



Ethiopia Institute of Architecture Building Construction and
City Development

Developing Parametric Solar Envelope for Ethiopian Cities

By

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and Development.

Advisor

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Declaration

I, the undersigned, declare that this thesis is my own original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged, following the scientific guidelines of the Institute.

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Confirmation

The thesis can be submitted for examination with my approval as an Institute's advisor.

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ABSTRACT

The effects of poorly designed buildings in terms of limited access to sunlight on critical times affect the health of building occupants and become the growing concerns about global warming, Ozone layer, depletion of fossil energy source and soaring oil prices. So, planning in a way to allow for sun access by regulating the form, height, orientation and organization of the built environment is important. This paper deals about the design and applicability of solar envelope to residential houses of Ethiopian cities to get access for solar or shade right. Solar envelope is a building volume limit that will not cast shadows on surrounding buildings at specified times so as to create comfortable indoor climate for humans based on the sun's movement (time) relative to the location and geometry of a site (space). The concept of solar envelope was first developed as a framework for architecture and urban design at the University of Southern California (USC) over the period 1969 to 1971 by Professor Ralph Knowles. For this end, NCEP stations found all over the country were tapped and their heating and cooling degree days have been computed correlating the respective temperature with the standard base temperature, 18.3 ° c. Besides, reference cities were identified after the regionalizing Ethiopia based on their respective degree days. Then, sun path diagram for each region has been prepared and used to identify the critical sun angles, Azimuth and Altitude of the sun, for the specified time ranges. Finally, parametric solar envelopes have been developed for each zone of reference city and this will be a basic for energy efficient envelope building creation.

Key words: Solar right, Shade right, Solar envelope, Heating and Cooling Degree Days, Base temperature.

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Acronyms and Abbreviations.

ALT	Altitude
AM	Air Mass
ASHRAE	American Society of Heating, Refrigerating and Air- Conditioning Engineers
AZM	Azimuth
CDD	Cooling Degree Days
DEC	Declination
EPW	Energy Plus Weather File
GIS	Geographic Information System
HDD	Heating Degree Days
IDW	Inverse Distance Weight
ITCZ	Inter Convergence Zone
KWH	Killo Watt Hour
MS	Multiple Sclerosis
NCEP	National Center for Environmental Prediction
NMAE	National Meteorological Agency of Ethiopia
SAD	Seasonal Affective Disorder
SBS	Sick Building Syndrome
SCE	Solar Collection Envelope
SE	Solar Envelope
SRE	Solar Right Envelope

LIST OF EQUATION

Equation 1: Heating Degree Day (HDD) = (base temperature – Average Temperature) +	13
Equation 2: Cooling Degree Day (CDD) = (Average Temperature – base temperature) +.....	13
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Equation 5: $AZM = \sin^{-1}[\cos (DEC) \sin (HOUR)/\cos (ALT)]$	14
Equation 6: $SUN\ RISE = 12 - 1/15^\circ \cos^{-1}(-\sin (LAT) \cdot \sin (DEC) / \cos (DEC) \cdot \cos (LAT))$	14
Equation 7: $SUN\ SET = 12 + 1/15^\circ \cos^{-1}(-\sin (LAT) \cdot \sin (DEC) / \cos (DEC) \cdot \cos (LAT))$	14
Equation 8: $Q = mcT$	14

Where, Dec = Declination Angle

Lat = Latitude

Cos = Cosine

Sine =Sine

Tan = Tangent

Hdd = Heating Degree Days

Cdd = Cooling Degree Days

Alt = Altitude

Azm = Azimuth

Q = Heat transfer

M = mass of air

C = specific heat capacity

T = Temperature change

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CHAPTER ONE

INTRODUCTION

A design that doesn't consider the solar or shade rights of people may cause uncomfortable conditions inside the buildings and outdoors (Capeluto et al., 2006). So, to bring solar envelope as a design tool for the consideration of solar or shade rights in urban design for the comfort condition of building is important.

Solar envelope is a zoning concept, a construct of space and time devised to provide urban solar access (Knowles., 2003), to facilitate the control of the amount of sunlight received by buildings in urban area and to regulate the construction of new buildings with in imaginary borders derived from apparent sun path (Knowles., 2000).

The solar envelope was first proposed in 1976 in the school of architecture, southern California for concerns voiced by Steele and others about energy and buildings. The aim was to develop and test the solar envelope as a zoning device to achieve solar access by regulating development within limits derived from the sun relative motion (Knowles., 2003).

The consideration of solar right in building is essential to energy conservation and quality of lives (Knowles., 2003), to comfort conditions of people in streets, sidewalks and open space by guaranting access to sun (Capeluto et al., 2006).

Many cities and countries in the world defined many regulations to keep solar rights. somewhere created from a public point of view to keep open space and sidewalks insolation as defined in cities such as New York, Sanfransisco, Toronto and Telaviv. In other places regulations were defined to ensure the full use of private properties such as private open space and solar collectors (Capeluto et al., 2006). In ancient Greeks and china defined regulations based on local climate to achieve comfort condition passively (Dubin and Arch., 1982).

The construction of a solar envelope is complex, tedious and time consuming, which needs an expert in understanding its geography and descriptive geometry (Brown and Dekay., 2001).

The development of different software's such as Sol CAD, Solvelope, Sustarc and ladybug is a step in the direction of making this process simple for users, experts and beginners.

The research in the field has progressed and more complex models has been emerging, such as models of solar envelope for determining maximum building height (Arumi., 1979), for assuring solar access (Knowles., 1981), for allowing daylight (Dekay., 2012). Other models that couple solar envelope with AutoCAD are Sol CAD (Juyal et al., 2003), CalcSolar (Noble and kensek., 1998), and the sustarc model (Capeluto and Shaviv., 1997).

The work in this paper was extended to the regionalization of Ethiopian cities in to five climatic zone based on the Cooling and Heating Degree Days of ASHRAE standard. Consequently, the solar envelopes were constructed with respect to different street orientation and climatic zones.

To perform the described work, data from Global Weather Data for NCEP for analyzing and understanding the main climatic variables temperature, humidity, heating and cooling degree days and comfort zone of the cities with respect to the climate zone were studied.

As a result, regional map of climate based classification for Ethiopia was prepared with GIS tools followed by analysis and calculation of solar position including solar geometric variables integrated with Microsoft Excel and websites for mapping sun path were used to construct solar envelope, which assure solar access for buildings with AutoCAD 3D modeling software as a tool. Finally, user friendly parametric solar envelopes were produced for the referenced climatic zones of Ethiopian cities.

1.1. Problem Statement

sunlight is vital to life. It facilitates essential connection with nature and giving one a sense of time and positions in that daily cycle. The effects of poorly designed buildings whether in terms of limited access to sunlight on critical times or considerations to a more lenient approach of limiting the ratio between land area and built floor area (Capeluto et al., 2006) affect the health of building occupants and the growing concerns about global warming, Ozone layer, depletion of fossil energy source and soaring oil prices (Knowles., 2000).

In 1998 World Health Organization report up to 30 % of new and remodeled buildings worldwide may be linked to a health problem, described as sick building syndrome (SBS), problems associated

with household cooking energy sources, cooking practice, and incensing habits of occupants. In Ethiopia, for instance in Gonder town the SBS accounts for 21.7 % (Belachew, 2018) coverage. The situation results building occupants thermal discomfort usually when the air temperature is below 18 °c and the global horizontal radiation is higher than 500 W/m² (Capeluto et al., 2006), developing abnormal behaviors due to diurnal cycle distribution like drastic mode swings, lowered energy and depression commonly characterized by SAD ,which can be treated by bright light therapy (Rosenthal., 1986), in adequate vitamin D levels, there by exacerbating a number of health problems including bone thinning (Holick., 2004), cancer (Grant and Garland., 2006), high blood pressure (Colas et al., 1988) and such immune system disorders multiple sclerosis (MS), rheumatoid, arthritis and diabetes (Stein., 2004) and formation of mold and mildew spores, when the lack of sunlight combined with high humidity (Boubekri., 2008). Accordingly, it is estimated that 2.5 million people is with multiple sclerosis deaths, more than a million American diagnosed with skin cancer in 2007 (Boubekri., 2008). In Ethiopia, for instance in Gonder town due to SBS, skin symptoms account 10 %, rhinitis 8 %, Mucosal symptoms account for 64 % (Belachew, 2018). So, to function optimally for human comfort buildings need to be designed to create filter between human being and nature.

1.2. Objective

Main objective:

To develop solar envelope standard for Ethiopian cities.

Specific objectives

1. To regionalize Ethiopian cities so as to make it convenient for reference Solar envelope.
2. To map the sun path diagram so as to understand the sun position with respect to the selected period of insolation.
3. To construct and produce user friendly parametric solar envelope for reference cities of Ethiopia for the four cardinal direction and their respective inverse.

1.3. Research question

Main question

How can reference or standard solar envelope be generated for Ethiopian cities?

Specific question

1. How are Ethiopian cities regionalized for identifying reference cities of Solar envelope generation?
2. How is sun path diagram analyzed and mapped so as to know sun position for reference cities of Ethiopia?
3. How is user-friendly parametric solar envelope be constructed for 4 cardinal direction and their inverse?

1.4. Scope

The study was done for Ethiopian towns and cities and settlements found within its boundaries. it only focused on developing standard solar envelope for identified reference cities after regionalizing Ethiopia limit for solar envelope.

1.5. Limitation

The study was constrained by the limitation of cost for buying recent software, since most of the tools for constructing solar envelope are not freely accessible to use. There was also un available data type with incomplete data record and conversion system of energy plus weather (EPW) format file from Ethiopia meteorology agency, because the most efficient and recent construction of solar envelope is using Rhinoceros integrated with grasshopper and ladybug tools that uses EPW format. Though with all the limitations, the solar envelopes were done with data from Global Weather Data for NCEP Excel file format and most commonly useable Auto CAD 3D modeling software.

1.6. Research design

The whole work flow for this study is shown in figure 1 below.

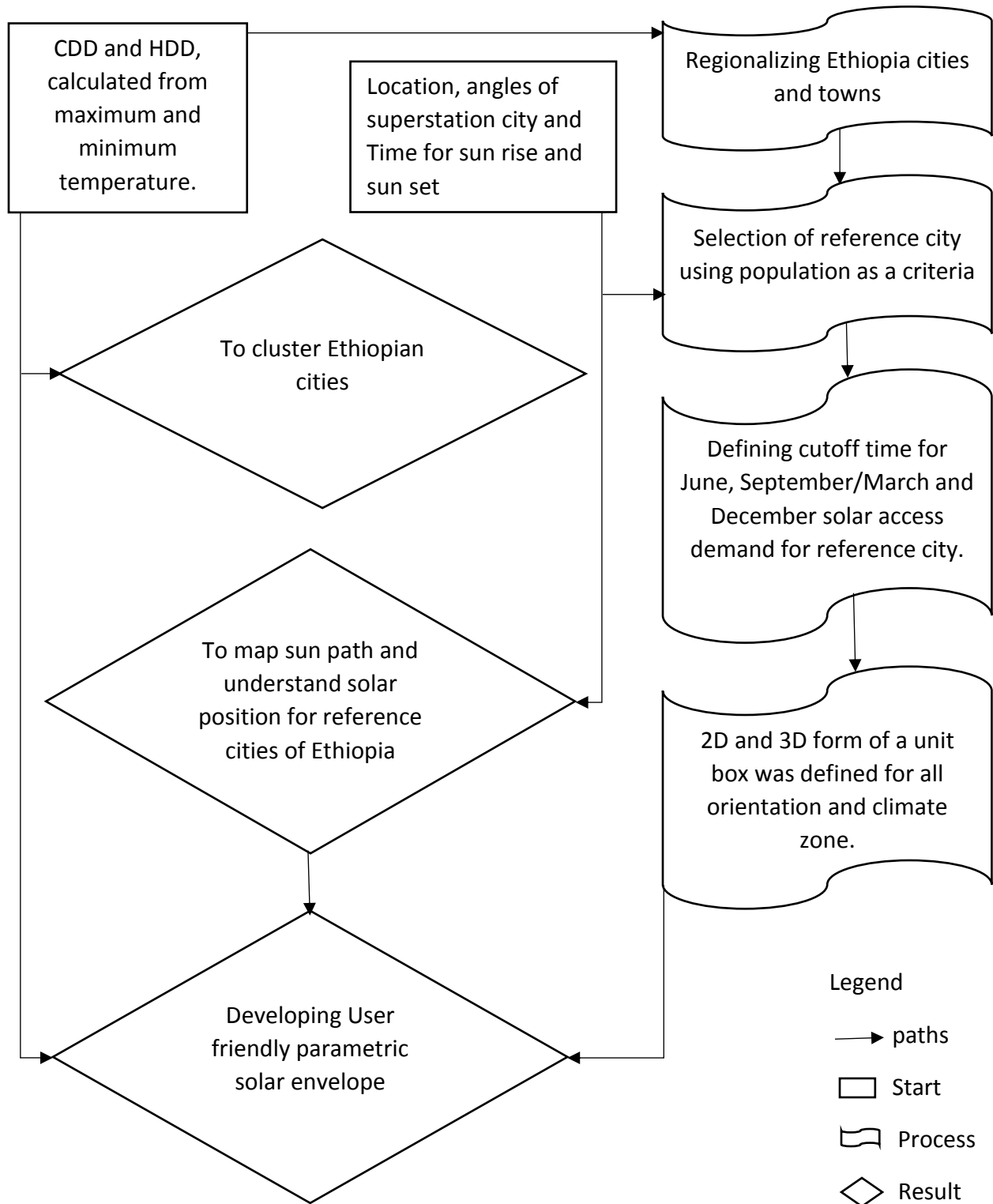


Figure 1: Research design

1.7. Significance of the study

The study has been very important for people to live comfortable and high quality of life by ensuring daylight access and respecting solar rights of neighboring communities (solar communities).

It can also be used for researcher and design professional for guiding climate responsive building design that evaluate the resources of local climate and quantify the passive performance of the building in a way that is sensitive and accurate enough to reflect the impact of small design changes.

Finally, the study has brought a rule for planning authorities to control development, to develop new energy codes for a specific climatic area, to verify the applicability and performance of new technologies.

1.8. Organization of the paper

This paper contains seven chapters. It starts with introduction part which introduce about Solar Envelope, problem statement, objectives, research questions, scope and limitation, the research design and significance of the research. The second chapter is a literature review having, theoretical and contextual review. The third chapter describes the method and techniques of the research. The fourth chapter includes the analysis of the research. The fifth chapter will present result of the paper. The six chapter is about Discussion and finally, Chapter seven which includes Finding, conclusion and recommendation of the study. References and appendices are also included.

CHAPTER TWO

LITERATURE REVIEW

2.1. Theoretical Review

The many variations of climate from place to place as determined by different combinations of climatic controls, produce correspondingly a large number of climate types. In order to facilitate the mapping of these climatic regions, it is necessary to classify these climatic types and establish criteria for their identifications (Bansal and Minke., 1995).

Classification of climate is an important tool to enabling knowledge of the climatic characteristics of a region, an aid to the functional design of different types of building, to describe weather and climate of an area, to compare the climate of one place to another region far away and to familiarize the designer with the character and location of the zones as it is indicative of the climatic problems likely to encounter (Bansal and Minke., 1995).

The climate classification concept has been widely applied to a broad range of topics in climate and climate change research as well as in physical geography, hydrology, agriculture, biology and educational aspects (Kottek et al.,2006).

The first quantitative classification of world climates was presented by the German scientist Wladimir Koppen in 1906 (Kottek et al., 2006). It refined by Koppen (1936) and later improved by Geiger (1954), Koppen Trewartha (kt), Thornthwaite (1948) and finally modified by Maluf (2000) (CM) (Aparecido., 2006).

Since most energy performance standards and building envelopes are mainly shaped by climatic characteristics of the surrounding environment, regional Climate classification becomes an essential matter. Classifications for India, Turkey and America are discussed below.

In America and Canada climate classification is developed to be used in the implementation of building energy codes, standards, design guide lines and building energy analysis by ASHRAE transactions. In USA the classification is made in two ways the first is divided into three main groups of marine, dry and humid definition, secondly it is divided into 8 major climate regions

and 17 sub climate regions named by koppen climate classification category based on heating and cooling degree days thermal reference (Briggs et al., 2003).

In India bureau of Indian standard classified the climate of India into four types relevant to building design (Sekar & S.P., 2009).

In turkey, the Turkish climate standard classified the regions as thermal insulation regions by degree day method to determine consumption values and insulation requirement (Esiyok., 2006).

There are different methods for analyzing energy consumption patterns of buildings and climate zoning, yet, the Degree-days (DDs) method, invented by Lt-Gen. Sir Richard Strachey in 1878, is a simple and reliable method to establish energy analysis of buildings (Mushtaq et al., 2018).

Base Temperature and Degree Day Method

Base temperature is a fundamental notation which gives an understanding of the relationship between climate, occupancy, building construction design and the energy flow paths in a building. It is the outdoor air temperature at which the indoor temperature is in comfortable range without the use of any mechanical heating or cooling (Bhatnagar et al., 2018).

It is considered to be a human comfort temperature, where 18 °c is widely used for both HDD and CDD. However, it varies across countries and regions depending on the regional human physiology, energy supply, the level of economic development and characteristics of temperature change (Shi Y et al., 2018).

Example; base temperature for heating in USA (18.3° c), UK (15.5° c), Greek (14° c), South Korea (14.7-19° c) and 26° c for cooling, Saudi Arabia (18.3° c) for both cooling and heating. The neutral base temperature based on ASHREA for both heating and cooling is 18.3° c, which is mostly used and applied for this research also.

Degree Day is defined as the difference between the daily mean temperature and a given reference temperature (Shi Y et al., 2018). It is important to estimate building energy consumption and carbon dioxide emissions due to space heating and cooling for new build and major refurbishments, for on-going energy monitoring and analysis of existing buildings based on historical data, to analyze the impact of climate change on building energy consumption, to

analyze historical trends and forecasting of energy use in future, to classify climate zones (Bhatnagar et al., 2018), Which is used in this paper also for Ethiopia regionalization.

Heating Degree-Days

Heating degree days express the severity of the cold over a specific time period taking into consideration outdoor temperature and room temperature (Nobatek., 2016). It is calculated by using mean temperature and then compared with an experimentally determined basic air temperature (Shi Y et al., 2018). See equation 1 (page 13 below).

Cooling Degree-Days

CDD is an indicator, which allows evaluating the influence of the climate on the building cooling energy consumption (Lopes & Lamberts., 2018). It is Calculated with Equation 2 (page 13 below).

2.2. Contextual Review

2.2.1. Climate Characteristics of Ethiopia

Ethiopia weather and climate zones vary from the world's hottest and driest desert ranging from the world's hottest and driest desert (Dalol) to cold wet mountains and seasonally wet savannahs (Ras Dashen) (Gonfa., 1996).

The highest mean maximum temperatures in Ethiopia, about 45 °C from April to September and 40 °C from October to March, are recorded from the Afar Depression in north east Ethiopia. The other hot areas are the north-western lowlands, which experience a mean maximum temperature of 40 °C in June and the western and southeastern lowlands with mean maximum temperatures of 35 °C to 40 °C during April. The lowest mean temperatures of 4 °C or lower are recorded at night in highland areas between November and February (National Meteorological Services Agency., 1989).

Due to a wide variety of marked contrasts in relief and temperature and its geographic position close to the equator and Indian ocean the country is subjected to a large spatial variation in climate.

The climate of Ethiopia is mainly controlled by the seasonal migration of the Intertropical Convergence Zone (ITCZ), associated atmospheric circulations and the complex topography of the country (Fazzini et al., 2017).

There are different studies of climate zoning for Ethiopia. According to Köppen Classification The world is divided into five main climatic zones tropical, arid, temperate, continental and polar climates and Ethiopia is situated in the temperate Mediterranean climatic and geographical zone.

Based on the variations in altitude and temperature Ethiopia has five climatic zones: hot, warm to hot, warm to cool, cool to cold and moist temperate zones (Fazzini et al., 2017).

2.2.2. Energy and HAVAC In Ethiopia

Buildings in developing countries are often designed without taking sufficient account of the climatic Factors such as site characteristics, orientation, architectural design of the building and choice of building materials. Consequently, buildings often have a poor indoor climate which affects comfort, health and efficiency (Rosenlund., 2000).

Higher living standards lead to active climatization of high energy consumption for heating and cooling of offices, hotels, and residential buildings. Especially, in the industrialized world, buildings account directly for over 50% of total energy consumption (Rosenlund., 2000).

Now a days, Ethiopia is developing rapidly in various aspects. The living standard and seeking for comfort condition of the population in both working and residential area is also increasing rapidly from time to time. Especially modern buildings such as; Hotels in Addis Ababa like Capital Hotel, Radison blue, Harmony, Kenenisa, lexus and the like. Not only in Addis but also in other parts like Semera almost all governmental office buildings using split AC, in Mekele example Yirdaw Hotel, and hotels and conference halls in Bahir Dar have designed Air conditioner (Worku, 2014).

For the building to be energy efficient it is necessary to control the input of energy through regulatory systems of Air-conditioning plants, which leads to excessive energy consumption, high cost and may also damage the building (Adamson & Åberg., 1993) or through 'passive' techniques, normally requires more interaction, monitoring and knowledge by the user and is more sensitive to human factors (Rosenlund., 2000).

Therefore, when designing an individual building using passive technique, the general outdoor climate is to be regarded as a given condition to affect the microclimate by urban and building design. The sun may be described as the 'engine' of the climate since it supplies a large amount of energy to the earth.

In Ethiopia Only 16 % of population have a potential to access the national grid. But only 6 % accessed as it is not affordable to many, only 10 % is supplied by electric power, wood fuel and dung. The increase in price of energy sources are also crucial given the very low income of the people to use HAVAC for energy consumption in household and to bring comfort.

Therefore, the need for alternative energy source of Solar Power is a potential to access all for any needs of passive energy system, since it is clean and promotes environmental issues. Among the methods Solar responsive building envelope sensitive to solar energy and its effect on heat transfer has been studied in this paper. The transfer of heat in the building can be seen with temperature change. Heating or accessing sun in the building increases the temperature while cooling or shading decreases the temperature need of the building.

The quantitative relationship between heat transfer and temperature change contains all three factors: mass of the substance(m), the change in temperature (t) and Specific heat Capacity (c).

CHAPTER THREE

MATERIAL AND METHOD

3.1. Study Area Description

Ethiopia lies between the Equator and Tropic of Cancer, between the 3° N and 15° N Latitude or 33° E and 48° E Longitude. Its weather & climate zones vary from the world's hottest and driest desert (Dalol) to cold wet mountains and seasonally wet savannahs (Ras Dashen) (Gonfa., 1996). See figure 2 below.

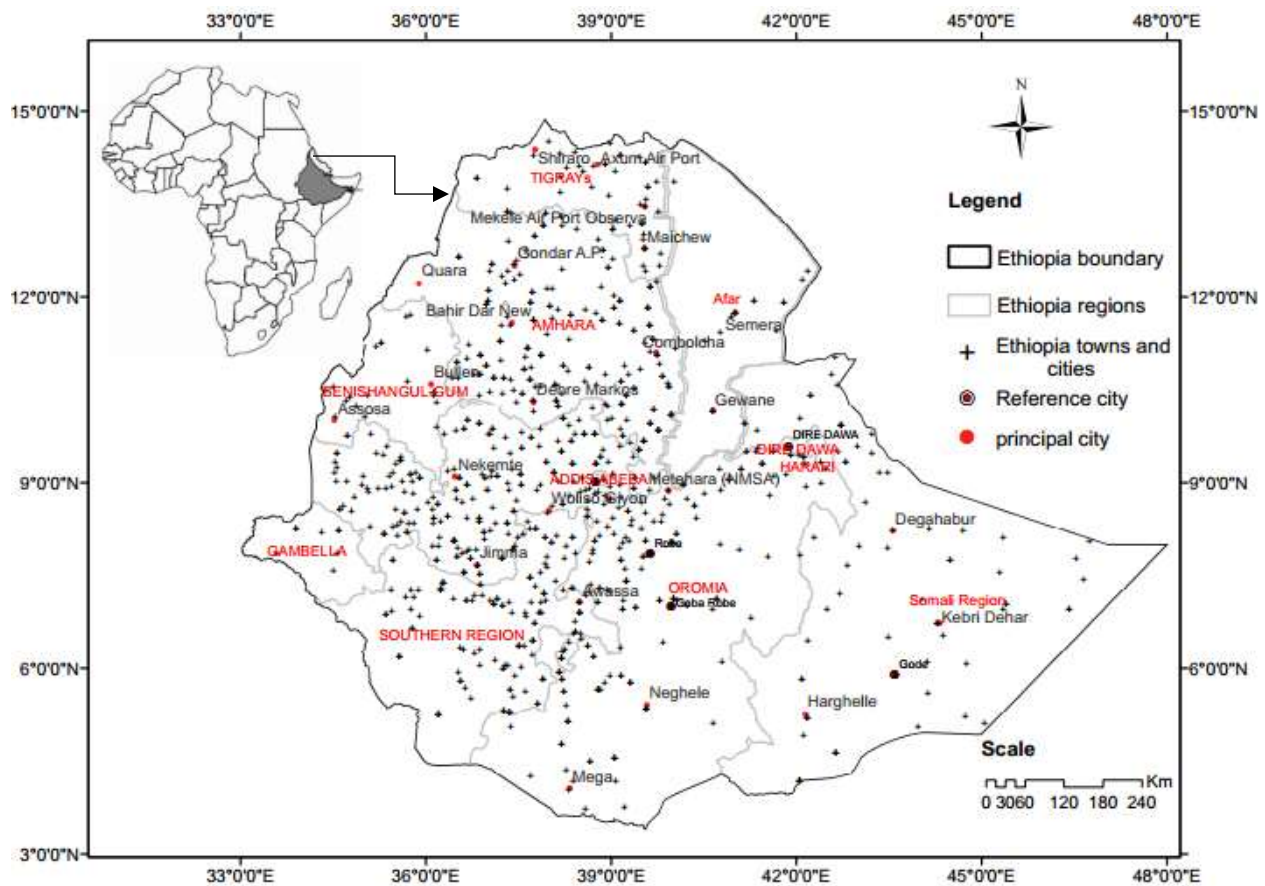


Figure 2: Location map of Ethiopia

4.1. Method

For the purpose of this work, 952 NCEP stations found in Ethiopia weather data for 30 years from 1974 – 2013 available data were tapped. To regionalize Ethiopia for solar envelope, Kriging method of Arc GIS for raster mapping of cooling and heating degree days of 952 stations was

used. The base temperature is set to be 18.3 °c, which is neutral from cooling and heating energy demand and calculated with equation 1 and 2 below for HDD and CDD, respectively. Then, by proximity tools of Thissen polygon method in Arc GIS, a map was converted into vectors that represent each raster cells distance coverage for both parameter and using intersect tool and specifying criteria the classification of the country was done. To calculate HDD and CDD of Ethiopian cities, Shi, Zhang & Zhou 2018 study as below equation 1 and 2 were adapted.

$$\text{Heating Degree Day (HDD)} = (\text{base temperature} - \text{Average Temperature}) + \dots\dots\dots \text{Equation (1)}$$

$$\text{Cooling Degree Day (CDD)} = (\text{Average Temperature} - \text{base temperature}) + \dots\dots\dots \text{Equation (2)}$$

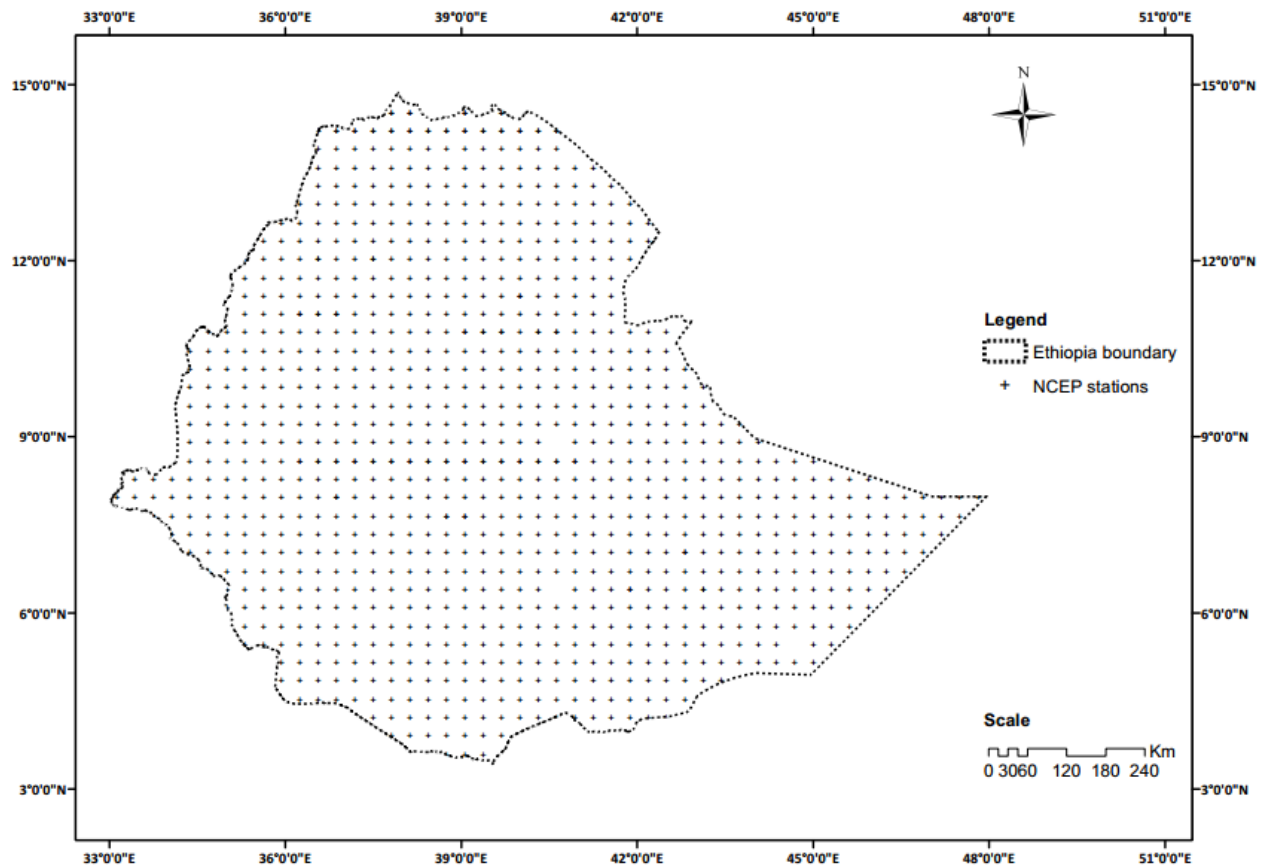


Figure 3: NCEP stations that fall with in Ethiopia

After clustering cities in each climatic zone, selection of reference cities has been important to reflect the climatic condition for each zone. Using population living in urban area as a criteria, cities having highest number of populations in the same zone has been considered as a reference city, for which the climatic character of each zone and the solar envelope were produced.

Secondly, altitude, azimuth, declination, sun rise and sun set of solar geometry were analyzed and calculated with equation below to understand the sun position in sun path diagram obtained from Jaloxa for reference cities and the extreme case of energy demand for cooling and heating months were set for cutoff time. The formula has been calculated by (Uen-Fang Patricia, 1992).

Solar Declination

The value of solar declination of the representative city varies from +23.0° to -23.0° that occurs on June 22 and December 22 respectively. It can be calculated Using Equation 3 below.

$$DEC = -23.45^\circ \cos [0.986(DAY + 10.5)] \dots\dots\dots \text{Equation (3)}$$

Solar Altitude Angle (ALT)

Sets the height of the solar envelope for a particular time. It is given by Equation 4 below

$$ALT = \sin^{-1}[\cos (DEC) \cos (LAT) \cos (HOUR) + \sin (DEC) \sin (LAT)] \dots\dots\dots \text{Equation (4)}$$

Solar Azimuth Angle (AZM)

Set the shadow edge on the boundary line Equation 5 can be used to calculate azimuth angle:

$$AZM = \sin^{-1}[\cos (DEC) \sin (HOUR)/\cos (ALT)] \dots\dots\dots \text{Equation (5)}$$

Day light time

Equation 6 and 7 are used to calculate sunrise and sunset time of the day, respectively.

$$SUN \ RISE = 12 - 1/15^\circ \cos^{-1}(-\sin (LAT). \sin (DEC) / \cos (DEC). \cos (LAT)) \dots\dots\dots \text{Equation (6)}$$

$$SUN \ SET = 12 + 1/15^\circ \cos^{-1}(-\sin (LAT). \sin (DEC) / \cos (DEC). \cos (LAT)) \dots\dots\dots \text{Equation (7)}$$

Finally, the geometry of solar building envelope was constructed for each orientation and climate zone with Auto CAD 3D modelling of Extrude tool and mass prop tool for finding the volume of the solid form for competing densities for each climatic zone.

To estimate the rise of 1°c temperature of air or heat transfer in the cooling and heating of building equation 8 below was used, using the quantitative relationship between mass of air (m), specific capacity of air (C) and temperature change (T).

$$Q = mcT \dots\dots\dots \text{Equation (8)}$$

CHAPTER FOUR

ANALYSIS

4.1. Regionalization of Ethiopian Climate

Life patterns of people, activities and behavior are greatly influenced by the elements of climate, namely air temperature, solar radiation, humidity, rainfall and wind which form the general climate of a place called region.

Climatology of an area is important to discover and explain natural behavior of the atmosphere and earth in order to harness natural resources, thermal comfort for buildings beside environmental pollution issues, energy crisis, global warming and urban heat island for human demands and to recognize the different climate potentials for human life benefits. Among other variables such as building envelope, heating system, type of use etc., climate is the most important element and has the greatest influence on the determination and selection of design strategies and material choice on providing comfortable and energy efficient living spaces (Esiyok., 2007). The classification used in this paper has been developed for the design of buildings for the protection and comfort of people based on Cooling and Heating Degree Days method. See table 1 below for classification criteria.

Table 1: Climate classification criteria

Climate Zone Classification	Cooling Degree Days (CDD)	Heating Degree Days (HDD)
1	CDD < 500	HDD > 1750
2	CDD < 500	HDD > 1000 and < 1750
3	CDD < 500	HDD < 1000
4	CDD \geq 500 AND < 2000	HDD < 1000
5	CDD \geq 2000	HDD < 1000

Source: ASHRAE., 1991

Climate Zone 1

Table 2: Geographic location of reference city for climate zone 1

Reference city	Latitude	Longitude	Elevation
Goba Robe	7.025°	40°	2608 masl

This region has a climate of mostly cool and cold temperatures that often drop far below 0 °c in the winter. During summer the humidity in combination with the temperature is too high with short hot periods see figure 4 below for location distribution. In figure 5 (page 17) the extreme maximum temperature range can reach more than 26.7 °c during summer season and minimum reach -4.5 °c in winter for this climate zone. Averagely, in all season this climatic zone has 191.5 HDDs and zero CDD. The average annual precipitation is about 3224 mm. From figure 7 (page 18) the maximum wind speed is about 5.07 m/s that occurs in winter and the minimum is 0.75 m/s that occurs in Autumn. For some representative towns related to this zone see Appendix 1.

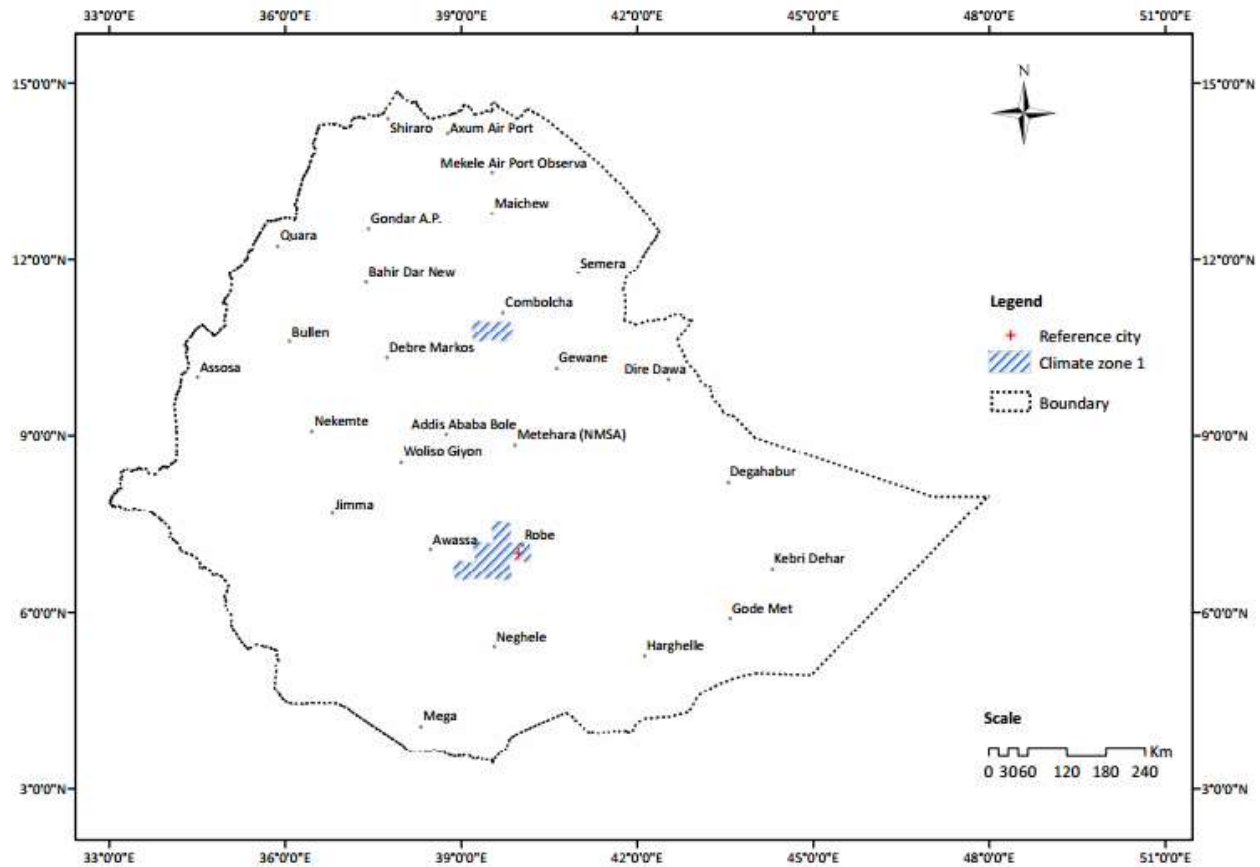


Figure 4: Ethiopia Climate zone 1

Temperature (Typical comfort zone 20 - 26.7 °c)

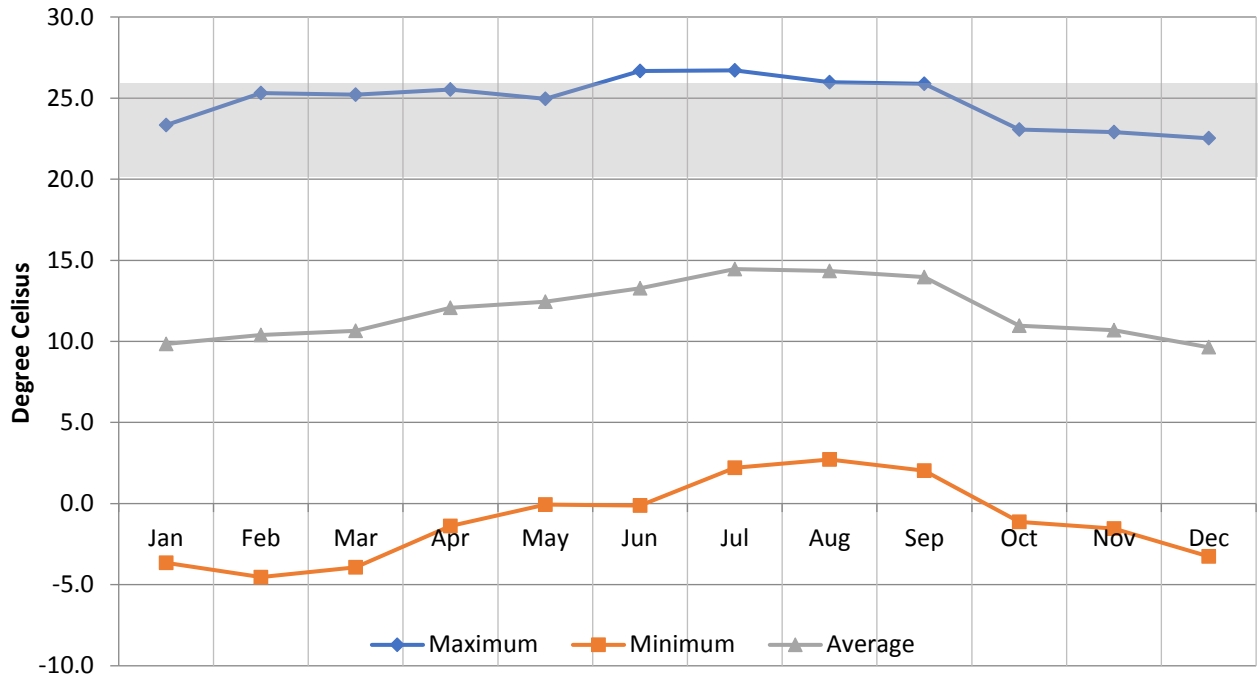


Figure 5: Temperature variations in Goba Robe

Relative Humidity (Typical comfort zone 20 - 80 %)

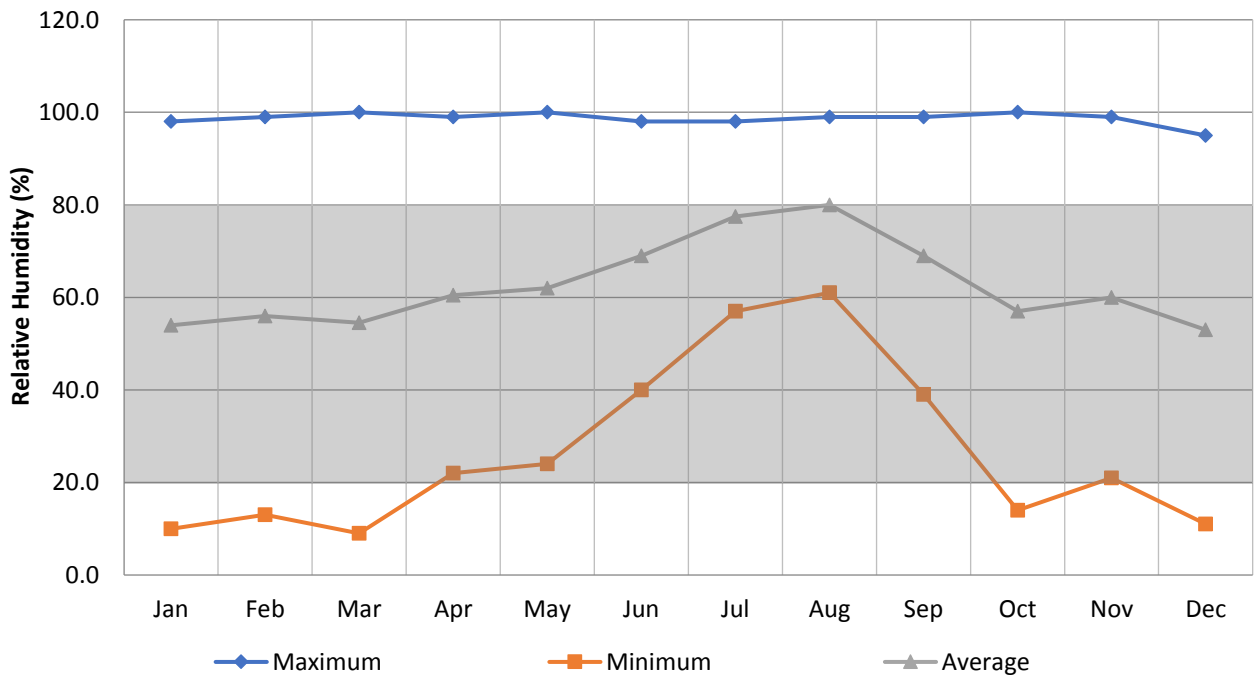


Figure 6: Relative humidity in Goba Robe

Wind speed

Natural ventilation is most effective when wind speed is 5 mph or greater.

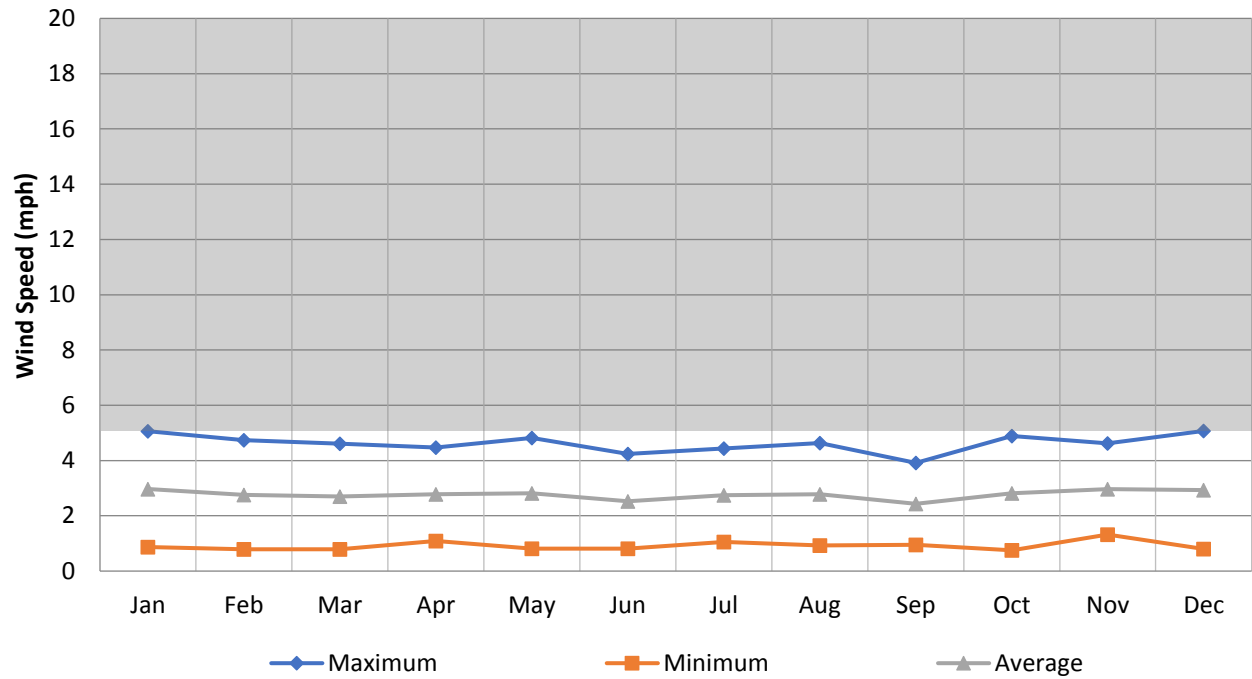


Figure 7: Wind speed in Goba Robe

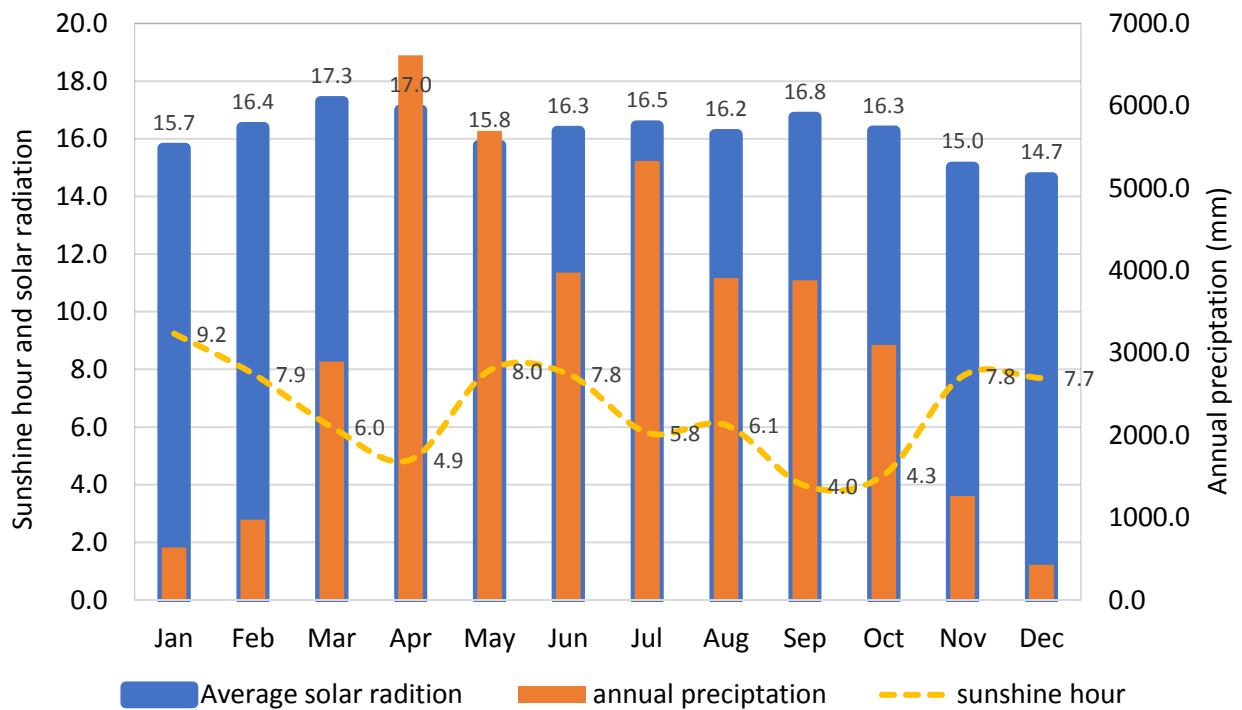


Figure 8: Sunshine hour, solar radiation and annual precipitation in Goba Robe

Climate Zone 2

Table 3: Geographic location of reference city for climate zone 2

Reference city	Latitude	Longitude	Elevation
Robe	7.96184°	39.6875°	2503 masl

This region has also a climate of cool and cold temperatures more in the winter. During summer the humidity in combination with the temperature is also too high with short hot periods figure 9 below shows its location. In figure 10 (page 20) the extreme maximum temperature range can reach more than 31.2°C during summer season and minimum reach -6.9 °C in Autumn.

Averagely, this climatic zone has CDDs of 0.9 and HDDs of 145.3. The average annual precipitation is about 4767mm that occurs uniformly with highest in summer season. The maximum wind speed is about 5.07 m/s that occurs in winter and the minimum is 0.75 m/s that occurs in Autumn shown figure 12 (page 21). For some representative towns related to this zone see Appendix 2.

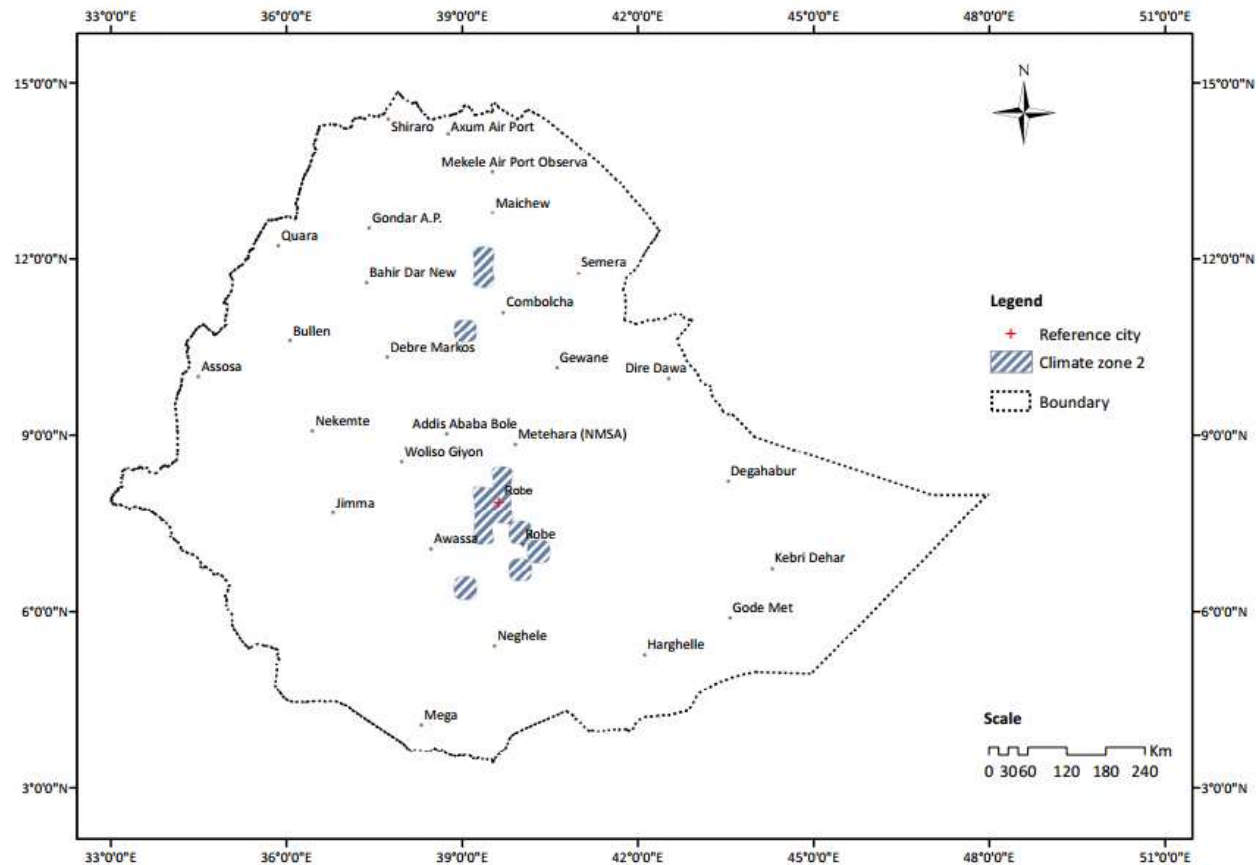


Figure 9: Ethiopia climate zone 2

Temperature

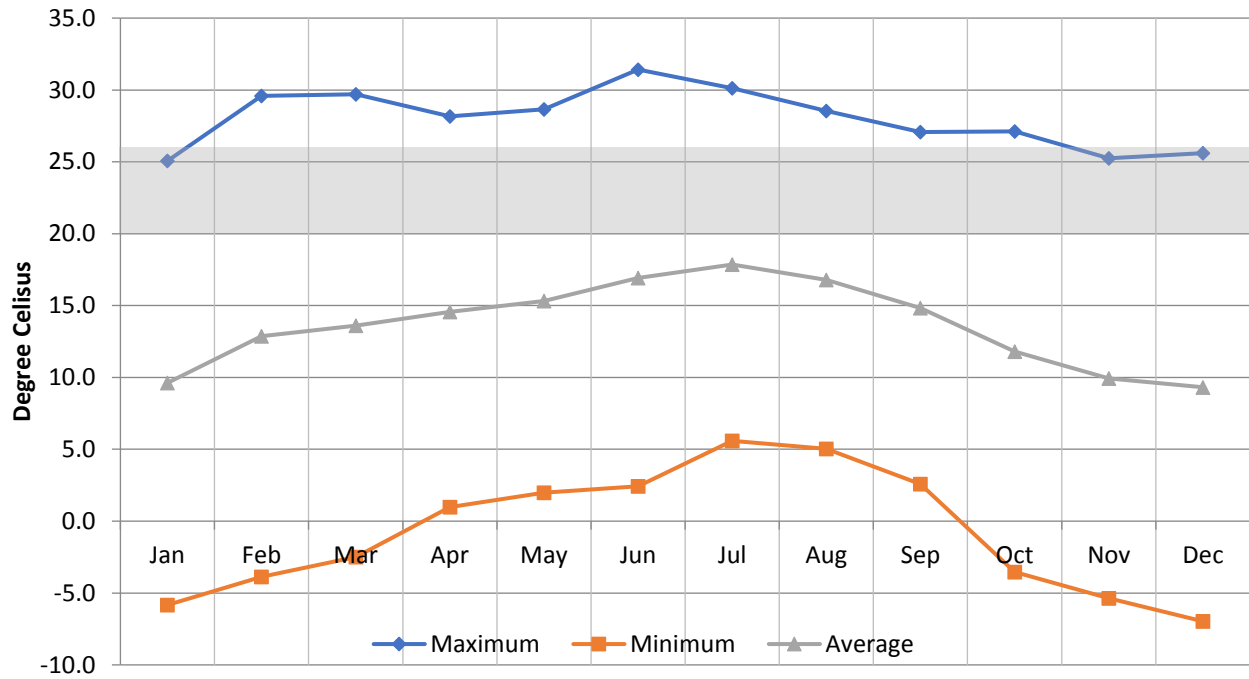


Figure 10: Temperature variation in Robe

Relative Humidity

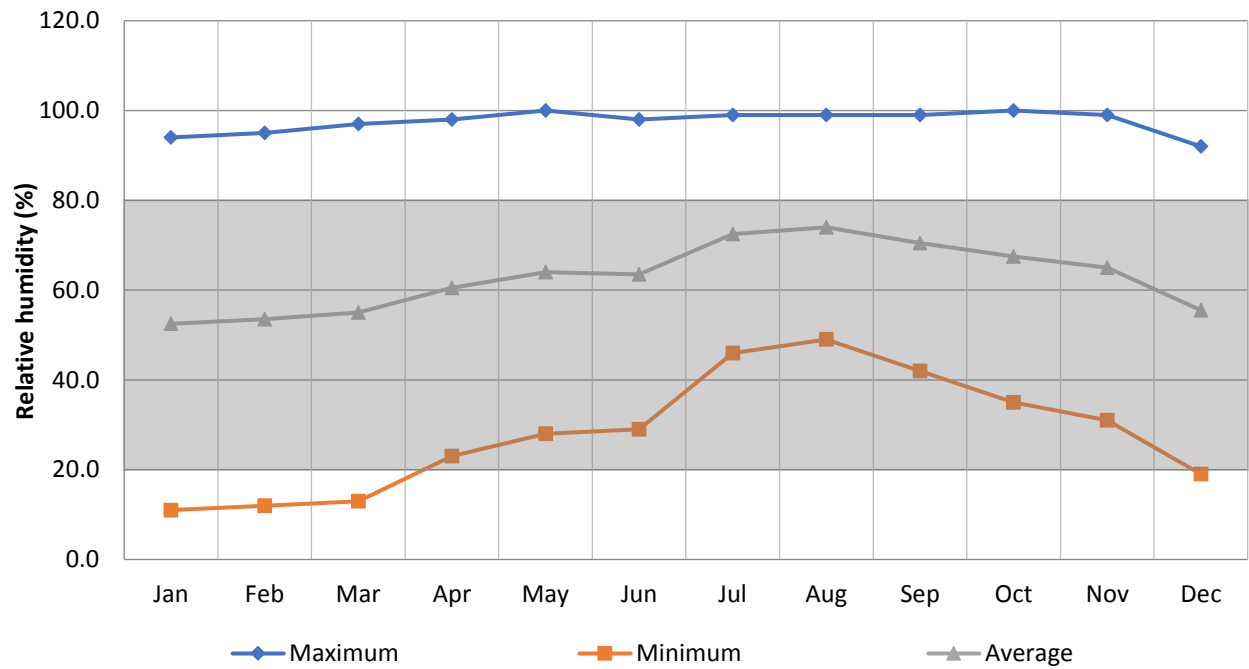


Figure 11: Relative humidity in Robe

Wind speed

Natural ventilation is most effective when wind speed is 5 mph or greater

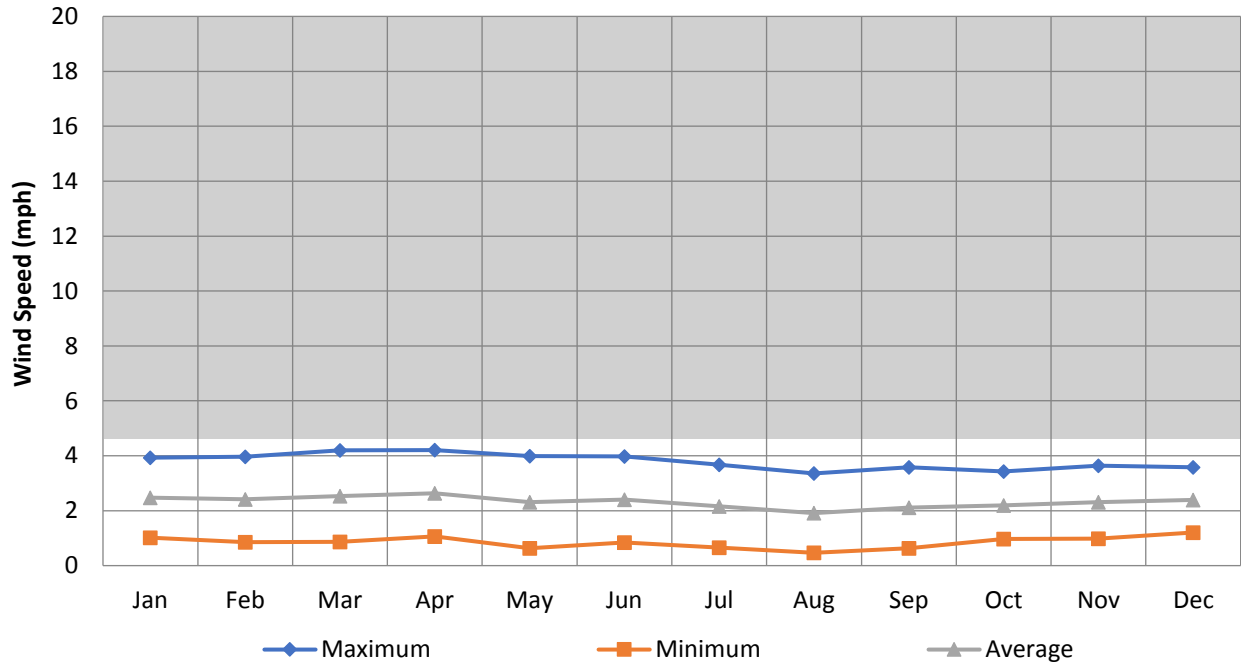


Figure 12: Wind speed in Robe

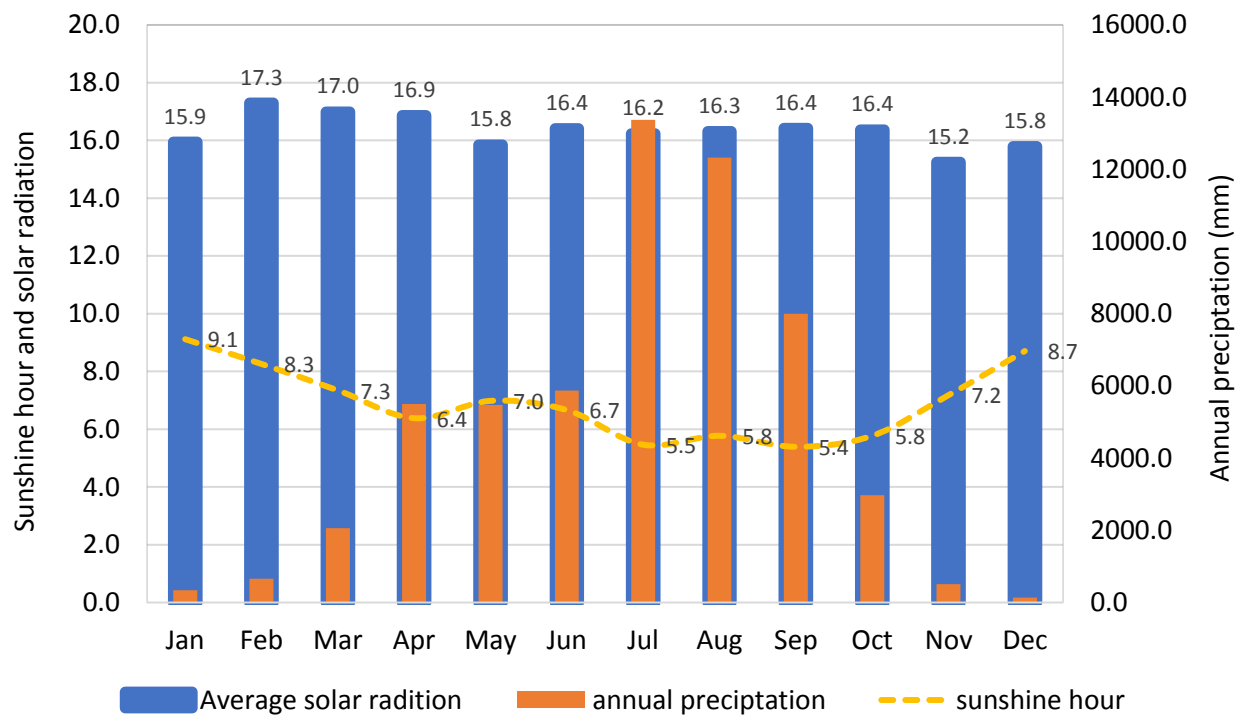


Figure 13: Sunshine hour, solar radiation and annual precipitation in Robe

Climate Zone 3

Table 4: Geographic location of reference city for climate zone 3

Reference city	Latitude	Longitude	Elevation
Addis Ababa	8.89852°	38.75°	2138 masl

This region figure 14 below has a climate of moderate average temperatures. The extreme maximum temperature range can reach more than 33.9 °c during spring season and minimum reach -1.0 °c in winter shown figure 15 (page 23) for this climate zone.

Averagely, this climatic zone has a CDD of about 41.2 and HDDs of 20.9. The average annual precipitation is about 1716 mm that occurs with highest in summer season. From figure 17 (page 24) maximum wind speed is about 4.7 m/s that occurs in spring and the minimum is 0.66 m/s that occurs in Autumn. For some representative towns related to this zone see Appendix 3.

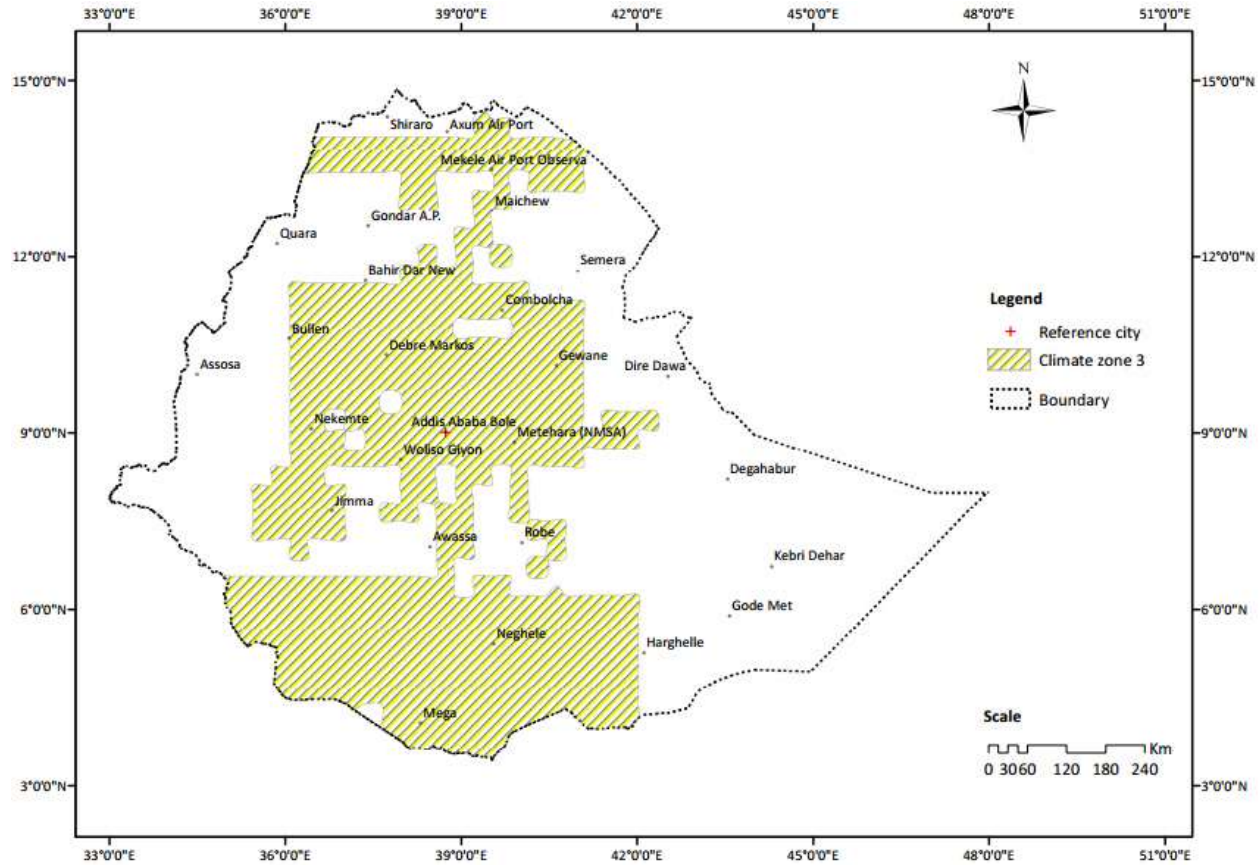


Figure 14: Ethiopia climate zone 3

Temperature

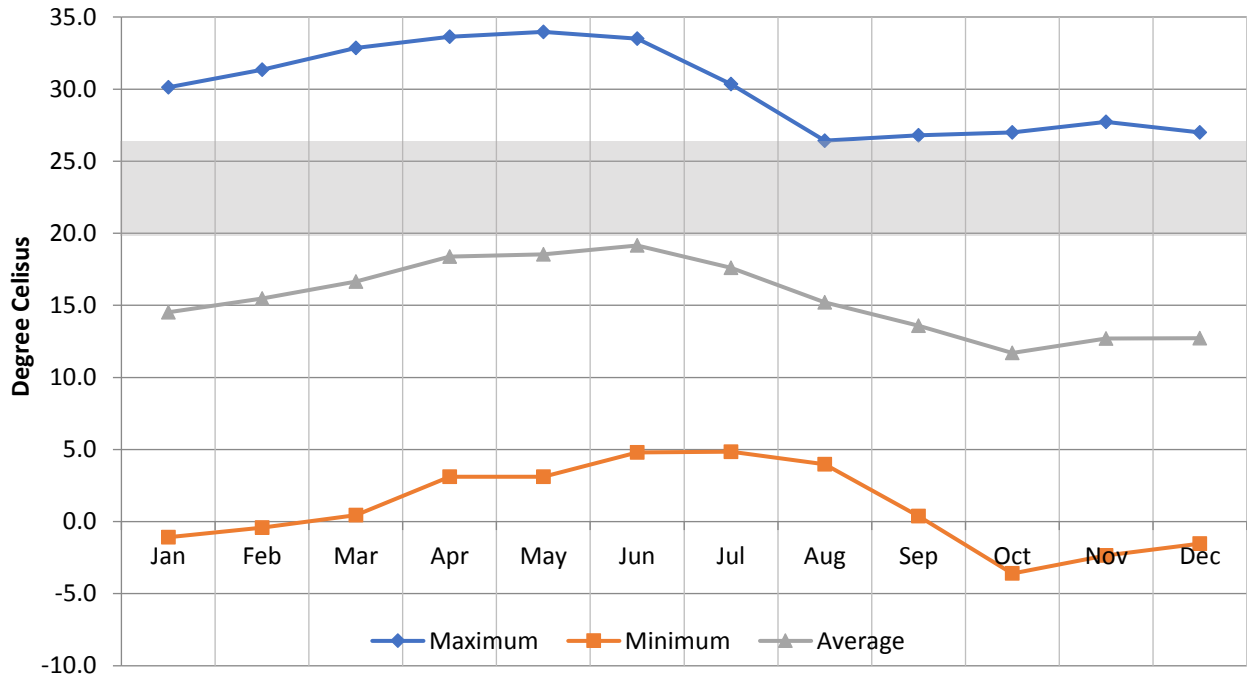


Figure 15: Temperature variation in Addis Ababa

Relative Humidity

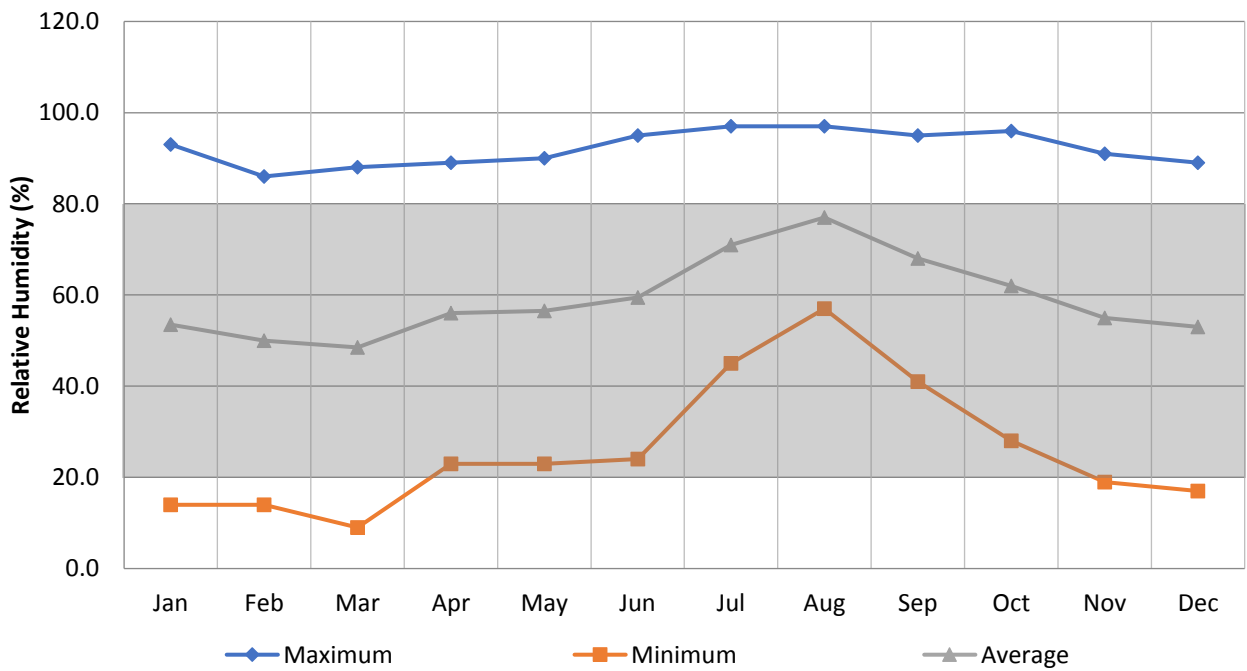


Figure 16: Relative humidity in Addis Ababa

Wind speed

Natural ventilation is most effective when wind speed is 5 mph or greater.

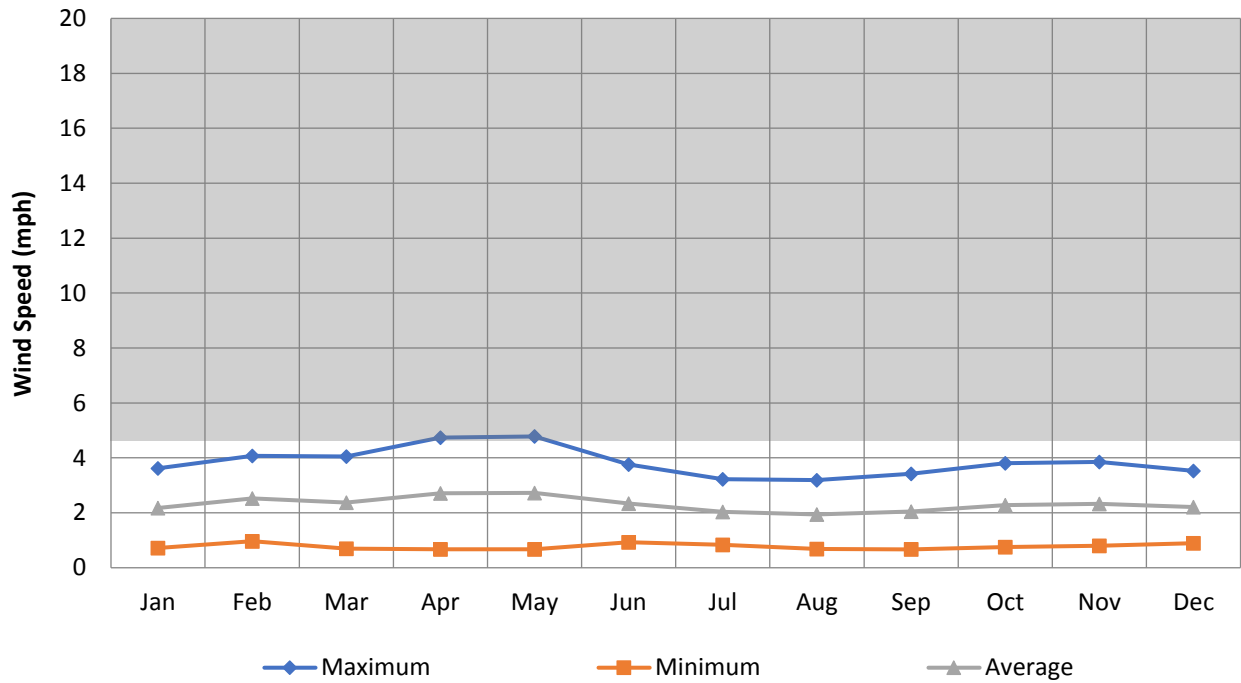


Figure 17: Wind speed in Addis Ababa

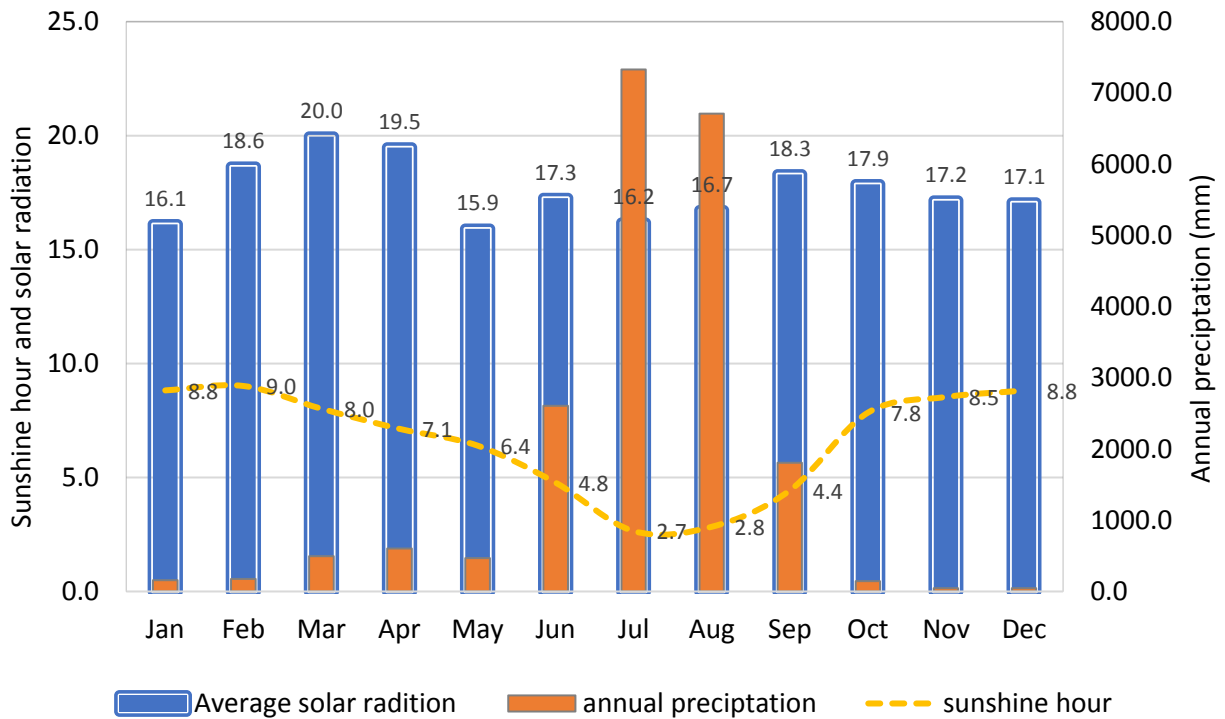


Figure 18: Sunshine hour, solar radiation and annual precipitation in Addis Ababa

Climate Zone 4

Table 5: Geographic location of reference city for climate zone 4

Reference city	Latitude	Longitude	Elevation
Dire Dawa	9.52298°	41.875°	1434 masl

This climate region figure 19 below is characterized by hot and dry summers and moderately cold winters. The extreme maximum temperature range can reach more than 36.3 °c during Autumn season and minimum reach -1.0 °c in winter shown in figure 20 (page 26).

Averagely, this climatic zone has a CDDs of about 84.6 to cool the hot periods in all seasons and HDDs of 19.5 to heat in winter and autumn energy demand. The average precipitation is about 953 mm that occurs with highest in spring and autumn season. From figure 22 (page 27) maximum wind speed is about 6.47 m/s that occurs in summer and the minimum is 0.66 m/s that occurs in Autumn. For some representative towns related to this zone see Appendix 4.

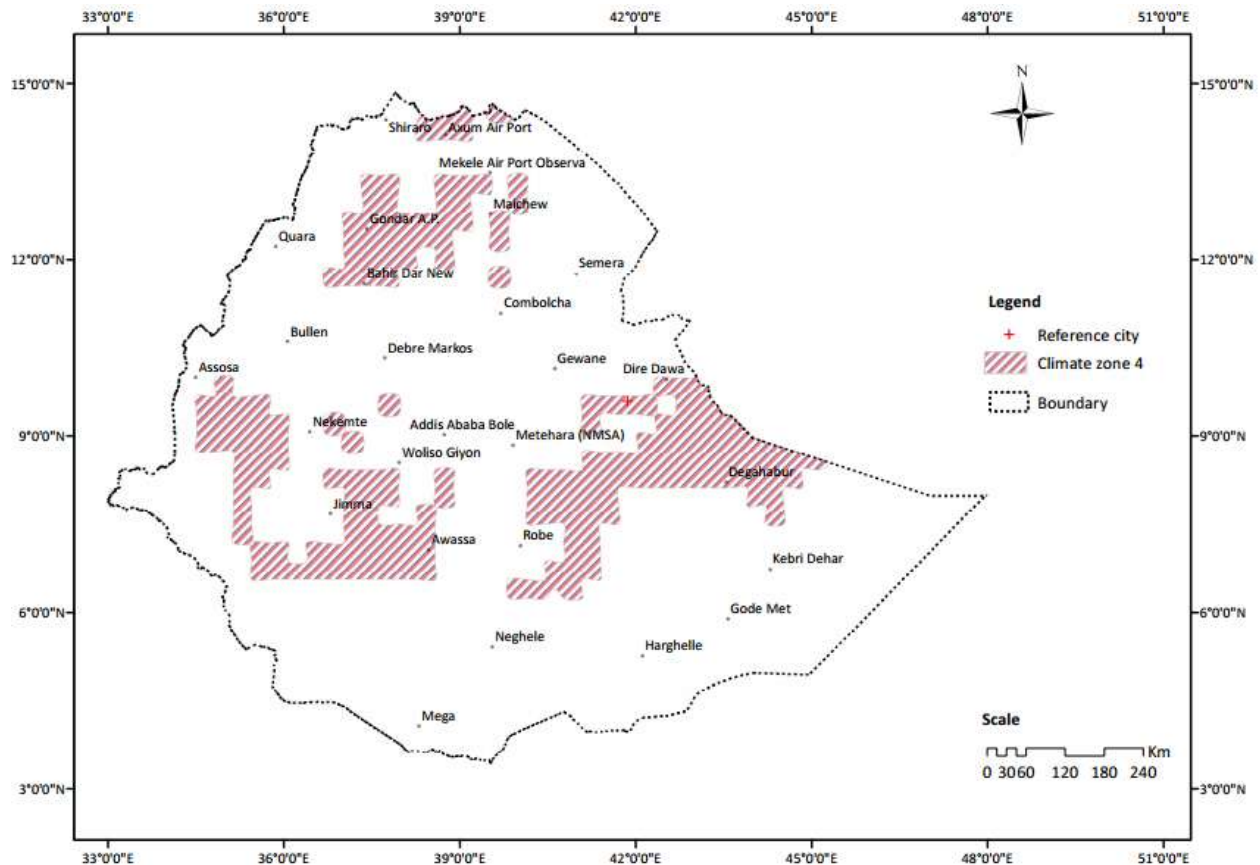


Figure 19: Ethiopia climate zone 4

Temperature

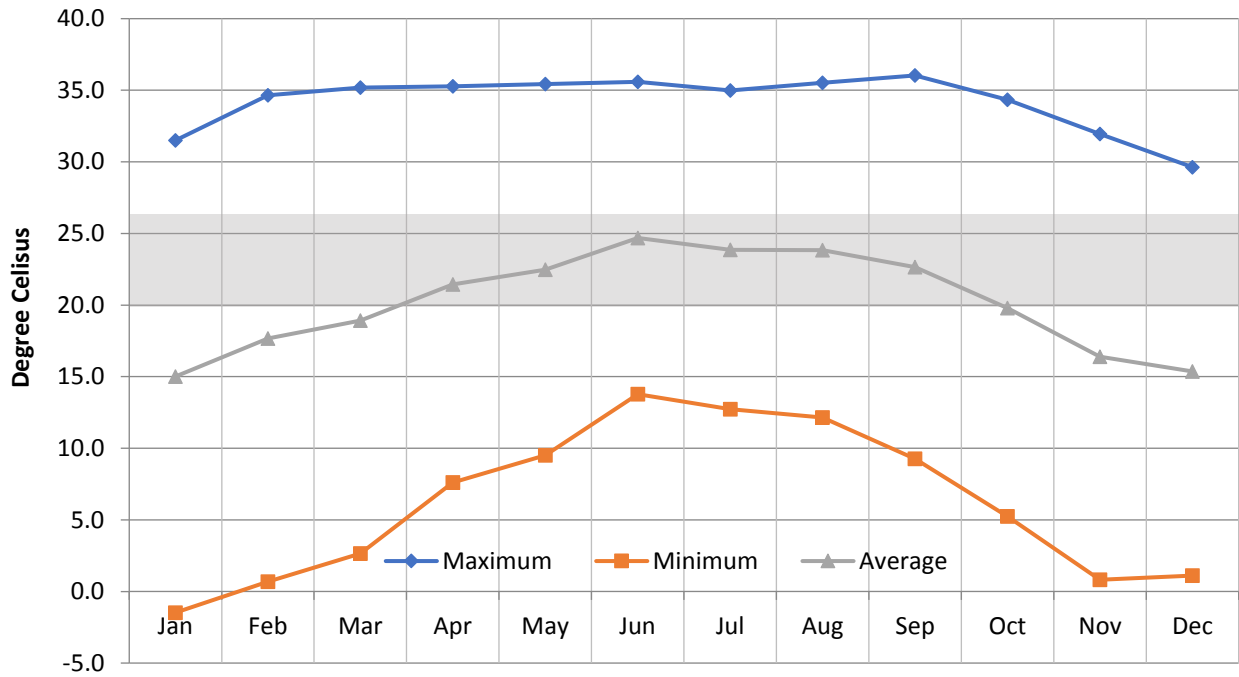


Figure 20: Temperature variation in Dire Dawa

Relative Humidity

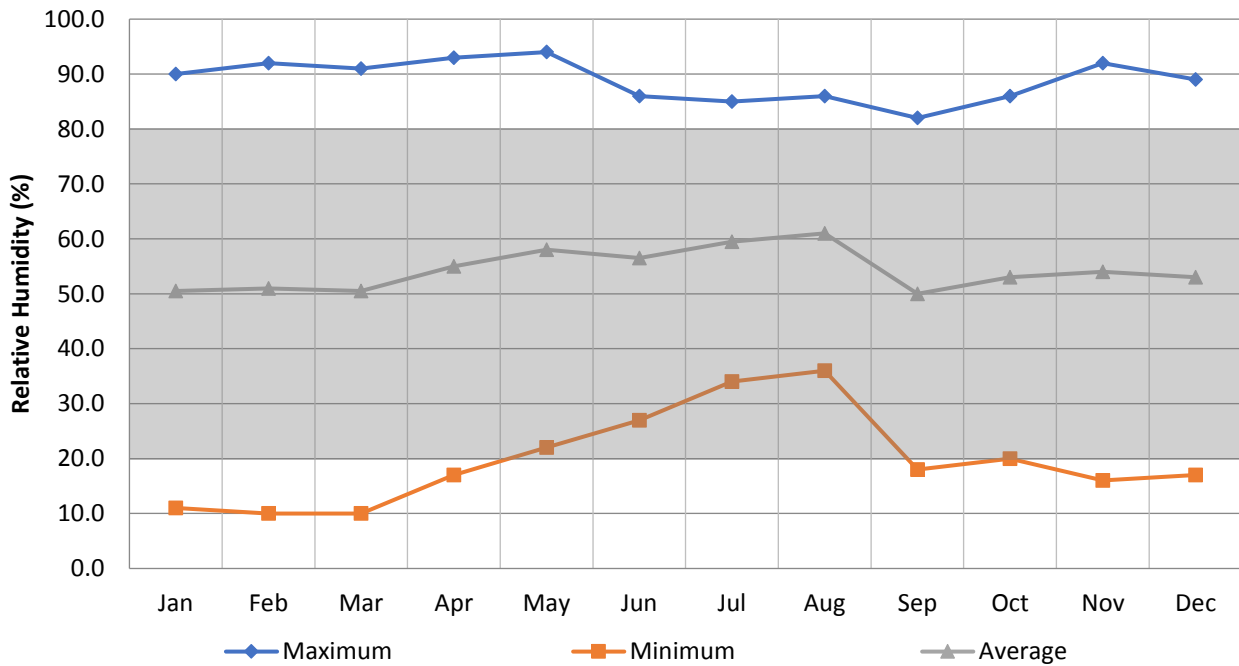


Figure 21: Relative humidity in Dire Dawa

Wind speed

Natural ventilation is most effective when wind speed is 5 mph or greater

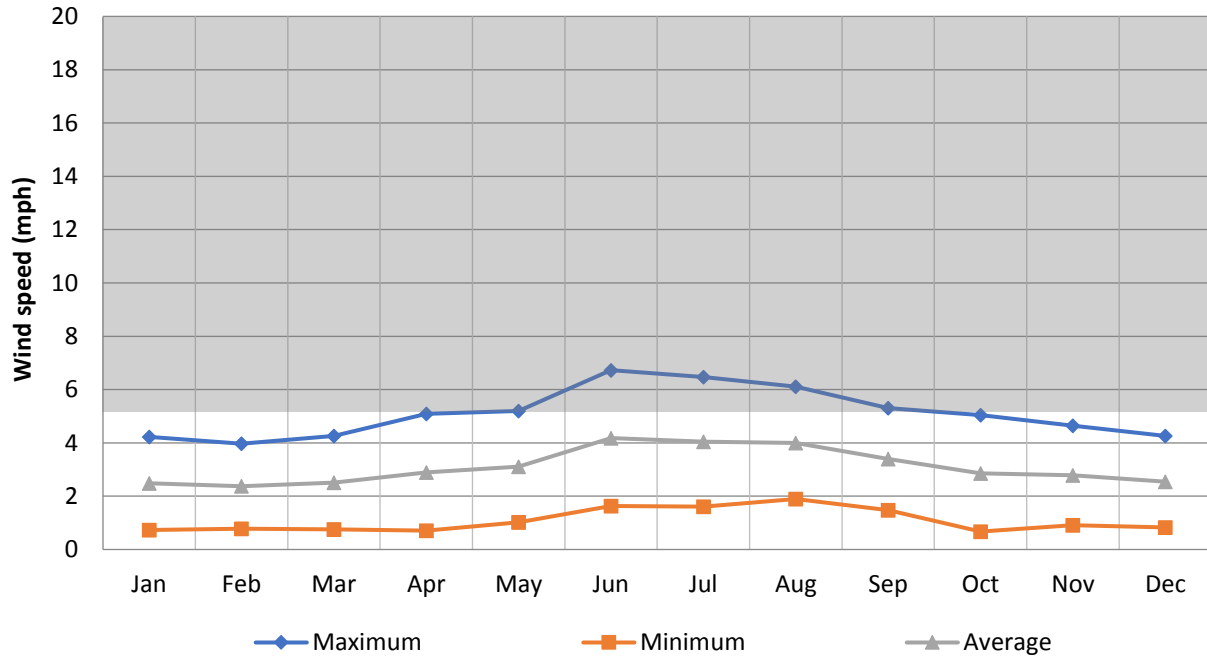


Figure 22: Wind speed in Dire Dawa

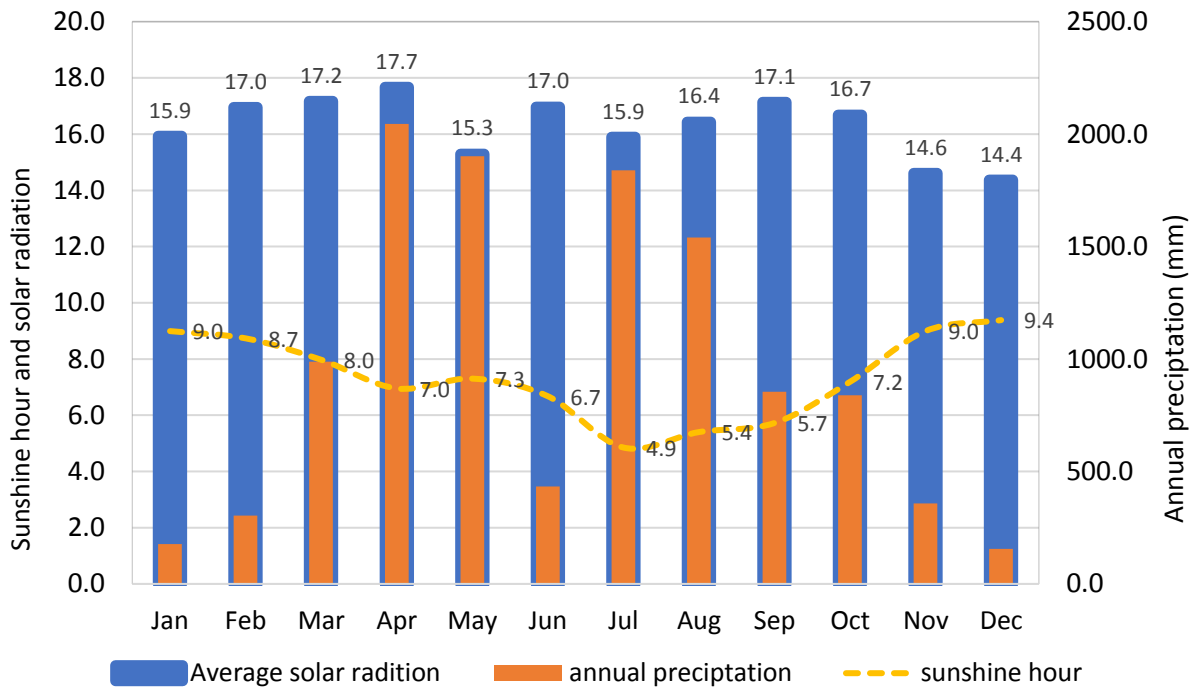


Figure 23: Sunshine hour, solar radiation and annual precipitation in Dire Dawa

Climate Zone 5

Table 6: Geographic location of reference city for climate zone 5

Reference city	Latitude	Longitude	Elevation
Gode	5.77623°	43.4375°	331 masl

This climate region is characterized by extremely hot and dry throughout the year. see figure 24 below for its locational coverage. The extreme maximum temperature range can reach 41.2 °c during spring season and minimum reach 13.6 °c in winter shown in figure 25 (page 29) for this climate zone. Averagely, this climatic zone has a CDDs of about 290.7 to cool the hot periods in all seasons and zero HDDs demand. The average precipitation is about 976 mm that occurs with highest in spring and autumn season. The maximum wind speed is about 7.7 m/s that occurs in summer and the minimum is 0.84 m/s that occurs in Autumn shown in figure 27 (page 30). For some representative towns related to this zone see Appendix 5.

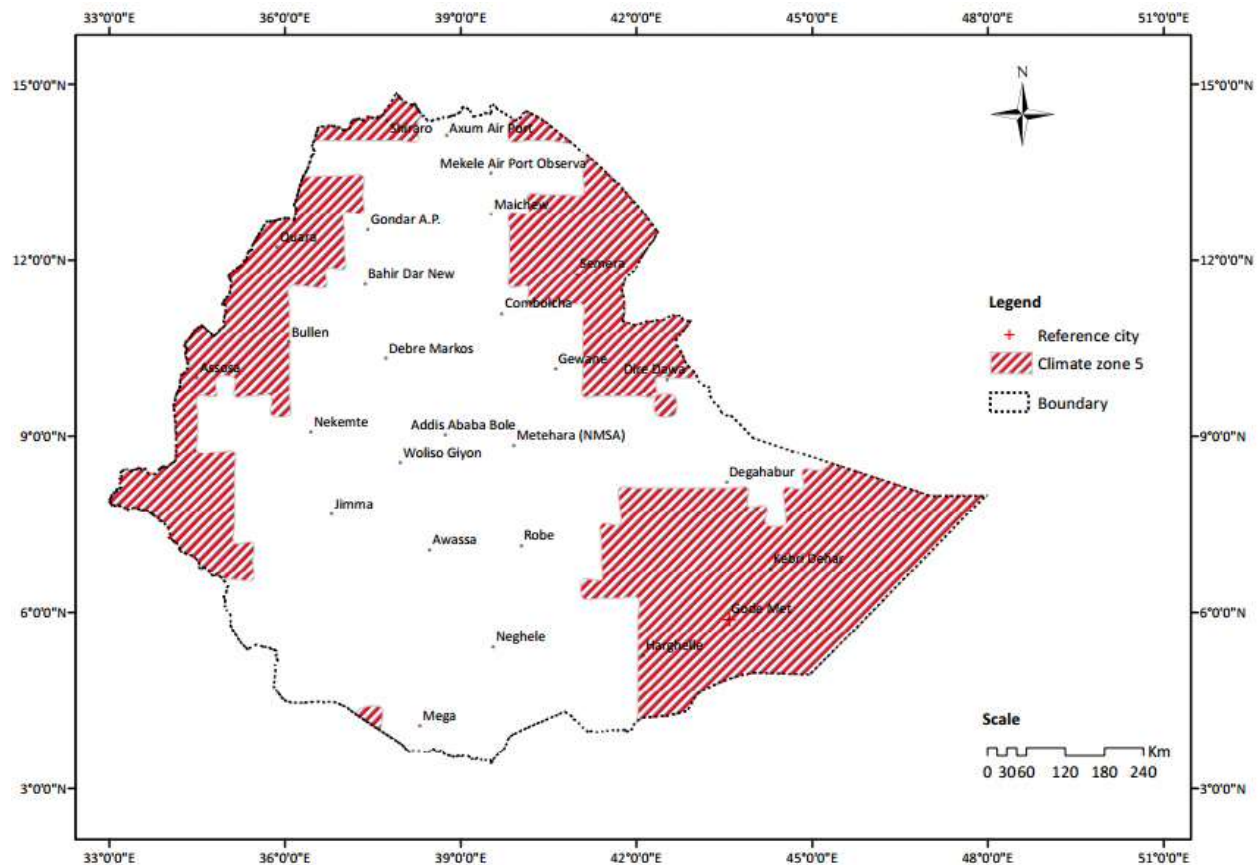


Figure 24: Ethiopia climate zone 5

Temperature

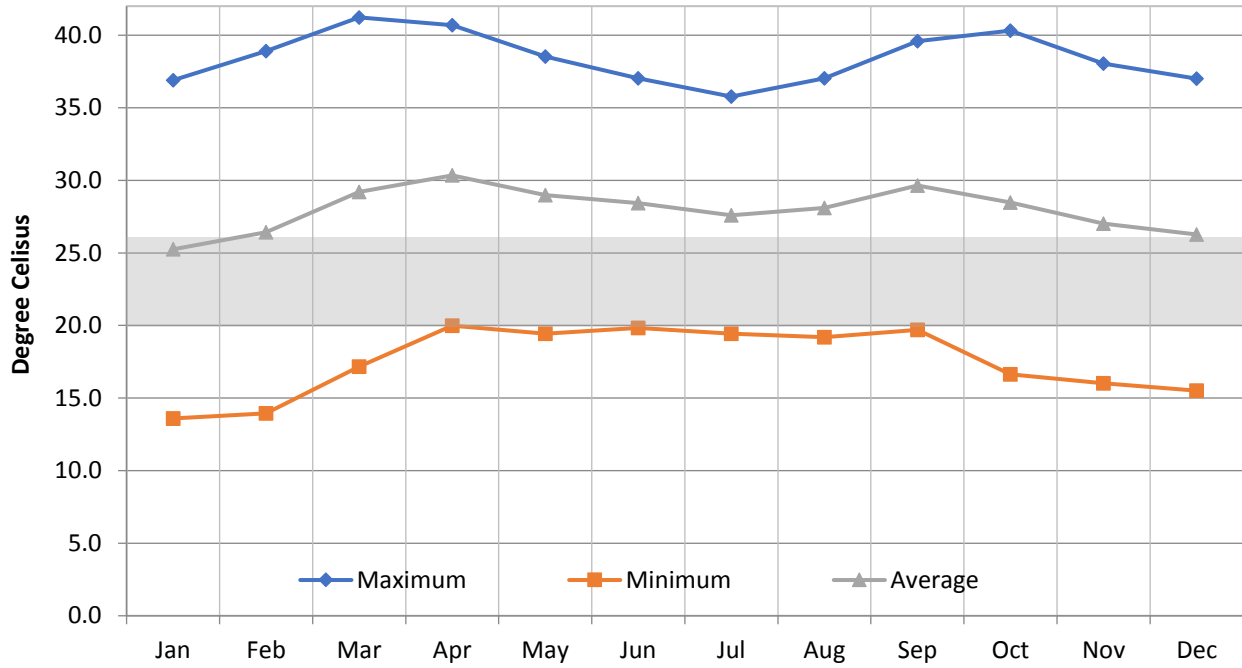


Figure 25: Temperature variation in Gode

Relative Humidity

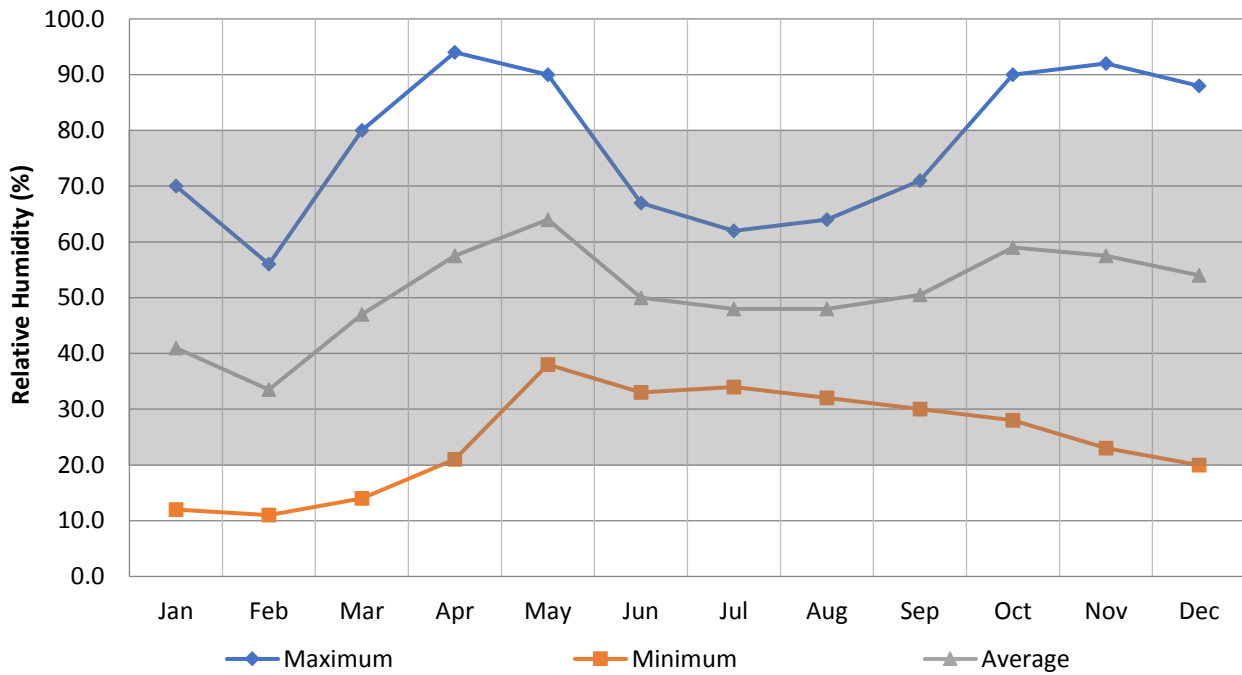


Figure 26: Relative humidity in Gode

Wind speed

Natural ventilation is most effective when wind speed is 5 mph or greater

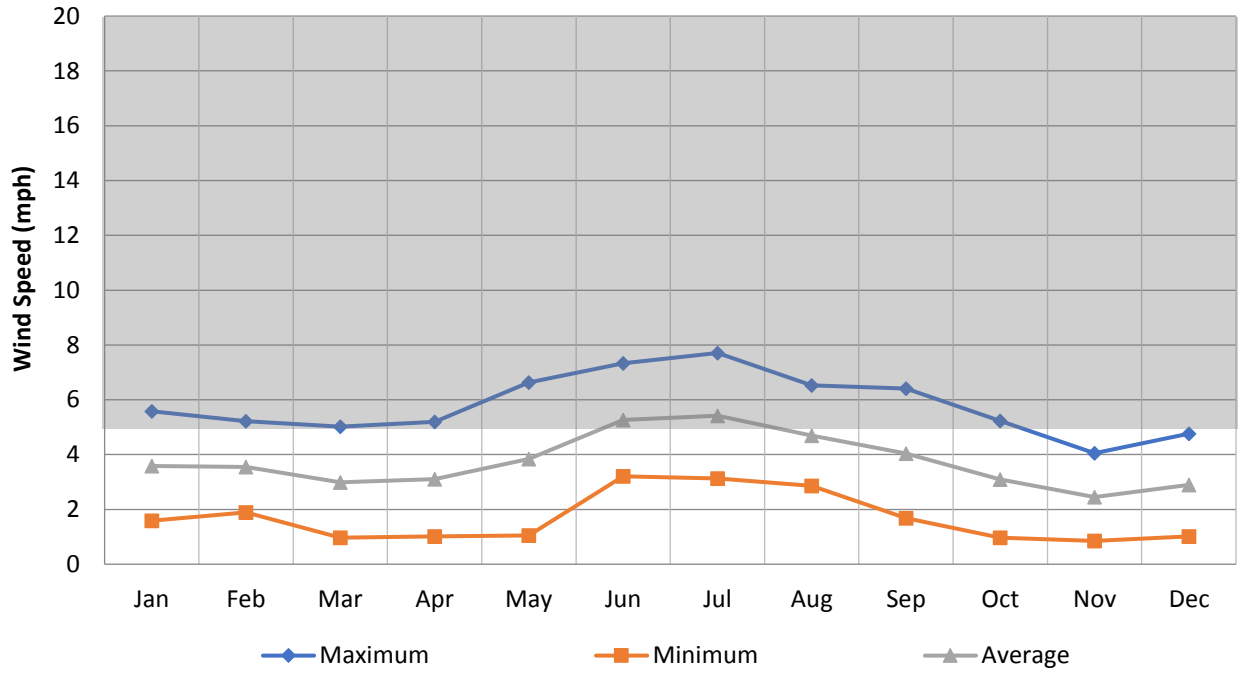


Figure 27: Wind speed in Gode

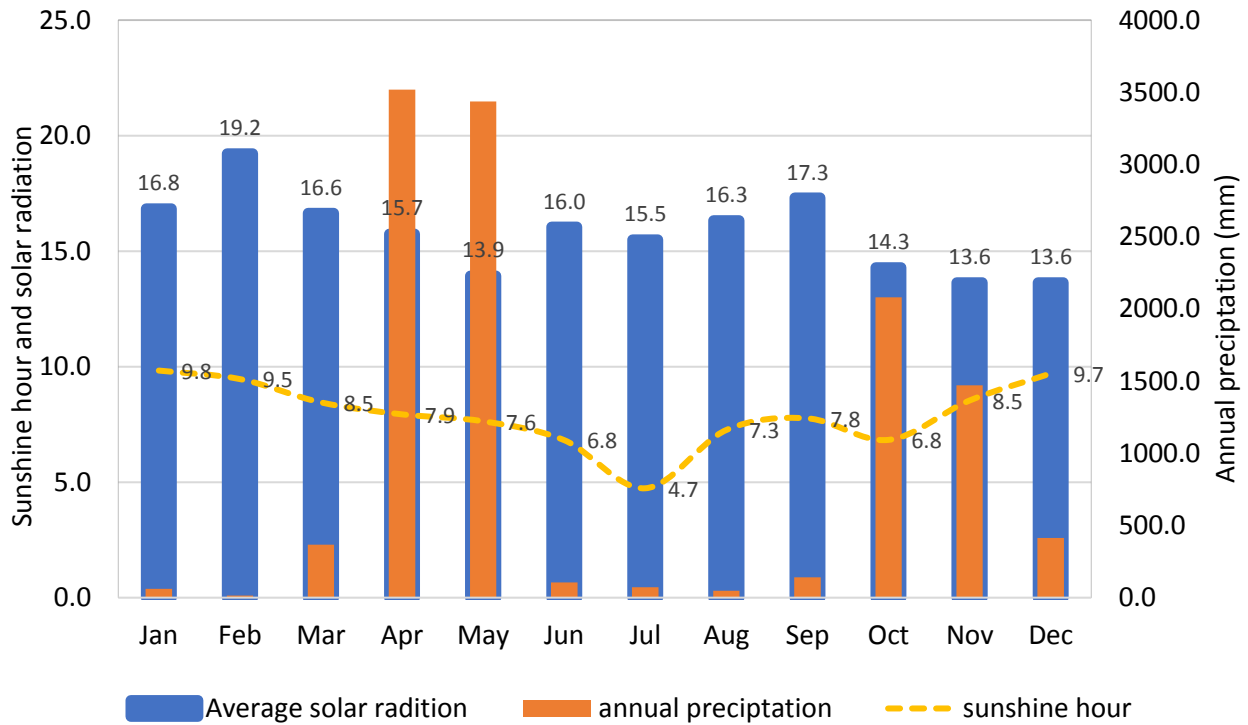


Figure 28: Sunshine hour, solar radiation and annual precipitation in Gode

Table 7: Summary of the regional character of each climatic zone (1-5 zone) with respect to climatic parameters horizontally listed.

Region	Reference city	Altitude (m.a.s.l)	Average Temp (°C)	Average RH (%)	Average Precipitation (mm)	Sunshine hour (Hr./day)	Max wind speed (m/s)	Min wind speed (m/s)	Average CDD	Average HDD
1	Goba Robe	2608	11.89	62.71	2.96	6.6	5.07 Dece	0.75 Oct	0.00	191.50
2	Robe	2503	13.62	62.83	2.96	6.9	4.21 April	0.47 August	0.09	145.31
3	Addis Ababa	2138	15.52	59.17	14.95	6.6	4.78 May	0.67 Sept	41.23	20.91
4	Dire Dawa	1434	20.17	54.33	22.26	7.3	6.73 June	0.67 Octo	84.67	19.58
5	Gode	331	27.98	50.83	22.37	7.9	7.71 July	0.85 Nove	290.71	0.00

4.2. Analyzing and visualize the sun path diagram and sun angles for reference cities of Ethiopia to decide cut off times.

The process of accommodation to change in the variableness of solar access, defined as the paths of daily and seasonal variation in the suns relationship to earth can define the quality of our lives, the energy performance of building and human comfort level (Knowles., 1981). Solar access has unlimited significance to human physical comfort, maintenance of thermal equilibrium between human body temperature and environment, to ensure appropriate distribution of daylight and visual access.

Complete understanding of solar positioning is necessary for reasonable solar design and climatic response or to study its movement, lighting or heating impact and behavior. Depending on the day of the year and latitudinal location it is simple to know where the sun exactly rises or sets and its relative position to spot on the earth using altitude and bearing angle (Szokolay., 1996). By using this time data and suns position angle one can define a building envelope to control shadows or to keep the solar right and construct the solar building envelope.

To construct the solar envelope it is important firstly, to trace the path of sun over each representative city using Sun path diagrams which is a convenient way of representing the annual changes in the path of the Sun through the sky on a single 2D stereographic diagram derived from Latitudinal location, declination angle, azimuth, altitude and hour angle.

Secondly, deciding the cut-off time or important period of insolation to protect solar access to the surroundings. From the point of view of energy conservation, because the solar collectors need direct exposure to the sun, the most desired hours would be about three hours before and afternoon or six hours daily. Starting from that, the envelope can be constructed as a 3D surface using standard CAD commands to create solids through extrusion and to apply Boolean operations on them.

Goba Robe Town Sun path diagram (zone 1)

The sun appears at maximum altitude or noon (82.3°) in September at 12 PM and minimum altitude (-16.1°) at 4.6 AM sun rise and 19.4 PM sun set time during December and June solstice, respectively. The maximum Azimuth angle observed at sun rise and sun set time is 89.25° as shown below figure 29.

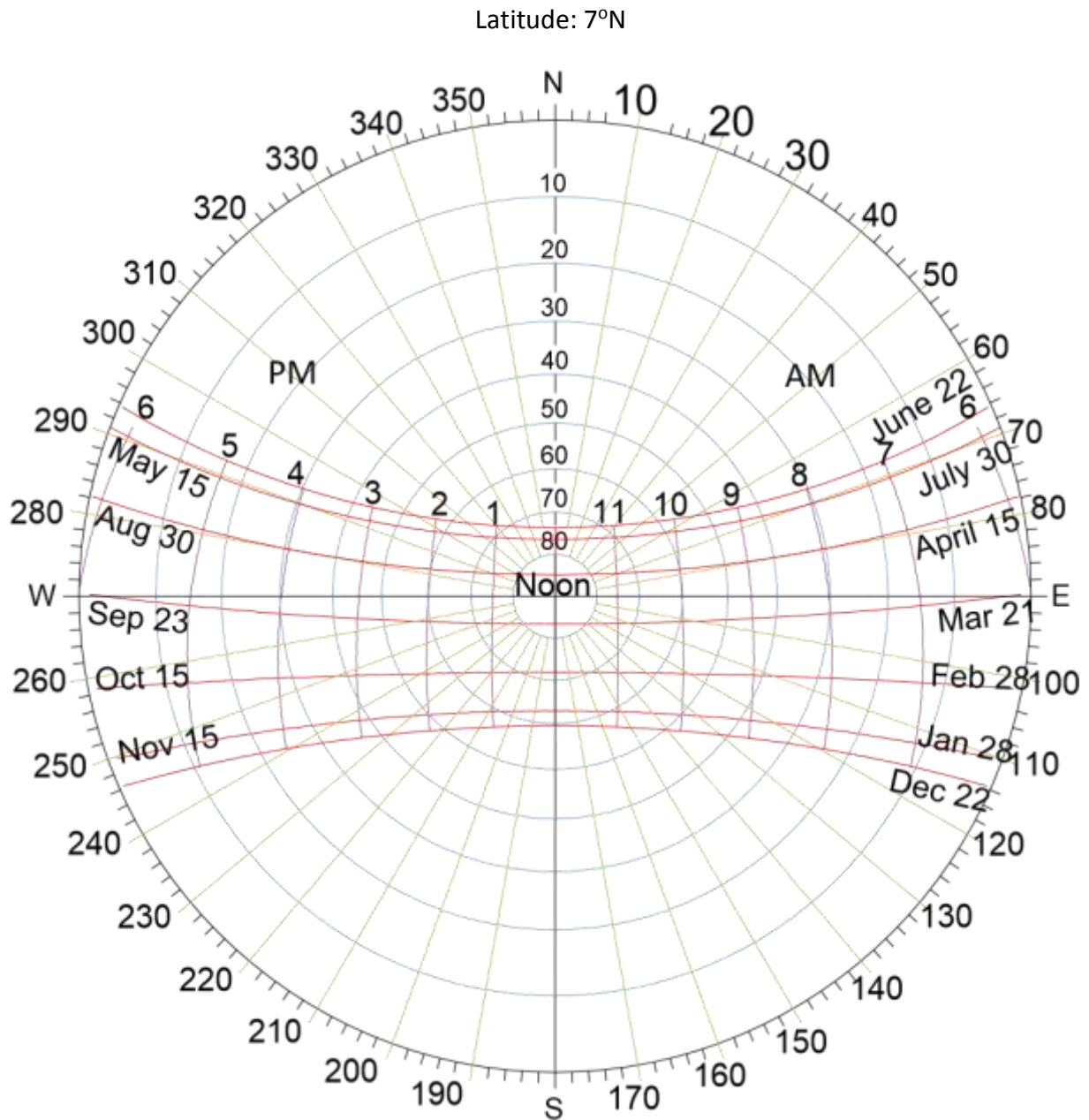
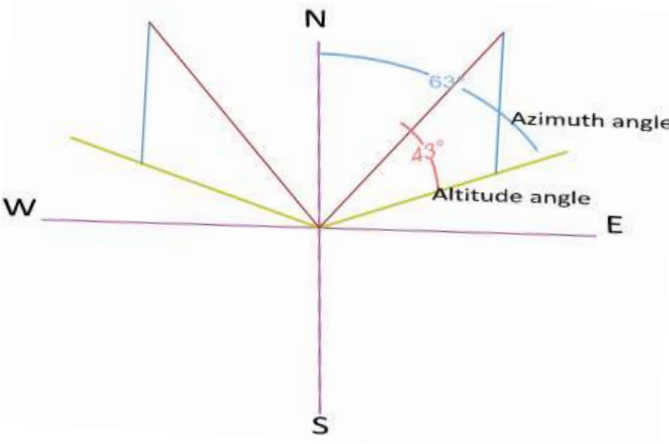
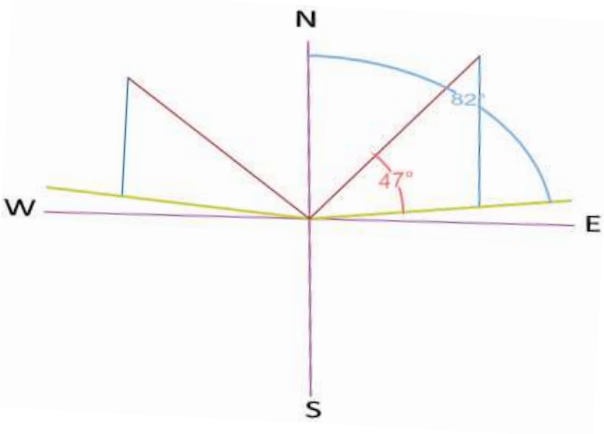
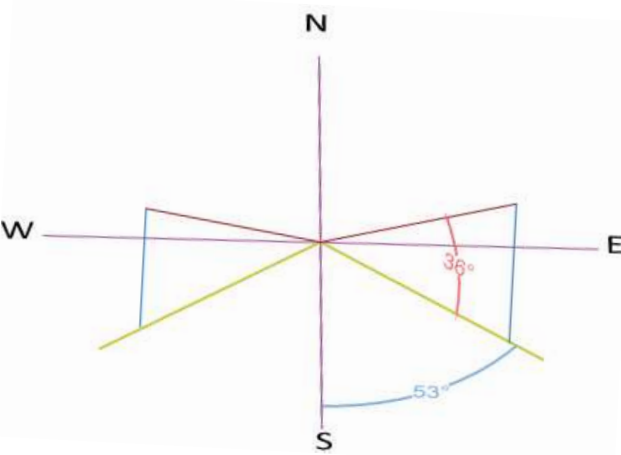


Figure 29: Sun path Diagram for Goba Robe Town (zone 1)

Table 8: Extreme Case of June, September and December Cut Off Times for Goba Robe Town

Cutoff times	June	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	43.82	43.82
	Azimuth	-63.99	63.99
	September	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	44.45	44.45
	Azimuth	-82.10	82.10
	December	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	36.50	36.50
	Azimuth	-53.78	53.78

Robe Town Sun path diagram (zone 2)

The sun appears at maximum altitude or noon (81.36°) in September at 12 PM and minimum altitude (-15.67°) at 4.6 AM sun rise and 19.4 PM sun set time during December and June solstice. The maximum Azimuth angle observed at sun rise and sun set time with 89.32° below figure 30 sun path diagram in September near to equator.

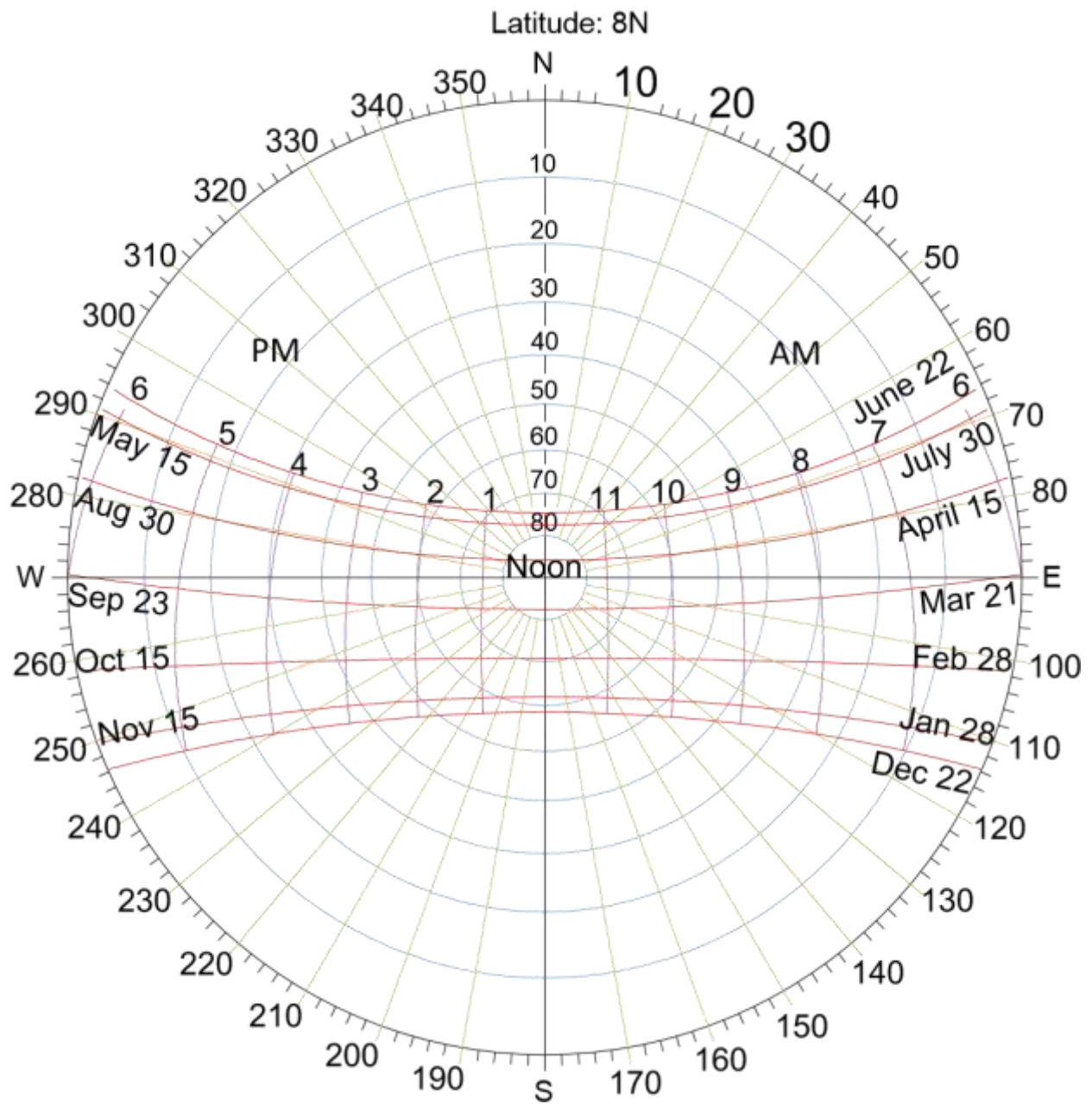
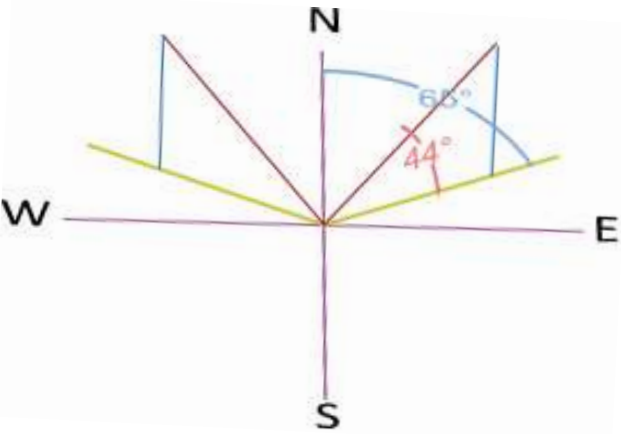
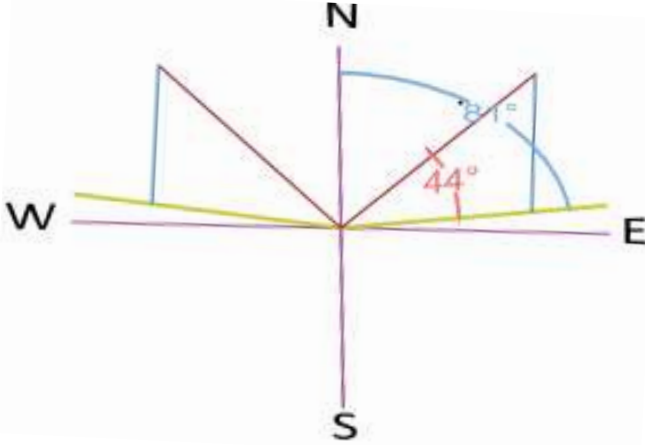
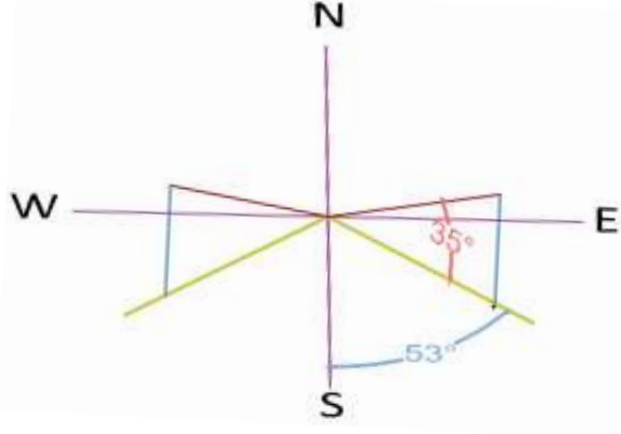


Figure 30: Sun path diagram for Robe Town (zone 2)

Table 9: Extreme Case of June, September and December Cut Off Times for Robe Town

Cutoff times	June	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	44.22	44.22
	Azimuth	-64.81	64.81
	September	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	44.32	44.32
	Azimuth	-81.19	81.19
	December	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	35.95	35.95
	Azimuth	-53.23	53.23

Addis Ababa City Sun path diagram (zone 3)

The sun appears at maximum altitude or noon (80.42°) in September at 12 PM and minimum altitude (-15.2°) at 4.6 AM sun rise and 19.4 PM sun set time during December and June solstice. The maximum Azimuth angle observed at sun rise and sun set time with 89.24° below figure 31 sun path diagram in September near to equator.

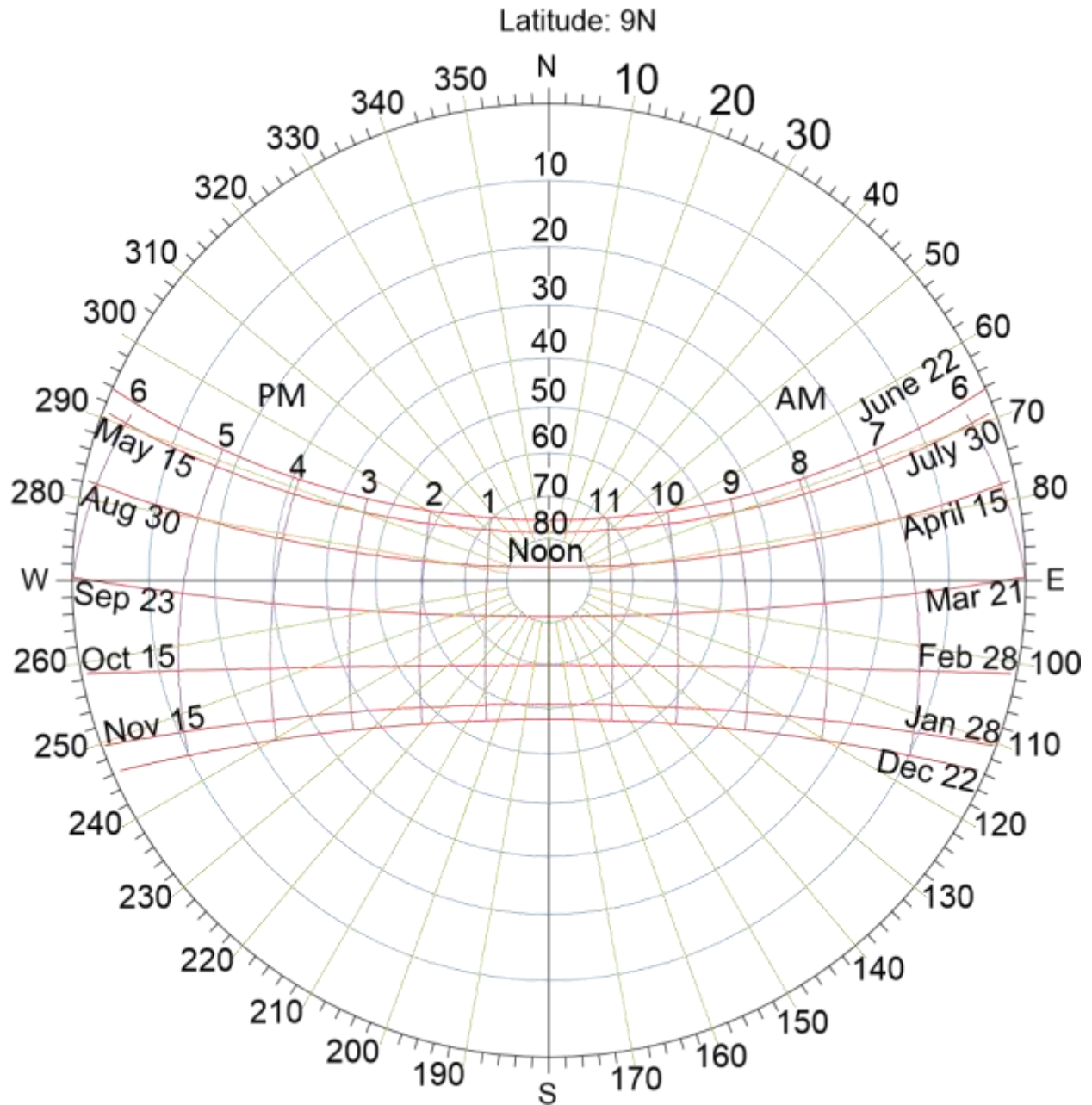
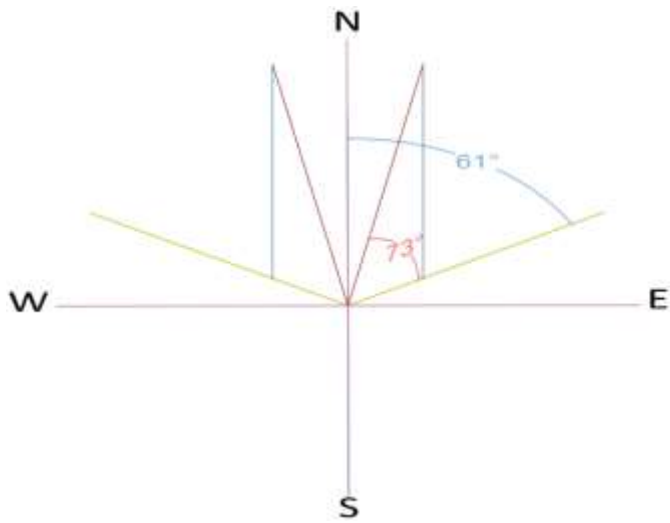
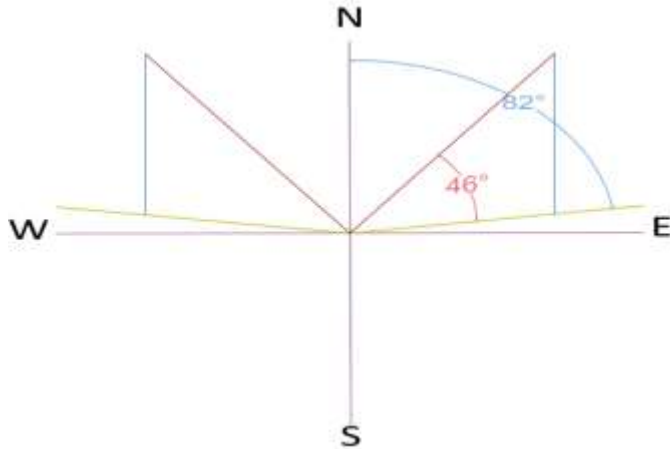
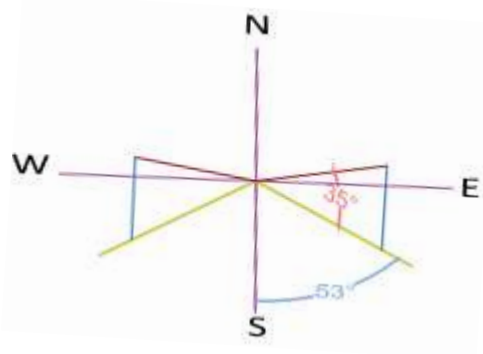


Figure 31: sun path diagram for Addis Ababa City (zone 3)

Table 10: Extreme Case of March ,December and August Cut Off Times for Addis Ababa City

Cutoff times	March	Morning	Afternoon
	Time	11:00 AM	13:00 PM
	Altitude	-72.89	72.89
	Azimuth	-61.43	61.43
	August	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	-45.7	45.7
	Azimuth	-82.9	82.9
	December	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	-35	35
	Azimuth	-53	53

Dire Dawa City Sun Path Diagram (zone 4)

The sun appears at maximum altitude or noon (79.9°) in September at 12 PM and minimum altitude (-14.9°) at 4.6 AM sun rise and 19.4 sun set time during December and June solstice. The maximum Azimuth angle observed at sun rise and sun set time with 89.32° below figure 32 sun path diagram in September near to equator.

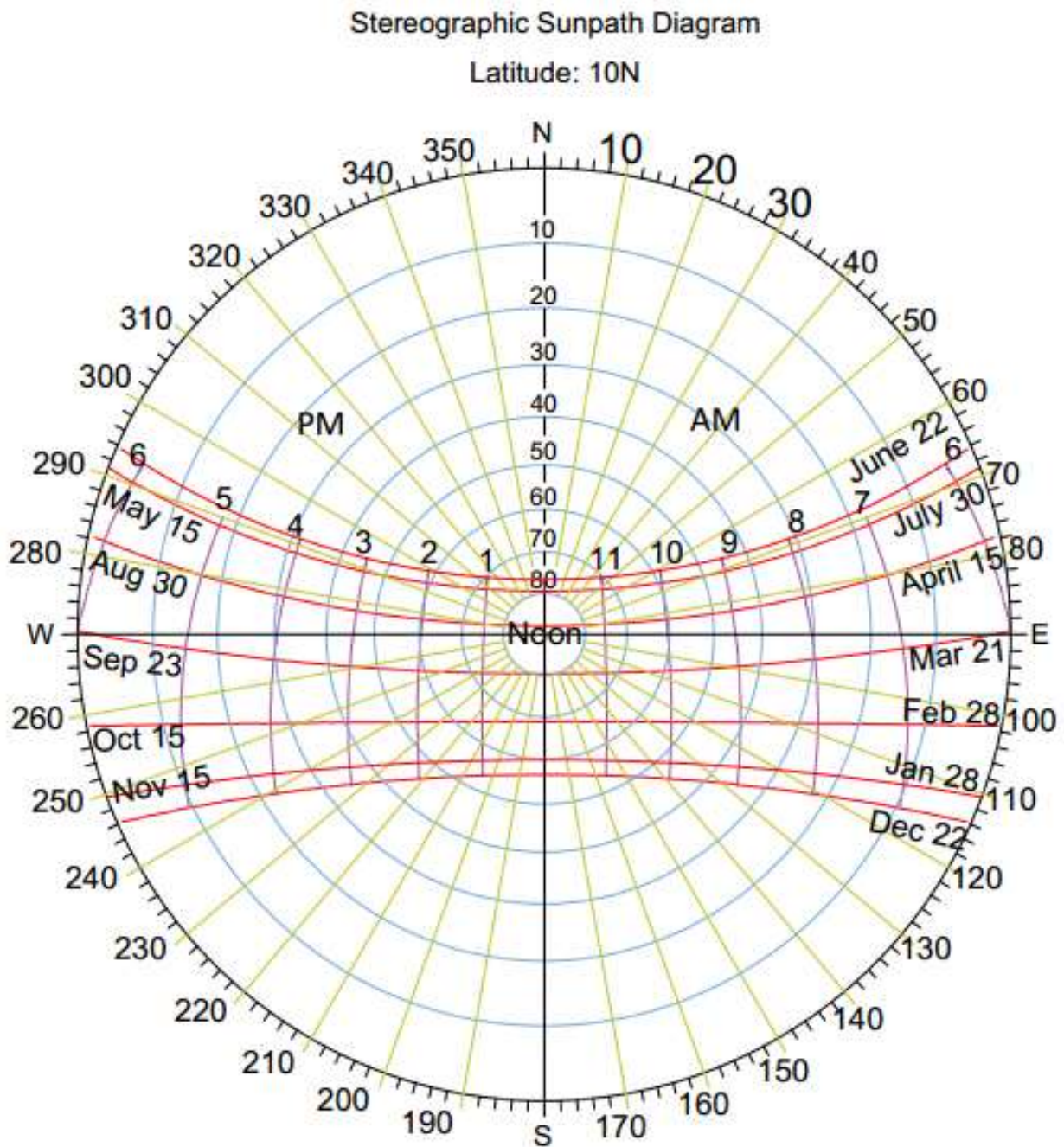


Figure 32: Sun path diagram for Dire Dawa city (zone 4)

Table 11: Extreme Case of June, September and December Cut Off Times for Dire Dawa City

Cutoff times		June	Morning	Afternoon
	Time		9:00 AM	15:00 PM
	Altitude		-69.98	69.98
	Azimuth		-45.9	45.9
	September	Morning	Afternoon	
	Time		9:00 AM	15:00 PM
	Altitude		43.06	43.06
	Azimuth		-79.69	79.69
	December	Morning	Afternoon	
	Time		9:00 AM	15:00 PM
	Altitude		34.00	34.00
	Azimuth		-52.34	52.34

Gode Town Sun Path Diagram (zone 5)

The sun appears at maximum altitude or noon (73.69°) in September at 12 PM and minimum altitude (-20.9°) at 4.6 PM sun rise and 19.4 AM sun set time during December and June solstice. The maximum Azimuth angle observed at sun rise and sun set time with 89.26° below figure 33 sun path diagram in September near to equator.

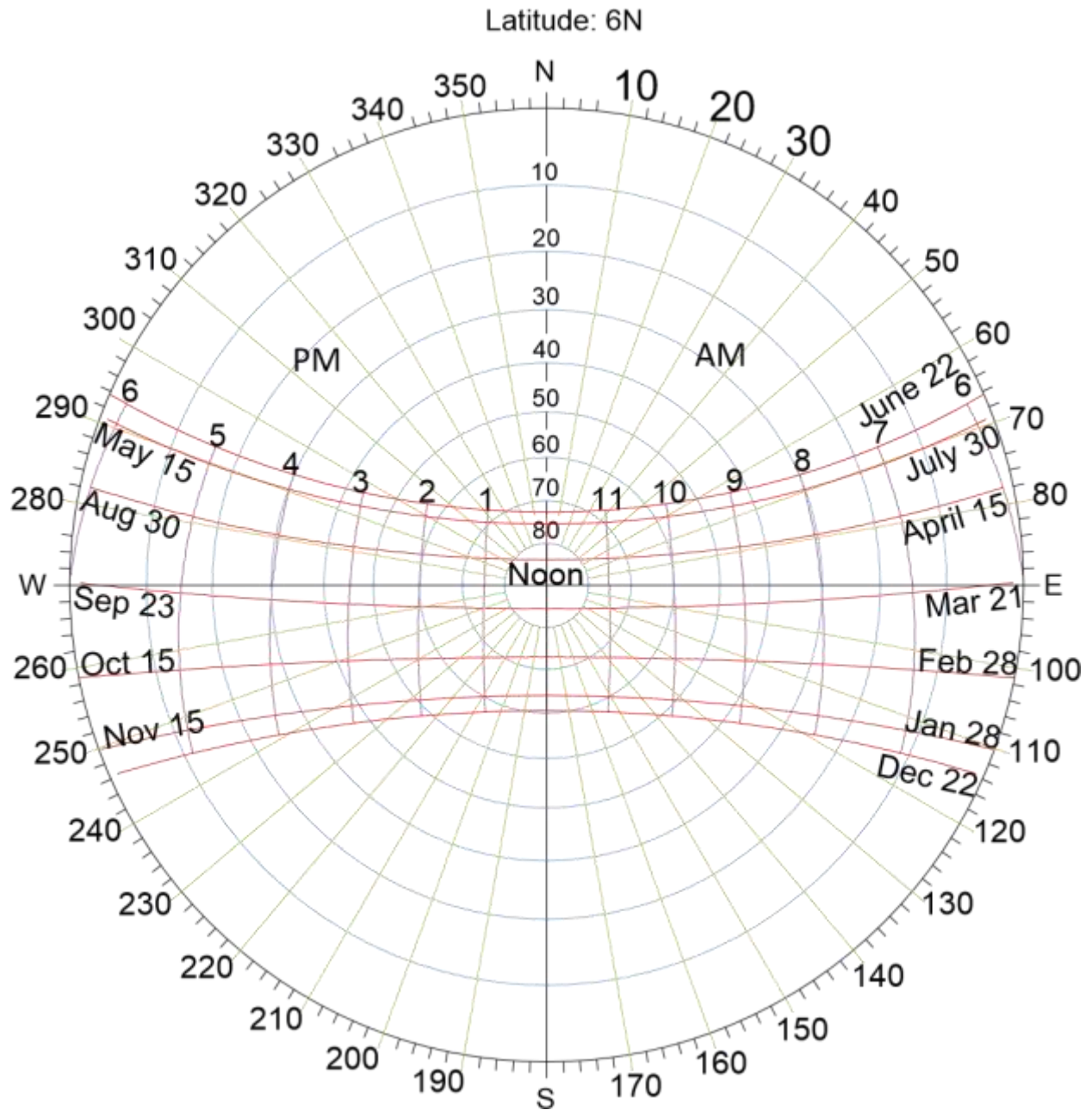
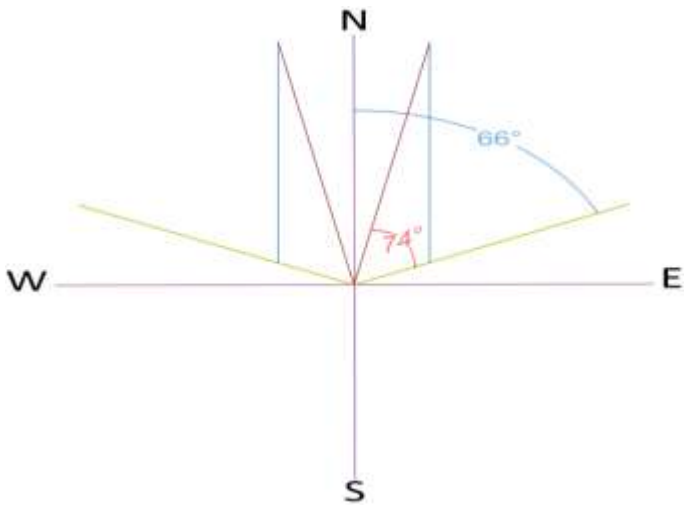
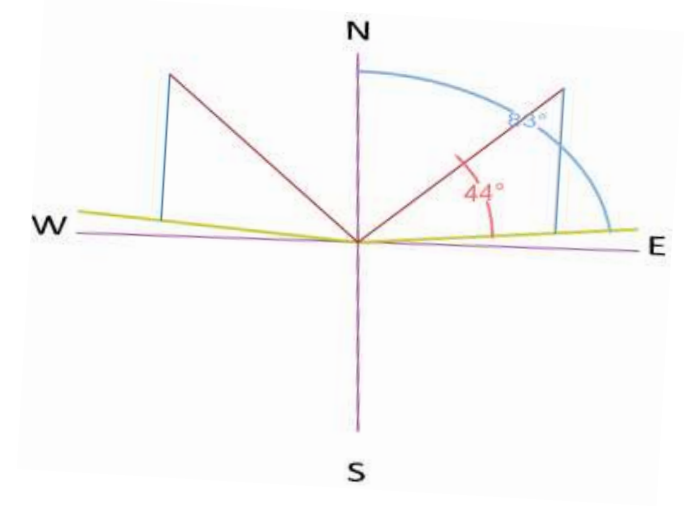
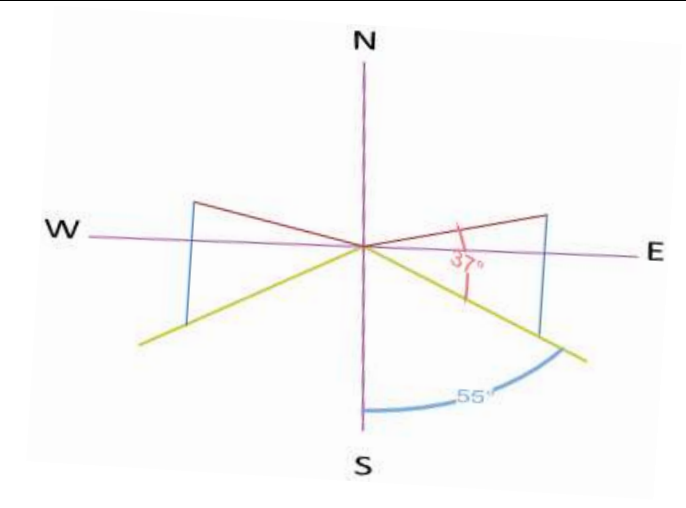


Figure 33: Sun path diagram for Gode Town (zone 5)

Table 12: Extreme Case of April, September and December Cut Off Times for Gode Town

Cutoff times	April	Morning	Afternoon
	Time	11:00 AM	13:00 PM
	Altitude	-73.92	73.92
	Azimuth	-66.09	66.09
	September	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	44.61	44.61
	December	Morning	Afternoon
	Time	9:00 AM	15:00 PM
	Altitude	37.23	37.23
	Azimuth	-54.54	54.54

CHAPTER FIVE

RESULT

5.1 Cooling Degree Days of Ethiopia

Analyzing the calculated data from 952 stations the value of CDDs varies from region to region. The highest value of CDDs about 2659 degree days for the whole period is recorded in the Eastern and western borders of Ethiopia as shown in Figure 34 below.

In contrast, the lowest value of CDDs is zero degree days recorded in the central part of Ethiopia shown below in Figure 34. This large difference in CDD values from region to region shows the intense contrast in the climatic characteristics between geographic points and it gives an idea about variability of their energy demands. Between the two extremes, intermediate CDDs are observed.

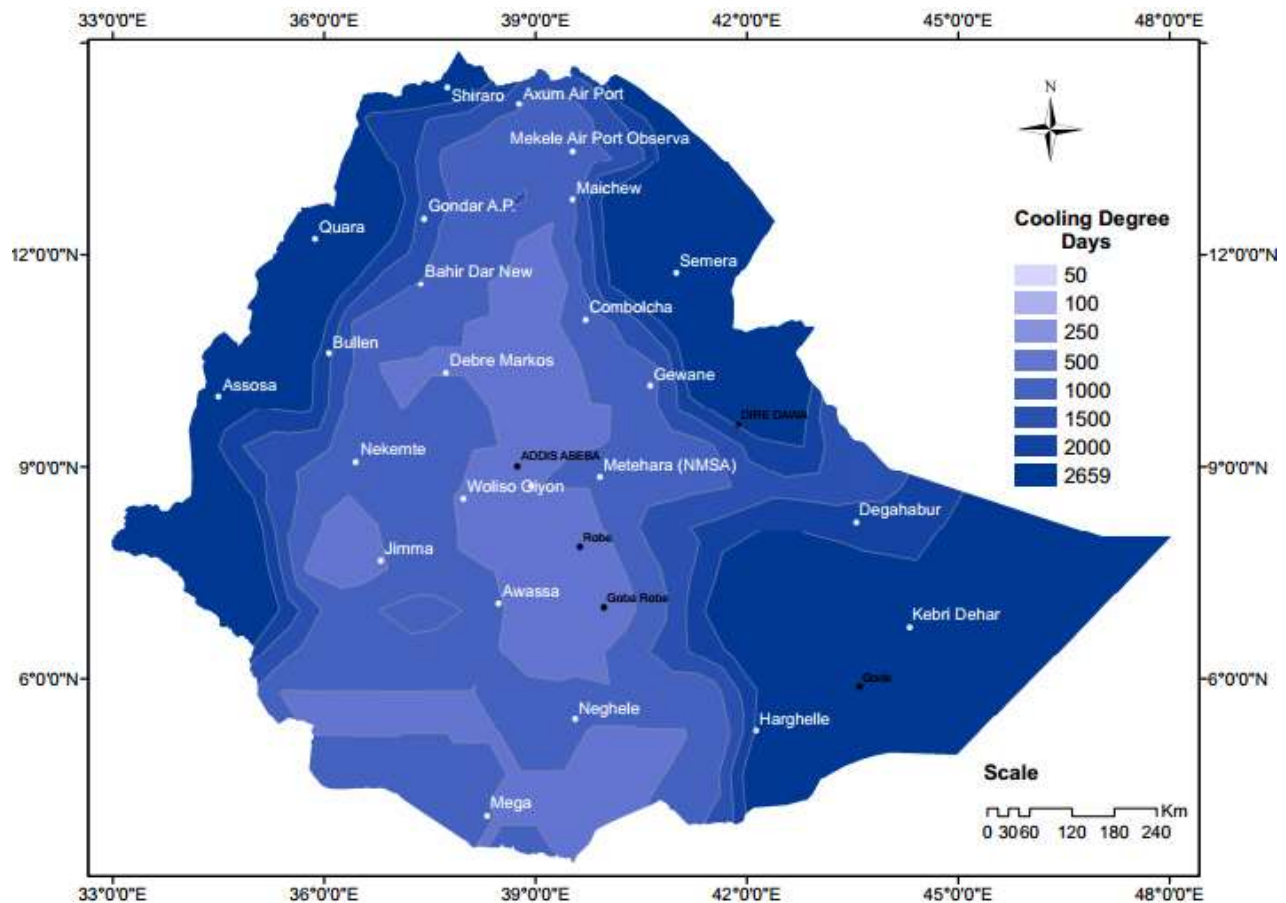


Figure 34: Cooling Degree Days for Ethiopia climate zone

5.2. Heating Degree Days of Ethiopia

Similarly, the value of HDDs varies considerably from region to region. The highest value of HDDs (about 2659 degree days) for the whole period is recorded in the central part of Ethiopia around Robe town in Oromia region as shown below figure 35. The lowest is observed or found in the Eastern and Western peripheral parts of Ethiopia as shown in figure 35 below. This implies that more heating is needed to avoid the coldness.

The difference in HDD values from region to region shows the intense contrast in the climatic characteristics between geographic points; and it gives an idea about the energy demands.

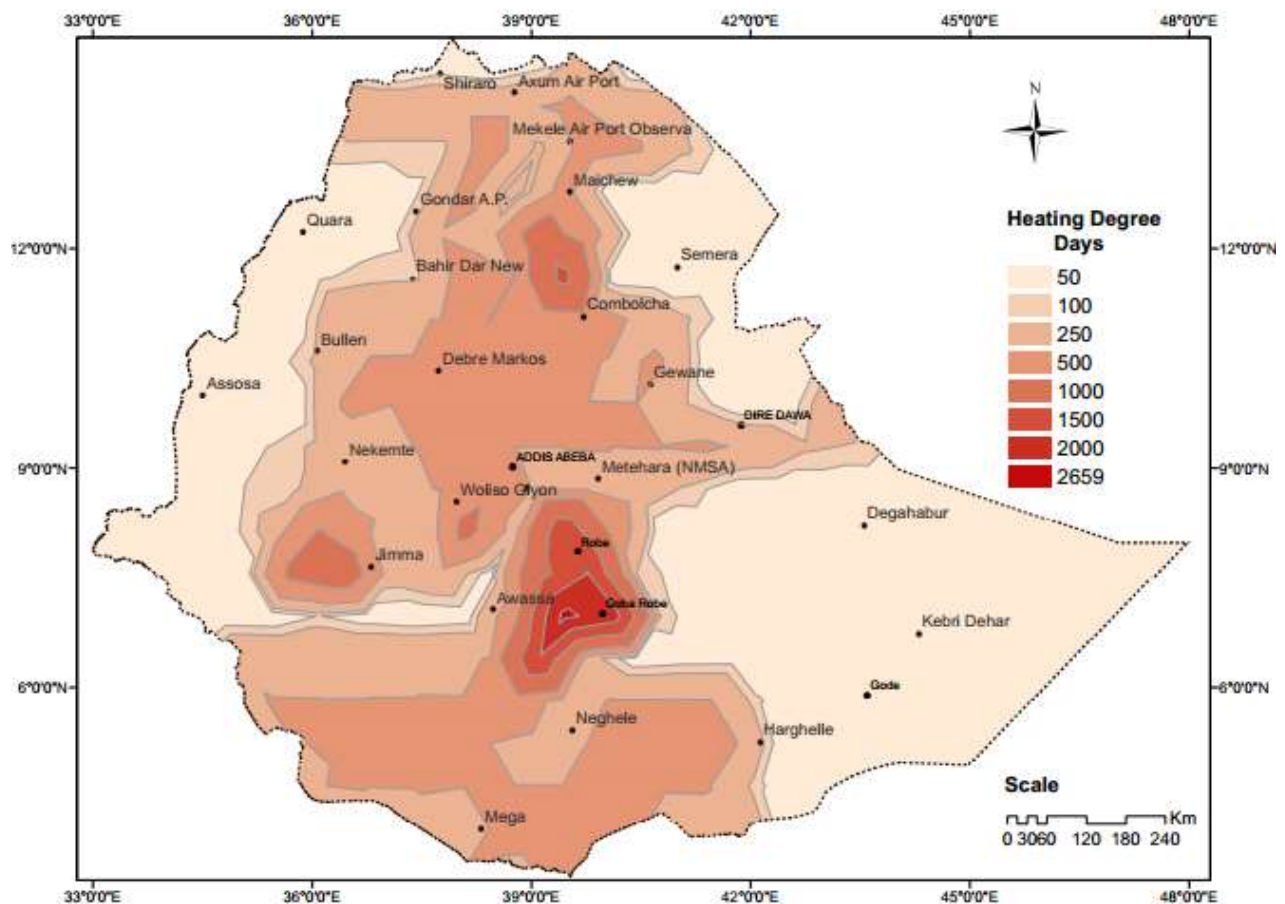


Figure 35: Heating Degree Days for Ethiopia climate zone

5.3. Ethiopian Climatic Zones based on Cooling and Heating Energy demand

The climate of Ethiopia is classified into five zones based on above Table 1 (page 10) ASHRAE energy standard and presented below in Figure 36. The energy requirements for heating in zone 1, 2 and few in 3 is higher in comparison with values recorded in zone 4 and 5, a place located in South Eastern, North Western and Eastern part of Ethiopia. The elevation is higher in central part of Ethiopia which needs heating or having high HDD than the warm and hot areas of zone 5 and 6 having low HDD and high CDD.

zone 1, 2 and 3 are moderate and are places where a high concentration of cities and towns which needs optimum HDD and CDD are found. their energy requirement to heat and cool is low compared to zone 5 and 6. Shading is highly required for zone 5 and 6 than zone 1, 2 and 3.

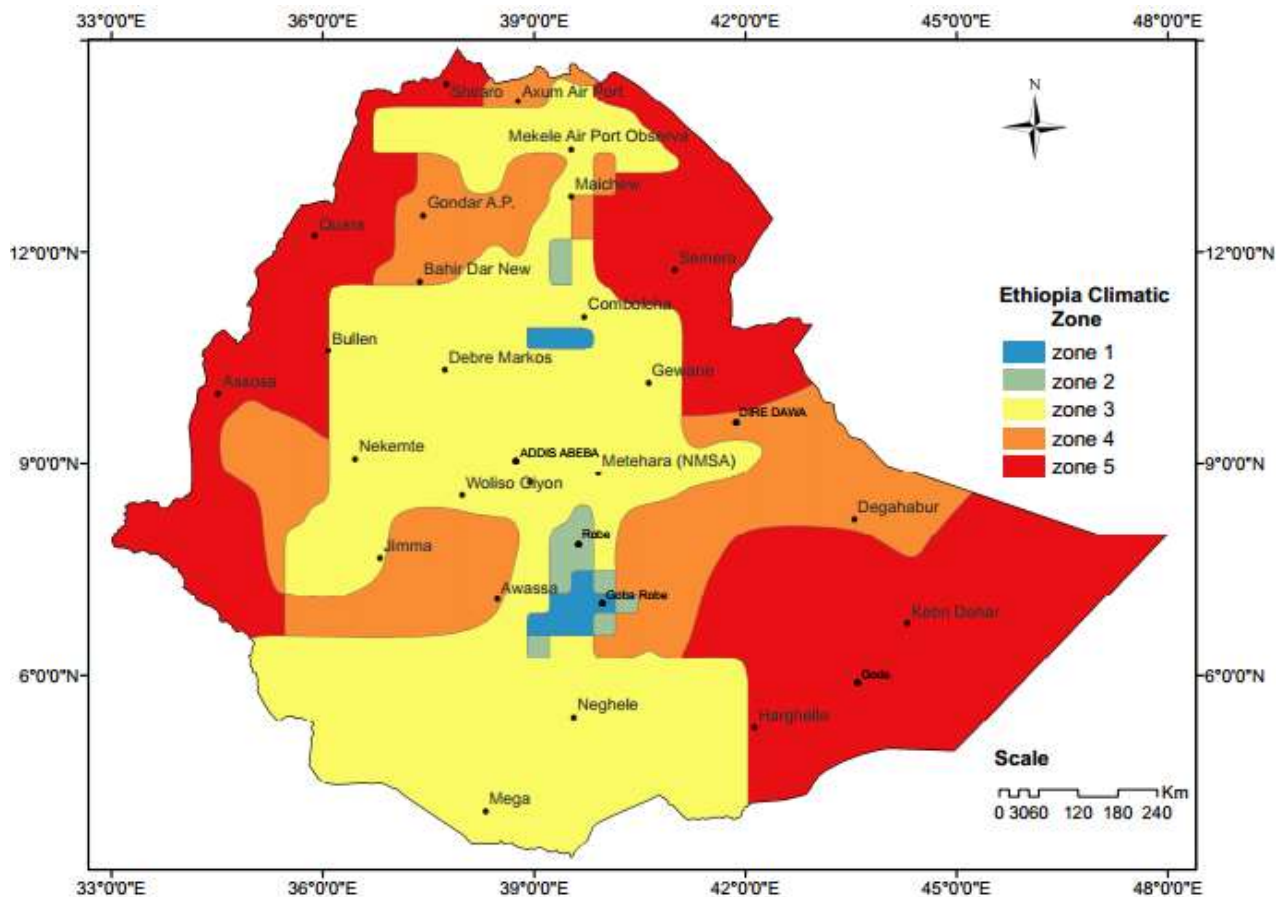


Figure 36: Ethiopia climate zone

Goba Robe Degree Days

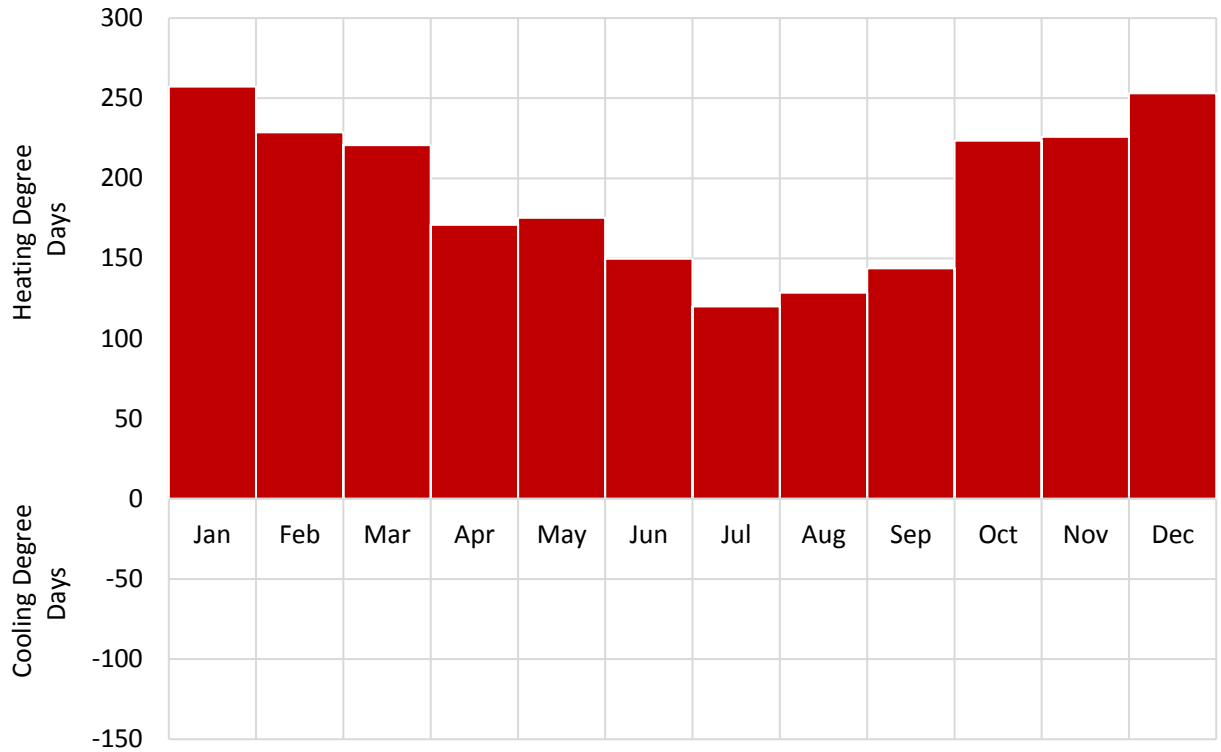


Figure 37: Goba Robe Heating and Cooling Degree Days

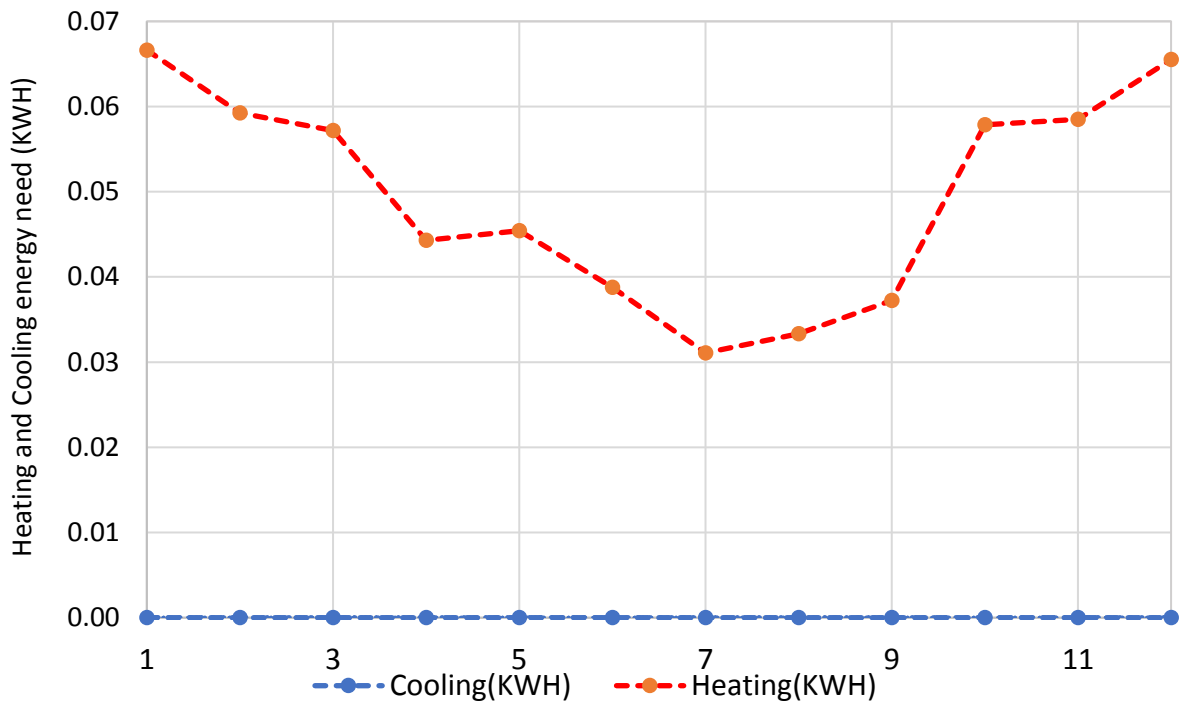


Figure 38: Goba Robe Cooling and Heating energy demand (KWH)

Zone one represented by Goba Robe town, as shown in figure 37 and 38 above the heating energy demand is high. The heating degree days range from 100 (July) to 250 (January),

this demands energy from 0.03 to 0.07 KWH to raise 1° c. The comfort zone monthly variation is shown in figure 39 below.

Goba Robe Comfort zone

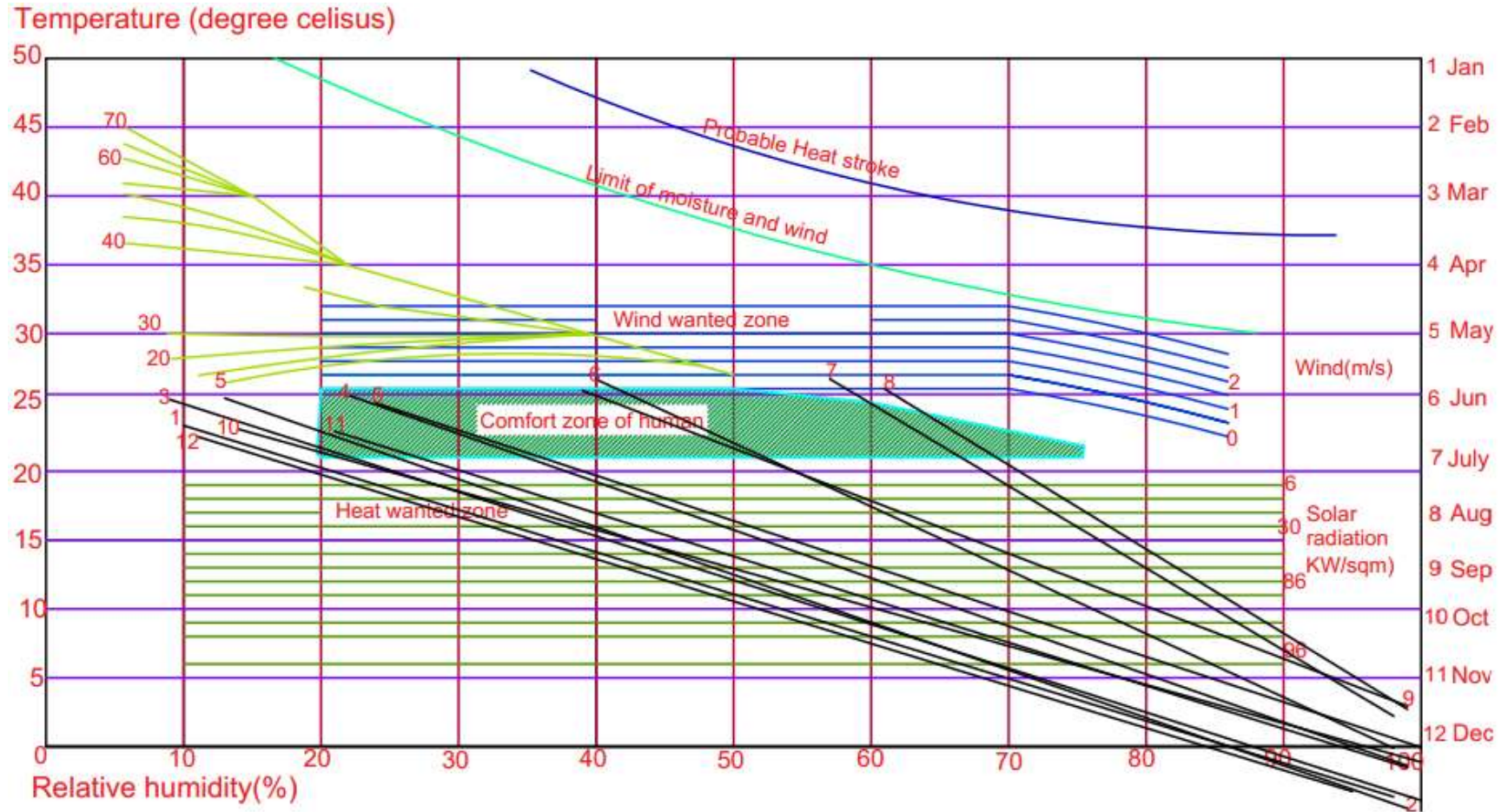


Figure 39: Goba Robe Comfort Chart

Robe Degree Days

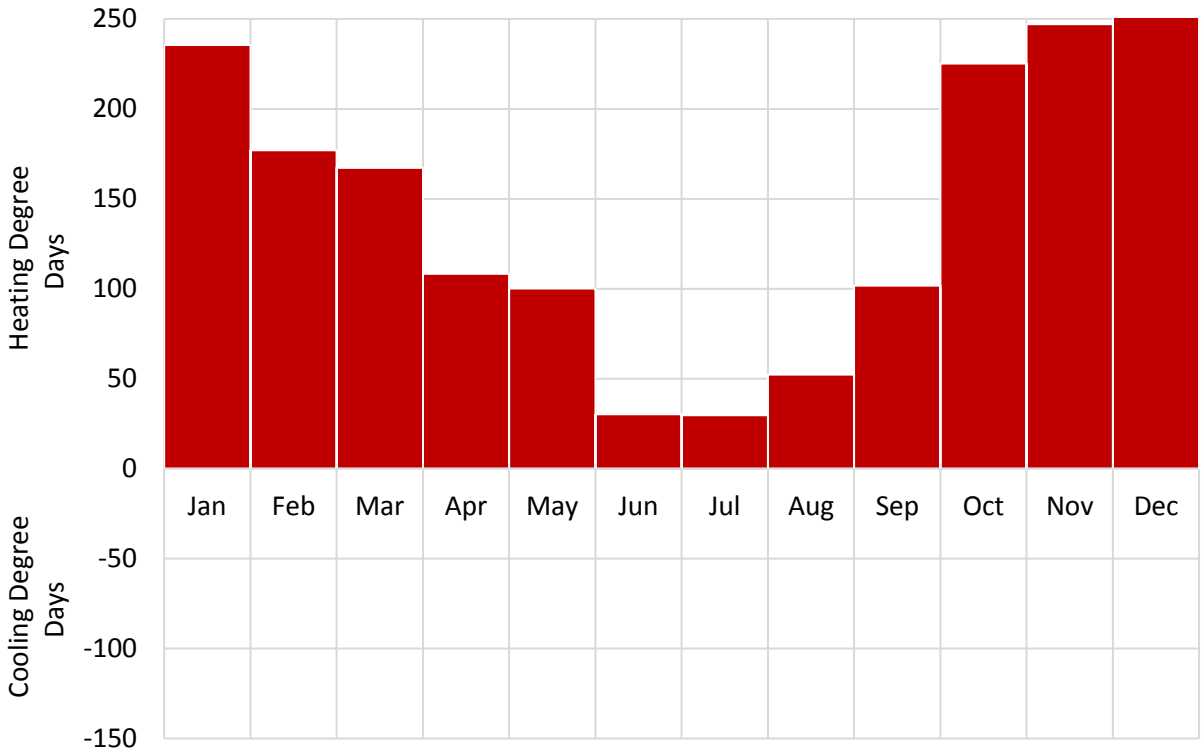


Figure 40: Robe Heating and Cooling Degree Days

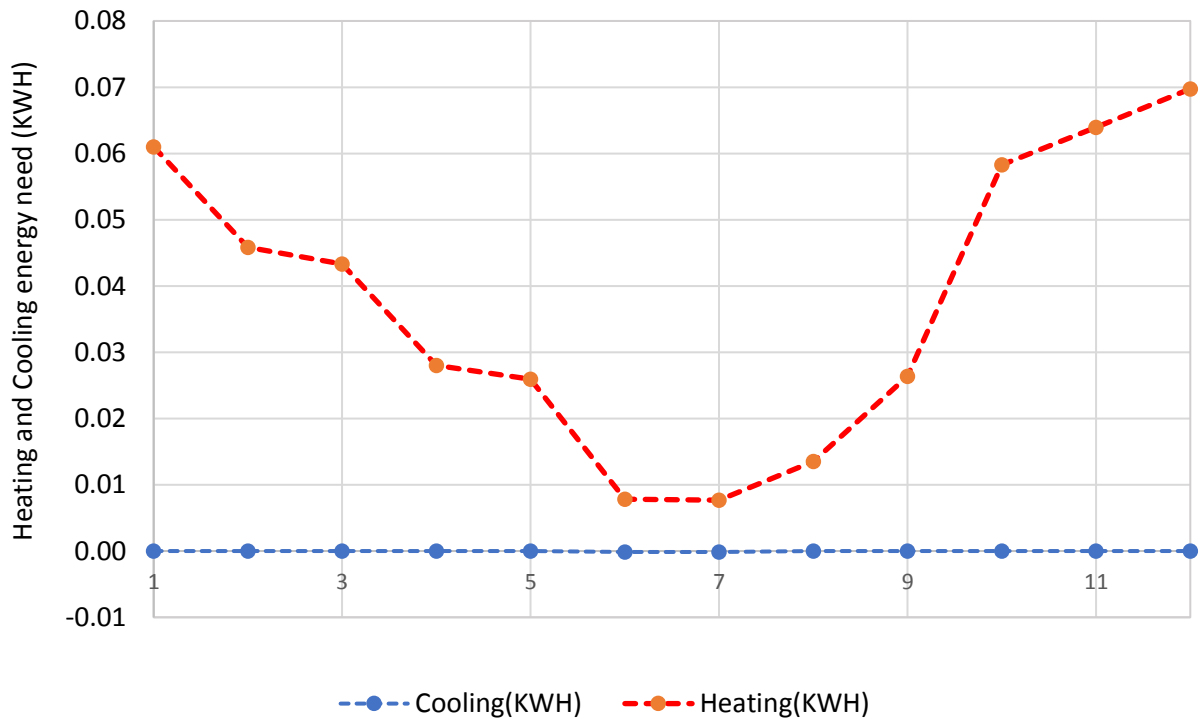


Figure 41: Robe Cooling and Heating energy demand (KWH)

Zone two represented by Robe town, as shown in figure 40 and energy from 0.01 to 0.07 KWH to raise 1° c. The comfort zone 41 above the heating energy demand is high. The heating degree monthly variation is shown in figure 42 below. days range from 20 (July) to 250 (December), this demands

Robe Comfort zone

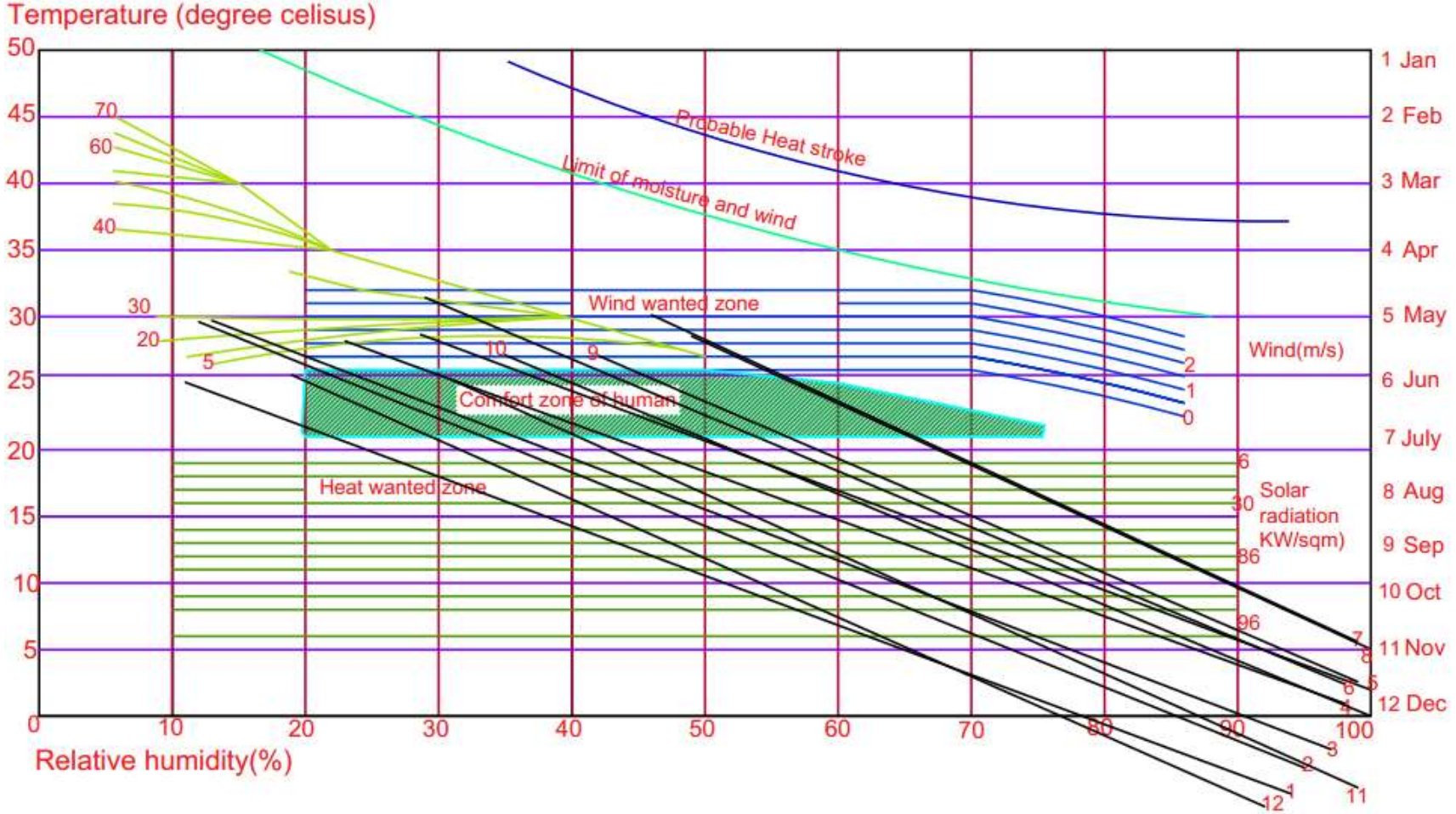


Figure 42: Robe Comfort Chart

Addis Ababa Degree Days

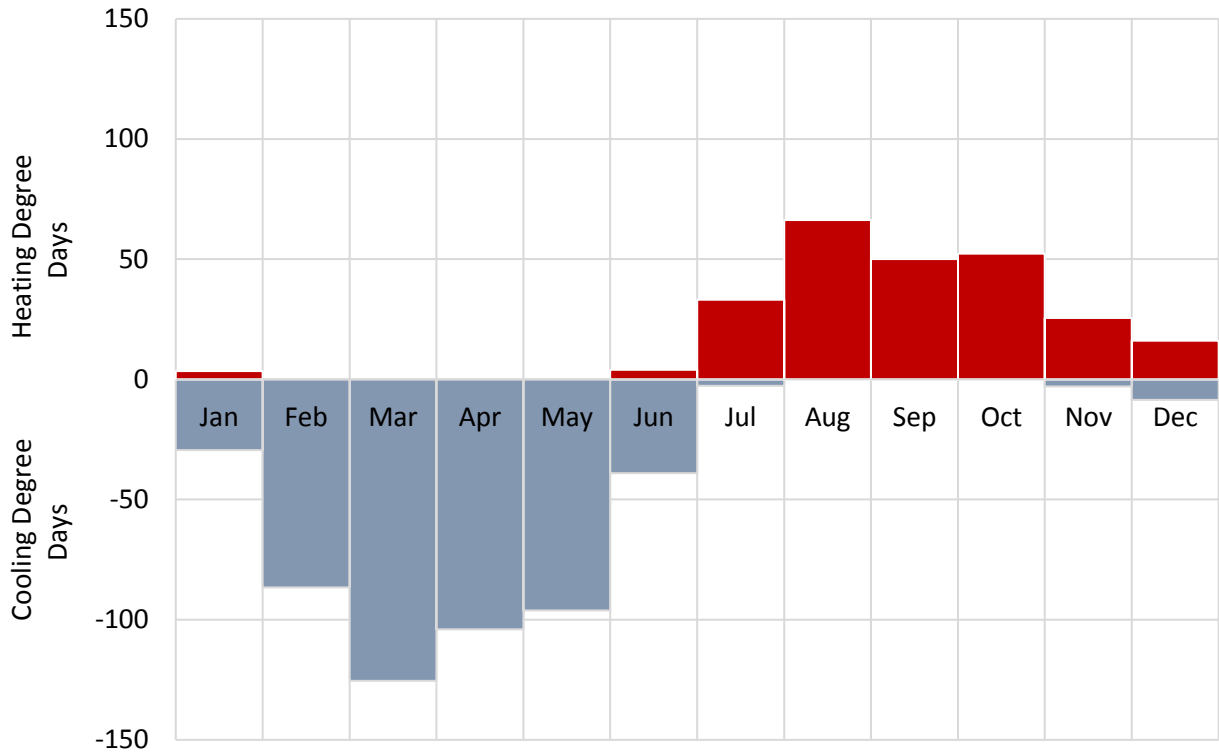


Figure 43: Addis Ababa Heating and Cooling Degree Days

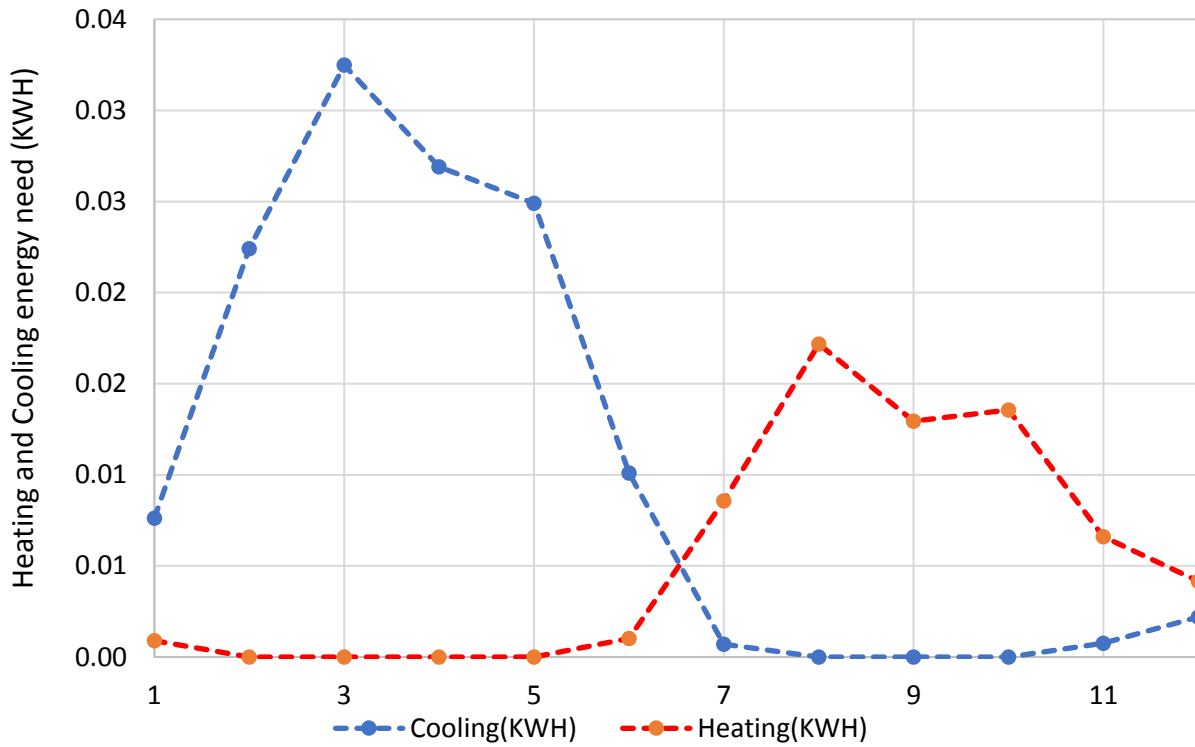


Figure 44: Addis Ababa Cooling and Heating energy demand (KWH)

Zone three represented by Addis Ababa city, as shown in figure 43 and 44 above the heating and cooling energy demand is varies. The heating degree days range from 0 winter to 70 (August), this demands energy from 0.0 to 0.25

KWH to raise 1° c. The cooling energy demand also ranges from 0 (winter) to 130 (March). The comfort zone monthly variation is shown in figure 45 below.

Addis Ababa Comfort zone

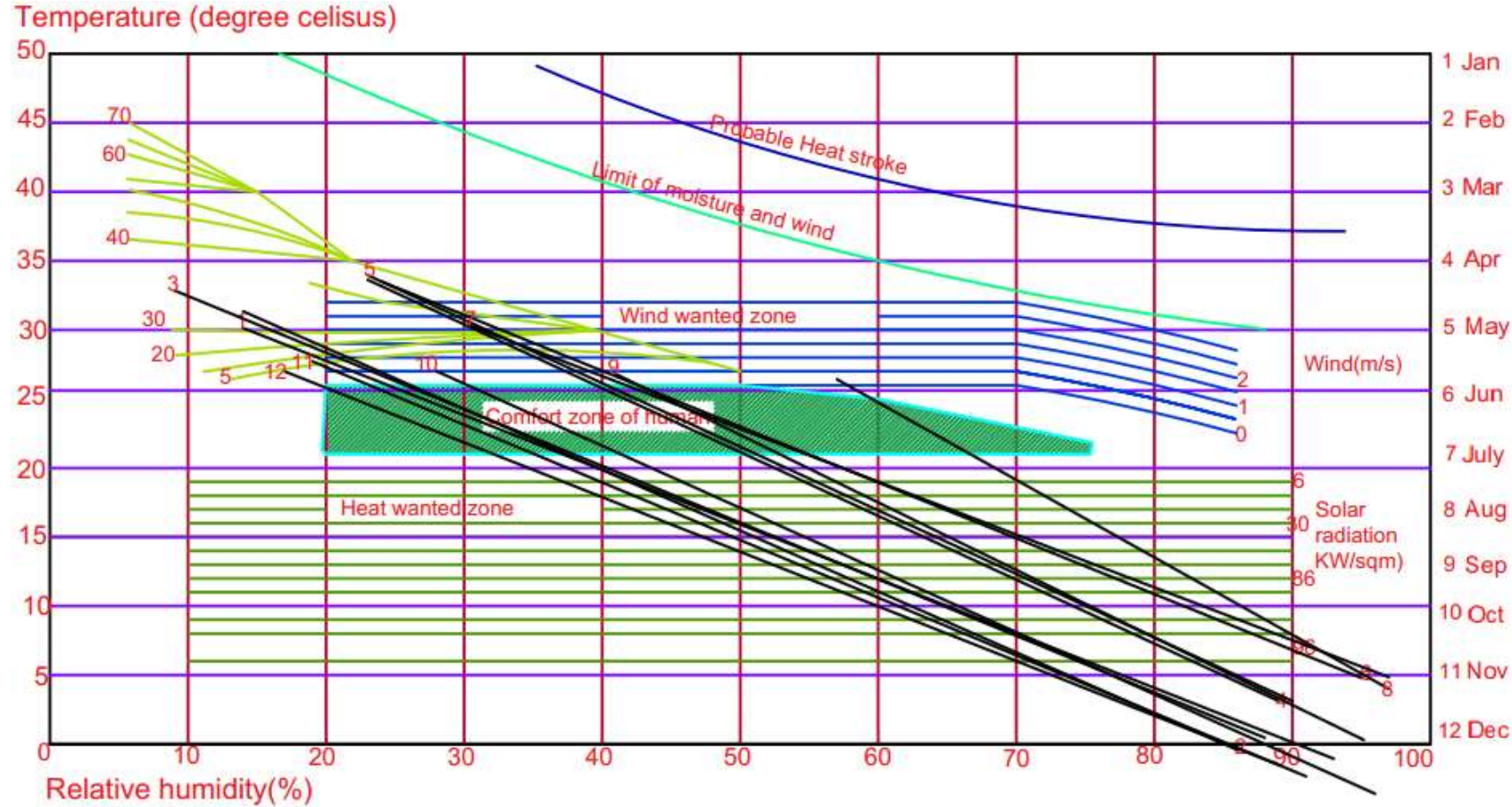


Figure 45: Addis Ababa Comfort Chart

Dire Dawa Degree Days

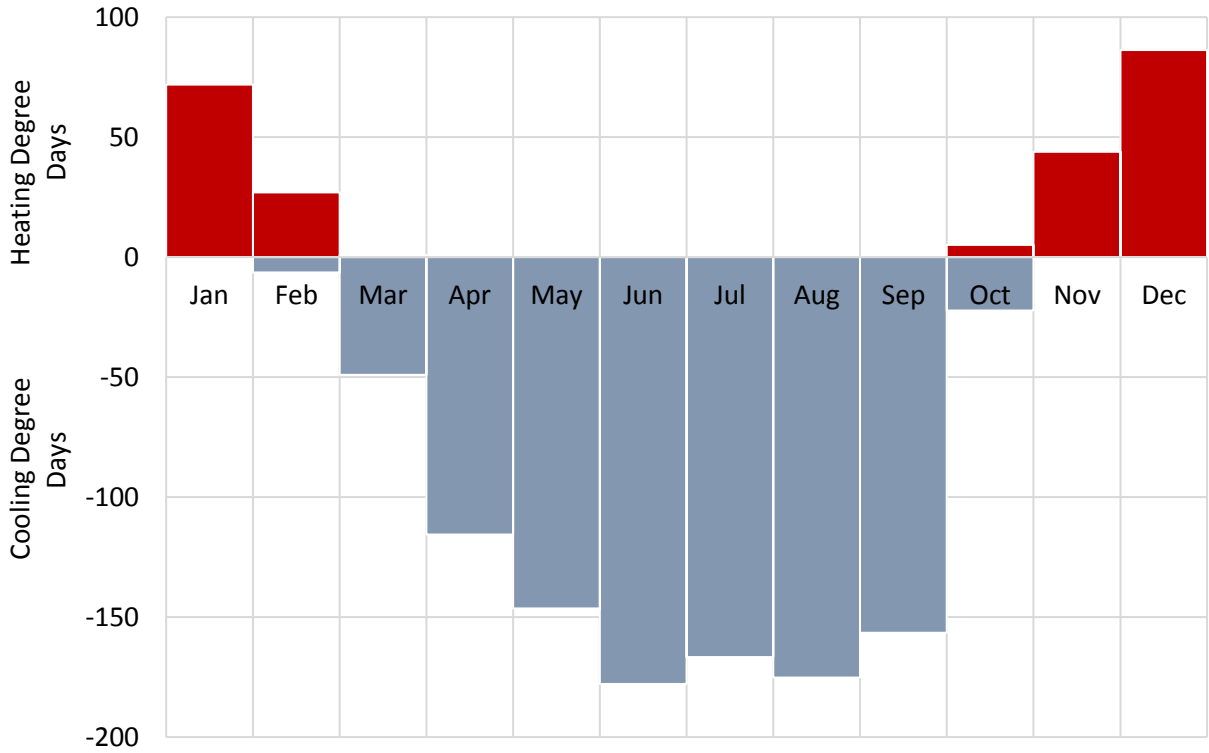


Figure 46: Dire Dawa Heating and Cooling Degree Days

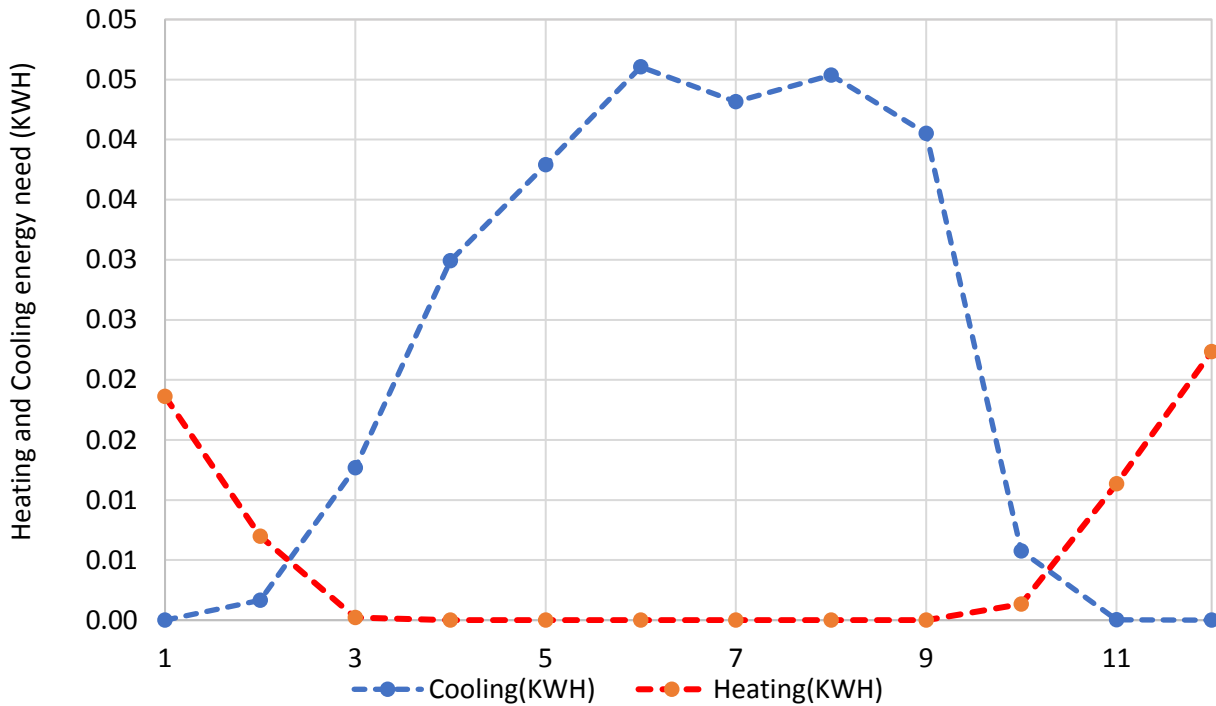


Figure 47: Dire Dawa Cooling and Heating energy demand (KWH)

Zone Four represented by Dire Dawa City, as shown in figure 46 and 47 above the Cooling energy demand is high. The Cooling degree days range from 1 (Feb) to 275 (June), this

demands energy from 0.01 to 0.05 KWH to raise 1° c. The comfort zone monthly variation is shown in figure 48 below.

Dire Dawa Comfort zone

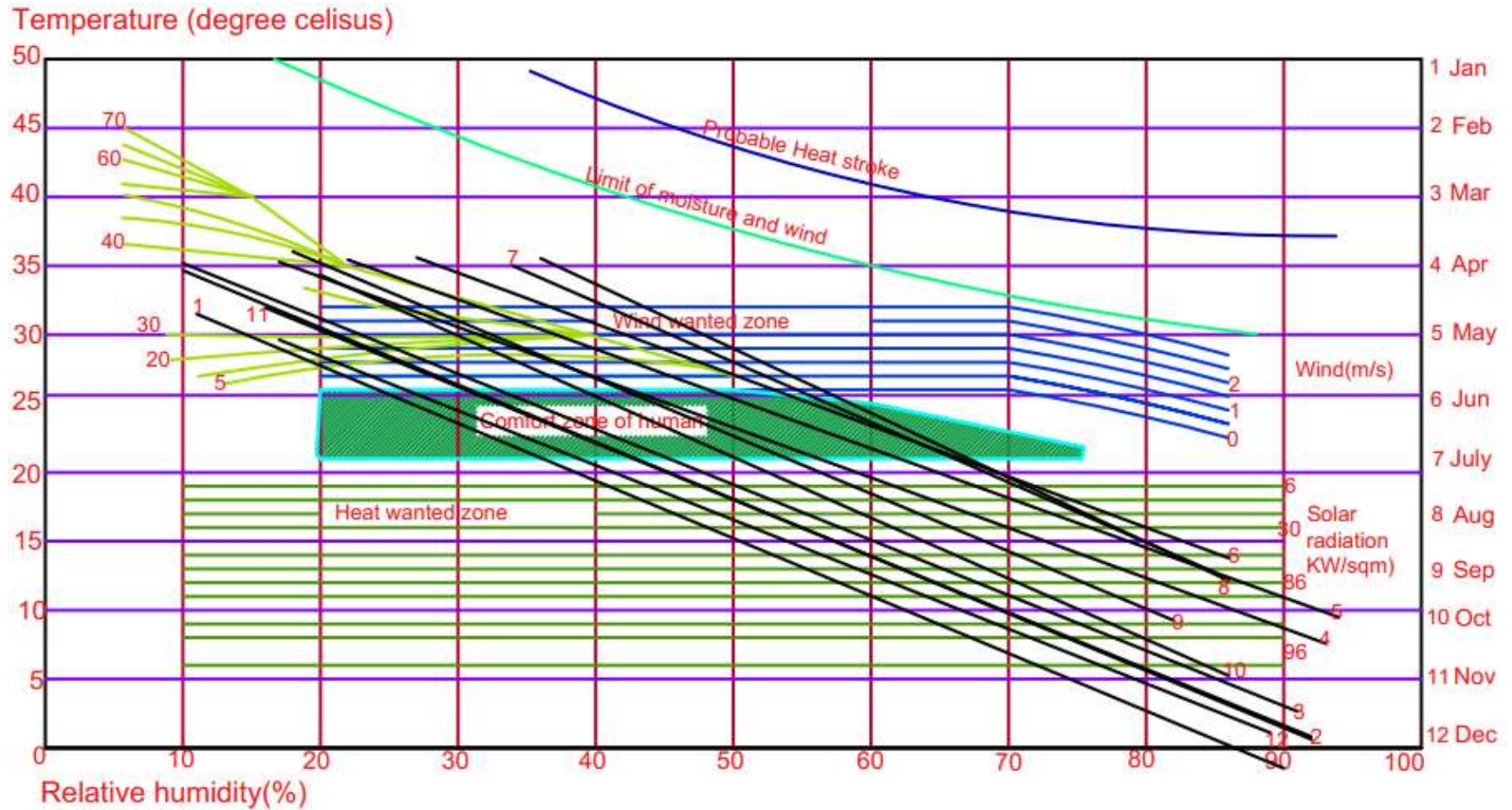


Figure 48: Dire Dawa Comfort Chart

Gode Degree Days

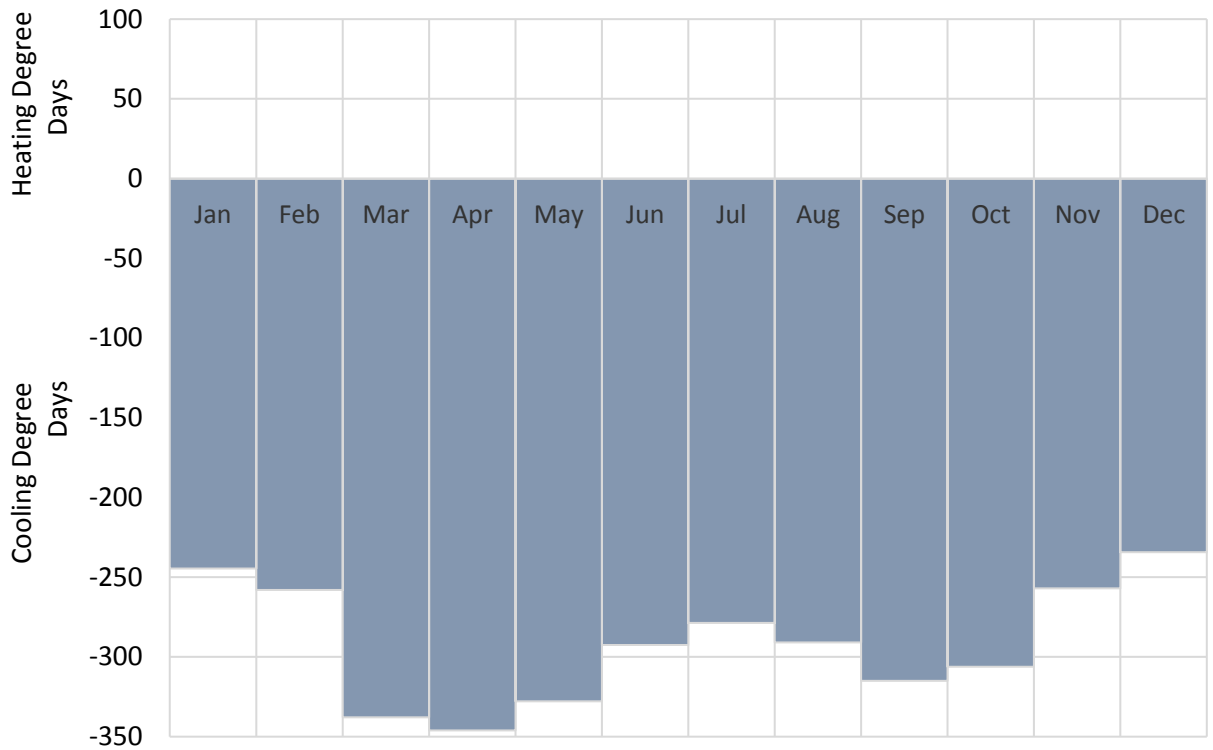


Figure 49: Gode Heating and Cooling Degree Days

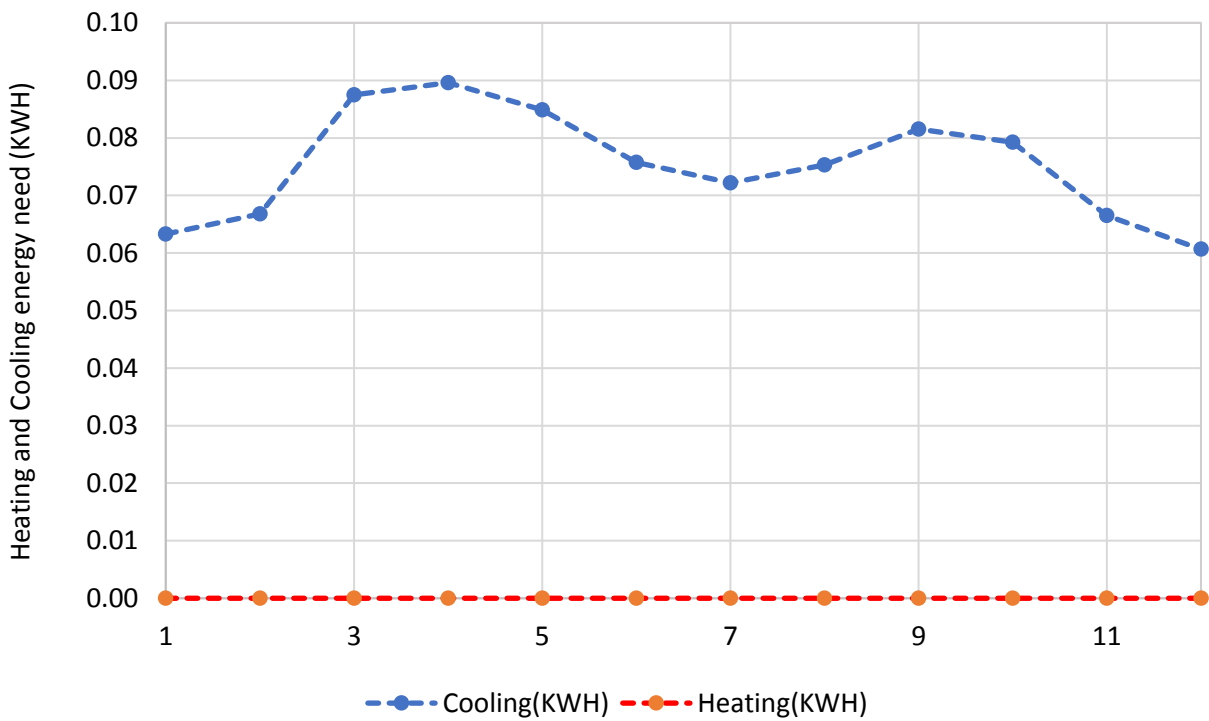


Figure 50: Gode Cooling and Heating energy demand (KWH)

Zone Five represented by Gode town, as shown in figure 49 and 50 above the cooling energy demand is high. The cooling degree days range from 250 (January) to 350 (April), this

demands energy from 0.06 to 0.09 KWH to raise 1° c. The comfort zone monthly variation is shown in figure 51 below.

Gode Comfort zone

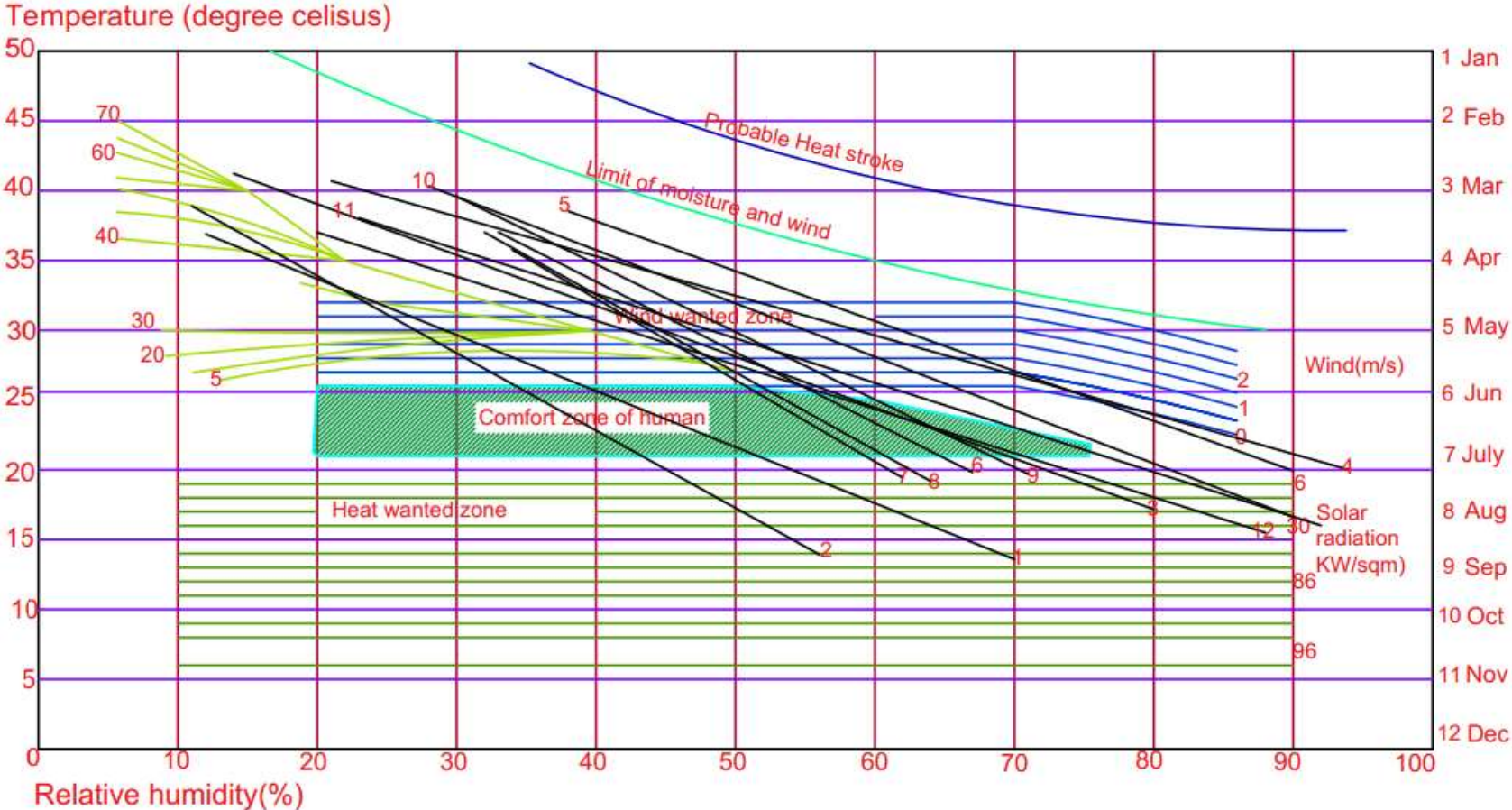


Figure 51: Gode Comfort Chart

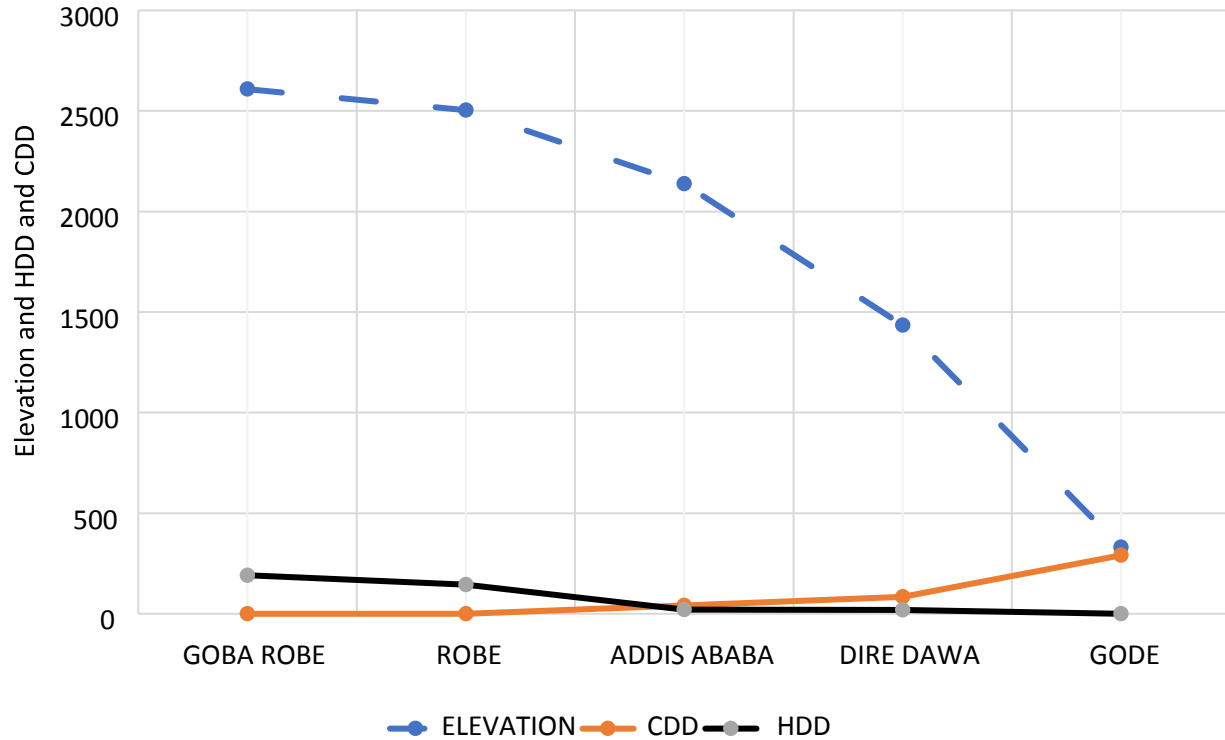


Figure 52: Comparison of Elevation (m), CDD and HDD (degree days)

Figure 52 above shows the relationship between Elevation and CDD and HDD. Accordingly, the energy requirement to cool or heat increases or decreases.


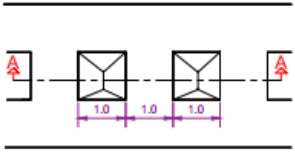
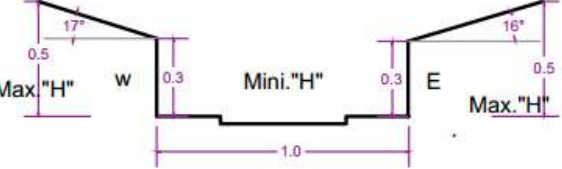
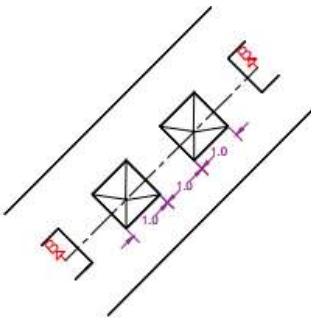

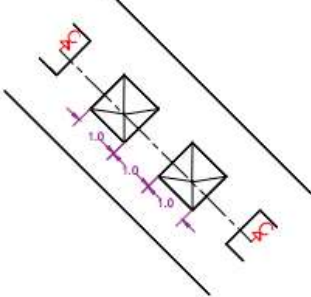
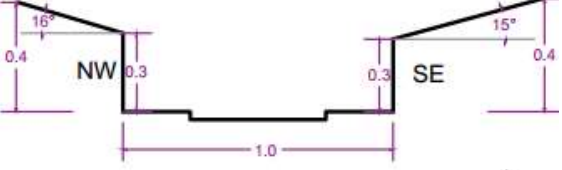
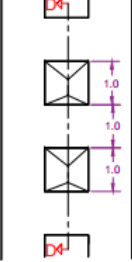
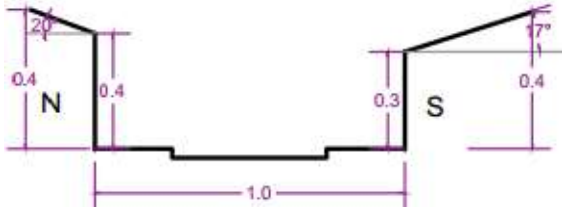
5.4. Generation of Solar Envelope for the Reference Cities of Ethiopia

In this section the effect of block orientations on size and shape of solar envelopes for the extreme heating and cooling energy requirement were demonstrated in the following tables for each climate zone. The solar envelope is developed for four cardinal directions namely, North-South (N-S), East-West (E-W), Northeast-Southwest (NE-SW) and Northwest-Southeast (NW-SE). The inverse of building envelope to these four cardinal directions has been considered as a mirror. As a result, solar envelopes for each reference city has been constructed in the following section, for a unit box of building (i.e., 1*1*1 m³ box).

For ‘X’ width of street and ‘Y’ height of building with zero setback the appropriate relation of street width and building height to keep solar right of neighboring building a regulation was formulated with respect to each orientation in the respective table below for each climate zone as shown in table 13, 14, 15, 16 and 17.

Goba Robe Town Solar Envelope

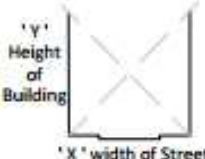
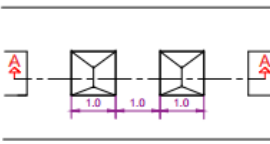
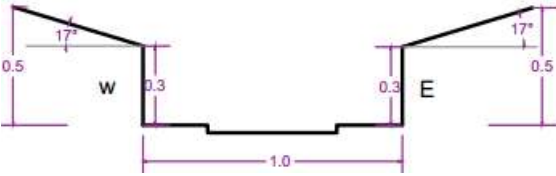
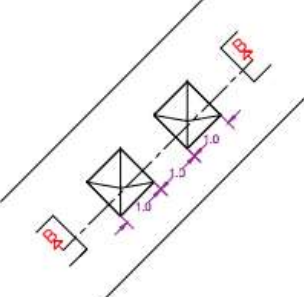

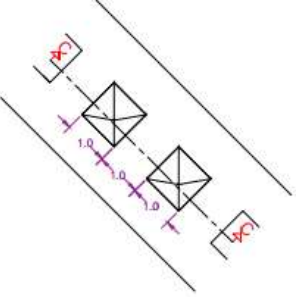
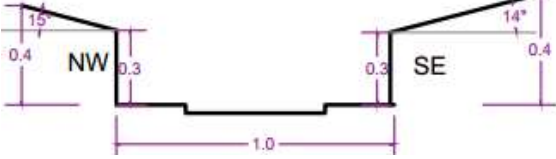
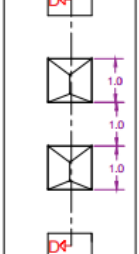
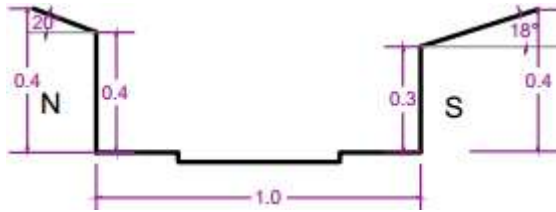
Table 13: Goba Robe Solar Responsive Building Envelope

Orientation	Solar Responsive Building Envelope Plan	Section View	
W-E		 <p style="text-align: center;">Section A_A</p>	$y = -0.55x + 1.55$
SW-NE		 <p style="text-align: center;">Section B_B</p>	$y = -0.58x + 1.58$
NW-SE		 <p style="text-align: center;">Section C_C</p>	$y = -0.58x + 1.58$
S-N		 <p style="text-align: center;">Section D_D</p>	$y = -0.55x + 1.55$

NB: The minimum building height for solar access to adjacent building is 0.3 m along All orientation.

Robe Town Solar Envelope


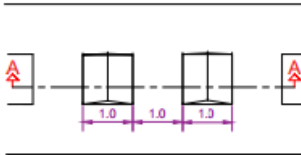

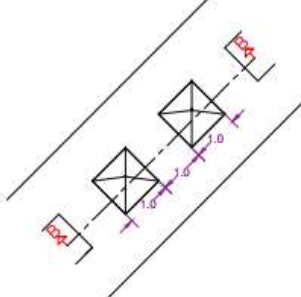
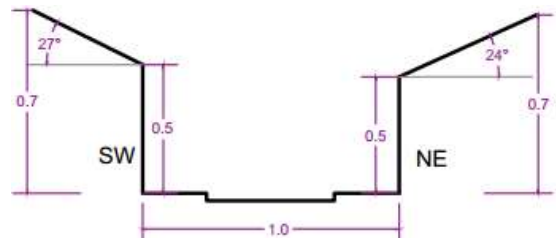
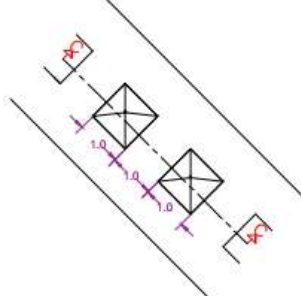
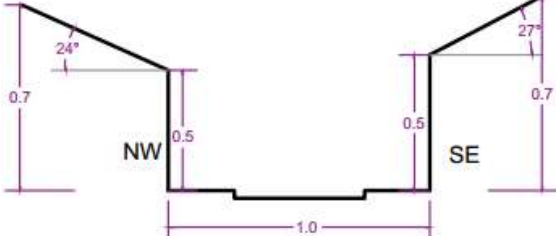
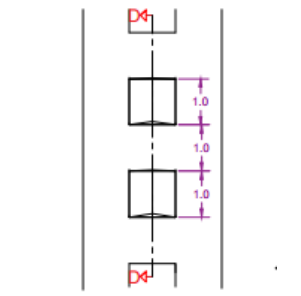

Table 14: Robe Solar Responsive Building Envelope

Orientation	Solar Responsive Building Envelope Plan	Section View	
W-E		 <p style="text-align: center;">Section A_A</p>	$y = -0.55x + 1.55$
SW-NE		 <p style="text-align: center;">Section B_B</p>	$y = -0.61x + 1.61$
NW-SE		 <p style="text-align: center;">Section C_C</p>	$y = -0.61x + 1.61$
S-N		 <p style="text-align: center;">Section D_D</p>	$y = -0.55x + 1.55$

NB: the minimum building height for solar access to adjacent building is 0.3 m along all orientation.

Addis Abeba City Solar Envelope

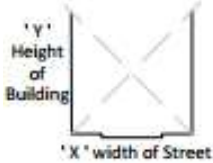
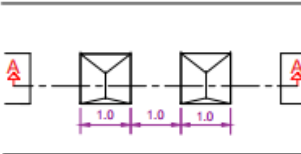
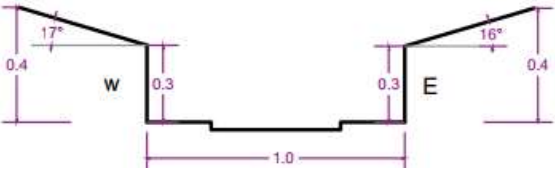
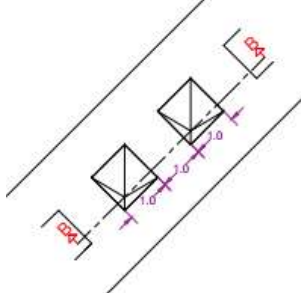
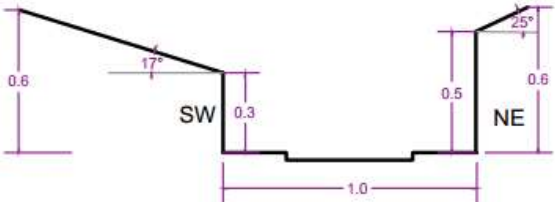
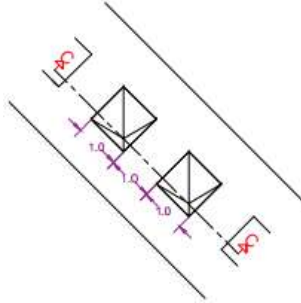
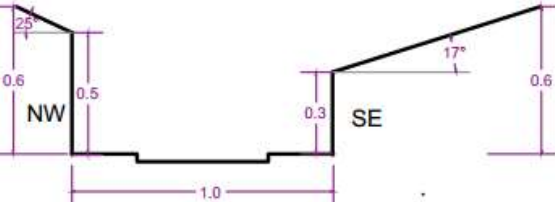
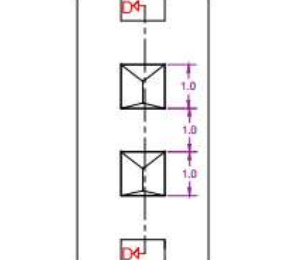
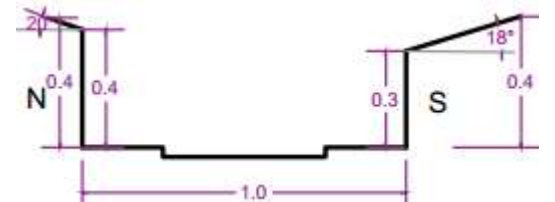
Table 15: Addis Abeba Solar Responsive Building Envelope

Orientation	Solar Responsive Building Envelope Plan	Section View	
W-E		 <p style="text-align: center;">Section A_A</p>	$y = -0.05x + 0.55$
SW-NE		 <p style="text-align: center;">Section B_B</p>	$y = -0.62x + 1.62$
NW-SE		 <p style="text-align: center;">Section C_C</p>	$y = -0.62x + 1.62$
S-N		 <p style="text-align: center;">Section D_D</p>	$y = 0.05x + 0.55$

NB: The minimum building height for keeping solar access is 0.3 m high along E-W orientation in a unit box of building and the maximum height for shading is 0.7 m along diagonal orientation.

Dire Dawa City Solar Envelope


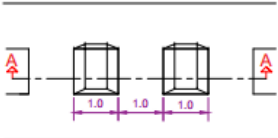
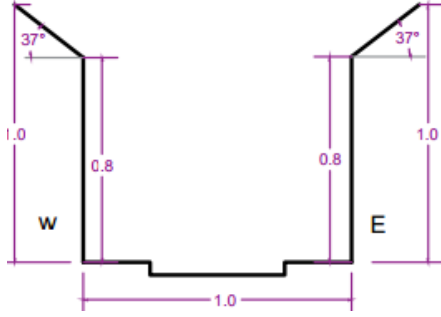
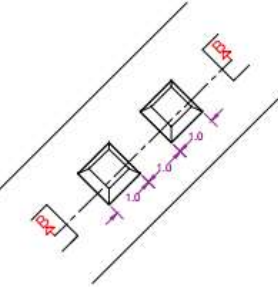
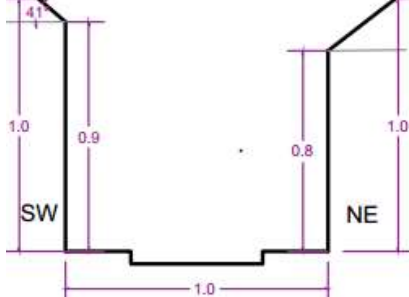
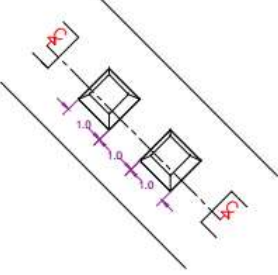
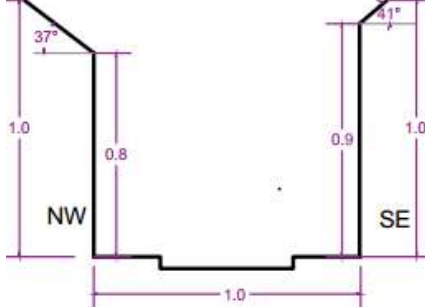
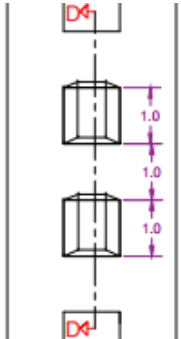
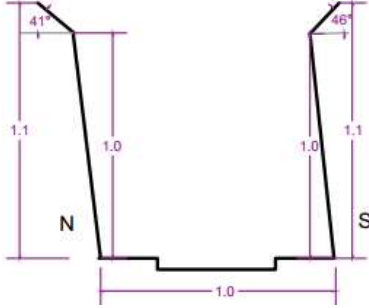
Table 16: Dire Dawa Solar Responsive Building Envelope

Orientation	Solar Responsive Building Envelope Plan	Section View	
W-E		 <p style="text-align: center;">Section A_A</p>	$y = -0.59x + 1.59$
SW-NE		 <p style="text-align: center;">Section B_B</p>	$y = -0.44x + 1.44$
NW-SE		 <p style="text-align: center;">Section C_C</p>	$y = -0.44x + 1.44$
S-N		 <p style="text-align: center;">Section D_D</p>	$y = -0.59x + 1.59$

NB: Since zone 4 (table 16 above) and Zone 5 (table 17 below) needs shading, the minimum building height for shading street is 0.3 m and 0.8 m along SW-NE and NW-SE block orientation for zone 4 and zone 5 respectively.

Gode Town Solar Envelope

Table 17: Gode Solar Responsive Building Envelope

Orientation	Plan	Section View	
E-W		 <p style="text-align: center;">Section A_A</p>	$Y = -0.04X + 1.04$
SW-NE		 <p style="text-align: center;">Section B_B</p>	$y = -0.04x + 1.04$
NW-SE		 <p style="text-align: center;">Section C_C</p>	$y = -0.04x + 1.04$
S_N		 <p style="text-align: center;">Section D_D</p>	$y = -0.04x + 1.04$

CHAPTER SIX

DISCUSSION

Analyzing the calculated data from 952 stations the value of CDDs and HDDs varies from region to region. The highest value of CDDs and the lowest value of HDDs are found in the Somali, Afar, Benishangul gums, Gambela and some in Amhara and Tigray region. In contrast the lowest value of CDDs and the highest value of HDDs are found in the central parts of Ethiopia. This large difference in CDD and HDD values from region to region shows the intense contrast in the climatic characteristics between geographic points and it gives an idea about the energy demands.

The energy requirements for heating in zone 1, 2 and few in 3 is higher in comparison with values recorded in the warm and hot areas of zone 4 and 5 having low HDD and high CDD, a place located in South Eastern, North Western and Eastern part of Ethiopia. As a result, the envelope for climatic zone 1 and 2 is constructed for the extreme heating demand of June, September and December from Heating degree days. For climate zone 3 or reference city of Addis Ababa the envelope is responsive for high cooling demand in March and for minimum six-hour heating requirement of August months. For climatic zone 4, reference city of Dire Dawa the envelope is responsive for high cooling demand in June and minimum heating requirement in December. Finally, the envelope for climate zone 5, reference city of Gode is responsive for high cooling demand in April.

Comparing densities as shown in Figure 53 like (Knowles., 2003), solar envelope studies in a square plot size along the diagonal orientation has the least density than N - S and E- W orientation having Highest density, in the case of a unit box plot size in this study also occurred except for climate zone 4 , envelope along diagonal have high density than N-S and E-W orientation shown in figure 53 below. This is because of the minimum six-hour heating energy demand for December solar fence.

In order to test the sensitivity of the results to different climate conditions, volumetric comparison of reference city was presented in the following figure 53.

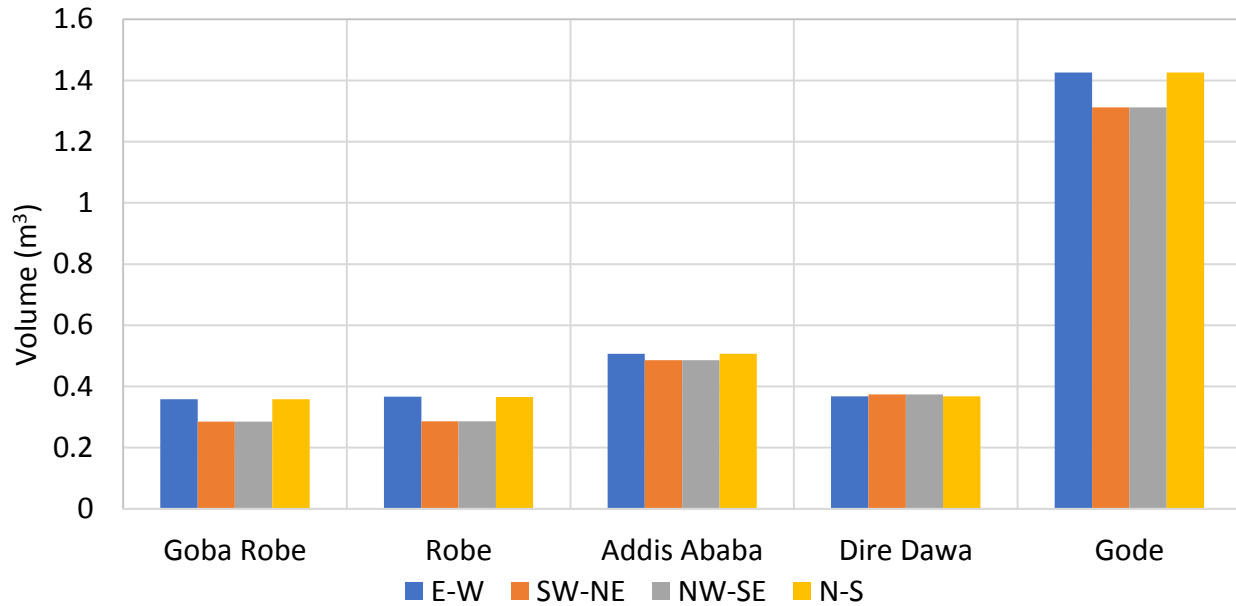


Figure 53: volumetric comparison of reference city

From studies in Tel Aviv, buildings having long elevation facing east and west gave highest density but not recommended for residential buildings. Buildings facing north and south results lower in buildings and less far rates but climatically better and the diagonal one has high far rates and good orientation (Capeluto et al., 2006). Studies about solar envelope by Thanos Stasinopoulos, buildings facing N-S orientation have larger envelopes and more beneficial east - west orientation (Stasinopoulos., 2018). The studies in this paper is brought a method to secure solar and shading right based on the climatic need to bring human comfort unlike previous studies that mainly focus on solar right.

CHAPTER SEVEN

Finding, Conclusion and Recommendations

7.1. Finding

Ethiopia is regionalized into five regions based on Heating and Cooling Degree Days of ASHREA standard. Accordingly, some of the findings are

- ✓ The maximum CDD and HDD is 350 ° c in Gode, zone 5 and 250° c in Goba Robe, zone 1 respectively.
- ✓ The minimum CDD and HDD is zero in Goba Robe, zone 1 and in Gode, zone 5 respectively.
- ✓ The energy demand for Cooling and heating in Ethiopia reaches to 1.29 and 1.17 kWh respectively to raise 1° c.

The envelopes from intersection of the extreme months for all cases of climatic zone decides the solar responsive building shape and size.

- ✓ E-W and N-S orientation have elongated and maximum height from South edge and large volume than SW-NE and NW-SE orientation, but have equal volume.
- ✓ In the diagonal orientation of SW-NE and NW-SE the envelopes have equal and less volume than E-W and N-S orientation with highest ridge in the South East and in S-W edge respectively.
- ✓ For climate zone 4, reference city of Dire Dawa envelope along diagonal have high density than N-S and E-W orientation. This is because of the minimum six-hour heating energy demand for December solar fence.

7.2. Conclusion

Guaranteed solar access offers to society a chance to develop a renewable energy source, aesthetic possibilities and a desire of maximum comfort that people seek for. The work in this paper was intended to define the significance of solar access to keep solar rights of a building, form generation and energy conservation based on the energy code of residents which defines the needed exposure to solar radiation in each orientation and climatic zone required to reduce energy consumption.

The climate of Ethiopia has been classified into five different climatic zones. To characterize this climate zone reference city of Goba Robe, Robe, Addis Ababa, Dire Dawa and Gode were selected. As a result, climatic responsive forms of solar envelopes were constructed for each region along E-W orientation and N-S orientation have equal and highest density than along 45-degree cardinal direction having least volume in all climate zone except climate zone 4.

The period of solar access volumetrically constrained the building solar envelope. Less time means more volume; more time means less volume. This is because of the sun's angle defines the slope of the envelope. Hence, on a daily basis progressively increasing the hours of solar access will set cut-off times that provide progressively less and less building volume under the envelope. Determining exactly what cut-off times might be used, then will depend not only on desired insolation but also on how much building volume is required to accommodate development needs.

7.3. Recommendation

Daylight in general and sunlight in particular are vital to life on earth. The introduction of solar envelopes in urban planning can enhance the urban environment in terms of daylight, ventilation, and vistas, it provides choice to a designer and improve the quality of lives, offers the chance to replace unreliable energy. Therefore, solar envelope has to be proposed as a regulatory device to achieve solar access, depending on the sun's relative motion and optimum period of insolation that responses for each climatic zone of energy and comfort needs. The ministry of Housing and Urban Development can utilize it as a base to regulate the morphologies of Ethiopian cities.

Designer can use it to shape their building responsive envelope. To achieve the energy need, the building has not cast shadow surrounding building properties during critical period of day and year. One thing here was the solar envelope building volume required to function was small than the conventional to handle this challenge, it is possible to rise the volume by adding a plinth height from its base for buildings that don't need much sun in day and night and adding cutoff time finish and start to early and late at morning and night. Designers who break it lose the choice of architectural means to sustain building comfort and must depend on energy-intensive mechanical systems.

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Appendix 1: Zone 1 Climatic Cities of Ethiopia

TOWN_NAME	LONG_EAST	LAT_NORTH			
			Gasera	40.07	7.09
Goba Robe	39.97	7.01	Ali	40.00	7.12
Robe	40.00	7.12	Dinshu	39.78	7.10
Kemise	39.83	10.74	Koke Ager	39.22	10.90
Adaba	39.40	7.00	Kabe	39.47	10.82
Harbu	39.79	10.91	Kurkura	39.28	10.77
Agarfa	39.78	7.10	Sede	40.00	7.12
Mekoy	39.83	10.74	Hako	39.40	7.00

Appendix 2: Zone 2 Climatic Cities of Ethiopia

TOWN_NAME	LONG_EAST	LAT_NORTH			
			Habe	39.63	7.86
Robe	39.63	7.86	Kula	39.63	7.86
Bekoji	39.23	7.61	Sedika	39.63	7.86
Iteya	39.23	8.12	Ligwama	39.16	10.65
Gobesa	39.49	7.61	Angada	39.81	8.38
Arboye	39.69	8.38	Wolonkomi	39.30	8.05
Hamda Diskis	39.56	8.05	Gimbite	39.25	7.40
Siltana	39.25	7.40	Selka	40.22	7.03
Ticho	39.52	7.80	Mejo	39.14	6.33
Kelela	39.16	10.65	Bulala	39.56	8.05
Meraro	39.25	7.40	Kelo	39.52	7.80
Koke Ager	39.22	10.90	Genet	38.91	10.75

Appendix 3: Zone 3 Climatic Cities of Ethiopia

TOWN_NAME	LONG_EAST	LAT_NORTH			
			Chagni	36.50	10.95
ADDIS ABEBA	38.75	9.02	Korem	39.52	12.50
NAZRET	39.27	8.54	Holota	38.52	9.09
DESE	39.63	11.13	Wukro	39.59	13.79
MEKELE	39.47	13.50	Sawla	36.88	6.30
JIMMA	36.84	7.68	Shakiso	38.90	5.76
HARER	42.13	9.30	Dangla	36.70	11.24
DEBRE ZEYT	38.99	8.74	Humera	36.83	13.91
DEBRE	37.73	10.33	Shewa Robit	39.97	10.09
MARKOS			Sebeta	38.59	8.89
NEKEMTE	36.54	9.09	Bati	40.04	11.18
ARBA MINCH	37.54	6.01	Dodola	39.18	6.97
Kombolcha	39.74	11.08	Finote Selam	37.27	10.69
DEBRE	39.53	9.67	Bure	37.10	10.71
BIRHAN			Wenji	39.27	8.54
ADIGRAT	39.46	14.27	Agere	38.24	5.63
DILA	38.31	6.41	Mariyam		
Hosaina	37.85	7.55	Bichena	38.20	10.45
Ambo	37.85	8.97	Jinka	36.56	5.79
Weliso	37.97	8.53	Adet	37.64	11.17
Negele	39.57	5.34	Ginir	40.71	7.14
Agaro	36.59	7.86	Metehara	39.91	8.89
Debre Tabor	38.01	11.85	Bedele	36.35	8.45
Mojo	39.12	8.59	Welenchiti	39.49	8.68
Fiche	38.73	9.80	Fincha-a	37.37	9.49
Kobo	39.63	12.16	Yirga Chefe	38.20	6.16
Butajira	38.38	8.12	Shambu	37.10	9.56
Kibre Mengist	38.98	5.88	Gebre	38.41	9.80
Asbe Teferi	40.91	9.05	Guracha		
Mota	37.87	11.07	Asasa	39.20	7.10

Bonga	36.28	7.39	Debre Sina	39.76	9.84
Gelemso	40.52	8.81	Kuyera	38.65	7.24
Bedesa	40.78	8.90	Alem Ketema	39.01	10.04
Nefas	38.35	11.72	Mena	39.84	6.41
Mewcha			Mehal Meda	39.69	10.18
Abomsa	39.83	8.48	Deder	41.44	9.30
Ginchi	38.15	9.02	Gent	36.95	8.09
Moyale	39.04	3.53	Melka Sede	40.17	8.98
Bako	37.06	9.12	Arjo	36.50	8.76
Yabelo	38.20	4.78	Arerti	39.37	8.91
Kwiha	39.54	13.47	Bore	38.62	6.37
Guder	37.80	8.89	Mertule	38.30	10.81
Dera	39.32	8.32	Maryam		
Merawi	37.21	11.31	Sire	39.49	8.27
Mekane	38.05	11.65	Waja	39.63	12.16
Eyesus			Amanuel	37.57	10.44
Dejen	38.13	10.24	Were Ilu	39.37	10.53
Dembecha	37.42	10.50	Chencha	37.59	6.35
Lalibela	39.04	12.03	Mieso	40.76	9.23
Hayk	39.68	11.31	Gedo	37.54	8.96
Gidole	37.36	5.65	Ataye	39.94	10.55
Debre Werk	38.10	10.58	Melka Werer	40.17	8.98
Tulu Bolo	38.21	8.65	Sagure	39.16	7.75
Abiy Adi	38.96	13.63	Sendafa	39.03	9.15
Durbete	37.21	11.31	Lumame	38.10	10.33
Alem Tena	38.94	8.29	Filtu	40.65	5.11
Adis Alem	38.39	9.04	Inda Baguna	38.18	13.94
Gewane	40.65	10.16	Gimja Bet	36.87	10.77
Jiga	37.38	10.67	Wirgesa	39.62	11.54
Ayana	36.62	9.87	Sheno	39.35	9.42
Kofele	38.78	7.08	Shindi	36.87	10.77
Mersa	39.62	11.54	Robit	39.63	12.16

Inewari	39.15	9.89	Metagefersa	39.05	4.54
Kumbabe	36.12	8.36	Efeson	39.94	10.55
Mega	38.31	4.06	Seka	36.62	7.56
Tilili	36.98	10.88	Shebe	36.62	7.56
Wenago	38.25	6.32	Dalocha	38.24	7.79
Kersa	38.93	7.28	Gunde Weyn	38.22	10.88
Shire	38.98	7.25	Wichale	39.62	11.54
Mekane	38.64	10.87	Wadera	39.31	5.78
Selam			Obera	37.08	9.88
Hagere Selam	38.52	6.49	Koka	39.03	8.43
Idaga Hamus	39.56	14.19	Solemo	38.71	6.20
Dukem	38.90	8.79	Yejube	37.74	10.15
Filakit	38.76	11.76	Adis Kidane	36.89	11.08
Gedeb	38.16	5.95	Bule	38.62	6.37
ASELA	39.14	7.95	Yayu	35.81	8.34
Chancho	38.75	9.30	Harawacha	41.44	9.30
Alem Gena	38.65	8.91	Adele	39.99	8.03
Wegeda	38.32	11.33	Eliyas	37.47	10.30
Inchini	38.38	9.31	Bulbula	38.65	7.72
Toba	36.51	7.96	Dembi	36.46	8.07
Soyema	37.81	5.44	Bedeno	41.64	9.11
Wukro	38.55	14.04	Gechi	36.35	8.45
Kobo	41.44	9.30	Jara	40.71	7.14
Goro	40.65	6.95	Keber	38.27	7.98
Mechara	40.35	8.63	Serbo	36.84	7.68
Karakore	39.94	10.55	Atsbi Inda	39.73	13.87
Gembe	36.66	7.89	Silase		
Chelelektu	38.16	5.95	Koshe	38.38	8.12
Wegel Tena	39.13	11.56	Teltele	37.38	5.07
Goja	38.07	9.18	Abderafi	36.83	13.91
Gosha Tsiyon	38.23	10.05	Debre Tsige	38.73	9.80
Girawa	41.84	9.13	Chefe Donsa	39.14	8.96

Choche	36.71	7.93	Tora	38.42	7.86
Bulen	36.13	10.48	Ogokho	39.04	8.17
Molale	39.69	10.18	Jewha	39.97	10.09
Gundo Meskel	38.70	10.22	Adi Remets	37.32	13.75
Sheboka	37.16	9.11	Debre Libanos	38.73	9.80
Amed Ber	38.01	11.85	Chira	36.17	7.76
Birbir	37.73	6.23	Dilela	38.05	8.63
Micheta	40.35	8.63	Morsito	37.94	7.70
Bulki	36.79	6.26	Tefki	38.50	8.84
Yebu	36.72	7.78	Shenen	37.47	8.72
Werka	39.18	6.97	Chacha	39.45	9.52
Kele	37.89	5.83	Arsi Negele	38.67	7.36
Senbete	39.97	10.09	Fiseha Genet	38.20	6.16
Muke Turi	38.87	9.55	Tenta	39.37	11.45
Chole	39.99	8.03	Gatira	36.20	7.98
Wetet Abay	37.21	11.31	Kilaj	36.53	10.69
Dogolo	39.25	10.42	Getema	36.49	8.89
Arjo	36.36	9.20	Azena	36.78	10.76
Segen	37.61	5.63	Gonde	39.19	8.02
Dibate	36.43	10.71	Tibe	37.16	9.11
Mankusa	37.10	10.71	Melka	38.63	8.72
Kuta Ber	39.54	11.27	Kunture		
Lemi	38.73	9.80	Laska	36.61	6.30
Gelila	36.49	9.84	Kuyi	38.10	10.58
Koso Ber	36.98	10.88	Meshenti	37.22	11.54
Arb Gebeya	38.35	11.72	Kemba	37.25	5.99
Deneba	39.19	9.75	Ambuye	36.81	7.92
Bele	39.99	8.03	Ajibar	38.64	10.87
Kombolcha	37.55	9.57	Kiremu	36.86	9.95
Aqena	38.12	8.15	Amde Werk	38.96	12.49
Bu-i	38.62	8.46	Muja	39.14	11.94
Gerese	37.25	5.99	Alibo	37.08	9.88

Achigi	36.87	10.77	Rob Gebeya	37.77	10.54
Jimate	39.92	10.61	Megado	38.79	5.65
Mida	39.17	10.26	Shikute	37.95	9.33
Armanaya	39.76	9.84	Nunu	36.59	8.69
Tarmaber	39.76	9.84	Bitu Genet	35.76	7.28
Godo Beret	39.76	9.84	Seru	39.99	8.03
Dinbaro	39.53	9.67	Feres Bet	37.59	10.85
Mendida	39.31	9.65	Adulala	38.89	8.67
Duber	38.83	9.43	Yetmen	38.10	10.33
Gorfo	38.83	9.43	Chiri	36.24	7.27
Akaki Beseka	38.79	8.86	Maji	35.57	6.18
Kondaltiti	38.62	8.46	Tulu Miki	38.32	9.92
Fonko	37.96	7.64	Aliyu Amba	39.53	9.67
Munesa	38.81	7.31	Mezezo	39.63	9.96
Degaga	38.81	7.31	Balchi	39.37	8.91
Koti	38.22	6.29	Dedu	37.55	9.57
Mele	37.44	5.89	Kon	38.86	11.63
El Melbana	38.58	3.74	Shino	38.38	9.31
El Gof	39.22	3.77	Sela Dingay	39.63	9.96
Degem	38.56	9.80	Jara Gedo	37.96	11.41
Ejere	38.47	10.02	Beshash	36.51	7.81
Lemen	38.61	8.58	Mandura	36.50	10.95
Felege Birhan	38.10	10.58	Bidire	39.31	5.78
Gish Abay	37.22	10.99	Wishwish	36.24	7.30
Meranya	39.17	10.26	Bilo	36.99	8.89
Sigamo	36.11	7.99	Sede	37.87	11.07
Selam Ber	37.51	6.35	Kone	36.19	8.66
Jihur	39.25	10.01	Sulula	39.68	11.31
Fetire	38.94	10.02	Gasay	38.14	11.79
Arkit	38.04	8.03	Meteh Bila	39.70	9.07
Rema	38.91	10.26	Kesa	36.98	10.88
Omorate	36.20	5.28	Ankober	39.53	9.67

Gina Ager	39.45	9.52	Amba Lamba	39.05	11.83
Bantu	38.21	8.65	Bete Hor	38.86	11.63
Ejere	39.15	8.76	Segora	39.37	11.45
Dusta	36.17	7.76	Firida Mareja	39.13	11.56
Debra	38.75	9.30	Agta	37.64	11.17
Yirba Moda	38.71	6.20	Gonj	37.64	11.17
Zefne	37.74	6.45	Kidamaja	36.67	11.00
Wib Hamer	36.53	5.94	Dabi	37.61	11.05
Toom	35.57	6.18	Agut	37.10	10.71
Rabel	39.37	10.53	Achewa Bado	38.22	10.88
Chelekko	40.23	8.76	Genet	37.27	10.69
Timuga	40.38	8.44	Tame	37.59	10.85
Yebokile	37.86	10.55	Zigin	36.13	10.48
Keraniya	37.87	11.07	Werk Amba	38.57	10.64
Hare Kelo	39.31	5.78	Senyin	37.68	10.66
Bila	37.07	9.21	Wegeti	38.76	10.58
Ancharo	39.74	11.08	Shelel	37.68	10.66
Dilibza	38.44	13.12	Hibino	38.94	10.25
Inda Tekle	39.56	14.19	Galesa	36.13	10.41
Haymanot			Gomer	36.86	10.43
Senkata	39.59	13.79	Kuch	37.04	10.47
May Mekdan	39.57	13.58	Yewla	37.57	10.44
May Tsamri	38.18	13.70	Inewend	37.24	10.44
Shehet	39.77	13.38	Webrje	38.10	10.33
Gich	38.20	13.29	Dehabo	40.65	10.16
Chennek	38.20	13.29	Korka	36.17	10.29
Hiwane	39.53	13.02	Gende Bune	39.17	10.26
Deresge	38.21	13.16	Debel	39.97	10.09
Ambalage	39.51	12.94	Yekoza	38.13	10.24
Kulmesk	39.14	11.94	Agemsa	36.86	9.95
Debre Zebit	38.59	11.81	Kelo	36.67	10.01
Debr	39.05	11.83	Jangir	36.67	10.01

Bete Nigus	37.86	9.87	Rob Geba	37.54	9.13
Surge	36.18	9.90	Hunde Lafto	40.91	9.05
Hose	38.23	10.05	Adami	36.54	9.09
Dire	36.62	9.87	Arba Reketi	40.91	9.05
Kokofe	36.86	9.95	Awash	40.17	8.98
Sasit	39.63	9.96	Fechase	36.67	8.96
Haro	36.30	9.79	Irensa	37.54	8.96
Kewo	37.56	9.83	Kewisa	36.49	8.89
Jardega	37.02	9.80	Bandiro	36.67	8.96
Anchekorer	39.19	9.75	Melka Jilo	39.62	8.88
Biriti	38.36	9.68	Godino	38.98	8.95
Kere Dobi	37.71	9.73	Boneya	38.73	8.82
Sombo	37.04	9.79	Debre Genet	38.33	8.78
Weberi	39.14	9.60	Wama Adere	36.76	8.76
Chulute	37.71	9.73	Abadir	39.88	8.75
Achane	37.30	9.72	Majo Weldya	41.57	8.79
Jemo Lefo	38.14	9.67	Dino	39.95	8.66
Daleti	38.56	9.80	Alga	37.08	8.60
Minare	38.36	9.68	Silk Amba	37.42	8.53
Kembolcha	38.20	9.50	Adis Hiywet	39.55	8.50
Mekoda	38.20	9.50	Kemise	36.13	8.42
Asagirt	39.45	9.52	Dire Godu	37.42	8.53
Welenkombi	38.38	9.31	Aba Bor	36.13	8.42
Ketket	38.20	9.50	Sodere	39.33	8.40
Mulo	38.75	9.30	Abdela	36.24	8.36
Gola	38.07	9.18	Bido	36.46	8.07
Wenoda	38.95	9.34	Yembero	36.46	8.07
Bicho	38.07	9.18	Gololcha	40.06	8.18
Aleltu	39.03	9.15	Setema	36.46	8.07
Bitile	37.54	9.13	Ageyo	36.46	8.07
Golo	36.46	9.21	Jembero	38.04	8.03
Goben	37.39	9.22	Kemise	36.51	7.81

Senyo Gebeya	36.72	7.78	Kilenso	38.24	5.63
Sembo	36.62	7.56	Melka Jewe	37.89	5.83
Dedo	36.88	7.52	Gato	37.41	5.55
Metoso	36.88	7.35	Goche	37.81	5.44
Gimbo	36.28	7.39	Soda	38.79	5.65
Dara	35.88	7.26	Bitata	39.57	5.34
Soyema	36.88	7.35	Gewada	37.26	5.32
Anderacha	36.24	7.27	Finchawa	38.27	5.39
Aba	36.91	7.19	Bekawile	37.36	5.29
Guguma	38.78	7.08	Dawa	38.79	5.65
Wajifo	37.74	6.45	Kolme	37.26	5.32
Morka	37.51	6.35	Gemole	37.36	5.29
Gidicho	37.74	6.45	Fasha	37.36	5.29
Otolo	37.12	6.15	Dedertu	38.29	5.14
Kofele	38.20	6.16	Mugayo	39.57	5.34
Belta	37.28	6.06	Surupa	38.29	5.14
Bonke Beza	37.33	6.05	Tedim	38.29	5.14
Beto	36.88	6.06	Bolekedo	38.20	4.78
Kulu	35.57	6.18	Arero	38.66	4.49
Tore	38.16	5.95	Hudat	39.05	4.54
Zembaba	39.17	5.89	Fejel	36.20	5.28
Wiha			Wachile	39.05	4.54
Bako	36.56	5.79	Tiltek	37.70	4.26
Jelo	37.89	5.83	Dubuluk	38.27	4.36
Belesa Koricha	39.17	5.89	Sogiya	38.66	4.49
Kercha	38.21	5.83	Sodo	38.39	4.20
Gerba	38.21	5.83	Dekewat	39.08	4.19
Alona	38.79	5.65	Muger	38.75	9.30
Arguba	37.36	5.65	Chobi	37.95	9.33
Birbirsu Bera	38.79	5.65	Filikilik	38.23	10.05
Kaka	36.64	5.67	Digelu	39.16	7.75
Cheketa	38.83	5.66			

Hamus	37.54	9.13	Chemoga	37.73	10.33
Gebeya			Kebechi	36.28	7.39
Yanfa	36.66	8.44	Dimeka	36.20	5.28
Deri	36.28	7.39	Mahbere	38.69	13.77
Digo Tsiyon	37.71	10.88	Tsige		
Berahile	40.02	13.86	Asketema	38.96	12.49
Ali Doro	38.56	9.80	Bir Afaf	39.14	11.94
Boru	39.68	11.31	Anjeni	37.68	10.66
Chancho	40.06	8.18	Dulecha	39.76	9.84
Shola Gebeya	39.38	9.08	Tulema	36.12	8.77
Fogota	36.89	11.08	Guto	36.19	8.66
Bole Arebsa	38.88	9.06	Gesecha	36.22	8.14
Injbara	36.89	11.08	Sineso	36.46	8.07
Wacha	37.51	6.35	Boneya	36.88	7.52
Key Afer	36.73	5.52	Mote	36.99	8.89
Shil Afaf	39.25	10.42	Hana	36.55	6.35
Kolobo	36.54	9.09	Harodibe	40.79	6.10
Gute	36.67	8.96	Koremas	39.38	9.08

Appendix 4: Zone 4 Climatic Cities of Ethiopia

TOWN_NAME	LONG_EAST	LAT_NORTH			
			Tepi	35.44	7.27
DIRE DAWA	41.87	9.59	Bako	37.06	9.12
GONDER	37.47	12.60	Mendi	35.10	9.79
BAHR DAR	37.37	11.56	Ibnat	38.05	12.13
Welkite	37.78	8.27	Deror	44.69	8.24
AWASSA	38.48	7.06	Hirna	41.10	9.21
JIJIGA	42.80	9.35	Babile	42.46	9.21
SHASHEMENE	38.59	7.20	Kola Diba	37.32	12.42
Soddo	37.82	6.91	Kebri Beyah	43.35	9.16
Degeh Bur	43.56	8.22	Shinile	41.87	9.59
Axum	38.71	14.13	Dabat	37.77	12.98
Alamata	39.56	12.42	Funyan Bira	42.40	9.35
INDA SILASE	38.28	14.10	Fik	42.29	8.13
WELDIYA	39.59	11.83	Alem Maya	42.04	9.44
Adwa	38.90	14.16	Aykel	37.07	12.55
Yirga Alem	38.41	6.75	Melka Jeldu	41.87	9.59
Kobo	39.63	12.16	Sekota	39.03	12.63
Gimbi	35.84	9.17	Sire	36.96	9.09
Meki	38.81	8.15	Mersa	39.62	11.54
Ziway	38.71	7.93	Gore	35.54	8.15
Maychew	39.54	12.78	Durame	37.91	7.22
Metu	35.54	8.33	Hamusit	37.69	11.92
Woreta	37.69	11.92	Mender		
Kulito	38.10	7.41	Gemesha	37.91	7.22
Debark	37.90	13.16	Mena	39.84	6.41
Adis Zemen	37.72	12.08	Ijaji	37.33	8.99
Boditi	37.86	7.07	Adi Gudom	39.51	13.18
Areka	37.71	7.07	Harshin	43.48	9.16
Aleta Wendo	38.42	6.60	Bike	41.19	9.52
Nejo	35.60	9.41	Masha	35.47	7.75

Waja	39.63	12.16	Angecha	37.77	7.33
Meksenyit	37.53	12.37	Hurumu	35.72	8.33
Wirgesa	39.62	11.54	Aje	38.35	7.31
Melka Rafu	42.12	9.43	Wendo Genet	38.48	7.06
Robit	39.63	12.16	Aware	44.15	8.26
Asendabo	37.23	7.77	Yara	35.41	9.10
Deneba	37.42	7.93	Arb Gebeya	37.74	11.63
Chwahit	37.23	12.33	Alem Teferi	35.22	8.90
Mender			Arbe Gona	38.51	6.56
Adami Tulu	38.70	7.86	Jajura	37.68	7.46
Erer	41.38	9.56	Gesuba	37.62	6.83
Gibe	37.23	7.77	Medula	37.68	7.46
Amba Giyorgis	37.62	12.76	Gidami	34.54	9.01
Chuko	38.42	6.60	Water	41.91	9.45
Rama	38.98	14.50	Yifag	37.72	12.08
Chelenko	41.63	9.51	Gorgora	37.29	12.24
Gimbichu	37.68	7.46	Kake	35.05	8.93
Guliso	35.46	9.16	Tebela	37.76	6.73
Kachisi	37.84	9.59	Zarima	37.95	13.36
Bila	35.59	9.36	Guji	35.78	9.01
Adi Shoh	39.54	12.78	Bube	35.80	8.84
Selekleka	38.48	14.12	Boku	42.15	8.94
Tis Abay	37.74	11.63	Arabi	42.72	9.93
Lefe Isa	42.98	9.61	Kulubi	41.63	9.51
Wacha	35.81	7.16	Bedesa	37.86	6.89
Wichale	39.62	11.54	Ano	36.96	9.09
Shekosh	44.49	7.75	Anbesame	37.74	11.63
Waka	37.10	7.04	Rob Gebeya	34.84	8.76
Adi Arkay	37.95	13.36	Mesela	41.10	9.21
Chanka	35.07	8.86	Babo	36.94	8.19
Sekoru	37.42	7.93	Dupa	35.51	8.58
Inango	35.75	9.13	Indibir	37.92	8.11

Hurso	41.63	9.51	Bilo	36.99	8.89
Wekin	37.77	12.98	Genji	35.62	9.03
Bizet	39.15	14.28	Dimtu	37.86	6.89
Samre	39.30	13.15	Dimtu	37.23	7.77
Nada	37.23	7.77	Yubdo	35.45	8.95
Abela Lida	38.49	6.91	Seraba	37.07	12.55
Teferi Kela	38.38	6.56	Kumbi	37.49	8.12
Debeka	35.20	9.47	Gecha	35.47	7.75
Atnago	36.87	8.36	Nopa	35.60	8.38
Supe	35.66	8.52	Tocha	37.04	7.09
Weyra Wuha	39.78	12.50	Uka	35.32	8.19
Ropi	38.23	7.28	Fofa	37.42	7.93
Abosa	38.73	8.05	Dawo Kebe	34.97	8.98
Dega	36.11	8.58	Bila	37.07	9.21
Kersa	41.91	9.45	Kose	37.96	7.82
Seyo	37.35	8.87	Debre Damo	39.15	14.28
Sibo	35.32	8.19	Inticho	39.15	14.28
Idaga Arbi	39.07	14.04	Adi Abun	38.90	14.16
Kober	34.56	9.47	May Keyah	39.51	13.18
Gunchire	37.92	8.11	Adi Teweld	37.38	13.35
Alge	35.66	8.52	Medhin		
Zege	37.31	11.69	Dib Bahir	37.90	13.16
Felege Selam	36.44	7.14	Sankaber	37.90	13.16
Yechilay	39.07	13.25	Adi Zeyla	39.03	13.11
Denbel	42.72	9.93	Aberqele	39.03	13.11
Seka	36.94	8.19	Azezo	37.43	12.55
Bachuma	35.89	6.83	Chandiba	37.03	12.41
Gubre	37.78	8.27	Robit	37.43	12.28
Chida	36.79	7.17	Gwaliya	37.95	12.15
Afdem	41.19	9.52	Wanzaye	37.69	11.92
Jarso	35.32	9.44	Sirinka	39.59	11.83
Ameya	36.66	7.11	Gogti	42.72	9.93

Biye Anod	42.72	9.93	Dugda	38.73	8.05
Teferi Ber	43.22	9.79	Tiro	37.34	8.17
Toba	35.37	9.60	Aroresa	44.49	7.75
Togochale	43.23	9.49	Toba	37.42	7.93
Nopa	34.56	9.47	Durgu	37.35	7.08
Gota	41.34	9.52	Bura	38.38	7.30
Kombolcha	42.12	9.43	Mazoriya	37.91	7.22
Hadew	42.80	9.35	Tocha Sodo	37.16	7.14
Hena	35.59	9.36	Shone	37.95	7.10
Tobi	34.56	9.24	Genji	36.75	7.11
Deboko	35.59	9.36	Temenja Yazhi	35.67	7.15
Mekenejo	35.75	9.13	Meri	37.10	7.04
Rob Gebeya	36.91	9.15	Tulema	37.24	7.01
Sichawo	34.98	9.10	Shewa Gimira	35.76	6.97
Keki	35.90	9.08	Tula	38.49	6.91
Hamus	35.90	9.08	Wijigra	38.49	6.91
Gebeya			Bele	37.61	6.90
Jogir	35.90	9.08	Hogiso	38.49	6.91
Tibe	34.72	9.04	Chelchel	41.26	6.83
Kelo	35.35	8.91	Gachit	35.77	6.65
Obele	43.12	8.68	Kindo Halato	37.40	6.91
Koma	36.86	8.44	Gelcha	37.76	6.73
Botor Keta	37.32	8.36	Natri	37.44	7.97
Botor Bocho	37.32	8.36	Becho	35.69	8.20
Ombole	38.78	8.36	Meko	36.03	8.67
Tedele	37.65	8.38	Elemo	35.87	8.57
Burusa	35.46	8.29	Welde Hane	37.16	7.14
Bege	37.13	8.36	Debeso	35.65	8.84
Toley	37.32	8.36	Muklemi	35.51	9.32
Tawula	37.68	8.27	Jemu	35.77	6.65
Mecha	37.05	8.24	Loma Bale	37.24	7.01
Abelti	37.57	8.17	Legehida	41.07	7.93

Hintalo	39.51	13.18	Zobl	39.74	12.26
Birbirs	35.32	8.19	Kulf Amba	39.59	11.83
Leka	35.69	8.20	Bisidimo	42.40	9.01
Adi Mendi	38.41	14.33	Koye	36.86	8.44
Kedamit	38.79	12.92	Ulawarta	36.87	8.36
Didigsala	39.80	12.71	Sheki Husen	40.76	8.01
Zuna	38.86	12.77	Gowa	36.66	7.11
Siska	38.86	12.77	Wishaye Bele	37.10	7.04
Guhala	38.21	12.44	Mote	36.99	8.89
Ayna	38.84	12.16	Hada	41.54	7.80

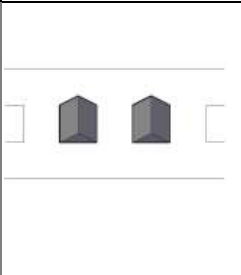


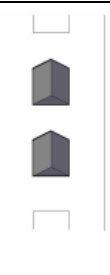
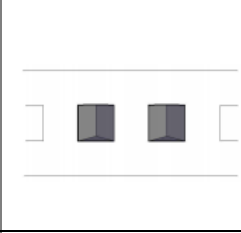
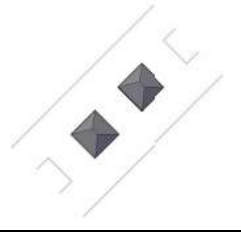


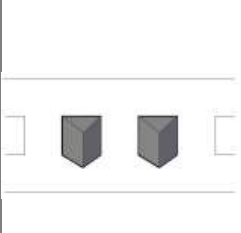
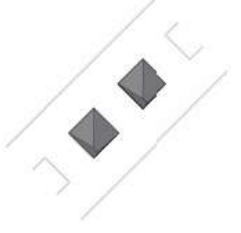

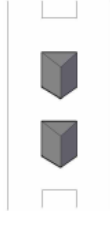
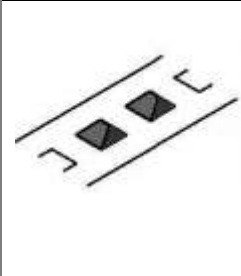
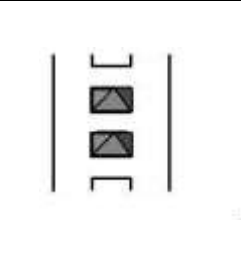
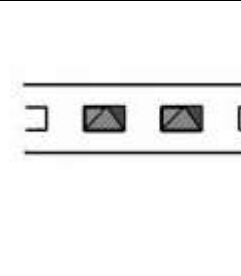
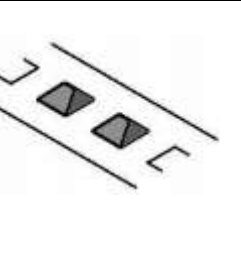
Appendix 5: Zone 5 Climatic Cities of Ethiopia

TOWN_NAME	LONG_EAST	LAT_NORTH			
			Adi Da-iro	38.18	14.32
Gode	43.60	5.89	Bambesi	34.73	9.75
INDA SILASE	38.28	14.10	Kunzila	36.98	11.88
Kebri Dehar	44.28	6.74	Begi	34.53	9.34
Dembidolo	34.80	8.53	Boh	46.65	7.45
GAMBELA	34.59	8.24	Gashamo	45.35	8.12
AYISAITA	41.31	11.95	Loqiya	41.00	11.75
Suftu	42.06	4.18	Metema	36.17	12.93
ASOSA	34.53	10.06	Yismala	36.98	11.88
Mizan Teferi	35.45	6.93	Korahe	44.38	6.54
Dubti	41.00	11.75	Ferfer	45.05	5.11
Kelafo	44.13	5.60	Segeg	42.83	7.67
Funyan Bira	42.40	9.35	Mile	40.76	11.42
Shiraro	37.74	14.29	Debre Zeyit	35.70	10.63
Chinaksen	42.68	9.51	Hamero	42.06	7.85
Geladin	46.41	6.97	Dewelee	42.63	11.03
Denan	43.49	6.50	Harawa	42.06	10.05
Welwel	45.40	7.05	Bure	35.10	8.28
Welwel	45.34	6.97	Itang	34.31	8.20
Chereti	42.17	5.22	Asbuli	41.16	9.97
Woldya	42.06	4.18	Godere	43.97	5.06
Adigala	42.24	10.42	Bekolmag	42.06	4.18
Pawe	36.02	11.15	Punydo	34.50	7.58
Harqele	42.17	5.22	Adi Awalo	37.99	14.52
Mustahil	44.73	5.24	Degeh Medo	43.02	7.98
Bare	42.63	4.63	Dinqil Ber	37.01	11.93
Delgi	37.02	12.10	Aydora	41.36	9.85
Mugi	34.60	8.56	Abobo	34.56	7.86
Shelabo	44.76	6.09	Imi	42.18	6.46
Tikil Dingay	37.33	12.91	Dihun	42.70	7.21

Ayisha	42.57	10.75	Adadile	42.50	6.97
Kere	42.09	5.84	Debe Weyin	44.12	6.11
Afker	42.17	5.22	El-Kere	42.09	5.84
Mesfinto	37.32	13.39	Lema Shilnich	42.11	4.93
Densha	37.32	13.39	Yet	42.63	4.63
Wehini	36.54	12.66	Burkale	42.06	4.18
Sulula	42.10	12.29	Bur	42.06	4.18
Amistiya	37.02	12.10	Melda	42.06	4.18
Amistiya	37.01	11.93	Manda	42.18	12.41
Serdo	41.31	11.95	Jikawo	33.90	8.27
Hayu	41.80	11.90	Mankush	35.28	11.27
Deday	41.80	11.90	Danot	45.29	7.56
Tendaho	40.95	11.69	Genda Wuha	36.54	12.66
Weranso	40.52	11.30	Mahbere	36.54	12.66
Guba	35.28	11.27	Silase		
Adi Gala	42.24	10.42	Omedila	35.68	11.69
Asbuli	41.16	9.97	Omedila	35.19	11.22
Biye Gurgur	42.66	10.60	Tirgol	33.25	7.78
Benguwa	34.73	9.75	Penkow	33.58	7.86
Kelem	34.52	9.15	Badhi	42.63	4.63
Sedi	34.66	8.64	Kurmuk	34.38	10.49
Wanke	33.90	8.27	Tewodros	35.74	11.72
Shebel	34.60	8.56	Ketema		
Bonga	34.59	8.24	Mega	34.76	10.38
Kurmis	46.53	7.77	Gizen	34.50	10.55
Domo	46.75	8.07	Godere	35.06	10.42
Birkot	43.48	7.94	Komosh	34.71	10.33
Benado	44.28	6.74	Daleti	35.01	10.09
Geledid	44.28	6.74	Gura Ferda	35.35	6.87
Agere Weyin	45.40	7.05	Afambo	41.67	11.46
Dubub	46.41	6.97	Girar Woha	36.17	12.93
Bebeka	35.35	6.87	Dabus	34.87	10.24

Appendix 6: 3D Illustration of Ethiopia climatic zones with respect to critical months and their Solar responsive building shapes.










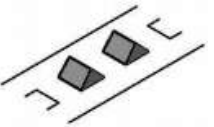

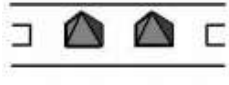
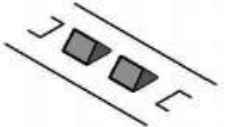
Climate zone 1, Goba Robe 3D Envelope Illustration

Orientation	E-W	SW-NE	NW-SE	N-S
June				
September				
December				
Solar Responsive Building Envelope				


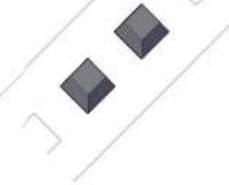



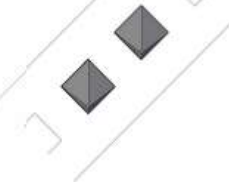



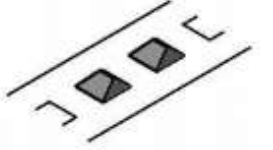
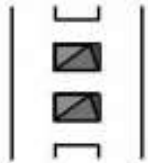

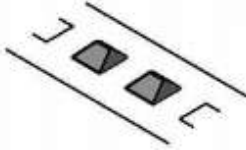
Climate zone 2, Robe 3D Envelope Illustration

Orientation	E-W	SW-NE	NW-SE	N-S
June				
September				
December				
Solar Responsive Building Envelope				

Climate zone 3, Addis Abeba 3D Envelope Illustration

Orientation	E-W	SW-NE	NW-SE	N-S
March				
August				
Solar Responsive Building Envelope 				

Climate zone 4, Dire Dawa 3D Envelope Illustration

Orientation	E-W	SW-NE	NW-SE	N-S
June				
December				
Solar Responsive Building Envelope 				

Climate zone 5, Gode 3D Envelope Illustration

Orientation	E-W	SW-NE	NW-SE	N-S
September (5:00 Am)				
September (6:00 Noon)				
September (7:00 Pm)				
Solar Responsive Building Envelope 