sodober condominium site	2 blocks	3 blocks	--	2 blocks
6	Atenatera condominium site	2 blocks	2 blocks	1 block 3 blocks	3 blocks
7	Silase condominium site	--	2 blocks	2 blocks 5 blocks	3 blocks
8	Cherkacherk condominium site	1 block 2 blocks	4 blocks	--	--

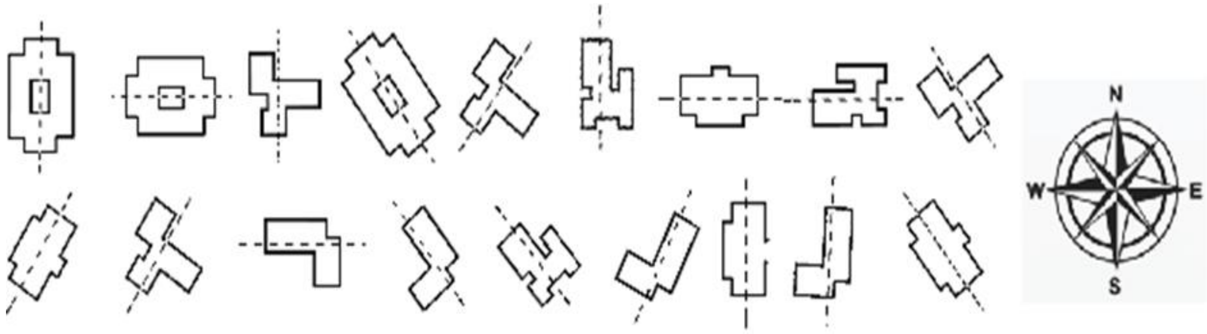


Figure 4.28: Different condominium orientation in Adama city

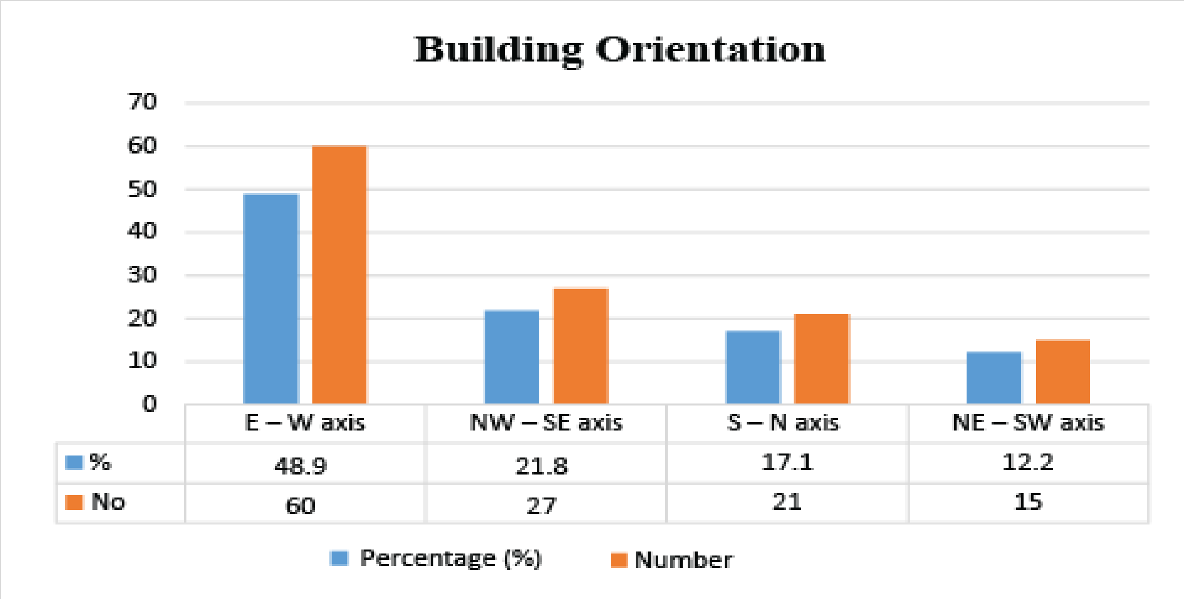


Figure 4.29: Building orientation in Adama

According to figure 4.29, most existing condominium buildings in Adama are either south-faced or east-west faced (48.9%), even if there are also other-faced buildings. In an east-west orientation, the long face is aligned with the south face. The envelopes that let the most solar radiation flow through them. The majority of the doors and windows, as well as the long wall, are oriented to the south. In Adama condominium building, the amount of daily solar energy incident per unit area on north-facing walls is substantially less than on south-facing walls.

In the Adama condominium building, the south-north orientation or northern face is least exposed to the sun. In actuality, the sun's rays are virtually tangential to the surface of the wall only during the early and late hours of summer days, when the angle of altitude is low and the angle of declination is such that the sun's rays are almost tangential to the surface of the wall. An advantage to rooms opening on this face is there is low solar radiation which means low indoor temperature. The southern aspect, on the other hand, receives a lot of sunlight.

As a result, these facades get the most solar radiation, hence the surface area of the building exposed to them should be as little as possible, and windows on these facades should be avoided. Therefore, the longer axis of the structure should lay along the south-north axis, i.e. the wall with the bigger surface area should face either East or West, for the lowest solar heat uptake by the building envelope. The amount of solar radiation received by the building envelope is determined by its orientation. The direction of solar radiation dispersion is an important factor to consider when designing energy-efficient facades. When the weather of Adama is hot, buildings should be designed such that covered interior and outdoor living areas are available. Solar radiation on the south face is still strong in the midday and afternoon, while it is low on the north face in the middle of the day.

4.3.1 Wall face

According to figure 4.30, the wide wall facade has a thermal comfort influence on the inner atmosphere on sunny days. During periods of intense sunlight, high solar radiation in the indoor chamber causes pain. The solar path diagram is well studied to investigate critical hours and days as well as to understand the position of the sun concerning the building orientation. More than 70% of long face of walls are orientated to East-West axis.

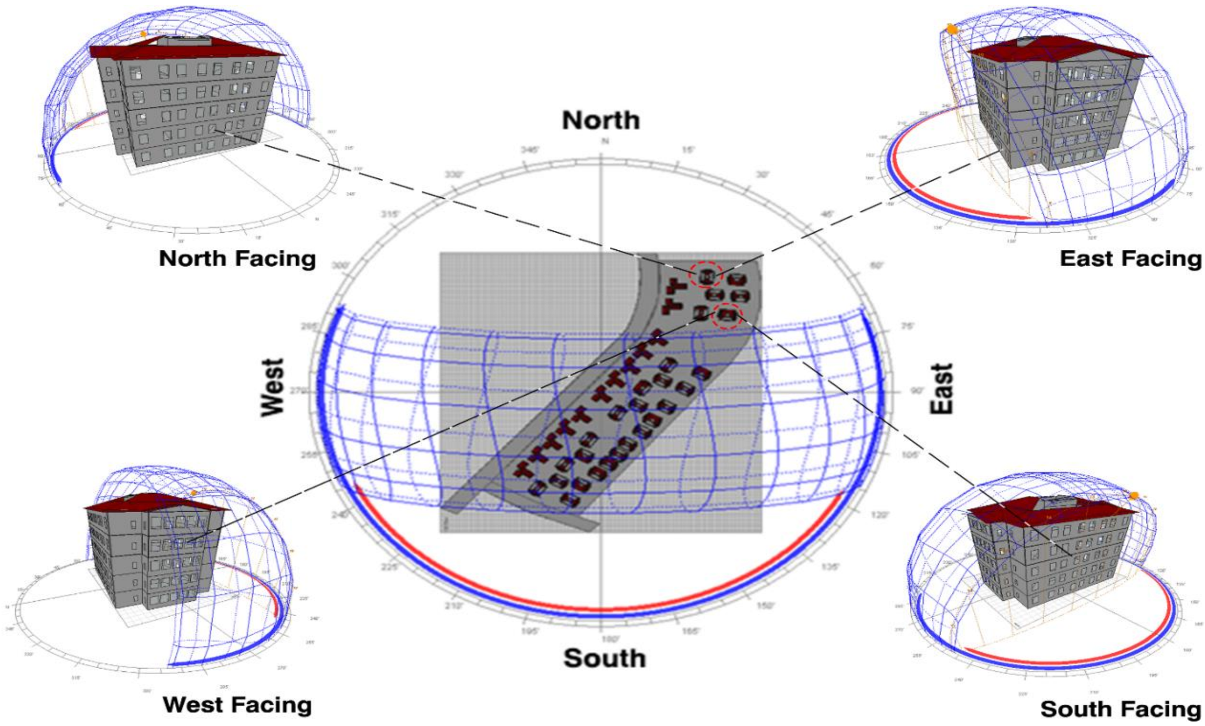


Figure 4.30: wall face and location of both E-W an S-N orientation

Each orientation has a different window design. In the south orientation there is 52.7% WWR and 25.3% in the north orientation, where solar radiation is high there is high WWR. South windows, however, need shade from the midday and early afternoon sun. WWR windows should be few and small. Wide sun radiation with low shadow on the challenging east and west faces.

4.3.2 Opening

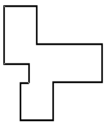
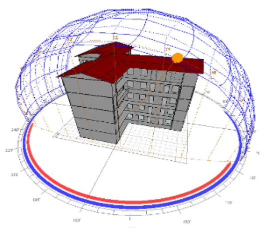
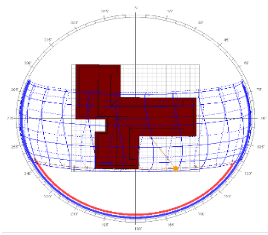
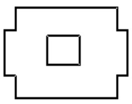
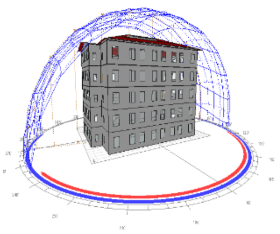
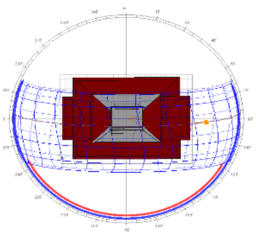
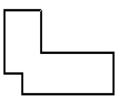
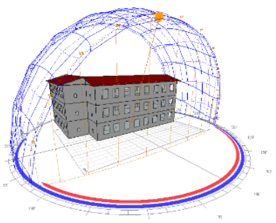
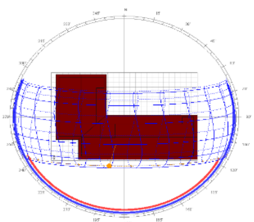
Depend on figure 4.31, the opening orientation was located in four directions (S, N, E, W) of the building and they have not orientated openings according to the season of the wind and solar radiation. The majority of the openings face the opposite direction of the wind. On south orientated, windows are good to enable excess natural light and ventilation but using these many windows on every side is not good for room temperature and sunlight prevention. Most of the windows are located on the south face, but for Adama climatic conditions such window orientation is not recommended.

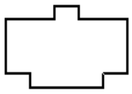
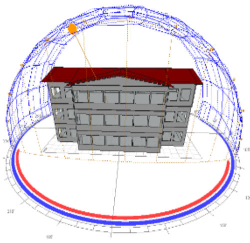
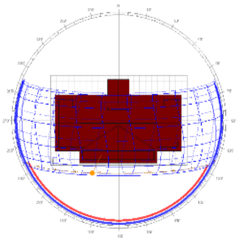
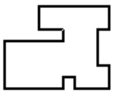
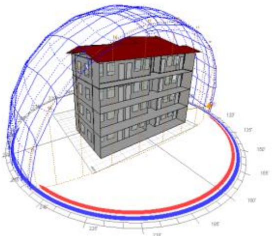
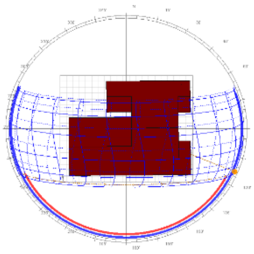
Figure 4.31: A) south facing B) north facing C) west south facing D) north east facing

4.3.3 Window to wall ratio and aspect ratio

Depend on table 4.11, most of the openings in the building are situated on the two opposite-facing walls on each side of the building. WWR on south faced is the worst ranging between 25 to 53%. But on north faced it ranges 18% to 24.5%. Many wide windows penetrate the direct sun according to observation and survey. Particularly south and west windows are penetrating the sunlight and they are the reason of increase room temperature, however, the buildings are not considered the sun direction and sun path. The other window characteristics are similar to this. According to the visualization of the building, the temperature is optimum from summer to winter except for slight cold during winter and slightly warm during summer.

Table 4.11: Aspect Ratio and WWR

Typologies	Solstice and 3D form	Plan	Aspect Ratio	Window to wall ratio
			Length: 24m Width: 20m Height: 15m Aspect Ratio: 83.3%	South: 30.8% East: 25% West: 25% North: 19.9%
			Length: 28m Width: 16m Height: 15m Aspect Ratio: 57.2%	South: 52.7% East: 35.5% West: 41.6% North: 25.3%
			Length:24m Width:16m Height: 9m Aspect Ratio: 66.6%	South: 33.3% East: 10.5% West: 14.2% North: 41.7%

			Length: 20m Width: 12m Height: 9m Aspect Ratio: 60%	South: 41.3% East: 42.4% West: 41.8% North: 19.4%
			Length: 18m Width: 14m Height: 12m Aspect Ratio: 77.8%	South: 32.9% East: 19.0% West: 43.1% North: 10.5%

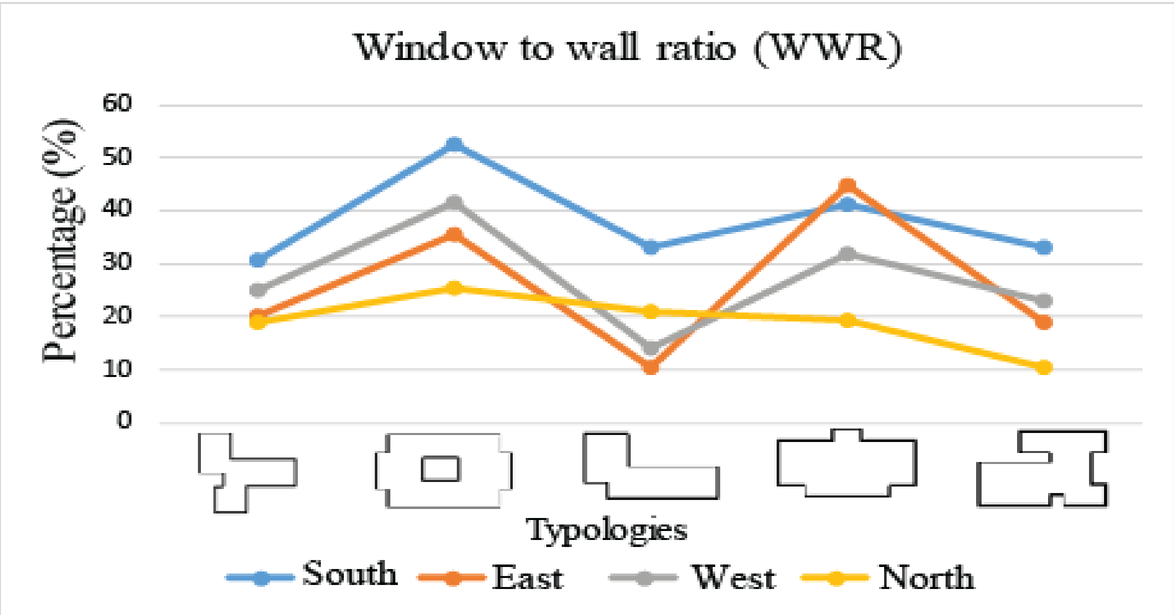


Figure 4.32: Window to wall ratio (source: own analysis)

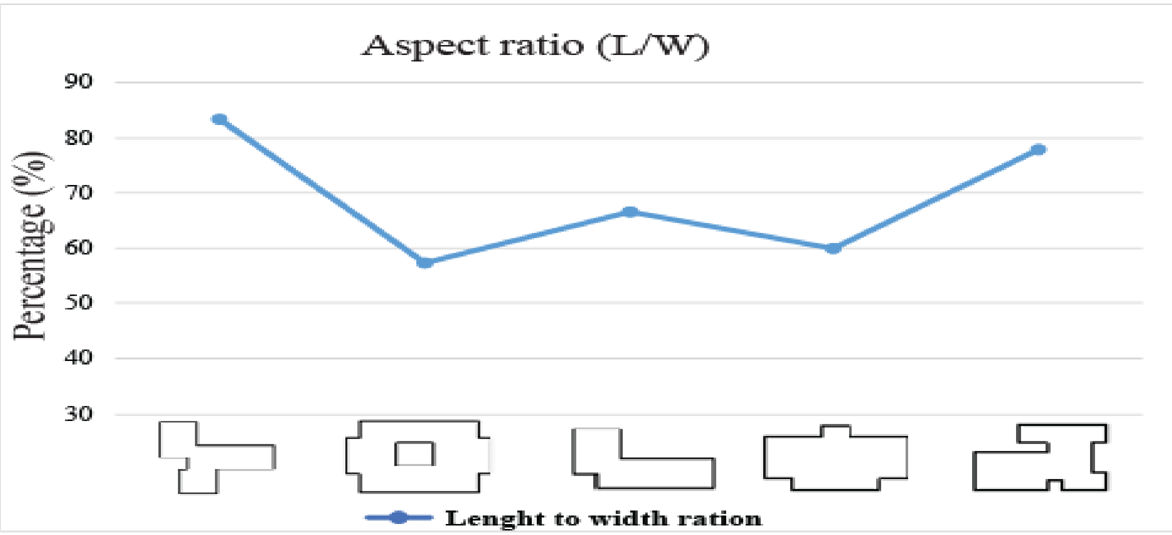
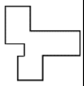
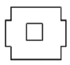
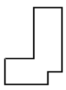
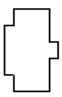
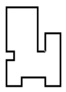


Figure 4.33: Aspect ratio

According to figure 4.32, Openings are believed to collect more than 50 percent of the unwanted heat that accumulates in a building. The interaction of outside and interior air is influenced by openings, which has an impact on energy consumption, indoor air quality, and thermal performance. The amount of light available in the rooms is influenced by the size of the windows. As a result, windows should account for at least 10% of the room's window-to-wall ratio area, with at least 5% of that space able to be opened for ventilation. When no shading devices are employed, the space depth must be no more than 2.5 times the window head height and no more than 2 times the window head height (when shading devices are used).

Table 4.12: Opening, bare wall area of building typologies

Typologies	Opening area	Bare wall area	Total surface area	Story	Orientation	Construction material	No of blocks
	S-80m^2 E-68m^2 N-68m^2 W-70m^2	S-260m^2 E-272m^2 N-272m^2 W-270m^2	South and north-340m^2 East and west-340m^2	G+4	It oriented toward E-W and NW-SE at an angel of 45^0 to 225^0	Single glazed window and HCB wall with cement plaster as internal and external covering	30
	S-129m^2 E-46m^2 N-62m^2 W-62m^2	S-245m^2 E-129m^2 N-245m^2 W-149m^2	South and north-365m^2 East and west-225m^2	G+4	It oriented toward E-W and S-N at an angel of 315^o and 175^o	Single glazed window and HCB wall with cement plaster as internal and external covering	47
	S-72m^2 E-18m^2 N-36m^2 W-56m^2	S-216m^2 E-172m^2 N-252m^2 W-134m^2	South and north-288m^2 East and west-190m^2	G+4 G+3	It oriented toward S-N and NE-SW	Single glazed window and HCB wall	20
	S-38m^2 E-28m^2 N-26m^2 W-36m^2	S-92m^2 E-58m^2 N-134m^2 W-44m^2	South and north-160m^2 East and west-80m^2	G+3 G+2	It oriented toward NE-SW E-W and NW-SE	Single glazed window and HCB wall	26
	S-52m^2 E-24m^2 N-20m^2 W-52m^2	S-158m^2 E-126m^2 N-190m^2 W-98m^2	South and north-210m^2 East and west-150m^2	G+3 G+2	It oriented toward East-west and NW-SE, E-	Single glazed window and HCB wall with	26

					W, N-S and NE-SW at horizontal and vertical axis.	cement plaster as internal and external covering	
Total Blocks - 123				Total Households - 2,279			

The study assesses the impacts of a parameters in the Three key a) orientation variables, b) WWR, and c) Aspect ratio (L/W) on energy consumption and incident solar radiation.

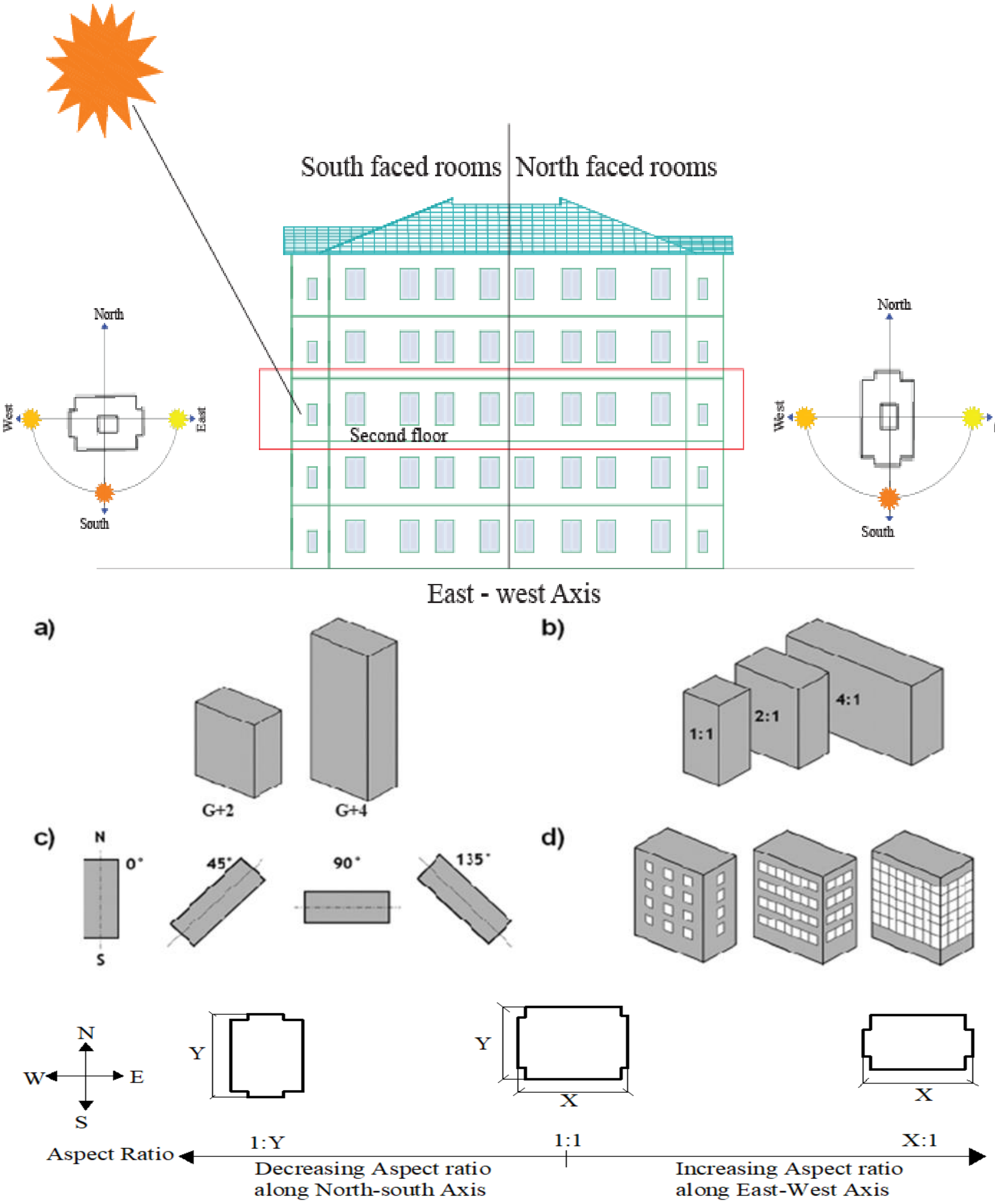
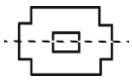
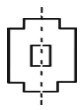


Figure 4.34: WWR and aspect ratio for sample building

Depend on figure 4.34, the North-South direction (0^0N) to (180^0S) or (1: y) is considered the best, but the East-West orientation (90^0E) to (270^0W) or (x:1) is considered the worst orientation. The North-South orientation (0^0N) to (180^0S) or (1: y) is considered the optimum orientation in all cases while the East-West orientation from (90^0E) to (270^0W) or (x:1) is considered as the worst orientation.

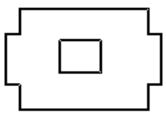
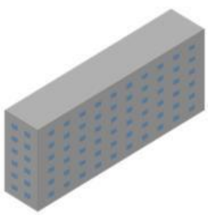
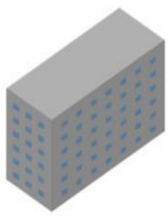
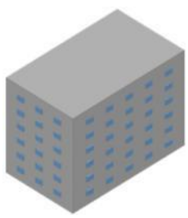
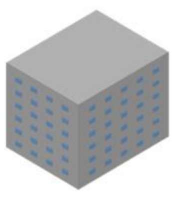
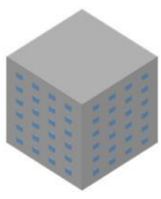
Table 4.13: Window to wall ratio and Aspect ratio of sample building

Typologies	Length	Width	Height	Aspect Ratio (L/W)	Window Area	Wall Area	Window to wall ratio (WWR)
 (East-West axis)	28m	16m	15m	57.2% =0.57	S-120m^2 W-76m^2 N-62m^2 E-96m^2	S-245m^2 W-149m^2 N-303m^2 E-129m^2	South: 52.7% East: 35.5% West: 41.6% North: 25.3%
 (South-North axis)	16m	28m	15m	52.8% =0.43	S-76m^2 W-62m^2 N-96m^2 E-120m^2	S-149m^2 W-245m^2 N-129m^2 E-303m^2	South: 35.5% East: 52.7% West: 25.3% North: 41.6%

According to table 4.13, the building is aligned in such a manner that just a long portion of the building is exposed to solar radiation. The east-west building orientations are aligned with the long axis and south-north axis is aligned with short portion. The goal of this research is to determine the availability of incident solar radiation on diverse surfaces and locations across the world.

WWR and Aspect ratio: Regarding aspect ratio, L/W values were evaluated, namely 20%, 40%, 60%, 80% and 100%, expressed as a percentage of the gross window to wall ratio. For rectangular residential buildings, the recommended WWR is between 80 and 100%.

Table 4.14: Distribution of the Aspect ratio for sample building

Typologies	L/W=20% 0.2	L/W=40% 0.4	L/W=60% 0.6	L/W=80% 0.8	L/W=110% 1
					

4.3.4 Wind direction analysis

Natural ventilation can provide building occupants with thermal comfort and a healthy indoor environment. According to figure 4.35, Buildings have no enough ventilation and maintain an internal temperature below that of the outside environment.

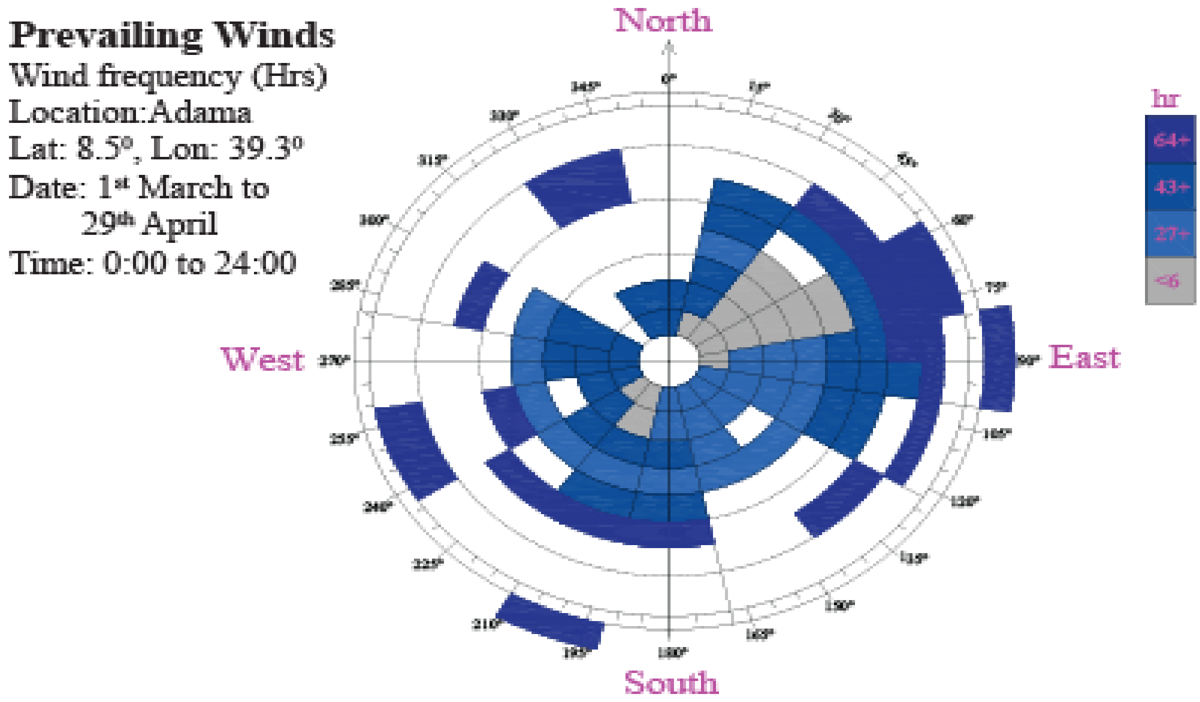


Figure 4.35: March and April prevailing winds of Adama

According to figure 4.36, the wind blows directly into the opening, the airflow rate is highest. However, because the rooms are oriented in the opposite direction of the wind, airspeed is low on the east-west axis for south-facing rooms. However, because the rooms are oriented to the wind direction, the airspeed on the south-north axis on the north facing is high, maintaining the thermal comfort.

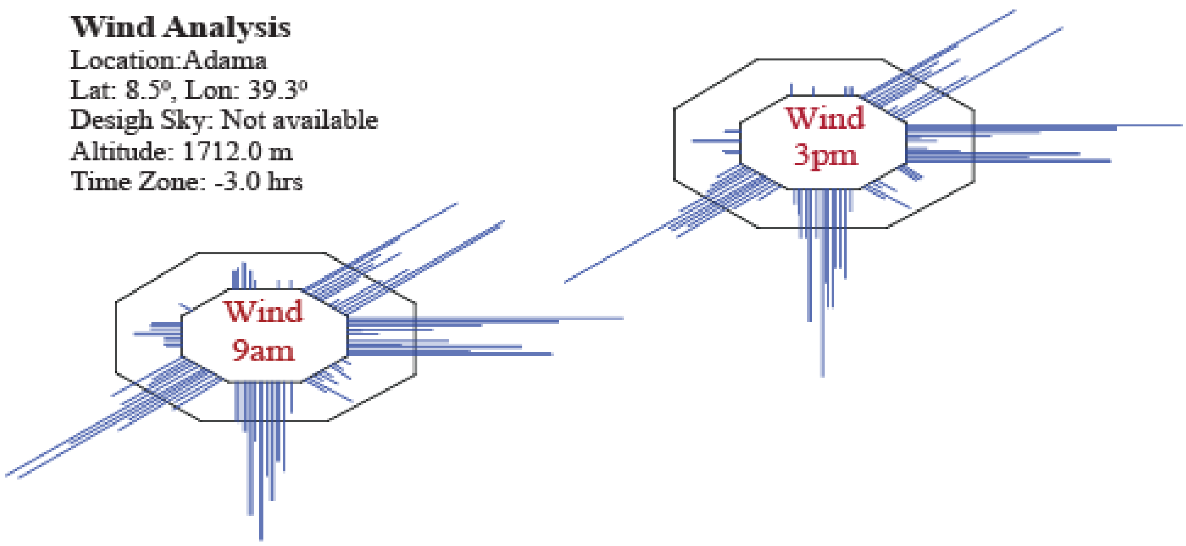
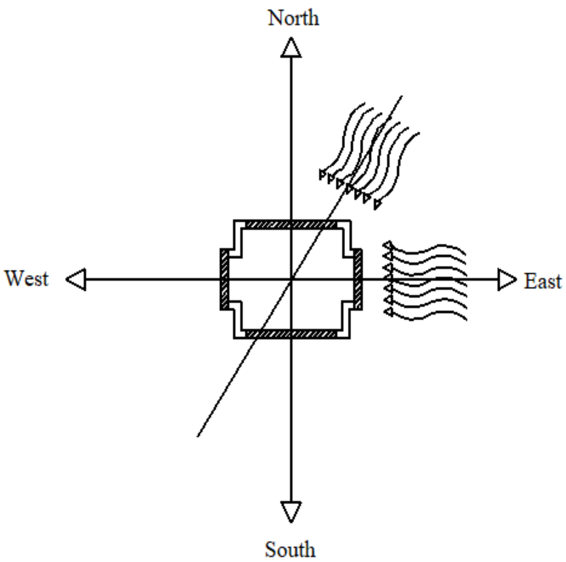
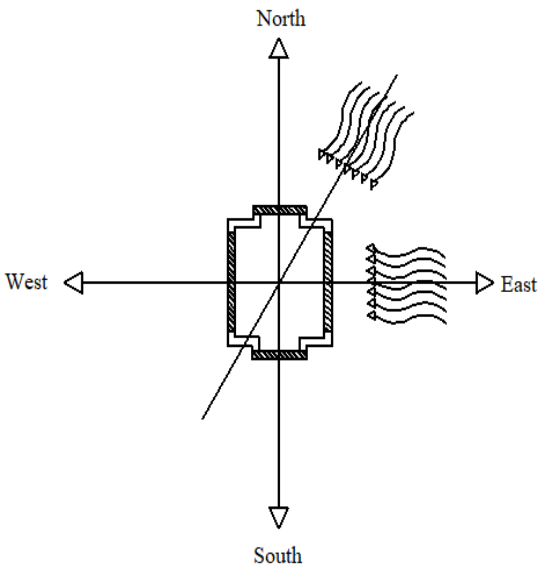


Figure 4:36: Adama's wind direction in March and April (source: Ecotect analysis)

Table 4.15 depicts that the airflow rate is greatest when the wind blows straight into the opening. Changes in building orientation to either side have an influence on the value of natural ventilation effectiveness. according to analysis, East and West openings have greater potential for good natural ventilation than North and South openings. The natural ventilation of the interior is determined by the direction of the wind in respect to the opening. There are two airflow angles in each cardinal direction, one perpendicular (90^0) to the window and the other with 45^0.

According to the study, single side window openings can breathe a space to a depth of 6 to 7 meters, whereas cross ventilation can ventilate a space to a depth of 15 meters. In hot and dry seasons, increasing the air circulation rate in indoor places improves cooling efficiency. The direction of the wind has an impact on thermal comfort by enhancing evaporative loss via the skin and convectional heat transfer between the body and the environment. To better regulate the temperature environment in hot climates, it is best to prevent wind. North facing windows are the most favorable and south-facing windows cannot get the direction of wind it is opposite to the wind direction. This has an impact on the thermal comfort of rooms facing south. Prevailing wind of Adama is depicted on figure 4.36.

Table 4.15: Opening orientation at different angle with relation to Wind Direction

East-West axis (90^0-180^0) building at 90^0 and 45^0 to the wind direction	North-South axis (0^0-270^0) building at 90^0 and 45^0 to the wind direction
	

4.4 Occupants perception

4.4.1 Thermal preference Scale

The preferred thermal environment is defined by the ASHRAE 55 standard. As a result, the survey data of the respondents is provided below.

Table 4.16: ASHRAE 55 thermal Preference scale (Humphreys, 2007)

PMV Value		3	2	1	0	-1	-2	-3
Thermal Preference		Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
Time	3:00am	0 0.0%	0 0.0%	29 24.6%	78 66.1%	11 9.3%	0 0.0%	0 0.0%
	7:00pm	55 46.6%	32 27.1%	18 15.3%	13 11.0%	0 0.0%	0 0.0%	0 0.0%
	10:00pm	28 23.7%	44 37.3%	26 22.1%	20 16.9%	0 0.0%	0 0.0%	0 0.0%

According to Table 4.16, the thermal comfort response over East- West axis (south-oriented) 7:00pm shows the highest thermal preference about 55=46.6%, 32=27.1%, 18=15.3%, 13=11.0%, 0=0.0%, 0=0.0% and 0=0.0% of respondent where feel hot (+3), warm (+2), slightly warm (+1) neutral (0), slightly cool (-1), cool (-2) and cold (-3) respectively. The thermal comfort response of a building that faces south has the weakest performance.

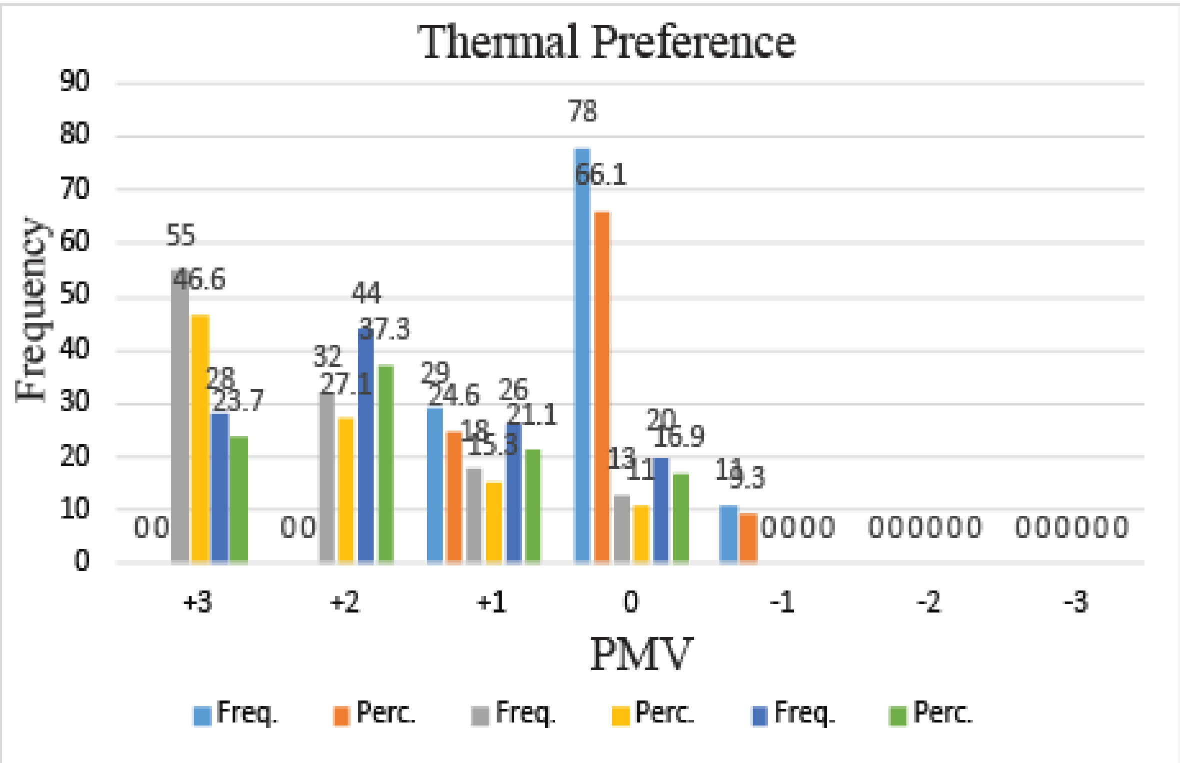


Figure 4.37: Overall Thermal preference votes of occupants (source: data survey)

4.4.2 Thermal sensational Scale

Table 4.17: ASHRAE 55 Sensational scale (Series & Science, 2018)

Level of Scale	3	2	1	0	-1	-2	-3
Thermal Sensation	Very Un Comfort able	Un Comfort able	Slightly Uncomfort able	Neutral	Slightly comfort able	Comfort able	Very Comfort able
3:00am	0 0.0%	8 6.8%	27 22.9%	62 52.6%	16 13.5%	5 4.2%	0 0.0%
7:00pm	24 20.3%	49 41.5%	33 27.9%	12 10.3%	0 0.0%	0 0.0%	0 0.0%
10:00pm	10 8.5%	35 29.7%	48 40.6%	25 21.2%	0 0.0%	0 0.0%	0 0.0%

According to table 4.17, the collected data on E-W orientation, 7:00pm concerning to satisfaction scale indicates that 24=20.3% were said very uncomfortable, 49=41.5% were uncomfortable, 33=27.9% were slightly uncomfortable, 12=10.3% were neutral, 0=0.0% slightly comfortable, 0=0.0% comfortable and 0=0.0% very uncomfortable. Accordingly, the residents of the E-W orientation (south oriented) were not comfortable as the data indicates that the highest respondents answered uncomfortably and the number of discomforts is greater than the comfort.

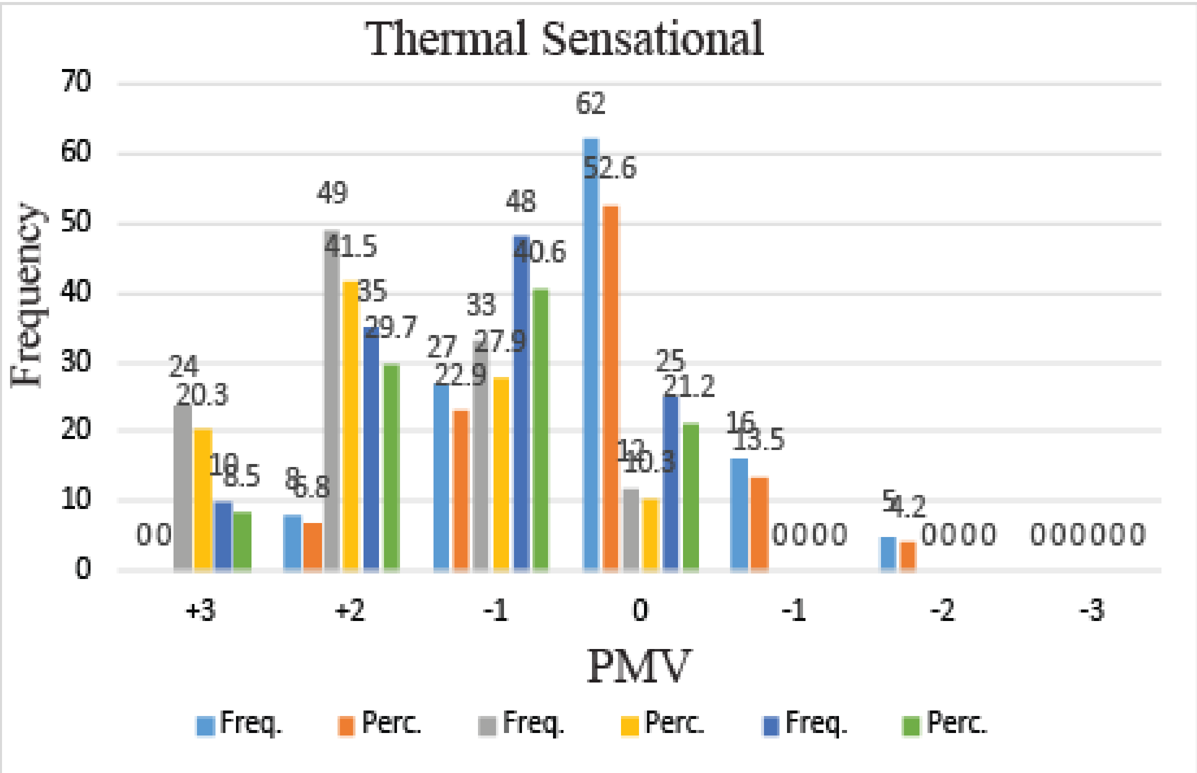


Figure 4.38: Overall Thermal sensation votes of occupants (source: data survey)

4.5 Measurement of environmental variables

4.5.1 Indoor Temperature of East-West Axis

According to Figure 4.39, At peak times of day, the maximum indoor temperatures of all volumes were 32.1^{0}C. living room ranges from 25.9 to 32.1^{0}C, bedroom ranges from 25.4 to 31.8^{0}C, kitchen ranges from 25.3 to 31.4^{0}C, toilet ranges from 25.0 to 31.0^{0}C and outdoor ranges from 26.3 to 33.5^{0}C. The inside temperature of the building E-W oriented with open floor plan ranged from 25.0 to 32.1 degrees Celsius, in contrast the building S-N orientated ranged from 22.5 to 29.8 degrees Celsius. The highest temperature was primarily recorded at midday (7:00 pm) and the lowest recorded at morning (3:00 am).

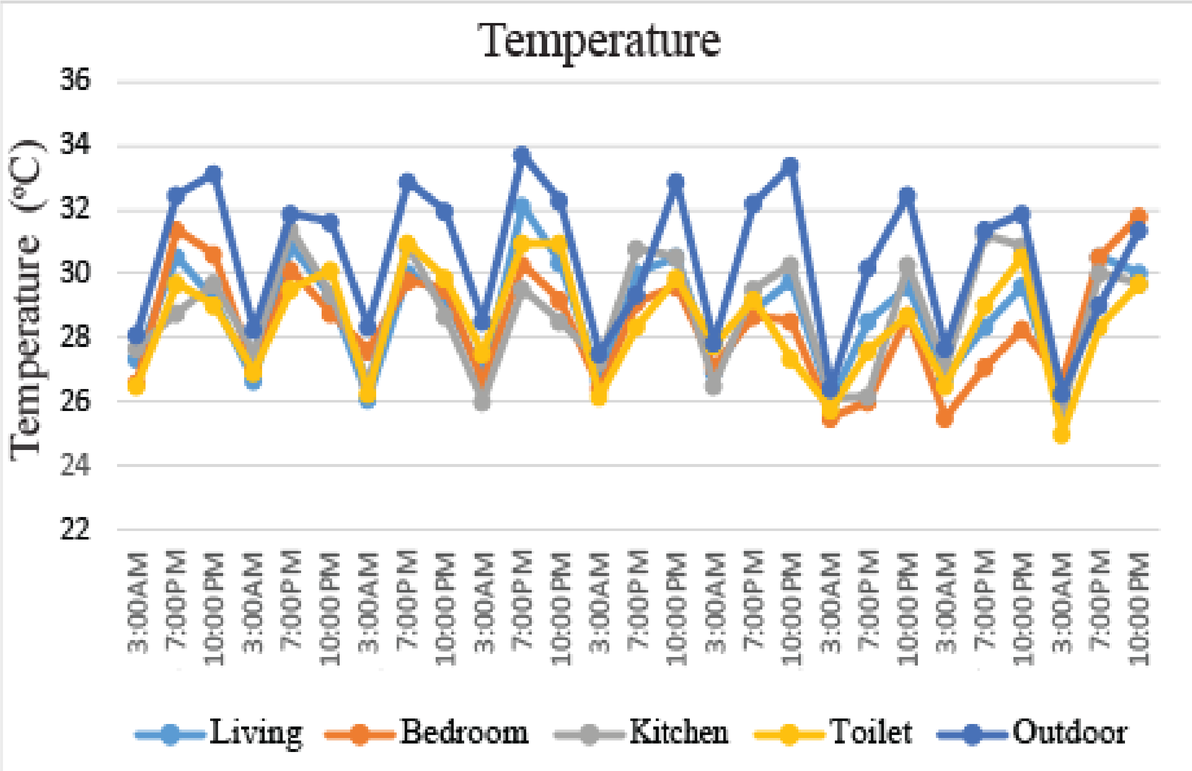


Figure 4.39: Temperature data of East-West Axis (source: data survey)

4.5.2 Indoor Temperature of North-South Axis

According to Figure 4.40, the maximum indoor temperature of N-S oriented (north faced) is 29.1^{0}C- 30.4ºC outdoor and the minimum temperature is 22.5^{0}C were recorded. The maximum temperature was recorded outside (30.4ºC), while the minimum temperature was recorded indoor (22.5^{0}C). living room ranges from 22.9 to 29.1^{0}C, bedroom ranges from 23.3 to 28.8^{0}C, kitchen ranges from 23.0 to 28.9^{0}C, toilet ranges from 22.5 to 28.9^{0}C, and outdoor ranges from 24.4 to 30.4^{0}C. The temperature flow has the same pattern for the four spaces including outdoor temperature. The indoor temperature is relatively low at 3:00 am rising at 7:00 pm and stayed till 10:00pm with a slight decrement.

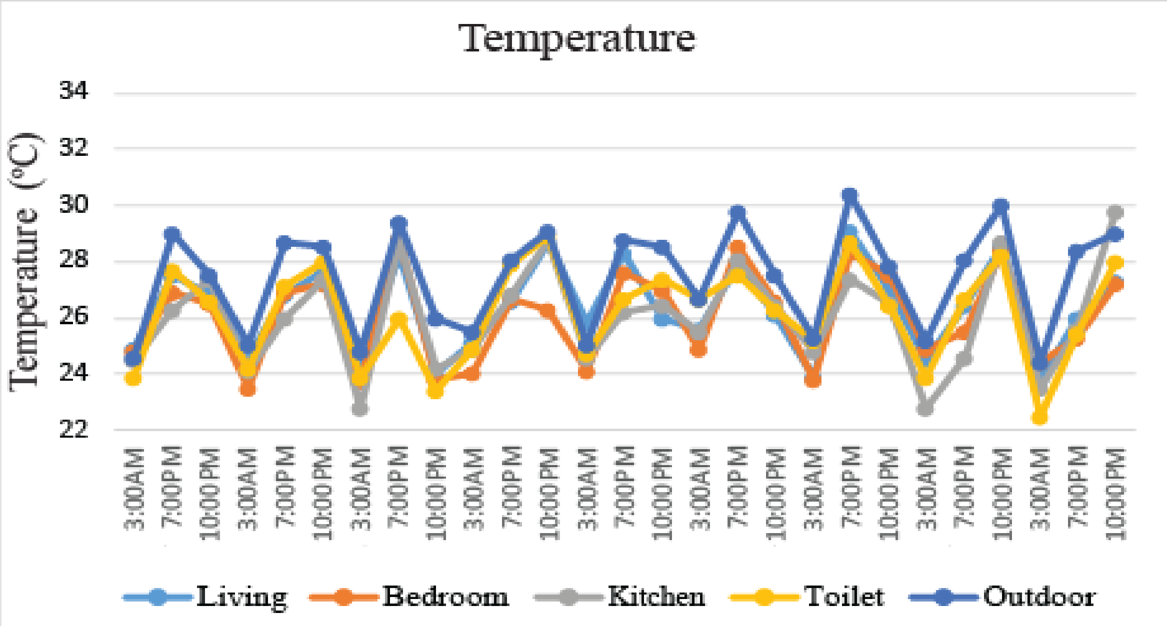


Figure 4.40: Temperature data of North-South Axis (source: data survey)

4.5.3 Daylight illumination of East-West Axis

The Lux meter measurements show that some areas of the floor space have an excess level of illuminance (>2000 lux) in the midday (6:00-8:00 pm), In the afternoon (10:00-11:00 pm), other places have an overabundance of illuminance (>1500 lux). According to Figure 4.41, outdoor daylight illumination ranges from 560lux to 1990lux, living room ranges from 224lux to 680lux, kitchen ranges from 178lux to 610lux, and toilet ranges from 195 to 565lux. Indoor minimum illuminance was 185 (bedroom) and the maximum was 680 (living room).

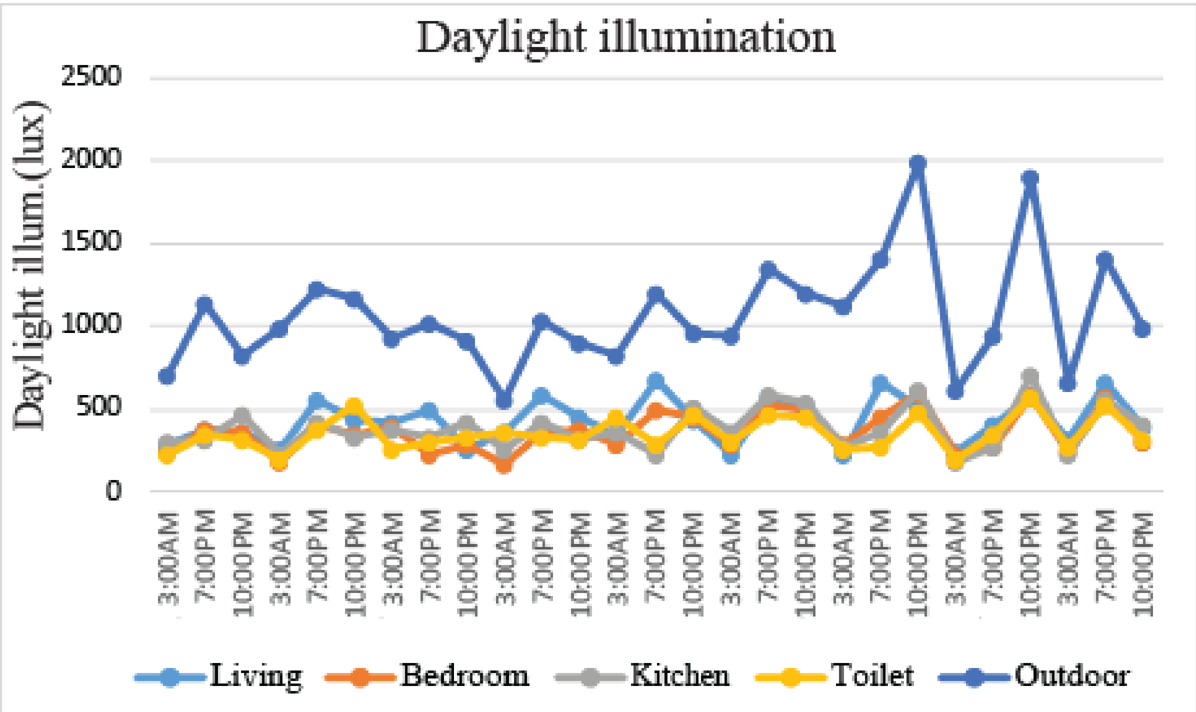


Figure 4.41: Daylight data of East-West Axis (source: data survey)

4.5.4 Daylight illumination of North-South Axis

Throughout the day, the Lux meter measurements reveal that some portions of the indoor daylight illumination are excessive (385lux), while others have low illuminance (020lux). Outdoor daylight lighting extends from 105lux to 620lux, living room illumination ranges from 020lux to 385lux, and kitchen illumination ranges 052lux to 356lux, according to Figure 4.42.

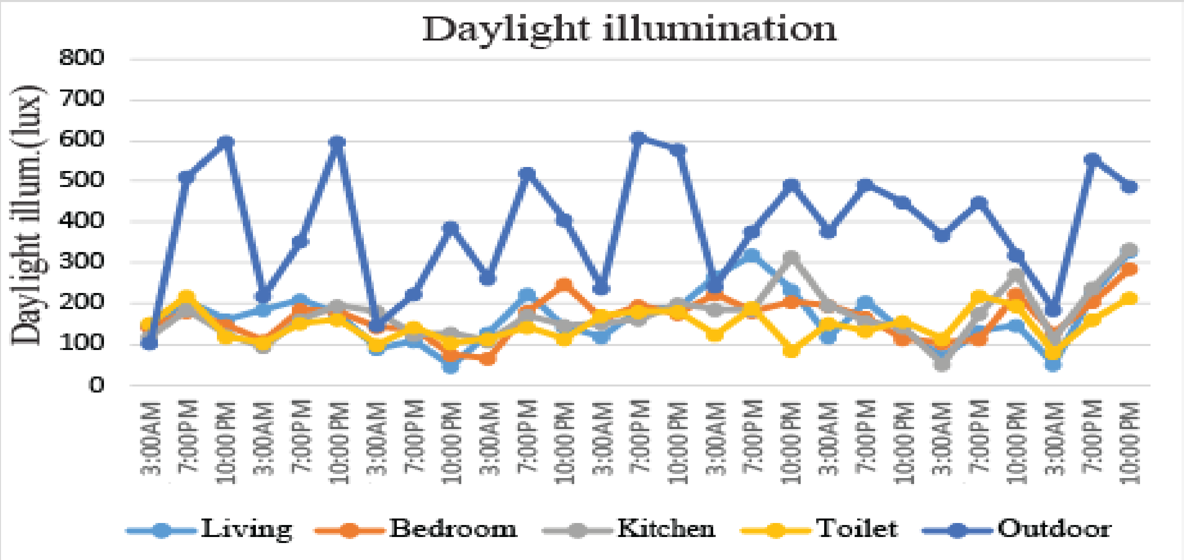


Figure 4.42: Daylight data of North-South Axis (source: data survey)

4.5.5 Relative humidity of East-West Axis

Figure 4.43 indicates the maximum humidity of the East-West Axis was 34% and 22% was the minimum recorded. The maximum humidity was recorded in the toilet (34%), while the minimum humidity was recorded outdoor (20%). living room ranges from 23 to 32%, bedroom ranges from 23 to 32%, kitchen ranges from 22 to 30%, toilet ranges from 24 to 34% and outdoor ranges from 20 to 30%. The pattern of the recording has almost the same consistency in the four sample rooms and outdoor.

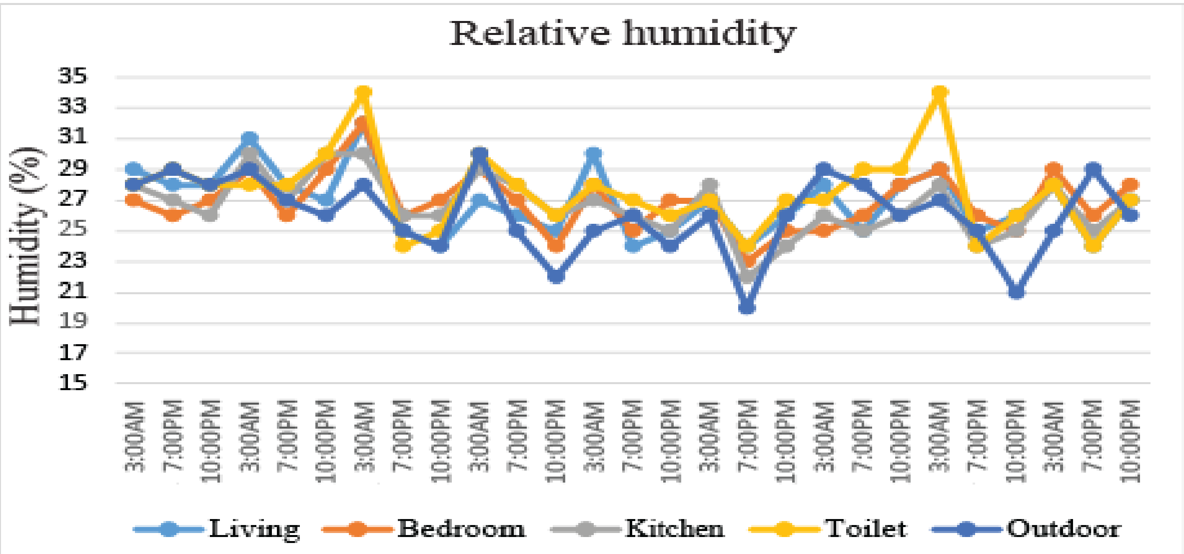


Figure 4.43: Humidity data of East-West Axis (source: data survey)

4.5.6 Relative humidity of North-South Axis

According to figure 4.44, the maximum humidity of the North-South Axis was 38% and 24% was the minimum recorded. The maximum humidity was recorded in living (38%). living room ranges from 24 to 38%, bedroom ranges from 37 to 24%, kitchen ranges from 24 to 35%, toilet ranges from 25 to 34% and outdoor ranges from 24 to 32%. The relative humidity in a north-facing room, on the other hand, ranges from 24 to 38 percent.

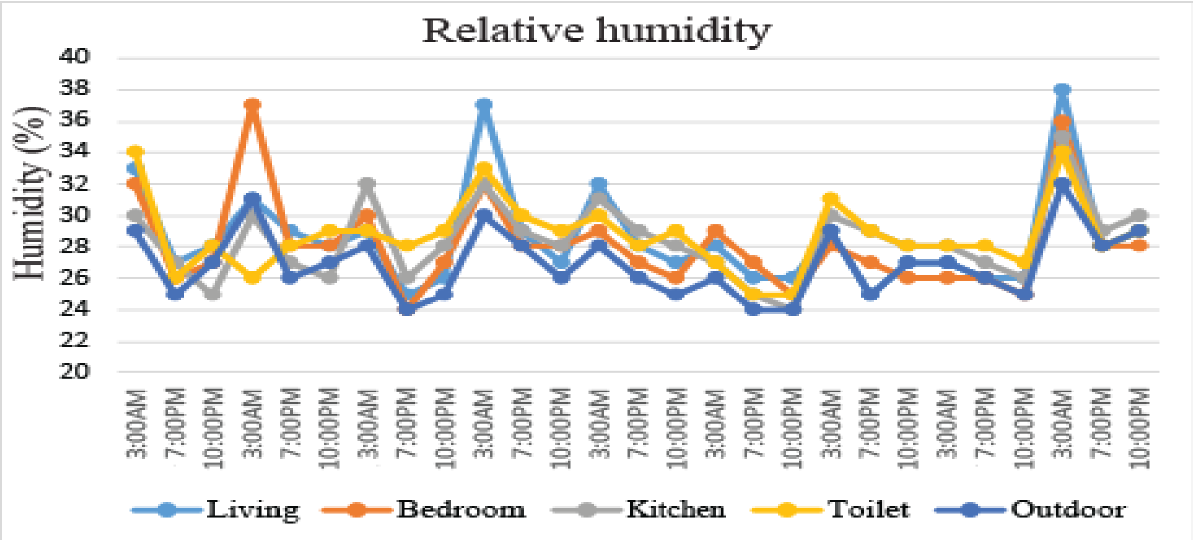


Figure 4.44: Humidity data of North-South Axis (source: data survey)

4.5.7 Air speed of East-West Axis

According to the figure 4.45, the air velocity in the room ranged from 0.00 to 0.55m/s. The indoor air velocity of living room ranging between 0.00 to 0.52m/s, bedroom between 0.00 to 0.55m/s, kitchen between 0.00 to 0.52m/s, and outdoor airspeed was between 0.45 to 2.93m/s. north-south axis rooms have a higher airspeed than east-west axis rooms (i.e. living room ranges 0.50 to 1.94m/s, bedroom ranges 0.20m/s to 1.25m/s, kitchen ranges 0.00 to 1.15m/s, and toilet ranges 0.02 to 1.40m/s and 0.45 to 3.50m/s on the outdoor).

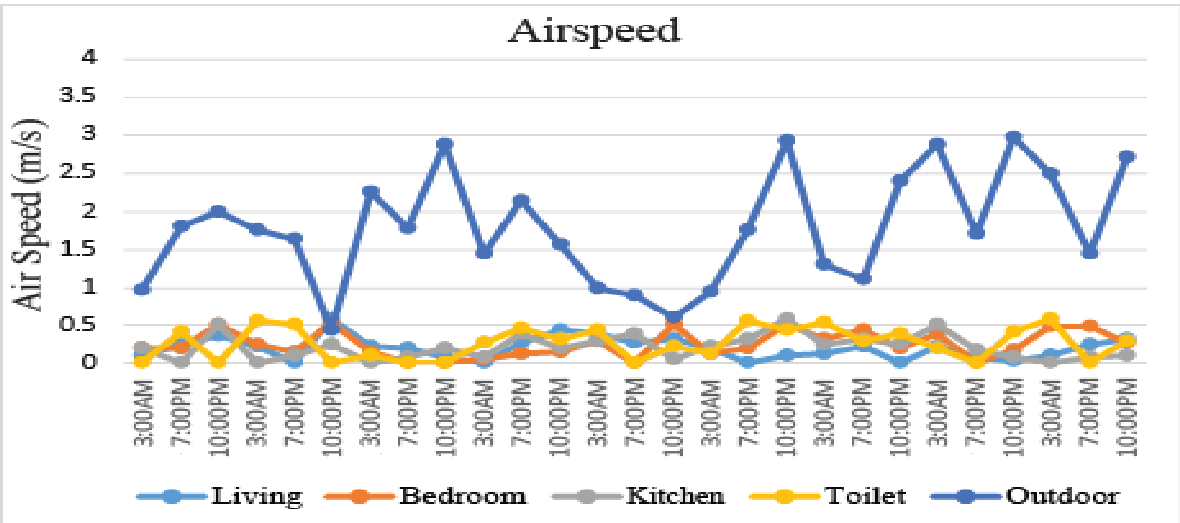


Figure 4.45: Airspeed data of East-West Axis (source: data survey)

4.5.8 Air speed of North-South Axis

According to the figure 4.46, the air velocity in the room ranged from 0.00 to 1.94 meters per second. North-south axis rooms have a higher air speed than east-west axis rooms (i.e. living room ranges 0.50 to 1.94m/s, bedroom ranges 0.20m/s to 1.25m/s, kitchen ranges 0.00 to 1.15m/s, and toilet ranges 0.02 to 1.40m/s and 0.45 to 3.50m/s on the outdoor).

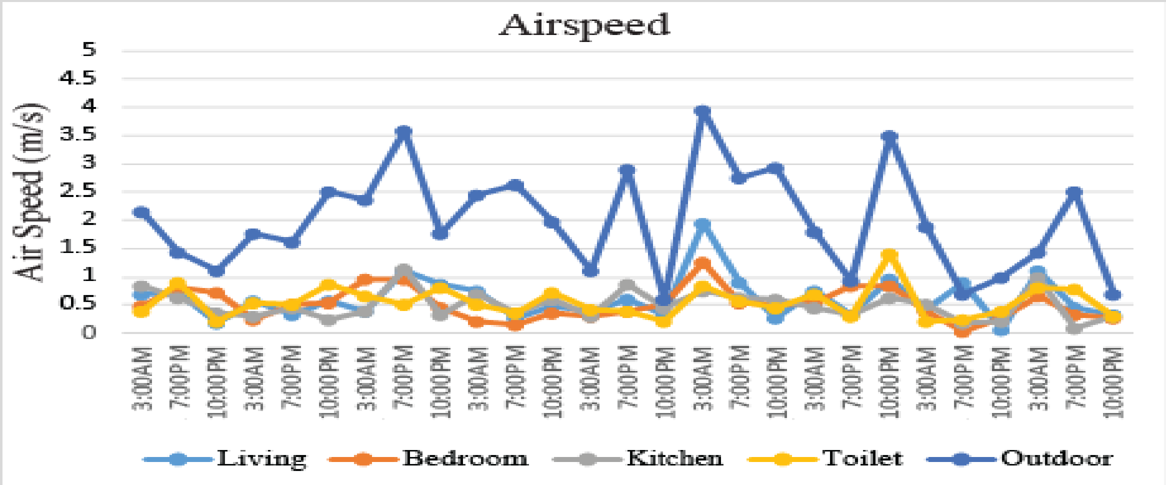


Figure 4.46: Airspeed data of North-South Axis (source: data survey)

4.6 Thermal comfort analysis

4.6.1 Indoor temperature and relative humidity

i. The ASHRAE 55 and ISO 7730 standards

According to figure 4.47, the ASHRAE 55 standard, the comfort range for most individuals (80%) is between 20°C and 26°C, with a humidity level below 80% and no lower humidity limit, while the outdoor temperature is 18°C (ASHRAE, 2020). The allowable temperature ranges in winter and summer, according to ISO 7730, are 20°C-23°C and 23°C-26°C, respectively, while relative humidity is fixed between 30% and 70% in both summer and winter.

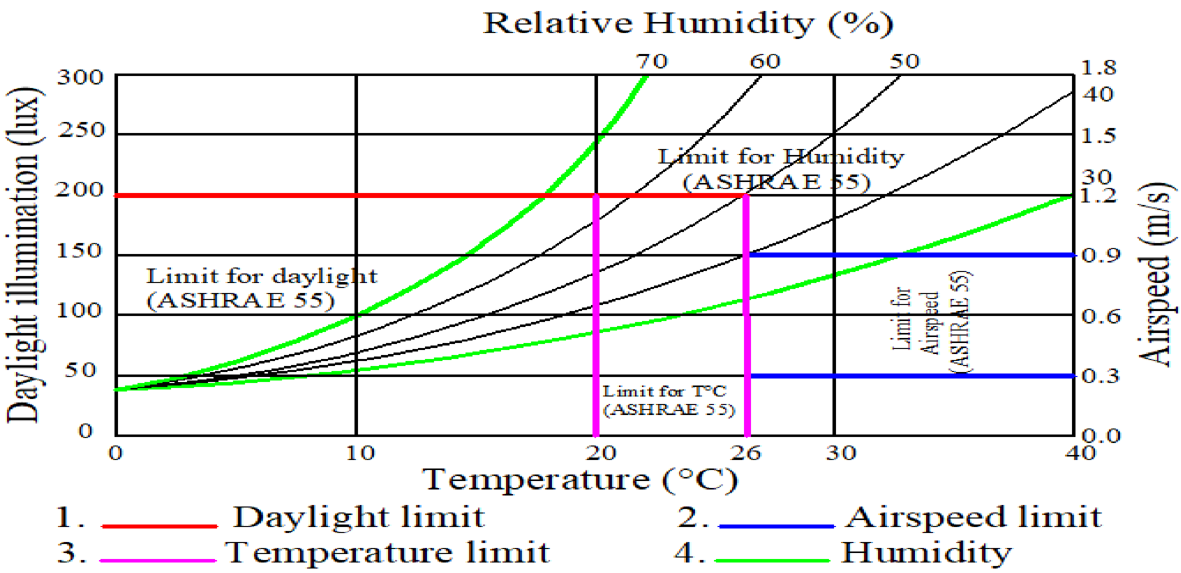


Figure 4.47: ASHRAE 55 standard for environmental variables (source, (Paliaga et al., 2013)

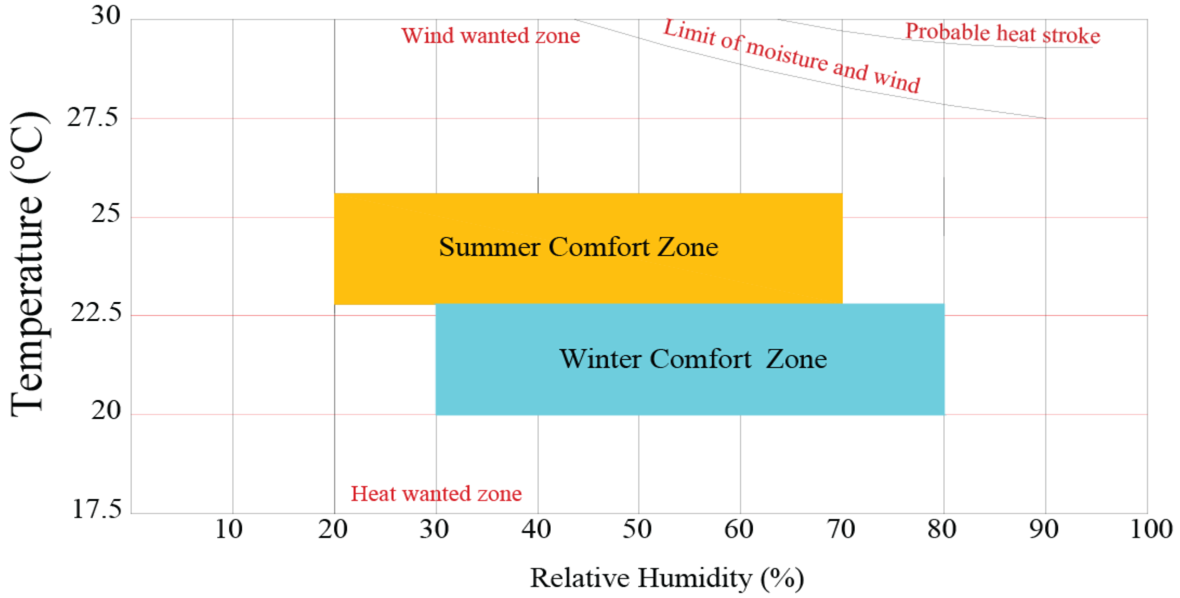


Figure 4.48: The ASHRAE 55 and ISO 7730 comfort zones (source: (Paliaga et al., 2013b)

Temperature changes over time may also have an impact on the occupants' thermal comfort. As a result, cyclic operational temperature changes are limited to 1.1°C, with drifts and ramps up to 3.3°C depending on time (ISO 7730, 2005). The indoor temperature fluctuation between March 26 and April 20, 2022, according to field data, is 3 to 4°C.

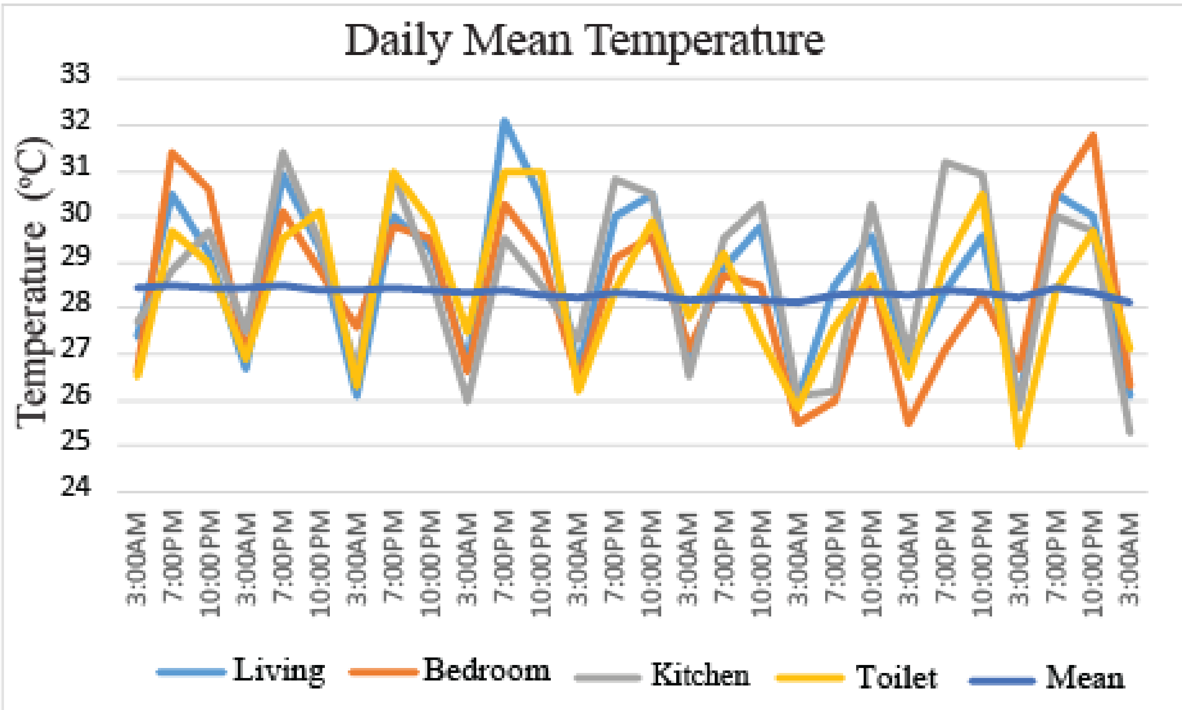


Figure 4.49: Average temperature of south-facing (source, field survey)

According to Figure 4.39, for the external surface, the daily maximum temperature reached 33.5°C at 6:00 pm in the south-facing wall, and 32.4°C at 10:00 pm. The daily minimum temperatures appeared at 03:00 pm, which was 22.5°C in the north-facing wall and 25.0°C in the south-facing wall respectively.

The daily maximum temperatures for the internal surface reached 32.1°C in the south-facing wall at 7:00 pm and 29.8°C in the north-facing wall at 7:00 pm, respectively. A south-facing room's average temperature is 28.6°C, which is below standard thermal comfort. However, the average temperature in the north is 25.5°C. From 7:00 pm to 10:00 pm, the heat was transferred from the external to the inside wall surface, and the situation was reversed for the rest of the day. According to the recorded data temperature level fluctuation of south-facing is larger than the standard level. Thermal comfort is reduced when the temperature and relative humidity are both high (Fang, 2004), the sample space's inside temperature is high, with varying low humidity, according to field survey data obtained. This implies the building needs appropriate orientation to mitigate the external temperature or increase the level of humidity.

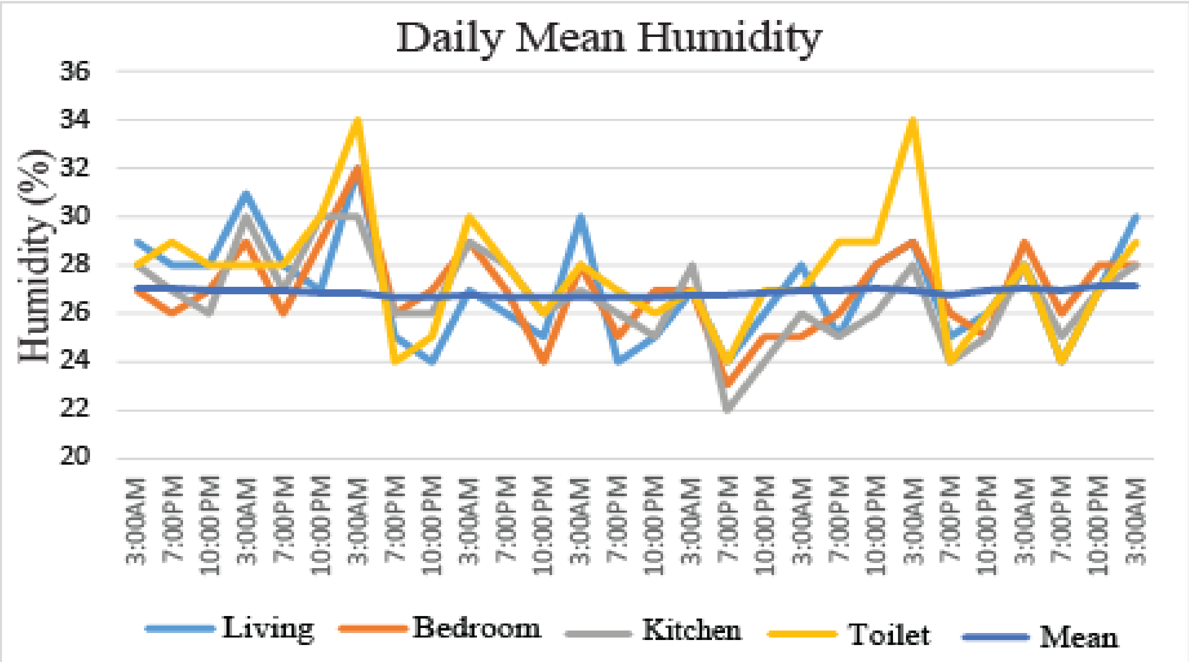


Figure 4.50: Average humidity of south-facing (source, field survey)

Regarding to figure 4.50, north-oriented recorded humidity data were better than the south-oriented in all three sample spaces. In the first month maximum was 32% and a minimum of 28% were recorded in the second month 34% maximum and 22% maximum were recorded. The humidity level of north-oriented is better than that humidity level of south-oriented. Rooms with a south-facing orientation have a 27% average humidity. This average was calculated using the ASHRAE 55 and ISO 7730 standards. According to the figure 5:63 the recorded humidity indicates that on average almost all rooms are out of comfort zone. The thermal sensation is a measure of complete thermal comfort and acceptance at lower humidity levels. As the temperature rises, the moisture content of the air decreases. This result is also examined by the thermal sensational scale of the residents and the result is similar to what the recording data indicates.

4.6.2 Airspeed

ii. The ASHRAE 55 and ISO 7730 standards

The top limit on average air speed for operative temperatures over 25.5°C is 0.9 m/s, according to figure 4.51. The average air speed limit for operative temperatures below 25.5°C is 0.3 m/s. Based on Figure 4.45 the airspeed of the East-West Axis was low regarding outdoor airspeed, we can see outdoor air velocity is high (3m/s). In the east-west orientation, the average inside airspeed (0.22 m/s) is below conventional comfort, with a range of 0.00 to 0.55 m/s indoors and 2.95 m/s outside. Because of the position of the opening, no outside air could enter. This implies the building needs an appropriate passive strategy to mitigate the external air in the indoor environment. The figure below presents the airspeed recorded from March 26 to April 26. 2022. Outside air velocity ranges from 0.45m/s to 2.95m/s, according to Figure 4.45. The room's air velocity varied from 0.00 to 0.55 meters per second.

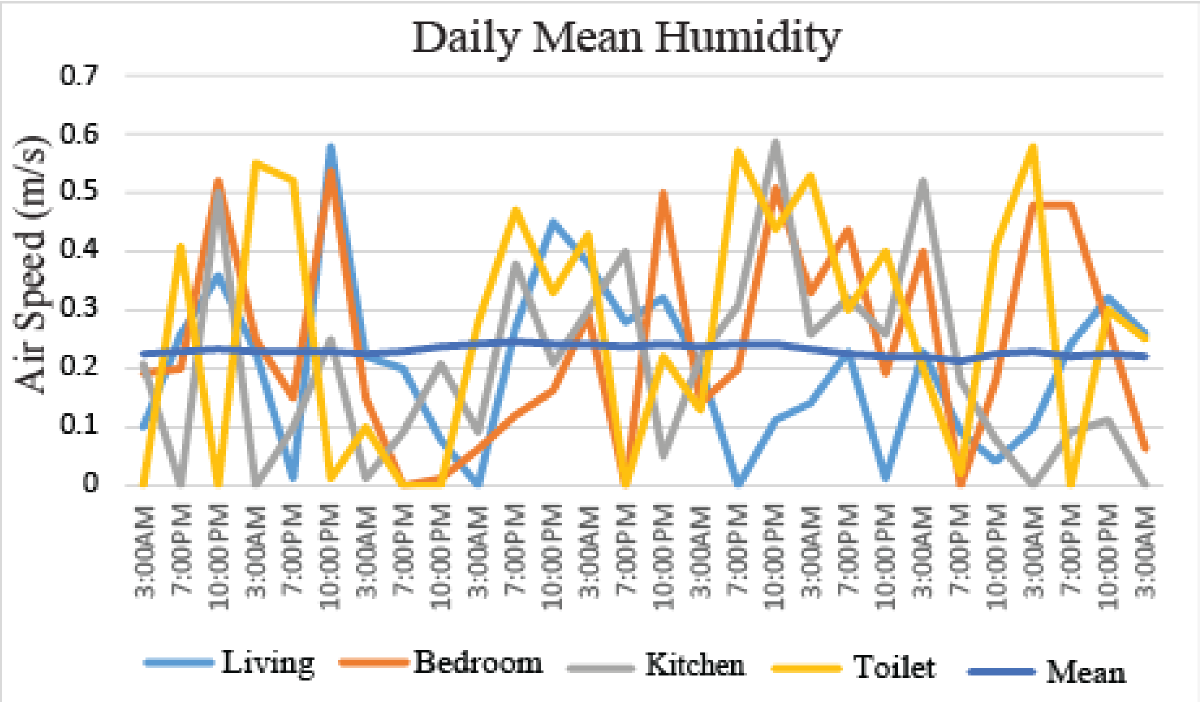


Figure 4.51: Airspeed data (source, field survey)

4.6.3 Daylight illumination

iii. The EBCS and ASHRAE 55 standards

A minimum rated illuminance of 200.0lux must be given for indoor workplaces (EBCS). The ASHRAE 55 standard recommends daylight lighting ranges of 150-200 lux for the living room, 100-200 lux for the kitchen, 050–200 lux for the bedroom, and 100-200 lux for the toilet. According to the statistics, the amount of daylight observed fluctuates significantly at high indoor temperatures.

When the temperature and daylight illumination are both low, thermal comfort is lowered. As seen in the figure 4.52, the average illumination of daylight is more than 200lux. The living room is 200-680 lux, the bedroom is 150-690 lux, the kitchen is 180-700 lux, and the toilet is 210-650 lux. The interior spaces receive more than the average required 200lux, and 20% of the outdoor illumination penetrates the indoor space, according to requirements. North-facing rooms, on the other hand, receive less light than south-facing rooms. At the clear sky, the illuminance measurement revealed a very high light level in the inhabitants' primary living room.

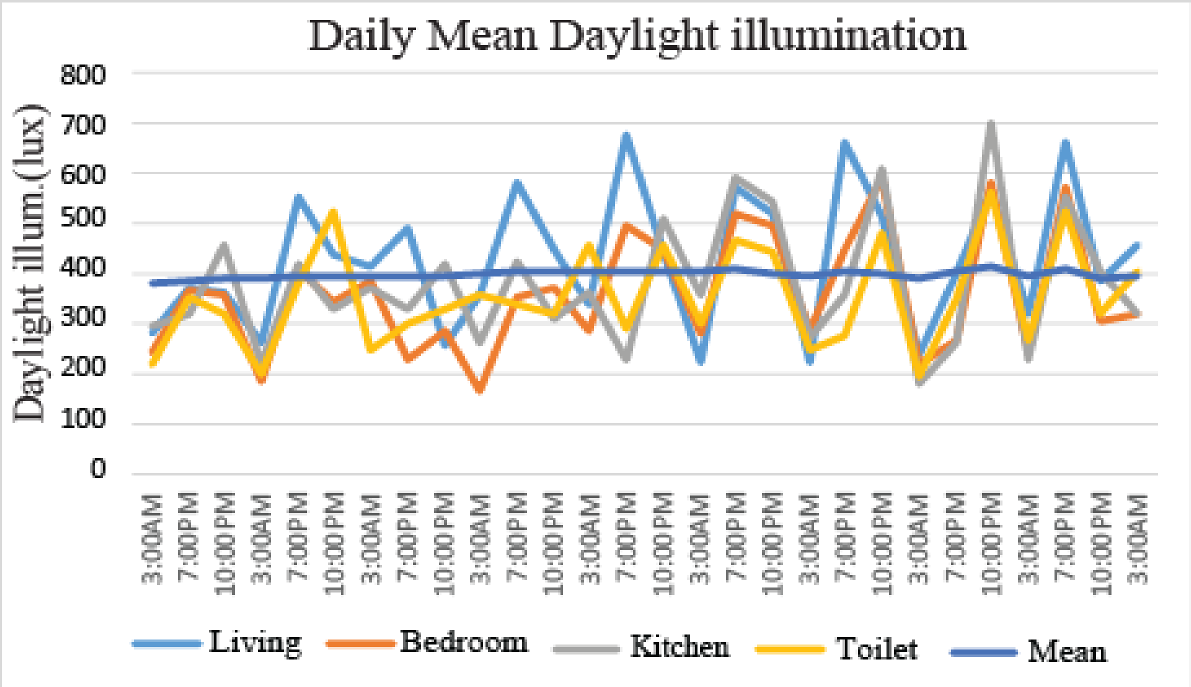


Figure 4.52: Average daylight illumination (source, field survey)

4.6.4 Window wall ratio (WWR)

iv. The EBCS and ASHRAE 55 standards

According to ASHAREA and ISO research on residential building, minimum WWR should be between 22 to 27% (south facing) based on the minimum daylight point of view and 50 to 60% would be optimal for north facing. According to EBCS, WWR should provide an opening of not less than l/l0th of the inner room's floor area of 2.5 m^2. A space designed for human occupation must have a minimum net glazed area of 15% of the total floor area of the room served (EBCS). All south-facing rooms were fully out of the range when compared to the ASHRAE 55 and ISO 7730 comfort criteria, and the majority of the analyzing were considerably outside the comfort zone. Indicating the spaces are uncomfortable. Because, the orientation and opening (WWR) of building affect and cause to rise the in temperature as well as solar radiation in to the room.

4.7 Environmental variables with respect to the chart of thermal comfort

According to figure 4.53, the psychometric chart is standard use by ASHRAE 55 and ISO 7730 to analyze whether or not the measured level of thermal is in the comfort zone or not. However, the thermal comfort zone differs from place to place as the climate zone the internationally developed comfort zone available is ASHRAE standard. Air temperature/air bulb temperature, relative humidity ratio, Enthalpy, and radiant temperature are all used in psychometrics. For the matter of availability of measuring instruments, this study used the air temperature and relative humidity ratio to identify the level of room temperature and comfort level. In the south, humidity levels range from 22 to 34 percent., air velocity ranges from 0.00m/s to 0.55m/s and outdoor ranges from 0.45m/s to 2.93m/s, daylight illumination ranges from 178lux to 680lux, and outdoor ranges from 560lux to 1990lux, and temperature ranges from 25.00C to 32.10C and outdoor ranges from 26.30C to 33.50C. The north-oriented humidity ranges from 24% to 38%, temperature ranges from 22.50C to 29.80C and outdoor ranges from 24.40C to 30.40C, and daylight illumination ranges from 020lux to 3854lux, and outdoor ranges from 105lux to 620lux. Accordingly, the measured variables in each orientation overlapped or were traced to the ASHRAE 55 psychometric chart, the comfort zone from the ASHRAE standard identified in the figure 4.51.

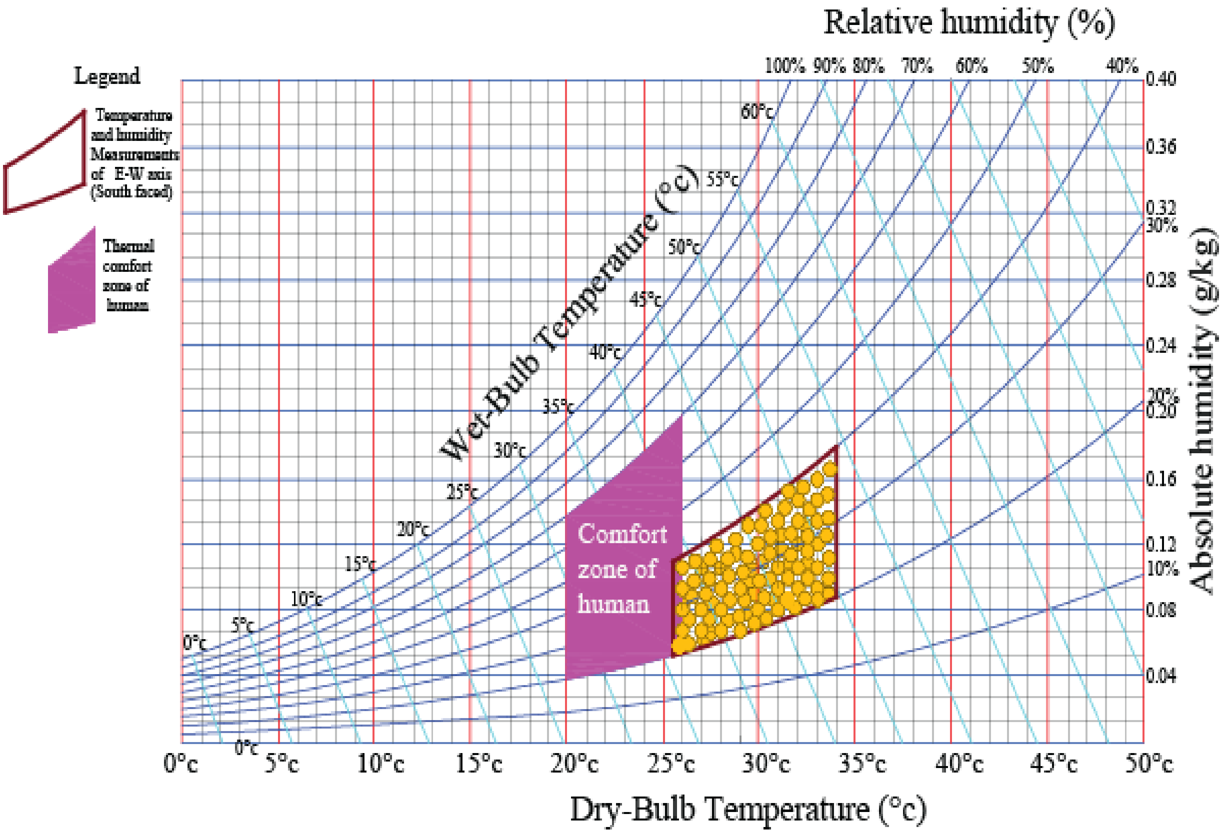


Figure 4.53: Environmental variables relative to the comfort range, south facing room

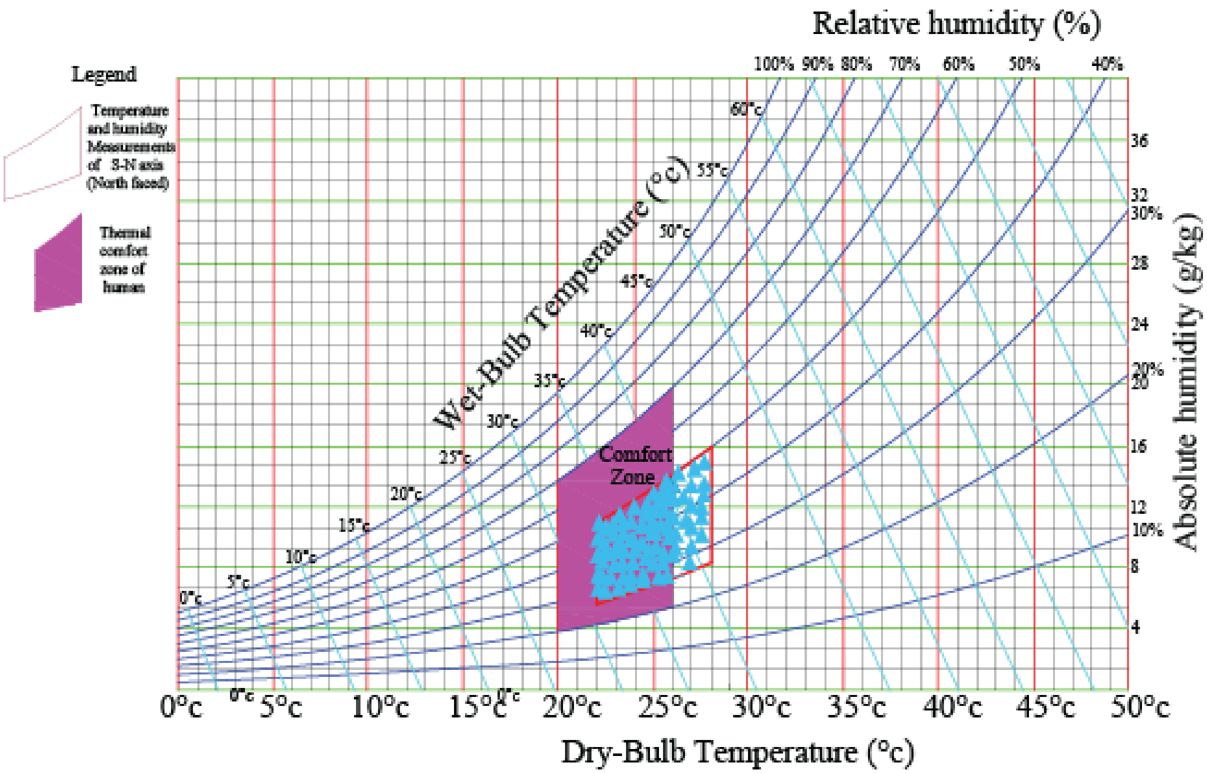


Figure 4.54: Environmental variables relative to the comfort range, south facing room

4.8 Correlation between indoor temperature and daylight illumination

Figure 4.55 indicates that when the outside daylight illumination rises, the internal temperature also rises. The temperature range of the internal and external surroundings varies during the day depending on this. The morning session had a low thermal discomfort rate, however, the afternoon session had a high thermal discomfort rate. The connection between indoor daylight illumination and indoor air temperatures is depicted in the graph below.

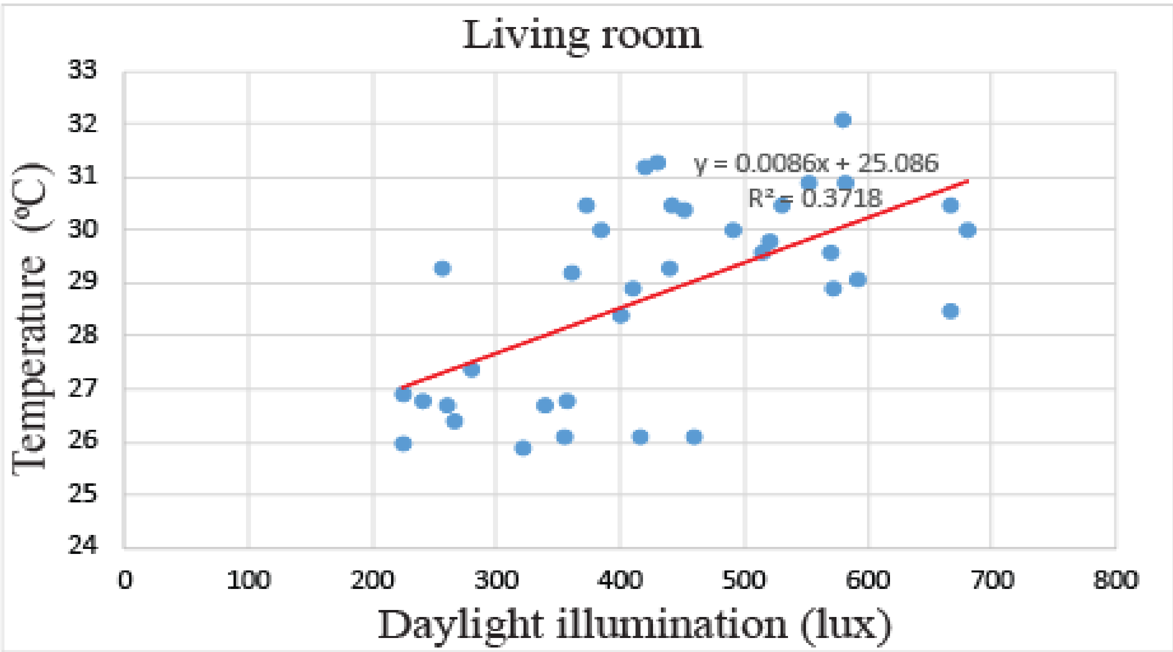


Figure 4.55: Correlation between indoor temperature and daylight illumination

Correlation coefficient R^2=0.3718, shows a high positive relationship with indoor temperature. As the daylight illumination increase, temperature increases, and the thermal discomfort level also increases between R^2=0.3718. It indicates a high level of heating is expected. When R^2= close to zero, the temperature had a slight correlation with satisfaction level. The two variables had a 37% of probability of finding the difference.

4.9 Correlation between indoor and outdoor temperature

Outdoor and indoor temperatures revealed a strong positive correlation, as seen in figure 4.56. since the temperature differential between inside and outside changes throughout the day. The morning session was quite low, whereas the afternoon session was relatively high. Even if the inside and outdoor temperatures differ in magnitude, they are linked. The correlation coefficient is 0.67 shows a high positive relationship, indicating that the difference in indoor and outdoor temperatures is high. Additional heat sources for the interior environment include high accommodation levels. The orientation, WWR, and aspect ratio of the building allow excessive heat into the indoor space.

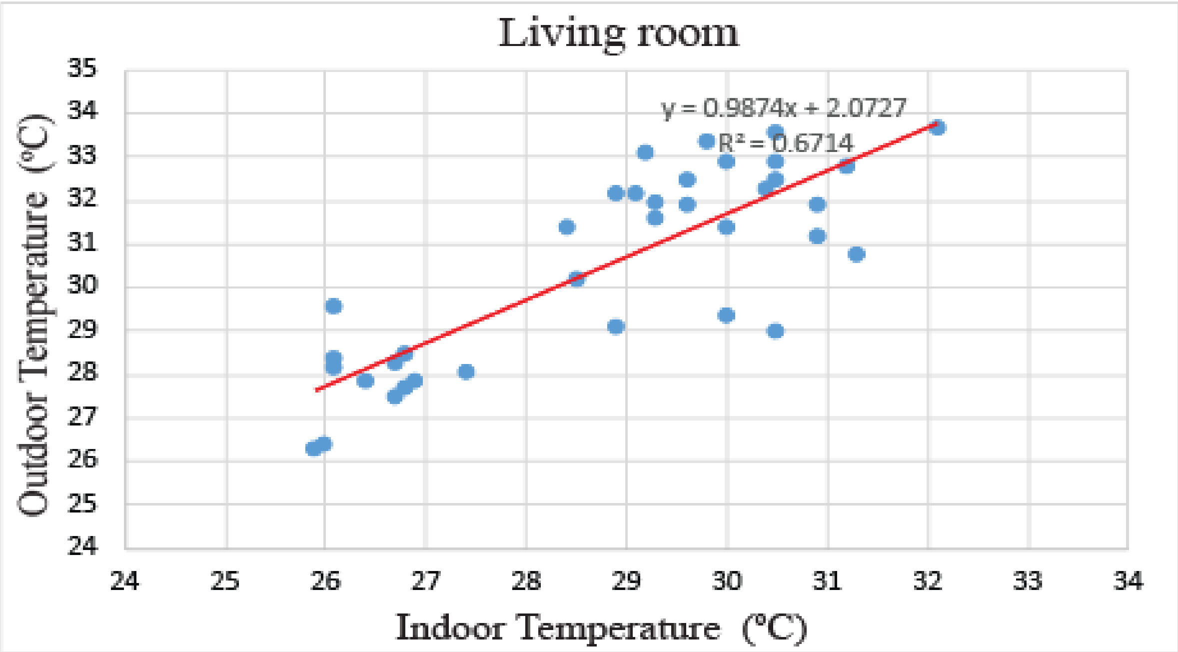


Figure 4.56: Scatter plot of indoor and outdoor temperature

4.10 Correlation between thermal preference and satisfaction

The figure 4.57 shows the relation between the indoor temperature range of perception level. The correlation between thermal preference and thermal satisfaction, concerning the PMV Value of occupant's vote. It shows that as daylight illumination and indoor temperature rise, so does thermal preference (from hot to cold) and thermal satisfaction (from very uncomfortable to very comfortable).

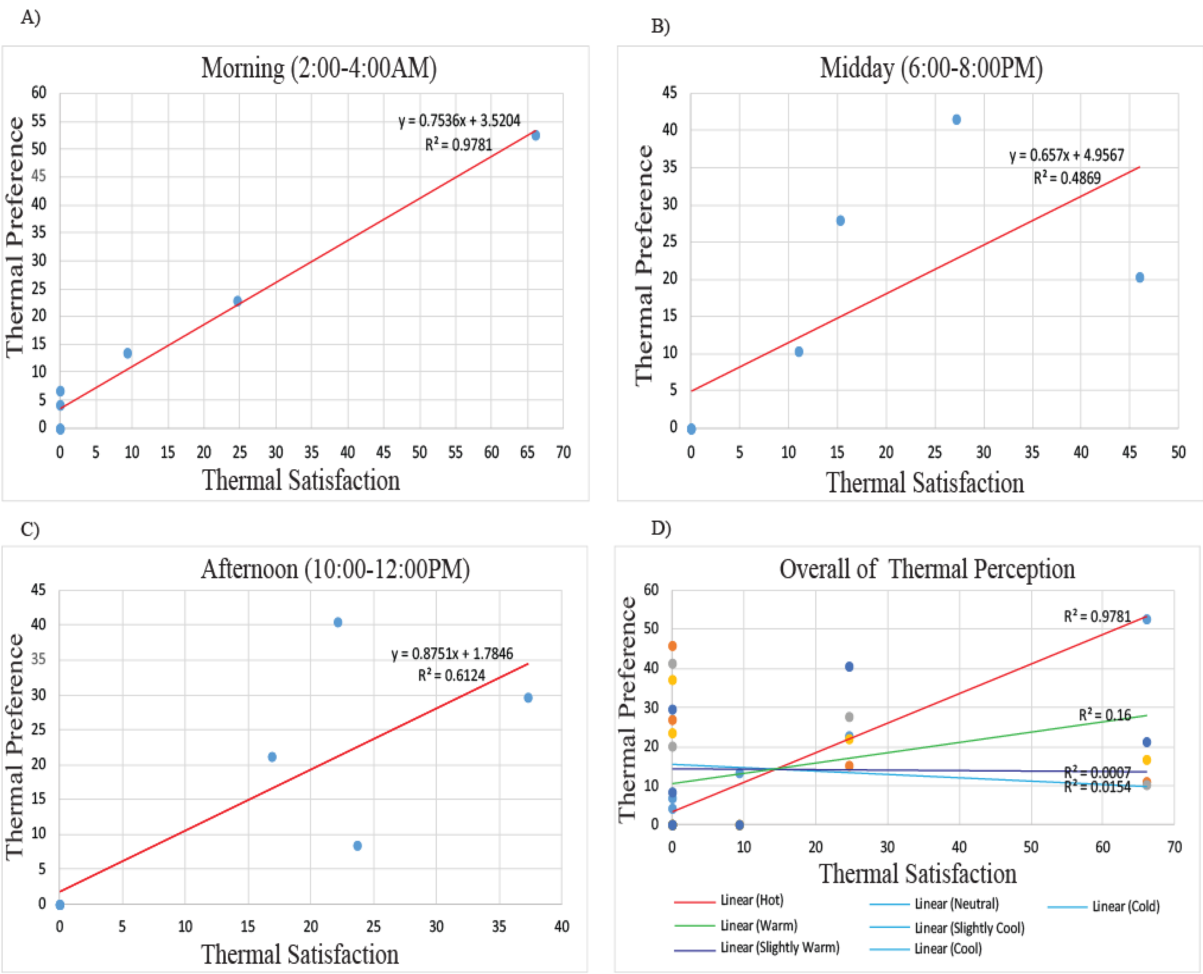


Figure 4.57: Scatter plot of thermal preference and satisfaction

4.11 Thermal discomfort hour

Figure 4.58 shows that the most thermally uncomfortable time in all buildings is in the afternoon from 6:00 pm to 10:00 pm, with a little drop at 11:00 pm. Based on the results obtained from the subjective analysis, the thermal perception of occupants in the morning is in the comfort range relatively.

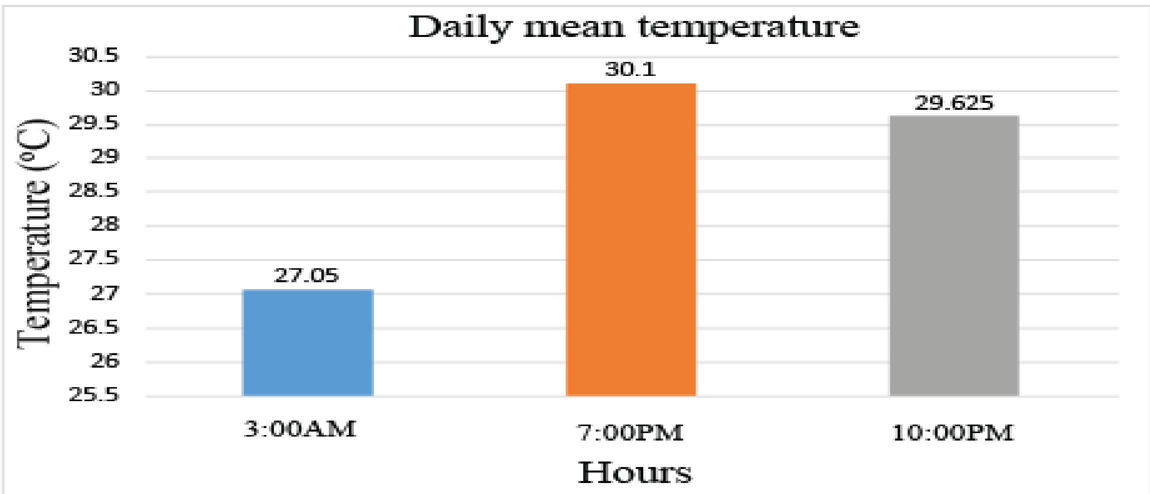


Figure 4.58: Daily mean temperature (source, field survey)

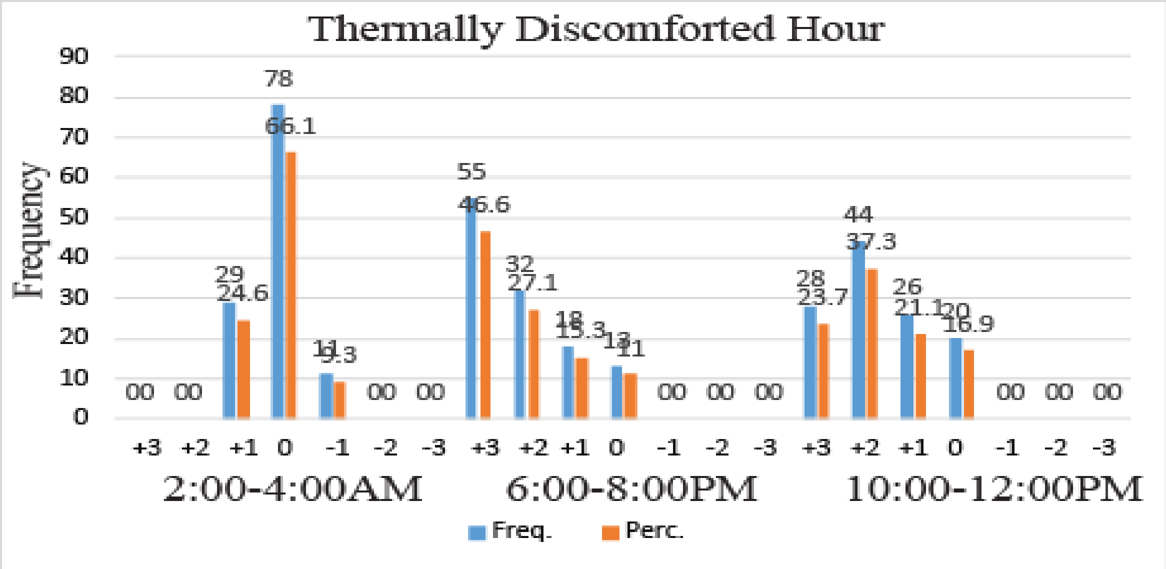


Figure 4.59: Thermally discomforted hour (source, field survey)

As seen in figure 4.59, the low-temperature range observed between 3:00 am and 6:00 pm corresponds to this, occupants' discomfort levels began to rise the midday. From 6:00 pm-8:00 pm in the daytime, the thermal sensation of the occupants in the south-facing rooms was within the ASHARE 55 comfort level. The degree of heat discomfort grew with time, as did the temperature indoors and outdoors at midday. Building north-oriented rooms perform better and south-oriented rooms perform the poorest based on occupant thermal experience. Both room orientations complain about the heat environment in the afternoon from 6:00 pm to 8:00 pm.

4.12 Average clothing insulation

Figure 4.60 show that average clothing insulation changes with interior temperature, as illustrated in the graph below. As can be seen, insulation irradiation diminishes as the temperature rises.

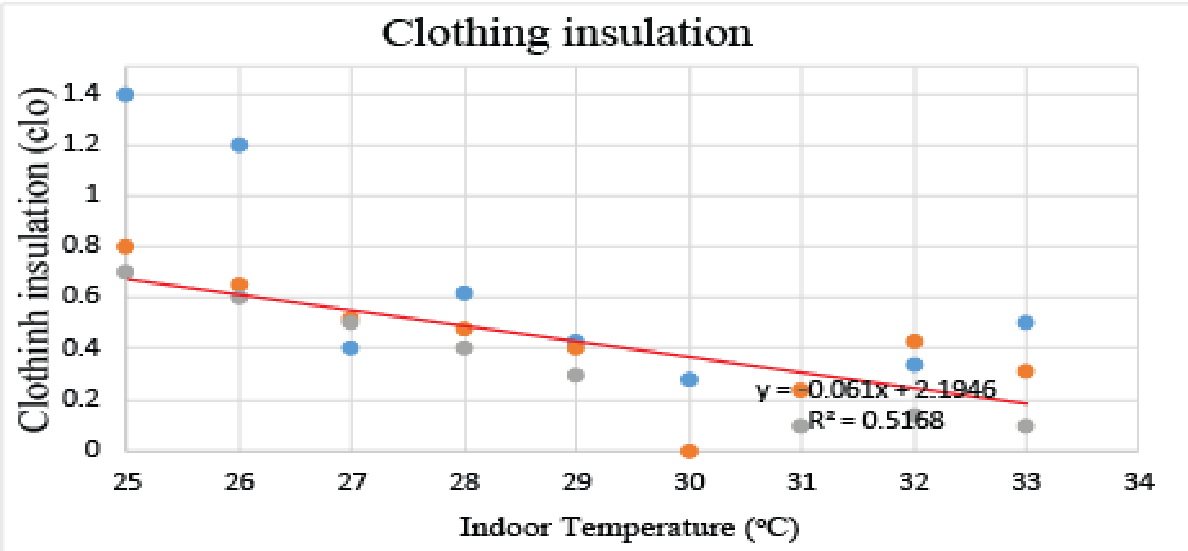


Figure 4.60: Clothing insulation (source, own analysis)

The figure 4.60 can be explained by the fact that responders choose light clothing during the hottest seasons, when the temperature rises. Clothing insulation was found to be 0.9 clo on average. for example, in these different condominiums, the average clothing insulation for women respondents was 1clo, and the age ranged from 25 to 40 years. Furthermore, the average male respondent's clothing insulation was 0.85clo. These findings are consistent with those of (Moujalled,2008), who discovered a strong relationship between thermal insulation and climatic seasons. I_{clo}=0.061T+2.1946met; R^2 = 0.5168.

4.13 PMV analysis

Figure 4.61 shows that the level of thermal comfort and room temperature is the predicted mean vote in which respondents respond to the environment they feel and they prefer. This is dependent on the ASHRAE 55 standard for the number of temperature levels. When it comes to addressing thermal comfort, two main concepts may be used. Fanger offered the first, which was based on a climate chamber experiment. The 7-point thermal feeling scale of the PMV model goes from (+3) Hot to (-3) Cold. Physiological adaptation, behavioral adaptation, and psychological adaptation are the three types of adaptation. The ASHRAE standard is used to calculate the sensation of temperature levels.

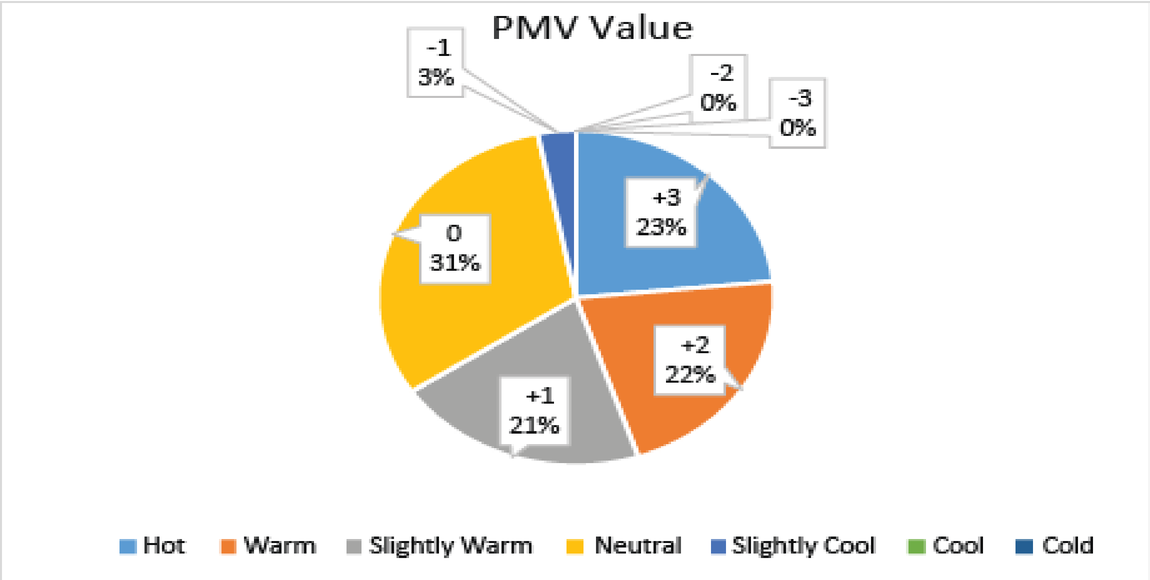


Figure 4.61: Thermal perception of respondents (source, field survey)

The results revealed that 64.8% of respondents were uncomfortable with the indoor thermal comfort of the east-west axis (south orientated). According to survey result discussed in section 4.5 on 3:00am, 0=0.0% very uncomfortable, 8=6.8% uncomfortable, 27=22.9% slightly uncomfortable, 62=52.6% neutral, 16=13.5% slightly comfortable, 5=4.2% comfortable, 0=0.0% very comfortable. It is a somewhat neutral feeling for respondents. on 7:00pm, 24=20.3% very uncomfortable, 49=41.5% uncomfortable, 33=27.9% slightly uncomfortable, 12=10.3% neutral, 0=0.0% slightly comfortable, 0=0.0% comfortable, 0=0.0% very comfortable. It is a somewhat uncomfortable feeling for respondents and on 10:00pm, 10=8.5% very uncomfortable, 35=29.7% uncomfortable, 48=40.6% slightly uncomfortable, 25=21.2% neutral, 0=0.0% slightly comfortable, 0=0.0% comfortable, 0=0.0% very comfortable. It is also a somewhat uncomfortable feeling for respondents. 7:00pm, PMV values are outside of ASHREA's comfort zone (very comfort to very uncomfortable).

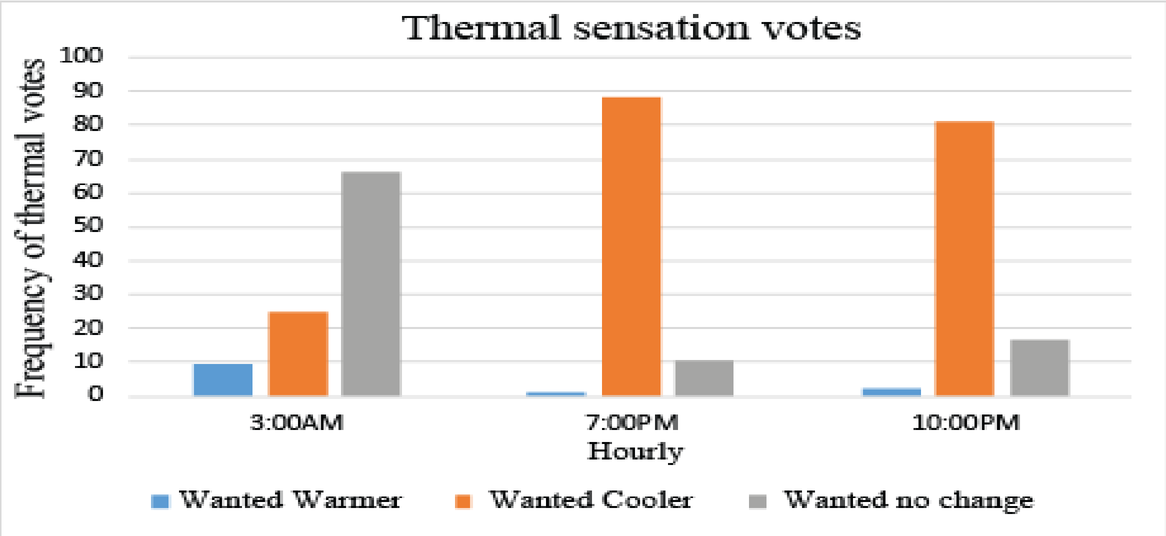


Figure 4.62: Thermal sensation votes of residents (source, field survey)

According to the figure 4.62, at 3:00 a.m., 10% of residents "desire warmer," 24.6 percent "want cooler," and 66.1 percent prefer "no change," according to the graph above. Nearly 0 percent of residents prefer "warmer," 88.3 percent prefer "cooler," and 10.5 percent prefer "no change" around 7:00 p.m. At 10:00 p.m., 2% of inhabitants want it warmer, 81.6 percent want it cooler, and 16.7% want no change.

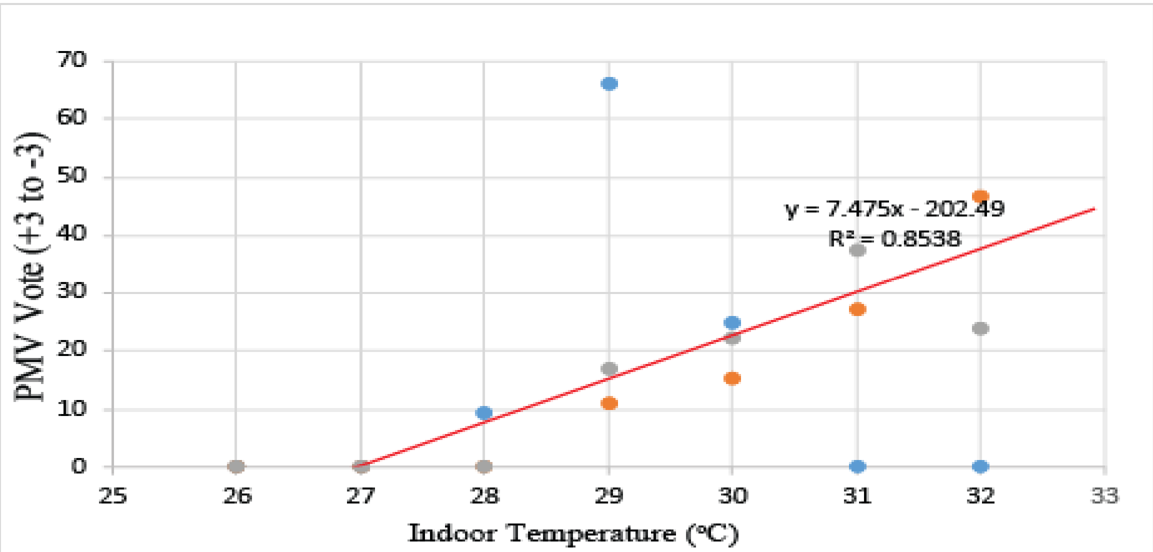


Figure 4.63: PMV versus indoor temperatures

According to figure 4.63, the obtained PMV correlation values were positive, indicating that the studied environment was related with a hot environment; this was supported by the various PMV values, which were almost positive increasing. The following association between the PMV and the indoor temperature is derived from the figure above. PMV=7.45T-202.49; R^2 =0.8538

4.14 Thermal comfort for naturally ventilated spaces

4.14.1 ASHREA 55: Adaptive Chart

Figure 4.64 depict that the standard states that more than 80% should be within comfort range, but only 5.0% did. The Indoor thermal comfort as perceived by the respondents is uncomfortable with 64.8 % confirming it to be conducive. figure 5:86 shows that only a very few of the respondents found the interior thermal comfort comforting.

80% acceptability limits = Operative temperature: 23.6 to 26.6 °C Comfortable

90% acceptability limits = Operative temperature: 24.6 to 27.6 °C Comfortable

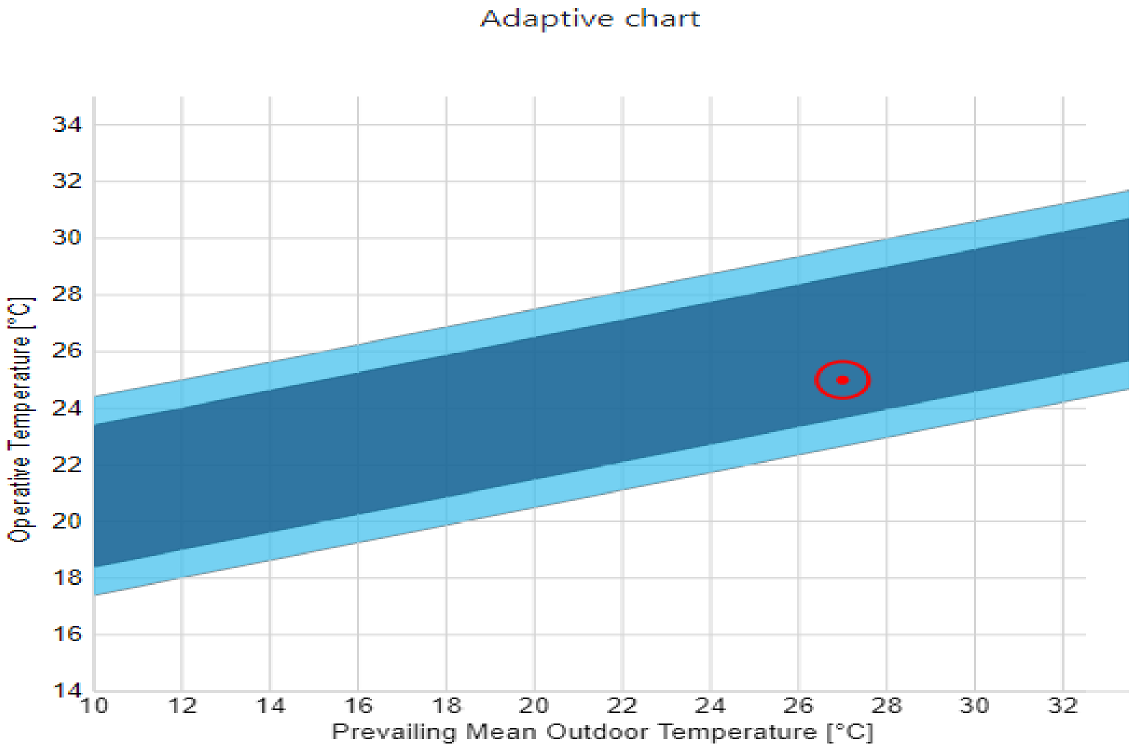


Figure 4.64: Acceptable operating temperature ranges (source, CBE thermal comfort)

Only occupant-controlled naturally conditioned areas that satisfy all of the following criteria are eligible for this approach. a) A mechanical cooling system is not fitted. There is no heating system in use. b) Metabolic rates of 1.0 to 1.3 met; c) occupants are allowed to adjust their attire to the interior or outdoor thermal situation within a range of 0.5 to 1.0 clo.

4.15 Comparative analysis

4.15.1 indoor temperature of East-West with North-South Axis

Both orientations show significant differences in midday average internal temperatures, and the building has a high temperature in comparison to others. The interior temperature variance of the entire structure was not permitted, and the humidity range in all buildings was not allowed, according to ASHARE 55. Except in north-facing rooms, the average interior temperature, daylight and WWR were exceeded the ISO 7730 and ASHARE 55 limits. According to measurements, buildings facing south had higher internal temperatures than those facing north. The East-West Axis had the highest internal temperature (25 to 31^{o}C), whereas the North-South axis had the lowest. In both directions, the environment with closed windows outperformed the structure with open windows, and the exterior temperature was higher than the volume's interior temperature. The inside temperature of the south-facing structure is 4°C lower than that of the north-facing structure. Because the rectangular structures' long facades were oriented between 25.0^{o}C and 33.5^{o}C, this discrepancy was found.

Short facades oriented between 22.8^{o}C and 29.8^{o}C of the E-W line have the benefit of having one of their facades shaded since one of their facades will face south, where it will never get direct sun radiation. Because the volumes with one façade facing south were favored over those with one facade facing north in that configuration, the temperatures within the volumes facing south were roughly 4^{o}C higher than those within the volumes facing north.

4.15.2 Daylight illumination of East-West with North-South Axis

According to figure 4.65, at 6:00 pm the air temperature for the north-south orientation of the building is between 25 and 31 degrees Celsius (figure 4:70). The air temperature is between 23 and 29 degrees Celsius when the building is orientated east-west. While daylight illumination for north-south building orientation is 200-700lux, daylight illumination for south-north building orientation is 030-300lux. The total thermal performance of a building is greatly influenced by the weather (i.e. temperature, humidity, airspeed, and daylight). Variations in daylight illumination throughout the day have a direct impact on the thermal behavior of the building. Excessive sun radiation caused high external surface temperatures on the southern wall due to the south orientation, but not on the north-facing wall. The northern wall received only scattered solar light. In comparison to the east-west orientation (south oriented), incident daylight illumination on the building's north wall's outer surfaces was reduced in the south-north orientation (north orientated) (south oriented). However, the most important change was the considerable increase in solar radiation on the south side due to the higher sun height in the sky, resulting in greater summer temperatures when the biggest window (WWR) side faces the south. Throughout the day, the substantial solar radiation that falls on the southern wall serves as a major source of heat for the building. Because south-north windows do not gain more heat in the summer, altering the orientation of the building to the east-west will warm it up. During IHDP design, the effect of orientation on the overall thermal performance of buildings was neglected and the residents used as a complex measure and high-cost option to improve the thermal performance of the building, and the indoor thermal comfort of south-oriented required the mechanical cooling to sustain the occupant's thermal comfort.

i) The daylight illumination in the north is around 300lux lower than in the south.
ii) The temperature is around 3oC cooler in the north than in the south.
iii) The airspeed in the north is about 0.5 meters per second better than in the south.

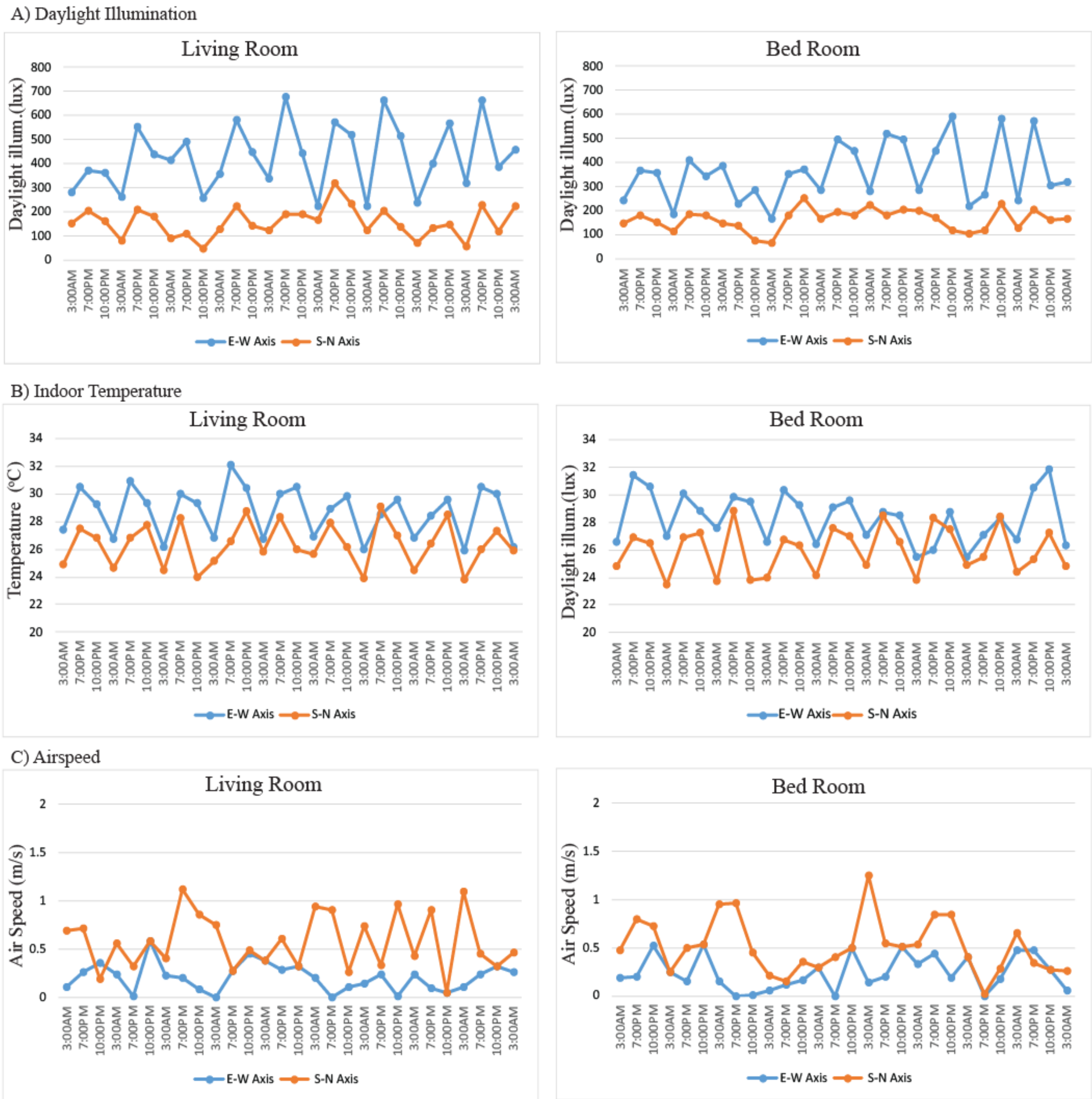


Figure 4.65: Comparisons between East-West With South-North (source, field survey)

4.15.3 Discomfort degree hours

In this study, two building orientations were investigated using the Ecotect on a model. The model was utilized between the hours of 00:00 and 24:00, and the effects of being too hot or too cold were monitored throughout the year. The indoor temperature for the south-north axis was found to be 23°-29.8°C, while the east-west axis was found to be 25°-32.2°C. The simulation was carried out in the model for various building orientations. The model was initially ported to the Ecotect software and connected with the sun inside this framework. Between 90° and 180° azimuth angle, a 10° angle increment.

4.15.4 Simulation results

According to table 4.18, simulations were run to determine the hot hours, cool hours, and total discomfort degree between 90° to 180°, and 0° to 90° azimuths in this study. According to the simulation results model, total discomfort degree hours was initially raised at 90° and subsequently dropped between the orientation intervals of 0° azimuths - 90° azimuth. In relation to the other orientations, surfaces facing North received the least discomfort degree hours ranging from 2608.5 to 2609.1hrs too hot and 954.3 to 951.3hrs too cool. The building was rotated by incrementing 10° azimuth angle in 19 various angles (without shading element) in the clockwise direction beginning from the north (azimuth 0°) – south (azimuth 180°) to find the optimal orientation angle. The azimuth building orientation is shown by the minimum discomfort degree hours of the total annual too hot and too cool hours. By increasing a 10° azimuth angle for the identified best orientation region of the smallest total yearly discomfort degree hours, the optimal orientation angle (the minimum annual total too hot and too cool hours) was discovered. The minimal discomfort degree hours were discovered at azimuth 0° to 10^0 north, as a consequence of the model's simulation. By incrementing a 10° azimuth angle for the identified orientation were considered, namely 0^0E, 10^0E, 20^0E, 30^0E, 40^0E, 50^0E, 60^0E, 70^0E, 80^0E and 90^0E as shown in figure 4.74.

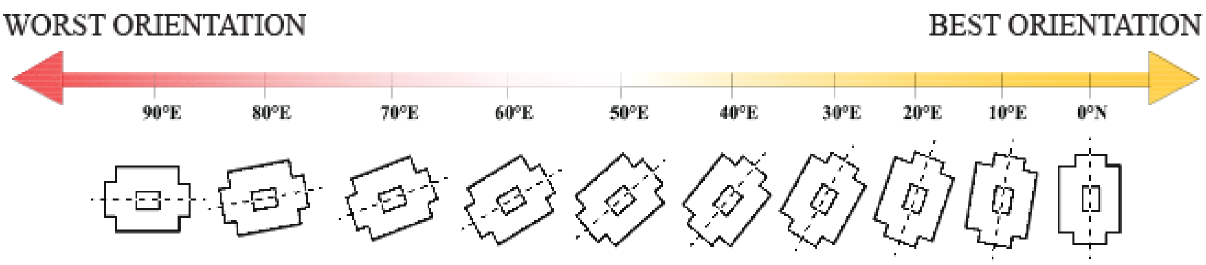
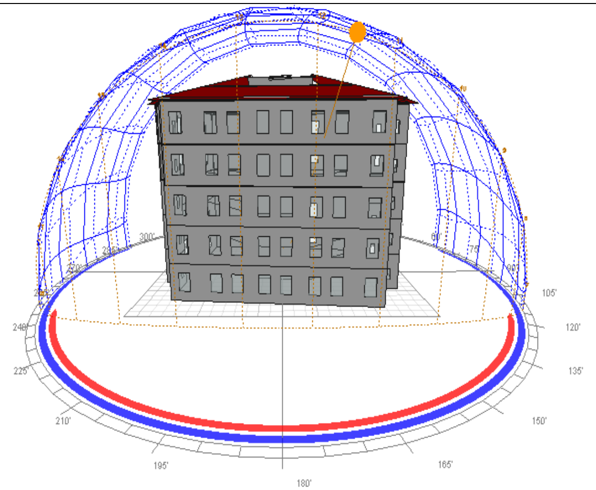
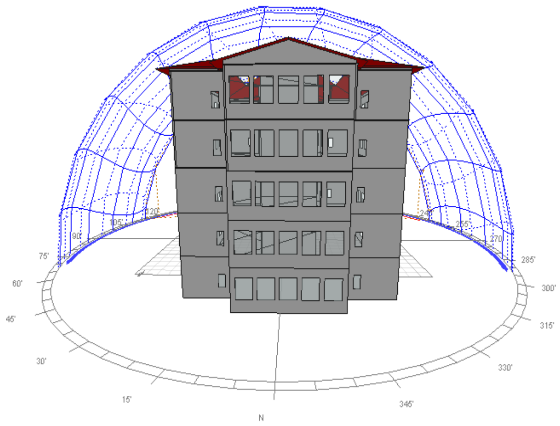


Figure 4.66: Incrementing 10° azimuth angle to find optimum orientation in the study

Table 4.18: Annual too hot and too cool of discomfort degree hours

Lay-out direction by the sun	Azimuth Angle	Too Hot (hrs.)	Too Cool (hrs.)	Total (hrs.)
 **East-West axis**	Azimuth 90°	54748.7	4259.1	59007.8
	Azimuth 100°	54741.0	4261.2	59002.2
	Azimuth 110°	54723.8	4268.6	58992.4
	Azimuth 120°	54693.4	4290.2	58983.6
	Azimuth 130°	54665.8	4310.9	58976.6
	Azimuth 140°	54661.1	4313.0	58971.1
	Azimuth 150°	54682.9	4297.3	58980.2
	Azimuth 160°	54710.2	4276.6	58986.9
	Azimuth 170°	54730.8	4270.3	59001.1
	Azimuth 180°	54737.1	4257.0	58994.2
 **South-North axis**	Azimuth 0°	2608.5	954.3	3562.8
	Azimuth 10°	2609.1	951.3	3560.4
	Azimuth 20°	2611.9	940.9	3552.7
	Azimuth 30°	2613.3	935.1	3548.4
	Azimuth 40°	2615.0	931.0	3546.0
	Azimuth 50°	2620.2	926.6	3546.8
	Azimuth 60°	2624.8	919.8	3544.6
	Azimuth 70°	2630.4	916.3	3546.7
	Azimuth 80°	2633.2	912.1	3545.3

4.16 Determination of optimum orientation of Adama

The connection of a building to the sun's path is determined by its orientation. This, in turn, defines the building's solar gain characteristics. Adama's optimum orientation, the sun's apparent course should be carefully investigated in order to identify the most efficient orientation of a given building in a certain area. According to figure 4.67, the best optimum orientation in Adama city has been found at the compromise to be 32.5^0 N, or have to be in the range between 328^0 N-40^0 E. Depending on this optimum orientation chart, there are solar radiation problems in the south angle from 45^0 E to 315^0 N, and therefore it needs solar radiation control. The worst orientation is found 122.5^0 SE.

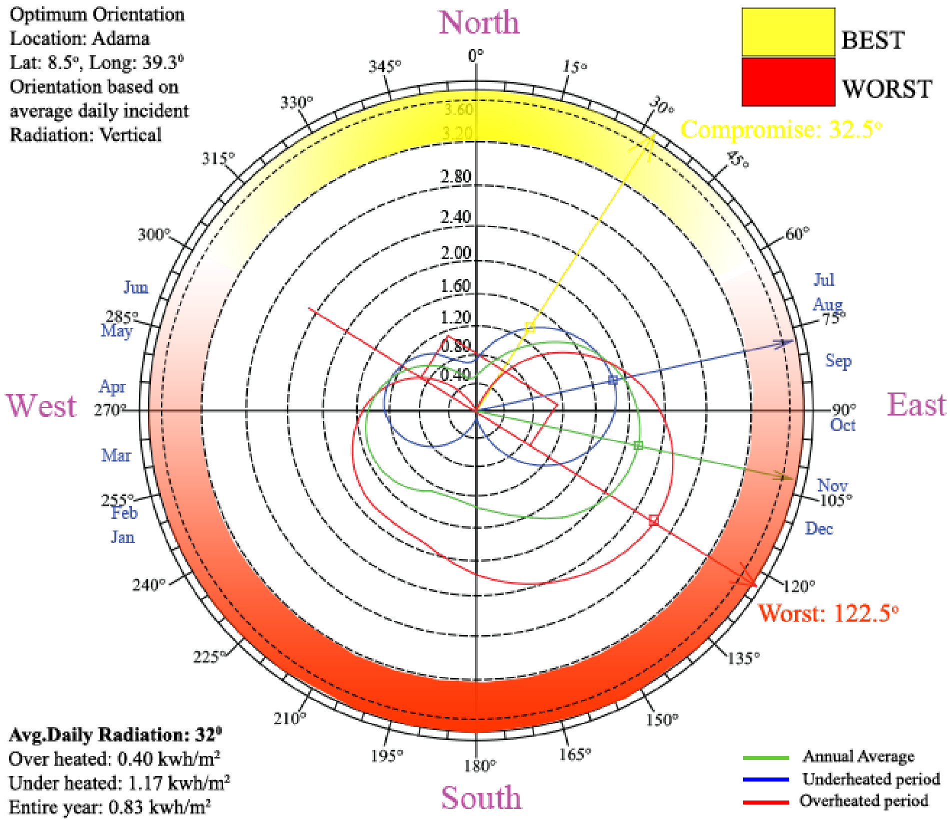


Figure 4.67: Optimum orientation of Adama

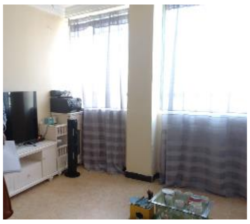
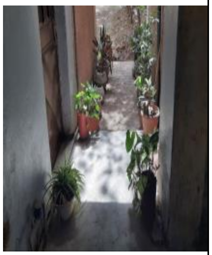
4.17 Summary of discussion

According to table 4.19, there are four (4) different building orientation possibilities employed in Adama condominium houses: East-west, South-North, Northeast-Southwest, and Northwest-Southeast axis. From those orientations, East-West and South-North axis were selected to check the thermal comfort indoors and to compare the environmental variables of both orientations. Different building orientation options had different takes on comfort within the building during the day; the south orientated had the highest percent of discomfort. The study found that building orientation affects thermal comfort, natural daylighting, and natural ventilation. There is also the variation in temperature, and daylight illumination between both orientated rooms. This difference influences the residents and makes their satisfaction also highly different. At 7:00 pm, the air temperature for the north-south orientation of the building is between 25 and 32 degrees Celsius. When the building is oriented east-west, the air temperature is between 23 and 29 degrees Celsius. While daylight illumination for north-south building orientation is 175-680lux, daylight illumination for south-north building orientation is 020-385lux. In Adama, daylight illumination on the south side increases significantly in the winter due to the higher sun altitude in the sky, resulting in warmer temperatures due to the improper opening and facing the south, where incident daylight illumination on the north and eastern walls is reduced compared to the south side rooms.

The proportion of walls to windows and the distribution of daylight can be affected by larger opening areas. South-facing windows get harsh sun glare, because there are several windows on the south side. Approximately 30% of the unnecessary heat that accumulates in a room enters through windows. The optimal orientation for WWR is south-north axis, whereas the worst direction is East-West axis.

Table 4.19: Compare and contrast different building orientations

parameters	East – west Axis (south facing)	South – north Axis (north facing)	NE - SW Axis (long face oriented East)	NW - SE Axis (long face oriented west)
Temperature level	Hot (temperature rise in indoor environment)	Neutral (temperature fall in indoor environment)	Neutral (temperature fall in indoor environment)	warm (temperature rise in indoor environment)
Satisfaction level	uncomfortable	comfortable	Neutral	uncomfortable
Humidity level	Dry	Medium	Medium	Dry
Level of solar radiation	High (4:00AM-11:00PM) Main challenge of indoor comfort is Direct solar radiation. too much heat and solar radiation entering rooms	Low (With simple strategies(orientation) good comfort can be Achieved when comparing with south orientation. Less solar radiation or heat all day	Low (4:00AM-11:00PM)	High (4:00AM-11:00PM)
Level of natural ventilation	Low (the wind direction of Adama is from east to west window facing is	Medium (Adama's wind direction is east to west, hence the window facing is not in the opposite	Medium (The wind direction in Adama is east to west, hence the window	Medium (the wind direction of Adama is from east to west window

	opposite to wind direction)	direction of the wind.)	facing does not match the wind direction.)	facing is not opposite to wind direction))
Level of air speed	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)
Time when room is too hot (uncomfortable)	Mid-day	-	morning and Mid-day	Afternoon
Season when room is too hot (uncomfortable)	Winter (March, April and May)	Winter (March, April and May)	Winter (March, April and May)	Winter (March, April and May)
Source of heat	Direct sun	indirect sun heat	Direct sun	Direct sun
Amount of solar radiation	Disturbing	Comfortable	Medium	Disturbing
Measures you use to regulate rooms temperature	Curtain Removing cloths Few pots of plants Ventilator Curtain 	-	Curtain Removing cloths Ventilator Few pots of plants 	Curtain Removing cloths Ventilator Few pots of plants 

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, the effect of building orientation on the thermal comfort of condominiums constructed by the government and orientated in different was carried out. The study was conducted using both subjective and objective evaluation methods such as structured questionnaires and environmental variable measurements (temperature, humidity, airspeed, and Daylight illumination) were recorded for the hottest months for 12 days by using different data loggers, including ASHRAE 55 7-points of sensational scale and the questionnaires distributed to 120 samples. When we compare the north orientated with south orientated, the north orientated rooms of the indoor environment is suitable and the residents have a good sensational scale, their preference also good for their dwellings and they have a good satisfaction on the indoor thermal comfort. Since in most sites the openings are exposed to harsh sun direction occupants are suffering from different space quality problems. This orientation of untreated building envelope directly affects the comfort of the indoor temperatures, while buildings with lengthy facades facing S-N had better performance. The south-north orientation recorded the lowest temperature and Daylight illumination with a range of 23^0C to 29^0C indoor temperature and 020lux to 385lux daylight illumination. During daylight afternoons, south-facing rooms are 3-4^{o}C hotter than north-facing rooms due to the effects of the window-to-wall ratio (WWR) and room orientation on hourly interior air temperature and daylight illumination. Because east-west orientation or south faced recorded 25^0C to 33.5^0C temperature and 175lux to 680lux daylight illumination (see Appendix V). A building's orientation and exposure to the south can have a big impact on thermal comfort. Considering the sun path and climate of the location, the optimal orientation would increase the thermal comfort of the building as well as its urban environment. The paper concludes that the East (90^0E) –West (270^0W) orientation is the worst orientation in all cases while the North (0^0N) –South (180^0S) orientation is considered as the optimum orientation.

5.2 Recommendation

From the results obtained from the research study, the following can be recommended;
Before designing any condominium house for any location IDHP should consider the climatic condition, sun path, and environmental existence of the location. They should incorporate the regulations and monitoring systems regarding building orientation to improve thermal comfort. The long axis of building in hot and dry places like Adama should be South-north axis (north orientated) to reduce the area of solar radiation exposure. The exposed walls of the Adama condominium home should be orientated on the South-North axis, i.e. facing South-North, to minimize solar heat intake. As a result, preventing winter light from reaching windows is one of the most efficient strategies to reduce a building's overheating. In the first instance, window alignment should be used, followed by the use of proper shading systems and glazing treatment. Because the size and location of openings impact the dwelling's internal thermal comfort. As a result, big openings on the west and south-facing facades should be situated away from direct sunlight due to the building's location in a hot-arid climatic area with high temperatures. Proper arrangement of the windows for cross-ventilation. Keeping the building's longer sides away from direct sun radiation. Wherever feasible, the primary living areas, such as the living, family, and dining rooms, should face north. Because west-facing rooms get low-angle late-afternoon light, they normally require some shade to avoid scorching and glare, especially in the summer. Buildings that are properly positioned improve indoor thermal comfort significantly. Building orientation should be examined with respect to the sun to decrease facades facing east and west and to accept local prevailing winds. Because of the interaction between building orientation and natural ventilation. The orientation of a building can reduce sun gain while promoting natural ventilation. This is done by using elongated, south-to-north forms with primary apertures pointing north.

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APPENDIX- I

Thermal comfort check list for tester (Health and Safety Executive, 2018)

City:_____ Site name:___________ Kebele: _____ No of block present in the site____

Block no: _______ Floor: _______ Surveyor name: Olyad G. Sign: _________

Types of community: Residences ☐ Downtown ☐ Others ☐

Dates:________ Time: _________ Weather: sunny ☐ cloudy ☐ rain ☐ snow ☐

Room Height:______m Typologies_______________ Type of Bedroom_____

1. Building structure:	Masonry-concrete structure ☐ Structure ☐ Reinforced Concrete ☐ others ☐
2. Building location:	Along the street ☐ Away from street ☐ Suburb ☐
3. Total floor:	Room floor_____ Total floor_____ Basement_____
4. Building orientation	South ☐ North ☐ East ☐ West ☐
5. Number Window for measuring room :	Two ☐ Three ☐ Four ☐ Five ☐ six ☐ more than 7 ☐ (height:__m, width:__m) Total area:__m^2
1. Window orientation for measuring room:	South ☐ North ☐ West ☐ East ☐
7. Type of rooms:	Living rooms ☐ Bedrooms ☐ kitchen ☐
8. Room areas:	Room areas:____m^2 opening areas:_____m^2
Housing type:	Detached ☐ Row ☐ Semi-detached ☐ Other types ☐
9. Types of windows:	Single frame with single glass ☐ single frame with double glass ☐ Double frames with double glass ☐
10. Activities for respondents:	Working ☐ sitting ☐ standing ☐ walking ☐
11. The window condition at present:	Open ☐ close ☐
12. The regulation method for indoor thermal environments at present:	Air-conditioning fan ☐ central cooling ☐ naturally ventilation, without regulation measures ☐ Others_____________________________
13. Is the air-conditioning opened? if so, the set-point is :	Yes ☐ No ☐ Under 20°C ☐ 20°C ☐ 21°C ☐ 22°C ☐ 23°C ☐ 24°C ☐ 25°C ☐ 26°C ☐ 27°C ☐ ≥28°C ☐ unclear ☐
14. Room quality:	High quality ☐ Medium ☐ Low quality ☐
15. Room visual comfort:	Attractive ☐ medium ☐ Not bad ☐ Not attractive ☐
16. Remarks:	________________________________ ________________________________

APPENDIX- II

Questionnaire Paper for the Residents (Occupants) (Paliaga, 2013)

Dear respondents the purpose of these questioner is to support Research on **Effect of building orientation on indoor thermal comfort of residential building: in case of condominium house in Adama city**. All responses will be treated in strict confidentiality and will be used for academic research only.

Thank you for your priceless time

Questioner N^{o}: ___ **Site name:** ____________________________ **Block no:** _______

Story number: _______ **Time:** ______________ **Date:** __________

A. Personal information

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

Sex Male ☐ Female ☐

Age Below 15 ☐ 15-30 ☐ 31-45 ☐ 46-60 ☐ 61 & above ☐

Body Weight below 30kg ☐ 31-60kg ☐ 61-90kg ☐ 91 and above ☐

Clothing type: **Upper:** shirt ☐ T-shirt ☐ sweater ☐ ☐t ☐

Lower : trousers ☐ shorts ☐ dresses ☐ ☐irts ☐

Shoes : sneaker ☐ leather shoe ☐ sandals ☐ ☐lipper ☐

others : ______________________________

Activity: Reclining ☐ walking ☐ sitting ☐

Standing ☐ relaxing ☐ Working ☐

Other___________________________________

How many years you are living in this house?

Less than 1 year ☐ 1-3 years ☐ 3-5 years ☐ 5-8 years ☐ More than 8 years ☐

B. Building information

Level of Solar radiation

High ☐ Medi☐ Low ☐

Level of natural ventilation

High ☐ Medi☐ Low ☐

C. Thermal Comfort Level

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

Daylight illumination (lux)_________

ASHRAE 55 thermal Preference scale (Humphreys, 2007)

Level of Scale		3	2	1	0	-1	-2	-3
Comfort feeling		Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
Color								
Time	3:00am							
	7:00am							
	10:00pm							

ASHRAE 55 Sensational scale (Series & Science, 2018)

Level of Scale		3	2	1	0	-1	-2	-3
Bedford scale		Very Un Comfort able	Un Comfort able	Slightly Un comfort able	Neutral	Slightly Comfort able	Comfort table	Very Comfort able
Color								
Time	3:00am							
	7:00pm							
	10:00pm							

Related Questions

1. What level of temperature do you prefer in your room?

Hot ☐ warm ☐ Neutral ☐ Cool ☐ Cold ☐

2. At what time the room is too hot?

Morning ☐ mid-day ☐ afternoon ☐ day decline ☐ all day ☐

3. What are source of heat in your room and environment?

Direct sun ☐ indirect sun heat ☐ Steam ☐

Equipment (__________________) ☐ If any other____________________

4. Feeling at present:

Humidity: Very humid ☐ Humidity ☐ neutral ☐ Dry ☐ too dry ☐

Air movement: too stuffy ☐ stuffy ☐ neutral ☐ breezy ☐ very breezy ☐

5. What time of the year you are thermally uncomfortable or feeling hot?

All year ☐ Summer ☐ Winter ☐

6. Depend up on Q. 5, if you are thermally uncomfortable during winter, how often does this occur? Every day during winter ☐ Most of winter period ☐ A few days in winter ☐

List down those months? ____

7. Which light is do you prefer?

Artificial ☐ Natural ☐ No Feeling ☐

8. Please indicate amount of glare (solar penetration) in your room: solar radiation amount__

Intolerable (unbearable) ☐ Disturbing ☐ Medium ☐

Comfortable ☐ No feeling ☐

9. What are the **measures** you use to **regulate** your rooms and protect solar intensity?

Curtain ☐ Removing upper cloths ☐ Mech.Ventilator ☐

Few pots of plants ☐ Window stickers ☐ Other_____________

10. Please add any comment or concerns about your room indoor thermal comfort?

APPENDIX- III

Amharic Questionnaire Paper for Residents *(Occupants)*

ይህ የክነሕንጻ ማስተርስ ድግሪ ጥናት የተፈለገዉ ለአንድ ቦታ የተሰሩ የመንግስት ኮንዶሚኒየም (Condominium) ቤቶዎችን በሌላ ቦታ ያለ በቂ ጥናት በተደጋጋሚ ስለ ተገነቡ በሙቀት መጠንና በኑዋርዎች ምቾት ላይ የሚኖረዉን ተጽእኖ መጠን ለመገምገም (የመኖሪያ ሕንፃ የቤት ውስጥ ሙቀት ጥራት ግምገማ ላይ የተደረገ ጥናት፡ በአዳማ ከተማ የኮንዶሚኒየም ቤት ጉዳይ።) በሚል ርዕስ ለማካሔደው ጥናት የነዋሪዎችና በቀን ተቀን ውሏቸው ላይ በርዕሱ ዙሪያ ያላቸውን ሃሳብ ወይም ስሜት በመጠየቅ፣ ለጥናቱ እንደ ግባት ለመውሰድ የተዘጋጀ ፎርም ነው። ስለሆነም እባክዎትን የተጠየቁ ጥያቄዎችን በአንክሮ በማንበብ፣ ለምርጫ ጥያቄወች መልስ የምትሏቸው ((√ ወይም X) በመምረጥና ዝርዝር ሃሳባችሁን ለሚፈልጉ ጥያቄዎች ደግሞ በተቀመጠው ክፍት ቦታ ገንቢ የሆነ ሃሳባችሁን እንድትሞሉልን በትህትና እንጠይቃለን።

<u>ስለ ትብብሮዎ እጅግ እናመሰግናለን !!</u>

<u>የጠያቂ ቁጥር፡ ________</u> <u>የጣቢያ ስም፡ ________________</u> <u>አግድ ቁጥር፡ ________</u> <u>የታሪክ ቁጥር፡ ________</u>

<u>ሰዓት፡ ____________</u> <u>ቀን፡ ________</u>

<u>ሀ. የግል መረጃ</u>

ጾታ ወንድ ☐ ሴ☐

እድሜ ከ 15 በታ☐ ☐5-30 ☐31-45 ☐ 46-60 ☐1 ና ከዛ በላይ

☐ ☐ ☐ ☐

የሰዉነት ክብደት (በኪሎ ግራም) ከ 30 በታች 31-60 61-90 91 ና ከዛ በላይ

የአልባሳት አይነት፡ የላይኛው፡ ሸሚዝ ☐ ቲሸርት ☐ ሹራብ ☐ ኮት ☐

የታችኛው፡ ሱሪ ☐ ቁምጣ ☐ ቀሚስ ☐

ጫማ፡ ስኒከር ☐ የቆዳ ጫማ ☐ ሌላ ☐

ተግባር፡- መራመድ ☐ ተቀምጦ ☐ ቆሞ ☐ ዘና የሚያደርግ ☐ በመስራት ላይ ☐ ሌላ __

በዚህ ቤት ውስጥ ስንት አመት ነው የኖሩት?

ከ 1 ዓመት በታች☐ 1-3 ዓመት ☐ 3-5 ዓመት ☐ 5-8 ዓመት ☐ ከ 8 ዓመት በላይ ☐

ለ.የግንባታ መረጃ: የፀሐይ ጨረር ደረጃ: ☐ ከፍተኛ(የሙቀት መጠን) ☐ መካከለኛ ☐ ዝቅተኛ ☐

የተፈጥሮ አየር ማናፈሻ ደረጃ: ከፍተኛ ☐ መካከለኛ ☐ ዝቅተኛ ☐

ሐ. የሙቀት ምቾት ደረጃ

የሚከተለውን ሰንጠረዥ ሙላ/ይ, ትክክለኛው የክፍል ሙቀት _________ አር. እርጥበት ______

የፀሐይ ጨረር ___________

ASHRAE 55 የሙቀት ደረጃ

ደረጃ		3	2	1	0	-1	-2	-3
የሙቀት መጠን		ሙቅ	ሞቅ ያለ	ትንሽ ሞቃት	መካከለኛ	ትንሽ ቀዝቃዛ	ቀዝቃዛ	ይበርዳል
ቀለም								
ሰዓት	3:00 ጥዋት							
	7:00 ቀትር							
	10:00 ከሰአት							

ASHRAE 55 የምቾት ደረጃ

ደረጃ		3	2	1	0	-1	-2	-3
የምቾት መጠን		በጣም የማይመች	የማይመች	ትንሽ የማይመች	መካከለኛ	ትንሽ ምቹ	ምቹ	በጣም ምቹ
ቀለም								
ሰዓት	3:00 ጥዋት							
	7:00 ቀትር							
	10:00 ከሰአት							

ተዛማጅ ጥያቄዎች:

1. በክፍውስጥ ምን ዓይነት የሙቀት መጠን ይመርጣሉ?

ሙቅ ☐ በጣም ይምሞቅ ☐ መካከለኛ ☐ ቀዝቃዛ ☐ ይበርዳል ☐

2.በምን ሰአት ክፍሉ በጣም ሞቃታማ ወይም የማይመች?

ጥዋት ☐ ቀትር ☐ ከሰአት ☐ አመሻሽ ☐ ቀን ሙሉ ☐

3.በክፍልዎ እና በአካባቢዎ ውስጥ የሙቀት ምንጭ ምንድን ናቸው?

የፀሐይ ሙቀት ☐ ቀጥተኛ ያልሆነ ☐ የእንፋሎት ☐

እቃዎች (________________) ☐ ሌላ ካለ____

4. በአሁኑ ጊዜ የሚሰማ ስሜት፡

እርጥበት፡ በጣም እርጥበት ያለው ☐ እርጥበት ☐ መካከለኛ ☐ ደረቅ ☐ በጣም ደረቅ ☐

የአየር እንቅስቃሴ: በጣም የተጨናነቀ ☐ የተጨናነቀ ☐ መካከለኛ ☐ ነፋሻማ ☐

በጣም ነፋሻማ ☐

5. በዓመቱ ውስጥ በሙቀት የማይመችዎት ?

ዓመቱን በሙሉ ☐ የበጋ ☐ የክረምት ☐

6. በቁ. 5 ላይ በመመስረት፣ የበጋ ወቅት በሙቀት የማይመች ከሆነ፣ ይህ ምን ያህል ጊዜ ይከሰታል?

በየቀኑ የበጋ ወቅት ☐ አብዛኛው የበጋ ወቅት ☐ የበጋ ጥቂት ቀናት ውስጥ ☐

በጣም ሞቃታማ የሆኑትን ወራት ይዘርዝሩ?____

7. የትኛውን ብርሃን ይመርጣሉ? ሰው ሰራሽ ☐ ተፈጥሯዊ ☐ ምንም ☐

8.እባክዎ በመኖሪያዎ ክፍልዎ ውስጥ ያለውን የብርሃን መጠን (የብርሃን መግባቱን) ያመልክቱ፡-

የፀሐይ ጨረር መጠን_______

ሊቋቋሙት የማይችሉት ☐ ይረበሽል ☐ መካከለኛ ☐ የምመች ☐ ምንም ☐

9. ክፍሎቻችሁን ለመቆጣጠር እና የፀሐይን መጠን ለመጠበቅ የምትጠቀሟቸው እርምጃዎች ምን ምን ናቸው?

መጋረጃ ☐ የላያችን ጨርቆች ማስወገድ ☐ ሜካኒካል አየር ማናፈሻ ☐

ጥቂት የእፅዋት ማሰሮዎች ☐ የመስኮት ተለጣፊዎች ☐ ሌላ?_____________

10.እባክዎ ስለ ክፍልዎ የቤት ውስጥ ሙቀት ጥራት ማንኛውንም አስተያየት ወይም ስጋት ይጨምሩ?____

____

APPENDIX- IV

Afaan Oromo Questionnaire Paper for Residents *(Occupants)*

Qorannoon Digirii Maastersii barnoota Invaromental Arkiteekcharii kun kan barbaachiseef condominiemi magalaa Adama keessatti argaman (bakka tokkotti ijaaraman) qorannaa gahaa malee bakka biroo irraa fudhamani yeroo ijaaraman dhiibbaa haala qilleensaa, Argama fi naannoo itti ijaaramu giddu galeessaa kan godhate miti. akkasumas jiraatoota irratti dhiibbaa isaan qaban baruufii adda baasuudhaafi. Isinis kana hubachuudhaan akka nudeeggartan kabajaan isin gaafanna!

GAALATOOMA

Lakk. Gaafi: ___ Maqaa siyitti condomini'emicha: _____________ lakk.Bilooki ___

Lakk.Gammoo _______ Sa'aatii ______________ Guyyaa __________

A. Odeeffanno dhunfaa

Gaffille armaan gadiif mallatto (√ yookin X) sanduqa kessatti guutuun deebisi.

Akkasuma bakka duwwa isa yaada keettin guutii.

Saala: Dhiiraa ☐ Dhalaa ☐

Umurii: 15 gadi ☐ 15-30 ☐ 31-45 ☐ 45-60 ☐ 60 ol ☐

Ulfaatina Qaama: 30k.g gadi ☐ 31-60 k.g ☐ 61-90k.g ☐ 91 fi isaa ol ☐

Gosa Uffataa: **Gubba** sherti ☐ T-sherti ☐ shuraba ☐ kooti ☐

Jalaa suure ☐ Quumxa ☐ Qaamisii ☐ urdi ☐

Caama snikeeri ☐ caama Qooda ☐ siileeperi ☐ rgando ☐

Kanbiroo_________________________________

Hoji/Socchi: Ta'umsaa adda ☐ deemsarran jira ☐ ta'een jira ☐

Dhabadhen jira ☐ hojii hojeechan jira ☐

Sochi biroo________________________________

Waggaa meeqaf condominiem kana keessa jiraate?

Wagga 1 gadi ☐ Waggaa 1-3 ☐ Waggaa 3-5 ☐ Wagga 5-8 ☐

Waggaa 8 ol ☐

B. Odeeffanno Gammo

Sadarkaa aaduu

Olaana ☐ Giddu galee☐a Gad anaa ☐

Sadarkaa qillensaa

Olaana ☐ Giddu galee☐a Gad anaa ☐

C. Haala Sadarkaa Ho'aa naannoo keeti akka armaan gaditti guuti.

Hamma ho'aa(^{O}C)______Hamma jidhinsaa(%)_________ Hamma ifaa Aduu(Lux)____

Haal Standardii ASHRAE 55 ttin

Sadarkaa		3	2	1	0	-1	-2	-3
Halaa qillensaa		Baay'ee Ho'aa	Ni ho'aa	Xiqqo Ni Ho'aa	Giddu Galeessa	Xiqqo ni qorra	Ni qorra	Baay'ee Qorra
haaluu								
Yeroo	3:00ganama							
	7:00guyya							
	10:00w.boda							

Haala Standardii ASHRAE 55 ttin

Sadarkaa		3	2	1	0	-1	-2	-3
Halaa qillensaa		Baay'ee Mijaata miti	Mijaata Miti	Xiqqo Mijata miti	Giddu Galeessa	Xiqqo mijaata	Mijaata	Baay'ee Mijaata
haaluu								
Yeroo	3:00ganama							
	7:00guyyaa							
	10:00w,booda							

Gaafiilee waal qabataan

1. Sadarka ho"insaa akkami feeta?

Baay'ee ho'a ☐ Ni ho'a ☐ Giddu galeessa ☐

Ni qorra ☐ Baay'ee qorra ☐

2. Sa'aatti akkamiti ho'ii garamalee sitti dhagahama?

Ganama ☐ Guyyaa ☐ Galagalla ☐ Guyya Guutu ☐

3. Maddi ho'insaa mana kee kessaa fi naannoo kana maalidha jete yaada?

Kallatidhan aduu irrayyu ☐ Al –kallatidhan ho'a aduuti ☐ Hurka (steam) ☐

Meeshaale mana keessaa irraa(________________)☐ Kan bira yoo jiraate______

4. Haala amma sitti dhagahama jiru guuti

Jidhinsa Baay'ee Jidhaadha ☐ Jidhaadha ☐ Giddu galeessa ☐

Gogaa ☐ Baay'ee Gogaa ☐

Qillensaa Bubisaa ☐ Qillensa qorraatu ☐ Giddu galeessa ☐

Qilleensa ☐ Sochi qillensa hin jiru ☐

5. Yeroo akkam ho'isii yookan Qorrinsii hin madalamnee kan sitti dhagahamu?

Wagga guutu ☐ Ganna ☐ Birraa ☐

6. G.5 irratti hunda'uun Yeroo Birra ho'insii hin maddalamnee yeroo akkam akkam sitti dhagahama?

Yeroo birra guyya hundumma ☐ Yeroo birra guyya murta'ee ☐

Yeroo biraa guyya xiqqoof ☐ Ji'oota baay'ee ho'an tarressii?___________

7. Ifaa akkami filataa?

Nam tolchee ☐ Umamma ☐ Hommayu ☐

8. Haala ho'insaa aduu irraa dhufuu akka arman gadditi ibsii

Ulfaatadha/Mijaata miti ☐ Ni jeeqaa ☐ Giddu galeessaa ☐

Baay'ee gaarii fi mijaatadha ☐ Homma ☐

9. Tarkanifileen ati haala qilleensaa fi jidhinsa kutaa keetii to'aachuf akkasumas rakkolle kan furuuf fudhattu maalifaadha?

Golgaa foddaatti gochuu ☐ Uffaata gubba ofirra hir'isu ☐ Ventileetaraa ☐

Biqiltuuwan xixxiqoo ☐ Foddaa hagugu ☐ Kan birro yoo jiratan_______

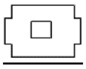
10. Yaada wa'ee ho'insaaa qillensaa man kana kessaatti qabduu ibsi?__________________

____

APPENDIX-V

1. **Daylight Illumination**

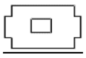
Site name:- Duket condominium site **Axis:-** East - West **Room Orientated:-** South

Typology:-  **Floors:-** Second floor **Room type:-** Three bed room

Daylight illumination data (lux)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2022	3:00AM	280	241	295	220	706
	7:00PM	372	367	318	351	1140
	10:00PM	360	356	460	319	820
Sunday, April, 17/2022	3:00AM	260	185	220	200	980
	7:00PM	551	409	418	380	1220
	10:00PM	440	345	331	525	1164
Tuesday, April, 19/2022	3:00AM	415	387	374	248	930
	7:00PM	491	230	329	300	1021
	10:00PM	255	287	420	330	916
Thursday, April, 21/2022	3:00AM	356	168	260	359	560
	7:00PM	580	354	425	337	1025
	10:00PM	450	370	309	320	900
Saturday, April, 23/2022	3:00AM	339	287	361	456	830
	7:00PM	680	495	227	290	1200
	10:00PM	441	449	510	458	960
Monday, April, 25/2022	3:00AM	225	280	355	300	939
	7:00PM	572	518	590	465	1341
	10:00PM	520	496	544	445	1200
Wednesday, April, 27/2022	3:00AM	224	287	270	249	1124
	7:00PM	665	450	355	277	1400
	10:00PM	514	594	610	480	1990
Friday, April, 29/2022	3:00AM	239	220	178	195	620
	7:00PM	400	268	263	350	946
	10:00PM	570	584	701	565	1905
Sunday, May, 1/2022	3:00AM	320	244	230	266	660
	7:00PM	665	571	554	526	1400
	10:00PM	384	303	405	320	980
Tuesday, May, 3/2022	3:00AM	458	318	320	404	608
	7:00PM	410	460	381	455	1400
	10:00PM	429	354	438	289	1800
Thursday, May, 5/2022	3:00AM	265	288	392	305	780
	7:00PM	582	409	418	380	1058
	10:00PM	420	445	371	485	1164
Saturday, May, 7/2022	3:00AM	355	397	374	250	930
	7:00PM	590	366	326	309	1005
	10:00PM	530	484	400	396	1210

2. **Air temperatures**

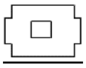
Site name: - Duket condominium site **Axis:-** East - West **Room Orientated:-** South

Typology:-  **Floors:-** Second floor **Room type:-** Three bed room

Temperature data (^{0}C)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2022	3:00AM	27.4	26.6	27.7	26.5	28.1
	7:00PM	30.5	31.4	28.8	29.7	32.5
	10:00PM	29.2	30.6	29.7	29.0	33.1
Sunday, April, 17/2022	3:00AM	26.7	27.0	27.5	26.9	28.3
	7:00PM	30.9	30.1	31.4	29.5	31.9
	10:00PM	29.3	28.8	29.4	30.1	31.6
Tuesday, April, 19/2022	3:00AM	26.1	27.6	26.6	26.3	28.4
	7:00PM	30.0	29.8	30.9	31.0	32.9
	10:00PM	29.3	29.5	28.7	29.9	32.0
Thursday, April, 21/2022	3:00AM	26.8	26.6	26.0	27.5	28.5
	7:00PM	32.1	30.3	29.5	31.0	33.7
	10:00PM	30.4	29.2	28.5	31.0	32.3
Saturday, April, 23/2022	3:00AM	26.7	26.4	27.3	26.2	27.5
	7:00PM	30.0	29.1	30.8	28.4	29.4
	10:00PM	30.5	29.6	30.5	29.9	32.9
Monday, April, 25/2022	3:00AM	26.9	27.1	26.5	27.8	27.9
	7:00PM	28.9	28.7	29.5	29.2	32.2
	10:00PM	29.8	28.5	30.3	27.4	33.4
Wednesday, April, 27/2022	3:00AM	26.0	25.5	26.1	25.8	26.4
	7:00PM	28.5	26.0	26.2	27.6	30.2
	10:00PM	29.6	28.7	30.3	28.7	32.5
Friday, April, 29/2022	3:00AM	26.8	25.5	27.0	26.5	27.7
	7:00PM	28.4	27.1	31.2	29.0	31.4
	10:00PM	29.6	28.3	30.9	30.5	31.9
Sunday, May, 1/2022	3:00AM	25.9	26.7	25.8	25.0	26.3
	7:00PM	30.5	30.5	30.0	28.4	29.0
	10:00PM	30.0	31.8	29.7	29.7	31.4
Tuesday, May, 3/2022	3:00AM	26.1	26.3	25.3	27.1	28.2
	7:00PM	28.9	29.3	28.4	28.5	29.1
	10:00PM	31.3	30.5	29.9	30.0	30.8
Thursday, May, 5/2022	3:00AM	26.4	25.8	26.0	25.8	27.9
	7:00PM	30.9	26.1	26.5	26.6	31.2
	10:00PM	31.2	29.8	27.4	28.6	32.8
Saturday, May, 7/2022	3:00AM	26.1	25.4	25.8	28.0	29.6
	7:00PM	29.1	29.9	26.0	29.5	32.2
	10:00PM	30.5	29.0	29.9	29.5	33.6

3. Relative Humidity

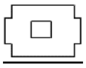
Site name: - Duket condominium site **Axis: -** East - West **Room Orientated: -** South

Typology:-  **Floors:-** Second floor **Room type:-** Three bed room

Relative Humidity data (%)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2022	3:00AM	29	27	28	28	28
	7:00PM	28	26	27	29	29
	10:00PM	28	27	26	28	28
Sunday, April, 17/2022	3:00AM	31	29	30	28	29
	7:00PM	28	26	27	28	27
	10:00PM	27	29	30	30	26
Tuesday, April, 19/2022	3:00AM	32	32	30	34	28
	7:00PM	25	26	26	24	25
	10:00PM	24	27	26	25	24
Thursday, April, 21/2022	3:00AM	27	29	29	30	30
	7:00PM	26	27	28	28	25
	10:00PM	25	24	26	26	22
Saturday, April, 23/2022	3:00AM	30	28	27	28	25
	7:00PM	24	25	26	27	26
	10:00PM	25	27	25	26	24
Monday, April, 25/2022	3:00AM	27	27	28	27	26
	7:00PM	24	23	22	24	20
	10:00PM	26	25	24	27	26
Wednesday, April, 27/2022	3:00AM	28	25	26	27	29
	7:00PM	25	26	25	29	28
	10:00PM	28	28	26	29	26
Friday, April, 29/2022	3:00AM	29	29	28	34	27
	7:00PM	25	26	24	24	25
	10:00PM	26	25	25	26	21
Sunday, May, 1/2022	3:00AM	28	29	28	28	25
	7:00PM	24	26	25	24	29
	10:00PM	27	28	27	27	26
Tuesday, May, 3/2022	3:00AM	30	28	28	29	29
	7:00PM	28	28	27	27	26
	10:00PM	29	29	29	29	29
Thursday, May, 5/2022	3:00AM	29	26	28	30	27
	7:00PM	23	24	25	24	21
	10:00PM	26	27	25	28	24
Saturday, May, 7/2022	3:00AM	26	27	28	30	24
	7:00PM	24	25	27	29	24
	10:00PM	25	26	26	28	29

4. Air Speed

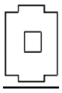
Site name: - Duket condominium site **Axis: -** East - West **Room Orientated: -** South

Typology:-  **Floors:-** Second floor **Room type:-** Three bed room

Air Speed data (m/s)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2022	3:00AM	0.10	0.19	0.21	0.00	0.97
	7:00PM	0.26	0.20	0.00	0.41	1.80
	10:00PM	0.36	0.52	0.50	0.00	2.00
Sunday, April, 17/2022	3:00AM	0.23	0.25	0.00	0.55	1.75
	7:00PM	0.01	0.15	0.10	0.52	1.63
	10:00PM	0.58	0.54	0.25	0.01	0.45
Tuesday, April, 19/2022	3:00AM	0.22	0.15	0.01	0.10	2.26
	7:00PM	0.20	0.00	0.09	0.00	1.78
	10:00PM	0.08	0.01	0.21	0.00	2.87
Thursday, April, 21/2022	3:00AM	0.00	0.06	0.09	0.28	1.45
	7:00PM	0.27	0.12	0.38	0.47	2.14
	10:00PM	0.45	0.16	0.21	0.33	1.56
Saturday, April, 23/2022	3:00AM	0.38	0.29	0.30	0.43	1.00
	7:00PM	0.28	0.00	0.40	0.00	0.90
	10:00PM	0.32	0.50	0.05	0.22	0.60
Monday, April, 25/2022	3:00AM	0.20	0.14	0.22	0.13	0.95
	7:00PM	0.00	0.20	0.31	0.57	1.75
	10:00PM	0.11	0.51	0.59	0.44	2.93
Wednesday, April, 27/2022	3:00AM	0.14	0.33	0.26	0.53	1.30
	7:00PM	0.23	0.44	0.32	0.30	1.12
	10:00PM	0.01	0.19	0.26	0.40	2.41
Friday, April, 29/2022	3:00AM	0.23	0.40	0.52	0.20	2.89
	7:00PM	0.09	0.00	0.18	0.02	1.70
	10:00PM	0.04	0.18	0.08	0.41	2.98
Sunday, May, 1/2022	3:00AM	0.10	0.48	0.00	0.58	2.50
	7:00PM	0.24	0.48	0.09	0.00	1.45
	10:00PM	0.32	0.27	0.11	0.30	2.70
Tuesday, May, 3/2022	3:00AM	0.26	0.06	0.00	0.25	1.52
	7:00PM	0.18	0.37	0.05	0.00	0.49
	10:00PM	0.10	0.31	0.29	0.11	1.00
Thursday, May, 5/2022	3:00AM	0.40	0.38	0.25	0.00	1.15
	7:00PM	0.31	0.06	0.60	0.45	1.40
	10:00PM	0.18	0.00	0.39	0.30	2.45
Saturday, May, 7/2022	3:00AM	0.30	0.00	0.01	0.00	0.69
	7:00PM	0.00	0.36	0.25	0.50	2.88
	10:00PM	0.42	0.29	0.50	000	1.91

1. **Daylight illumination**

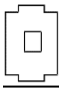
Site name: - Duket condominium site **Axis: -** South - North **Room Orientated: -** North

Typology:-  **Floors:-** Second floor **Room type:-** Two bed room

Daylight illumination data (lux)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2022	3:00AM	150	146	122	152	105
	7:00PM	205	182	189	220	510
	10:00PM	163	150	124	119	600
Sunday, April, 17/2022	3:00AM	188	112	095	104	219
	7:00PM	210	185	164	155	356
	10:00PM	178	181	195	163	597
Tuesday, April, 19/2022	3:00AM	091	145	183	100	150
	7:00PM	110	139	124	145	224
	10:00PM	048	075	128	105	387
Thursday, April, 21/2022	3:00AM	130	068	109	117	264
	7:00PM	223	180	172	146	520
	10:00PM	142	250	150	115	405
Saturday, April, 23/2022	3:00AM	122	165	154	174	238
	7:00PM	188	195	164	183	608
	10:00PM	190	178	200	180	580
Monday, April, 25/2022	3:00AM	266	225	187	125	245
	7:00PM	321	182	185	190	380
	10:00PM	235	206	314	085	492
Wednesday, April, 27/2022	3:00AM	121	198	195	154	377
	7:00PM	205	170	160	132	495
	10:00PM	136	117	145	160	448
Friday, April, 29/2022	3:00AM	070	104	052	115	370
	7:00PM	133	117	179	220	450
	10:00PM	148	226	275	197	321
Sunday, May, 1/2022	3:00AM	055	130	116	080	185
	7:00PM	227	205	238	162	553
	10:00PM	329	288	336	214	490
Tuesday, May, 3/2022	3:00AM	129	165	187	270	351
	7:00PM	244	250	269	310	620
	10:00PM	385	305	294	300	412
Thursday, May, 5/2022	3:00AM	025	040	120	175	220
	7:00PM	107	145	268	263	465
	10:00PM	140	187	184	201	563
Saturday, May, 7/2022	3:00AM	095	130	180	270	325
	7:00PM	110	087	098	150	430
	10:00PM	212	244	290	105	621

2. **Air temperature**

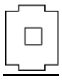
Site name: - Duket condominium site **Axis:-** South - North **Room Orientated:-** North

Typology:-  **Floors:-** Second floor **Room type:-** Two bed room

Temperature data (^{0}C)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2022	3:00AM	24.9	24.8	24.5	23.9	24.6
	7:00PM	27.5	26.9	26.3	27.7	29.0
	10:00PM	26.8	26.5	27.4	26.6	27.5
Sunday, April, 17/2022	3:00AM	24.6	23.5	24.1	24.2	25.0
	7:00PM	26.8	26.9	26.0	27.1	28.7
	10:00PM	27.7	27.2	27.4	28.0	28.5
Tuesday, April, 19/2022	3:00AM	24.5	23.7	22.8	23.9	24.8
	7:00PM	28.2	28.8	28.7	26.0	29.4
	10:00PM	24.0	23.8	24.2	23.4	26.0
Thursday, April, 21/2022	3:00AM	25.1	24.0	24.9	24.9	25.5
	7:00PM	26.6	26.7	26.8	27.9	28.1
	10:00PM	28.7	26.3	28.8	28.9	29.1
Saturday, April, 23/2022	3:00AM	25.8	24.1	24.6	24.7	25.0
	7:00PM	28.3	27.6	26.2	26.7	28.8
	10:00PM	26.0	27.0	26.4	27.4	28.5
Monday, April, 25/2022	3:00AM	25.6	24.9	25.5	26.7	26.7
	7:00PM	27.9	28.5	28.1	27.5	29.8
	10:00PM	26.1	26.6	26.4	26.3	27.5
Wednesday, April, 27/2022	3:00AM	23.9	23.8	24.8	25.2	25.3
	7:00PM	29.1	28.3	27.4	28.7	30.4
	10:00PM	27.0	27.5	26.5	26.4	27.8
Friday, April, 29/2022	3:00AM	24.5	24.9	22.8	23.9	25.2
	7:00PM	26.4	25.5	24.6	26.7	28.1
	10:00PM	28.5	28.4	28.7	28.2	30.0
Sunday, May, 1/2022	3:00AM	23.8	24.4	23.5	22.5	24.4
	7:00PM	26.0	25.3	25.6	25.4	28.4
	10:00PM	27.3	27.2	29.8	28.0	29.0
Tuesday, May, 3/2022	3:00AM	25.9	24.8	23.0	23.8	25.7
	7:00PM	26.2	26.8	26.3	26.8	27.9
	10:00PM	26.1	25.5	26.3	27.4	28.5
Thursday, May, 5/2022	3:00AM	25.2	23.3	24.5	24.9	25.1
	7:00PM	26.5	26.0	26.0	27.3	27.5
	10:00PM	26.8	26.9	27.1	27.4	28.5
Saturday, May, 7/2022	3:00AM	22.9	24.4	23.8	24.2	25.5
	7:00PM	26.4	28.7	26.8	26.9	28.2
	10:00PM	26.8	27.2	26.9	28.8	29.0

3. Relative Humidity

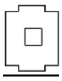
Site name: - Duket condominium site **Axis:-** South - North **Room Orientated:-** North

Typology:-  **Floors:-** Second floor **Room type:-** Two bed room

Relative Humidity data (%)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2022	3:00AM	33	32	30	34	29
	7:00PM	27	26	27	26	25
	10:00PM	28	27	25	28	27
Sunday, April, 17/2022	3:00AM	31	37	30	26	31
	7:00PM	29	28	27	28	26
	10:00PM	28	28	26	29	27
Tuesday, April, 19/2022	3:00AM	29	30	32	29	28
	7:00PM	25	24	26	28	24
	10:00PM	26	27	28	29	25
Thursday, April, 21/2022	3:00AM	37	32	32	33	30
	7:00PM	29	28	29	30	28
	10:00PM	27	28	28	29	26
Saturday, April, 23/2022	3:00AM	32	29	31	30	28
	7:00PM	28	27	29	28	26
	10:00PM	27	26	28	29	25
Monday, April, 25/2022	3:00AM	28	29	27	27	26
	7:00PM	26	27	25	25	24
	10:00PM	26	25	24	25	24
Wednesday, April, 27/2022	3:00AM	29	28	30	31	29
	7:00PM	25	27	29	29	25
	10:00PM	27	26	28	28	27
Friday, April, 29/2022	3:00AM	27	26	28	28	27
	7:00PM	26	26	27	28	26
	10:00PM	26	25	26	27	25
Sunday, May, 1/2022	3:00AM	38	36	35	34	32
	7:00PM	28	28	29	28	28
	10:00PM	29	28	30	29	29
Tuesday, May, 3/2022	3:00AM	32	30	34	33	32
	7:00PM	30	29	30	31	29
	10:00PM	29	30	29	33	29
Thursday, May, 5/2022	3:00AM	29	28	28	30	29
	7:00PM	27	26	25	25	24
	10:00PM	28	27	26	25	25
Saturday, May, 7/2022	3:00AM	33	38	36	37	34
	7:00PM	24	25	27	29	24
	10:00PM	27	26	28	30	25

4. **Air Speed**

Site nme: - Duket condominium site **Axis:-** South - North **Room Orientated:-** North

Typology:-  **Floors:-** Second floor **Room type:-** Two bed room

Air Speed data (m/s)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2022	3:00AM	0.69	0.48	0.83	0.38	2.14
	7:00PM	0.71	0.80	0.62	0.91	1.45
	10:00PM	0.19	0.73	0.35	0.21	1.10
Sunday, April, 17/2022	3:00AM	0.56	0.25	0.30	0.55	1.75
	7:00PM	0.32	0.50	0.46	0.52	1.63
	10:00PM	0.58	0.54	0.25	0.88	2.50
Tuesday, April, 19/2022	3:00AM	0.40	0.95	0.38	0.65	2.36
	7:00PM	1.12	0.97	1.15	0.51	3.58
	10:00PM	0.86	0.45	0.34	0.82	1.75
Thursday, April, 21/2022	3:00AM	0.75	0.21	0.70	0.51	2.45
	7:00PM	0.27	0.15	0.37	0.36	2.64
	10:00PM	0.49	0.36	0.61	0.73	1.96
Saturday, April, 23/2022	3:00AM	0.38	0.29	0.30	0.43	1.10
	7:00PM	0.61	0.40	0.88	0.39	2.90
	10:00PM	0.32	0.50	0.45	0.22	0.60
Monday, April, 25/2022	3:00AM	1.94	1.25	0.76	0.83	3.95
	7:00PM	0.90	0.55	0.62	0.57	2.75
	10:00PM	0.26	0.51	0.59	0.44	2.93
Wednesday, April, 27/2022	3:00AM	0.74	0.53	0.46	0.70	1.80
	7:00PM	0.33	0.84	0.32	0.30	0.94
	10:00PM	0.96	0.85	0.62	1.40	3.50
Friday, April, 29/2022	3:00AM	0.43	0.40	0.52	0.20	1.89
	7:00PM	0.90	0.02	0.18	0.24	0.70
	10:00PM	0.05	0.28	0.20	0.40	0.98
Sunday, May, 1/2022	3:00AM	1.10	0.66	1.00	0.81	1.44
	7:00PM	0.45	0.34	0.09	0.77	2.50
	10:00PM	0.32	0.27	0.31	0.30	0.70
Tuesday, May, 3/2022	3:00AM	0.46	0.26	0.00	0.35	0.52
	7:00PM	0.32	0.37	0.25	0.02	0.97
	10:00PM	1.03	0.50	0.97	0.88	3.08
Thursday, May, 5/2022	3:00AM	0.50	0.38	0.25	0.05	0.75
	7:00PM	0.41	0.46	0.60	0.45	0.80
	10:00PM	0.28	0.19	0.79	0.30	0.45
Saturday, May, 7/2022	3:00AM	0.40	0.62	0.51	0.08	0.69
	7:00PM	0.87	0.86	0.65	1.04	1.88
	10:00PM	0.92	0.99	0.50	0.15	0.91