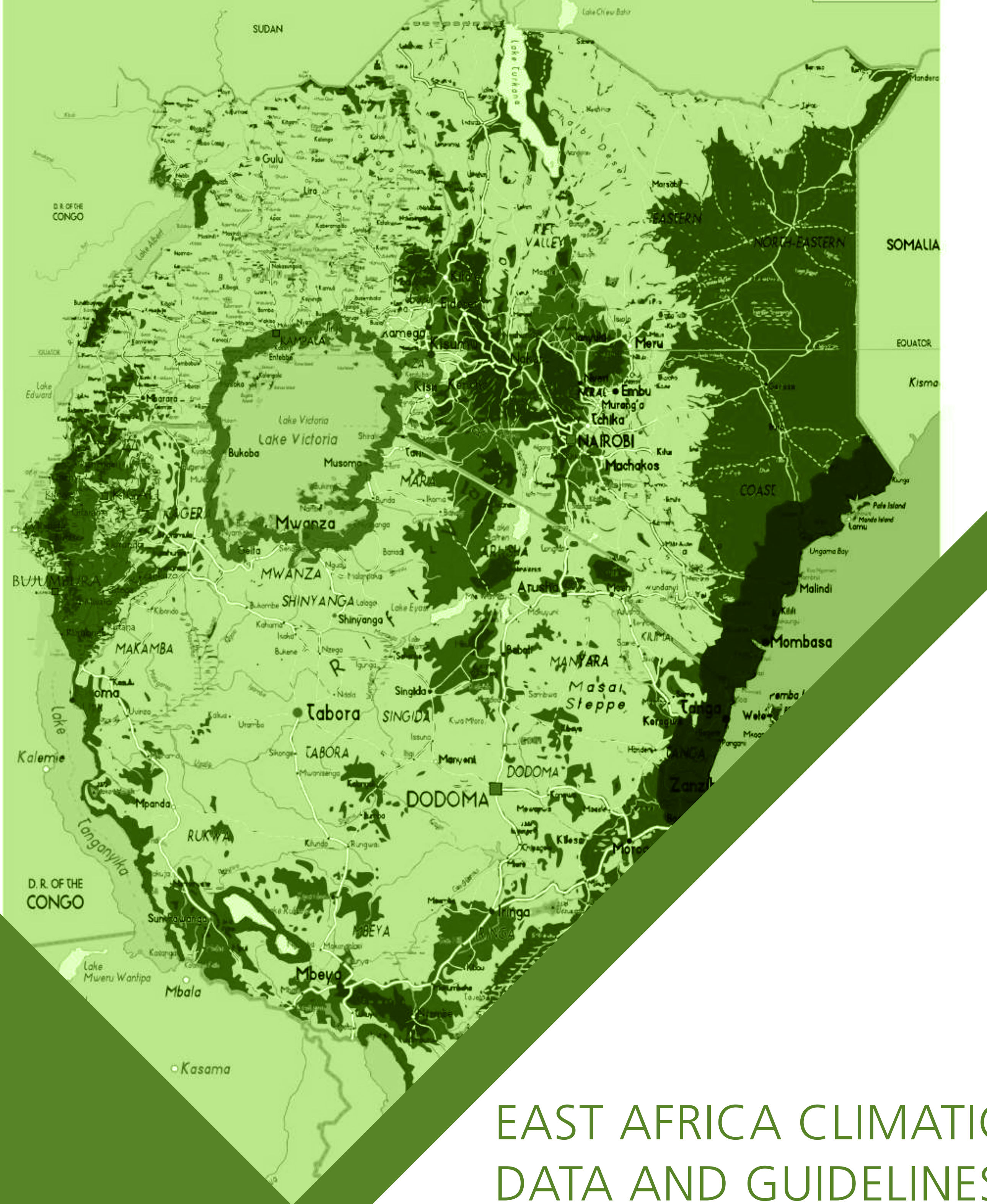

EAST AFRICA CLIMATIC DATA AND GUIDELINES FOR **BIOCLIMATIC ARCHITECTURAL DESIGN**

UN-HABITAT
FOR A BETTER URBAN FUTURE

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DISCLAIMER

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TABLE OF CONTENT

EXECUTIVE SUMMARY

This report presents climatic data of different regions in East Africa that was compiled within the project Promoting Energy Efficiency in Buildings in East Africa. This project was initiated by UN-Habitat in collaboration with the Governments of Kenya, Uganda, Tanzania, Rwanda and Burundi and the United Nations Environmental Program (UNEP). Funded by the Global Environment Facility (GEF) and co-funded by the five East African countries, the project was designed to help countries in East Africa to integrate energy efficiency measures into their building policies and practices to reduce energy demand.

East Africa is divided into six unique climatic regions – hot and humid e.g. Dar es Salaam, hot-arid e.g. Garissa, hot semi-arid / savannah e.g. Dodoma, great lakes e.g. Kampala, upland e.g. Kigali and high upland e.g. Eldoret - each requiring different design strategies to minimise energy consumption and maximise indoor thermal comfort.

Climatic data for 20 major towns in Kenya was obtained from the open database of the U.S. Department of Energy[1] while data from major towns in Tanzania (6), Uganda (1) and Rwanda (1) was obtained under license from Meteotest through the software Meteonorm[2]. These data sets, which are Typical Meteorological Year (TMY), contain hourly meteorological values for a 1-year period that characterise climatic conditions at a specific location over a long period of time such as 30 years.

The data was analysed and presented graphically (inform of psychrometric charts) using Climate Consultant 6.0 - a graphic based climate data analysis computer program. Microsoft Excel program was also used to generate climate data graphs. From the analysis, it was clear that each zone requires different passive building design strategies to achieve human thermal comfort as well as minimise the energy required for heating and cooling. Some of the interventions that are suited for all the climatic zones include:

- Orientation of the building along the east – west axis with major openings facing north and south.
- Protection of all openings using appropriate sun shading devices against unwanted solar radiation.
- Provision of openings for natural ventilation and daylighting – large openings are more suitable for hot and humid climates while small openings are preferred in hot arid and hot semi-arid / savannah climates.
- Single-banked floor plans in hot humid and great lakes climate to maximise cross ventilation while double-banked building forms are desirable for uplands and high upland climates.
- Open layouts are recommended for hot humid and great lakes climates to allow maximum ventilation while compact housing layouts are preferred in hot arid and hot semi-arid / savannah climates for mutual shading and provision of cool spaces when combined with plants and water features as well as protection against hot, dry winds.
- Use of light coloured or reflective external surfaces to reflected unwanted solar radiation.
- Light weight building envelope is recommended for hot and humid climates to maximise air flow; medium weight building structures are recommended for hot semi-arid / savannah and great lakes climate to even out indoor temperatures; and high thermal mass building materials are preferred for hot and arid climates because of the high daily temperature swing; and medium weight structures are recommended for uplands and high uplands climates for best exploitation of passive solar gains for passive heating.

1 *U.S Department of Energy (n.d.) Weather Data | EnergyPlus [Online]. Available from: <https://energyplus.net/weather>.*

2 *Meteotest (n.d.) Meteonorm: Irradiation Data for Every Place on Earth [Online]. Available from: <http://www.meteonorm.com/en/>.*

01 INTRODUCTION

In Africa, the building sector alone accounts for over 54% of primary energy. Majority of buildings in sub-Saharan Africa are replicas of buildings designed for the western world even though they are in the tropical climate. This results to heavy reliance on artificial means for cooling, heating and lighting. Additionally, tremendous energy wastage is caused by poor understanding of thermal comfort and passive building principles that leads to inefficient design as well as poor energy conscious behaviour.

However, energy saving potentials can be achieved if buildings are correctly designed with passive building strategies that are according to the climate in which they are located, resource efficient appliances are provided and renewable energy technologies are adopted. Knowledge of the climatic conditions of a place is important to develop appropriate designs and consequently select suitable materials that meet climatic constraints.

Climate may be described as the average course or condition of the weather at a place usually over a period of years (usually 30 years) as exhibited by patterns of temperature, wind, atmospheric pressure, solar radiation, precipitation, humidity and other meteorological variables.

Bioclimatic Architecture is described as a combination of design solutions that will create a satisfactory level of human comfort within a building. The building in question should be designed in such a way it works with the climate and natural energy sources; minimise the need for fossil fuel to run; have indoor thermal comfort etc[3].

Man responds to buildings, landscapes, trees and other elements as much as he responds to social experience[4]. However, modern buildings seem not to take into consideration the relationship between man and his behavioural response to the external climatic elements. They have been increasingly designed as copies of western standards with no consideration to the local climate thus the modern design separates the inside from the outside as much as possible, increasingly relying on mechanical devices and systems to do much of the work in creating thermal comfort.

Buildings have a strong potential to negatively or positively impact two important elements of everyday life: the environment and energy bills. Their contribution to climate change mitigation on greenhouse gas emission and higher or lower energy bills are directly related to the way they are designed in relation to local climate and site-specific characteristics.

The first step in creating thermal comfort in buildings is to understand the relationship between the climate and the need for shelter. Buildings are exposed to a wide range of weather parameters throughout the year and this influences the way they should be designed in relation to their location.

The objective of this report was to:

1. Provide guidelines in the collection and analysis of climatic data;

2. Highlight how the data will assist in energy efficient building design; and

3. Define climatic zones in East Africa and present climatic data of various towns, giving passive building design recommendations according to the climates in which they lie.

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3 *ENEA, (Italian Commisssion for Nuclear and Alternative Energy Sources & IN/ARCH Na) (1983) Architettura Bioclimatica: Bioclimatic Architecture. Rome: De Luca Editore.*

4 *Konya, A. (1980) Design Primer for Hot Climates. London: Architectural Press.*

02 SOURCES OF CLIMATIC DATA

CLIMATIC DATA COLLECTION

Climatic data can be collected through the following ways:

I. GOVERNMENT METEOROLOGICAL STATIONS

The main and most reliable source of climatic data is from the Governments' Meteorological Departments. The Kenya Meteorological Department[5] sells data to private organizations per parameter per location. For instance, temperature data from different weather stations like Nairobi, Mombasa etc. can be purchased separately for each month for each town for each climatic parameter. It is important to find out the logistics of collecting data from the Meteorological stations in your respective country.

II. CLIMATIC DESIGN PUBLICATIONS

Books and other publications on climatic design contain climatic data information that has been compiled from various sources. This data, in as much as it may not be as comprehensive as the one obtained from the meteorological department, may give a general overview of the climate of a particular location. These publications may also give general information on how the climatic parameters have been changing over the years and offer insight on rare phenomena in an area i.e. mudslides, flooding, earthquakes etc.

III. ATLASES

An atlas, which is a collection of maps, may contain reliable climatic data. Organisations that are concerned with climate and climate mitigation such as World Meteorological Organization (WMO)[6] are good sources of such publications.

5 *Kenya Meteorological Department (2015) Kenya Meteorological Department [Online]. Available from: <http://www.meteo.go.ke/>.*

6 *World Meteorological Organization (2016) World Meteorological Organization Extranet | Www.wmo.int [Online]. Available from: <http://www.wmo.int/pages/index_en.html>.*

IV. OPEN DATA BASE

The U.S Department of Energy[7] contains an open data base that has weather data for more than 2,100 locations worldwide which is classified by WMO region and country. These data is available in EnergyPlus weather format (.epw) that can be used in conjunction with software available in the market to simulate climatic conditions of a particular location. Some of these tools include Climate Consultant[8], Autodesk Ecotect[9], RETScreen[10], DesignBuilder[11], EnergyPlus[12] among others. These building simulation tools are important as they test a building's response to different climatic conditions.

V. ONLINE SOURCES

Numerous websites contain compiled climatic data information that has been derived from other sources. Data from such websites should be critically analysed and compared and therefore it is important to verify the sources before they are considered appropriate for use.

VI. AIRPORTS

Many countries use data collected at weather stations located at airports. In Kenya, the airport data collection centers are connected to the Kenya Meteorological Department. Most airports in the region however, tend to be located a few kilometres from the busy urban centers and the data collected is usually slightly different from the data needed in busy urban centers. A differential factor can be applied to the collected data to obtain relevant information.

7 *U.S Department of Energy (n.d.) Weather Data | EnergyPlus [Online]. Available from: <https://energyplus.net/weather>.*

8 *Climate Consultant (n.d.) [Online]. Available from: <http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php>.*

9 *http://www.autodesk.com.au/*

10 *Natural Resources Canada (2014) RET Screen International Home [Online]. Available from: <http://www.retscreen.net/ang/home.php>.*

11 *DesignBuilder Software Ltd (2015) DesignBuilder - Building Simulation Made Easy [Online]. DesignBuilder. Available from: <http://www.designbuilder.co.uk/content/view/43/64/>.*

12 *U.S Department of Energy (2015) EnergyPlus Energy Simulation Software [Online]. Energy Efficiency & Renewable Energy. Available from: <http://apps1.eere.energy.gov/buildings/energyplus/>.*

03 CLIMATIC DATA PARAMETERS AND IMPACT ON DESIGN

Designing according to the local climate is not only economically beneficial through the reduction of energy bills, but also improves indoor comfort. When designing a building for indoor comfort, the key elements to consider are; solar radiation, air temperature, relative humidity, wind (direction, frequency and velocity) and rainfall. The frequency and likely duration and nature of extreme climatic phenomenon must also be ascertained because even though they may be relatively rare and for short durations, they must be considered to ensure structural safety. Such phenomena include earthquakes, lightning, landslides, dust storms and floods.

A brief description of the climatic elements listed above and their impact on design is given below.

A) SOLAR RADIATION

This is radiation emitted by the sun in form of electromagnetic waves, infrared radiation, ultra violet radiation and visible light. As it is the source of almost all the earth's energy, it influences most of the climatic phenomena.

Global solar radiation, which is measured by pyranometers (see Figure 1), is a combination of three components – direct, diffuse and reflected solar radiation from the ground or surrounding surfaces (as illustrated in Figure 2).

Knowledge of the amount of solar radiation at a location will influence the building design in terms of the building form and orientation; location and size of openings; appropriate sun shading options; type of glazing; external surfaces - choice of materials, type of textures and finishes; insulation materials and location; roof space ventilation etc.

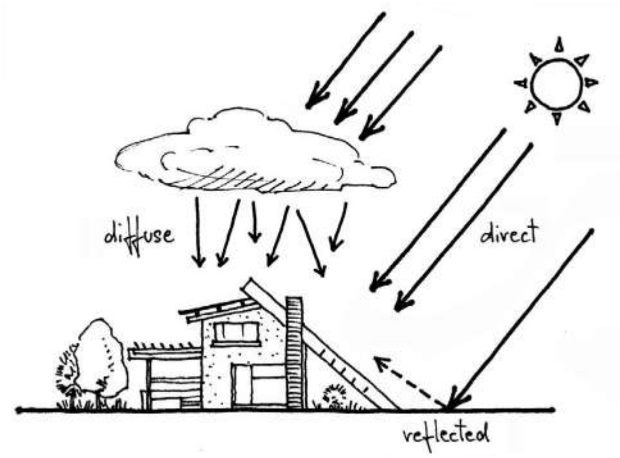
B) AIR TEMPERATURE

Air temperature, which is a measure of how hot or cold the air is, is the most commonly measured weather parameter. Measured by a thermometer (see Figure 3), it is greatly influenced by geographical factors (latitude, hydrography and topography), surface texture, solar radiation, wind and location (i.e. rural vs urban setting). Generally, air temperature reaches its lowest value just before sunrise and gradually increases to its maximum value in the early afternoon where it begins to decrease.

FIGURE 1 **PYRANOMETERS MEASURE TOTAL OR GLOBAL SOLAR RADIATION**

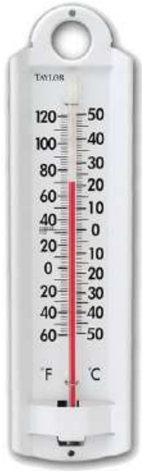
Source: *http://www.hukseflux.com/*

FIGURE 2 **WAYS IN WHICH A SURFACE RECEIVES GLOBAL SOLAR RADIATION**



Source: *UN-Habitat (2015) Sustainable Building Design for Tropical Climates: Principles and Applications for Eastern Africa. Nairobi, Kenya: UN-Habitat.*

FIGURE 3 **INDOOR / OUTDOOR WALL THERMOMETER**



Source: *https://www.weathershack.com*

FIGURE 4 **CUP ANEMOMETER THAT MEASURES WIND SPEED AND WIND DIRECTION**

Source: *http://climate.ncsu.edu/edu/ag/instruments*

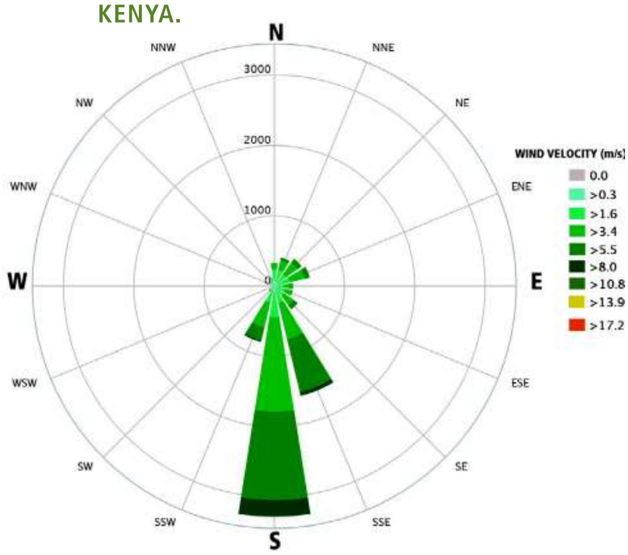
Daily and monthly temperature ranges enable the prediction of heat loss / gain in buildings. This allows the designer to make appropriate design responses to create indoor thermal comfort.

C) WIND

Wind is the movement of air masses caused by air temperature gradients as well as differences in atmospheric pressure. Direction, speed and frequency of calms, measured using an anemometer (see Figure 4), are important characteristics of wind. Natural air movement enables natural ventilation which is beneficial in the following ways: maintain the quality of air in buildings above a certain minimum level by replacing contaminated indoor air with outdoor fresh air; cool the building's structure and promote heat loss from the body thus providing thermal comfort[13].

13 *Hooper, C. (1975) Design for Climate: Guidelines for the Design of Low Cost Houses for the Climate of Kenya.*

FIGURE 5 **WIND ROSE DIAGRAM FOR MOMBASA, KENYA.**



Source: *https://www.meteoblue.com/*

Understanding the prevailing wind patterns of the site can be useful when designing ways to take advantage of natural ventilation or to protect the occupants from uncomfortable windy conditions. Knowledge of the wind characteristics of a location will enable the determination of proper building shape and orientation; type, size and position of openings; internal space configuration and siting of buildings on site.

A wind rose diagram (see Figure 5) is used to show wind speed and direction. It also analyses the characteristics of the wind by indicating its strength and frequency over a specified period (month, season and year). The longest spoke on the wind rose represents the greatest frequency of winds blowing from that direction over the specified time frame.

D) RELATIVE HUMIDITY

Relative humidity is the ratio of the actual humidity in a given volume of air to the maximum moisture capacity at that particular temperature[14]. It affects the behaviour of building materials and their rate of deterioration. High relative humidity quickens the corrosion of metals (such as galvanised iron sheets) and retards evaporation from wet surfaces which may lead to warping and cracking of certain materials (such as timber).

Combined with high temperature, it often results in the growth of surface mould on certain materials for example concrete and other cement products. It also affects the evaporation from the human body and thus has a direct effect on the thermal sensation and comfort[15]. Figure 6 shows a sling psychrometer, a type of instrument commonly used to measure relative humidity.

14 *Konya, A. (1980) Design Primer for Hot Climates. London: Architectural Press.*

15 *Hooper, C. (1975) Design for Climate: Guidelines for the Design of Low Cost Houses for the Climate of Kenya. Nairobi: Housing Research and Development Unit, University of Nairobi.*

FIGURE 6 **A SLING PSYCHROMETER (CONSISTING OF A WET-BULB THERMOMETER AND A DRY-BULB THERMOMETER) IS LARGELY USED TO DETERMINE RELATIVE HUMIDITY**

Source: *http://www.physicalgeography.net/fundamentals/8c.html*

E) RAINFALL

Rainfall results from condensed water vapour that precipitates forming droplets that fall from clouds due to gravity. The rate, intensity and amount of rainfall determines the drainage requirements, waterproofness of a structure, choice of roof pitch, size of roof overhangs, size of gutters, durability of walls etc. Rainfall is measured using a rain gauge (see Figure 7).

Other factors that do not constitute climatic parameters but influence the building design include:

1. TOPOGRAPHY

The natural features of a location / site such as the shape, orientation, altitude of hills, valleys, presence or absence of water bodies, vegetation etc. have an effect of temperature, solar radiation, wind and rainfall therefore affecting the micro climate. This in turn influences the design of the building and therefore proper site analysis is required to maximize the use of the existing micro climate.

FIGURE 7 **A RAIN GAUGE**

Source: *http://www.windandweather.com/*

2. LONGITUDE AND LATITUDE

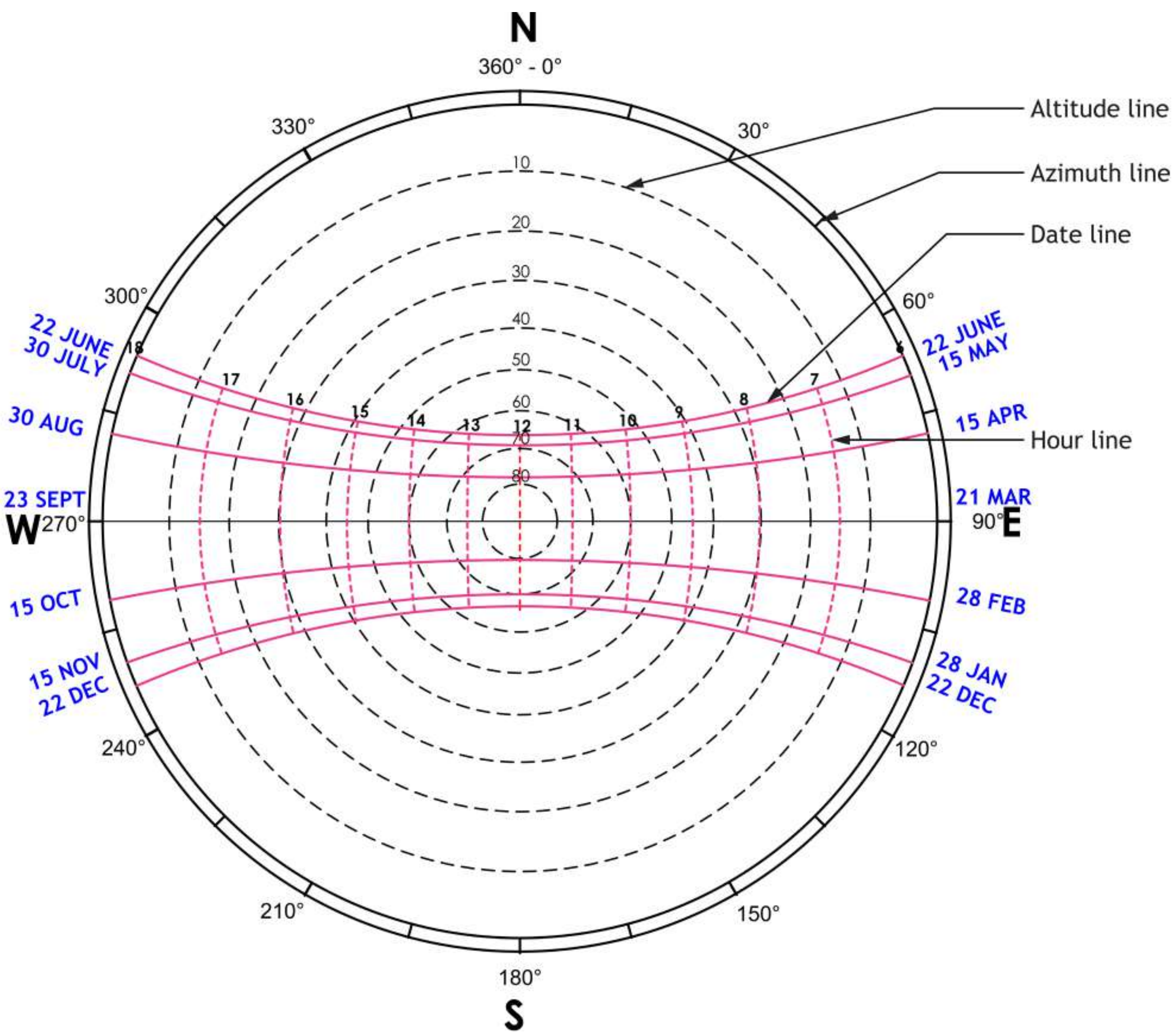
The geographic location of a place can be identified using longitude and latitude coordinates. One of the most important factors that affect climate is the latitude. The distance from the sun varies with the distance a site is in relation with the equator (latitude 0°). The further a site is from the equator, the longer it takes for the sun rays to reach the surface. This affects solar radiation, temperatures, precipitation and on some occasions humidity. This influences a building's orientation, sun shading, size of openings, type of glazing, building material etc.

The sun's changing position in the sky throughout the year can be conveniently represented by the sun path diagram (see Figure 8). It is represented with a coordinate system (altitude and azimuth) and can be read off directly from the diagram for any time of the day and month. This is useful in providing a summary of the solar position that should be considered when designing. The most used systems are the polar and the cylindrical sun path diagrams.

POLAR SUN PATH DIAGRAM

The polar representation gives the image of the celestial sphere by placing itself right above the zenith (the point of the sky directly overhead) of the area under consideration. In this type of representation, lines of equal solar altitude are spaced widely apart near the zenith of the sky but are concentrated quite closely together near the horizon. Each sun-path line is generated by determining the exact position of the sun as it passes through the sky (hourly) for each date. This is then projected from the sky dome onto the flat image (see Figure 8).

FIGURE 8 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (E.G. ELDORET TOWN 0° 31′ N 35° 17′ E)**



Reading the Position of the Sun (altitude and azimuth)

1. Select the chart of the correct latitude (each location has a different chart).
2. Select one date line to be analysed.
3. Select the hour line and mark its intersection with the date line.
4. Read from the concentric circles the altitude angle (sun's height from the ground).
5. Lay a straight line from the centre of the chart, through the marked time point to the outer circle and read the azimuth angle (sun orientation related to the north).

To find the optimal building orientation, place the building plan in the centre of the diagram, aligning it with the orientation under consideration.

04 METHODOLOGY

For useful energy efficiency design measures to be put in place, it is important to have hourly parameters over a 24-hour period, 1-week period, and 1-month period and so on. This report is an attempt to utilise the data most readily available for the designers that will assist in preliminary design measures given the recorded averages of the climatic parameters.

Climatic data collection in some of the East African countries like Kenya is expensive and difficult to get from the appropriate authorities which would make it increasingly difficult for individual designers to access important data to carry out their work. Considering the importance and necessity of these data to designers, it is paramount that it be more accessible to the professionals either through the relevant professional associations or the relevant bodies that provide the data.

A) CLIMATIC DATA PRESENTED IN THIS REPORT

Climatic data presented in this report was obtained from the open database of the U.S Department of Energy [16]which contains Typical Meteorological Year (TMY) files for more than 2,100 locations of the world.

Weather files for towns in Kenya presented in this report were obtained from this data base. Other weather files - Tanzania, Uganda and Rwanda - files were obtained under license from Meteotest through the software Meteonorm[17]. These TMY data sets contain hourly meteorological values for a 1-year period that characterise climatic conditions at a specific location over a long period of time such as 30 years.

B) ANALYSING CLIMATIC DATA

Different approaches can be used to determine passive design strategies for different climatic conditions. These include:

I. MAHONEY TABLES

Mahoney tables, named after architect Carl Mahoney, are a set of reference tables used in architecture as a guide to climate-appropriate design. They consist of tables that use readily available climate data – temperature, relative humidity, rainfall and wind - for comparison with requirements for thermal comfort appropriate design criteria. A sample of these tables are as seen in Appendix 1.

II. OLGYAY'S BIOCLIMATIC CHART

This is a simple tool for analysing climate by indicating human comfort zones based on ambient temperature, humidity, mean radiant temperature, wind speed, solar radiation and evaporative cooling (see Figure 9). Based on dry bulb temperature and relative humidity, a point on the chart can be determined if it lies within the comfort zone. Any point that falls beyond the comfort zone region, then corrective measures are required to restore the feeling of comfort.

III. GIVONI'S BIOCLIMATIC CHART

The Givoni bioclimatic chart shows air temperature (represented by vertical lines) against relative humidity, (represented by curved lines) and can be used to express human thermal comfort, design strategies, and energy requirements for those strategies.

This chart suggests design strategies to adapt a building's architecture to the prevailing climate according to six zones that are defined on the chart as shown in Figure 10. These zones include:

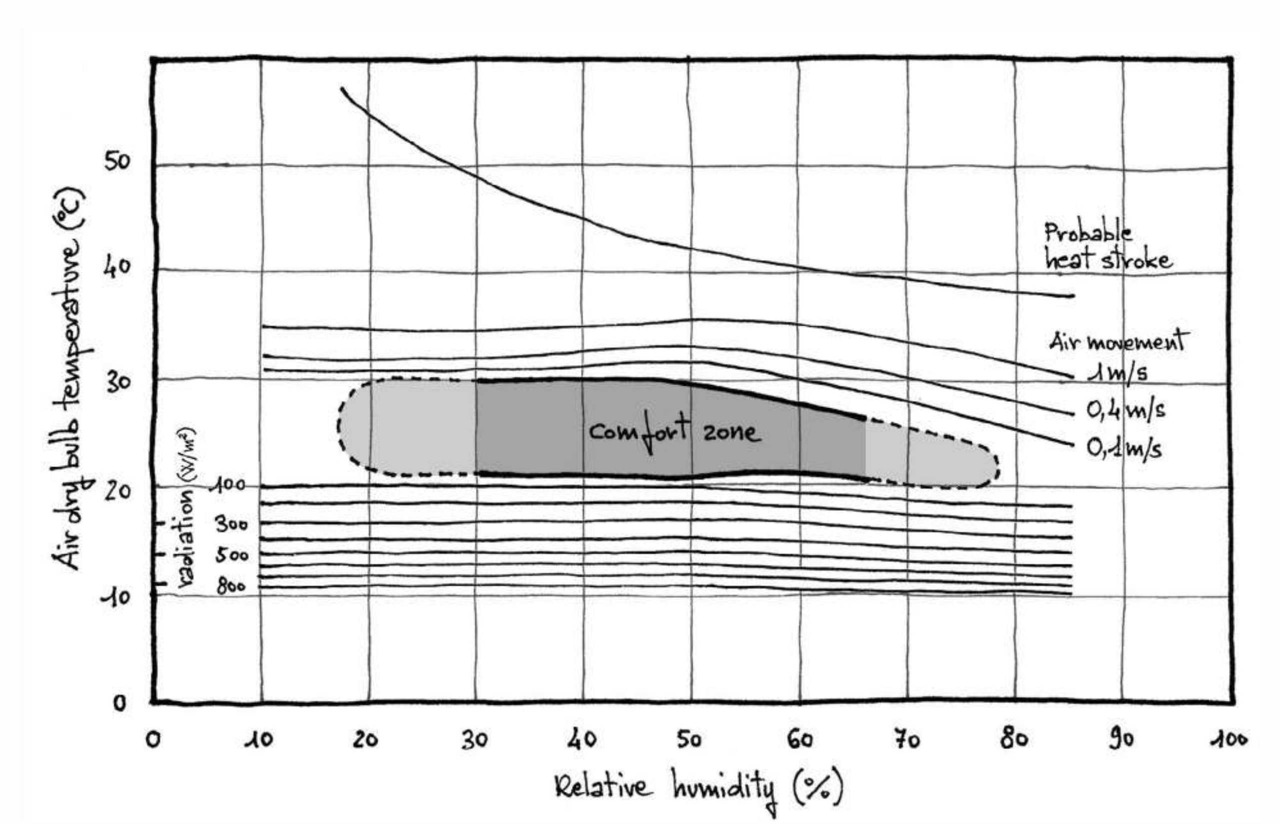
1. COMFORT ZONE

This is defined as the range within which occupants are satisfied with the surrounding conditions. Thermal comfort is experienced when the boundaries of air temperature are between 20 and 26 °C while relative humidity is between 20 and 80%.

16 *U.S Department of Energy (n.d.) Weather Data | EnergyPlus [Online]. Available from: <https://energyplus.net/weather>.*

17 *Meteotest (n.d.) Meteonorm: Irradiation Data for Every Place on Earth [Online]. Available from: <http://www.meteonorm.com/en/>.*

FIGURE 9 **OLGYAY'S BIOCLIMATIC CHART THAT IS MOSTLY APPLICABLE TO OUTDOOR CONDITIONS**



Source: *UN-Habitat (2015) Sustainable Building Design for Tropical Climates: Principles and Applications for Eastern Africa. Nairobi, Kenya: UN-Habitat.*

2. NATURAL VENTILATION ZONE

In cases where the air temperature exceeds 26 °C or relative humidity is quite high (above 50%), natural ventilation can improve the thermal comfort. This extends the thermal comfort up to an outdoor air temperature limit to 32 °C. On the other hand, in conditions where the temperature exceeds 26 °C and relative humidity is below 50%, night cooling would be more appropriate than day ventilation.

3. EVAPORATIVE COOLING ZONE

When the air temperature is high and relative humidity is low, water vapour can be used to extend the thermal comfort zone by reducing air temperature and increasing the relative humidity of a space.

4. HIGH THERMAL MASS ZONE

High thermal mass can be used in a building to reduce variation in indoor temperature compared to outdoor temperature as well as reducing peaks in conditions of high diurnal temperature swing[18].

5. HIGH THERMAL MASS AND NIGHT VENTILATION ZONE

Thermal mass in conjunction with night ventilation can be used to provide cooling in situations where the diurnal temperature swing is high and the night time temperature falls below 20 °C.

6. PASSIVE HEATING ZONE

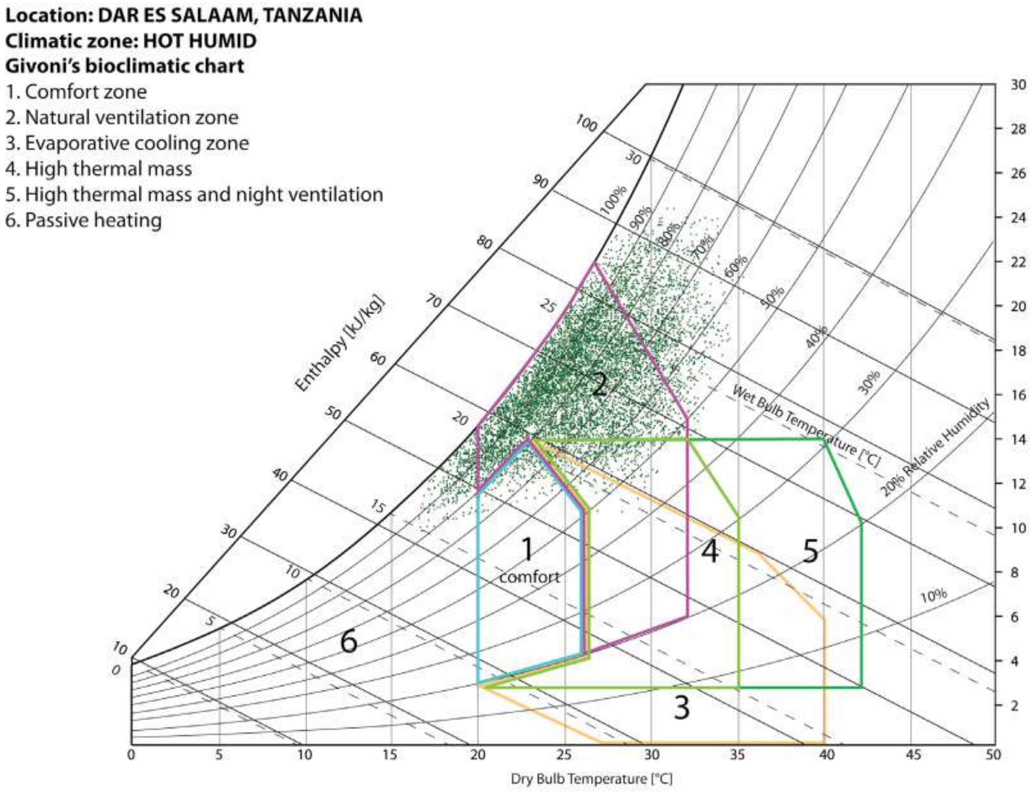
Where the air temperature is lower than 20 °C, the use of passive solar heating is suitable for extending the thermal comfort zone. Other strategies include use of insulation.

This report focuses on the Givoni bioclimatic chart in analysing the Typical Meteorological Year climatic data of the representative cities / towns as obtained from the open database of the U.S Department of Energy[19].

18 *A diurnal temperature swing is the cycle of temperatures over the course of one 24-hour period*

19 *U.S Department of Energy (n.d.) Weather Data | EnergyPlus [Online]. Available from: <https://energyplus.net/weather>.*

FIGURE 10 **GIVONI PSYCHROMETRIC CHART**



This psychrometric chart representing Dar es Salaam, Tanzania shows that most hourly data points fall to the right of the comfort zone.

This means that air temperature can be reduced by increasing air flow with natural ventilation.

Source: *UN-Habitat (2015) Sustainable Building Design for Tropical Climates: Principles and Applications for Eastern Africa. Nairobi, Kenya: UN-Habitat.*

C) SOFTWARE USED IN THIS REPORT

Climatic data for a given site - outdoor temperatures and relative humidity (monthly, daily or hourly) - can be plotted onto a psychrometric chart to determine which of the above zones the plotted conditions fall into.

Various software have been developed to suggest the best strategies for improving thermal comfort conditions based on the plotted climatic data. For this report, Climate Consultant[20] was used to generate psychrometric charts – which is a graphical representation of the relationship between air temperature and relative humidity. This helps to describe the climatic data and human thermal comfort conditions. Weather data files – obtained from the open database of the U.S. Department of Energy were uploaded into Climate Consultant resulting to data points for every hour of the year as seen in Figure 10 . The density of the data points on the chart decipher the average conditions enabling one to consider the most suitable passive design strategies to extend the thermal comfort zone.

20 Climate Consultant (n.d.) [Online]. Available from: <http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php>.

05 CLIMATE CLASSIFICATION

WORLD CLIMATE CLASSIFICATION

The Köppen-Geiger Climatic Classification System is the most widely used system to characterise the world's climatic conditions. Its categories are based on the monthly and annual averages of precipitation and temperature. According to the classification, the world is divided into 5 major climatic zones:

A. EQUATORIAL CLIMATE (TROPICAL MOIST)

This tropical climate zone with little seasonal variation, extends from 15° N to 15° S. It comprises of 3 sub-climates within it: tropical wet and humid climate, characterised by monthly average temperatures ranging between 24 – 30° C and abundant rainfall with total annual amounts of over 2000 mm; tropical monsoon and savannah, characterised by distinct wet and dry periods.

B. ARID CLIMATE (DRY)

This climatic zone is located between latitudes 15° – 30° N and 15° – 30° S and is characterised by very hot summer seasons and cooler winter seasons. They also experience high diurnal temperature.

Hot desert regions are characterised by high monthly and annual temperature (maximum temperatures of 40 - 45° C are common) with high diurnal temperature ranges; low relative humidity and cloud cover; low amount of rainfall (less than 25 mm per year) and high wind speeds

On the other hand, cold desert regions are characterised by low relative humidity and cloud cover; moderate monthly and annual temperatures; low amount of rainfall that occurs infrequently.

C. TEMPERATE CLIMATE

The temperate climates are generally located between 40 – 60° N and are characterised by seasonal changes between summer and winter without extremes of temperature and precipitation.

D. COLD CLIMATE

Most of these zones are located between the latitudes 40° - 70° N and are characterised by cool summers and cold winters. In the warmest months, these climates have an average of temperatures above 10° C and during the cold months, the temperatures average below -3° C.

E. POLAR CLIMATE

These climates, located between 60° N and the poles, are characterised by average temperatures below 10° C throughout the year.

The East African region falls within the boundaries of the Equatorial climate which extends from 15 °N and 15 °S. However, a wide range of climatic conditions are experienced within the region as illustrated in Figure 11. These can be divided into 6 climatic zones namely :

Zone 1: Hot-humid

Zone 2: Hot arid

Zone 3: Hot semi-arid /Savannah

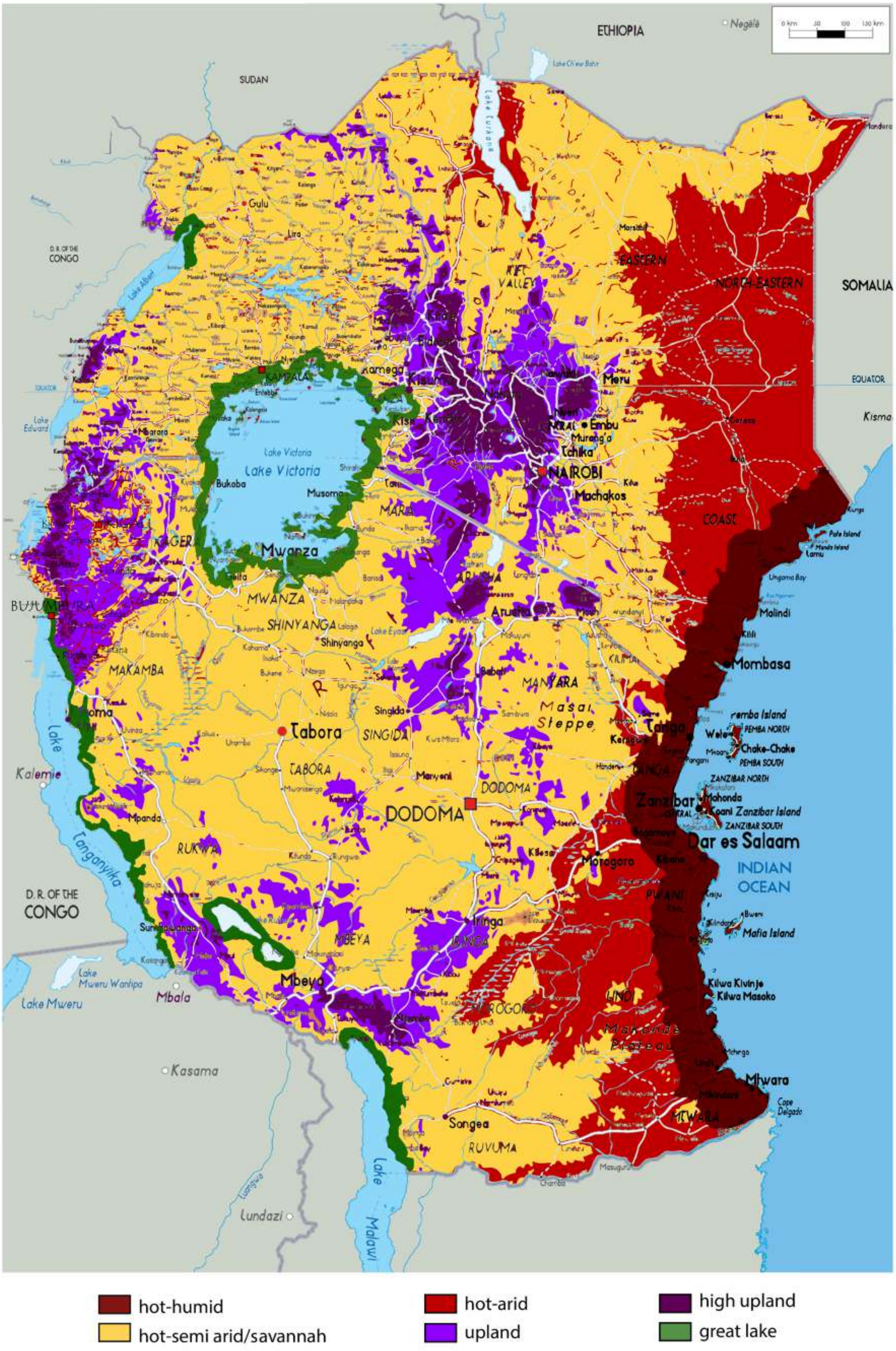
Zone 4: Great Lakes

Zone 5: Upland

Zone 6: High upland

Table 1 gives a summary of the general characteristics of the 6 climatic zones in East Africa as well as representative cities / towns of each.

FIGURE 11 **CLIMATIC ZONES OF EAST AFRICA**



Source: *UN-Habitat (2015) Sustainable Building Design for Tropical Climates: Principles and Applications for Eastern Africa. Nairobi, Kenya: UN-Habitat.*

TABLE 1 **CHARACTERISTICS OF THE MAJOR CLIMATIC ZONES IN EAST AFRICA**

ZONE	NAME	CHARACTERISTICS	REPRESENTATIVE CITIES
Zone 01	Hot humid / Hot and semi-humid	• Location: 0 – 100 km wide strip from the ocean coast • Altitude: <300m above sea level • Mean air temperature range: 25 – 32°C with a mean temperature swing of 3 – 7°C • Average annual rainfall: 900 -1,250mm • Mean relative humidity: approximately 80% around the coastline. From 20 - 100km, the relative humidity is 65 - 72% • Global solar radiation: 5.0 - 5.4kWh/m^2. It lowers one moves away from the coastline to 4.5kWh/m^2	Lamu, Kenya Malindi, Kenya Mombasa, Kenya Dar es Salaam, Tanzania Tanga, Tanzania
Zone 02	Hot arid	• Altitude: range from 0 m – 500 m above sea level • Mean air temperature range: 23 – 36°C with a mean temperature swing of 12°C • Average annual rainfall: 0 – 500 mm • Mean relative humidity: approximately 40% • Global solar radiation is around 7.0kWh/m^2	Garissa, Kenya Lodwar, Kenya
Zone 03	Hot semi-arid / Savannah	• Altitude: ranges from 500 – 1,000 m above sea level in semi-arid areas and rises to 1,500 m in the savannah plains • Mean air temperature range: 20 – 22°C and can rise to a mean temperature range of 29 – 31°C. In the semi-arid areas, the temperatures can go up to 33°C • Average annual rainfall: 50 – 750mm in semi-arid areas to 1,000 – 1,500mm in savannah regions • Mean relative humidity: 65% but can go as low as 42% in parts of the savannah plains • Global solar radiation: 6.3kWh/m^2	Isiolo, Kenya Machakos, Kenya Mavoko, Kenya Thika, Kenya Dodoma, Tanzania Tabora, Tanzania Gulu, Uganda Iganga, Uganda Kabale, Uganda Kasese, Uganda Lira, Uganda
Zone 04	Great Lakes	• Location: 0 - 25km wide strip along lake shores • Mean air temperature range: 16 – 29°C • Average annual rainfall: >1,200mm • Mean relative humidity: 60 - 70% • Global solar radiation: 5.5kWh/m^2	Homabay, Kenya Kisumu, Kenya Mwanza, Tanzania Jinja, Uganda Kampala, Uganda Kibuye, Rwanda Bujumbura, Burundi
Zone 05	Upland	• Altitude: 1,500 – 2,000 m above sea level • Mean air temperature range: 14 – 24°C. In the hot period, temperature range is about 26 – 27°C • Average annual rainfall: >1,250mm • Mean relative humidity: 65 – 75% • Global solar radiation: around 5.0 – 6.0 kWh/m^2	Kitale, Kenya Nairobi, Kenya Nakuru, Kenya Arusha, Tanzania Mbeya, Tanzania Fort Portal, Uganda Mbale, Uganda Kigali, Rwanda
Zone 06	High upland	• Altitude: >2,000 m above sea level • Mean air temperature range: 12 – 20°C • Average annual rainfall: >1,200mm • Mean relative humidity: 80% • Global solar radiation: 5.3 kWh/m^2	Eldoret, Kenya

06 MAJOR CITIES IN EAST AFRICA

Climatic data information representing 28 locations spread over the 6 climatic zones across East Africa are presented in the following sections. This information brings together data on the main climatic elements namely:

- air temperature
- relative humidity
- solar radiation
- rainfall and
- wind

TABLE 2 **EAST AFRICAN CITIES / TOWNS PRESENTED**

ZONE	CHARACTERISTICS
Kenya	Eldoret, Embu, Garissa, Kakamega, Kisii, Kisumu, Kitale, Lamu, Lodwar, Makindu, Malindi, Mandera, Meru, Mombasa, Moyale, Nairobi, Nakuru, Narok, Voi
Tanzania	Dar es Salaam Dodoma Mbeya Mwanza Tabora Tanga Zanzibar
Uganda	Kampala
Rwanda	Kigali

6.1 KENYA

FIGURE 12 **MAP OF AFRICA SHOWING THE LOCATION OF KENYA**

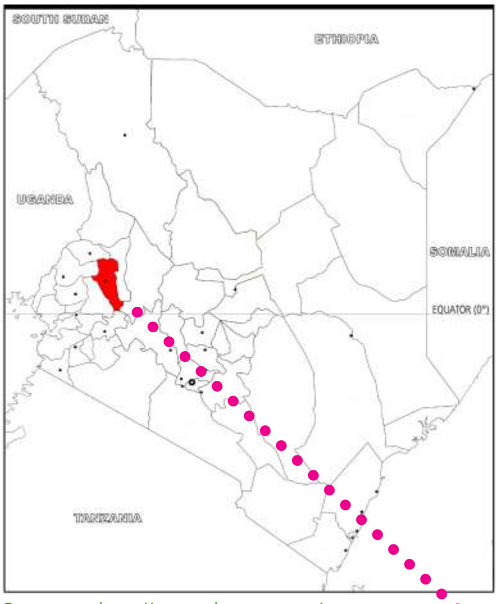
Source: *http://www.d-maps.com/*

TABLE 3 **REPRESENTATIVE TOWNS IN KENYA**

CITY/TOWN	ALTITUDE (M)	LATITUDE	LONGITUDE	CLIMATE ZONE
Eldoret	2,085 m	0° 31′ N	35° 16′ E	High upland
Embu	1,350 m	0° 32' S	37° 27' E	Upland
Garissa	147 m	0° 28′ S	39° 38′ E	Hot arid
Kakamega	1,500 m	0° 27′ S	34° 43′ E	Upland
Kisii	1,700 m	0° 41' S	34° 46' E	Upland
Kisumu	1,135 m	0° 05′ S	34° 45′ E	Great lakes
Kitale	1,900 m	1° 01′ N	34° 59′ E	Upland
Lamu	308 m	2°16′ S	40° 54′ E	Hot humid
Lodwar	477 m	3° 07′ N	35° 36′ E	Hot arid
Machakos	1,138 m	1° 30′ S	37° 15′ E	Hot semi-arid / Savannah
Makindu	1,070 m	2° 16' S	37° 49' E	Hot semi-arid / Savannah
Malindi	23 m	3° 13′ S	40° 07′ E	Hot humid
Mandera	231 m	3° 55′ N	41° 50′ E	Hot arid
Meru	1,582 m	0° 05′ N	37° 38′ E	Upland
Mombasa	55 m	4° 03′ S	39° 40′ E	Hot humid
Moyale	850 m	3° 30' N	39° 40' E	Hot arid
Nairobi	1,789 m	1°16′ S	36° 48′ E	Upland
Nakuru	1,850 m	0° 16′ S	36° 04′ E	Upland
Narok	1,827 m	1° 05′ S	35° 52′ E	Upland
Nyeri	1,768 m	0° 25′ S	36° 57′ E	Upland
Voi	580 m	3° 23′ S	38° 34′ E	Hot arid

ELDORET

FIGURE 13 **LOCATION OF UASIN GISHU COUNTY**



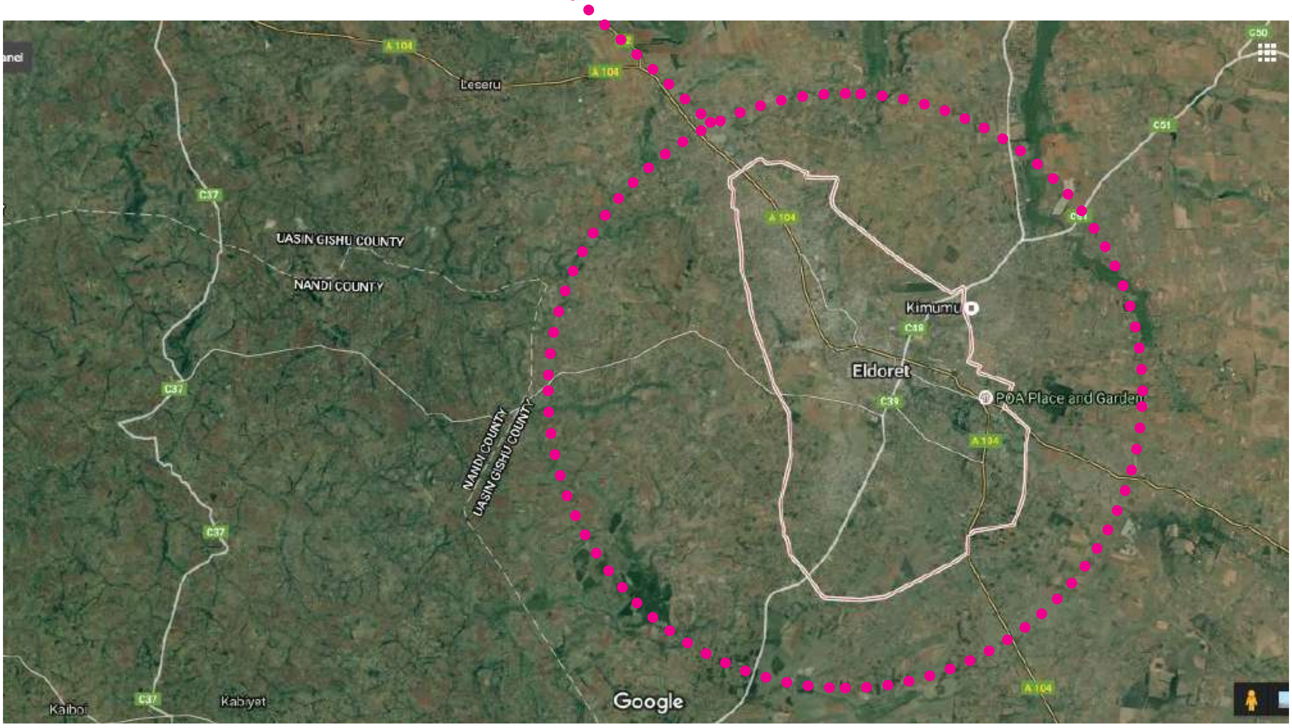
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	00° 31' N
Longitude	35° 16' E
Altitude	2,085 m

FIGURE 14 **AERIAL VIEW OF ELDORET TOWN**

Source: *Google map images © Sir Ray KILIMO*

FIGURE 15 **LOCATION OF ELDORET TOWN IN UASIN GISHU COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Eldoret, the largest town in Uasin Gishu county, has grown to become the fifth largest town in Kenya - after Nairobi, Mombasa, Kisumu and Nakuru. It is located at geographic coordinates of 0° 31′ N, 35° 17′ E at an average altitude of 2,085 m above sea level. The town receives over 1, 082 mm of annual rainfall with the highest amount received in the months of August and the least amount in January. It also experiences relatively cool temperatures with mean air temperatures averaging 16.9 °C. The coolest month of the year is July while the highest average temperature is recorded in February. Relative humidity averages at 70% annually while the wind velocity ranges 2.1 – 4.6 m/s with the predominant wind direction being East North East (ENE). The annual average global solar radiation in Eldoret is 5.8 kWh/m².

TABLE 4 **ELDORET MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	17.8	58.0	3.3	6.2	6.1	2.1	30
FEB	18.5	53.0	4.6	6.4	5.9	2.3	50
MAR	18.2	62.0	3.4	6.2	5.2	2.3	70
APR	17.1	74.0	3.4	5.6	4.0	2.6	150
MAY	16.7	73.0	2.7	5.5	4.4	2.4	140
JUN	16.1	77.0	2.4	5.3	4.2	2.4	120
JUL	15.3	80.0	2.7	5.0	3.6	2.5	160
AUG	15.9	78.0	2.1	5.3	3.8	2.6	180
SEPT	16.3	75.0	2.6	6.2	5.0	2.5	100
OCT	17.0	72.0	3.0	5.9	4.6	2.5	60
NOV	17.0	69.0	4.1	5.5	4.0	2.6	60
DEC	16.7	66.0	4.1	5.9	5.2	2.4	40

FIGURE 16 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR ELDORET**

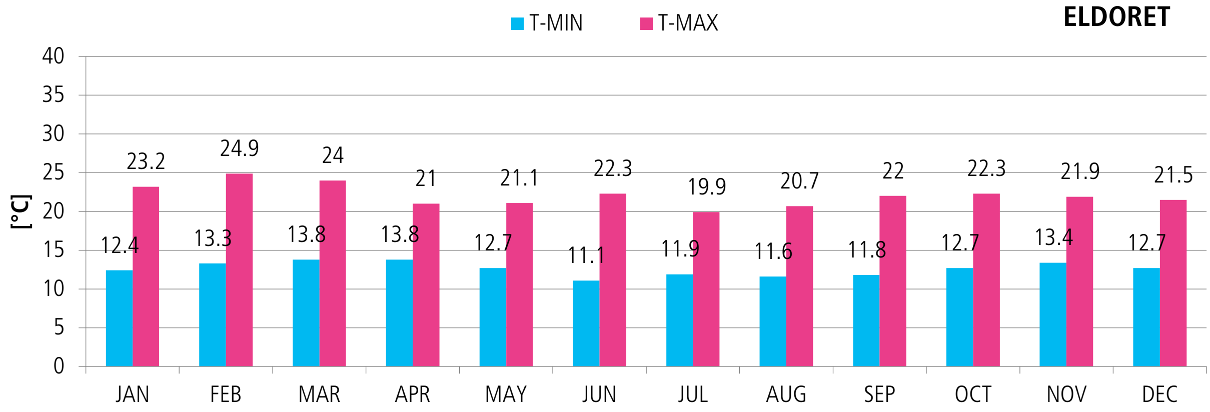


FIGURE 17 **MONTHLY MEAN RELATIVE HUMIDITY FOR ELDORET**

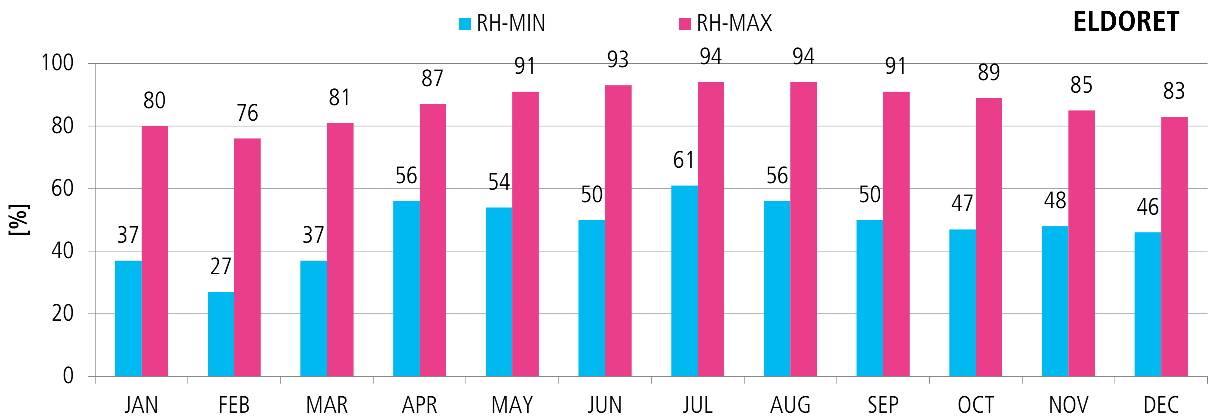


FIGURE 18 **MONTHLY AVERAGE RAINFALL FOR ELDORET**

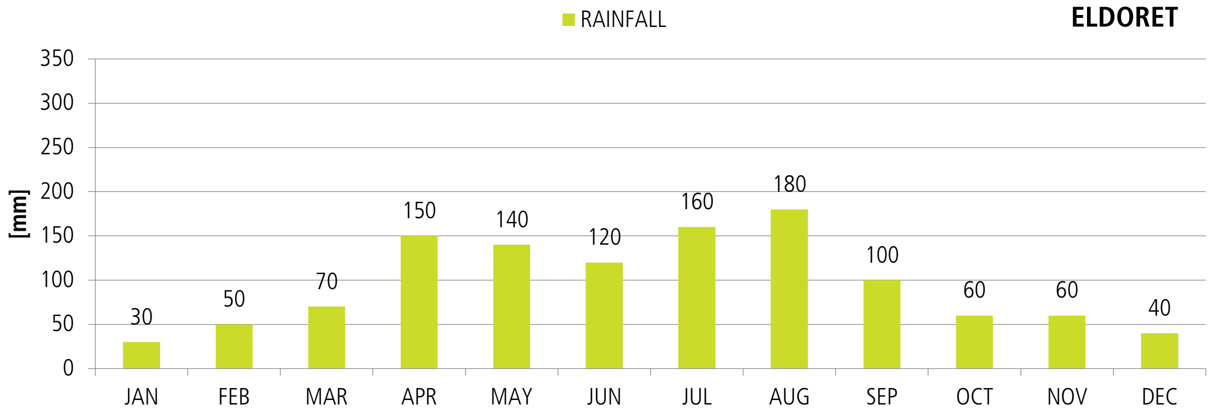


FIGURE 19 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

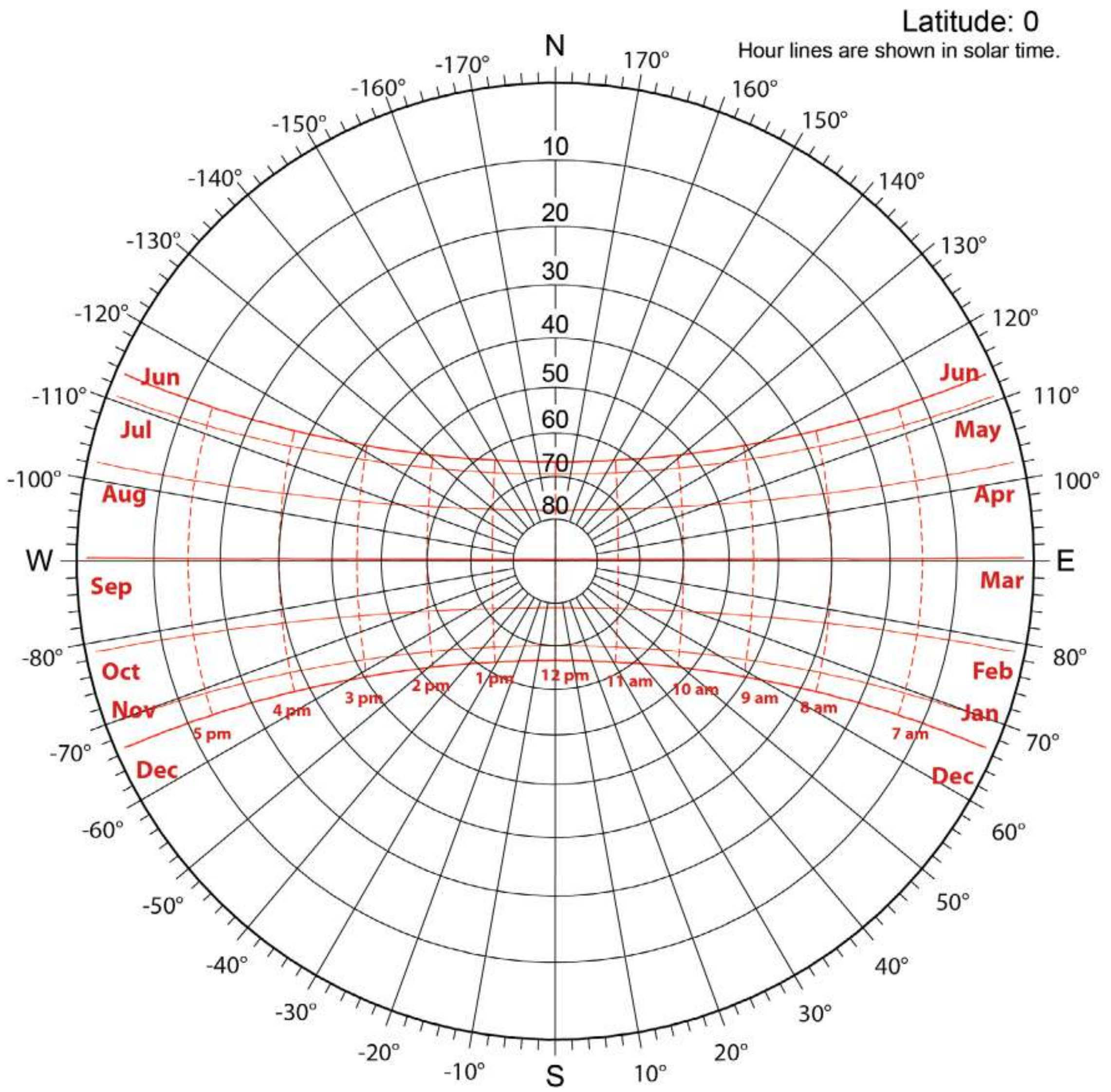


FIGURE 20 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN ELDORET**

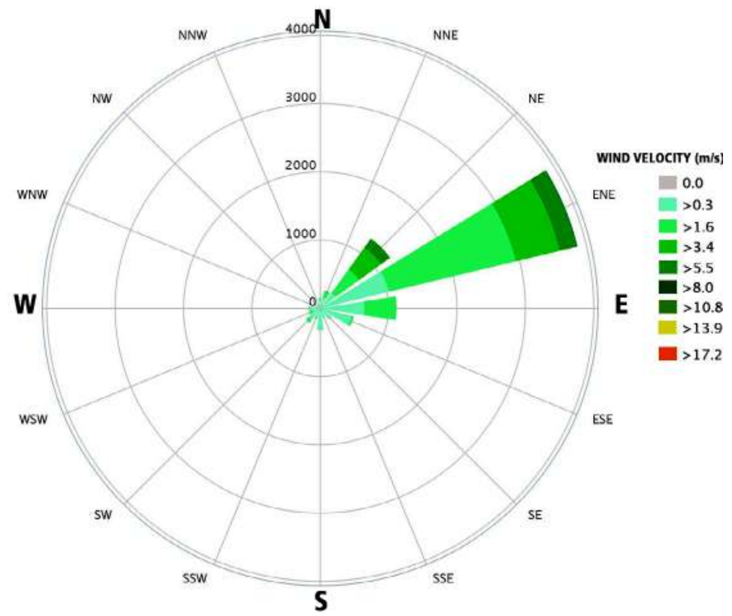
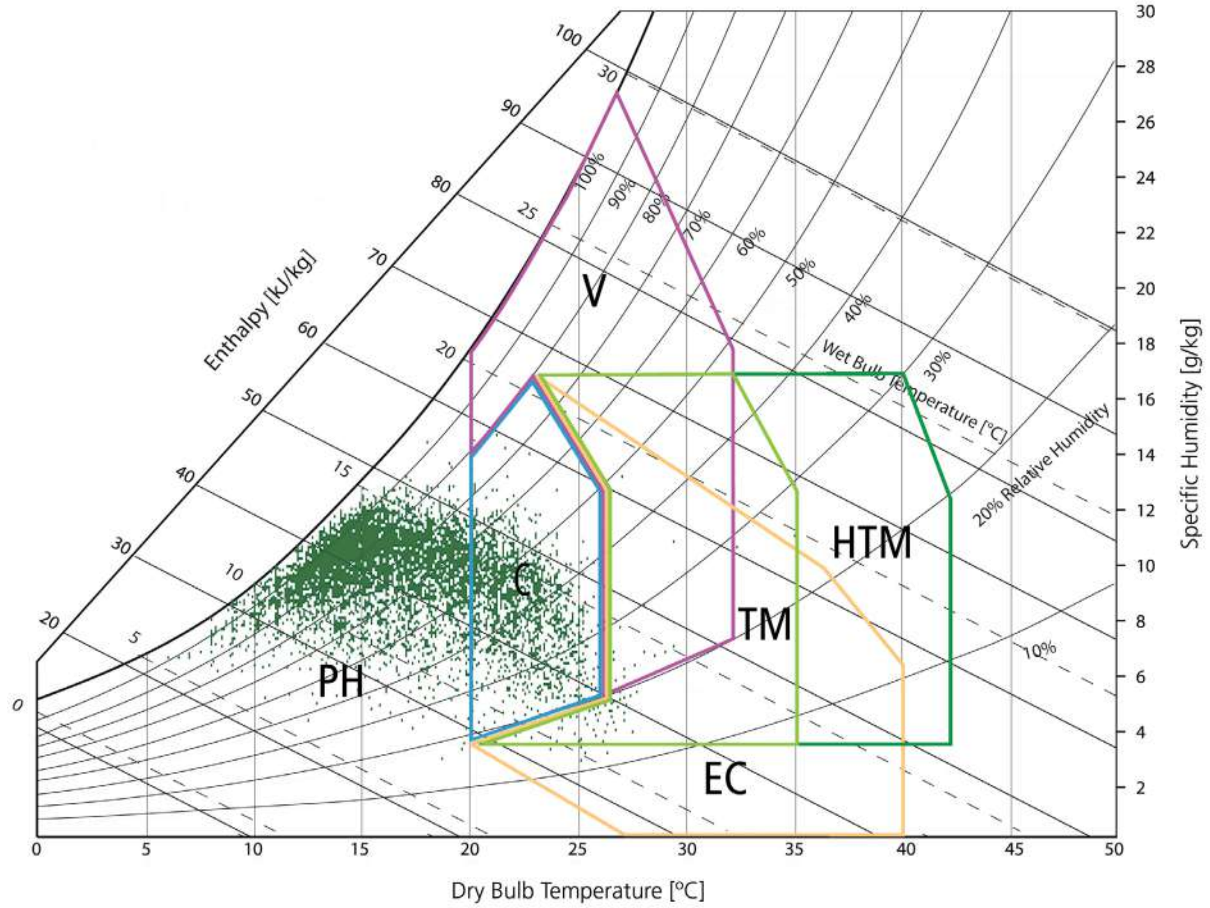


FIGURE 21 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR ELDORET**



C Comfort Zone
V Natural Ventilation
TM Thermal Mass
HTM High Thermal Mass
EC Evaporative Cooling
PH Passive Heating
AC Air Conditioning

INTERPRETATION

The hourly outdoor dry bulb and relative humidity data points indicate that Eldoret falls within the comfort zone during certain periods of the year (see Figure 21). However, for a substantial period, the temperatures are clearly below comfort with temperatures getting to below 10 °C at certain times. This means that the main design objective should be to increase indoor temperatures to comfort levels. The chart therefore shows that passive heating through direct solar heat gain and thermal mass is therefore the most essential strategy for extending the thermal comfort zone during this under heated period. In addition, internal heat gain from equipment, lights and occupants provide a valuable source of heat contribution to space heating.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Eldoret, the following design strategies are recommended for:

a. Enabling passive heating

- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive solar gains by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.
- Additional heating systems such as fireplaces can be incorporated in the design.
- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

b. Protection against heat gain in the hot period

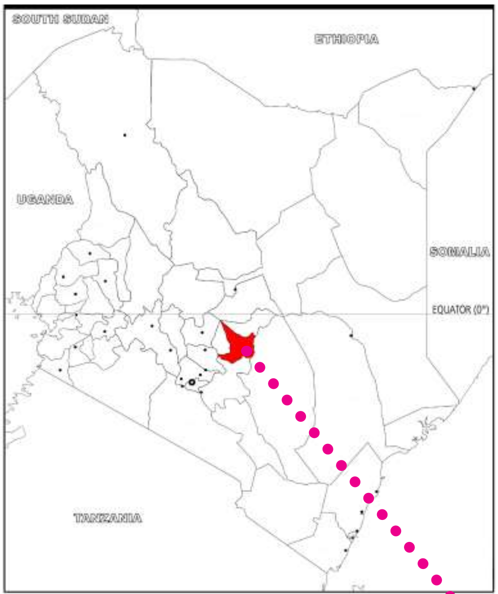
- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods (Figure 22).

FIGURE 22 **LARGE OVERHANGS PROVIDE SHADING TO THE GLAZED NORTH FACING FAÇADE**

Eldoret international airport
Source: *https://kaa.go.ke/airports/our-airports/eldoret-international-airport/ (left)*
http://www.jamiiforums.com/ (right)

EMBU

FIGURE 23 **LOCATION OF EMBU COUNTY**



Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	00° 32' N
Longitude	37° 27' E
Altitude	1,350 m

FIGURE 24 **VIEW OF A STREET IN EMBU TOWN**

Source: *http://www.nation.co.ke/ © Charles WANYORO*

FIGURE 25 **LOCATION OF EMBU TOWN IN EMBU COUNTY**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Embu town, which serves as the headquarters of Embu County, is located at the foothills of Mt. Kenya at geographic coordinates of 0° 32′ S, 37° 37′ E. It is elevated at 1,350 m above the sea level. The town receives an annual rainfall of 893 mm with the wettest month on average being April while the driest month being August. The average temperature for Embu is 18.9 °C – the warmest month is February while the coolest month is July. Relative humidity averages at 72.4% annually while the wind velocity ranges 1.1 – 2.9 m/s with the predominant wind direction being South East. The annual average global solar radiation in Embu is 5.1 kWh/m².

TABLE 5 **EMBU MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	19.5	70.0	2.9	6.2	5.3	2.5	41
FEB	20.7	63.0	2.9	6.5	5.7	2.4	34
MAR	20.6	64.0	2.1	5.9	4.2	2.7	64
APR	19.6	78.0	1.4	5.1	2.9	2.9	218
MAY	19.1	78.0	1.5	4.6	2.9	2.5	139
JUN	17.8	77.0	1.3	4.0	2.3	2.4	21
JUL	17.0	74.0	1.1	3.7	1.7	2.5	28
AUG	17.1	74.0	1.3	4.2	2.1	2.6	11
SEP	18.9	67.0	1.6	5.1	3.2	2.6	17
OCT	19.4	68.0	1.9	5.2	3.3	2.7	86
NOV	18.5	81.0	2.0	4.8	2.8	2.8	189
DEC	18.9	75.0	2.6	5.5	4.2	2.6	45

FIGURE 26 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR EMBU**

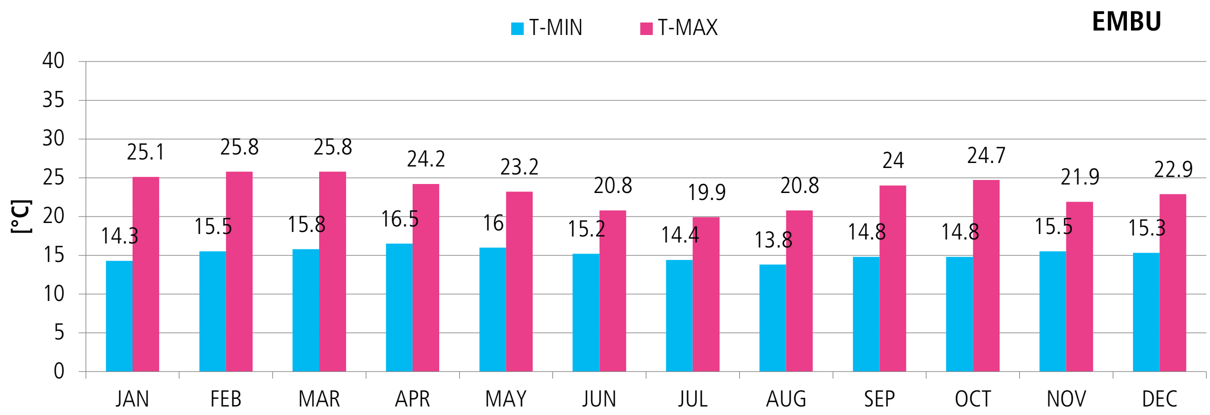


FIGURE 27 **MONTHLY MEAN RELATIVE HUMIDITY FOR EMBU**

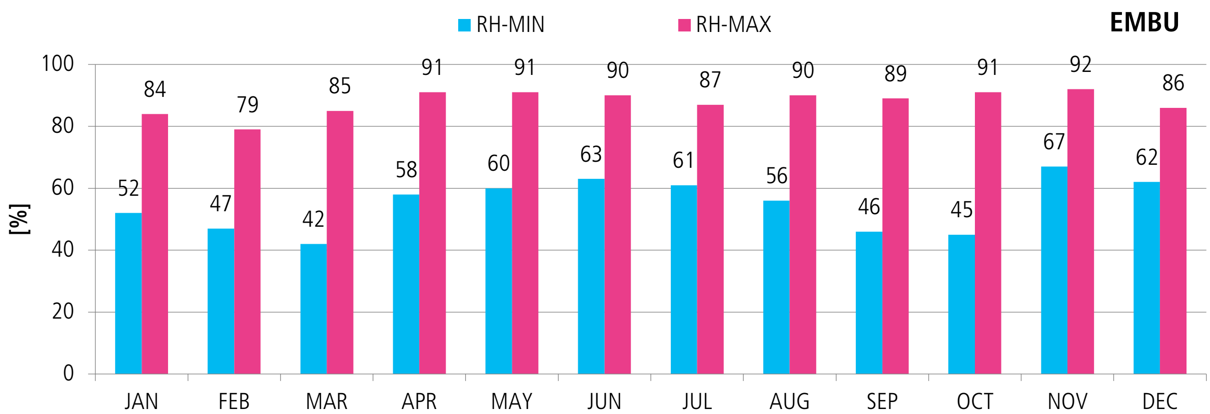


FIGURE 28 **MONTHLY AVERAGE RAINFALL FOR EMBU**

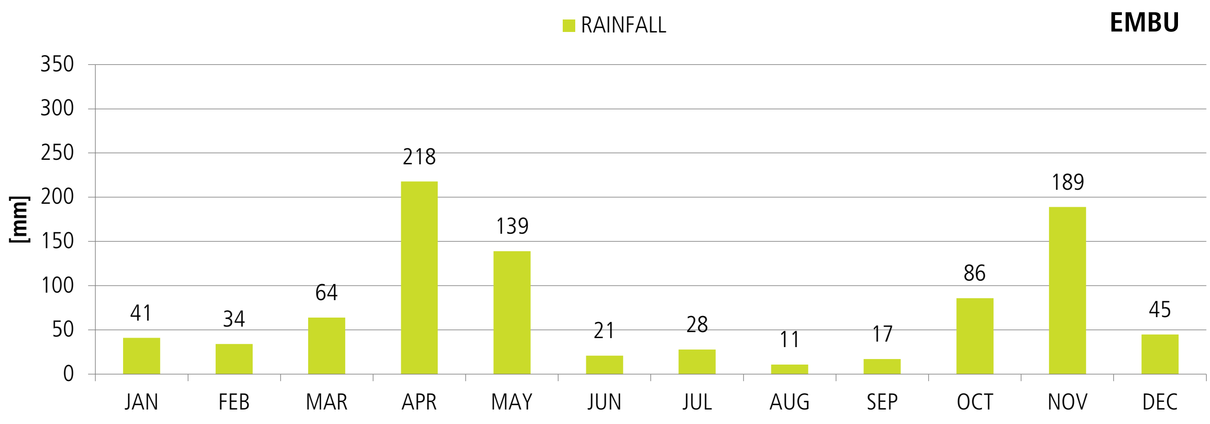


FIGURE 29 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

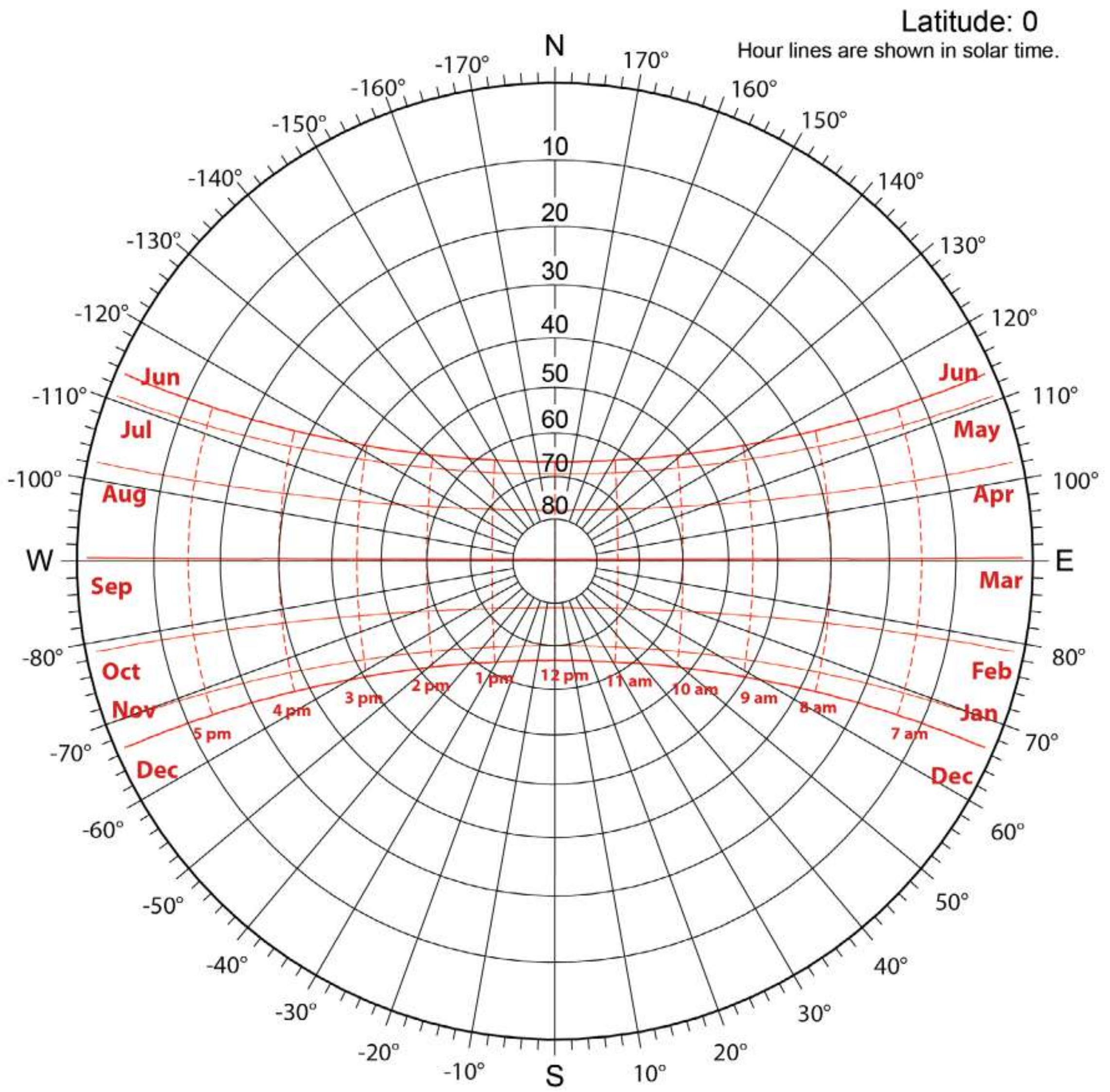


FIGURE 30 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN EMBU**

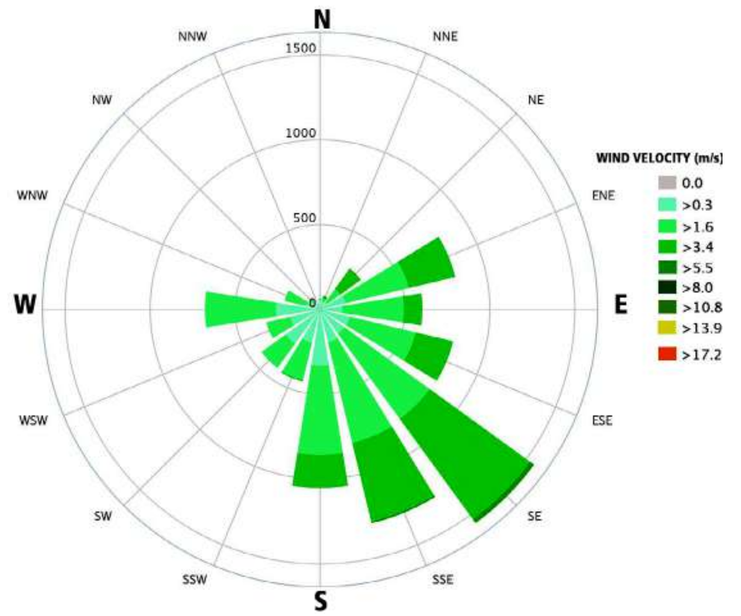
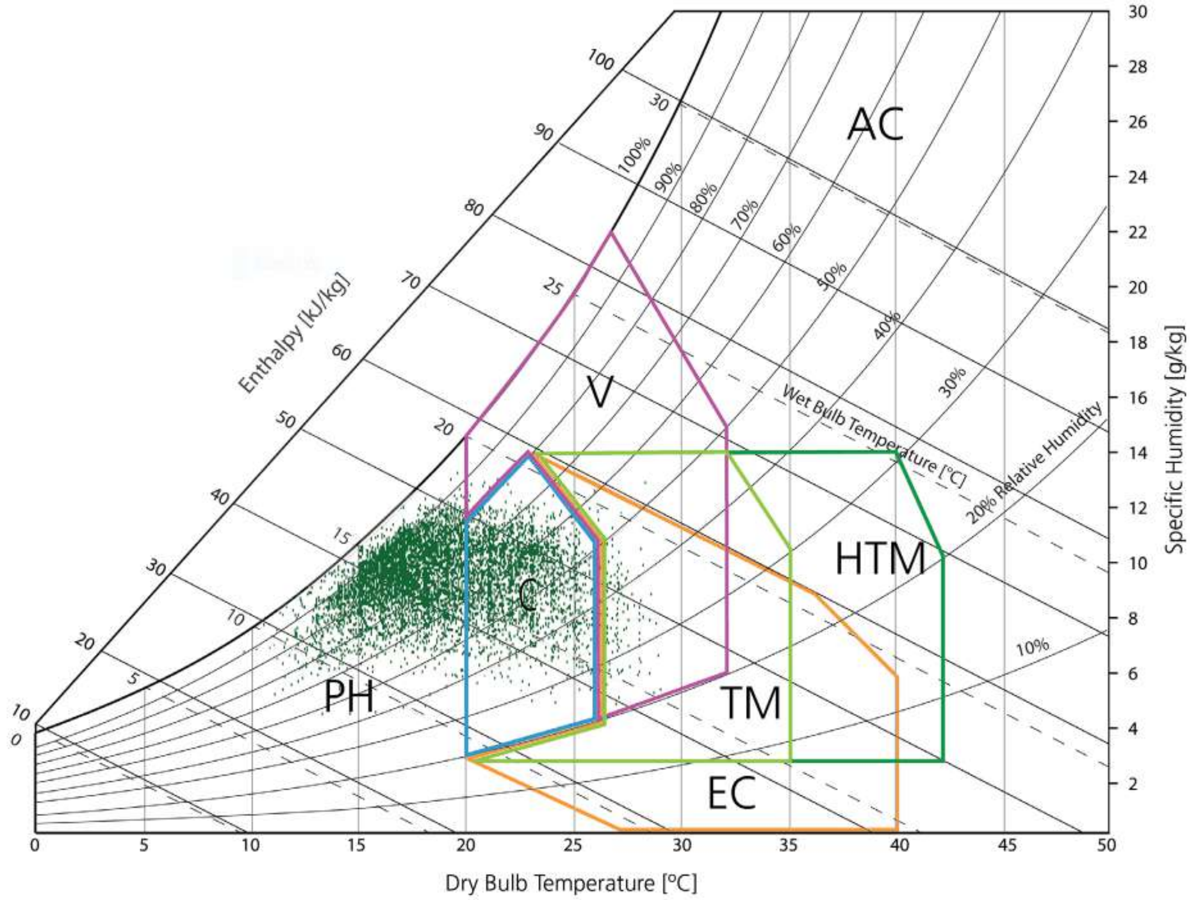


FIGURE 31 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR EMBU**



C Comfort Zone
V Natural Ventilation
TM Thermal Mass
HTM High Thermal Mass
EC Evaporative Cooling
PH Passive Heating
AC Air Conditioning

INTERPRETATION

The hourly outdoor dry bulb temperatures and relative humidity points, as seen in Figure 29, indicate that most of the time the region is within the comfort zone band. For the hours beyond this zone, thermal mass that stores solar heat gain can be used to enable thermal comfort by ensuring cool interiors during day time.

However, a substantial number of hours fall below the comfort zone making heating necessary most of the time. Therefore, the most suitable strategy to extend the limit of comfort during the under heated period is through passive solar heating through direct solar heat gain and thermal mass. In addition, internal heat gain from equipment, lights and occupants are also helpful in extending the thermal comfort and reducing heating demand.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Eldoret, the following design strategies are recommended for:

a. Enabling passive heating

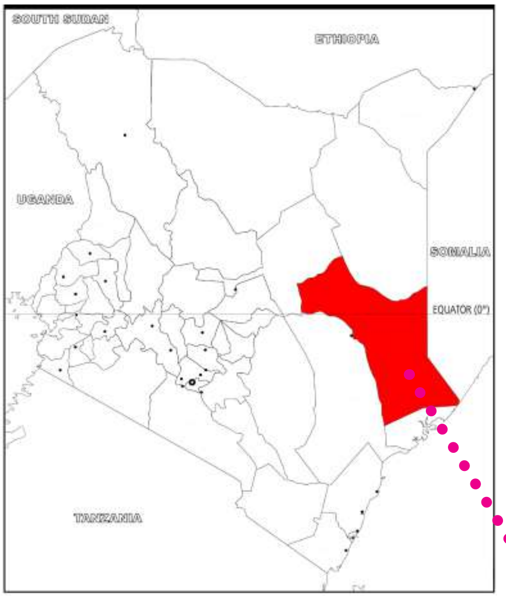
- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive solar heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.
- Additional heating systems such as fireplaces can be incorporated in the design.
- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

b. Protection against heat gain in the hot period

- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

GARISSA

FIGURE 32 **LOCATION OF GARISSA COUNTY**



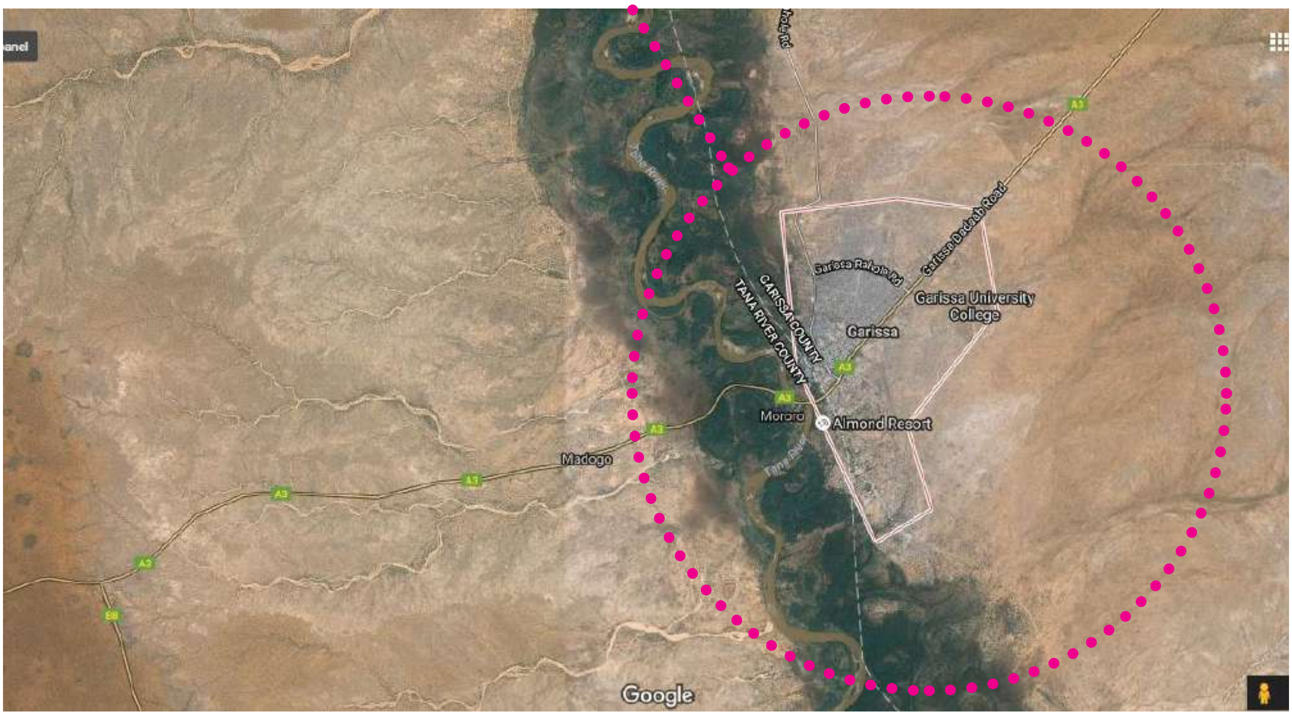
Source: *http://www.d-maps.com/*

Climatic Zone	HOT ARID
Latitude	00° 27' S
Longitude	39° 38' E
Altitude	147 m

FIGURE 33 **GARISSA TOWN CENTRE**

Source: *http://www.bauck.com/garissa/*

FIGURE 34 **LOCATION OF GARISSA TOWN IN GARISSA COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Garissa town, the commercial and administrative hub of Garissa county, is located at geographic coordinates of 0° 27′ S, 39° 39′ E at an altitude of 147 m above sea level. Being in an arid climate, the town experiences high temperatures with an annual average of 28.3 °C. The hottest month recorded is March and the coolest month is July. The town receives an average of 260 mm of annual rainfall with the highest amount received in the months of April and November (average of 70 mm). Relative humidity ranges 54 - 69% annually while the wind velocity averages at 4.0 m/s with the predominant wind direction being South South East (SSE). High wind velocity of 6.5 m/s is recorded in June. The annual average global solar radiation in Garissa is 5.3 kWh/m².

TABLE 6 **GARISSA MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	29.2	62.0	2.9	5.3	3.4	2.9	10
FEB	30.1	54.0	2.5	5.8	3.9	2.9	0
MAR	30.3	58.0	3.4	5.7	3.6	3.0	30
APR	29.0	67.0	3.4	5.4	3.1	3.1	70
MAY	28.4	65.0	4.3	5.1	3.5	2.7	10
JUN	27.0	63.0	6.5	5.0	3.4	2.6	0
JUL	26.6	60.0	6.1	4.9	3.2	2.6	0
AUG	26.2	64.0	4.8	5.0	3.1	2.8	0
SEP	27.5	59.0	5.0	5.5	3.4	2.9	0
OCT	28.6	59.0	4.2	5.4	3.5	2.8	20
NOV	28.5	69.0	2.4	5.1	3.0	2.9	70
DEC	28.7	64.0	2.3	4.9	2.8	2.9	50

FIGURE 35 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR GARISSA**

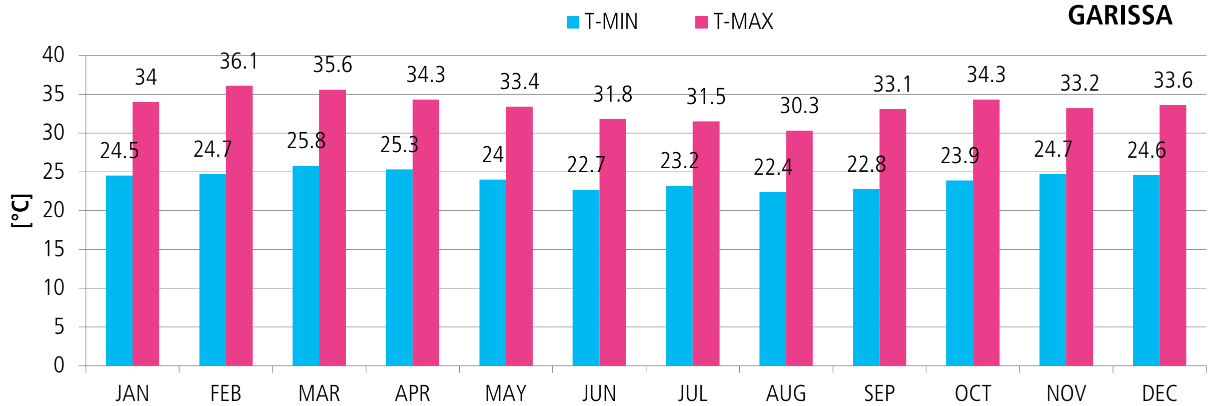


FIGURE 36 **MONTHLY MEAN RELATIVE HUMIDITY FOR GARISSA**

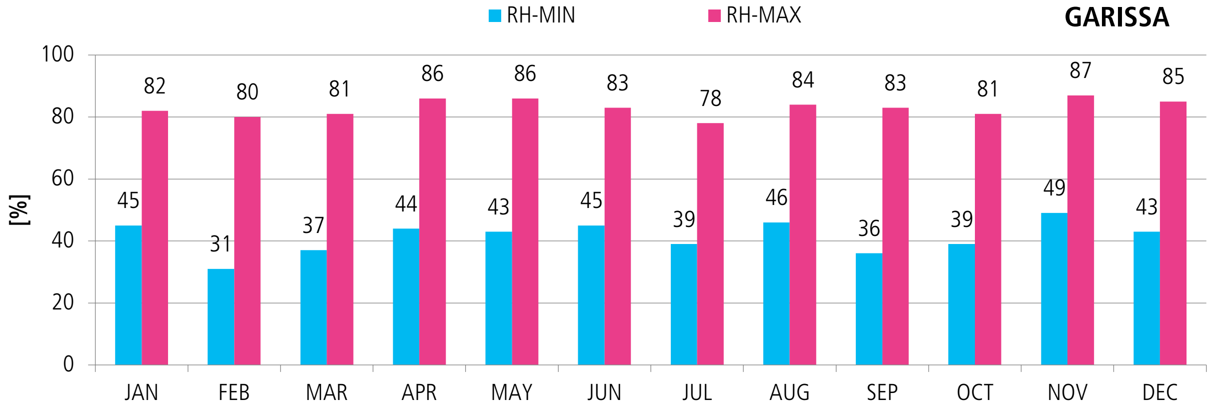


FIGURE 37 **MONTHLY AVERAGE RAINFALL FOR GARISSA**

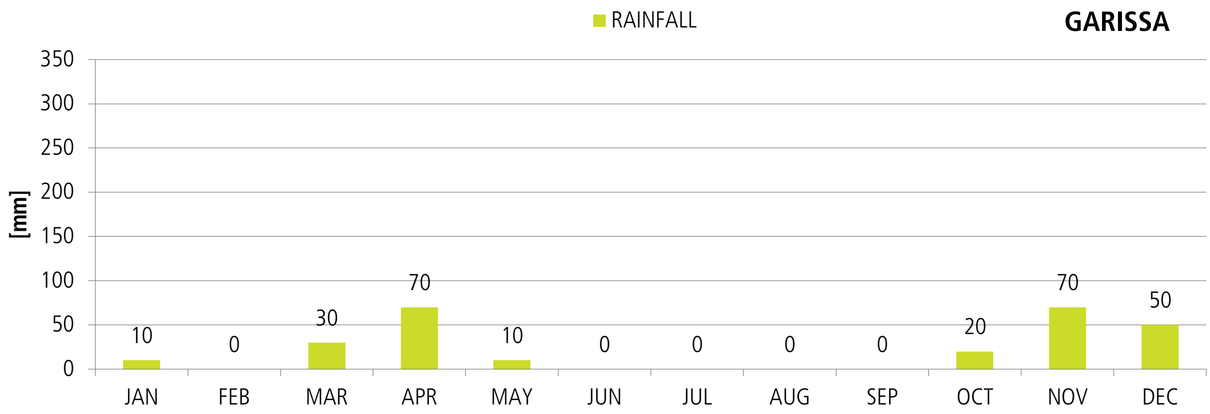


FIGURE 38 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

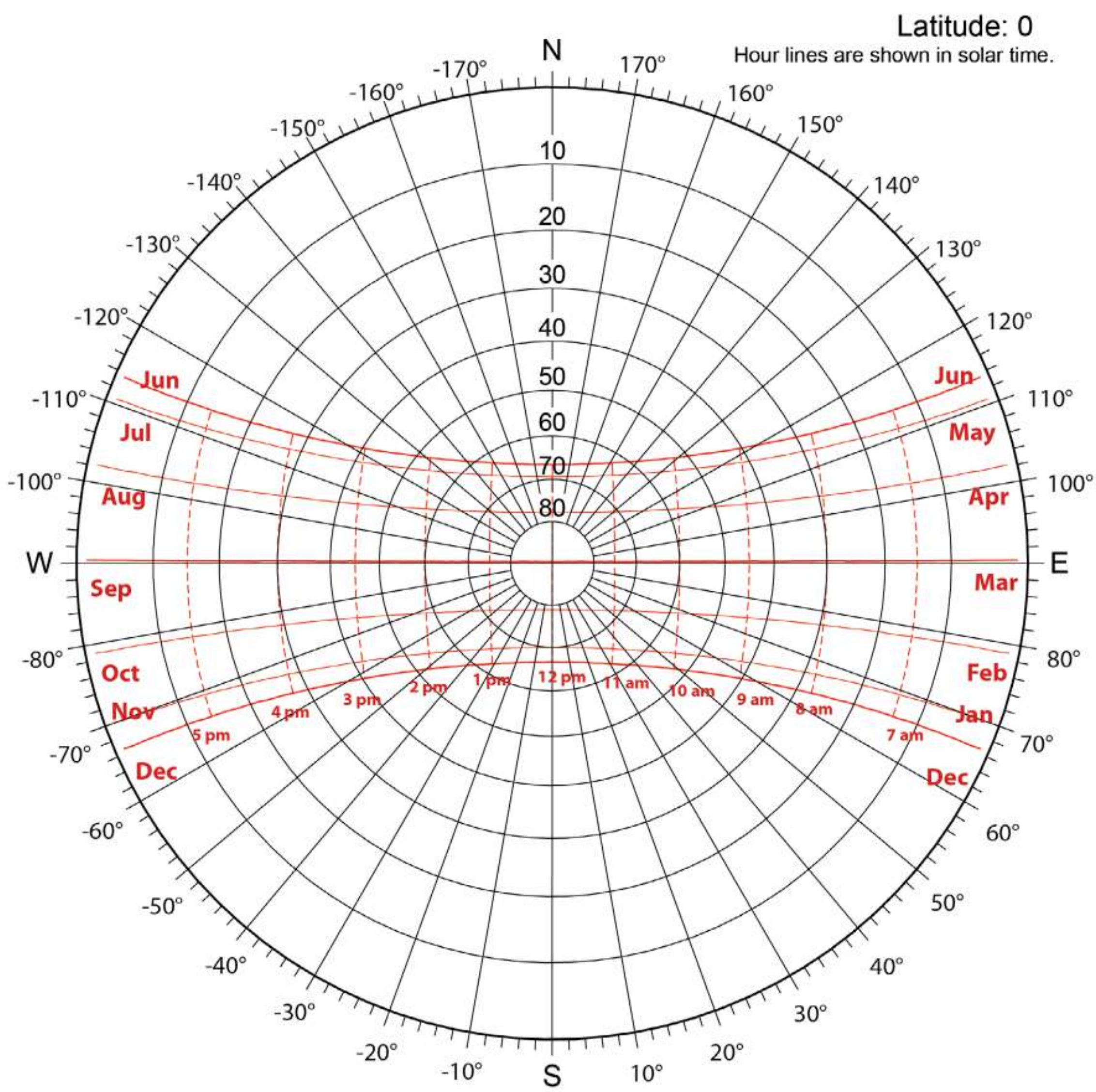


FIGURE 39 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN GARISSA**

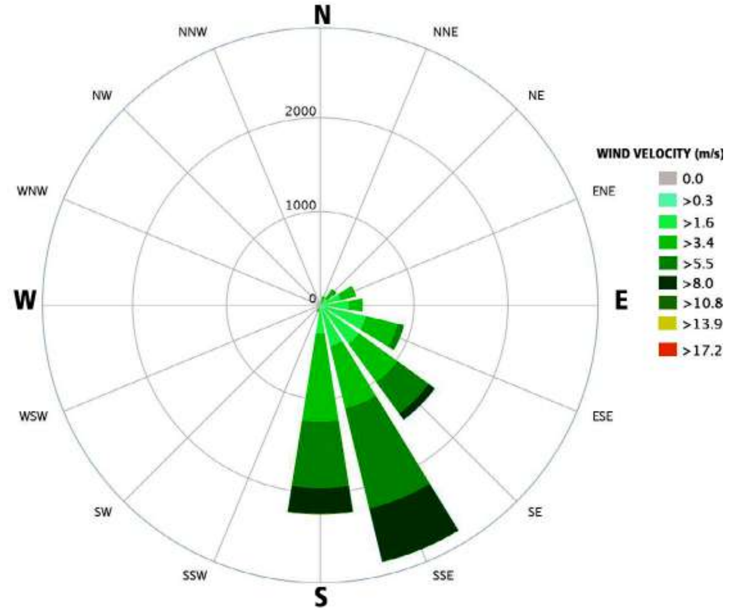
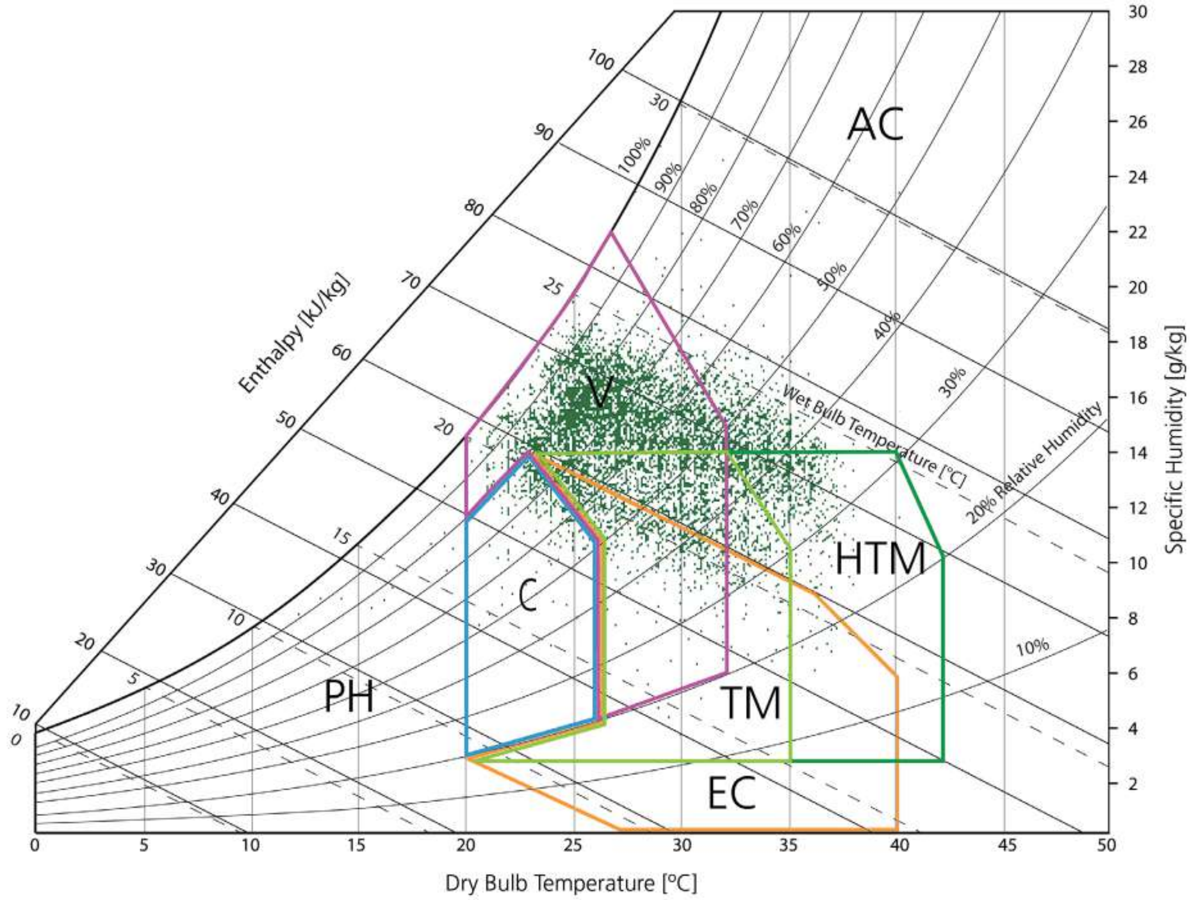


FIGURE 40 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR GARISSA**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

The psychrometric chart (see Figure 40) shows that Garissa is predominantly hot throughout the year with outside conditions (dry bulb temperature and relative humidity) falling beyond the comfort zone. Therefore, buildings need much more cooling and no heating at all. It also shows that at certain periods, relative humidity in this town is low, especially when the temperatures exceed 30 °C. Based on the psychrometric chart, the most appropriate cooling strategies to extend the limit of comfort include the following: shading, natural ventilation, high thermal mass with night ventilation (night flushing) and evaporative cooling.

However, some days are too hot and dry for the passive strategies to work successfully. Therefore, convectional cooling and humidification may be necessary during the overheated period to maintain thermal comfort.

BIOCLIMATIC RECOMMENDATIONS

The design objectives for Garissa should be to reduce uncomfortable conditions created by intense solar radiation, low relative humidity, large diurnal temperature range and dusty hot winds. The following design strategies are recommended:

a. To reduce effects of intense solar radiation

- Compact layout of buildings is recommended to provide mutual shading and minimise exposure to solar radiation.
- Courtyard design of buildings minimises the impact of solar radiation on the outer walls as well as provide cool spaces within the buildings / building layout. This increases the daytime cooled spaces (Figure 41).
- Buildings should be oriented along the east – west axis with the longer sides facing north and south to prevent solar heat gains. The building's surface area exposed to the east and west should be minimised.
- Openings should be located on the north and south facing façades. Small openings that are located high on the walls are recommended to facilitate natural ventilation as well as reduce glare from light reflected from the ground or surrounding buildings.
- Appropriate shading devices are necessary on all openings to minimise heat gain from solar radiation. Use of vegetation, verandas, covered walkways, pergolas etc. is recommended to provide shade to walls, openings and outdoor spaces.
- Use of reflective surfaces (roof) and light-coloured walls are effective in reflecting solar radiation thus minimising solar heat gains and consequently minimising internal daytime temperatures.

b. To counter low relative humidity

- Evaporative cooling is recommended in this climate to improve the microclimate by elevating the humidity level while at the same time cooling the surrounding air. The following strategies are recommended: fountains, spray ponds, water surfaces, moistened fabrics, sprinklers or porous pots etc.
- Use of vegetation is effective in improving the air quality by reducing the air temperature as well as elevate the humidity level because of the evaporative cooling effect of plants (Figure 42).

c. To balance diurnal temperature range

- Heavy weight building materials with high thermal capacity are recommended to balance temperature variations between day and night. These heat storing materials keep daytime temperatures down.
- Because of heat absorption qualities of the ground, earth-sheltered and underground housing are suited for this climate.

d. To ensure air circulation

- Openings should be located to take advantage of prevailing winds and allow for cross-ventilation.
- Ventilation through windows should be kept at a minimum during the daytime to keep hot and dusty air out. This also minimises heat gains. However, at night, windows may be opened to provide adequate ventilation for dissipation of heat accumulated during the day by walls and the roof to prevent overheating of the interior space.
- Other ventilation strategies include use of wind catchers, wind towers, solar chimneys, roof-mounted exhaust fans, high level vents etc.

e. To minimise problems associated with dust

- Vegetation can be used to filter dust from the air before it gets into the building.
- Closing windows during daytime prevents dust from getting into the building on windy days. Windows should be tight-fitting as possible to prevent dust from infiltrating.

FIGURE 41 **EXAMPLES OF COURTYARD DESIGN WITH VEGETATION, LIGHTLY COLOURED EXTERNAL FINISHES AND MUTUAL SHADING OF BUILDINGS**

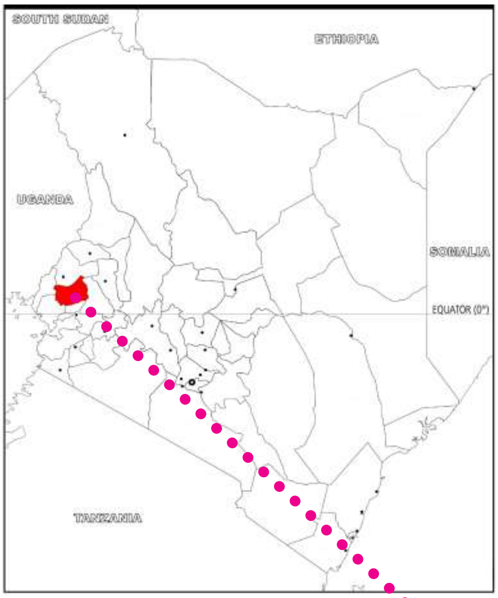
Almond resort hotel, Garissa
Source: *http://www.almond-resort.com/*

FIGURE 42 **USE OF VEGETATION FOR LANDSCAPING**

Almond resort hotel, Garissa
Source: *http://katharow.blogspot.co.ke/ / Amb. Abdikadir Aden HASSAN*

KAKAMEGA

FIGURE 43 **LOCATION OF KAKAMEGA COUNTY**



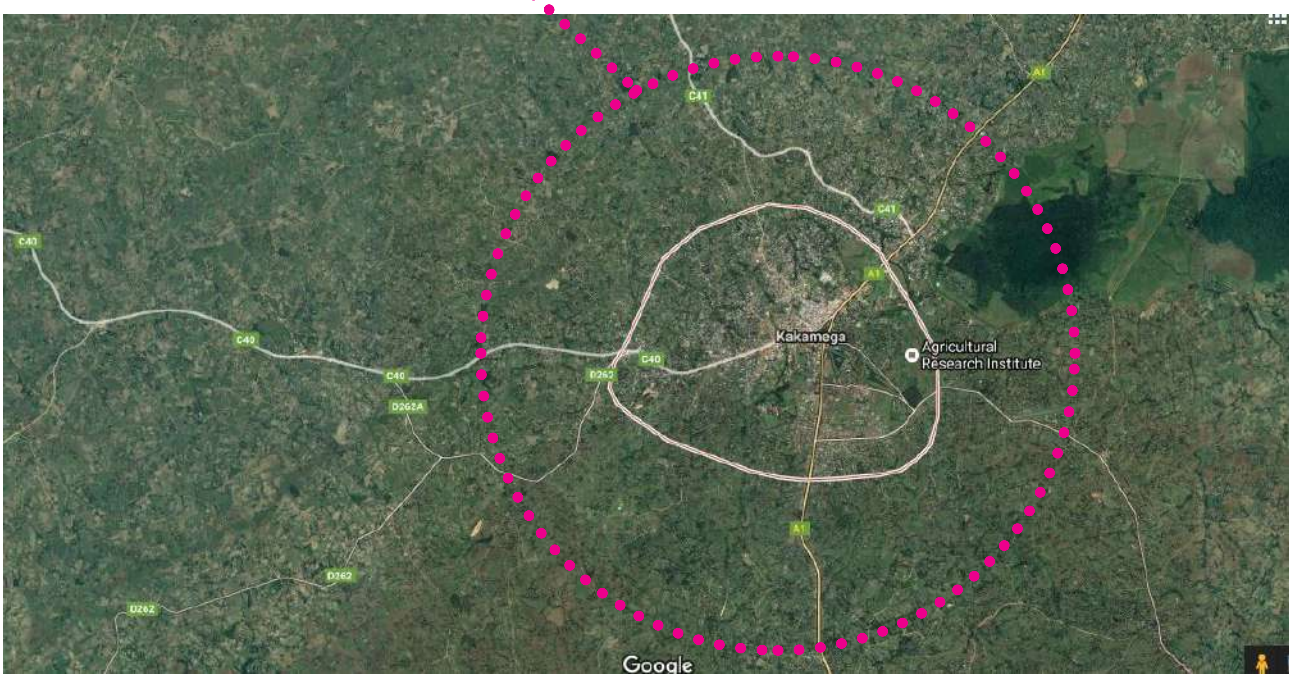
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	00° 17' N
Longitude	34° 45' E
Altitude	1,500 m

FIGURE 44 **VIEW OF KAKAMEGA TOWN HALL**

Source: *http://www.nation.co.ke/counties/1107872-1200334-3ktljez/index.html © Isaac WALE*

FIGURE 45 **LOCATION OF KAKAMEGA TOWN IN KAKAMEGA COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Kakamega town is the headquarters of Kakamega county – the most populous county after Nairobi city. It lies at geographic coordinates of 0° 17′ N, 34° 45′ E at an altitude of 1,500 m above sea level. The town receives an annual rainfall of 1,394 mm with the greatest amount occurring in April and the lowest in January. The average temperature in Kakamega is 19.6 °C. January is the hottest month of the year while July is the coolest. Relative humidity averages at 76% annually while the wind velocity ranges 1.4 – 2.0 m/s with the predominant wind direction being East North East (ENE). The annual average global solar radiation in Kakamega is 5.9 kWh/m².

TABLE 7 **KAKAMEGA MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	21.1	64.0	1.8	6.3	6.0	2.1	64.7
FEB	21.0	66.0	2.0	6.5	5.8	2.2	89.7
MAR	20.5	76.0	1.7	6.2	4.9	2.5	156.1
APR	19.9	80.0	1.7	5.6	4.2	2.5	211.7
MAY	19.1	85.0	1.4	5.4	4.0	2.4	182.4
JUN	19.0	81.0	1.9	5.4	4.4	2.2	87.2
JUL	18.4	79.0	1.5	5.4	4.2	2.4	70.8
AUG	18.5	80.0	1.8	5.8	4.3	2.5	104.2
SEP	18.8	77.0	1.6	6.2	4.9	2.4	97.6
OCT	19.0	78.0	1.6	6.0	4.5	2.6	92.2
NOV	19.5	78.0	1.8	5.6	4.2	2.6	140.3
DEC	20.7	68.0	2.0	6.1	5.7	2.2	97.5

FIGURE 46 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR KAKAMEGA**

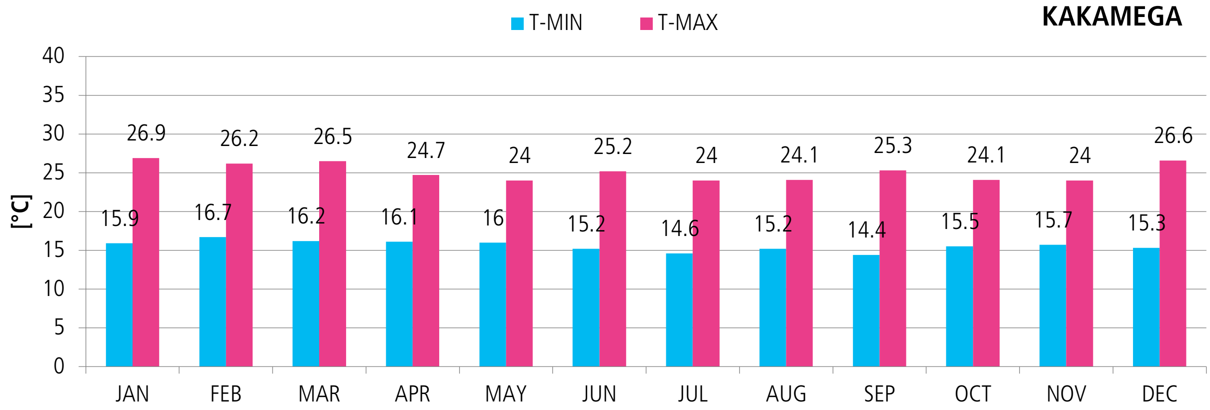


FIGURE 47 **MONTHLY MEAN RELATIVE HUMIDITY FOR KAKAMEGA**

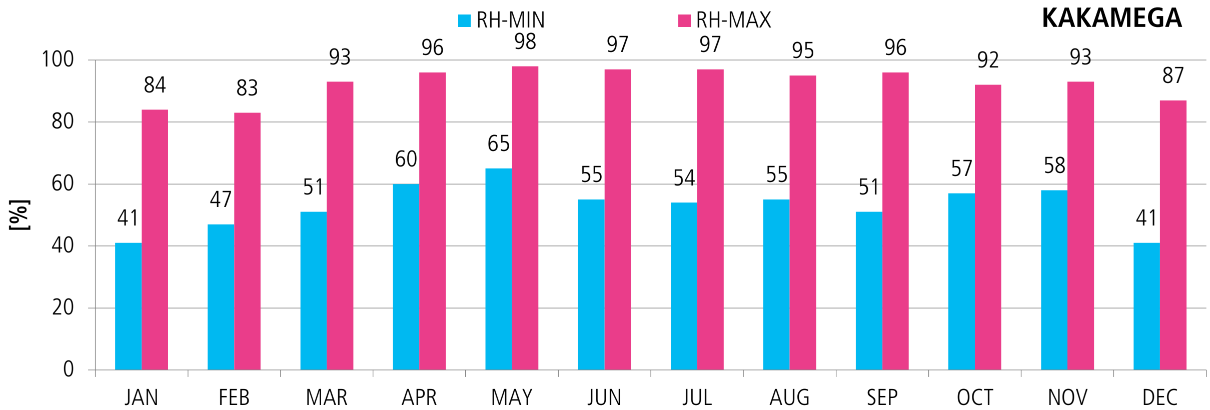


FIGURE 48 **MONTHLY AVERAGE RAINFALL FOR KAKAMEGA**

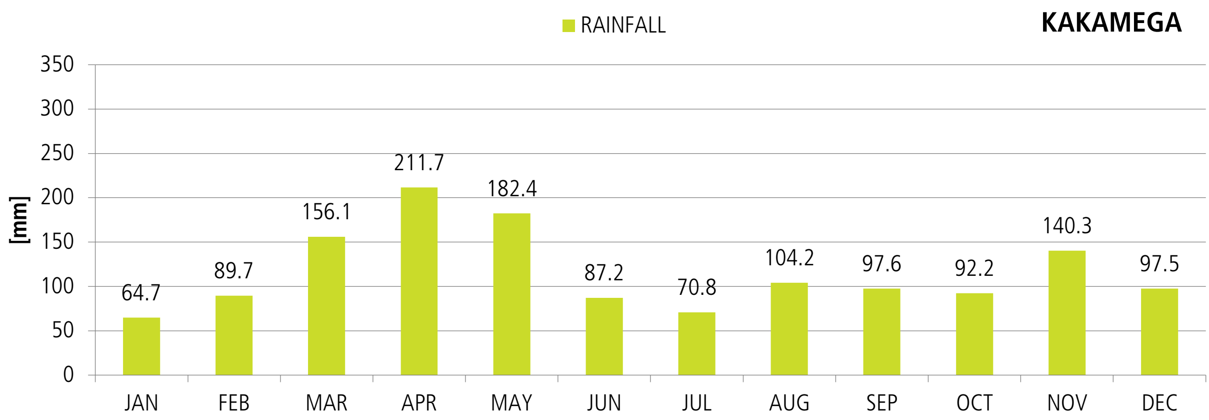


FIGURE 49 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

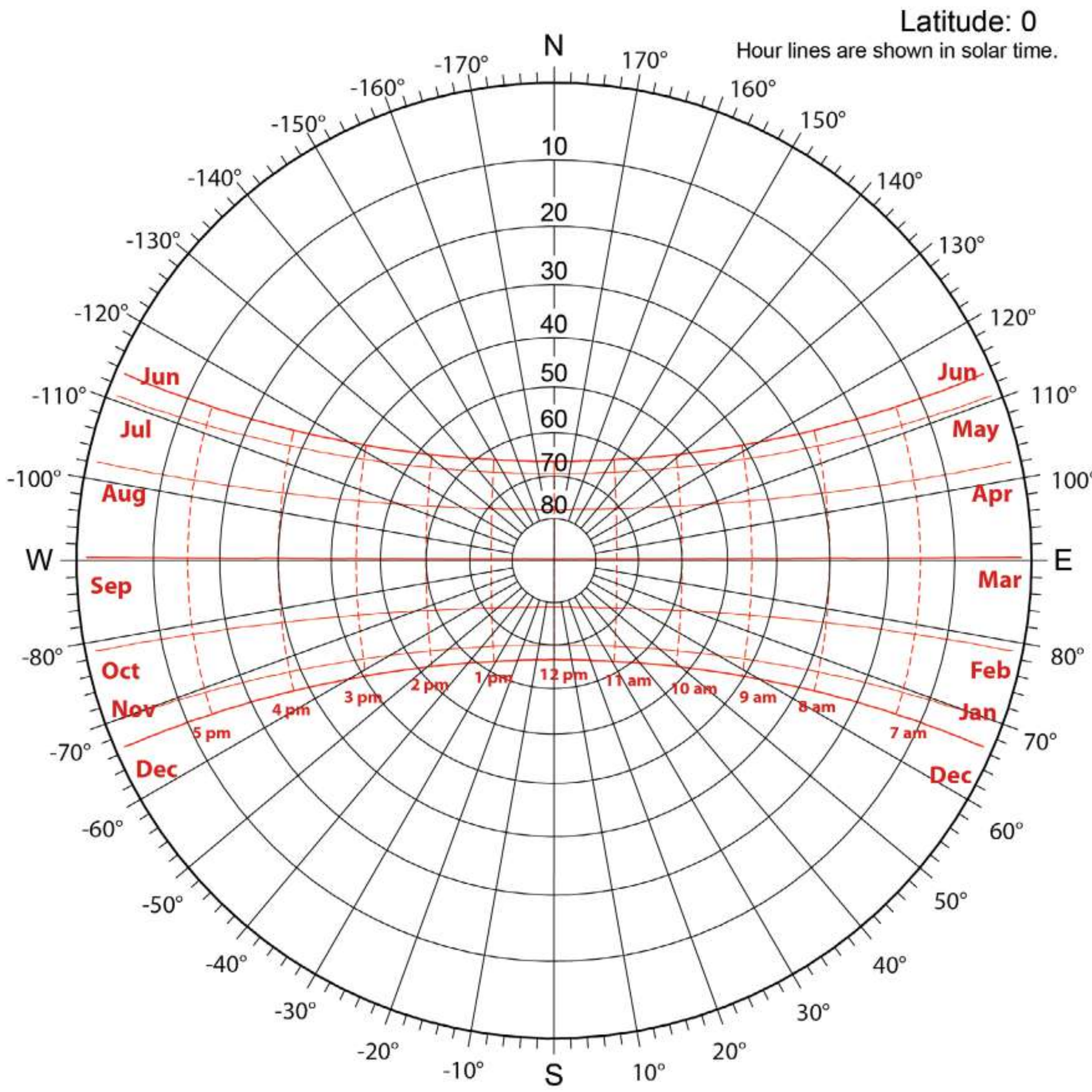


FIGURE 50 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN KAKAMEGA**

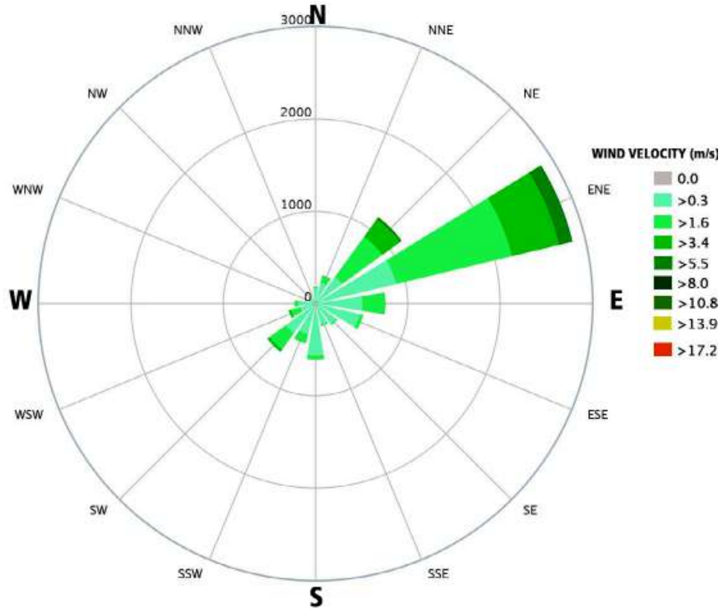
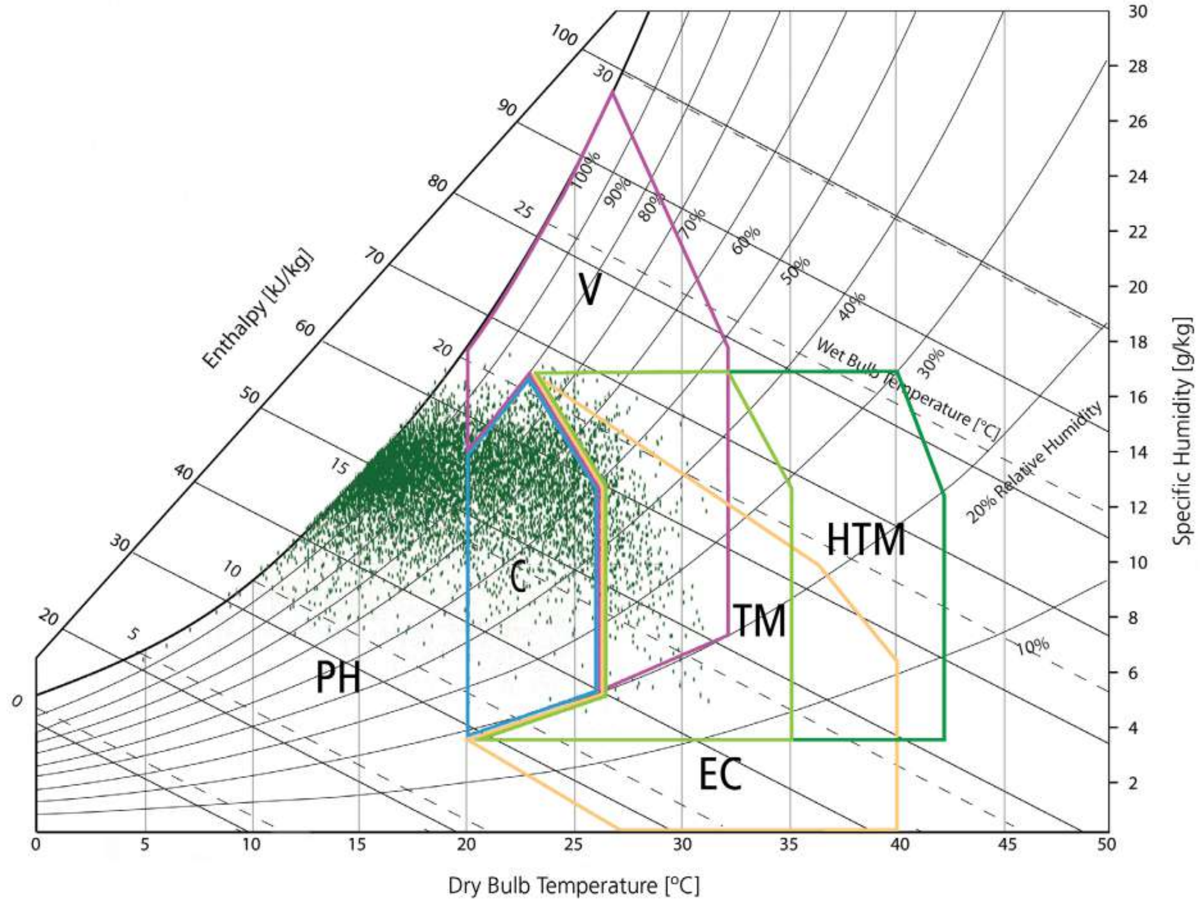


FIGURE 51 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR KAKAMEGA**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

The psychrometric chart (see Figure 51) shows that Kakamega is predominantly cool with outdoor conditions of hourly dry bulb temperatures and relative humidity falling within as well as below the comfort zone. This indicates that heating is necessary during the under heated period. The chart therefore suggests that the most effective strategy for extending the thermal comfort zone would be passive heating through direct solar heat gain and thermal mass. In addition, internal heat gain from occupants, equipment and lights would contribute to a reduction in heating needs.

However, during certain times of the year, the hourly data points (outdoor dry bulb temperature and relative humidity) fall beyond the comfort zone. Thermal mass is effective in extending the comfort zone by absorbing and storing daytime solar heat for release at night when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Kakamega, the following design strategies are recommended for:

a. Enabling passive heating

- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.

- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.

- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.

- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.

- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.

- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.

- Additional heating systems such as fireplaces can be incorporated in the design.

- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

b. Protection against heat gain in the hot period

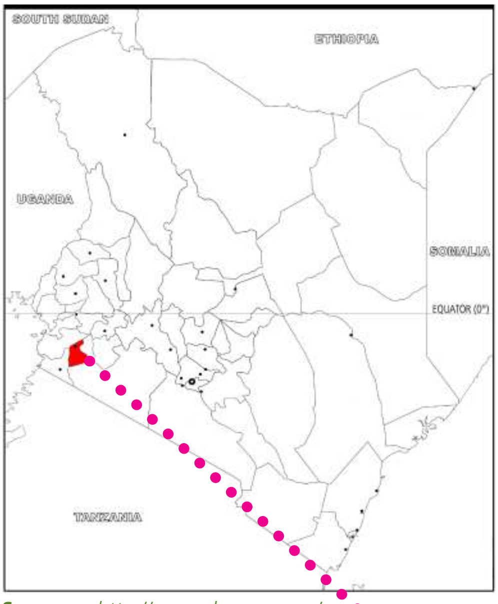
- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.

- Large windows should be avoided on the east and west facing façades.

- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

KISII

FIGURE 52 **LOCATION OF KISII COUNTY**



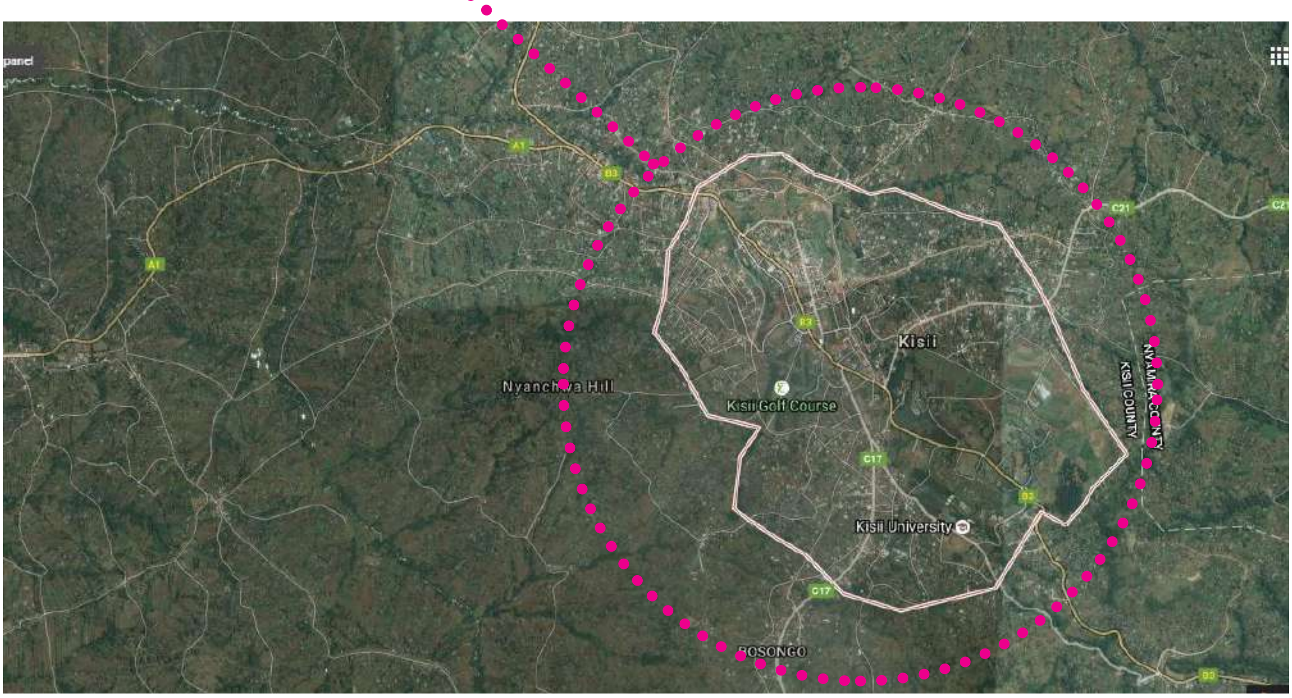
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	00° 17′ N
Longitude	34° 45′ E
Altitude	1,700 m

FIGURE 53 **VIEW OF KISII LEVEL 5 HOSPITAL**

Source: *http://webstaging.info/tropical/location.html*

FIGURE 54 **LOCATION OF KISII TOWN IN KISII COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Kisii town is the headquarters of Kisii county – known as the home to the best stone carvers in Kenya. It is located at geographic coordinates of 0° 41′ S, 34° 46′ E and at an altitude of 1,700 m above sea level, it enjoys an upland climate with rainfall recorded throughout the year at an average of 1,840 mm. The greatest amount occurs in April while the least amount is recorded in January. The average annual temperature is 19.5 °C with the warmest month on average being February. The lowest temperature average occurs in July. Relative humidity averages at 70% annually while the wind velocity ranges 2.2 – 4.2 m/s with the predominant wind direction being East and East South East (ESE). The annual average global solar radiation in this town is 5.5 kWh/m².

TABLE 8 **KISII MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	20.4	61.0	2.6	5.7	4.6	2.5	89.7
FEB	20.4	66.8	2.6	5.9	4.9	2.3	104.6
MAR	20.3	70.8	2.2	5.7	4.4	2.5	172
APR	19.8	74.4	2.5	5.3	3.7	2.6	252.1
MAY	19.1	75.5	3.7	5.1	3.6	2.5	201.4
JUN	18.9	75.6	3.6	4.9	3.7	2.3	153.4
JUL	18.8	69.5	4.2	5.2	4.1	2.3	114.6
AUG	19.3	64.1	4.2	5.7	4.4	2.4	148.6
SEP	19.2	65.7	3.5	5.9	4.4	2.5	140.7
OCT	19.7	68.8	2.6	5.7	4.0	2.6	143.6
NOV	18.9	71.9	3.7	5.1	3.3	2.7	194.3
DEC	19.6	71.3	2.6	5.5	4.5	2.4	125.4

FIGURE 55 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR KISII**

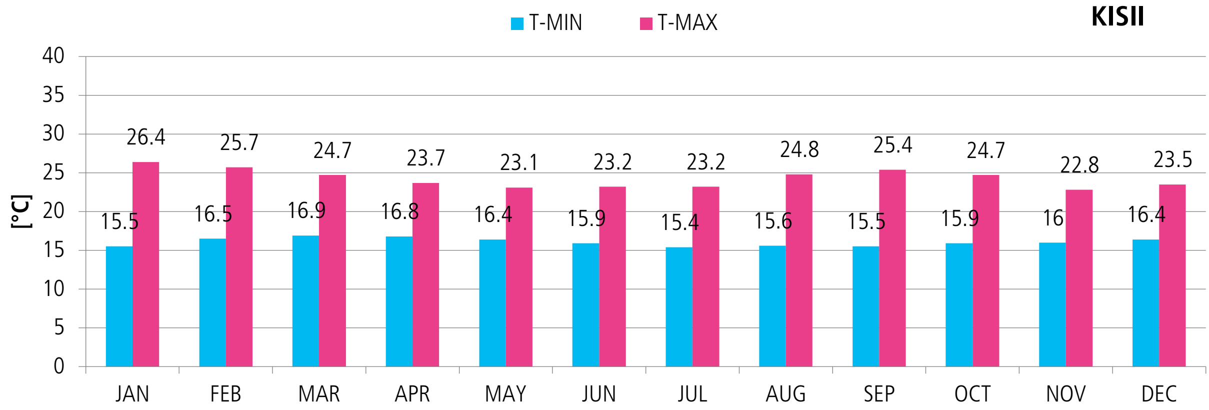


FIGURE 56 **MONTHLY MEAN RELATIVE HUMIDITY FOR KISII**

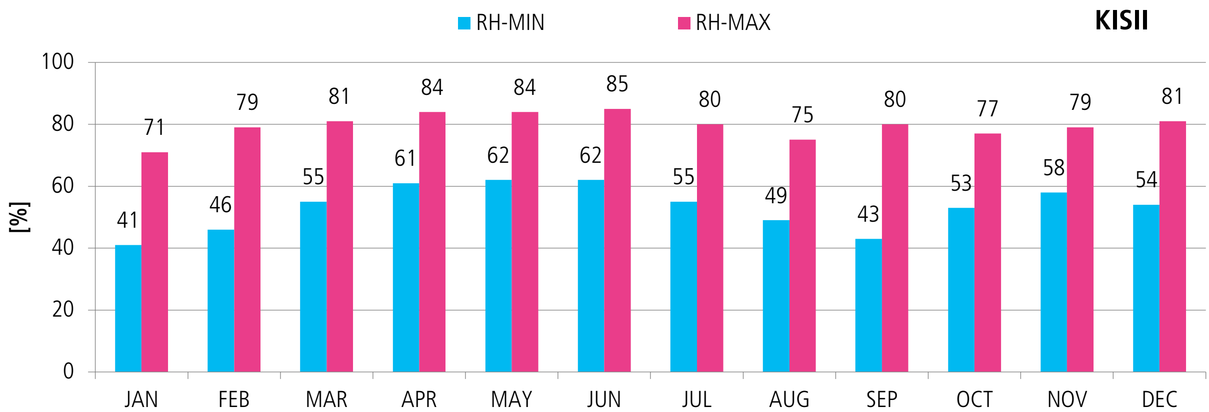


FIGURE 57 **MONTHLY AVERAGE RAINFALL FOR KISII**

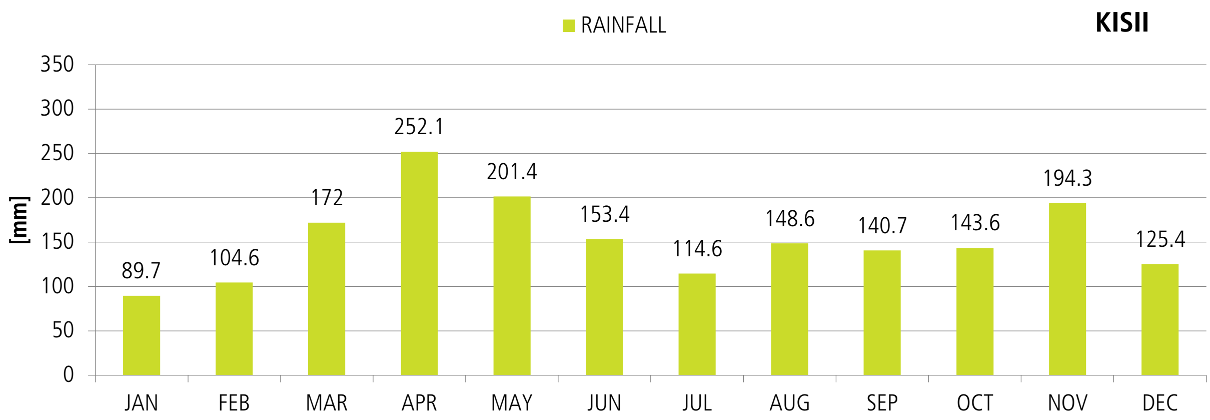


FIGURE 58 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

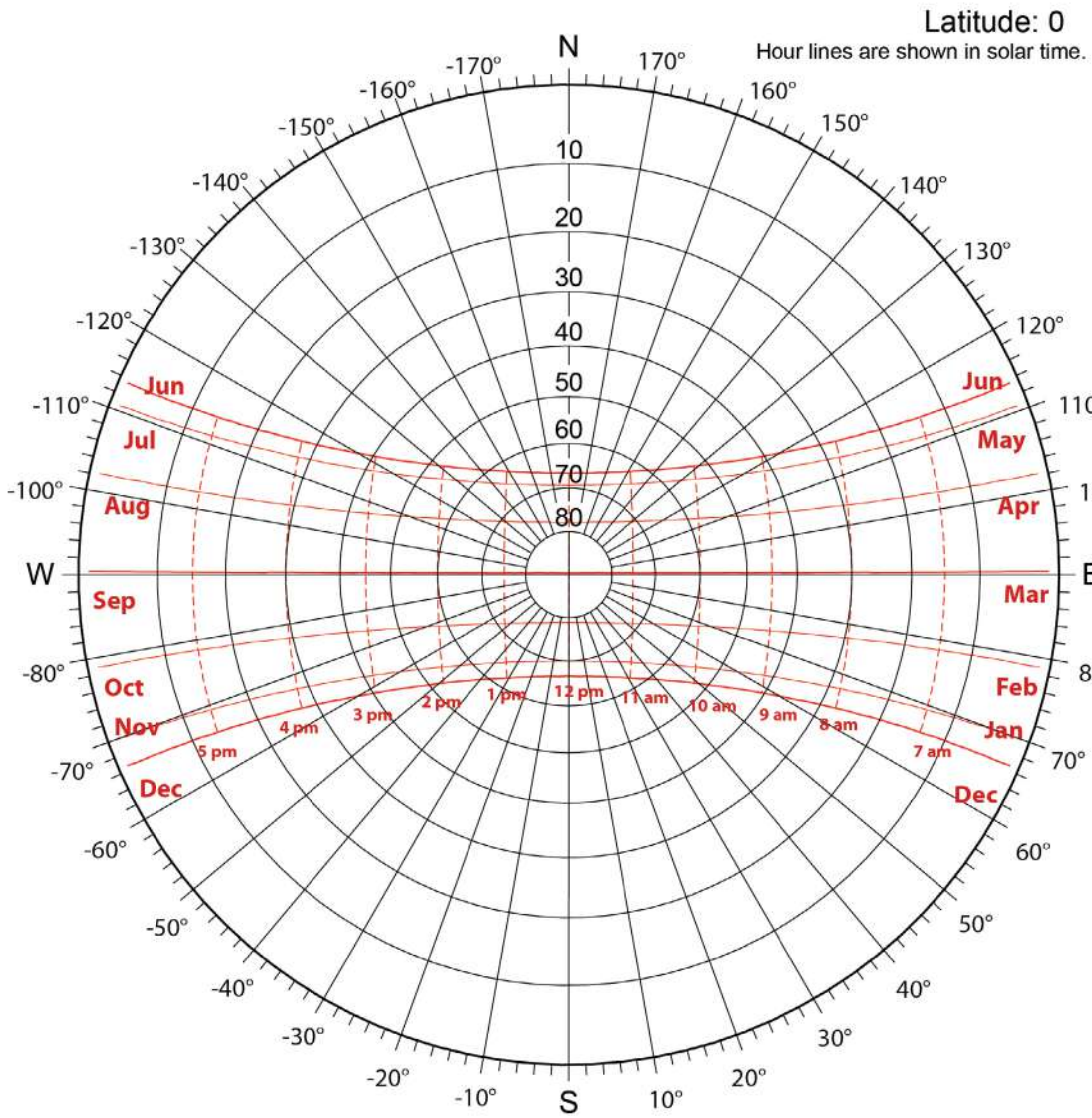


FIGURE 59 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN KISII**

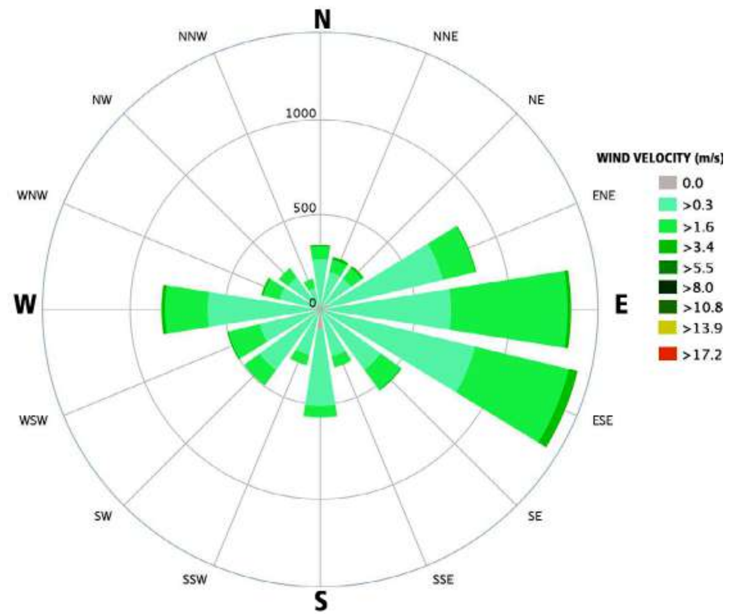
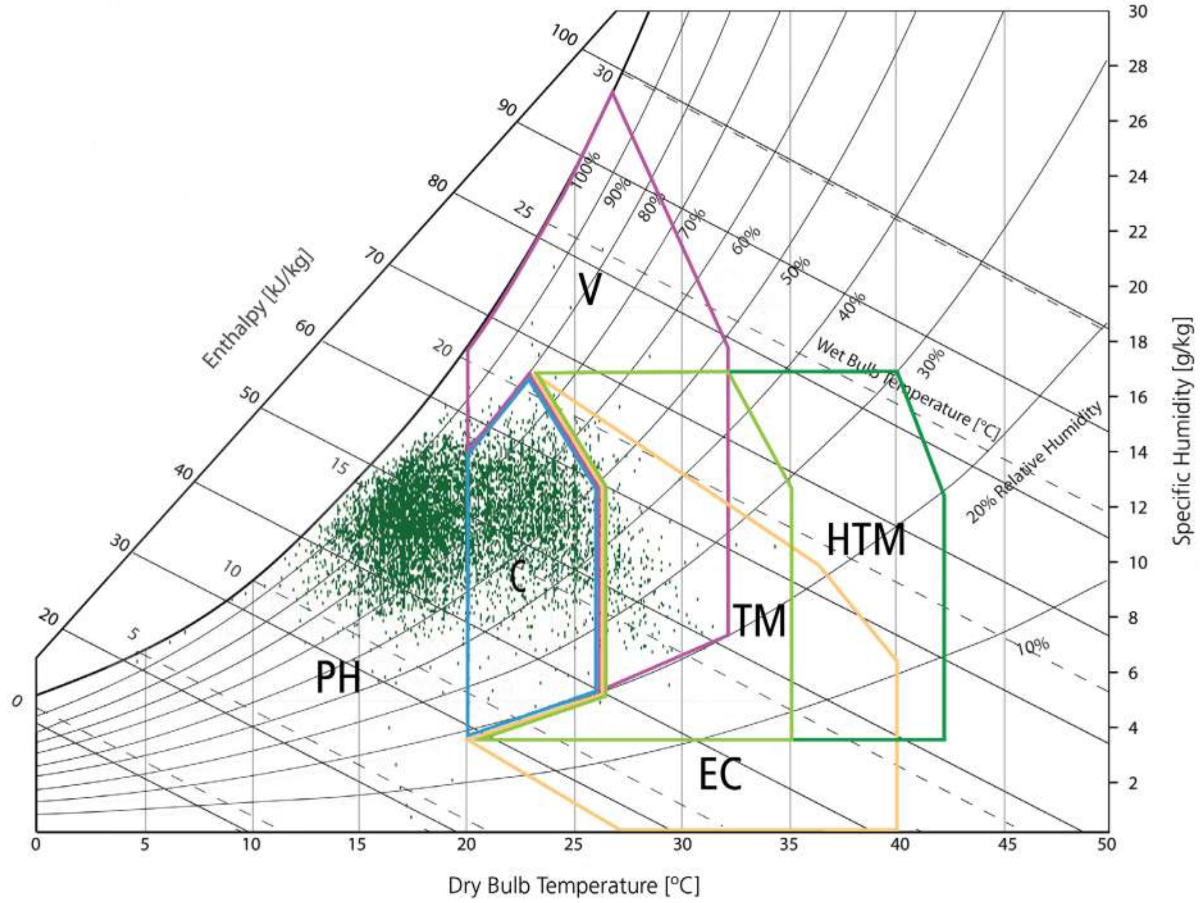


FIGURE 60 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR KISII**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

The hourly outdoor dry bulb temperatures and relative humidity points, as seen in Figure 60, indicate that most of the time the region is within the comfort zone band with a few hours beyond the comfort zone. During this period, thermal mass is effective in extending the comfort zone by absorbing and storing daytime solar heat for release at night when the temperatures fall below the comfort zone.

The psychrometric chart also shows that most of the time the data points go below the comfort zone therefore indicating the need for heating. To extend the comfort zone during this period, passive heating through direct solar heat gain and thermal mass are the most effective design strategies. Furthermore, internal heat gain from occupants, equipment and lights would contribute to a reduction in heating needs.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Kisii, the following design strategies are recommended for:

a. Enabling passive heating

- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.
- Additional heating systems such as fireplaces can be incorporated in the design.
- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

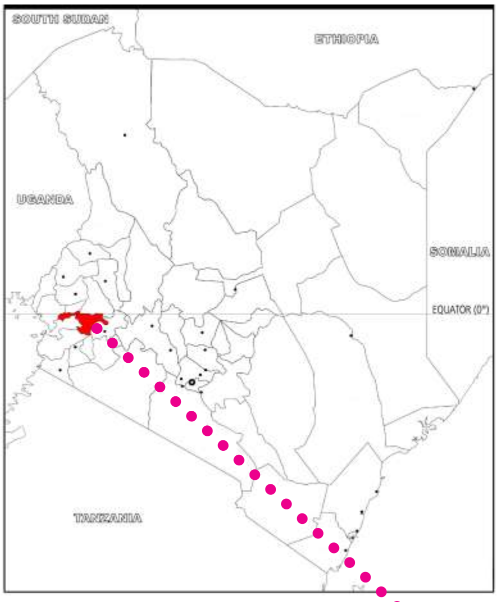
b. Protection against heat gain in the hot period

- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

KISUMU

Climatic Zone	GREAT LAKES
Latitude	00° 06′ S
Longitude	34° 45′ E
Altitude	1,131 m

FIGURE 61 **LOCATION OF KISUMU COUNTY**



Source: *http://www.d-maps.com/*

FIGURE 62 **AERIAL VIEW OF KISUMU CITY**

Source: *http://www.africatravelresource.com/kisumu-town-safari/*

FIGURE 63 **LOCATION OF KISUMU TOWN IN KISUMU COUNTY**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Kisumu city, the headquarters of Kisumu county, is the third largest city in Kenya. It is located at geographic coordinates 00° 06′ S, 34° 45′ E at an altitude of 1,131 m above sea level. Its climate is characterised by rainfall being recorded throughout the year with an average amount of 1,350 mm. The month with the most amount of rainfall is April while July and August are recorded as the months with the least amount. The average annual temperature is 22.9 °C with the warmest month on average being February while the coolest month on average is July. Relative humidity averages at 69.4% annually while the wind velocity ranges 2.2 – 3.7 m/s with the predominant wind direction being East North East (ENE). The annual average global solar radiation in Kisumu is 5.7 kWh/m^2.

TABLE 9 **KISUMU MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m^2 day]	Direct normal solar radiation [kWh/m^2 day]	Diffuse solar radiation [kWh/m^2 day]	Rainfall [mm]
JAN	23.8	61.0	3.5	5.9	5.2	2.3	90
FEB	24.0	64.0	3.7	6.2	5.3	2.3	100
MAR	23.2	71.0	3.5	6.0	4.6	2.5	170
APR	23.4	73.0	3.0	5.4	3.7	2.6	180
MAY	22.3	79.0	2.2	5.2	3.8	2.5	170
JUN	22.0	74.0	2.3	5.3	4.1	2.3	90
JUL	21.6	71.0	3.1	5.3	4.0	2.5	70
AUG	22.1	69.0	2.6	5.7	4.2	2.5	70
SEP	22.9	65.0	2.8	6.0	4.5	2.6	90
OCT	23.0	69.0	2.9	5.8	4.1	2.7	100
NOV	23.2	69.0	3.1	5.4	3.7	2.7	130
DEC	23.4	68.0	2.8	5.7	4.6	2.4	90

FIGURE 64 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR KISUMU**

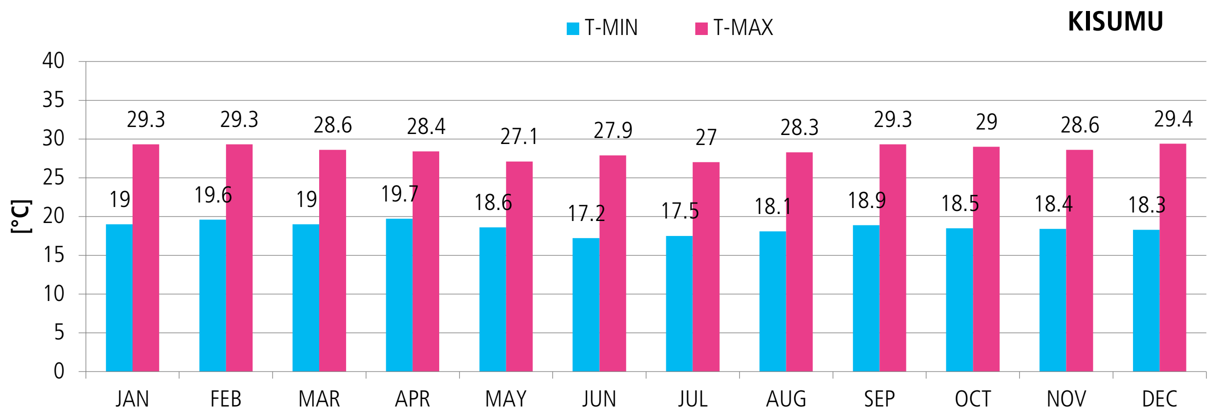


FIGURE 65 **MONTHLY MEAN RELATIVE HUMIDITY FOR KISUMU**

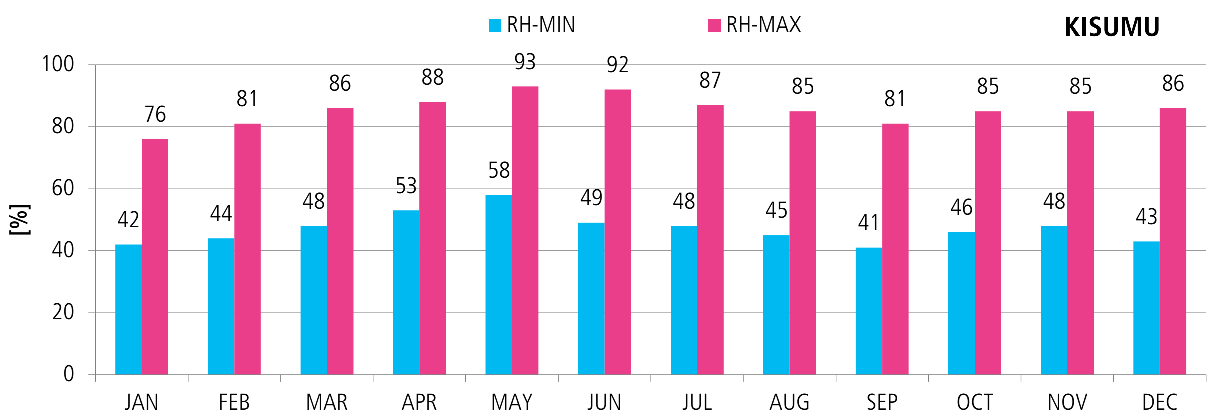


FIGURE 66 **MONTHLY AVERAGE RAINFALL FOR KISUMU**

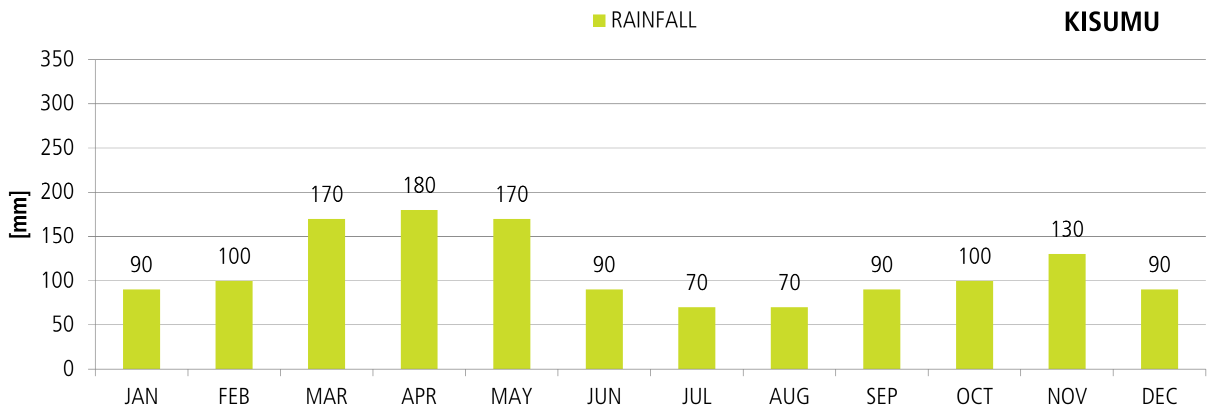


FIGURE 67 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

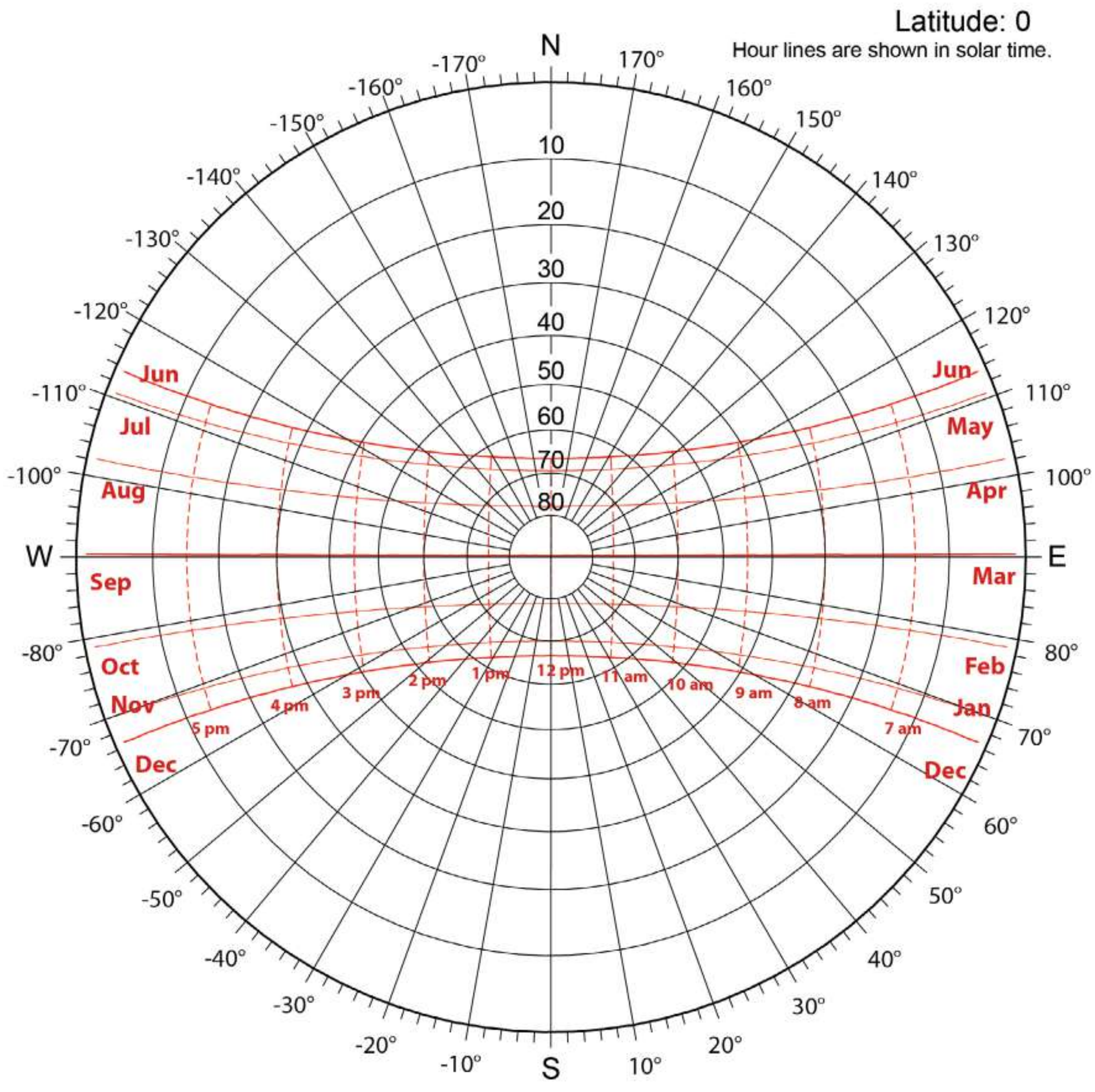


FIGURE 68 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN KISUMU**

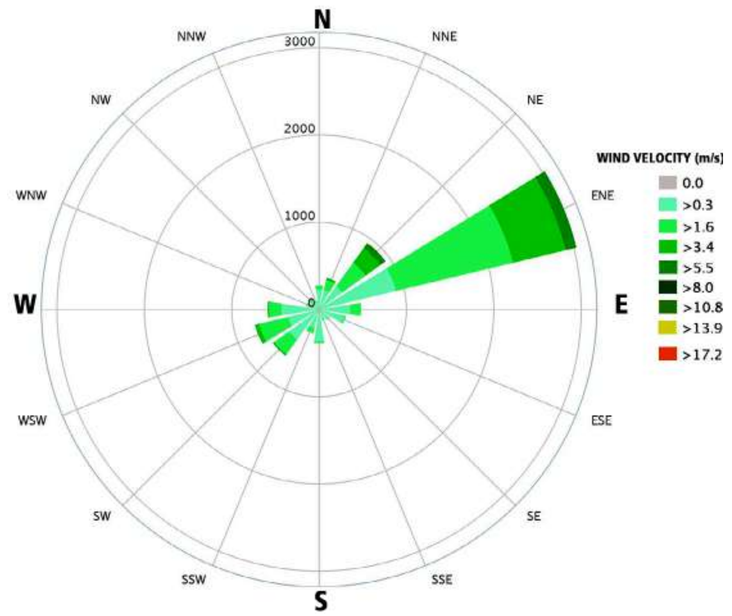
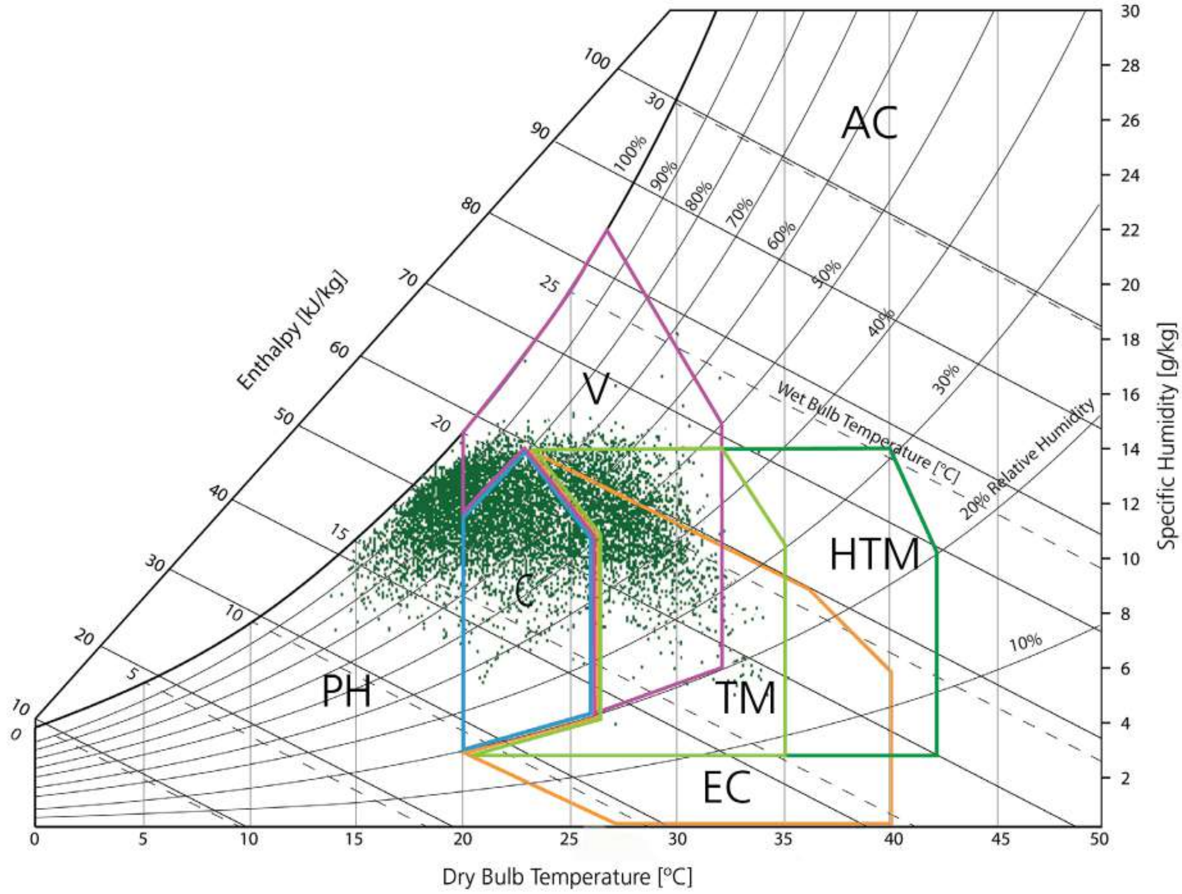


FIGURE 69 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR KISUMU**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

The psychrometric chart (see Figure 69) shows that the Great Lake climate of Kisumu experiences some degree of thermal comfort. It also shows that most of the hourly data points of outdoor dry bulb temperature and relative humidity fall beyond the comfort zone thus experiencing high temperature and humidity. Certain periods of the year have the outside conditions falling below the comfort zone. The chart therefore suggests that natural ventilation, passive heating through direct solar heat gain and thermal mass are the most effective strategies for improving thermal comfort.

BIOCLIMATIC RECOMMENDATIONS

The design objectives and responses for Great Lakes climate like Kisumu's should be to address issues due to high daily temperatures variation, high relative humidity and high solar radiation levels. The following passive design strategies may be used to address the cooling and heating requirements that result from the above climatic characteristics:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading.
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, vertical fins, covered verandas and porches etc (Figure 70).
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and minimise heat gains.

b. To promote maximum ventilation

- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings.
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum airflow through them.
- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.
- Openings should be located on opposite sides of walls to allow for proper cross-ventilations. Internal walls should also have openings for airflow through the internal space.
- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement (Figure 71).
- Ventilated double roofs enhance ventilation of the roof minimising overheating.

FIGURE 70 **EXTENSIVE USE OF HORIZONTAL AND VERTICAL SHADING DEVICES**

Vasity Plaza, Kisumu © UN-Habitat / Jerusha NGUNGUI

FIGURE 71 **RESIDENTIAL BUILDING SHOWING HORIZONTAL SHADING DEVICES PROTECTING OPENING FROM THE MIDDAY SUN, HIGH LEVEL VENTILATION BLOCKS ABOVE WINDOWS TO FACILITATE NATURAL VENTILATION AND LIGHT COLOURED EXTERNAL FINISHES TO REFLECT SOLAR RADIATION**

c. Enabling passive heating

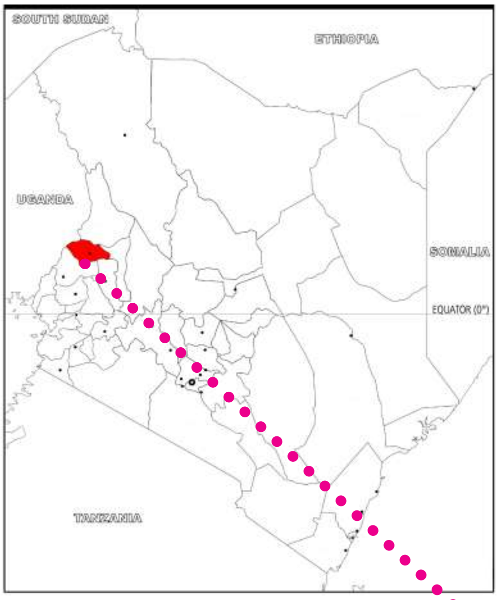
- Medium weight walls, floors and ceilings are recommended to explore passive solar gains by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.

- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.

- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone.

KITALE

FIGURE 72 **LOCATION OF TRANS NZOIA COUNTY**



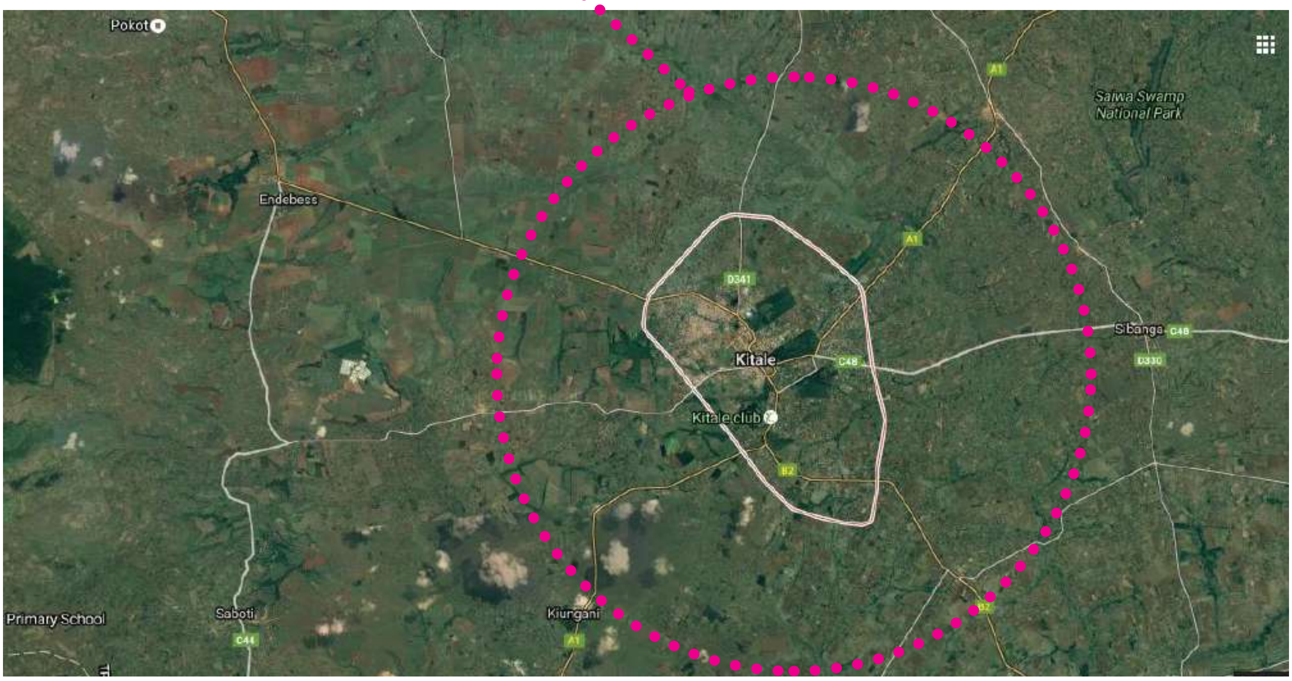
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	01° 01′ N
Longitude	35° 00′ E
Altitude	1,900 m

FIGURE 73 **STREET VIEW OF KITALE TOWN**

Source: *https://heartodarkness.wordpress.com/2006/11/01/the-road-to-loki1/*

FIGURE 74 **LOCATION OF KITALE TOWN IN TRANS NZOIA COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Kitale, an agricultural town, is the headquarters of Trans-Nzoia county and is located at geographic coordinates of 1° 01′ N, 35° 00′ E at an altitude of 1,900 m above sea level. It enjoys a predominantly cool upland climate with temperatures averaging at 18.1 °C annually. The period between July and September is the coolest, while February and March are the warmest months of the year. Annual rainfall averages 1,070 mm with the lowest amount occurring in January. Most rainfall occurs in May and August. Relative humidity averages at 71.3% annually while the wind velocity ranges 1.7 – 3.0 m/s with the predominant wind direction being North East and East North East (ENE). The annual average global solar radiation in Kitale is 5.4 kWh/m².

TABLE 10 **KITALE MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	18.8	57.0	3.0	5.8	5.1	2.4	10
FEB	19.7	54.0	2.7	6.2	5.7	2.2	40
MAR	19.9	63.0	3.0	5.8	4.2	2.7	70
APR	18.8	73.0	2.2	5.2	3.2	2.7	130
MAY	18.3	77.0	1.8	5.2	3.7	2.6	160
JUN	17.2	82.0	1.7	4.9	3.4	2.5	110
JUL	16.9	81.0	2.0	4.9	3.0	2.7	140
AUG	16.9	82.0	2.4	5.2	3.4	2.8	160
SEP	16.9	76.0	1.9	5.6	4.1	2.6	100
OCT	17.9	74.0	2.1	5.6	3.7	2.8	80
NOV	18.0	75.0	2.2	5.3	3.5	2.8	50
DEC	18.4	62.0	2.8	5.6	4.7	2.5	20

FIGURE 75 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR KITALE**

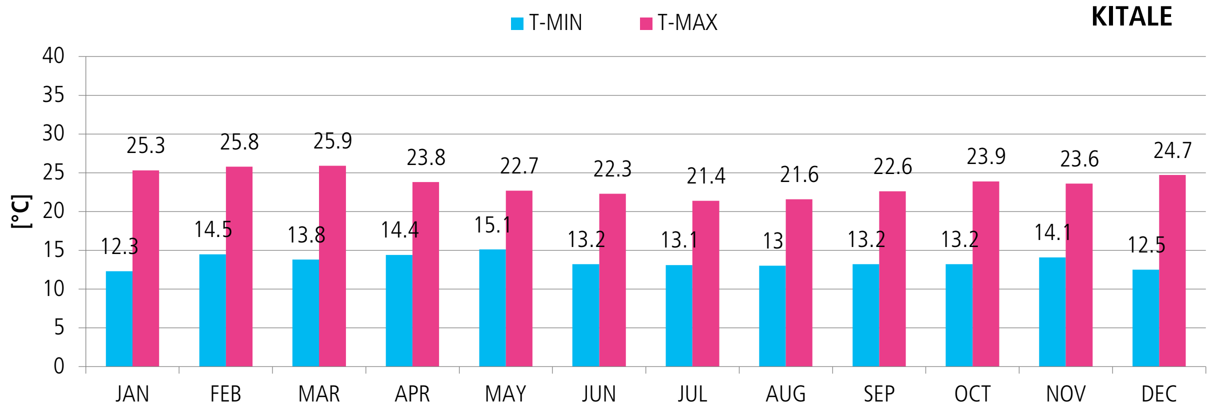


FIGURE 76 **MONTHLY MEAN RELATIVE HUMIDITY FOR KITALE**

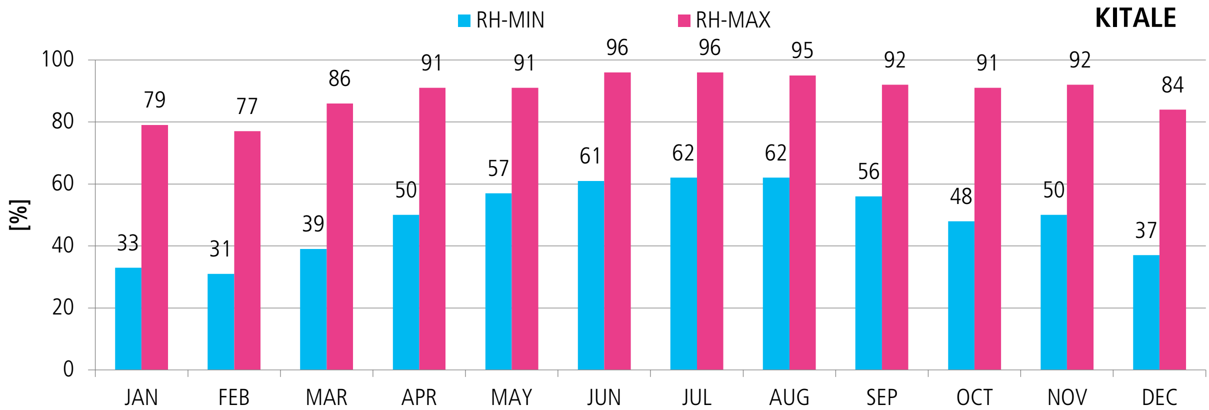


FIGURE 77 **MONTHLY AVERAGE RAINFALL FOR KITALE**

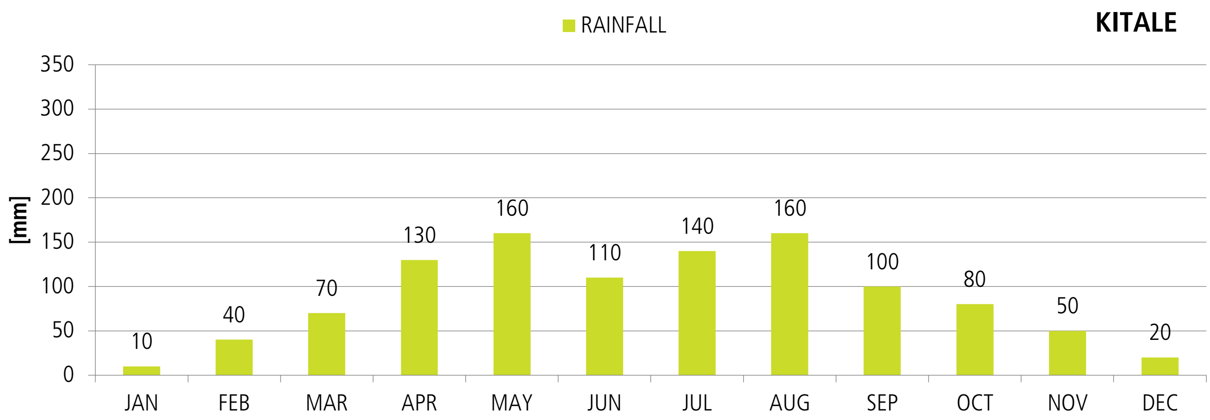


FIGURE 78 **POLAR SUN PATH DIAGRAM FOR LATITUDE 1° NORTH**

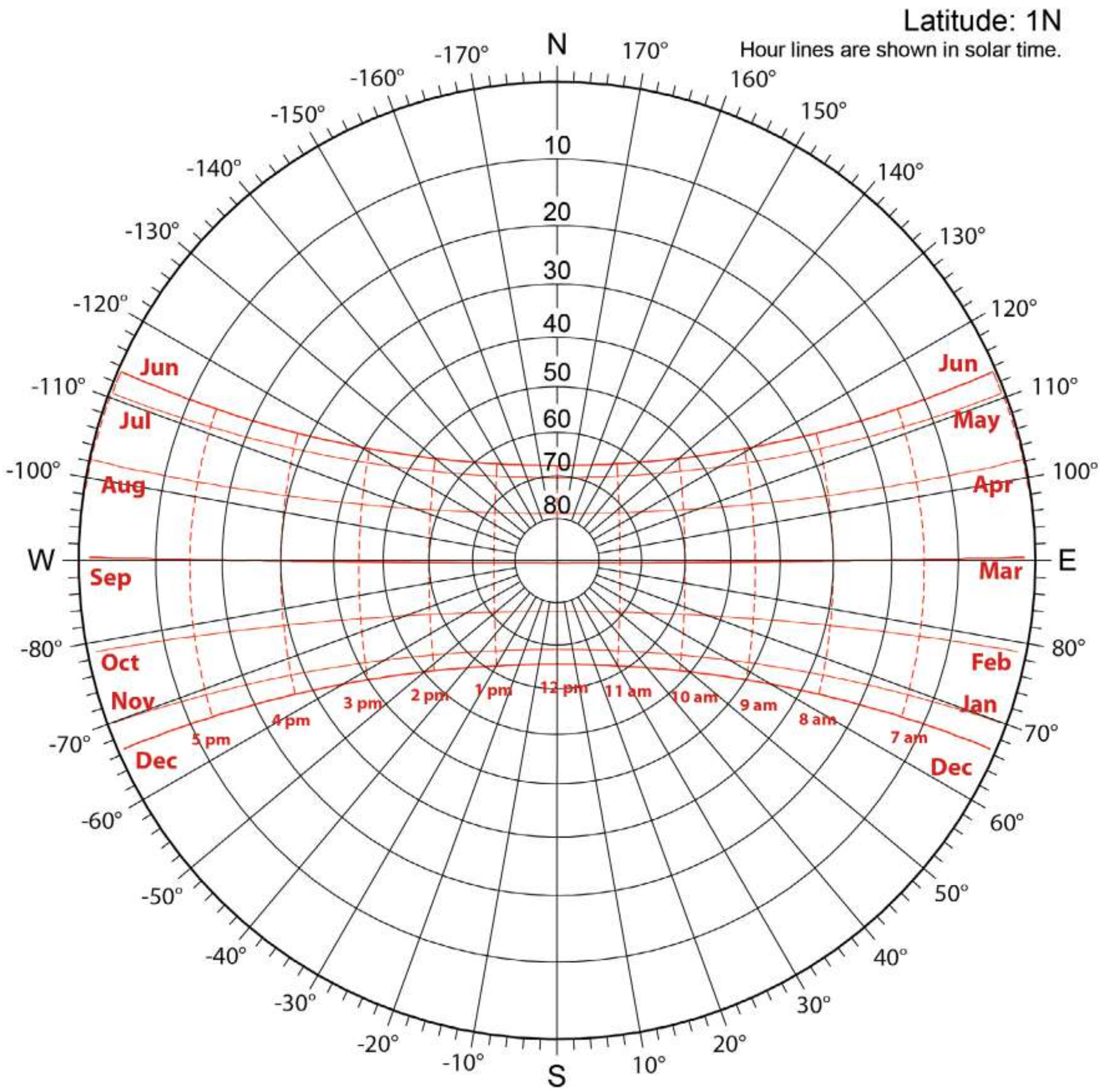


FIGURE 79 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN KITALE**

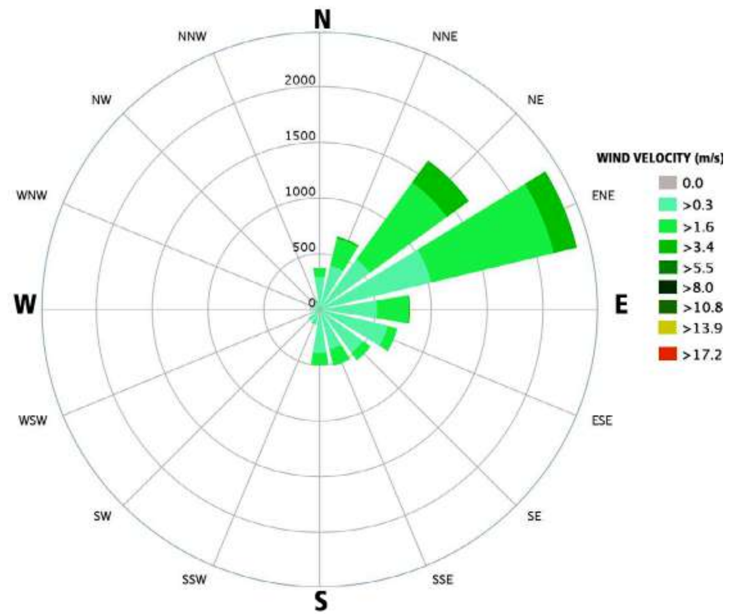
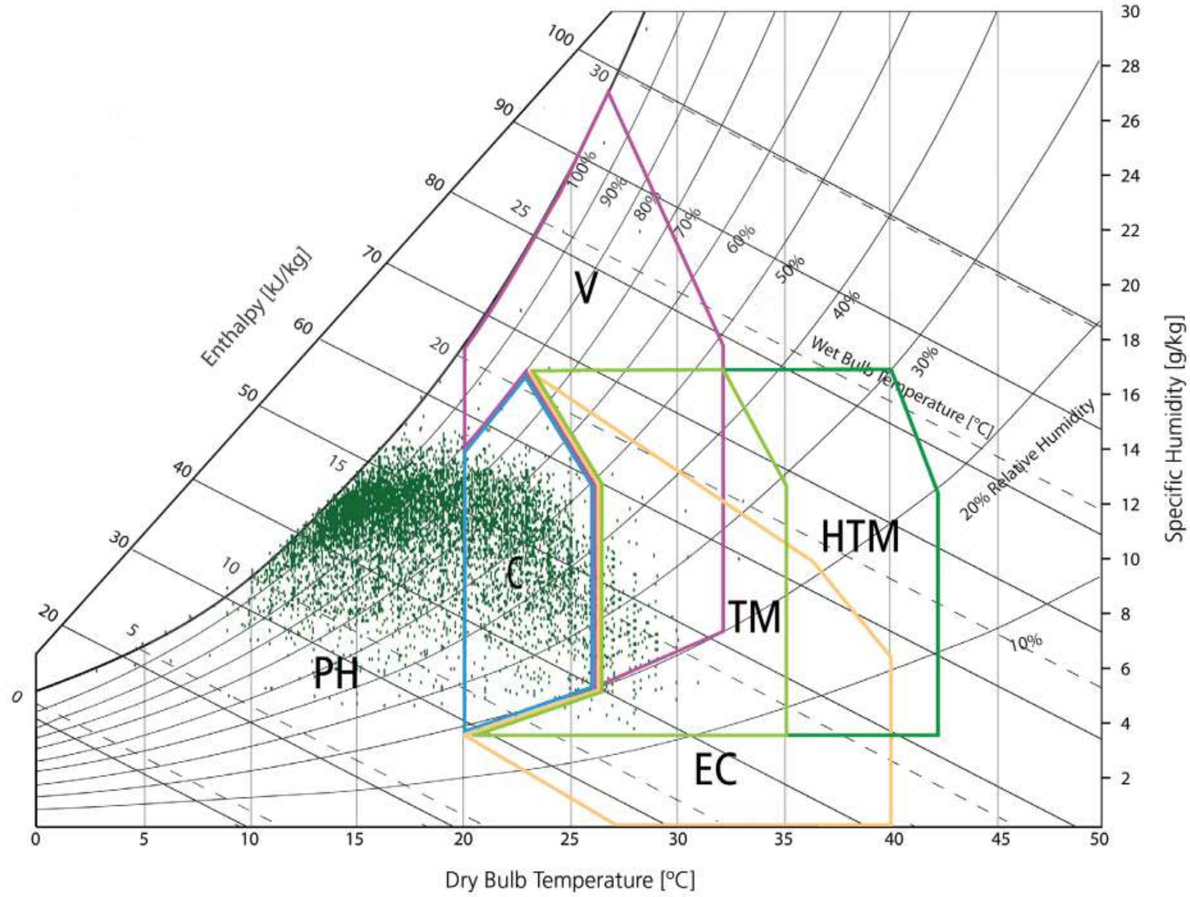


FIGURE 80 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR KITALE**



C Comfort Zone
V Natural Ventilation
TM Thermal Mass
HTM High Thermal Mass
EC Evaporative Cooling
PH Passive Heating
AC Air Conditioning

INTERPRETATION

The psychrometric chart (see Figure 80) shows that Kitale is predominantly cool with outdoor conditions of hourly dry bulb temperatures and relative humidity falling within as well as below the comfort zone. This indicates that heating is necessary during the under heated period. The chart therefore suggests that the most effective strategy for extending the thermal comfort zone would be through passive heating through direct solar heat gain and thermal mass. In addition, internal heat gain from occupants, equipment and lights would contribute to a reduction in heating needs.

However, during certain times of the year, the hourly data points (outdoor dry bulb temperature and relative humidity) fall beyond the comfort zone. Thermal mass is effective in extending the comfort zone by absorbing and storing daytime solar heat for release at night when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Kitale, the following design strategies are recommended for:

a. Enabling passive heating

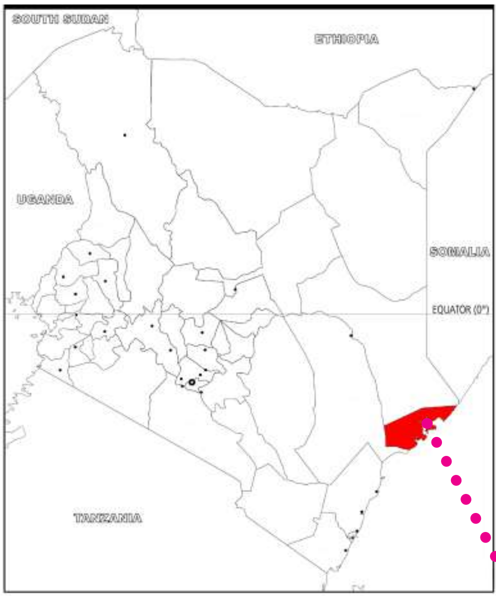
- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.
- Additional heating systems such as fireplaces can be incorporated in the design.
- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

b. Protection against heat gain in the hot period

- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

LAMU

FIGURE 81 **LOCATION OF LAMU COUNTY**



Source: *http://www.d-maps.com/*

Climatic Zone	HOT AND HUMID
Latitude	02° 16' 6
Longitude	40° 54' E
Altitude	308 m

FIGURE 82 **LAMU ISLAND SEAFRONT**

Source: *https://commons.wikimedia.org/wiki/File:Lamu,_Lamu_Island,_Kenya.jpg#/media/File:Lamu,_Lamu_Island,_Kenya.jpg © Erik HERSMAN*

FIGURE 83 **LOCATION OF LAMU TOWN IN LAMU COUNTY**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Lamu town, the headquarters of Lamu county is one of the oldest inhabited towns in Kenya and is a UNESCO World Heritage site. It is located at geographic coordinates of 2° 16′ S, 40° 54′ E at an altitude of 308 m above sea level. It enjoys a hot and humid climate with high temperatures throughout the year (average of 27.1 °C) while the annual mean relative humidity is around 78.2%.

The average amount of rainfall recorded annually is 895 mm with the highest recorded amount in May and the least amount in February. Wind velocity ranges 2.6 – 5.5 m/s with the predominant wind direction being East North East (December to March) and South (April to November). The annual average global solar radiation in Lamu is 5.6 kWh/m².

TABLE 11 **LAMU MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	27.6	77.0	4.6	6.1	5.0	2.4	7
FEB	28.0	76.0	3.4	6.4	5.5	2.4	3
MAR	28.6	76.0	3.2	6.2	4.8	2.5	32
APR	28.5	80.0	3.5	5.4	3.9	2.5	135
MAY	27.2	82.0	4.8	4.7	3.0	2.6	299
JUN	26.2	78.0	5.2	4.6	3.0	2.5	145
JUL	25.4	78.0	5.5	5.0	3.4	2.5	82
AUG	25.5	79.0	5.3	5.3	3.6	2.6	41
SEP	25.9	77.0	4.1	5.8	3.9	2.8	47
OCT	27.1	77.0	3.3	5.9	4.3	2.7	37
NOV	27.8	78.0	3.3	6.0	4.6	2.6	42
DEC	27.6	80.0	2.6	5.7	4.5	2.5	25

FIGURE 84 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR LAMU**

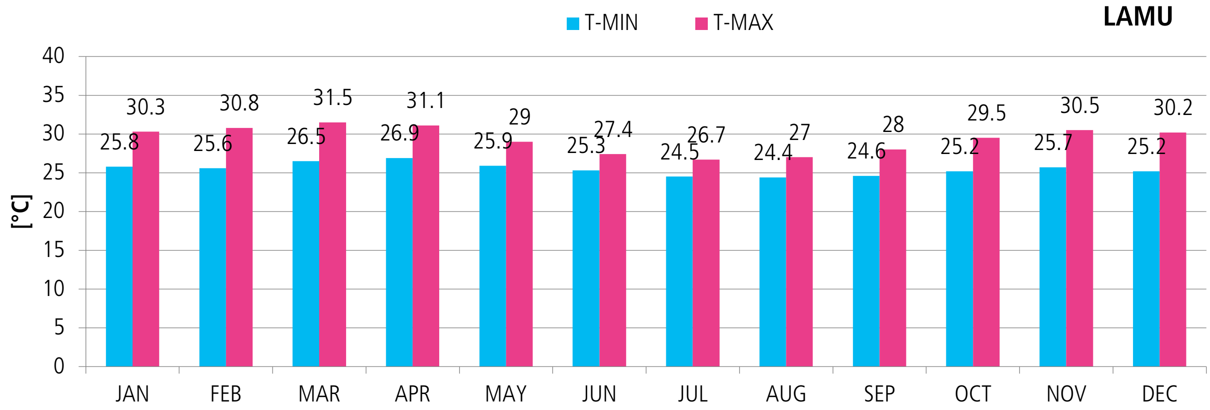


FIGURE 85 **MONTHLY MEAN RELATIVE HUMIDITY FOR LAMU**

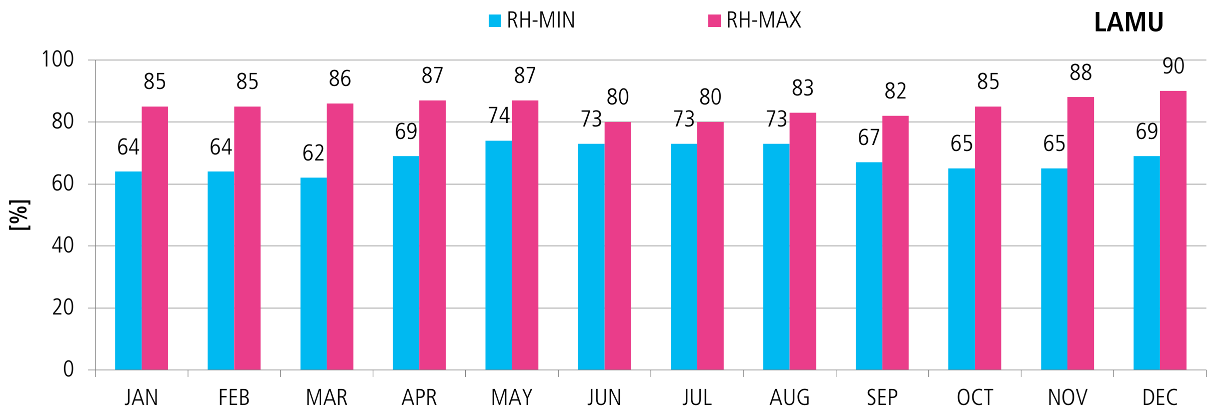


FIGURE 86 **MONTHLY AVERAGE RAINFALL FOR LAMU**

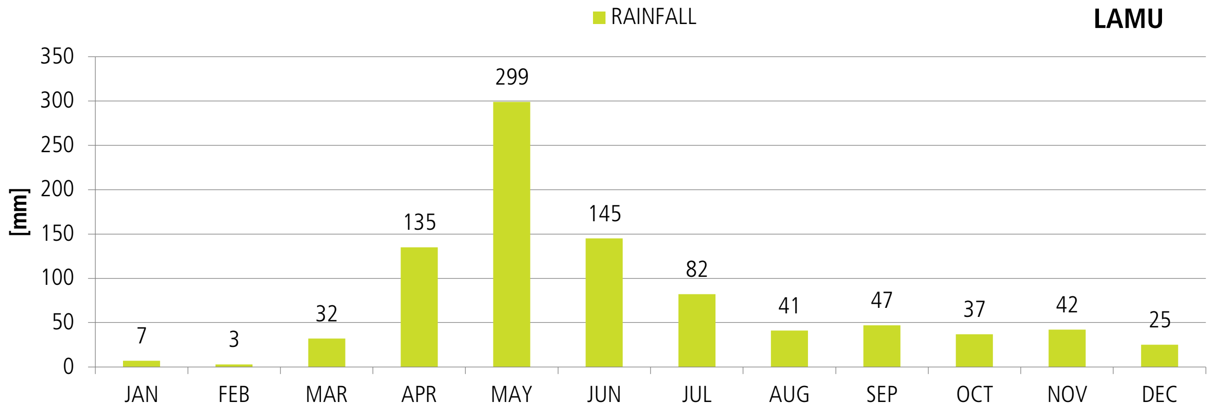


FIGURE 87 **POLAR SUN PATH DIAGRAM FOR LATITUDE 2° SOUTH**

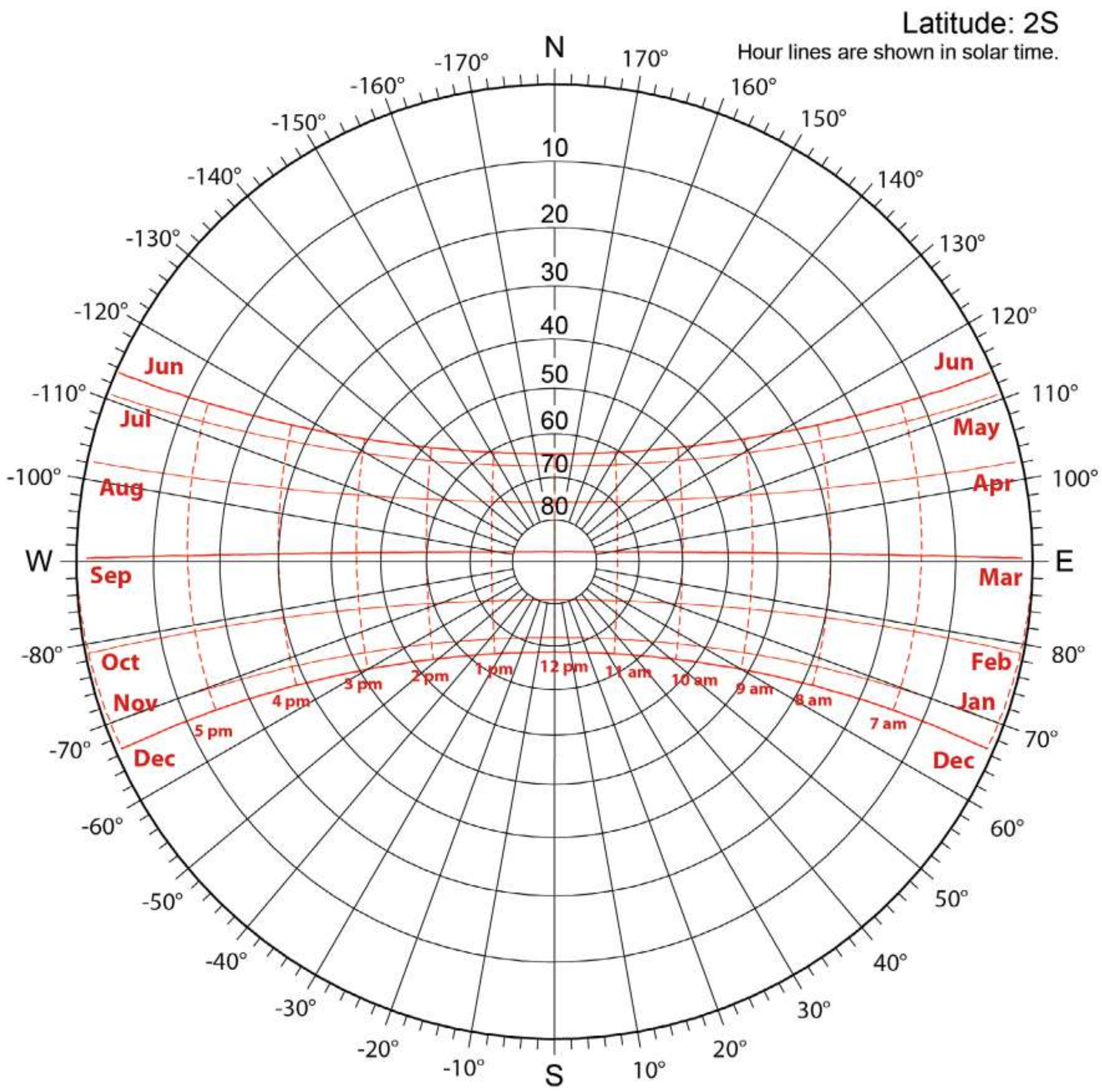


FIGURE 88 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN LAMU**

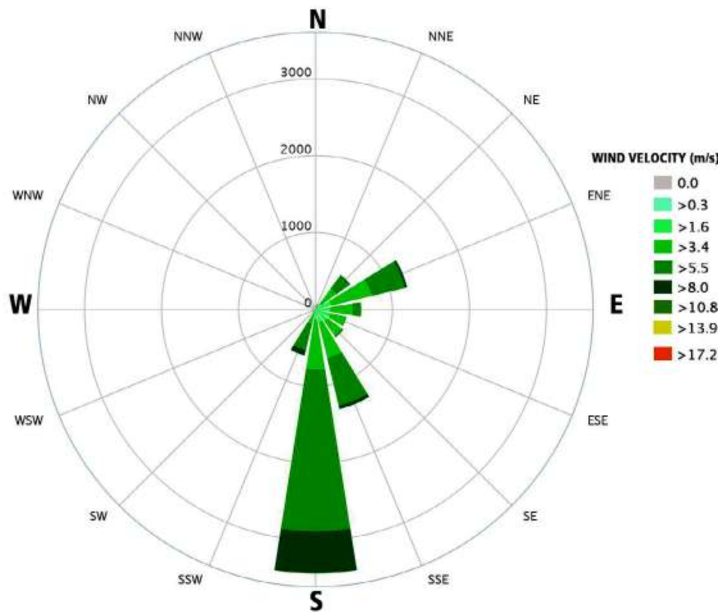
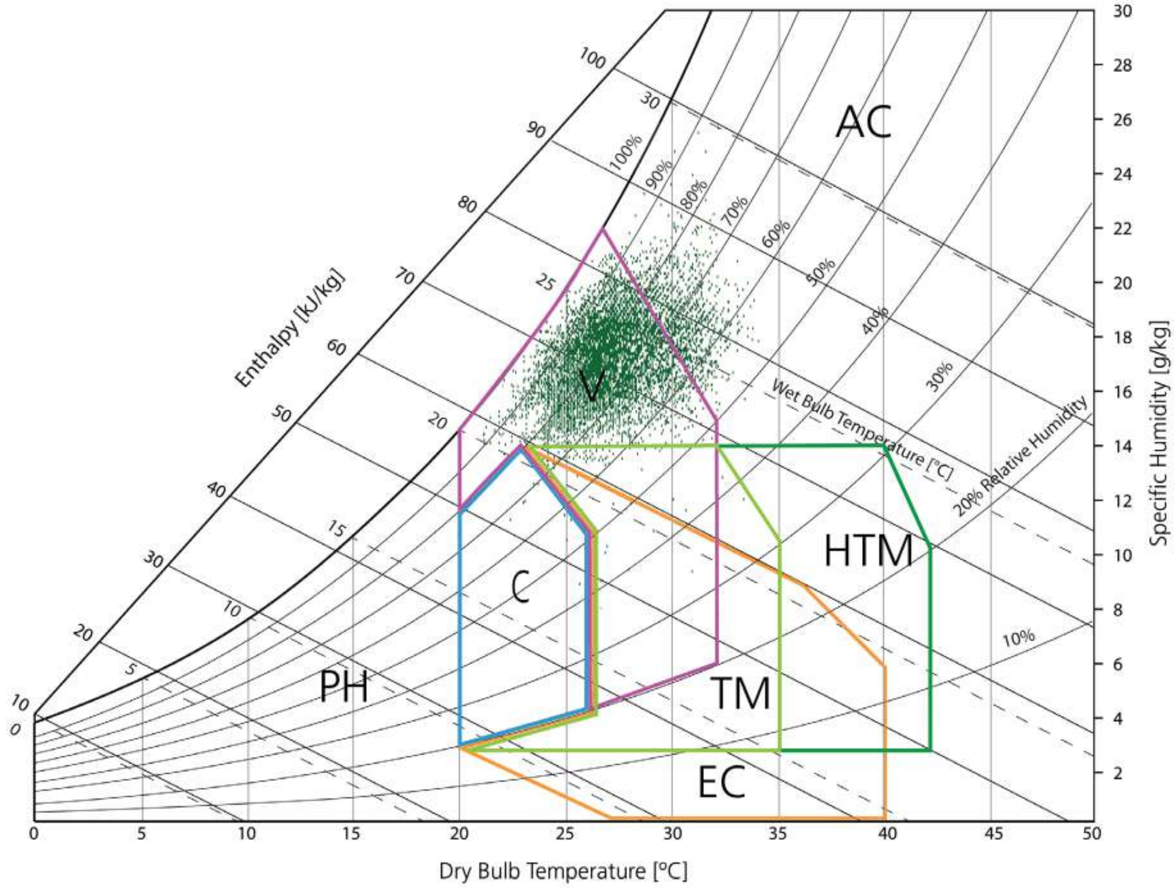


FIGURE 89 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR LAMU**



C Comfort Zone	EC Evaporative Cooling
V Natural Ventilation	PH Passive Heating
TM Thermal Mass	AC Air Conditioning
HTM High Thermal Mass	

INTERPRETATION

The outdoor hourly dry bulb temperatures and relative humidity data points indicate that Lamu is completely out of the comfort zone (see Figure 89). The resulting combination of high temperatures and high relative humidity causes discomfort in the region throughout the year. Thermal comfort can however be achieved passively through natural ventilation for temperatures below 33 °C but beyond the comfort zone. This makes it the most appropriate strategy to extend the comfort zone. However, Figure 90 indicates that artificial cooling using fans or air conditioners will be necessary for periods where temperatures are above 33 °C.

BIOCLIMATIC RECOMMENDATIONS

The design objectives and responses for a hot and humid climate like Lamu's should be to address issues due to high temperatures, high relative humidity and high solar radiation levels. The following passive design strategies may be used to address the cooling requirements that result from the above climatic characteristics:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading.
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, covered verandas and porches etc.
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and reduce heat gains (Figure 90).

FIGURE 90 **LIGHTLY COLOURED EXTERIOR SURFACES REFLECT UNWANTED SOLAR RADIATION, WHILE TIMBER SHUTTERS ENCOURAGE UNRESTRICTED AIR MOVEMENT IN AND OUT OF THE BUILDING WHILE AT THE SAME TIME CUTTING OUT DIRECT SUNLIGHT INTO THE INDOOR SPACES THUS MINIMISING HEAT GAIN.**

Swahili Dreams house, Lamu
Source: *http://urkosanchez.com/en/project/6/swahili-dreams.html © Corrie WINGATE, Urko Sánchez Architects*

- Lightweight building materials with low thermal capacity are recommended for walls, floors and roofs to allow rapid cooling at night.

b. To promote maximum ventilation

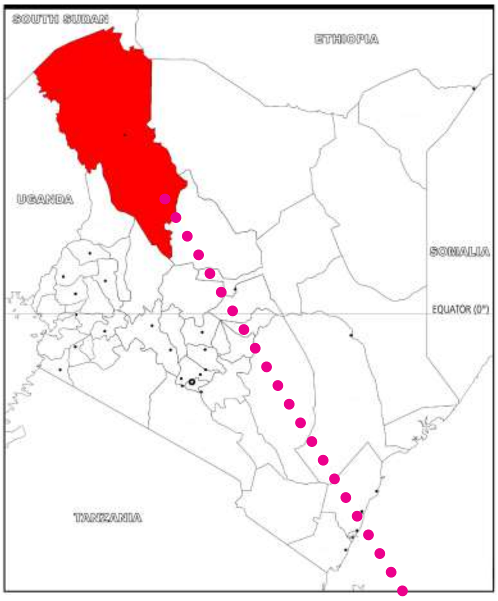
- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings (Figure 91).
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum ventilation.
- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.
- Openings should be located on opposite sides o walls to allow for proper cross-ventilations. Interna walls should also have openings for airflow through the internal space.
- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement.
- Ventilated double roofs enhance ventilation of the roof minimising overheating

FIGURE 91 **PASSIVE MEANS OF VENTILATION IS PROVIDED BY THE PROVISION OF LARGE OPENINGS THAT AIRFLOW ACROSS THE LIVING SPACES THEREFORE PROMOTING CROSS VENTILATION FOR NATURAL COOLING.**

The Red pepper house, Lamu
Source: *http://urkosanchez.com/en/project/11/the-red-pepper-house.html © Alberto HERAS, Steve MANN*

LODWAR

FIGURE 92 **LOCATION OF TURKANA COUNTY**



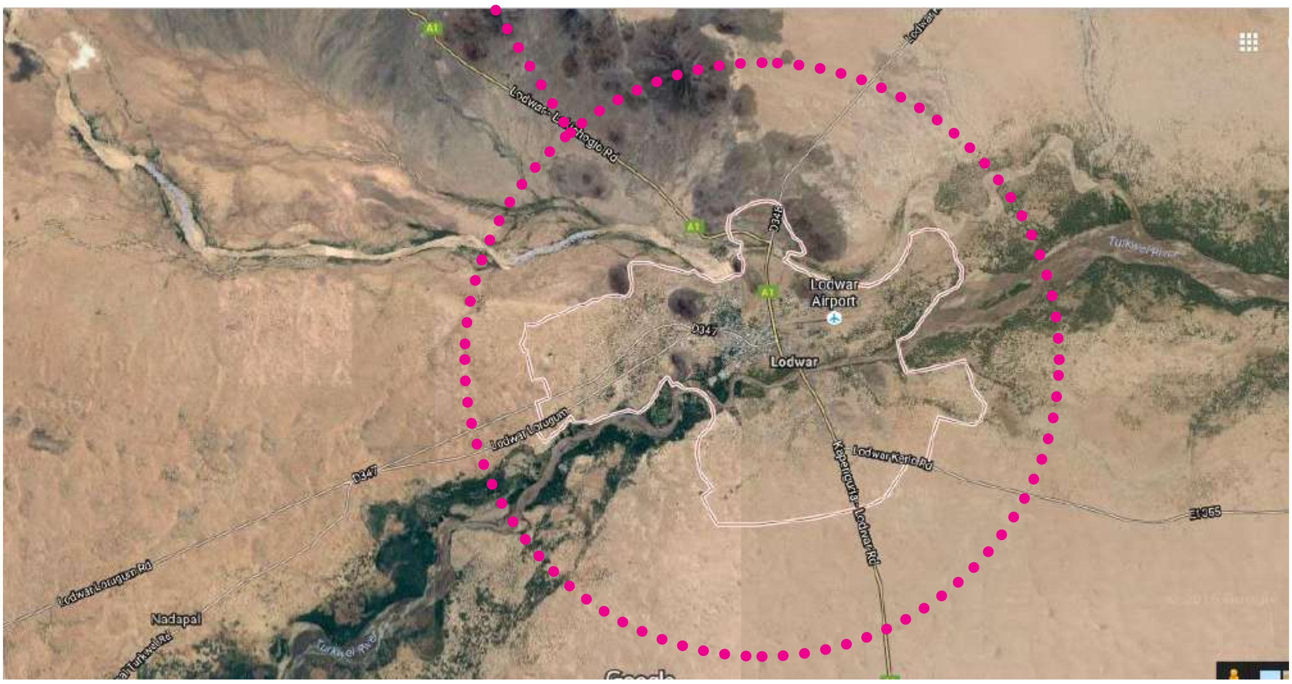
Source: *http://www.d-maps.com/*

Climatic Zone	HOT ARID
Latitude	03° 07’ N
Longitude	35° 36’ E
Altitude	477 m

FIGURE 93 **AERIAL VIEW OF LODWAR TOWN**

Source: *https://turkanamih.wordpress.com*

FIGURE 94 **LOCATION OF LODWAR TOWN IN TURKANA COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Lodwar town, located on the west of Lake Turkana, is the headquarters of Turkana county and is the largest town in the north-western Kenya. Its geographic location is 03° 07′ N, 35° 36′ E at an altitude of 477 m above sea level. Being in a hot arid climate, the town experiences high temperatures (annual mean of 29.7 °C) and little rainfall with an annual average of 231 mm. The hottest month recorded is March and the coolest month recorded is July. Relative humidity averages at 45% annually and can get to as low as 38% in February. Wind velocity ranges 3.1 – 4.9 m/s with the predominant wind direction being East and East North East (ENE). This town experiences intense solar radiation throughout the year with an annual average global solar radiation of 6.1 kWh/m^2.

TABLE 12 **LODWAR MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m^2 day]	Direct normal solar radiation [kWh/m^2 day]	Diffuse solar radiation [kWh/m^2 day]	Rainfall [mm]
JAN	29.5	41.0	3.7	6.2	5.3	2.5	11.6
FEB	30.3	38.0	3.6	6.5	5.2	2.7	9.2
MAR	30.6	43.0	4.9	6.3	4.3	2.9	27.8
APR	30.1	53.0	4.6	5.9	4.0	2.8	57.1
MAY	30.1	50.0	3.3	5.8	4.3	2.7	29.8
JUN	29.4	48.0	3.9	5.9	5.0	2.3	9
JUL	28.5	45.0	4.6	6.0	5.3	2.3	21.3
AUG	29.1	46.0	3.5	6.3	5.7	2.2	10
SEP	29.9	43.0	4.2	6.7	6.4	2.0	6.2
OCT	29.8	47.0	4.0	6.2	5.1	2.5	10.6
NOV	29.9	46.0	4.3	5.8	4.6	2.6	24.4
DEC	29.6	44.0	3.1	5.9	5.1	2.4	14.6

FIGURE 95 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR LODWAR**

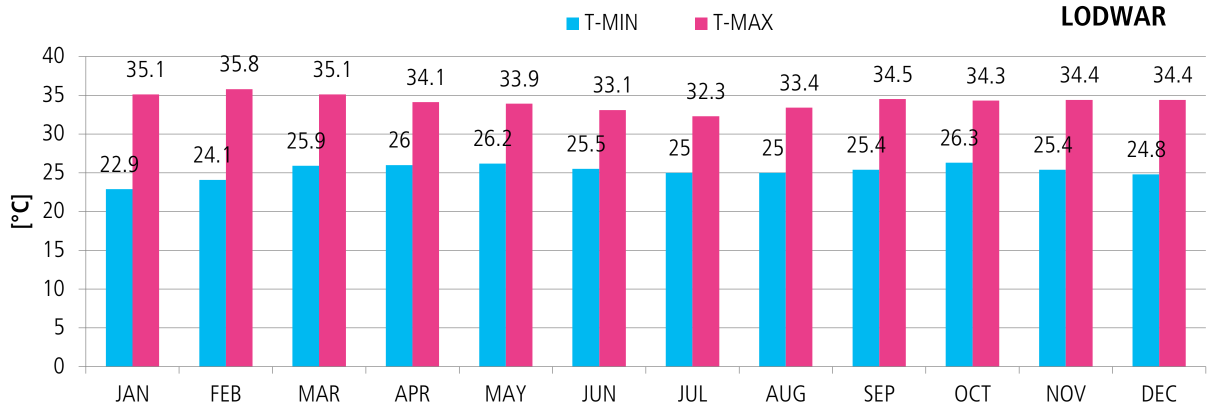


FIGURE 96 **MONTHLY MEAN RELATIVE HUMIDITY FOR LODWAR**

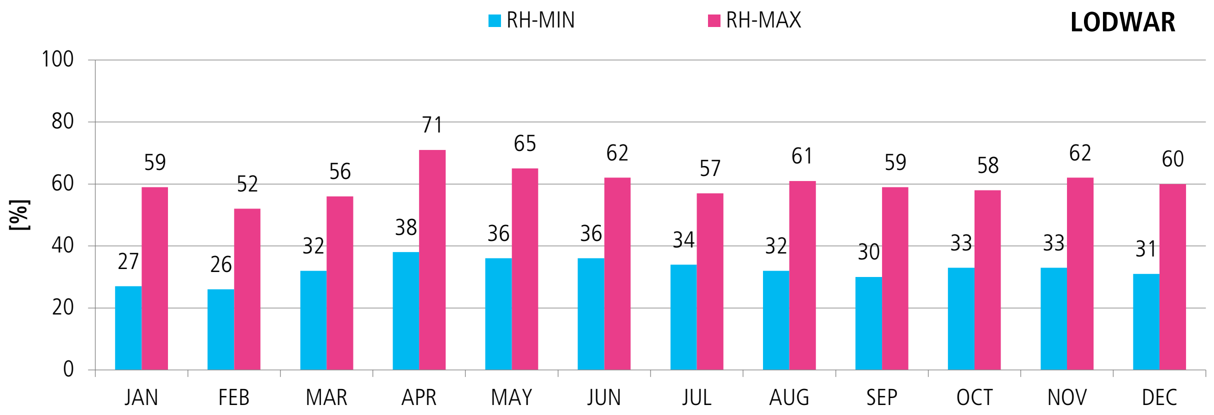


FIGURE 97 **MONTHLY AVERAGE RAINFALL FOR LODWAR**

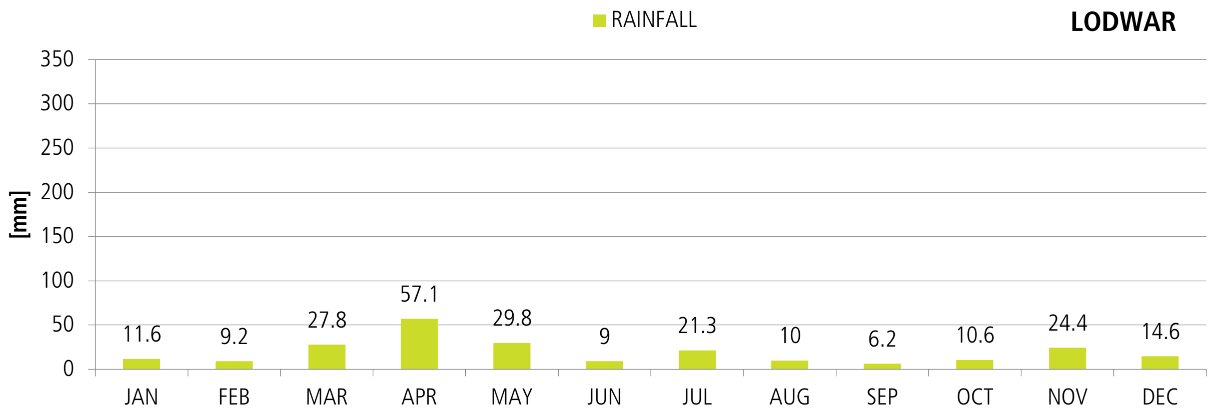


FIGURE 98 **POLAR SUN PATH DIAGRAM FOR LATITUDE 3° NORTH**

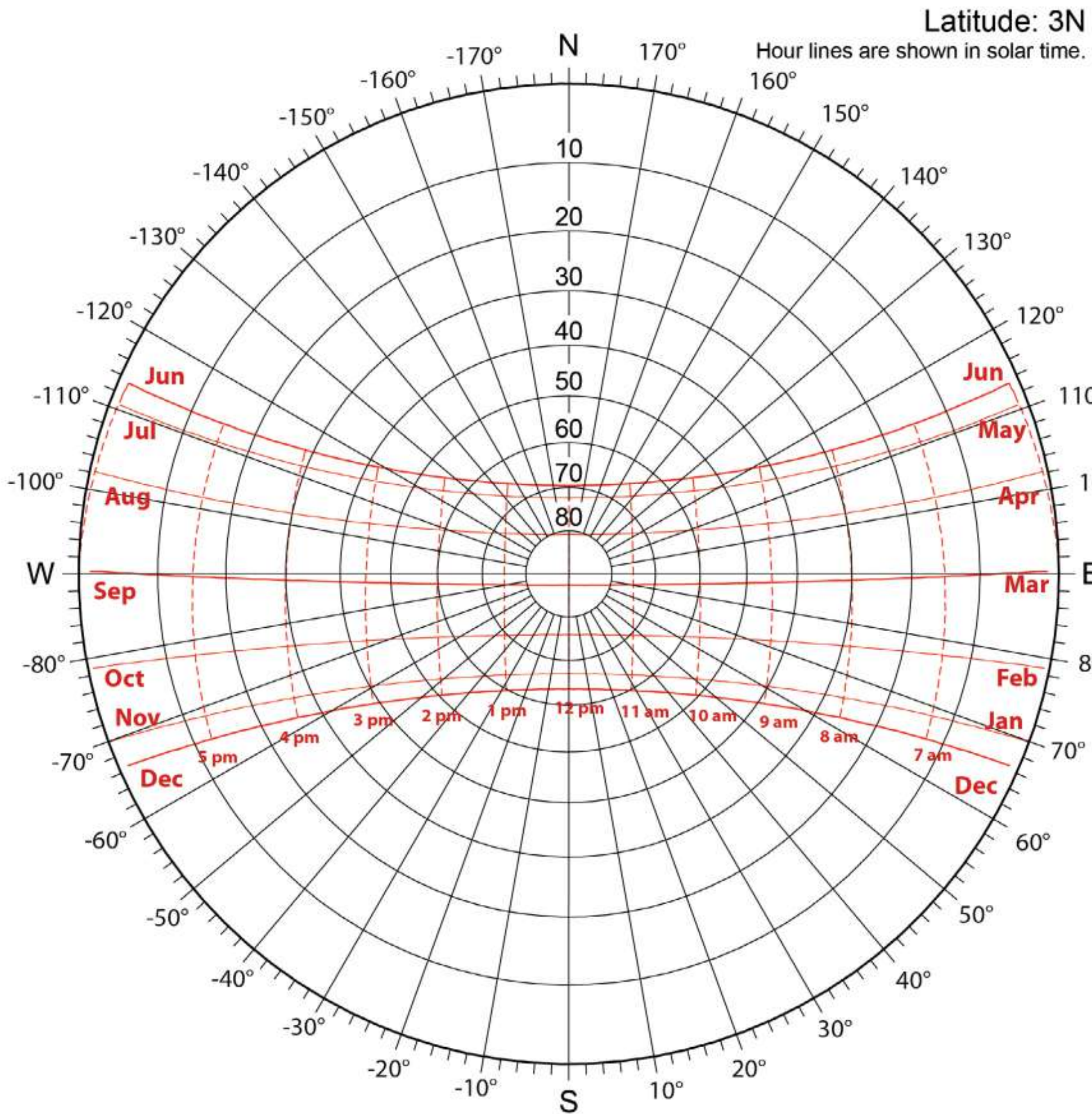


FIGURE 99 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN LODWAR**

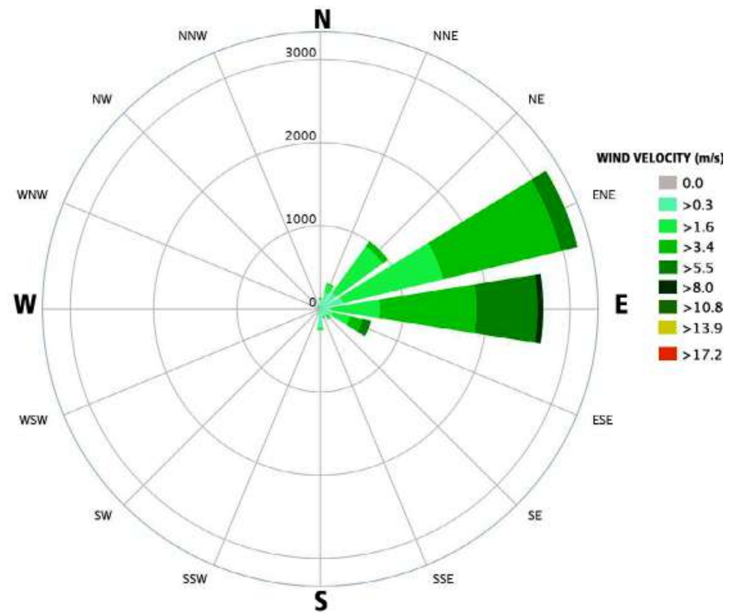
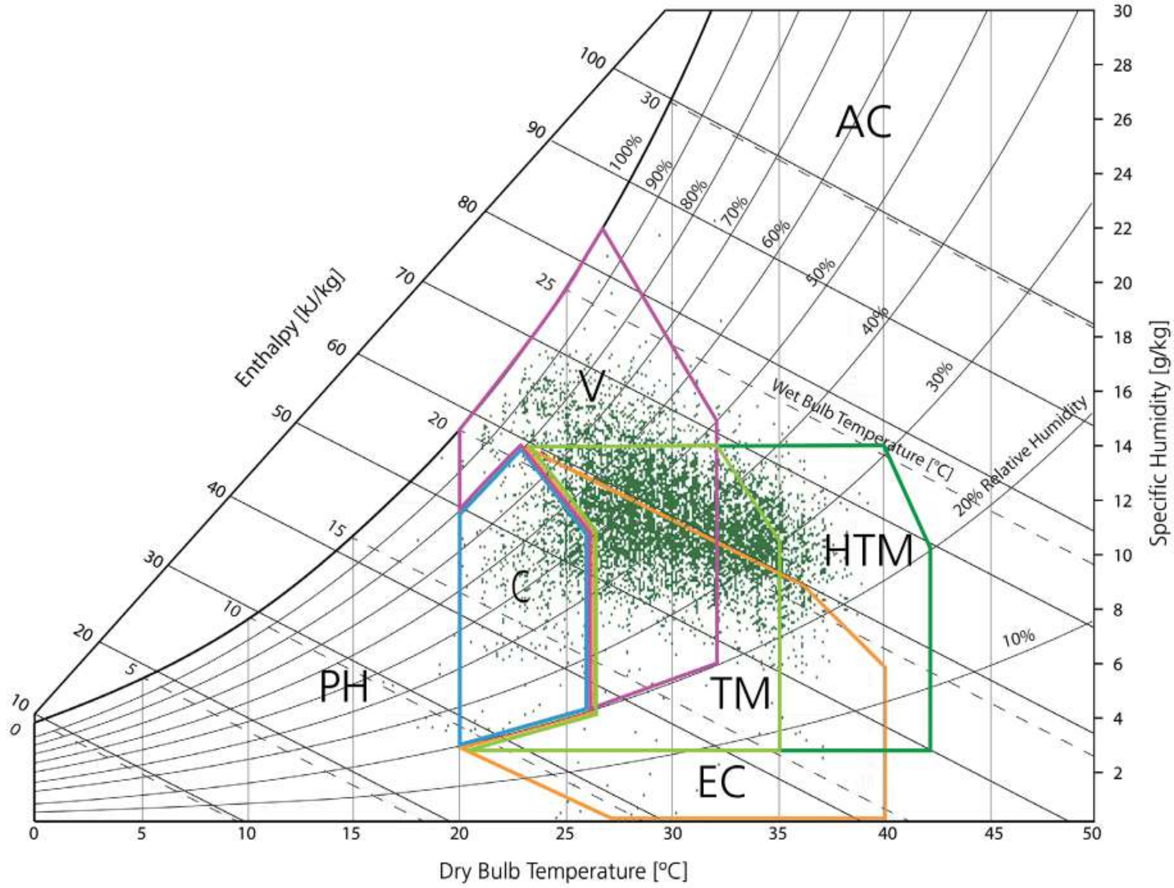


FIGURE 100 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR LODWAR**



C Comfort Zone	EC Evaporative Cooling
V Natural Ventilation	PH Passive Heating
TM Thermal Mass	AC Air Conditioning
HTM High Thermal Mass	

INTERPRETATION

Lodwar's climate is predominantly hot throughout the year with outside conditions (dry bulb temperature and relative humidity) beyond the comfort zone Therefore, cooling is very important and buildings need much more cooling and no heating at all. Based on the psychrometric chart (see Figure 100), the most appropriate cooling strategies to extend the limit of comfort include the following: shading, natural ventilation, high thermal mass with night ventilation (night flushing) and evaporative cooling.

BIOCLIMATIC RECOMMENDATIONS

The following passive design strategies may be used to address the cooling requirements of Lodwar's climate:

a. To reduce effects of intense solar radiation

- Compact layout of buildings is recommended to provide mutual shading and minimise exposure to solar radiation.
- Courtyard design of buildings minimises the impact of solar radiation on the outer walls as well as provide cool spaces within the buildings / building layout. This increases the daytime cooled spaces.
- Buildings should be oriented along the east – west axis with the longer sides facing north and south to prevent solar heat gains. The building's surface area exposed to the east and west should be minimised.
- Openings should be located on the north and south facing façades. Small openings that are located high on the walls are recommended to facilitate natural ventilation as well as reduce glare from light reflected from the ground or surrounding buildings.
- Appropriate shading devices are necessary on all openings to minimise heat gain from solar radiation. Use of vegetation, verandas, covered walkways, pergolas etc. is recommended to provide shade to walls, openings and outdoor spaces.
- Use of reflective surfaces (roof) and light-coloured walls are effective in reflecting solar radiation thus minimising solar heat gains and consequently minimising internal daytime temperatures.

b. To counter low relative humidity

- Evaporative cooling is recommended in this climate to improve the microclimate by elevating the humidity level while at the same time cooling the surrounding air. The following strategies are recommended: fountains, spray ponds, water surfaces, moistened fabrics, sprinklers or porous pots etc.
- Use of vegetation is effective in improving the air quality by reducing the air temperature as well as elevate the humidity level because of the evaporative cooling effect of plants.

c. To balance diurnal temperature range

- Heavy weight building materials with high thermal capacity are recommended to balance temperature variations between day and night. These heat storing materials keep daytime temperatures down.
- Due to the heat absorption qualities of the ground, earth-sheltered and underground housing are suited for this climate.

d. To ensure air circulation

- Openings should be located to take advantage of prevailing winds and allow for cross-ventilation.
- Ventilation through windows should be kept at a minimum during the daytime to keep hot and dusty air out. This also minimised heat gains. However, at night, windows may be opened to provide adequate ventilation for dissipation of heat accumulated during the day by walls and the roof to prevent overheating of the interior space.
- Other ventilation strategies include use of wind catchers, wind towers, solar chimneys, roof-mounted exhaust fans, high level vents etc.

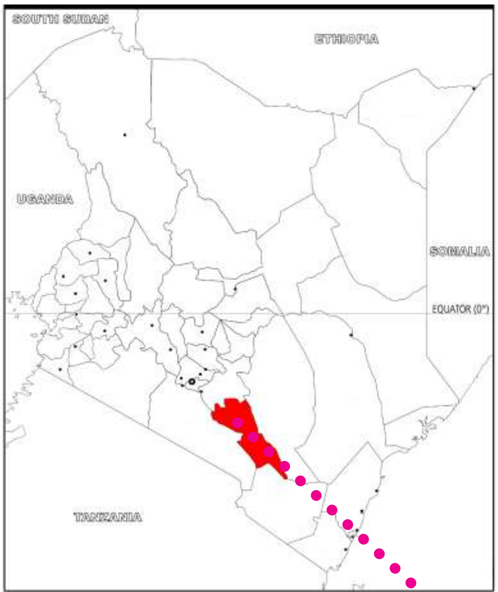
e. To minimise problems associated with dust

- Vegetation can be used to filter dust from the air before it gets into the building.
- Closing windows during daytime prevents dust from getting into the building on windy days. Windows should be tight-fitting as possible to prevent dust from infiltrating.

FIGURE 101 **TRADITIONAL HUT SHOWCASING USE OF NATURAL AND LOCAL MATERIALS. MAIN OPENING TO THE HUT IS ORIENTED AWAY FROM THE SUN.**

MAKINDU

FIGURE 102 **LOCATION OF MAKUENI COUNTY**



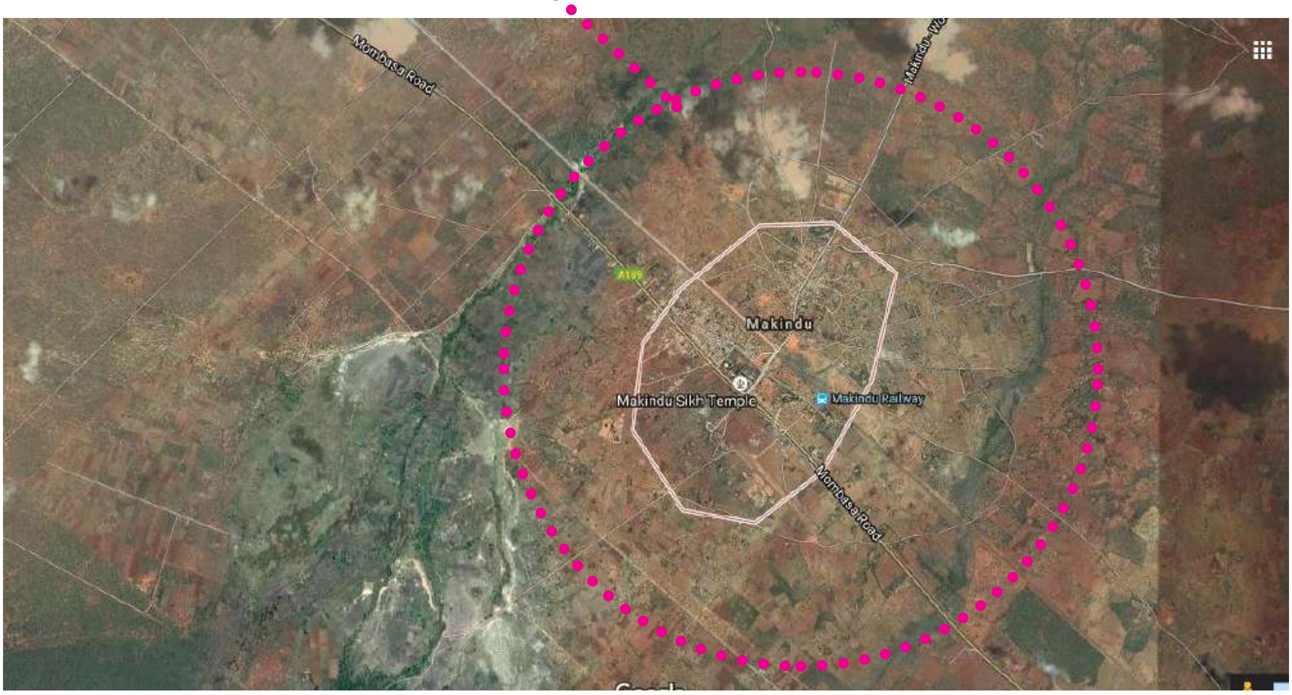
Source: *http://www.d-maps.com/*

Climatic Zone	HOT SEMI -ARID / SAVANNAH
Latitude	02° 16' 6
Longitude	37° 49' E
Altitude	1,070 m

FIGURE 103 **MAIN COMMERCIAL STREET IN MAKINDU TOWN**

© UN-Habitat / Jerusha NGUNGUI

FIGURE 104 **LOCATION OF MAKINDU TOWN IN MAKUENI COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Makindu is a town located in Makueni county at geographic coordinates of 02° 16′ S, 37° 49′ E. At an altitude of 1,070 m above sea level, the town has savannah climate with high temperatures (annual mean of 22.4 °C) and low amounts of rainfall (annual average of 690 mm). The warmest month on average is March while the coolest month on average is July. November is recorded as the month with the most amount of rainfall at an average of 170 mm. Relative humidity averages at 69.2% annually while the wind velocity averages at 2.6 m/s with the predominant wind direction being East South East (ESE) and South East. The annual average global solar radiation in Makindu is 5.5 kWh/m^2.

TABLE 13 **MAKINDU MONTHLY MEAN CLIMATIC DATA**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	22.4	77.0	2.2	5.8	4.3	2.8	40
FEB	23.9	63.0	2.5	6.0	4.5	2.7	30
MAR	24.9	67.0	2.9	6.0	4.4	2.7	80
APR	23.3	77.0	2.3	5.5	3.8	2.7	120
MAY	22.2	72.0	2.2	5.2	4.1	2.4	120
JUN	21.1	70.0	2.1	4.7	3.8	2.3	0
JUL	20.3	68.0	2.7	4.7	3.5	2.4	0
AUG	20.9	65.0	2.7	5.1	3.6	2.6	0
SEP	21.6	64.0	3.0	5.9	4.6	2.5	0
OCT	23.3	61.0	3.4	5.9	4.4	2.6	20
NOV	23.1	71.0	2.9	5.2	3.4	2.8	170
DEC	22.3	75.0	2.4	5.3	3.4	2.8	110

FIGURE 105 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR MAKINDU**

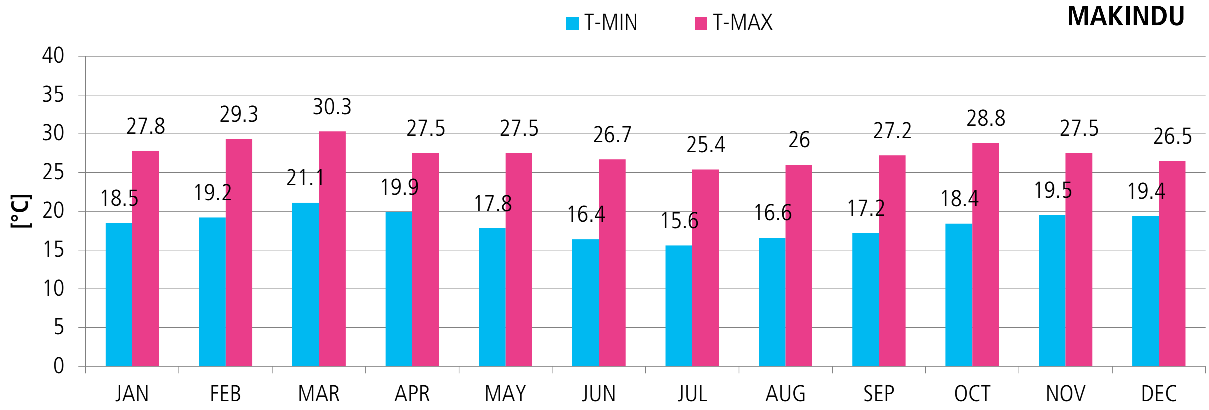


FIGURE 106 **MONTHLY MEAN RELATIVE HUMIDITY FOR MAKINDU**

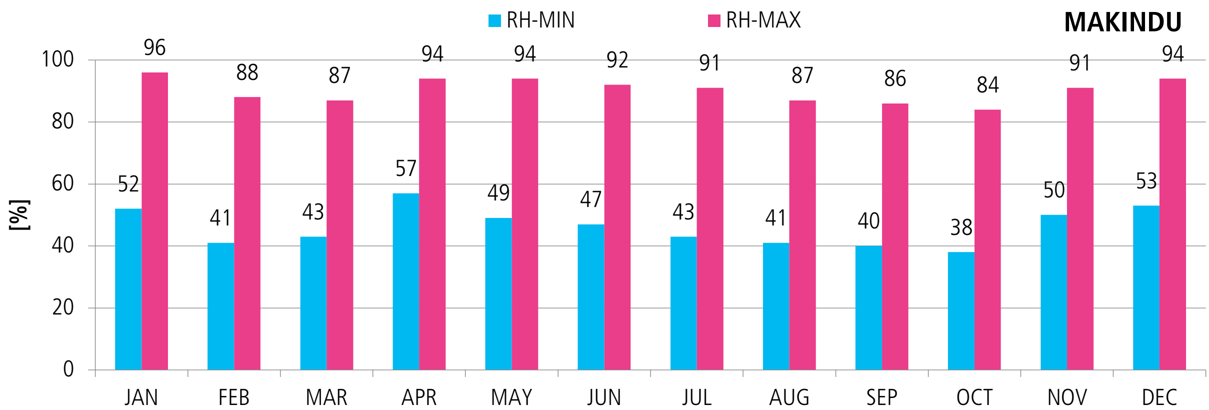


FIGURE 107 **MONTHLY AVERAGE RAINFALL FOR MAKINDU**

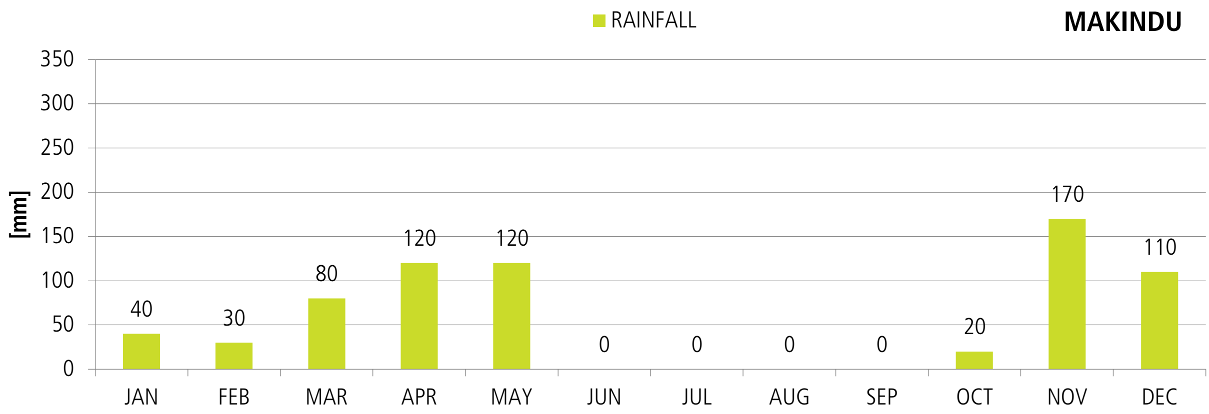


FIGURE 108 **POLAR SUN PATH DIAGRAM FOR LATITUDE 2° SOUTH**

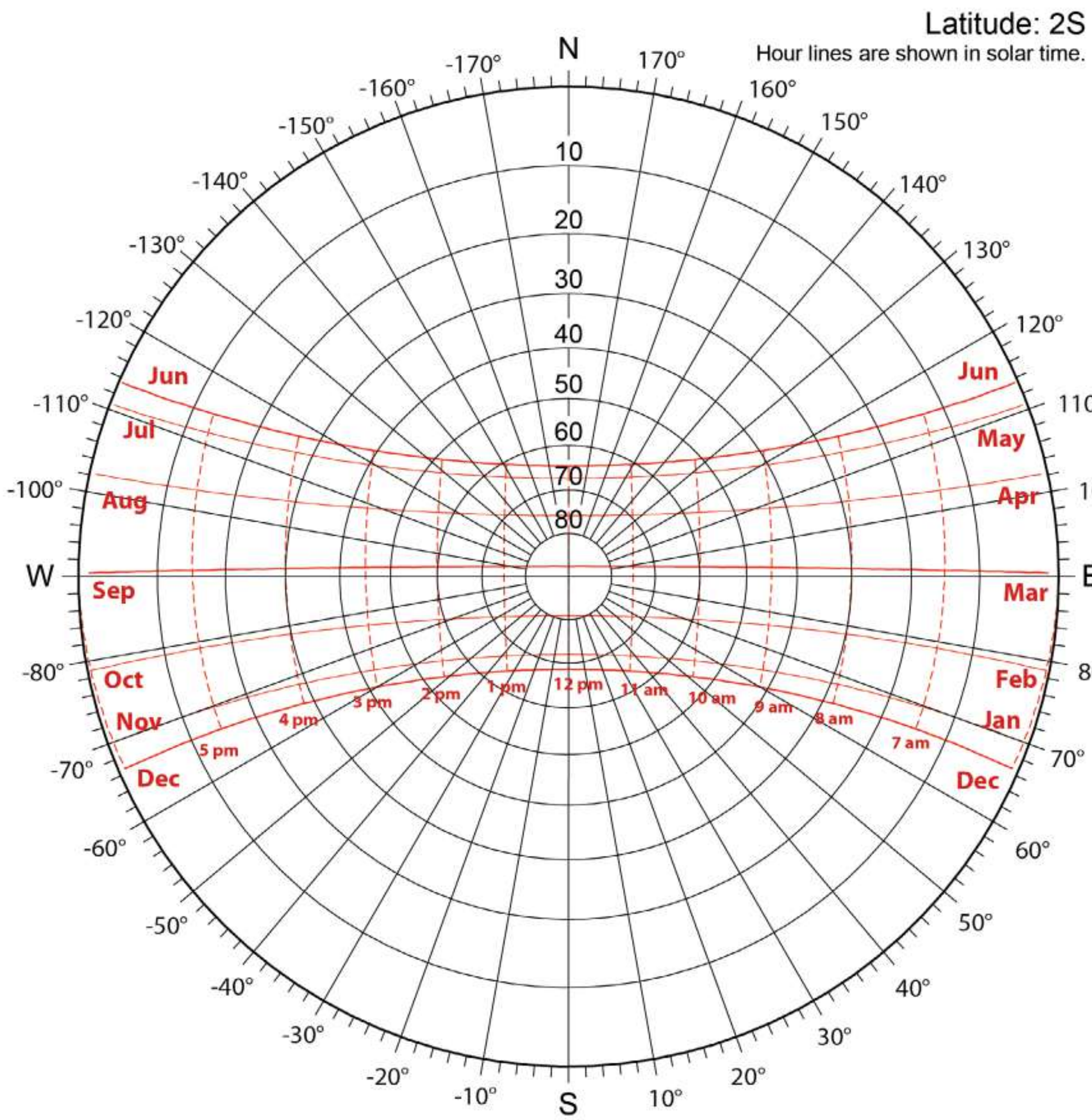


FIGURE 109 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN MAKINDU**

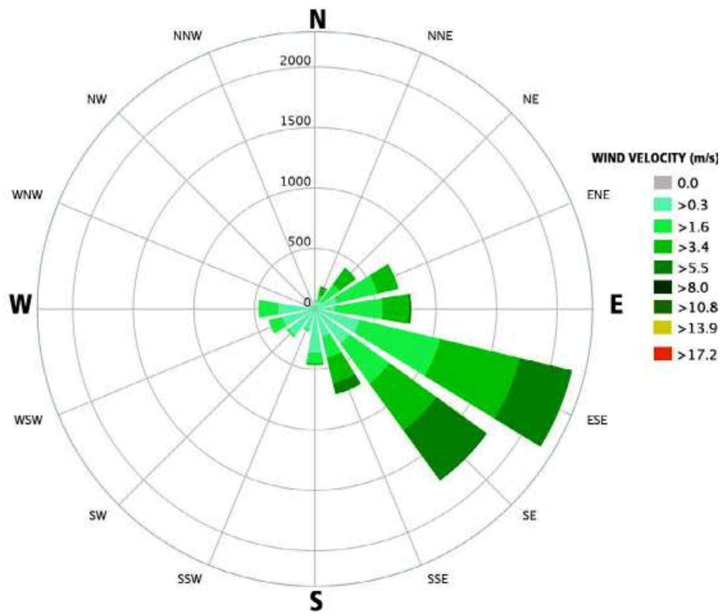
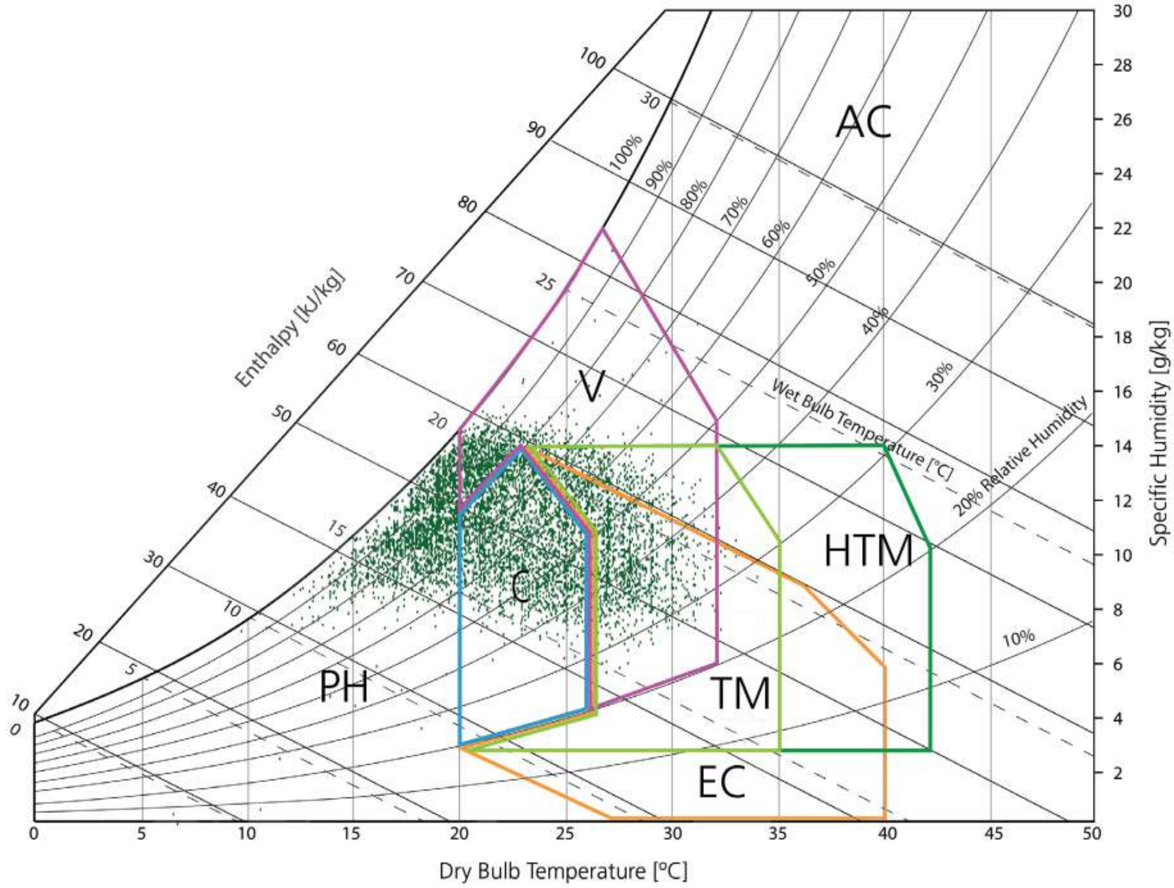


FIGURE 110 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR MAKINDU**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

Makindu experiences both hot and cold conditions that fall above and below the comfort zone respectively as seen in Figure 110. Based on the psychrometric chart, a combined effect of natural ventilation and thermal mass (along with night ventilation) are the most effective strategies to improve thermal comfort during the overheated period. In the case of the under heated period, passive heating through direct solar heat gain and thermal mass are effective in expanding the comfort zone when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

In Makindu, the design objective should be to balance the conflicting needs of the cold and hot periods to provide comfort. The following design strategies are recommended:

a. To reduce effects of intense solar radiation

- Compact layout of buildings is recommended to provide mutual shading and minimise exposure to solar radiation.
- Courtyard design of buildings minimises the impact of solar radiation on the outer walls as well as provide cool spaces with the buildings / building layout.
- Buildings should be oriented along the east – west axis with the longer sides facing north and south to prevent solar heat gains. The building's surface area exposed to the east and west should be minimised.
- Openings should be located on the north and south. Small openings that are located high on the walls are recommended to facilitate natural ventilation as well as reduce glare from light reflected from the ground or surrounding buildings.
- Appropriate shading devices are necessary on all openings to decrease heat gain from solar radiation. Use of vegetation, verandas, covered walkways, pergolas etc. is recommended to provide shade to walls, openings and outdoor spaces (Figure 111).
- Use of reflective surfaces (roof) and light coloured external walls are effective in reflecting solar radiation thus minimising solar heat gains and consequently minimising internal daytime temperatures.

b. To balance diurnal temperature range

- Medium weight building materials with high thermal capacity are recommended to balance temperature variations between day and night. These materials absorb heat during daytime keeping indoor temperatures lower than outdoor temperatures. The stored heat is later dissipated at night thereby providing indoor thermal comfort when the outdoor temperatures fall below the comfort zone.

c. To ensure air circulation

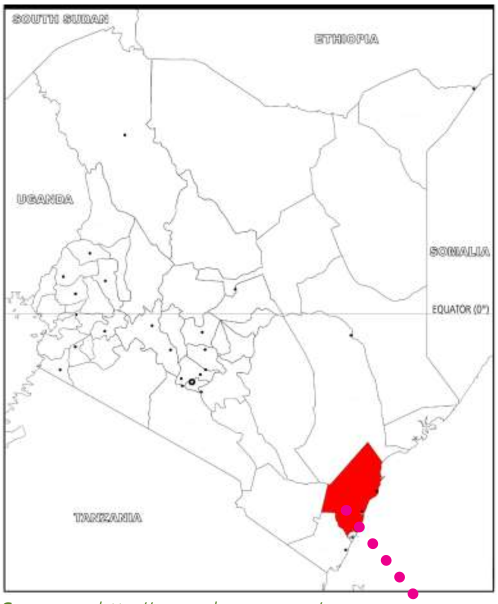
- Openings should be located to take advantage of prevailing winds and allow for cross-ventilation.
- Ventilation through windows should be kept at a minimum during the daytime to keep hot and dusty air out. However, at night, windows may be opened to provide adequate ventilation for dissipation of heat accumulated during the day by walls and the roof to prevent overheating of the interior space.
- Other ventilation strategies include use of wind catchers, wind towers, solar chimneys, roof-mounted exhaust fans etc.

FIGURE 111 **EXTENSIVE HORIZONTAL OVERHANGS PROVIDE SHADE TO THE WALLS AND OPENINGS BELOW THEM THUS MINIMISING HEAT GAIN. LANDSCAPING ALSO PROVIDES COOL SHADED OUTDOOR SPACES.**

Makindu Sikh Temple © Carmen MOLINA

MALINDI

FIGURE 112 **LOCATION OF KILIFI COUNTY**



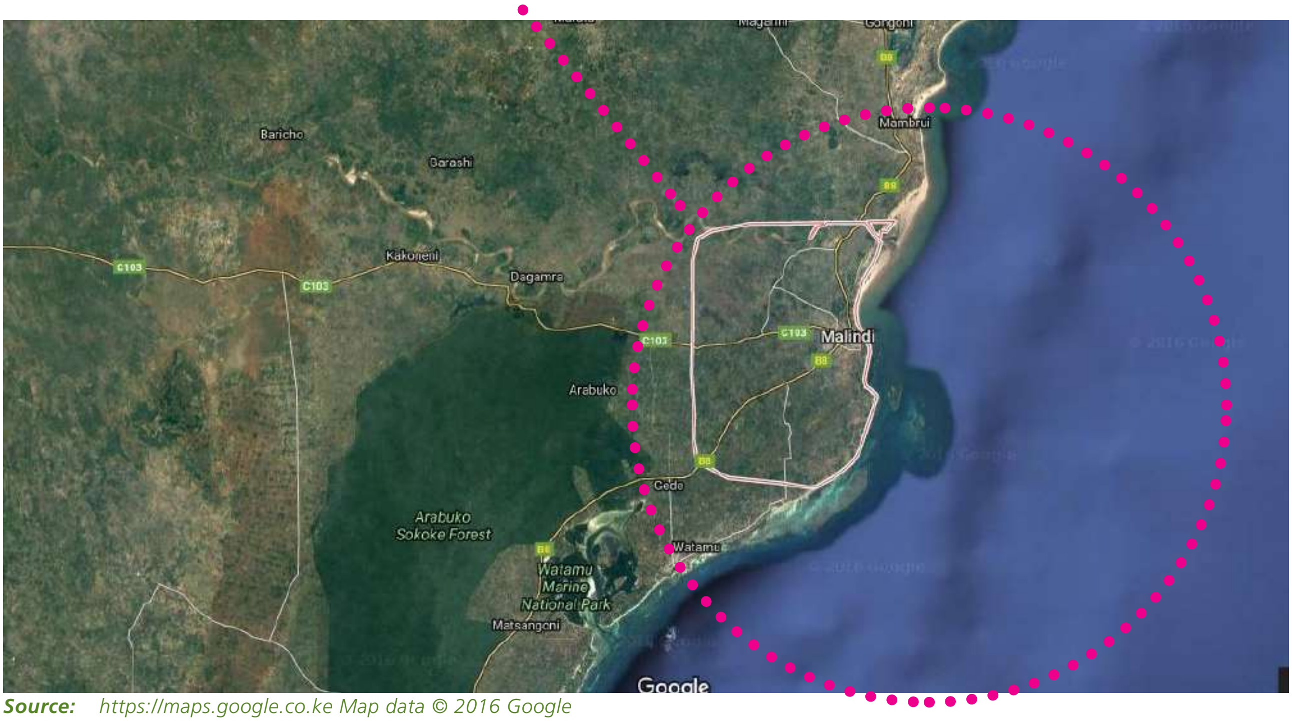
Source: *http://www.d-maps.com/*

Climatic Zone	HOT AND HUMID
Latitude	03° 13’ S
Longitude	40° 07’ E
Altitude	23 m

FIGURE 113 **VIEW OF MALINDI TOWN**

Source: *http://www.thegoldenscope.com/2014/04/malindi-where-to-go-for-an-authentic-experience/*

FIGURE 114 **LOCATION OF MALINDI TOWN IN KILIFI COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Malindi town, situated along the Indian Ocean coast of Kenya, is the largest urban centre in Kilifi county and is located at geographic coordinates of 03° 13′ S, 40° 7′ E and is elevated at 23 m above sea level. It enjoys a hot and humid climate with high temperatures throughout the year (average of 26.4 °C) as well as high relative humidity (annual mean of 78.4%). The average amount of rainfall recorded annually is 578 mm with the highest recorded amount in April and the least amount in August. High wind velocity is recorded annually at an average of 4.6 m/s with the predominant wind direction being East (December to March) and South (April to November). The annual average global solar radiation in Malindi is 5.5 kWh/m^2.

TABLE 14 **MALINDI MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m^2 day]	Direct normal solar radiation [kWh/m^2 day]	Diffuse solar radiation [kWh/m^2 day]	Rainfall [mm]
JAN	27.4	77.0	4.2	6.1	4.5	2.8	29
FEB	27.6	75.0	5.6	6.3	4.8	2.7	14
MAR	28.1	76.0	4.3	6.2	4.3	2.8	68
APR	27.3	81.0	3.5	5.3	3.5	2.7	126
MAY	25.9	82.0	4.5	4.5	2.8	2.5	25
JUN	25.4	79.0	5.4	4.6	3.2	2.4	10
JUL	24.6	79.0	6.0	4.6	3.2	2.4	12
AUG	24.8	77.0	5.2	5.1	3.6	2.5	9
SEP	25.0	78.0	4.4	5.7	3.9	2.7	29
OCT	26.0	78.0	3.9	6.0	4.3	2.7	66
NOV	27.0	81.0	3.7	5.8	4.3	2.6	86
DEC	27.4	78.0	4.0	5.7	4.2	2.6	104

FIGURE 115 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR MALINDI**

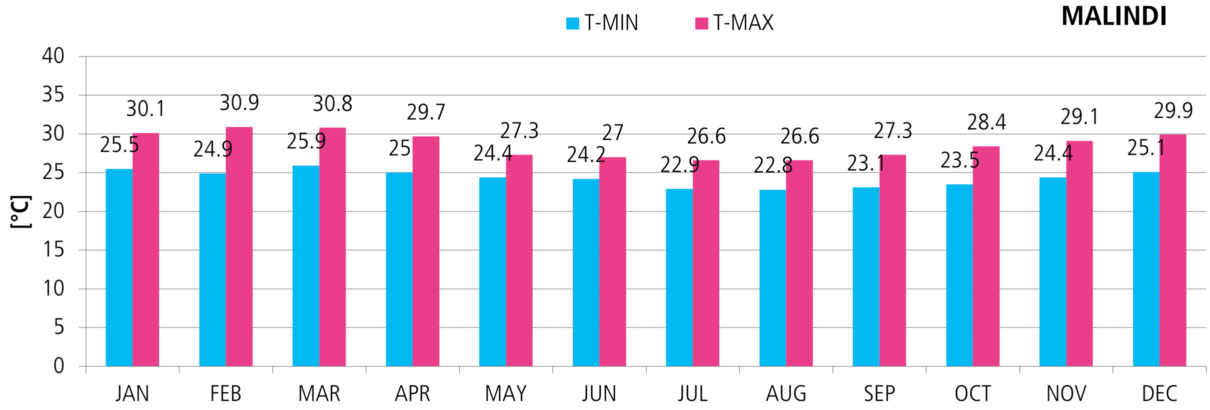


FIGURE 116 **MONTHLY MEAN RELATIVE HUMIDITY FOR MALINDI**

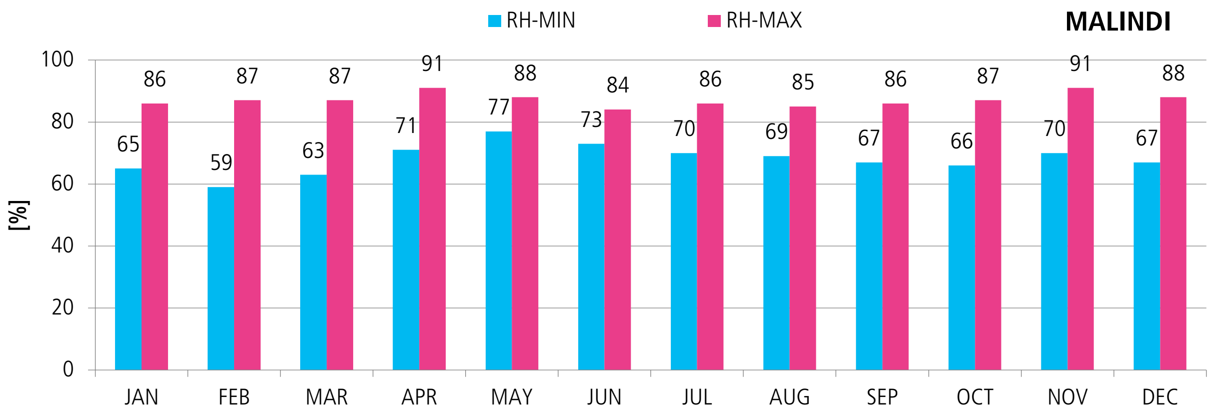


FIGURE 117 **MONTHLY AVERAGE RAINFALL FOR MALINDI**

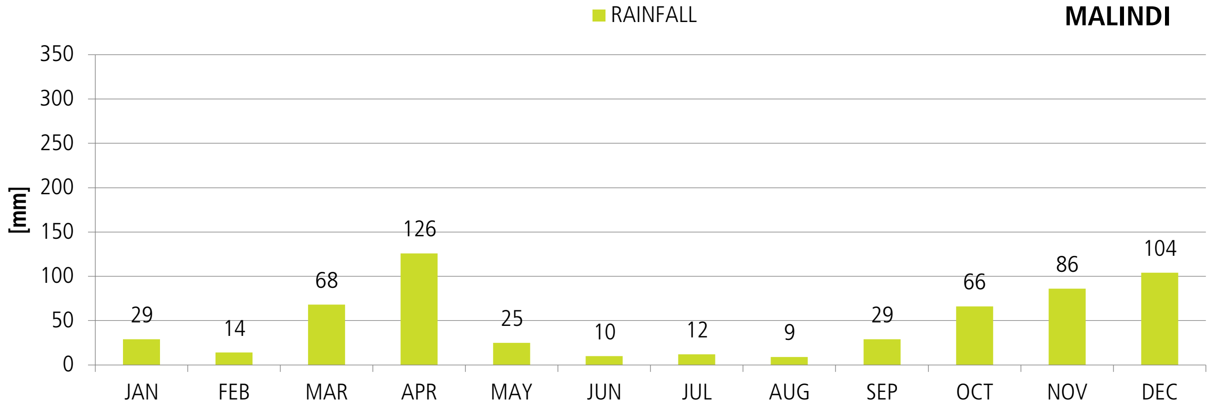


FIGURE 118 **POLAR SUN PATH DIAGRAM FOR LATITUDE 3° SOUTH**

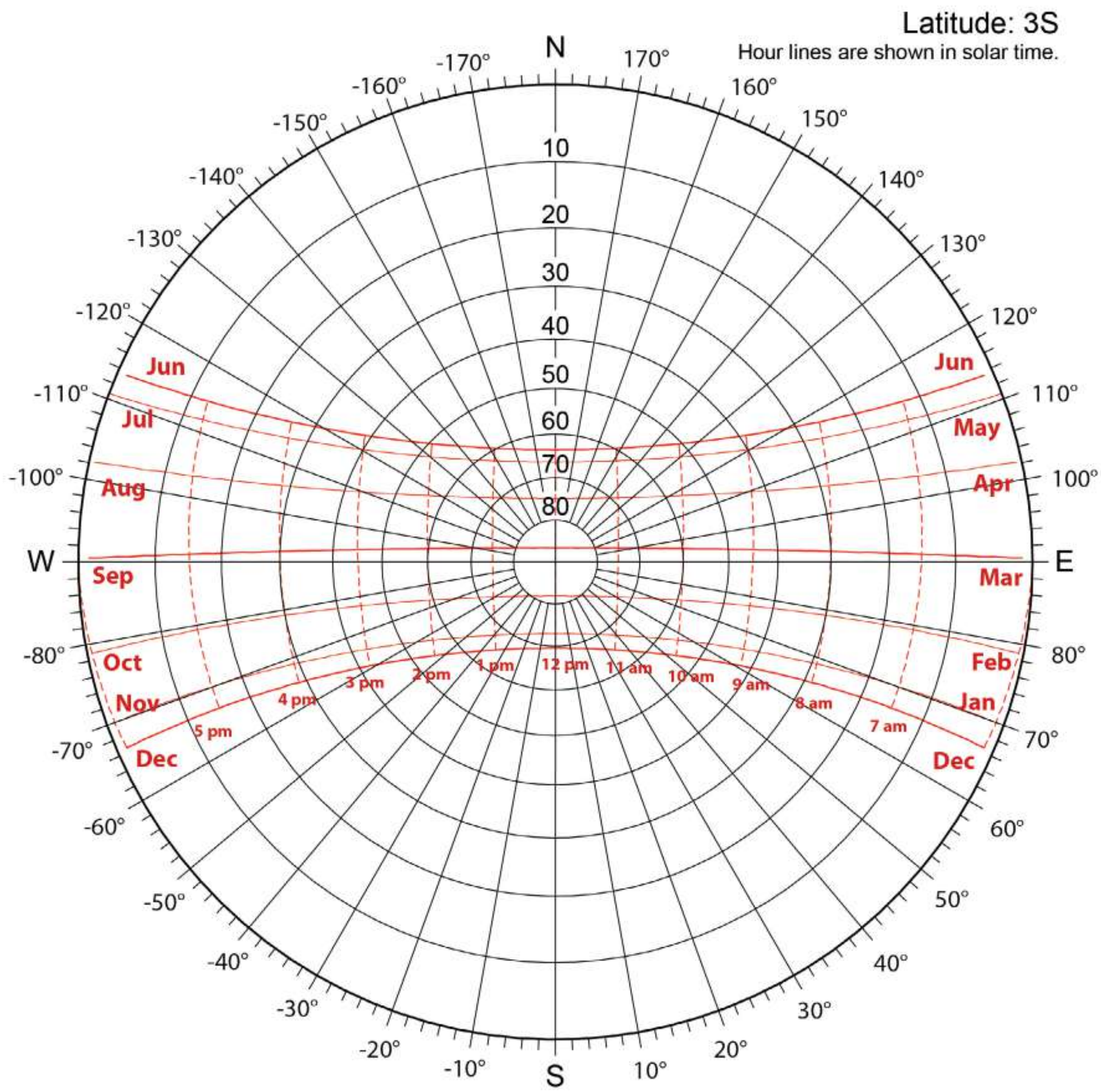


FIGURE 119 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN MALINDI**

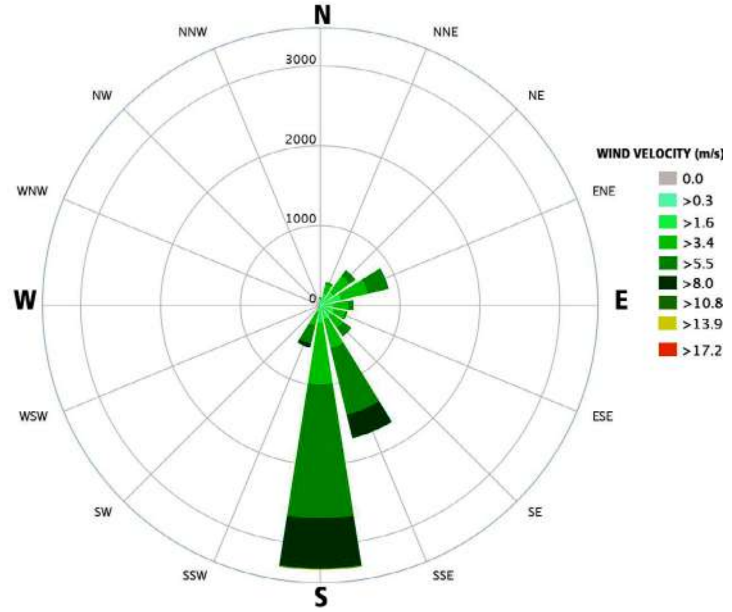
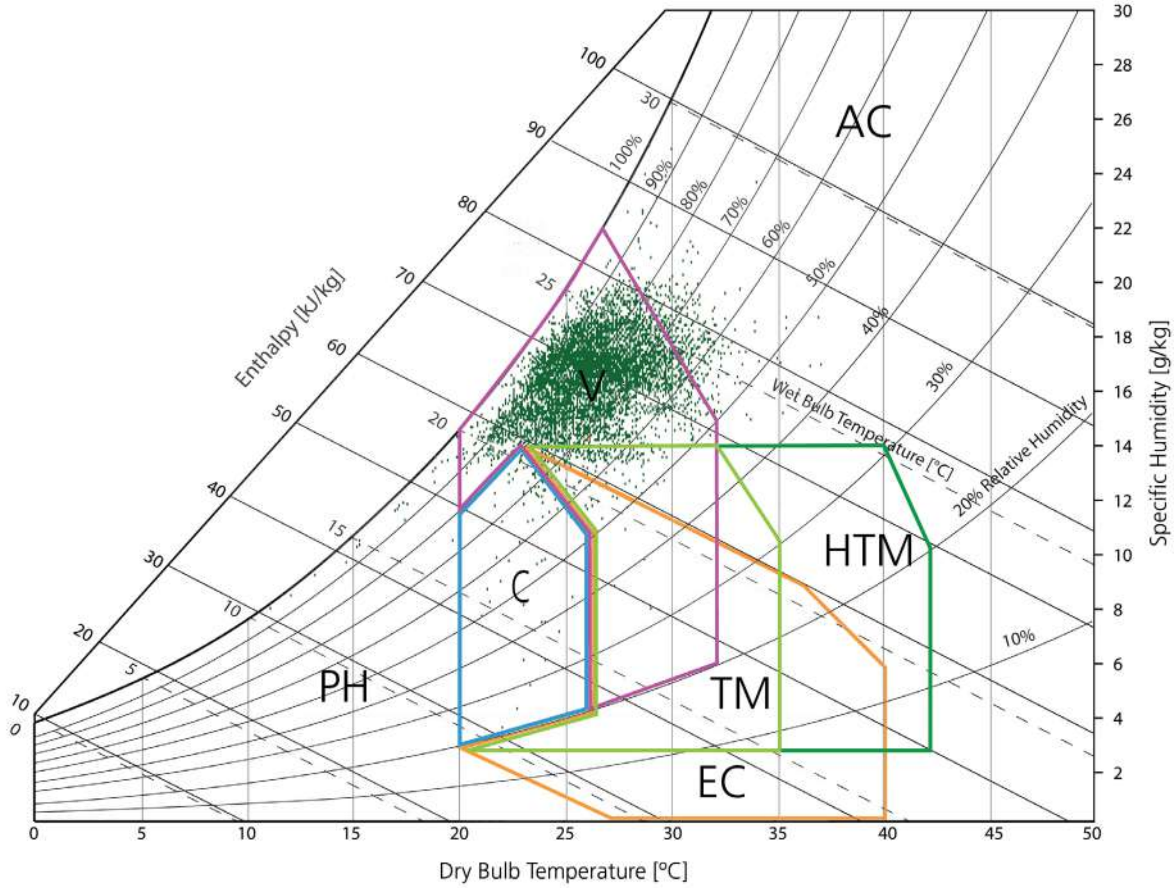


FIGURE 120 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR MALINDI**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

Figure 120 shows that Malindi lies outside the comfort zone throughout the year. The resulting combination of high hourly outdoor dry bulb temperatures and relative humidity causes discomfort. To improve thermal comfort, natural ventilation is the most appropriate strategy to adopt.

However, at certain times of the year, temperature go above the natural ventilation zone and mechanical cooling may be necessary to provide thermal comfort.

BIOCLIMATIC RECOMMENDATIONS

The design objectives and responses for a hot and humid climate like Malindi's should be to address issues due to high temperatures, high relative humidity and high solar radiation levels. The following passive design strategies may be used to address the cooling requirements that result from the above climatic characteristics:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading.
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, covered verandas and porches etc. (Figure 121).
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and reduce heat gains (Figure 122).
- Lightweight building materials with low thermal capacity are recommended for walls, floors and roofs to allow rapid cooling at night.

b. To promote maximum ventilation

- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings.
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum ventilation.
- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.

FIGURE 121 **VERANDAS AND PORCHES ARE A VERY EFFECTIVE MEANS OF PROVIDING SHADE. VEGETATION ABSORBS SOLAR RADIATION AND NOT REFLECT IT INTO THE BUILDING.**

Source: *http://azizirealtors.co.ke/property/mijikenda-villas-malindi/*

- Openings should be located on opposite sides of walls to allow for proper cross-ventilations. Internal walls should also have openings for airflow through the internal space.

- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement.

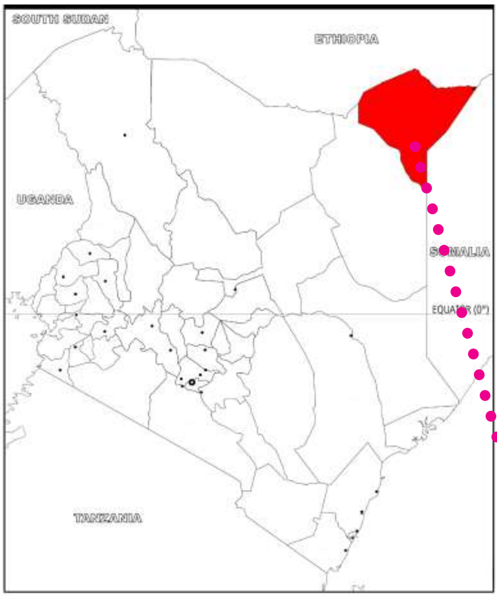
- Ventilated double roofs enhance ventilation of the roof minimising overheating.

FIGURE 122 **LIGHTLY COLOURED EXTERNAL SURFACES REFLECT UNWANTED SOLAR RADIATION HENCE MINIMISING HEAT GAIN**

Neem House, Malindi © http://www.neemhousekenya.com/

MANDERA

FIGURE 123 **LOCATION OF MANDERA COUNTY**



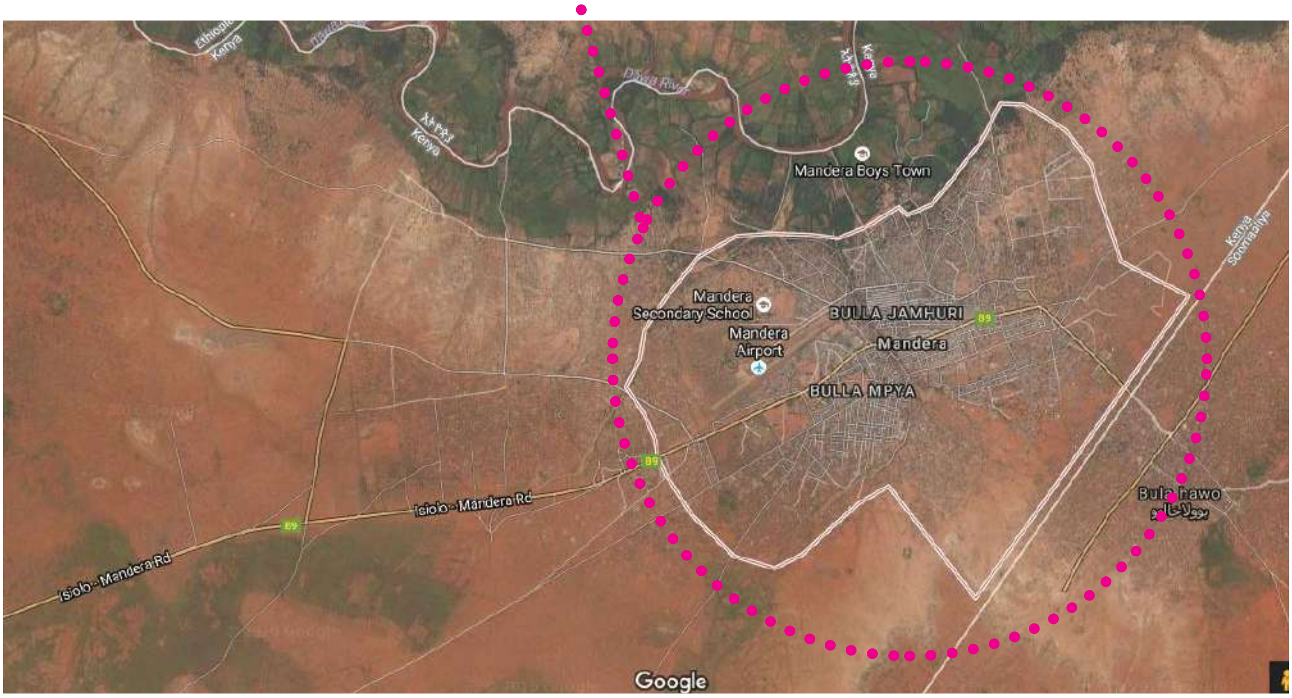
Source: *http://www.d-maps.com/*

Climatic Zone	HOT ARID
Latitude	03° 55' N
Longitude	41° 50' E
Altitude	231 m

FIGURE 124 **AERIAL VIEW OF MANDERA TOWN**

Source: *http://www.skyscrapercity.com/showthread.php?p=131709869*

FIGURE 125 **LOCATION OF MANDERA TOWN IN MANDERA COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Mandera which is the headquarters of Mandera county, is located at geographic coordinates of 03° 55′ N, 41° 50′ E at an altitude of 231 m above sea level. Its climate is categorized as hot arid with temperatures tending to be high throughout the year with an annual average of 29.5 °C. The hottest month is recorded as March and the coolest month recorded as July. Rainfall is extremely low with an annual average of 273 mm with the highest amount received in April. Low relative humidity is experienced with an annual average of 51% while the wind velocity averages ranges at 2.9 – 6.7 m/s with the predominant wind direction being South. The annual average global solar radiation in Mandera is 5.6 kWh/m².

TABLE 15 **MALINDI MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	30.4	45.0	3.4	6.4	6.5	2.0	1.4
FEB	30.9	38.0	4.9	6.8	6.8	2.0	5
MAR	31.5	46.0	4.1	6.4	5.1	2.6	17.7
APR	29.8	63.0	3.8	5.4	3.1	3.0	95.5
MAY	29.6	58.0	4.3	5.2	2.9	3.1	40.7
JUN	28.6	53.0	5.6	5.0	2.9	3.0	0.9
JUL	27.9	50.0	6.7	5.0	2.6	3.1	1.5
AUG	28.3	48.0	6.5	5.5	3.2	3.0	0.5
SEP	29.4	48.0	5.5	5.8	3.8	2.9	1.9
OCT	29.7	52.0	3.6	5.4	3.3	2.9	46.2
NOV	28.2	59.0	2.9	5.0	3.3	2.7	52
DEC	29.6	51.0	3.3	5.7	5.2	2.2	9.9

FIGURE 126 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR MANDERA**

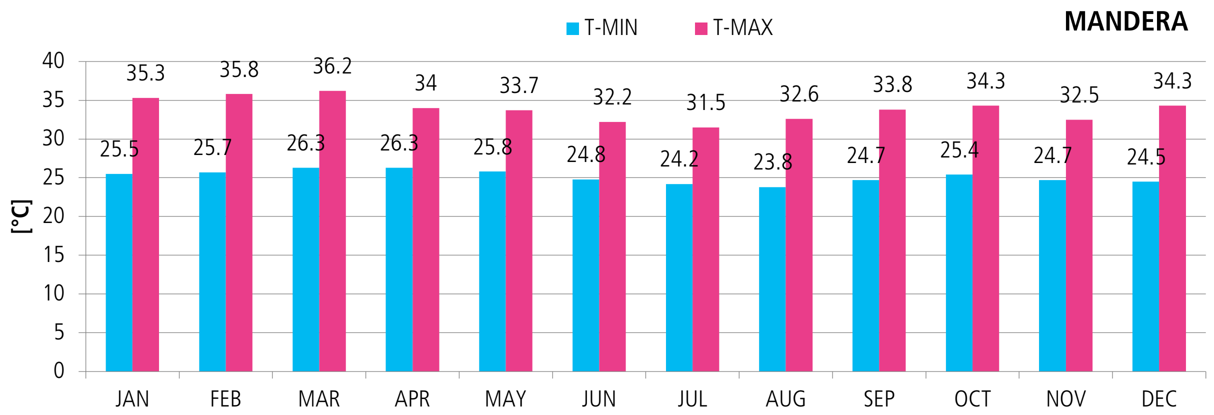


FIGURE 127 **MONTHLY MEAN RELATIVE HUMIDITY FOR MANDERA**

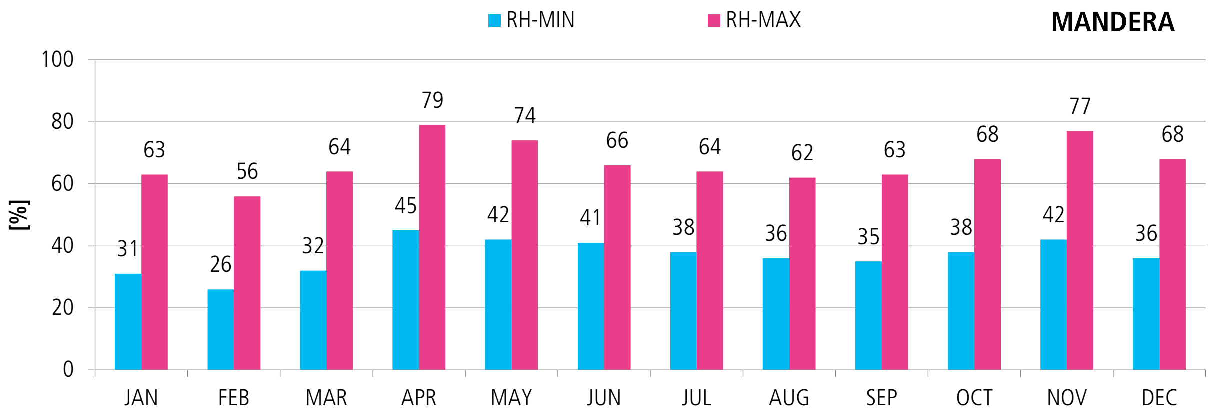


FIGURE 128 **MONTHLY AVERAGE RAINFALL FOR MANDERA**

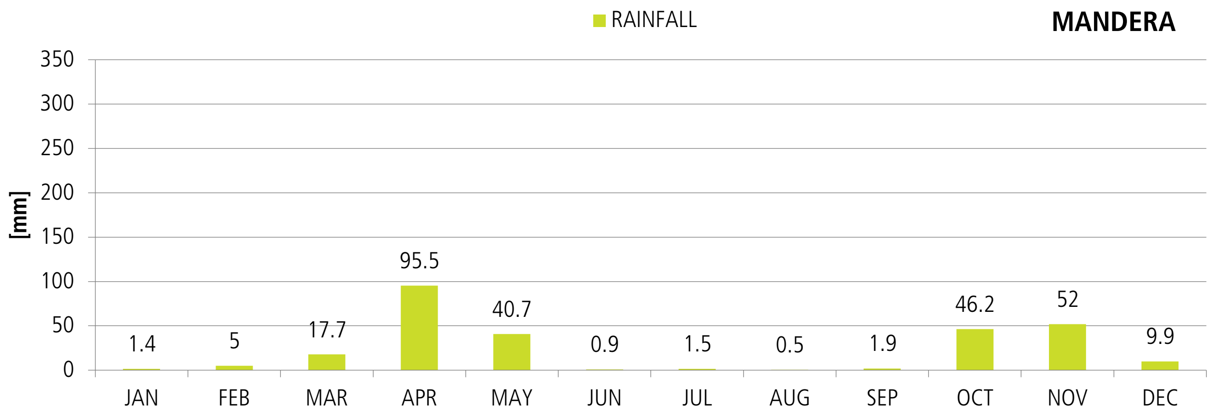


FIGURE 129 **POLAR SUN PATH DIAGRAM FOR LATITUDE 3° NORTH**

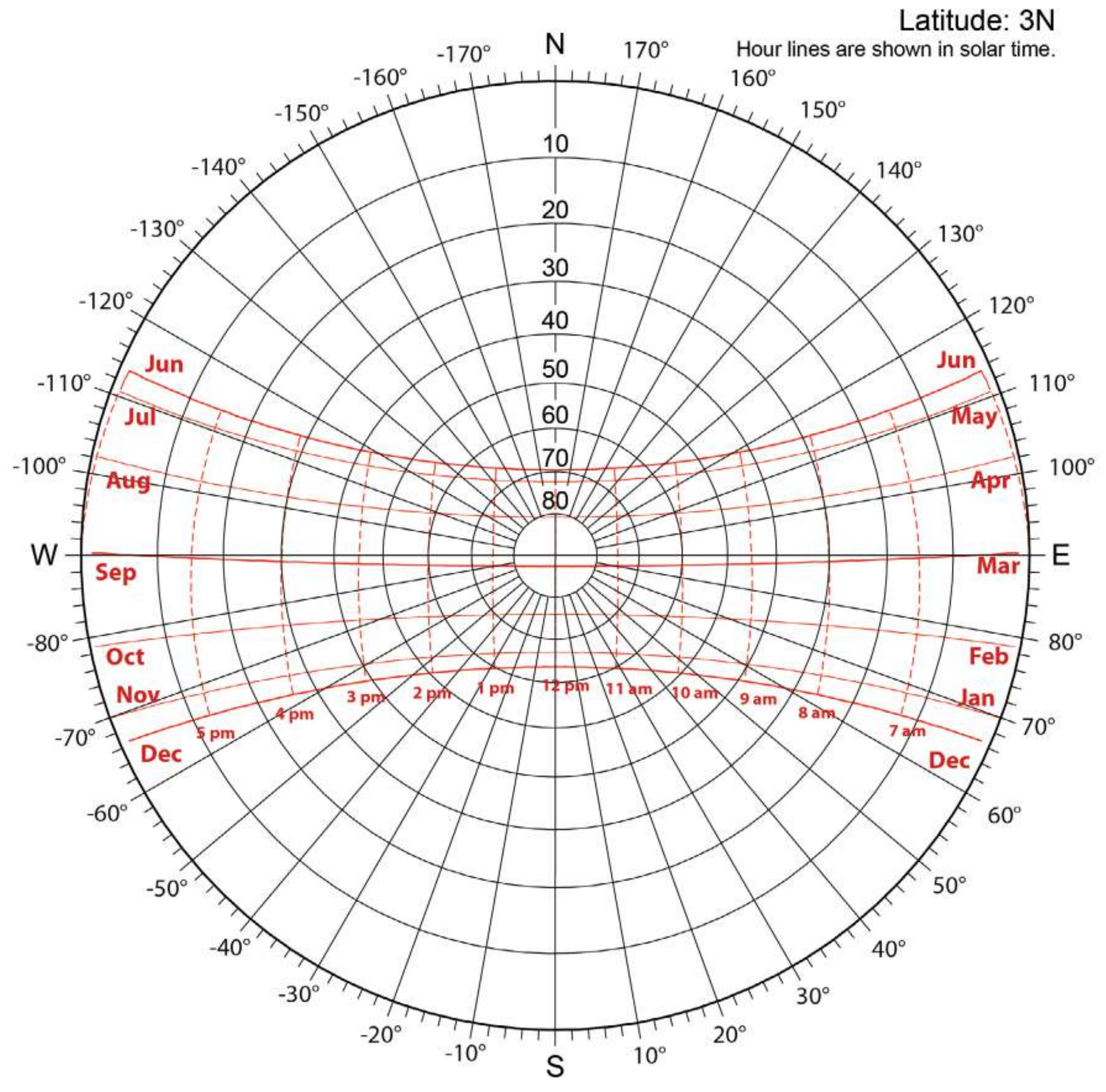


FIGURE 130 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN MANDERA**

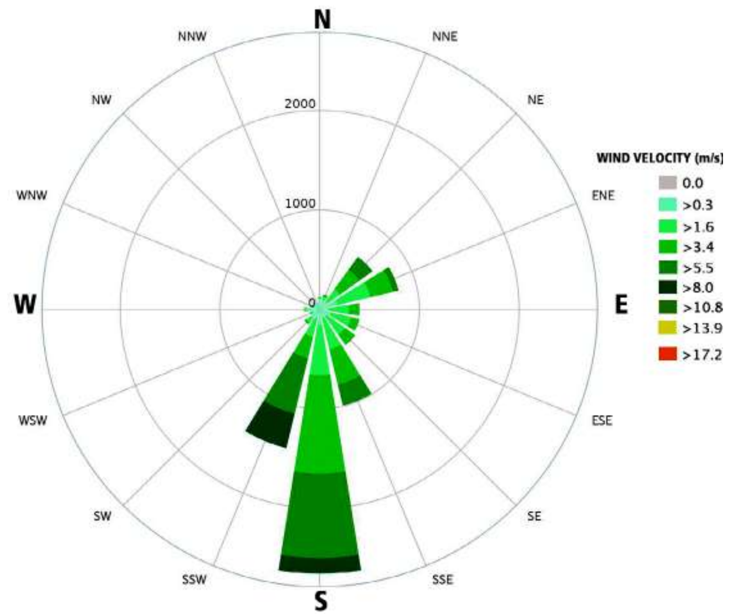
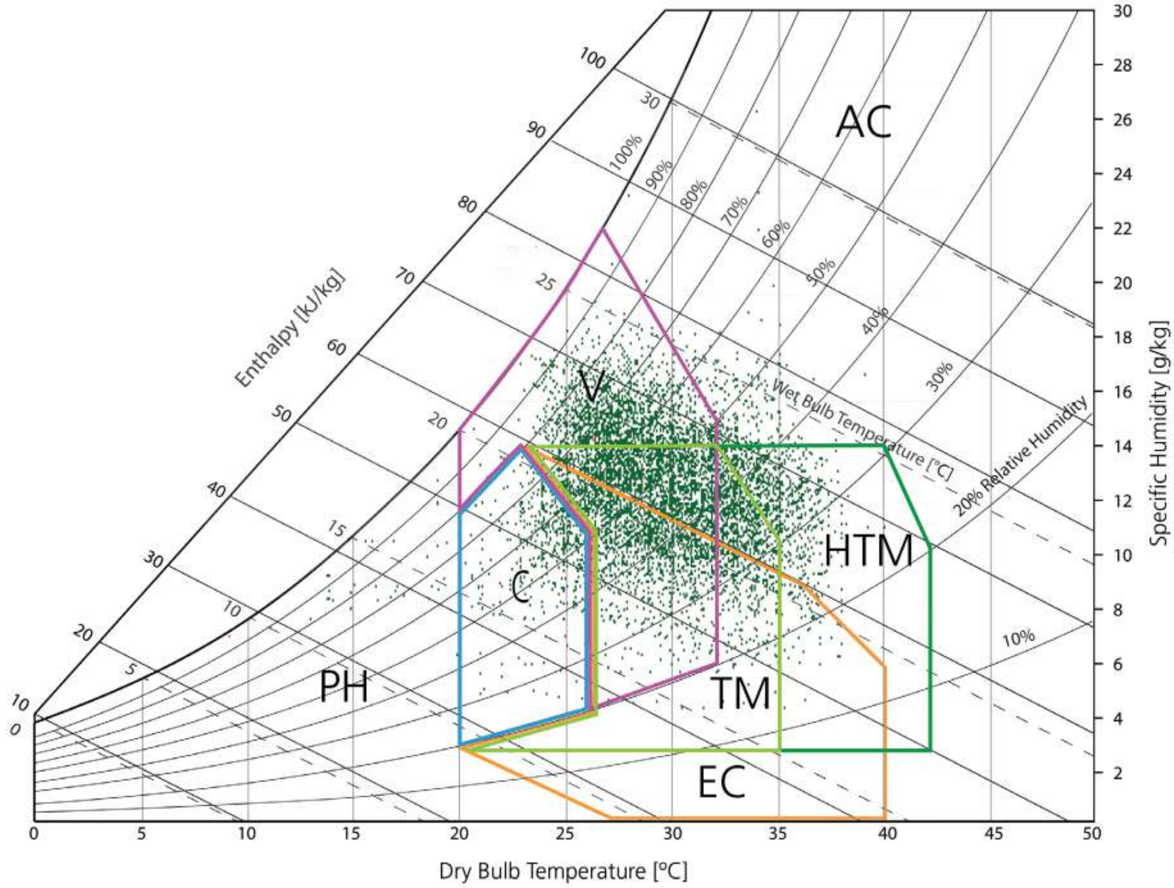


FIGURE 131 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR MANDERA**



C Comfort Zone	EC Evaporative Cooling
V Natural Ventilation	PH Passive Heating
TM Thermal Mass	AC Air Conditioning
HTM High Thermal Mass	

INTERPRETATION

Mandera's climate is predominantly hot throughout the year with outside conditions (dry bulb temperature and relative humidity) beyond the comfort zone (see Figure 131). Therefore, cooling is very important and buildings need much more cooling and no heating at all. Based on the psychrometric chart, the most appropriate cooling strategies to extend the limit of comfort include the following: shading, natural ventilation, high thermal mass with night ventilation (night flushing) and evaporative cooling. However, some days are too hot and dry for the passive strategies to work successfully. Therefore, convectional cooling and humidification may be necessary during the overheated period to maintain thermal comfort when the passive cooling strategies cannot fulfil the cooling demand.

BIOCLIMATIC RECOMMENDATIONS

The following passive design strategies may be used to address the cooling requirements of Mandera's climate:

a. To reduce effects of intense solar radiation

- Compact layout of buildings is recommended to provide mutual shading and minimise exposure to solar radiation.
- Courtyard design of buildings minimises the impact of solar radiation on the outer walls as well as provide cool spaces within the buildings / building layout. This increases the daytime cooled spaces (Figure 132).
- Buildings should be oriented along the east – west axis with the longer sides facing north and south to prevent solar heat gains. The building's surface area exposed to the east and west should be minimised.
- Openings should be located on the north and south facing façades. Small openings that are located high on the walls are recommended to facilitate natural ventilation as well as reduce glare from light reflected from the ground or surrounding buildings.
- Appropriate shading devices are necessary on all openings to decrease heat gain from solar radiation. Use of vegetation, verandas, covered walkways, pergolas etc. is recommended to provide shade to walls, openings and outdoor spaces.
- Use of reflective surfaces (roof) and light-coloured walls are effective in reflecting solar radiation thus minimising solar heat gains and consequently minimising internal daytime temperatures.

b. To counter low relative humidity

- Evaporative cooling is recommended in this climate to improve the microclimate by elevating the humidity level while at the same time cooling the surrounding air. The following strategies are recommended: fountains, spray ponds, water surfaces, moistened fabrics, sprinklers or porous pots etc.
- Use of vegetation is effective in improving the air quality by reducing the air temperature as well as elevate the humidity level because of the evaporative cooling effect of plants.

c. To balance diurnal temperature range

- Heavy weight building materials with high thermal capacity are recommended to balance temperature variations between day and night. These heat storing materials keep daytime temperatures down.
- As a result of heat absorption qualities of the ground, earth-sheltered and underground housing are suited for this climate.

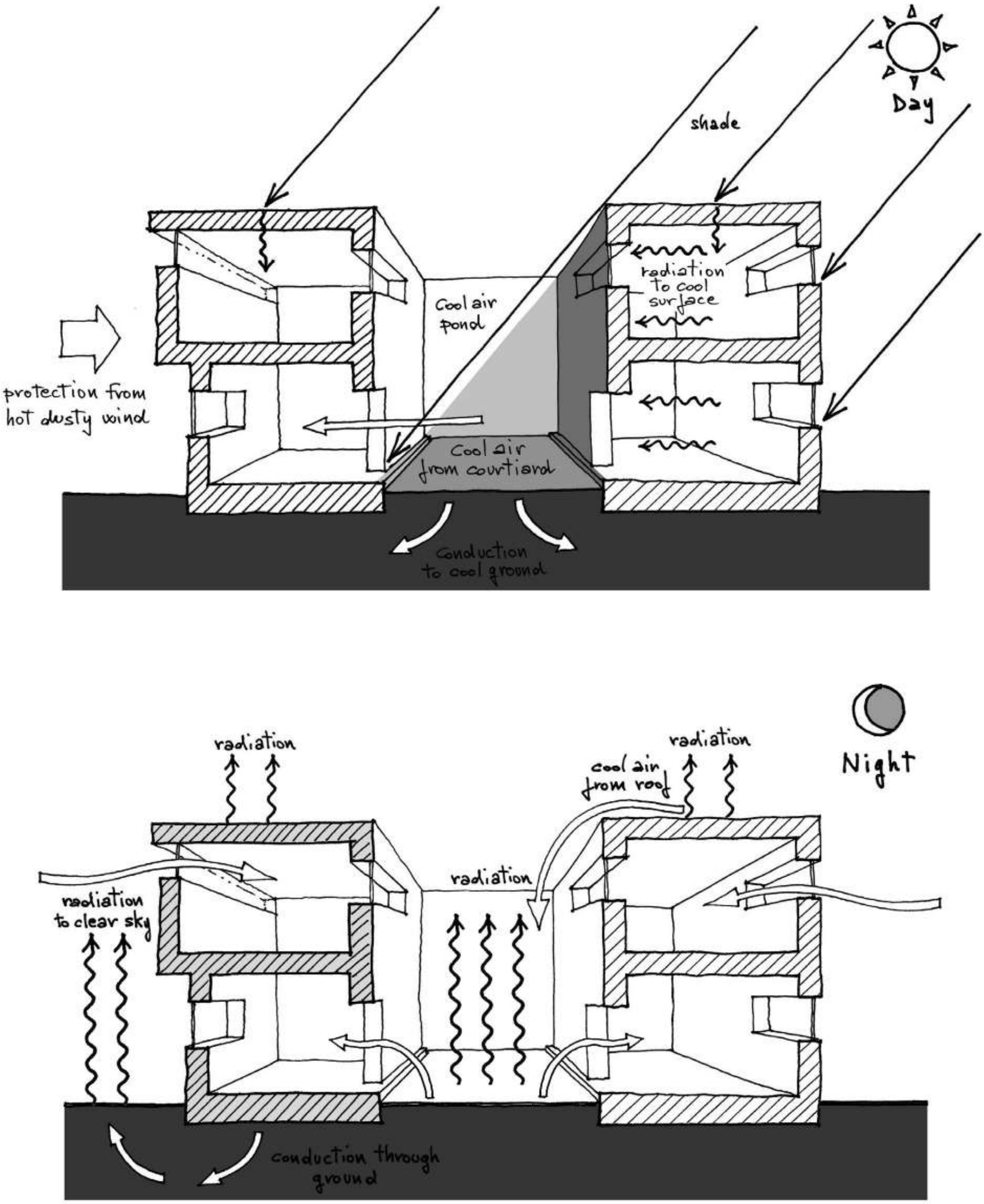
d. To ensure air circulation

- Openings should be located to take advantage of prevailing winds and allow for cross-ventilation.
- Ventilation through windows should be kept at a minimum during the daytime to keep hot and dusty air out. This also minimised heat gains. However, at night, windows may be opened to provide adequate ventilation for dissipation of heat accumulated during the day by walls and the roof to prevent overheating of the interior space.
- Other ventilation strategies include use of wind catchers, wind towers, solar chimneys, roof-mounted exhaust fans, high level vents etc.

e. To minimise problems associated with dust

- Vegetation can be used to filter dust from the air before it gets into the building.
- Closing windows during daytime prevents dust from getting into the building on windy days.
- Windows should be tight-fitting as possible to prevent dust from infiltrating.

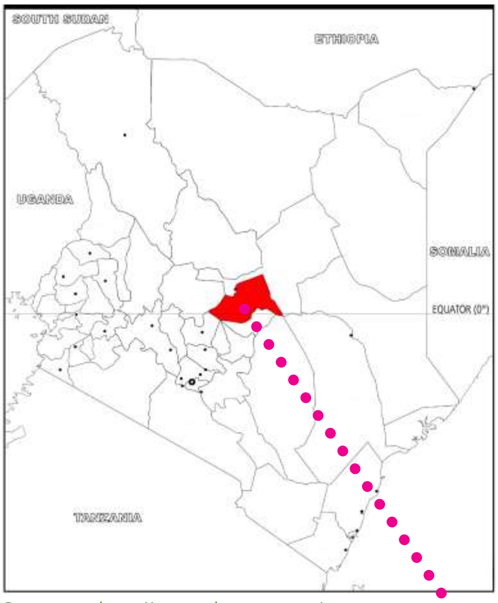
FIGURE 132 **HIGH WALLS CUT OFF THE SUN DURING THE DAY HENCE PROVIDING SHADE TO INNER WALLS AND FLOOR OF THE COURTYARD, PREVENTING EXCESSIVE HEATING. DURING THE NIGHT, HEAT ACCUMULATED DURING THE DAY IS DISSIPATED BY RE-RADIATION.**



Source: *UN-Habitat (2015) Sustainable Building Design for Tropical Climates: Principles and Applications for Eastern Africa. Nairobi, Kenya: UN-Habitat.*

MERU

FIGURE 133 **LOCATION OF MERU COUNTY**



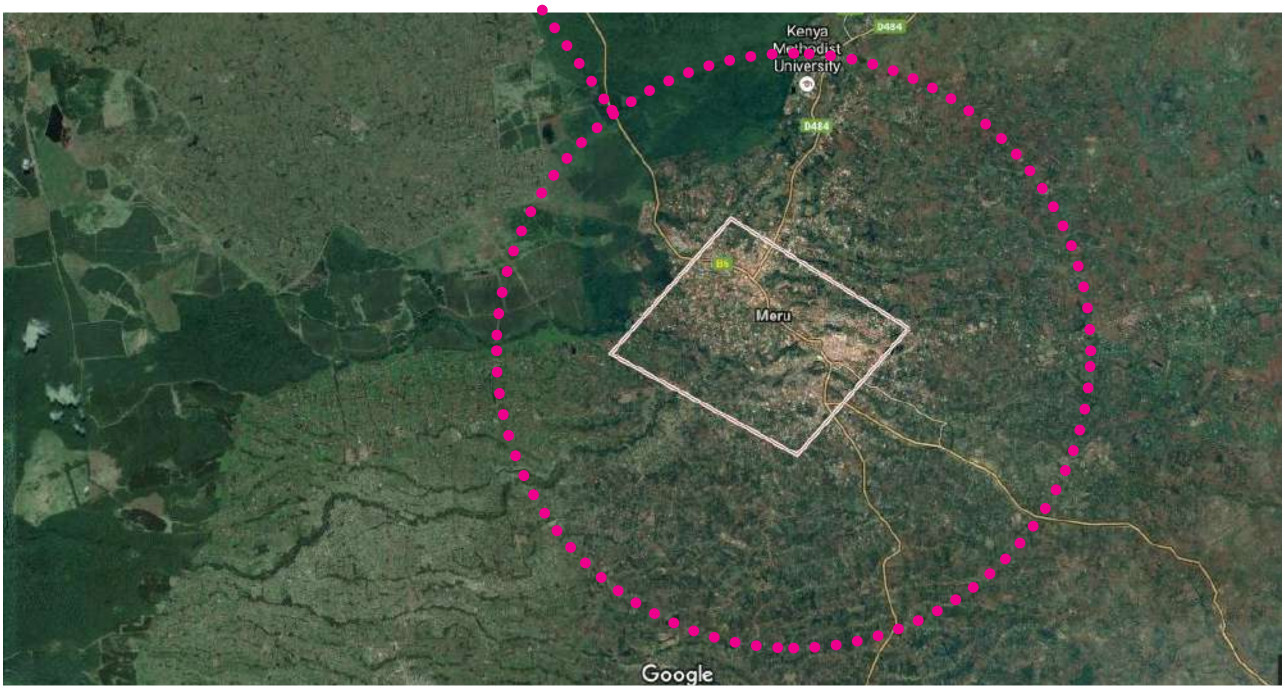
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	00° 03' N
Longitude	37° 39' E
Altitude	1,528 m

FIGURE 134 **VIEW OF A STREET IN MERU TOWN**

Source: *© marete2010 https://www.flickr.com/photos/maasai1/6206978783/in/photostream/*

FIGURE 135 **LOCATION OF MERU TOWN IN MERU COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Meru town, situated on the slopes of Mt. Kenya, is the headquarters of Meru county and located on the geographic coordinates of 00° 03′ N, 37° 39′ E. At an altitude of 1,528 m above sea level, the town enjoys an uplands climate with predominant cool temperatures of an annual average of 18.3 °C – the coolest and warmest months are July and March respectively. The town receives high amount of rainfall throughout the year (annual average of 1,708 mm) with the wettest month on average being April while the driest month being June. High relative humidity is recorded throughout the year with an annual average of 79%. This town experiences global solar radiation of 5.5 kWh/m2 with an annual average wind speed of 2.4 m/s blowing predominantly from South East.

TABLE 16 **MERU MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	18.1	80.0	2.1	5.9	5.3	2.3	57.5
FEB	18.2	76.0	2.3	6.5	5.9	2.3	56.7
MAR	19.7	77.0	2.4	6.1	5.0	2.5	117.3
APR	19.2	83.0	1.8	5.6	4.1	2.6	312.1
MAY	18.5	84.0	2.0	5.3	4.0	2.5	243.6
JUN	17.6	80.0	2.2	4.7	3.4	2.3	55.1
JUL	16.9	75.0	3.5	4.6	2.9	2.6	71.1
AUG	17.7	73.0	3.4	5.2	3.3	2.7	71
SEP	18.2	71.0	3.1	5.9	4.7	2.4	54.1
OCT	19.4	72.0	2.8	5.8	4.2	2.6	256.2
NOV	18.0	87.0	1.6	5.1	3.2	2.8	296.2
DEC	17.8	84.0	2.1	5.4	4.2	2.5	117.2

FIGURE 136 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR MERU**

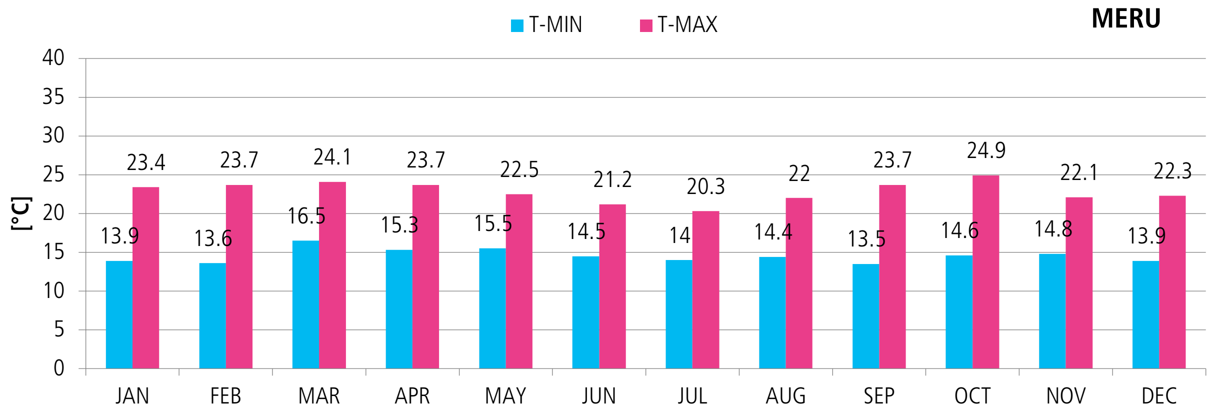


FIGURE 137 **MONTHLY MEAN RELATIVE HUMIDITY FOR MERU**

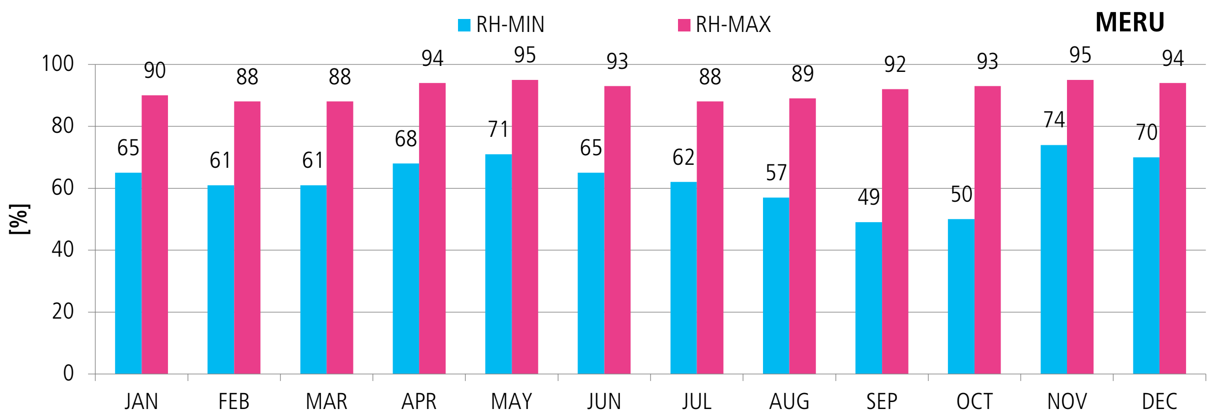


FIGURE 138 **MONTHLY AVERAGE RAINFALL FOR MERU**

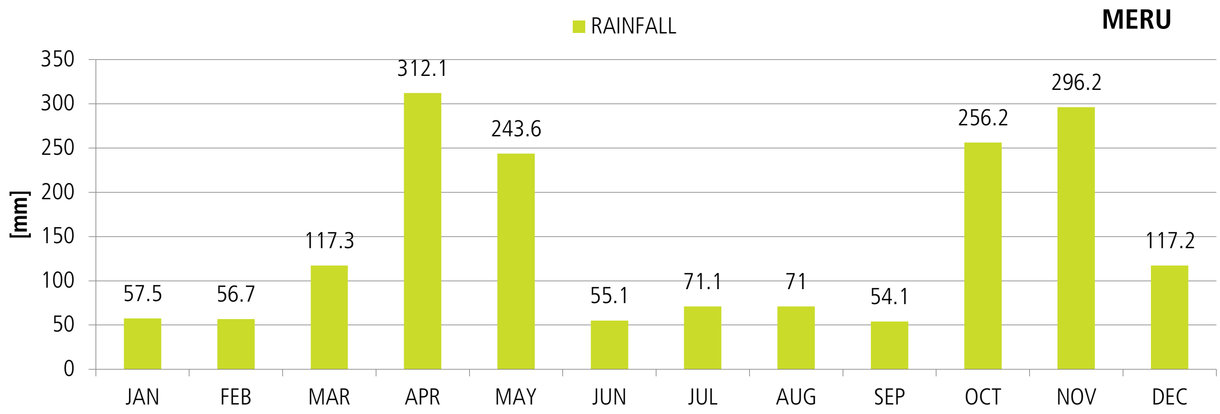


FIGURE 139 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

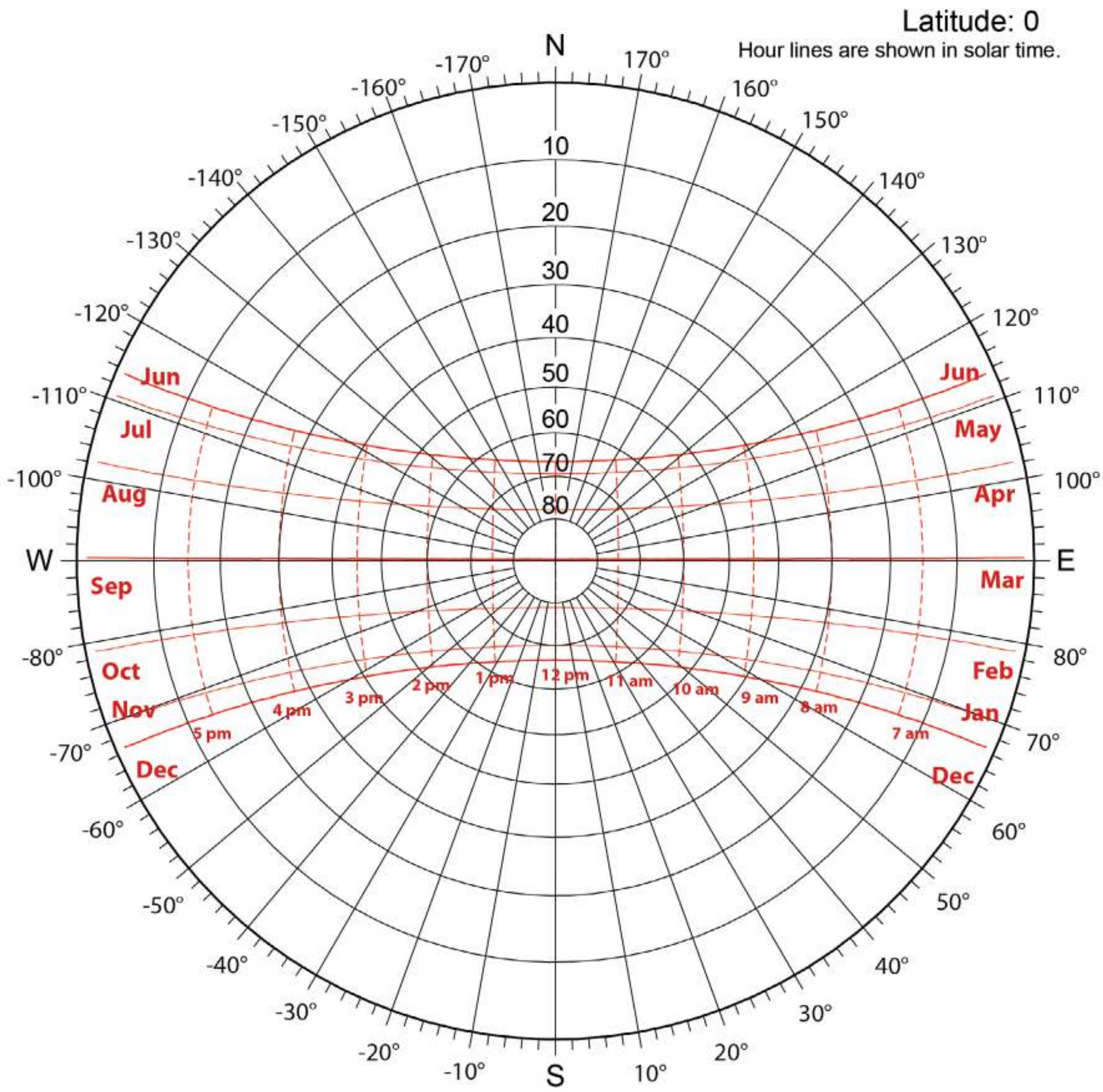


FIGURE 140 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN MERU**

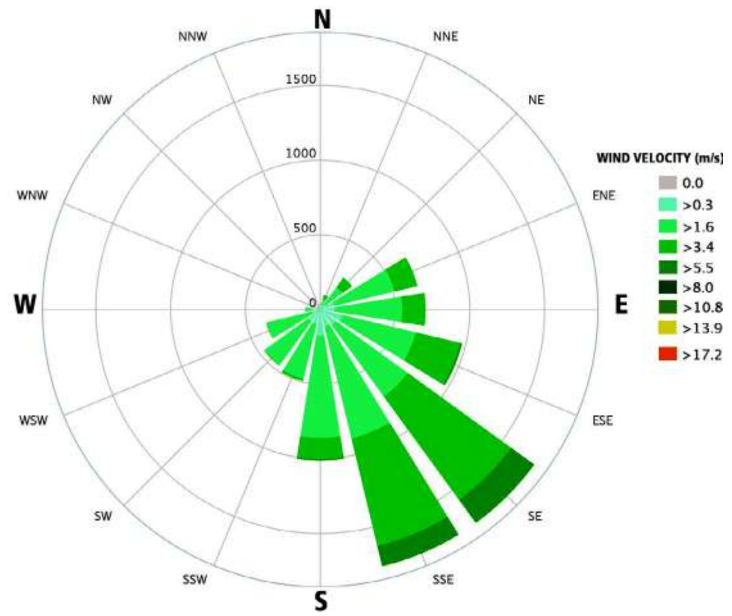
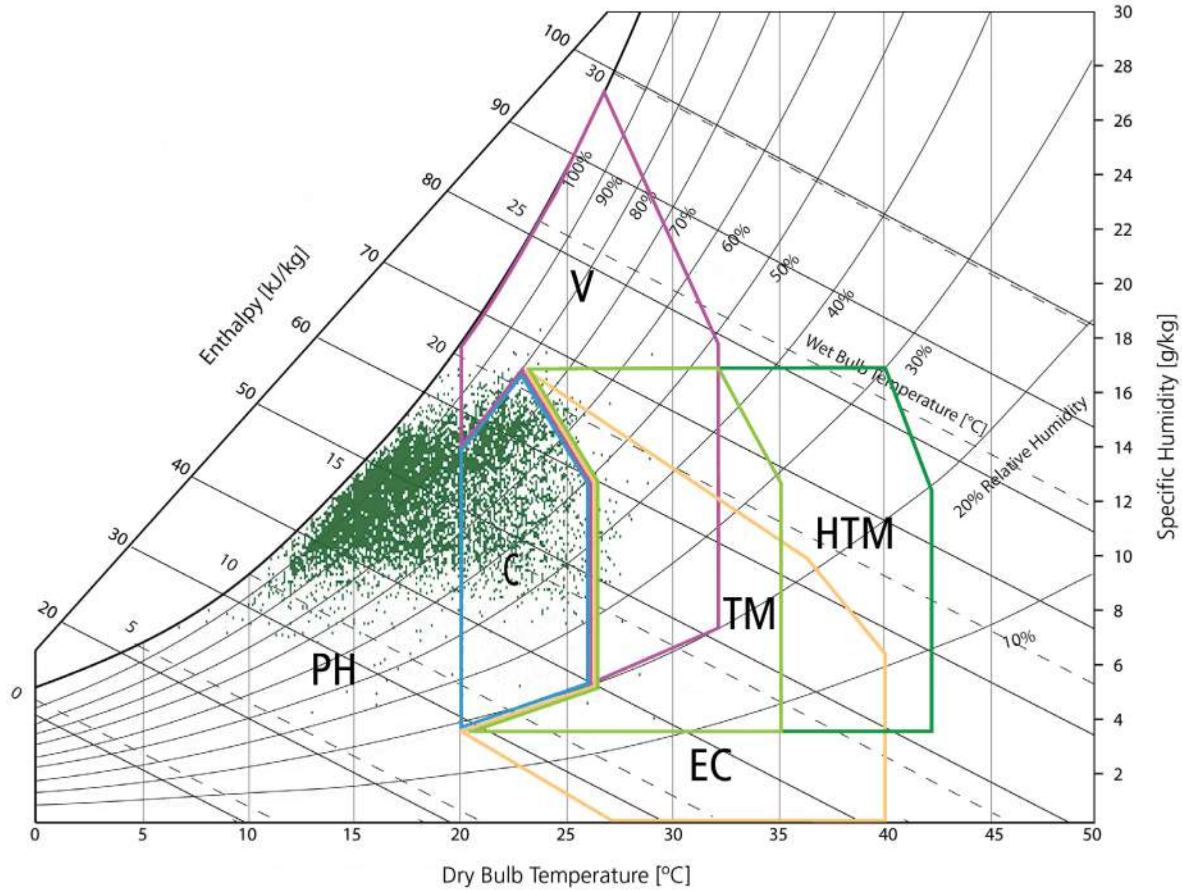


FIGURE 141 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR MERU**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

The outdoor hourly outdoor dry bulb and relative humidity data points indicate that Meru falls within the comfort zone during certain periods of the year (see Figure 141). However, for a substantial period of the year, the temperatures are clearly below comfort with temperatures getting to below 15 °C. Passive solar heating through direct solar gain heat and thermal mass is therefore the most essential strategy for extending the thermal comfort zone during this under heated period. In addition, internal heat gain from equipment, lights and occupants provide a valuable source of heat contribution to space heating.

BIOCLIMATIC RECOMMENDATIONS

The main design objective in Meru should be to increase indoor temperature and maximise thermal comfort during the prevalent under heated period. According to the climatic data for Meru, the following design strategies are recommended for:

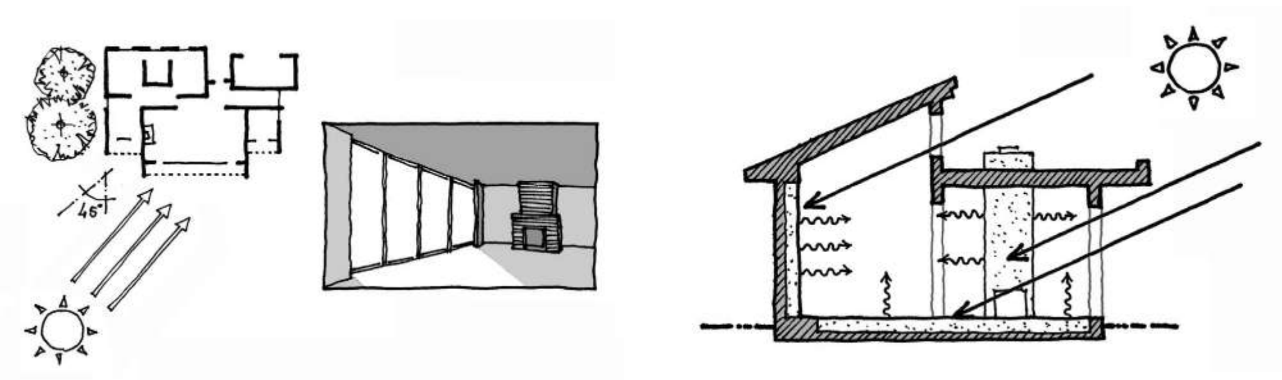
a. Enabling passive heating

- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods (Figure 142).
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.
- Additional heating systems such as fireplaces can be incorporated in the design.
- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

b. Protection against heat gain in the hot period

- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

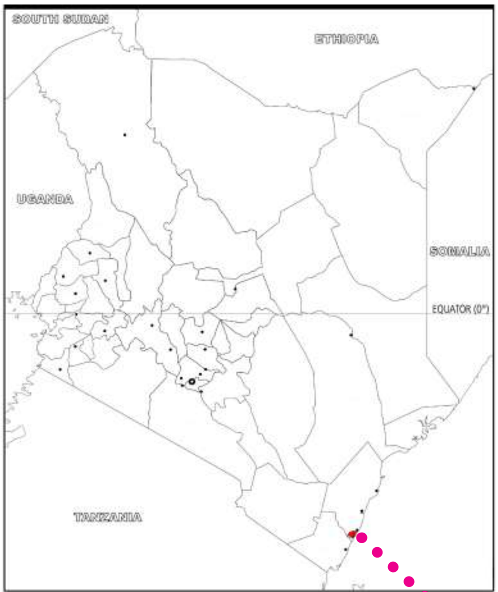
FIGURE 142 **SOLAR ACCESS CAN BE PROVIDED DURING THE COLD SEASON FOR PASSIVE HEATING**



Source: *UN-Habitat (2015) Sustainable Building Design for Tropical Climates: Principles and Applications for Eastern Africa. Nairobi, Kenya: UN-Habitat.*

MOMBASA

FIGURE 143 **LOCATION OF MOMBASA COUNTY**



Source: *http://www.d-maps.com/*

Climatic Zone	HOT AND HUMID
Latitude	04° 03’ S
Longitude	39° 40’ E
Altitude	50 m

FIGURE 144 **VIEW OF MOMBASA TUSKS ALONG MOI AVENUE**

Source: *http://nomad.sleepout.com/wp-content/uploads/2014/12/mombasa1.jpg*

FIGURE 145 **LOCATION OF MOMBASA TOWN IN MOMBASA COUNTY**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Mombasa, the headquarters of Mombasa county, is the second largest city in Kenya after Nairobi. At a geographic location of 04° 03′ S 39° 40′ E and an altitude of 50 m above sea level, the town's climates is characterised by permanent high humidity (annual average of 80%) and high temperatures (annual average of 25.9 °C) with minimum daily temperature swings. The hottest month is March while the coolest month is July. This city experiences intense solar radiation throughout the year with an annual average global solar radiation of 5.4 kWh/m2. With an annual average speed of 3.5 m/s, the predominant wind direction is East (December to March) and South (April to November).

TABLE 17 **MOMBASA MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	26.8	78.0	3.6	5.8	3.8	3.0	20
FEB	27.0	75.0	3.9	6.0	4.1	2.9	10
MAR	28.1	77.0	3.0	6.0	4.1	2.8	60
APR	26.9	82.0	3.2	5.3	3.4	2.8	180
MAY	26.0	82.0	4.2	4.5	2.8	2.5	270
JUN	24.9	80.0	4.3	4.7	3.4	2.4	100
JUL	23.7	84.0	3.4	4.6	3.4	2.3	80
AUG	24.1	82.0	3.6	5.1	3.8	2.5	60
SEP	24.6	82.0	4.0	5.7	4.2	2.5	60
OCT	25.7	79.0	3.0	5.9	4.1	2.8	90
NOV	26.2	81.0	2.7	5.8	4.2	2.7	90
DEC	26.9	80.0	3.1	5.5	3.5	2.9	60

FIGURE 146 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR MOMBASA**

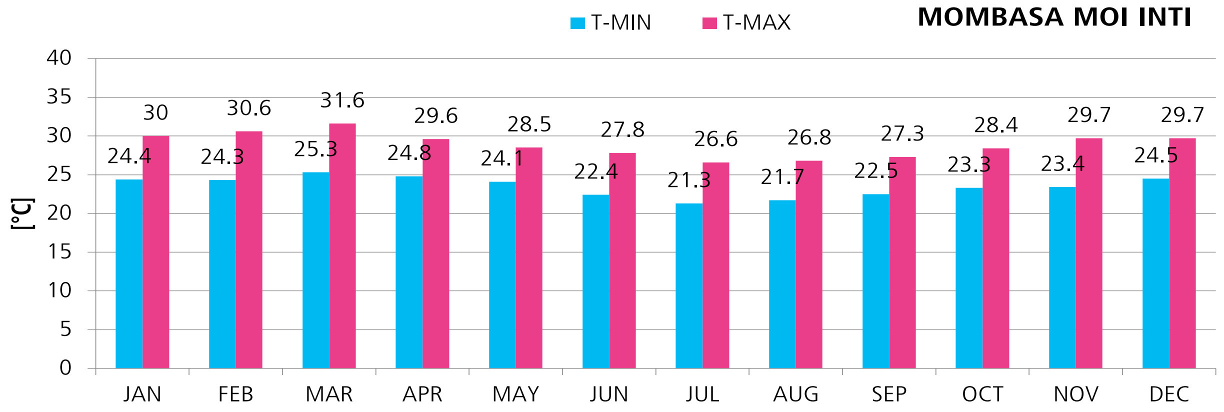


FIGURE 147 **MONTHLY MEAN RELATIVE HUMIDITY FOR MOMBASA**

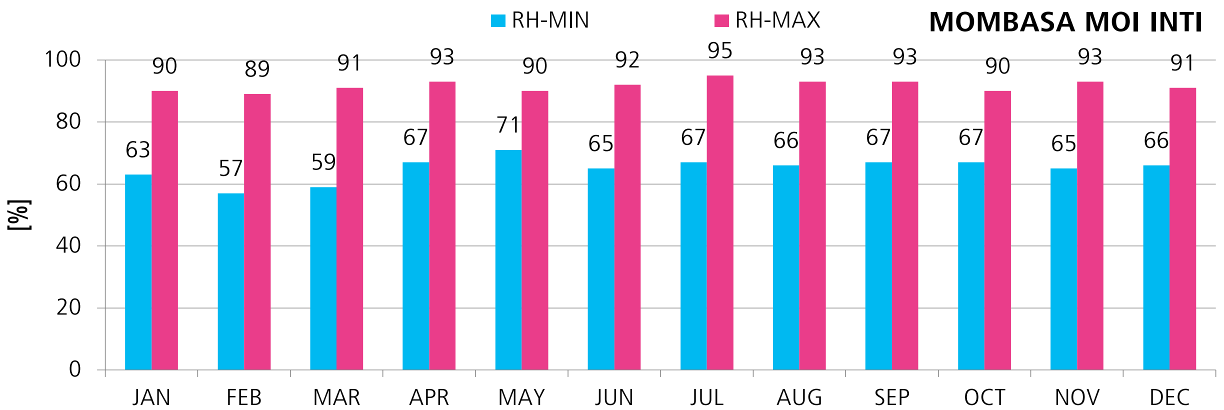


FIGURE 148 **MONTHLY AVERAGE RAINFALL FOR MOMBASA**

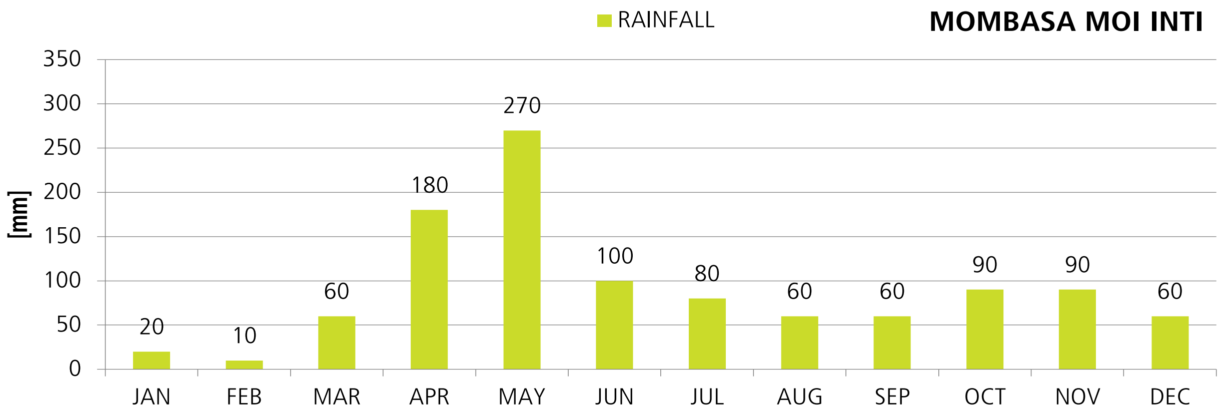


FIGURE 149 **POLAR SUN PATH DIAGRAM FOR LATITUDE 4° SOUTH**

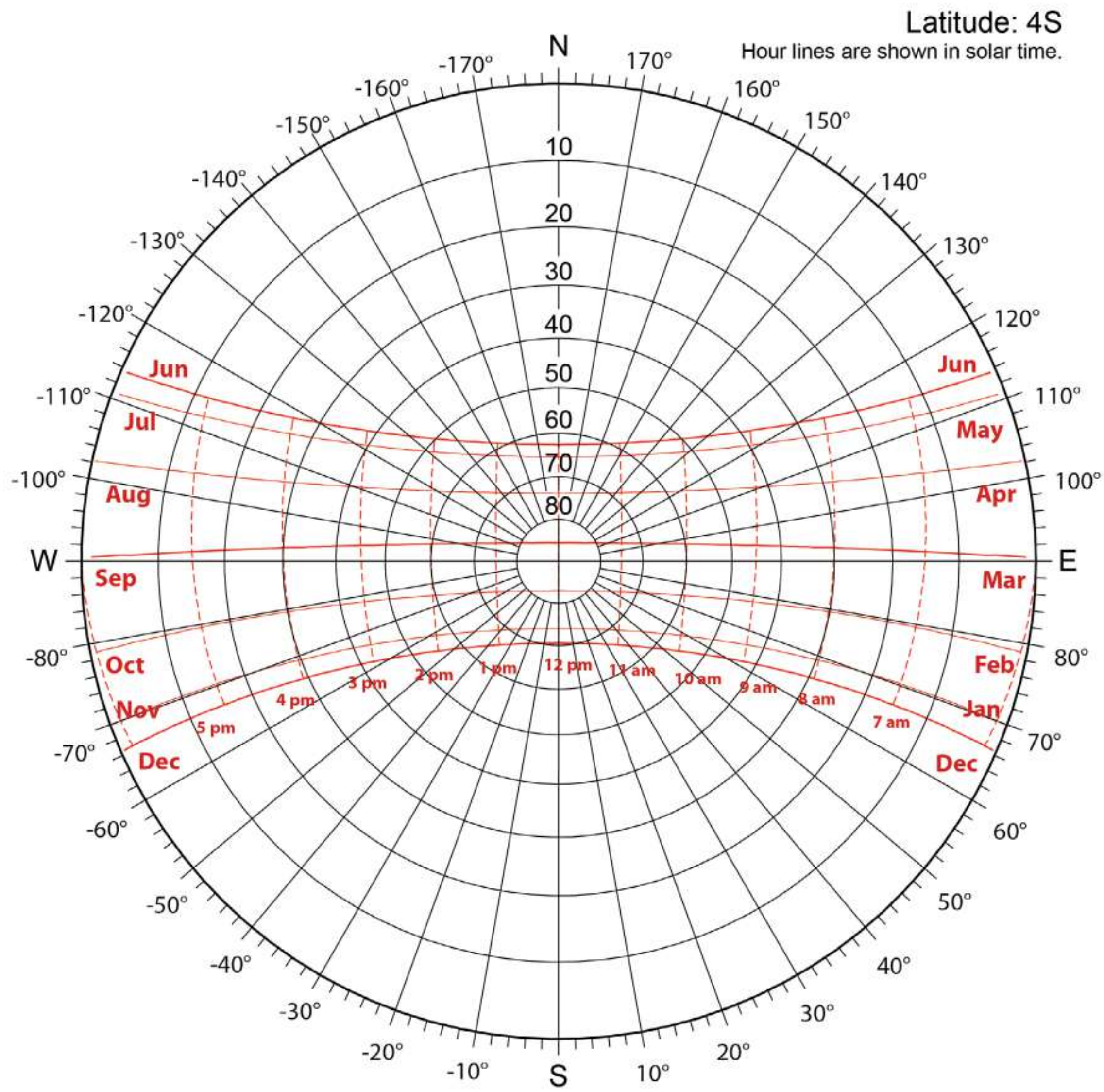


FIGURE 150 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN MOMBASA**

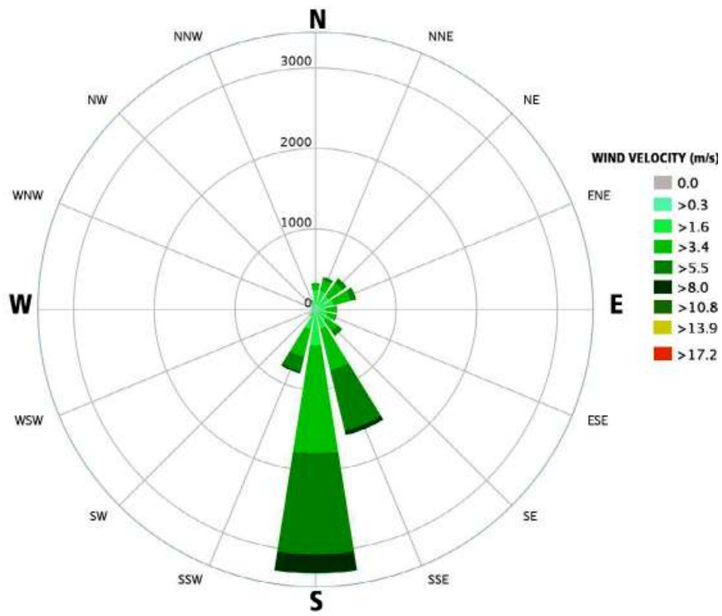
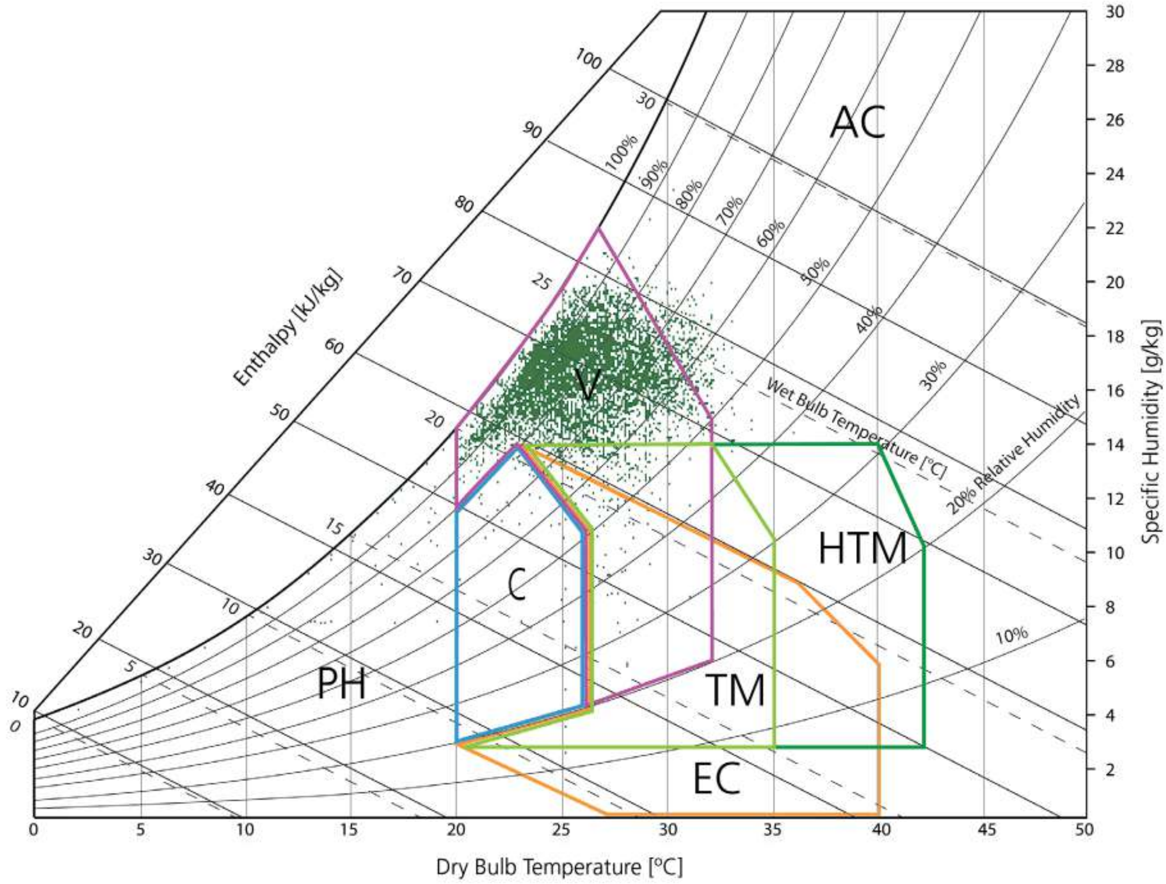


FIGURE 151 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR MOMBASA**



C Comfort Zone

V Natural Ventilation

TM Thermal Mass

HTM High Thermal Mass

EC Evaporative Cooling

PH Passive Heating

AC Air Conditioning

INTERPRETATION

Figure 151 shows that Mombasa has its comfort region defined between 20 – 26 °C. The hourly outdoor dry bulb temperatures and relative humidity points indicate that the region is of the comfort zone. The resulting combination of high temperatures and high relative humidity caused discomfort. Thermal comfort can however be achieved passively through natural ventilation for temperatures below 33 °C but beyond the comfort zone. This makes it the most appropriate strategy to extend the comfort zone. However, at certain periods, outdoor dry bulb temperature and relative humidity fall outside the limits of natural ventilation, thereby necessitating the use of mechanical cooling and dehumidification to improve thermal comfort.

BIOCLIMATIC RECOMMENDATIONS

According to the cooling needs required by a hot and humid climate like Mombasa's, the following passive design strategies may be used:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading (Figure 152).
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, covered verandas and porches etc.
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and reduce heat gains.
- Lightweight building materials with low thermal capacity are recommended for walls, floors and roofs to allow rapid cooling at night.

b. To promote maximum ventilation

- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings.
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum ventilation.

FIGURE 152 **PROPER ORIENTATION OF BUILDINGS ALONG THE EAST WEST AXIS AND MINIMAL OPENINGS ON THE WEST FACING FAÇADE. SLANTED GLAZED SURFACES AND PROVISION OF SUN SHADING DEVICES MINIMISE HEAT GAIN.**

Bank of India, Mombasa © UN-Habitat / Jerusha NGUNGUI

FIGURE 153 **EXAMPLE OF A VENTILATED ROOF**

© UN-Habitat / Jerusha NGUNGUI

- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.

- Openings should be located on opposite sides of walls to allow for proper cross-ventilations. Internal walls should also have openings for airflow through the internal space.

- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement.

- Ventilated double roofs enhance ventilation of the roof minimising overheating (Figure 153).

FIGURE 154 **USE OF TIMBER SCREENS FOR SHADING THE WEST FACING OPENINGS AGAINST THE LATER AFTERNOON SUN**

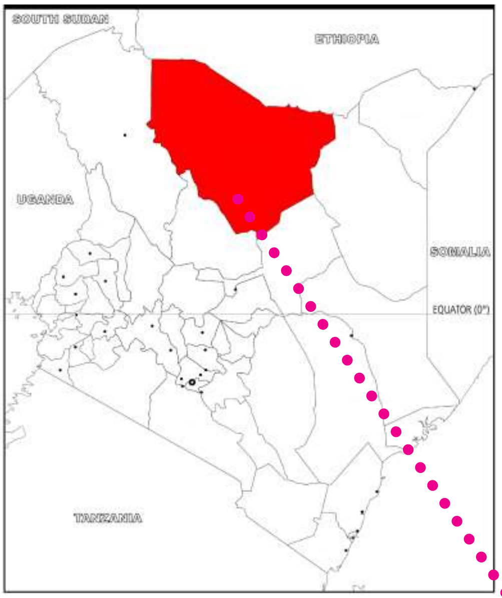
A typical vernacular Swahili building (the Old Post office building) in Old Town, Mombasa © UN-Habitat / Jerusha NGUNGUI

FIGURE 155 **PRESENCE OF PERMANENT OPENINGS ALONG WALLS ENABLES AIRFLOW THROUGH THE BUILDING. VEGETATION PROVIDES SHADING. LIGHTLY COLOURED EXTERNAL SURFACE TO REFLECT UNWANTED SOLAR RADIATION.**

Technical University of Mombasa © UN-Habitat / Jerusha NGUNGUI

MOYALE

FIGURE 156 **LOCATION OF MARSABIT COUNTY**



Source: *http://www.d-maps.com/*

Climatic Zone	HOT SEMI-ARID / SAVANNAH
Latitude	03° 31' N
Longitude	39° 3' E
Altitude	850 m

FIGURE 157 **AERIAL VIEW OF MOYALE TOWN**

Source: *http://mobile.nation.co.ke/*

FIGURE 158 **LOCATION OF MOYALE TOWN IN MARSABIT COUNTY**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Moyale town, located in Marsabit county, is a border town split between Kenya and Ethiopia. Its geographic location is 03° 31′ N, 39° 3′ E and at an altitude of 850 m above sea level. Its climate is characterized by high temperatures throughout the year – annual mean of 22.4 °C with February being the hottest month and July being the coolest month on average. An annual average of 714 mm of rainfall is recorded with the highest amount received in April while the lowest amount is recorded in August. The annual average global solar radiation in this town is 5.0 kWh/m². The predominant wind direction is South South East (SSE) at an annual mean velocity of 3.3 m/s.

TABLE 18 **MOYALE MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	24.8	44.0	4.2	6.0	5.8	2.1	17.2
FEB	25.8	48.0	3.4	6.3	5.8	2.3	19.6
MAR	24.5	61.0	3.5	5.6	4.0	2.7	55.3
APR	21.8	82.0	3.3	4.7	2.5	2.9	194.8
MAY	21.7	80.0	2.1	4.5	2.5	2.8	132.6
JUN	20.2	78.0	2.9	4.2	2.2	2.7	15.9
JUL	20.1	70.0	3.7	4.2	1.9	2.9	13.5
AUG	20.8	66.0	3.5	4.7	2.6	2.8	11.9
SEP	21.5	63.0	4.0	5.1	3.3	2.7	17.7
OCT	21.8	71.0	3.0	4.8	2.6	2.9	114.1
NOV	21.7	78.0	2.8	4.9	3.0	2.9	86.8
DEC	23.6	57.0	2.9	5.4	4.5	2.4	34.9

FIGURE 159 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR MOYALE**

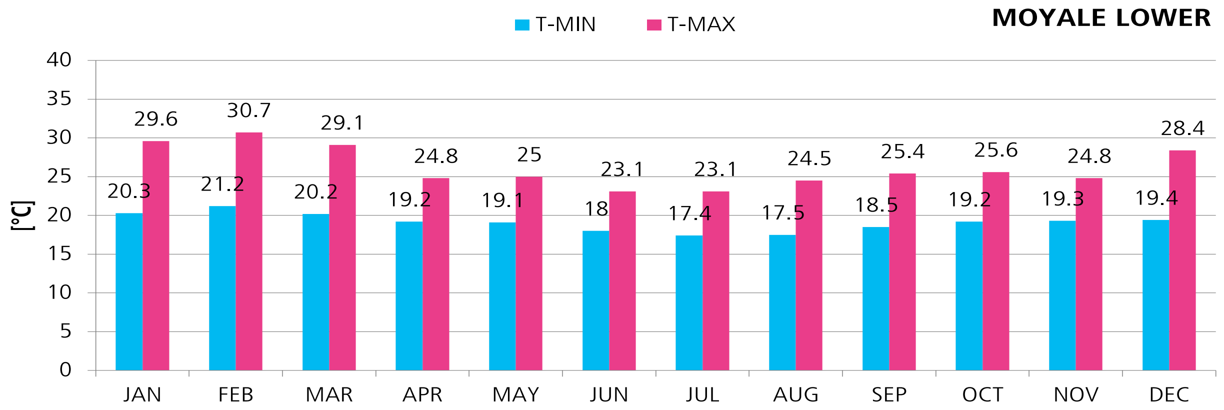


FIGURE 160 **MONTHLY MEAN RELATIVE HUMIDITY FOR MOYALE**

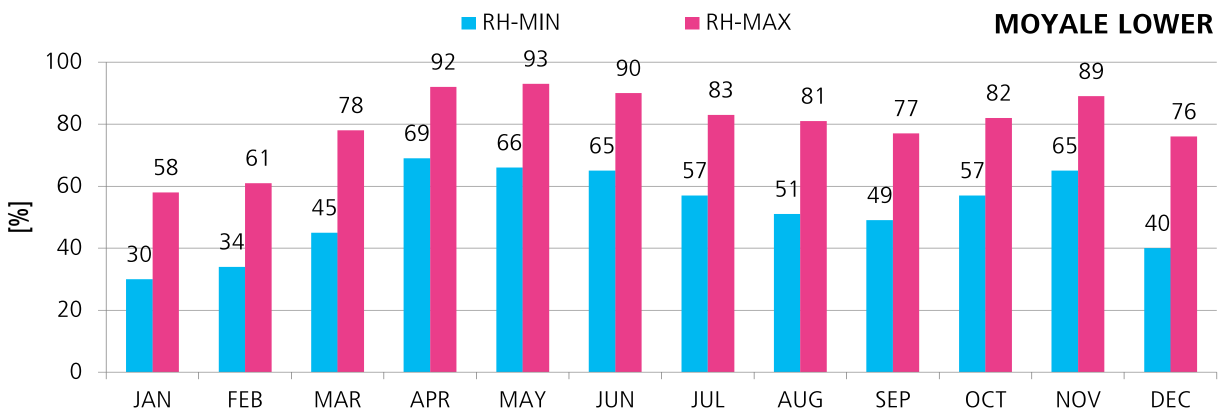


FIGURE 161 **MONTHLY AVERAGE RAINFALL FOR MOYALE**

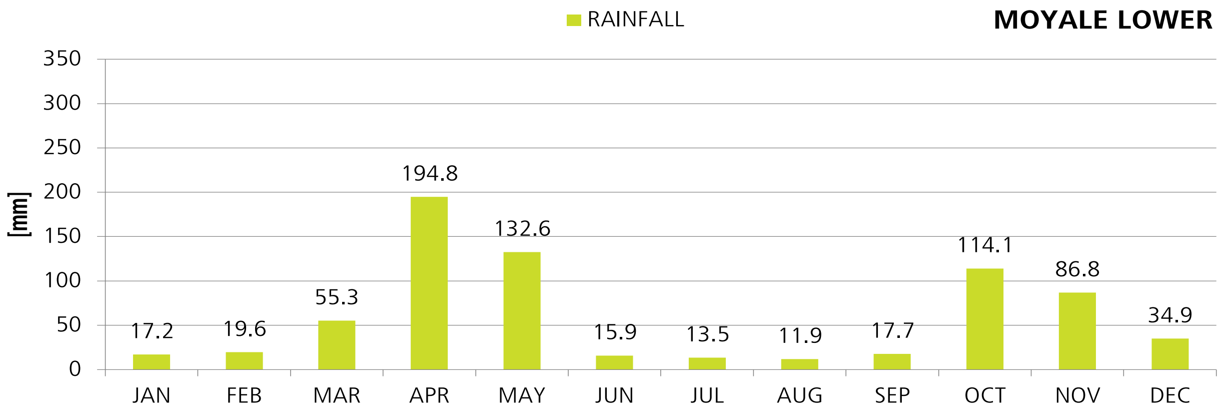


FIGURE 162 **POLAR SUN PATH DIAGRAM FOR LATITUDE 3° NORTH**

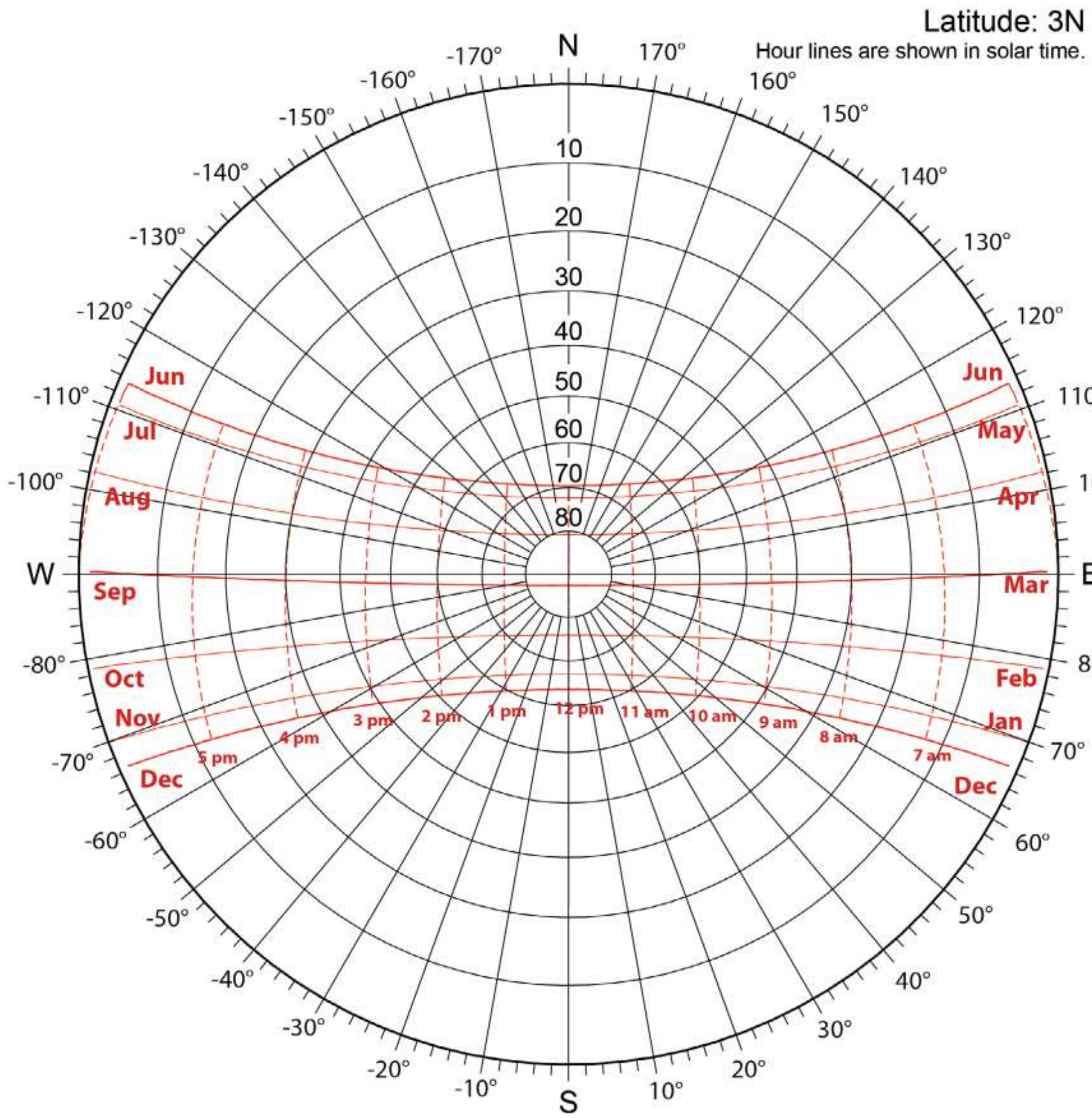


FIGURE 163 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN MOYALE**

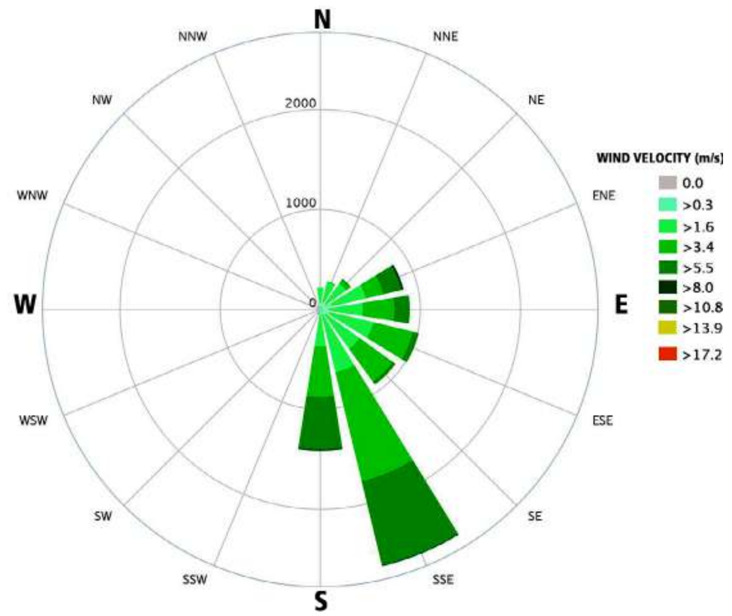
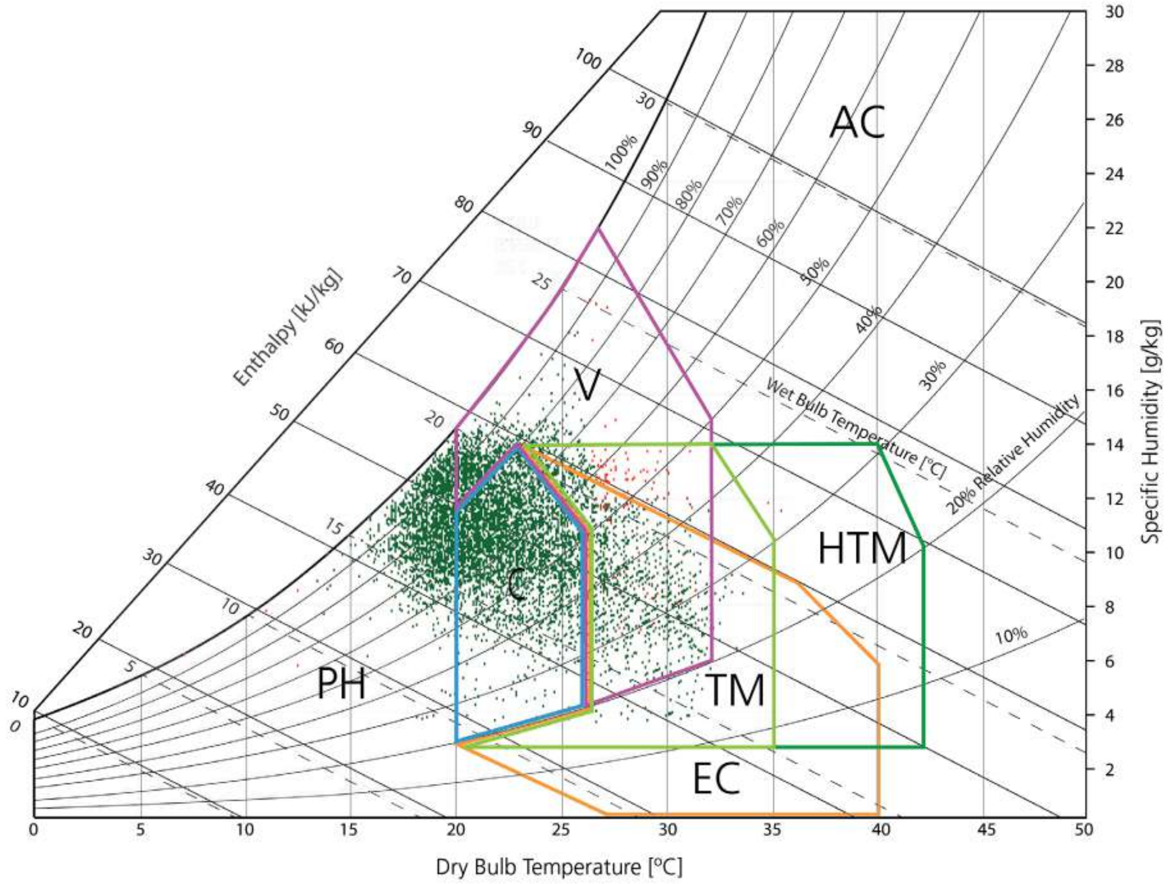


FIGURE 164 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR MOYALE**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

Most of the outdoor hourly dry bulb temperature and relative humidity data point fall within the comfort zone. However, the area experiences under heated periods with temperatures falling below the comfort zone to 15 °C as well as overheated periods with temperatures rising to 32 °C. Based on the psychrometric chart (see Figure 164), a combined effect of natural ventilation and thermal mass (along with night ventilation) are the most effective strategies to improve thermal comfort during the overheated period. In the case of the under heated period, passive heating through direct solar heat gain and thermal mass are effective in expanding the comfort zone when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

In Moyale, the design objective should be to balance the conflicting needs of the cold and hot periods to provide comfort. The following design strategies are recommended:

a. To reduce effects of intense solar radiation

- Compact layout of buildings is recommended to provide mutual shading and minimise exposure to solar radiation.
- Courtyard design of buildings minimises the impact of solar radiation on the outer walls as well as provide cool spaces with the buildings / building layout.
- Buildings should be oriented along the east – west axis with the longer sides facing north and south to prevent solar heat gains. The building's surface area exposed to the east and west should be minimised.
- Openings should be located on the north and south. Small openings that are located high on the walls are recommended to facilitate natural ventilation as well as reduce glare from light reflected from the ground or surrounding buildings.
- Appropriate shading devices are necessary on all openings to decrease heat gain from solar radiation. Use of vegetation, verandas, covered walkways, pergolas etc. is recommended to provide shade to walls, openings and outdoor spaces (Figure 165).
- Use of reflective surfaces (roof) and light-coloured walls are effective in reflecting solar radiation thus minimising solar heat gains and consequently minimising internal daytime temperatures.

b. To balance diurnal temperature range

- Medium weight building materials with high thermal capacity are recommended to balance temperature variations between day and night. These materials absorb heat during daytime keeping indoor temperatures lower than outdoor temperature. The stored heat is later dissipated at night thereby providing indoor thermal comfort when the outdoor temperatures fall below the comfort zone.

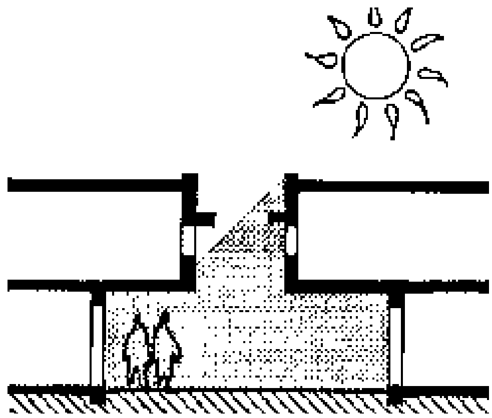
c. To ensure air circulation

- Openings should be located to take advantage of prevailing winds and allow for cross-ventilation.
- Ventilation through windows should be kept at a minimum during the daytime to keep hot and dusty air out. However, at night, windows may be opened to provide adequate ventilation for dissipation of heat accumulated during the day by walls and the roof to prevent overheating of the interior space.
- Other ventilation strategies include use of wind catchers, wind towers, solar chimneys, roof-mounted exhaust fans etc.

d. To minimise problems associated with dust

- Vegetation can be used to filter dust from the air before it gets into the building.
- Closing windows during daytime prevents dust from getting into the building on windy days. Windows should be tight-fitting as possible to prevent dust from infiltrating.

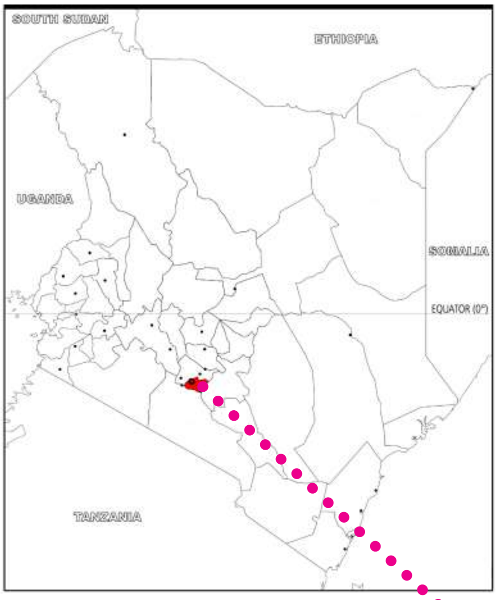
FIGURE 165 **CANTILEVERED CONSTRUCTION, ARCADES, LOGGIAS AND HIGH BUILDING PARTS PROVIDE MUTUAL SHADING OF BUILDINGS AS WELL AS SHADED OUTDOOR SPACES.**



Source: *Gut, P. & Ackerknecht, D. (1993) Climate Responsive Building: Appropriate Building Construction in Tropical and Subtropical Regions. St. Gallen, Switzerland: SKAT, Switzerland.*

NAIROBI

FIGURE 166 **LOCATION OF NAIROBI COUNTY**



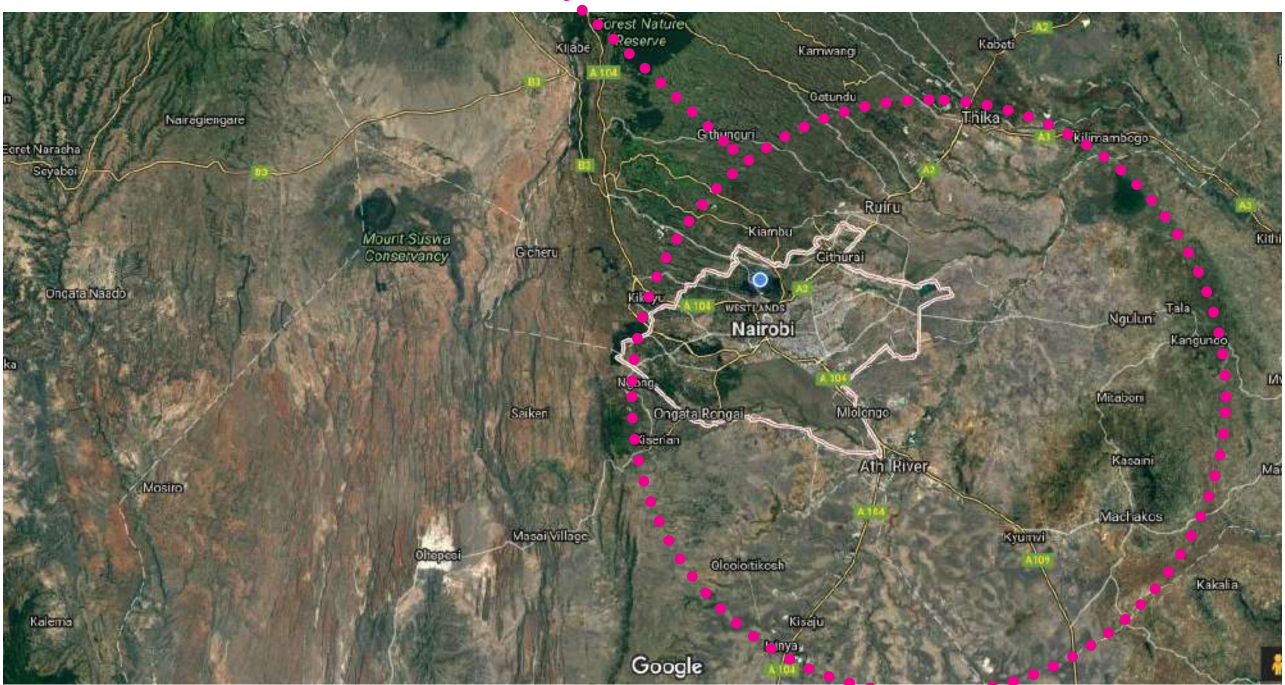
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	01° 17' S
Longitude	36° 49' E
Altitude	1,661 m

FIGURE 167 **NAIROBI SKYLINE**

Source: *http://www.panoramio.com/photo/31634398 © Klaus MERCKENS*

FIGURE 168 **LOCATION OF NAIROBI CITY IN NAIROBI COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Nairobi was founded in 1899 and is the political and capital city of Kenya. Located at geographic coordinates 01° 17′ S 36° 49′ E and at an altitude of 1,661 m above sea level, the city enjoys an upland climate with annual average temperature of 18.8 °C. The hottest and coolest months are March and July respectively. The average annual rainfall is recorded at 710 mm with the highest amount occurring in April / May and November / December. Relative humidity is above 60% throughout the year while the wind velocity ranges 0.9 – 2.9 m/s with the predominant wind direction being East North East (ENE) and East. The annual average global solar radiation in Nairobi is 5.1 kWh/m2.

TABLE 19 **NAIROBI (DAGORETTI) MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	18.8	71.0	2.4	6.0	4.9	2.5	40
FEB	19.5	62.0	2.4	6.6	5.7	2.4	40
MAR	20.0	68.0	2.8	5.8	3.9	2.8	70
APR	18.7	79.0	1.9	4.9	2.8	2.8	160
MAY	17.7	81.0	1.3	4.3	2.4	2.6	110
JUN	16.7	81.0	0.9	4.1	2.4	2.4	30
JUL	15.7	80.0	0.9	4.0	2.2	2.5	10
AUG	16.3	73.0	1.1	4.7	3.0	2.5	10
SEP	17.5	68.0	1.6	5.3	3.5	2.6	20
OCT	18.2	71.0	2.5	5.2	3.2	2.8	40
NOV	17.7	81.0	2.3	4.7	2.6	2.8	110
DEC	17.7	79.0	2.9	5.4	3.9	2.5	70

FIGURE 169 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR NAIROBI – DAGORETTI**

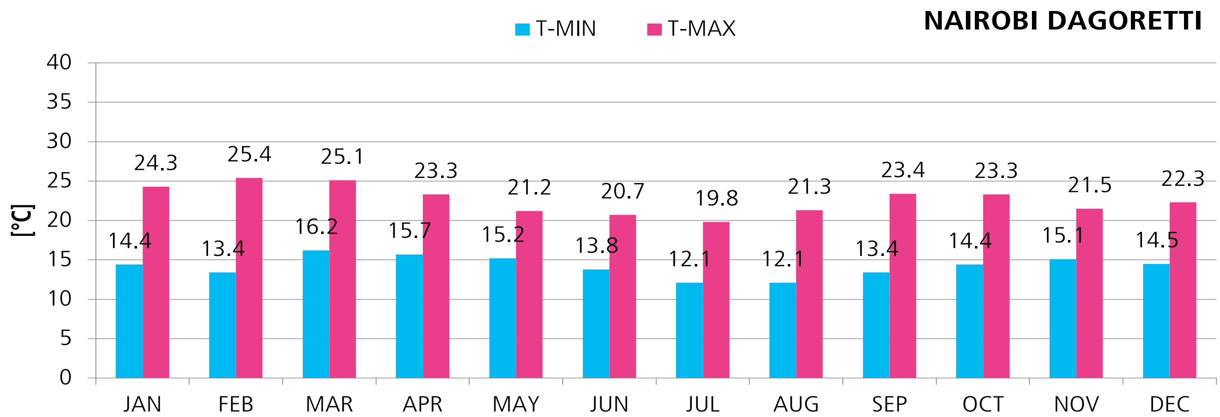


FIGURE 170 **MONTHLY MEAN RELATIVE HUMIDITY FOR NAIROBI - DAGORETTI**

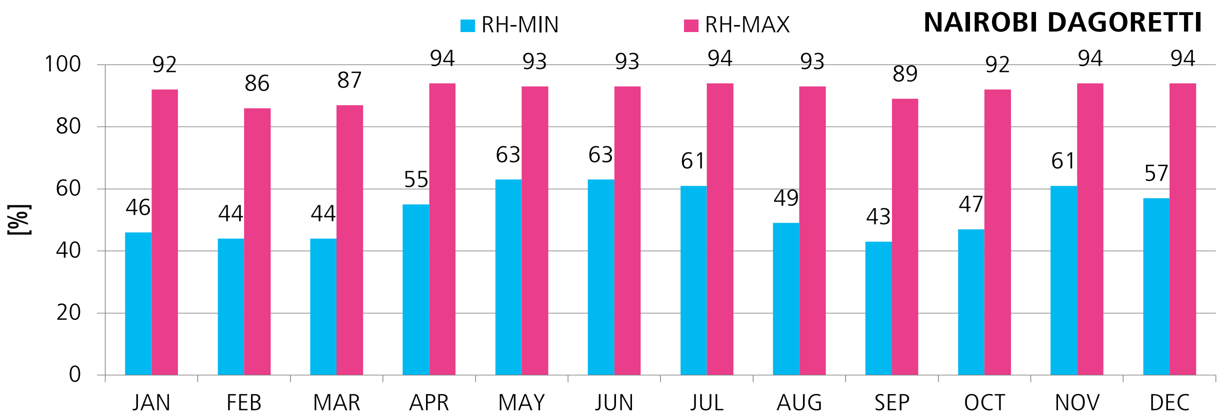


FIGURE 171 **MONTHLY AVERAGE RAINFALL FOR NAIROBI**

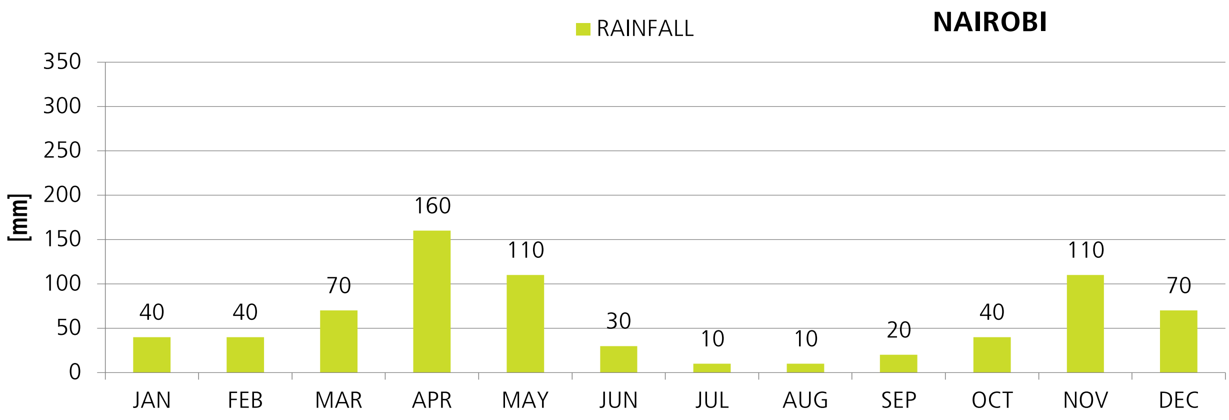


FIGURE 172 **POLAR SUN PATH DIAGRAM FOR LATITUDE 1° SOUTH**

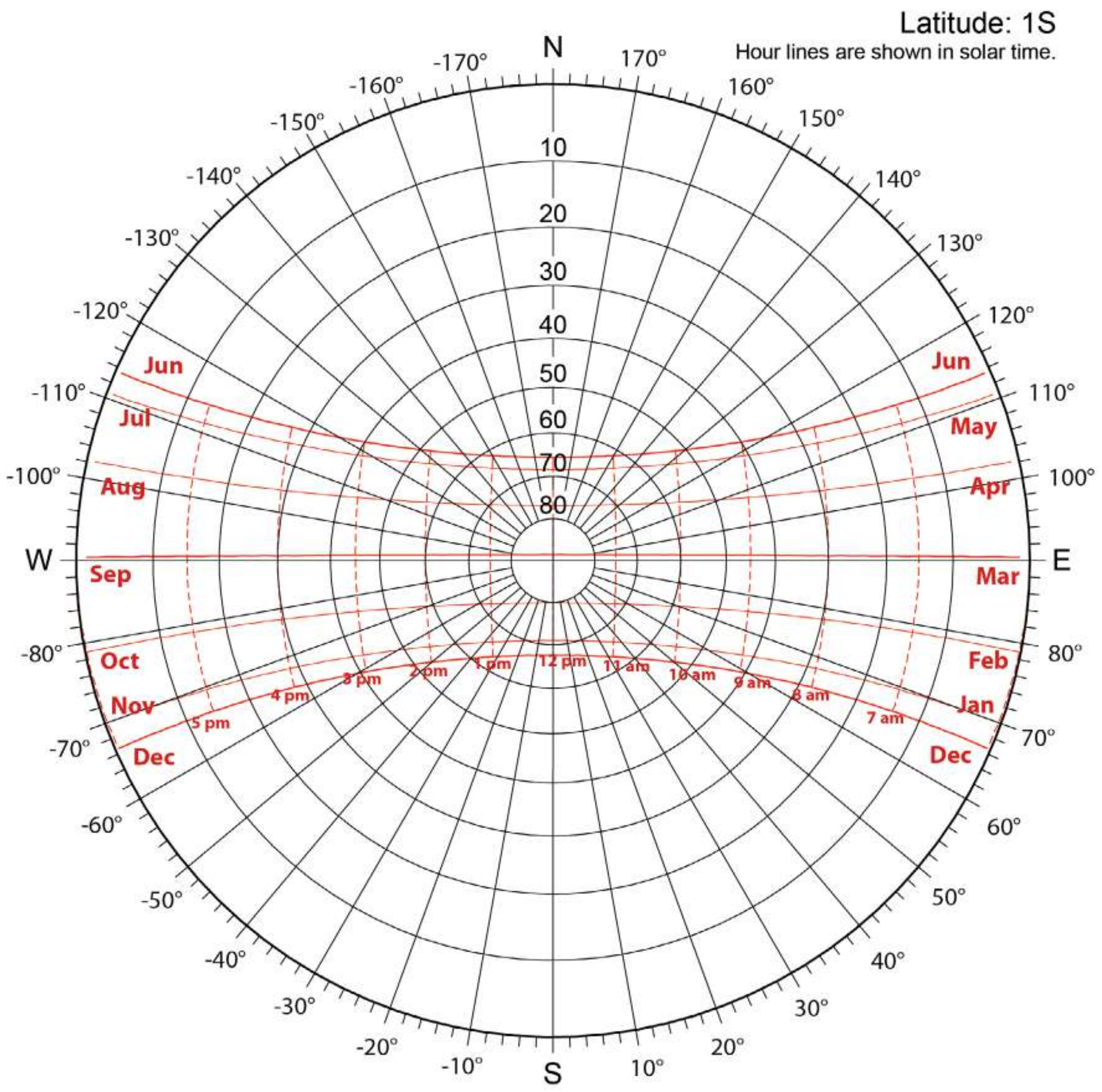


FIGURE 173 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN NAIROBI**

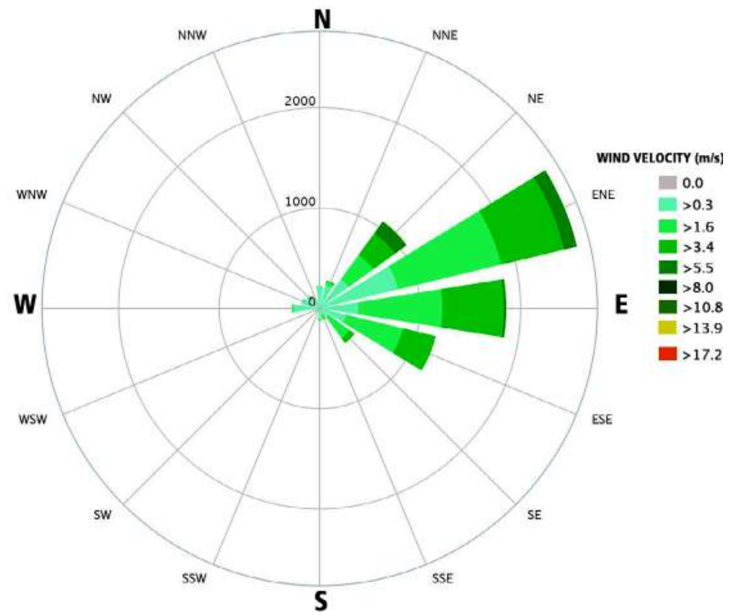
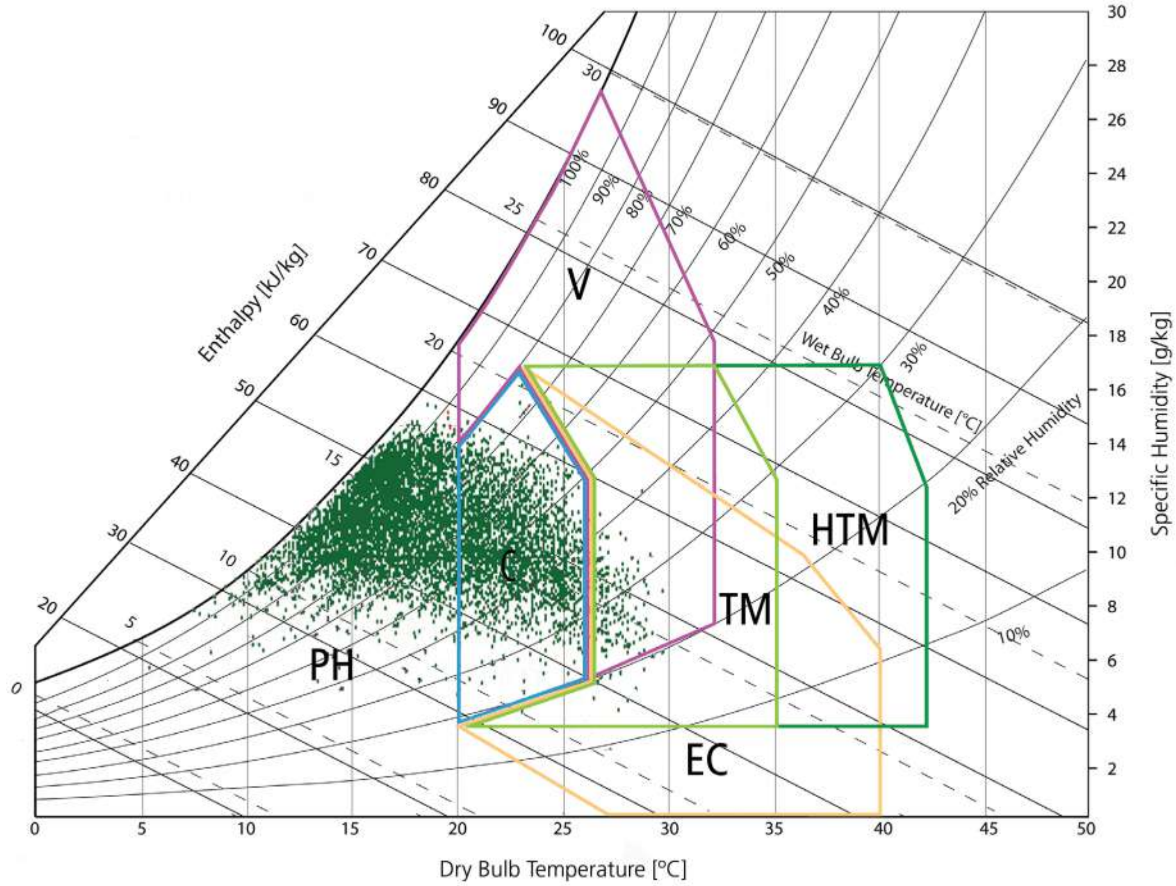


FIGURE 174 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR NAIROBI**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

In Nairobi, most of the hourly points of outdoor dry bulb temperature and relative humidity fall within the comfort zone. However, a substantial portion falls below the comfort zone as seen in Figure 174. This means that during that period, space heating is necessary to extend the limit of comfort zone. This can be done through passive heating through direct solar heat gain and thermal mass. Further, internal heat gain from equipment, lights and occupants are also helpful in extending the thermal comfort and reducing heading heating demand.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Nairobi, the following design strategies are recommended for:

a. Protection against heat gain in the hot period

- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods (Figure 175).
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods (Figure 176).

b. Enabling passive heating

- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.

FIGURE 175 **THE BUILDING IS ORIENTED WITH THE LONG SIDES FACING NORTH – SOUTH AND THE SHORT SIDES FACING EAST-WEST. OPENINGS ARE PLACED ALONG THE NORTH – SOUTH FACING FAÇADES.**

ICEA Building, Nairobi
Source: *http://www.jkuat.ac.ke/*

FIGURE 176 **EXTENSIVE USE OF HORIZONTAL AND VERTICAL SHADING DEVICES ALL AROUND THE BUILDING PROTECTS WINDOWS FROM DIRECT SOLAR PENETRATION**

Kenindia House, Nairobi
Source:*http://bauzeitgeist.blogspot.co.ke/2013/08/hauptstadt-von-ostafrika.html © MM Jones*

- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.

- Additional heating systems such as fireplaces can be incorporated in the design.

- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

FIGURE 177 **ALL WINDOWS IN THE MAIN FAÇADE ARE ORIENTED FACING NORTH. THEY ARE DEEPLY RECESSED TO PREVENT DIRECT SOLAR RADIATION AND GLARE. HORIZONTAL ALUMINIUM LIGHT SHELVES REFLECT SOLAR RADIATION WHILE REFLECTING LIGHT INTO THE INTERIOR SPACES**

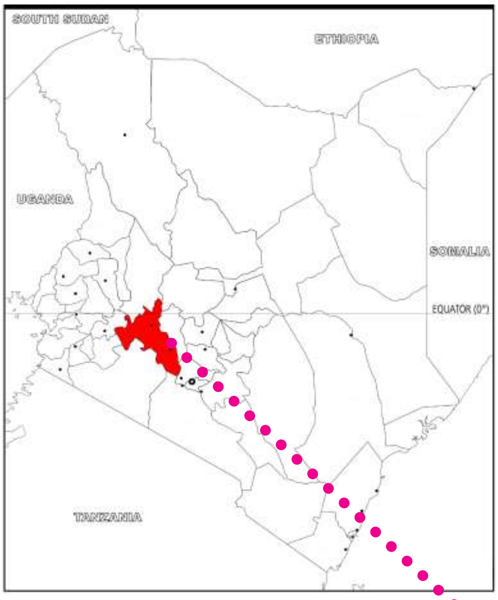
Coca cola building, Nairobi © UN-Habitat / Jerusha NGUNGUI

FIGURE 178 **THE WEST FACING FAÇADE IS SHADED USING WELL DESIGNED SUN SHADING ELEMENTS THAT COUPLE AS AESTHETIC ELEMENTS ENSURING NATURALLY LIT SPACES EXCLUDING SOLAR HEAT GAIN**

Administration Block, University of Nairobi
Source: *http://www.archidatum.com/projects/administration-block-university-of-nairobi/ © Karanja SAMUEL*

NAKURU

FIGURE 179 **LOCATION OF NAKURU COUNTY**



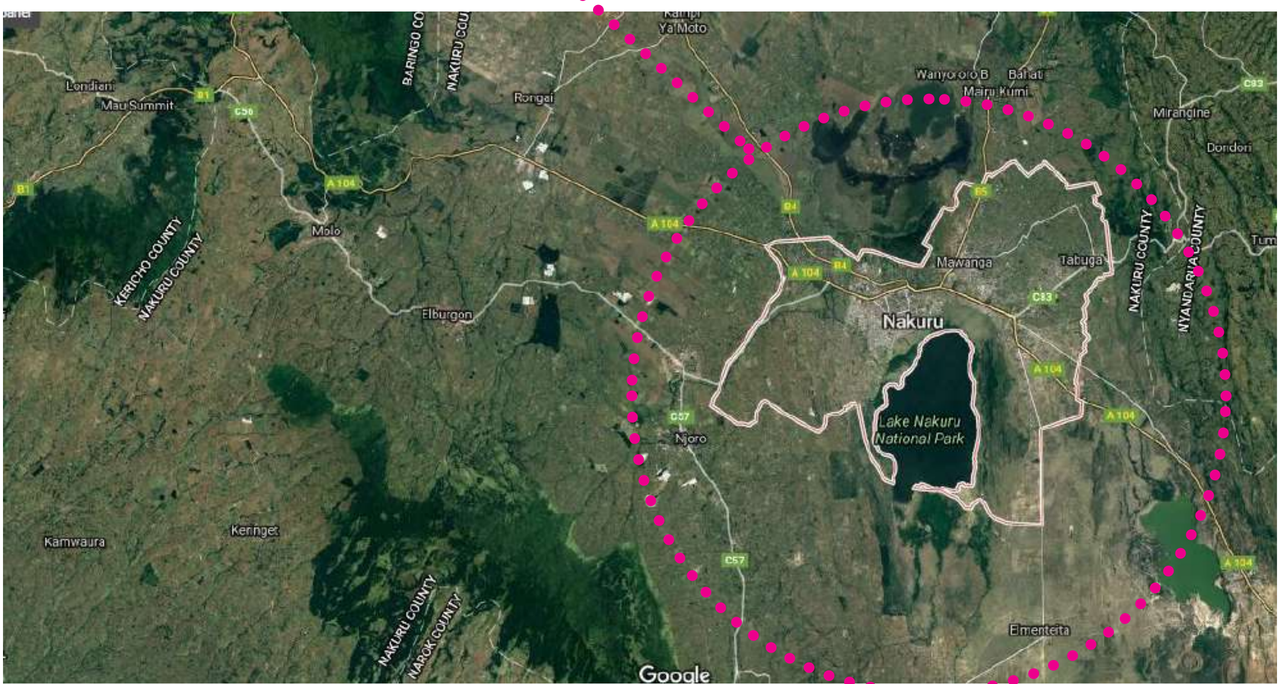
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	00° 18' S
Longitude	36° 04' E
Altitude	1,850 m

FIGURE 180 **AERIAL VIEW OF NAKURU TOWN**

Source: *https://www.flickr.com*

FIGURE 181 **LOCATION OF NAKURU TOWN IN NAKURU COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Nakuru town, the headquarters of Nakuru county, is the fourth largest urban centre in Kenya and is located at geographic coordinates of 0° 18′ S 36° 4′ E. At an elevation of 1,850 m above sea level, the town enjoys an upland climate characterised by cool temperatures (annual average of 17.8 °C) with the coolest month being July while the warmest month on average being February. The town receives over 1,120 mm of annual rainfall with the highest amount received in August and the least amount in January and February. Relative humidity is above 50% throughout the year while the wind velocity ranges 0.9 – 2.5 m/s with the predominant wind direction being North (October to April) and South East (May to September). The annual average global solar radiation in Nakuru is 5.5 kWh/m².

TABLE 20 **NAKURU MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	19.3	56.0	2.3	5.8	5.2	2.3	20
FEB	20.2	55.0	2.5	6.3	5.5	2.4	20
MAR	18.9	61.0	2.2	6.0	4.5	2.7	60
APR	18.1	75.0	1.7	5.2	3.3	2.8	180
MAY	17.9	75.0	1.8	5.2	3.7	2.6	140
JUN	17.1	73.0	1.3	5.0	3.8	2.4	120
JUL	15.9	75.0	1.6	5.1	3.6	2.5	150
AUG	17.0	72.0	1.7	5.4	3.7	2.7	190
SEP	17.1	71.0	1.9	5.8	4.2	2.6	100
OCT	17.3	73.0	1.2	5.6	3.8	2.7	50
NOV	17.2	75.0	0.9	4.9	2.9	2.8	50
DEC	17.9	67.0	2.0	5.6	4.6	2.5	40

FIGURE 182 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR NAKURU**

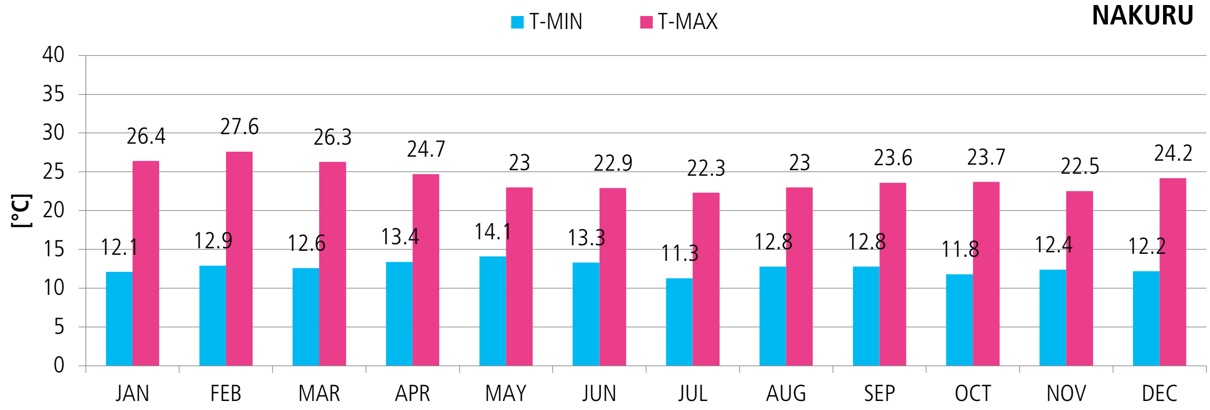


FIGURE 183 **MONTHLY MEAN RELATIVE HUMIDITY FOR NAKURU**

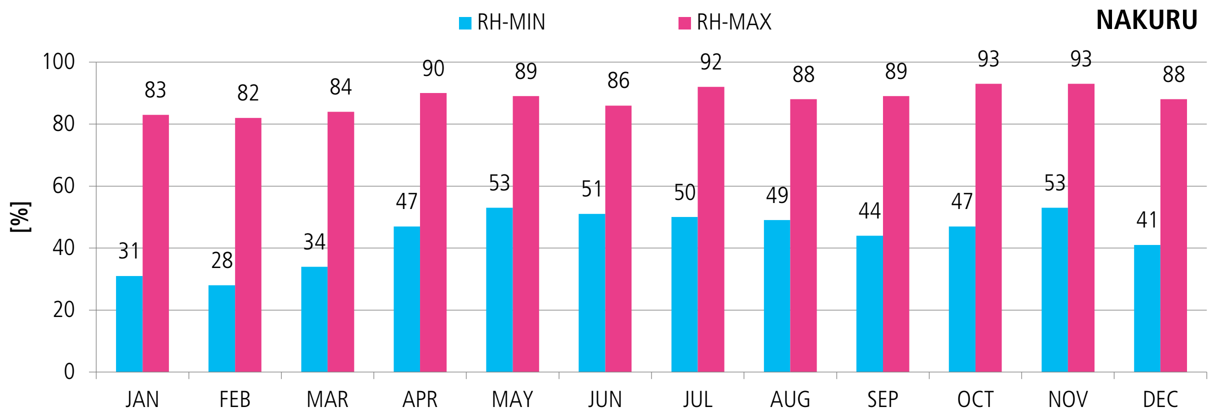


FIGURE 184 **MONTHLY AVERAGE RAINFALL FOR NAKURU**

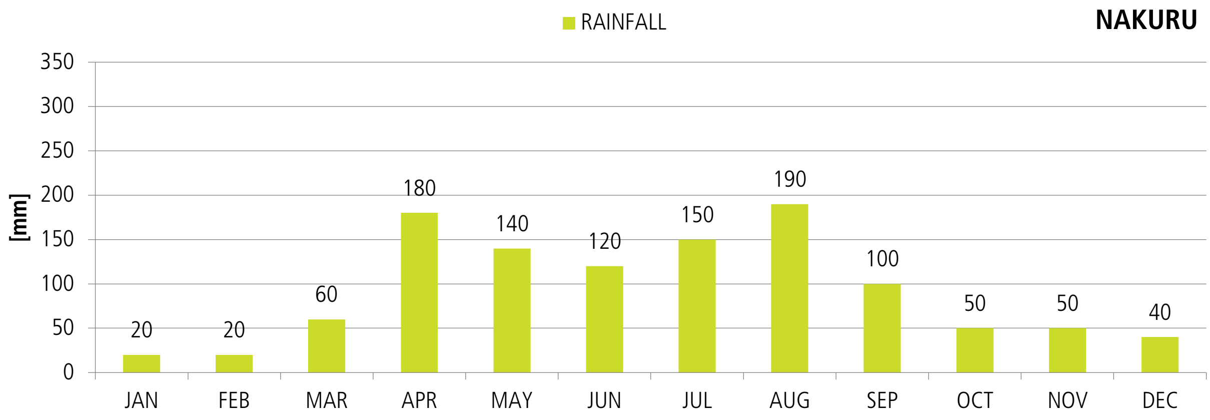


FIGURE 185 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

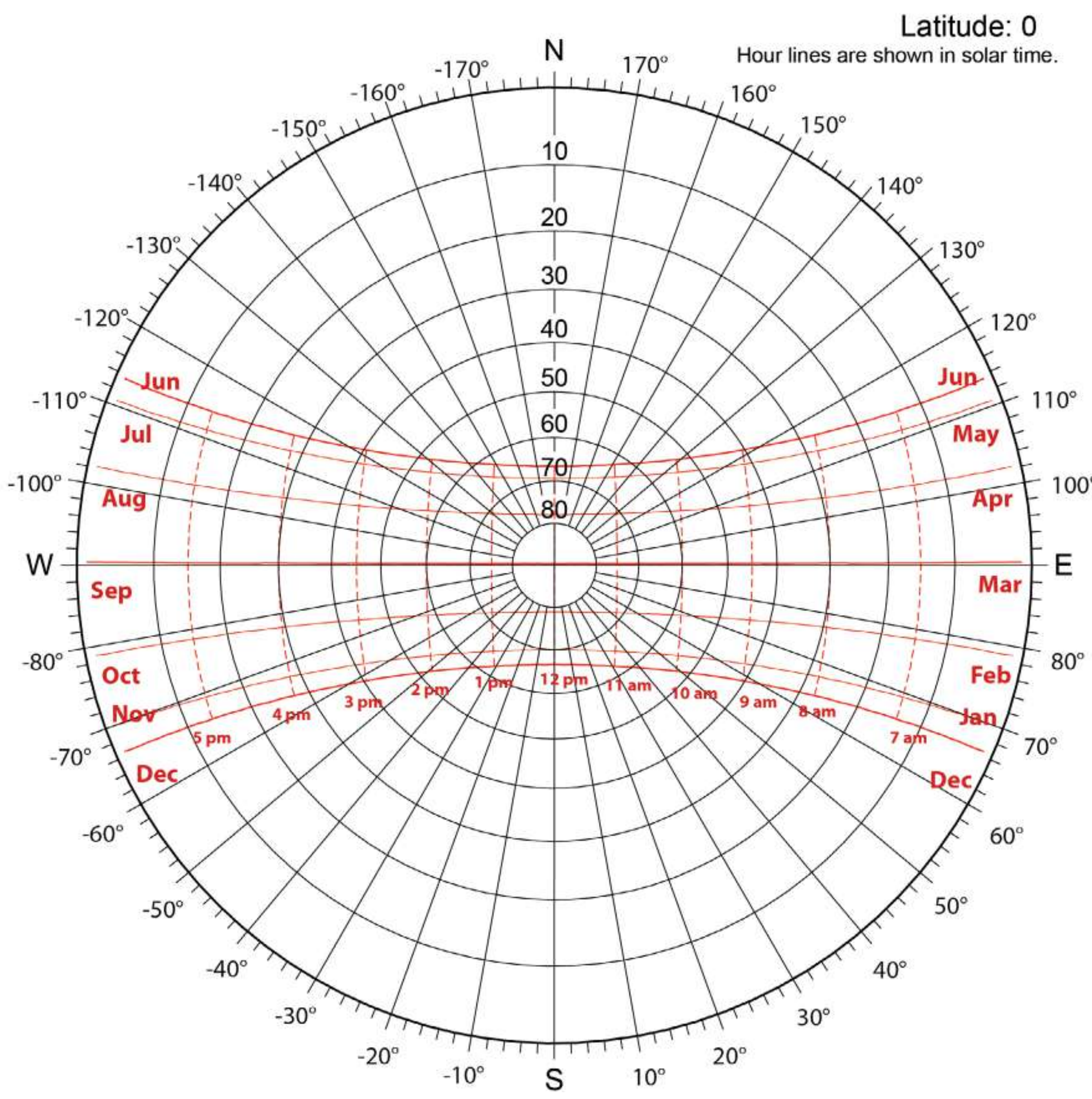


FIGURE 186 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN NAKURU**

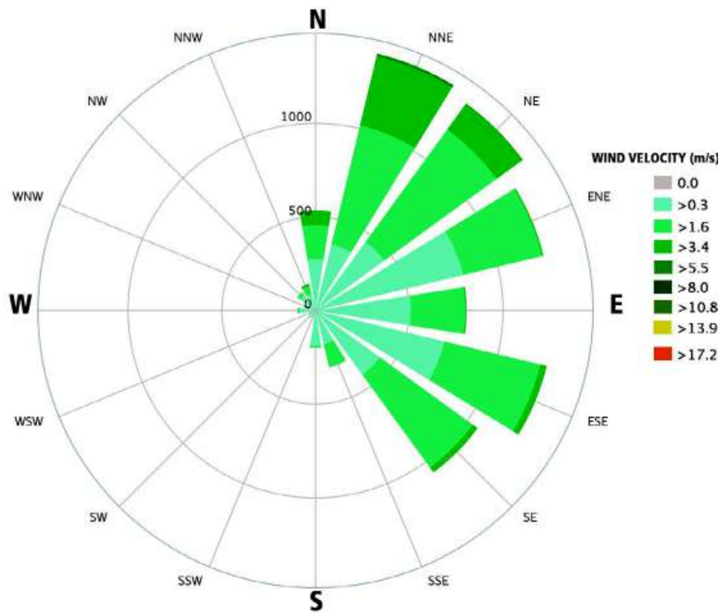
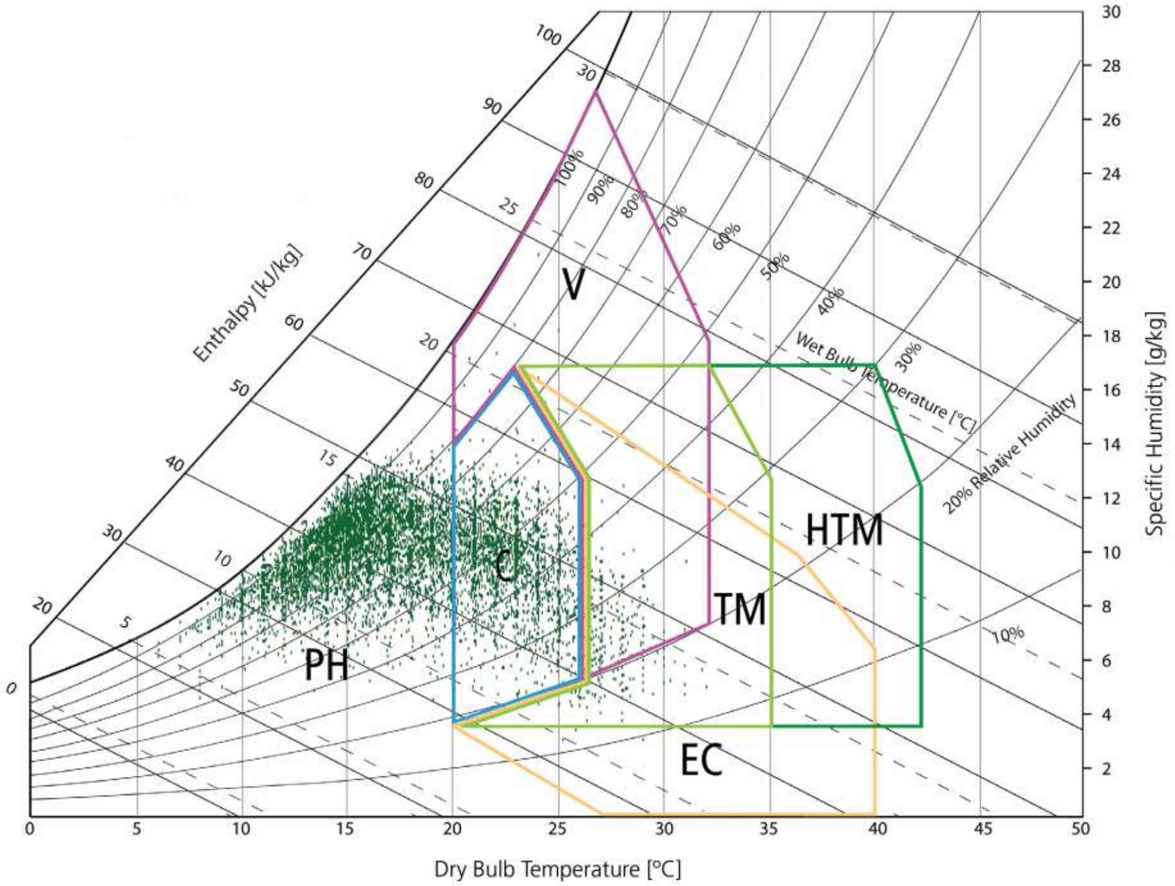


FIGURE 187 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR NAKURU**



C	Comfort Zone
V	Natural Ventilation
TM	Thermal Mass
HTM	High Thermal Mass
EC	Evaporative Cooling
PH	Passive Heating
AC	Air Conditioning

INTERPRETATION

The psychrometric chart (see Figure 187) shows that Nakuru is predominantly cool with outdoor conditions of hourly dry bulb temperatures and relative humidity falling within as well as below the comfort zone. Outdoor temperatures can go below 10 °C. This indicates that heating is necessary during the under heated period. The chart therefore suggests that the most effective strategy for extending the thermal comfort zone would be through passive heating through direct solar heat gain and thermal mass. In addition, internal heat gain from occupants, equipment and lights would contribute to a reduction in heating needs.

However, during certain times of the year, the hourly data points (outdoor dry bulb temperature and relative humidity) fall beyond the comfort zone. Thermal mass is effective in extending the comfort zone by absorbing and storing daytime solar heat for release at night when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Nakuru, the following design strategies are recommended for:

a. Enabling passive heating

- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.

FIGURE 188 **SOUTH WEST FACING ELEVATION HAS LOUVERED TIMBER OPENINGS THAT CAN BE CLOSED OFF DURING THE AFTERNOON THUS MINIMISING UNWANTED HEAT GAIN DURING THE HOT AFTERNOONS**

St. Jerome's Centre, Nakuru
Source: *https://orkidstudio.co.uk/ © Odysseas MOURTZOUCHOS*

- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.

- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.

- Additional heating systems such as fireplaces can be incorporated in the design.

- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

b. Protection against heat gain in the hot period

- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.

- Large windows should be avoided on the east and west facing façades.

- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

FIGURE 189 **EARTH BAGS, MADE FROM GRAIN BAGS FILLED LARGE QUANTITIES OF SOIL (20% CLAY CONTENT) ARE LAID LIKE OVERSIZED BRICKS TO CREATE DEEP HIGH THERMAL MASS WALLS. THESE WALLS ARE EFFECTIVE IN ABSORBING HEAT FROM THE SUN, THUS HELPING REGULATE TEMPERATURES DURING THE COOL NIGHTS.**

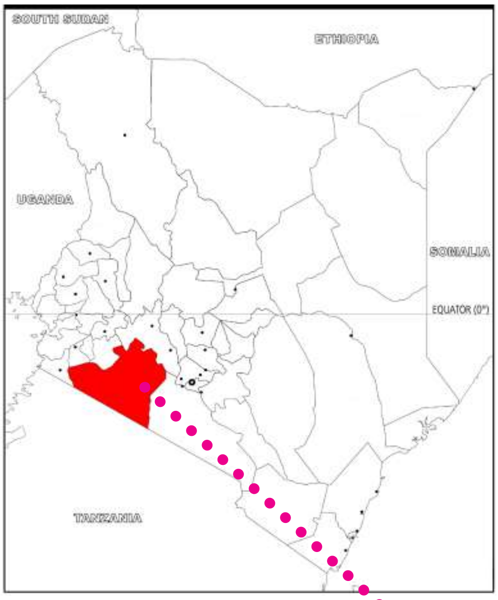
St. Jerome's Centre, Nakuru
Source: *https://orkidstudio.co.uk/ © Odysseas MOURTZOUCHOS*

FIGURE 190 **LOUVERED TIMBER OPENINGS ENABLE AIRFLOW THUS ENCOURAGING NATURAL VENTILATION**

St. Jerome's Centre, Nakuru
Source: *https://orkidstudio.co.uk/ © Odysseas MOURTZOUCHOS*

NAROK

FIGURE 191 **LOCATION OF NAROK COUNTY**



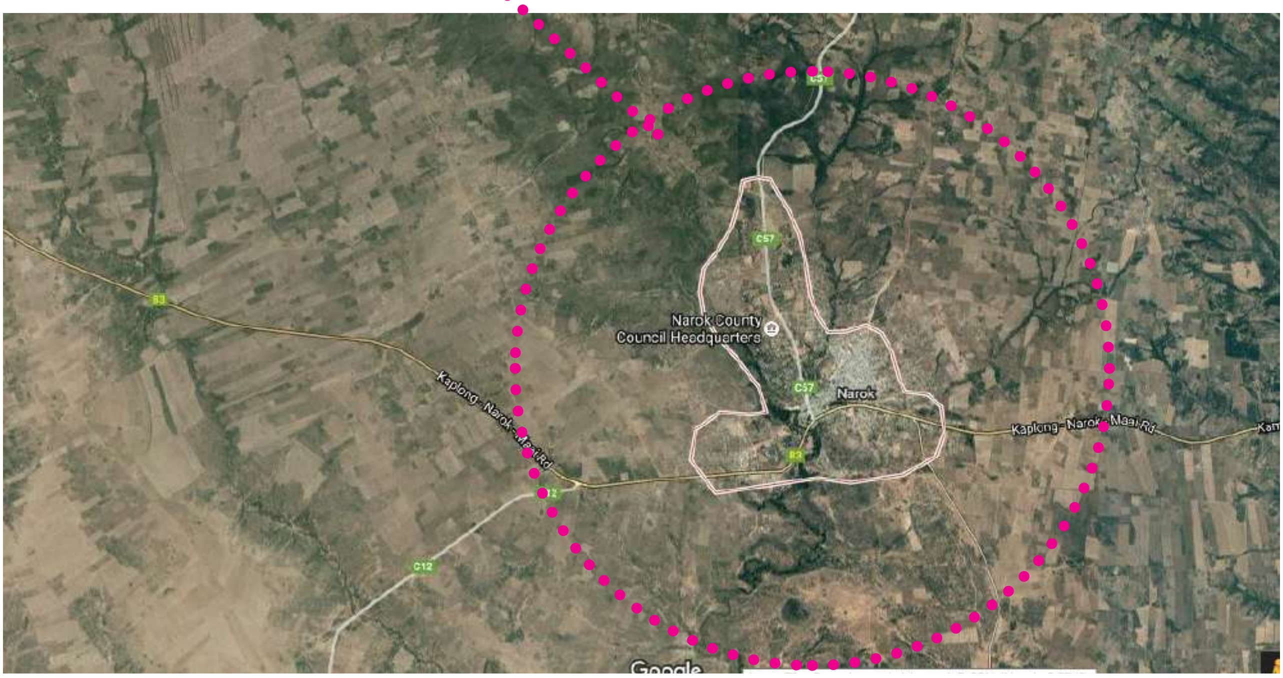
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	01° 05' N
Longitude	35° 52' E
Altitude	1,827 m

FIGURE 192 **VIEW OF NAROK TOWN**

Source: *http://www.mediamaxnetwork.co.ke/wp-content/uploads/2016/10/narok-town.jpg © Mayian Digital {James}*

FIGURE 193 **LOCATION OF NAROK TOWN IN NAROK COUNTY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Narok town, which is the headquarters of Narok county, is located at geographic coordinates of 01° 05′ S 35° 52′ E at an elevation of 1,827 m above sea level. Its climate is categorised as upland with average annual temperatures of 17.3 °C. The hottest month on average is March and the coolest month recorded is July. Rainfall in Narok averages 770 mm with the wettest month being April while the driest being July. Relative humidity is above 64% throughout the year while the wind velocity ranges 2.6 – 4.9 m/s with the predominant wind direction being North (October to March) and East / South East (April to September). The annual average global solar radiation in Narok is 5.3 kWh/m².

TABLE 21 **NAROK MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	17.8	72.0	2.4	5.6	4.8	2.3	74.6
FEB	18.3	67.0	3.7	6.1	5.1	2.4	69.1
MAR	18.4	67.0	4.0	5.9	4.5	2.5	90.6
APR	17.8	80.0	3.1	5.0	2.9	2.9	149.9
MAY	17.4	80.0	3.4	4.7	3.0	2.6	95.9
JUN	15.7	80.0	2.7	4.5	2.9	2.5	35.1
JUL	15.6	76.0	3.0	4.8	3.3	2.5	24.7
AUG	15.9	71.0	3.8	5.3	3.7	2.6	28.7
SEP	16.7	68.0	3.5	5.6	3.9	2.6	29.2
OCT	18.3	64.0	4.9	5.6	3.8	2.8	30.6
NOV	17.5	70.0	4.4	5.1	3.5	2.7	66.8
DEC	17.9	67.0	2.6	5.5	4.5	2.5	75.7

FIGURE 194 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR NAROK**

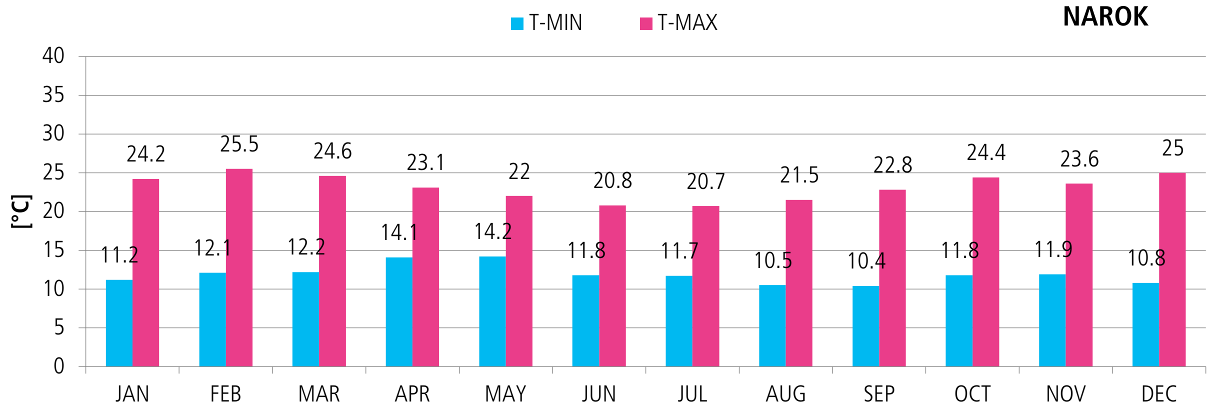


FIGURE 195 **MONTHLY MEAN RELATIVE HUMIDITY FOR NAROK**

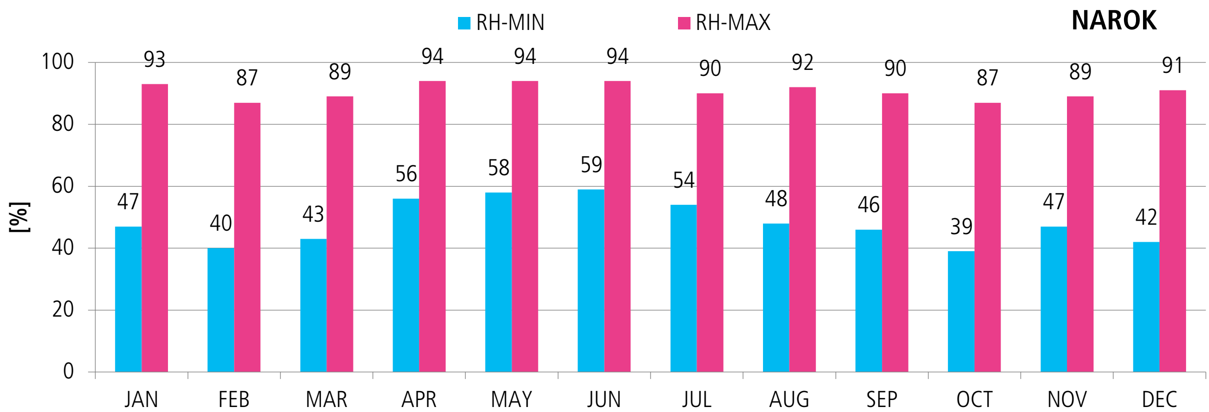


FIGURE 196 **MONTHLY AVERAGE RAINFALL FOR NAROK**

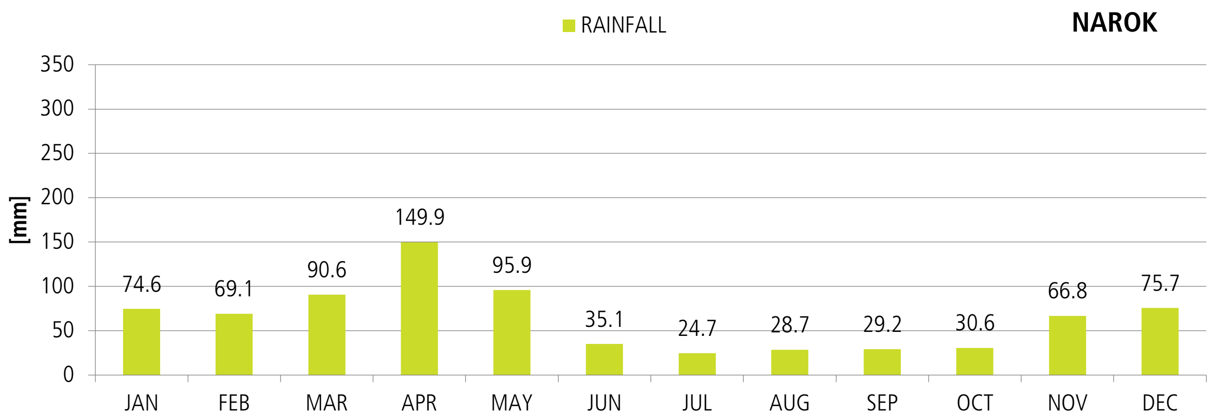


FIGURE 197 **POLAR SUN PATH DIAGRAM FOR LATITUDE 1° SOUTH**

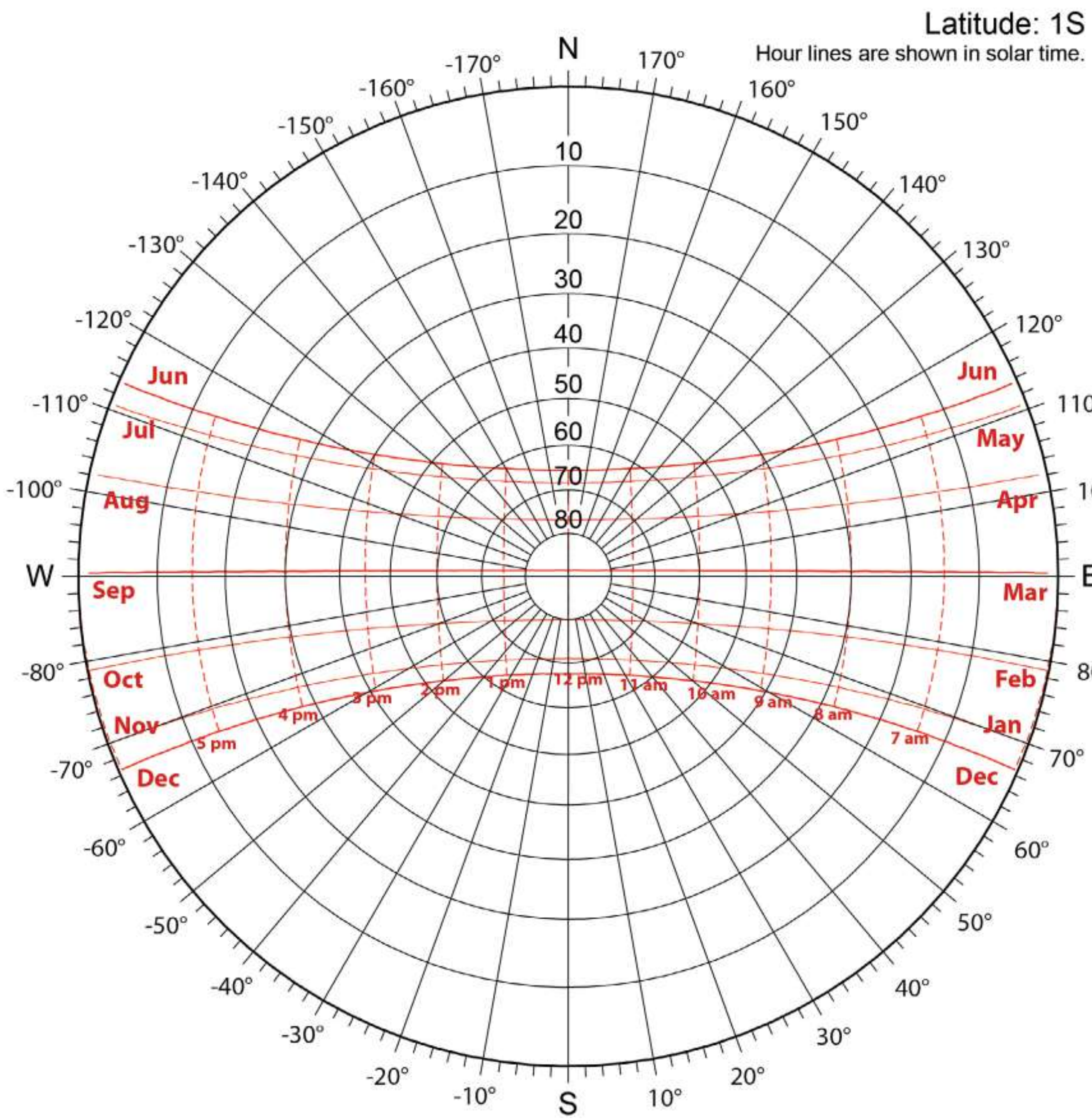


FIGURE 198 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN NAROK**

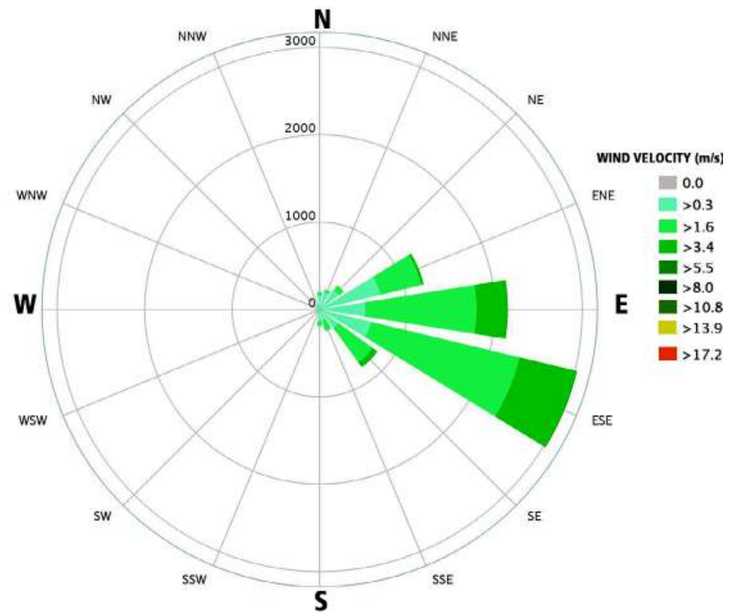
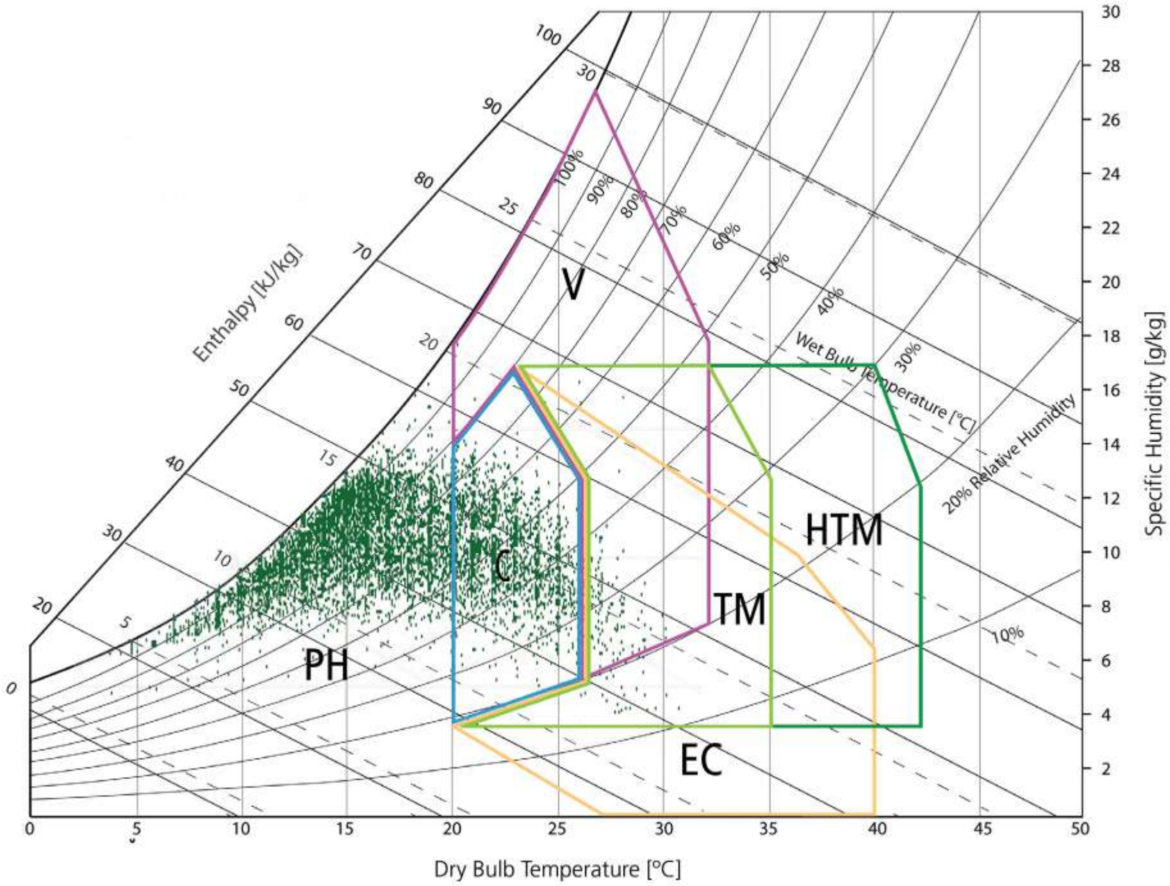


FIGURE 199 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR NAROK**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

Narok's climate is predominantly cool with outdoor conditions of hourly dry bulb temperatures and relative humidity falling within as well as below the comfort zone (see Figure 199). Outdoor temperatures can go as low as 5 °C. This indicates that heating is necessary during the under heated period. The chart therefore suggests that the most effective strategy for extending the thermal comfort zone would be through passive heating through direct solar heat gain and thermal mass. In addition, internal heat gain from occupants, equipment and lights would contribute to a reduction in heating needs.

However, during certain times of the year, the hourly data points (outdoor dry bulb temperature and relative humidity) fall beyond the comfort zone. Thermal mass is effective in extending the comfort zone by absorbing and storing daytime solar heat for release at night when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Narok, the following design strategies are recommended for:

a. Enabling passive heating

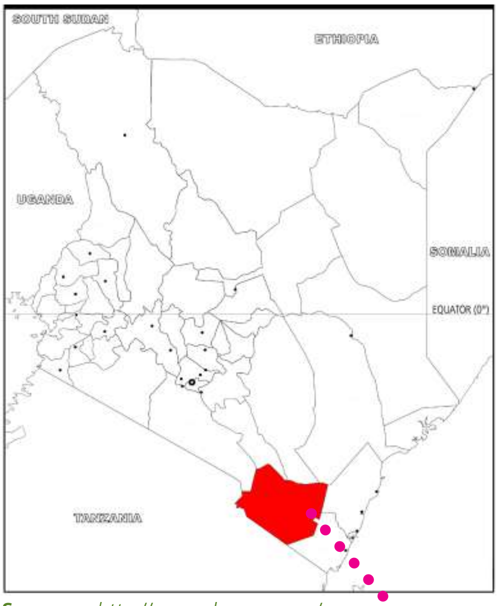
- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.
- Additional heating systems such as fireplaces can be incorporated in the design.
- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

b. Protection against heat gain in the hot period

- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

VOI

FIGURE 200 **LOCATION OF TAITA-TAVETA COUNTY**



Source: *http://www.d-maps.com/*

Climatic Zone	HOT SEMI-ARID / SAVANNAH
Latitude	03° 23′ S
Longitude	38° 34′ E
Altitude	580 m

FIGURE 201 **VOI TOWN CENTER**

Source: *© Makoto Questions - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=24729216*

FIGURE 202 **LOCATION OF VOI TOWN IN TAITA-TAVETA COUNTY**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Voi, the largest town in Taita - Taveta county, is located at geographic coordinates of 3° 23′ S 38° 34′ E. At an altitude of 580 m above sea level, the town has savannah climate with annual temperatures averaging 24.5 °C. The warmest month of the year is February. July and August present the months with the lowest average temperatures of the whole year. About 490 mm of rain falls annually with the most amount occurring in December. June, July and August present the driest months with no rainfall at all. Relative humidity averages at 67 % annually while the wind velocity ranges 2.2 – 4.2 m/s with the predominant wind direction being South and South East. The annual average global solar radiation in Voi is 5.2 kWh/m².

TABLE 22 **VOI MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	25.2	70.0	3.0	5.5	3.5	3.0	30
FEB	26.4	66.0	2.9	5.9	4.2	2.8	30
MAR	26.2	67.0	3.0	5.7	3.8	2.8	70
APR	25.5	70.0	3.5	5.2	3.2	2.8	90
MAY	24.3	71.0	3.4	4.7	3.3	2.5	30
JUN	23.4	64.0	4.0	4.7	3.6	2.3	0
JUL	22.8	62.0	3.9	4.6	3.6	2.3	0
AUG	22.3	64.0	4.2	4.9	3.7	2.4	0
SEP	23.2	64.0	4.0	5.4	3.8	2.6	10
OCT	24.6	64.0	3.0	5.6	3.8	2.8	20
NOV	25.2	70.0	2.7	5.2	3.1	2.9	90
DEC	24.4	76.0	2.2	5.0	3.0	2.8	120

FIGURE 203 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR VOI**

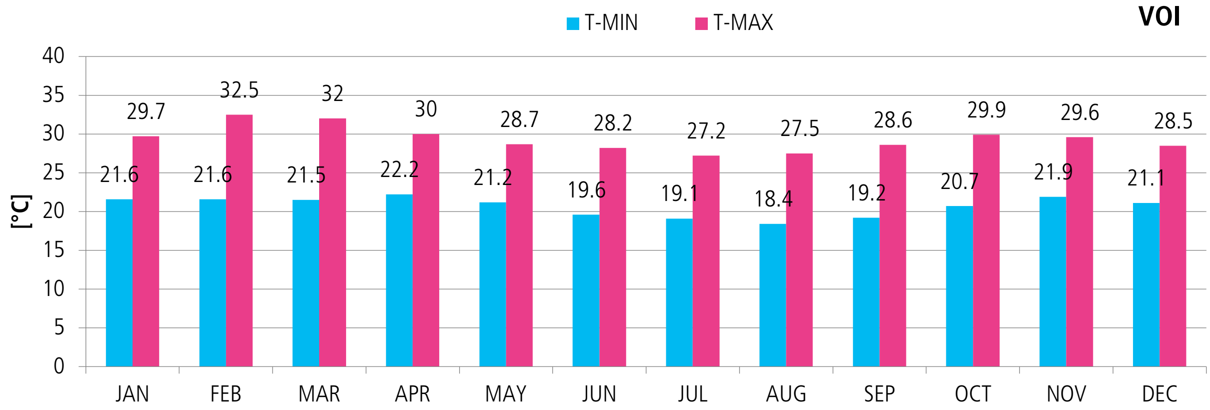


FIGURE 204 **MONTHLY MEAN RELATIVE HUMIDITY FOR VOI**

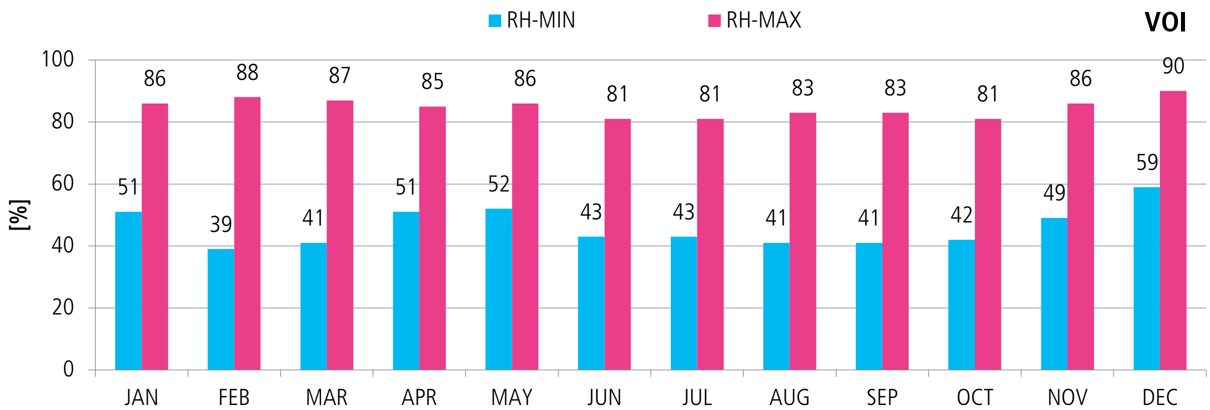


FIGURE 205 **MONTHLY AVERAGE RAINFALL FOR VOI**

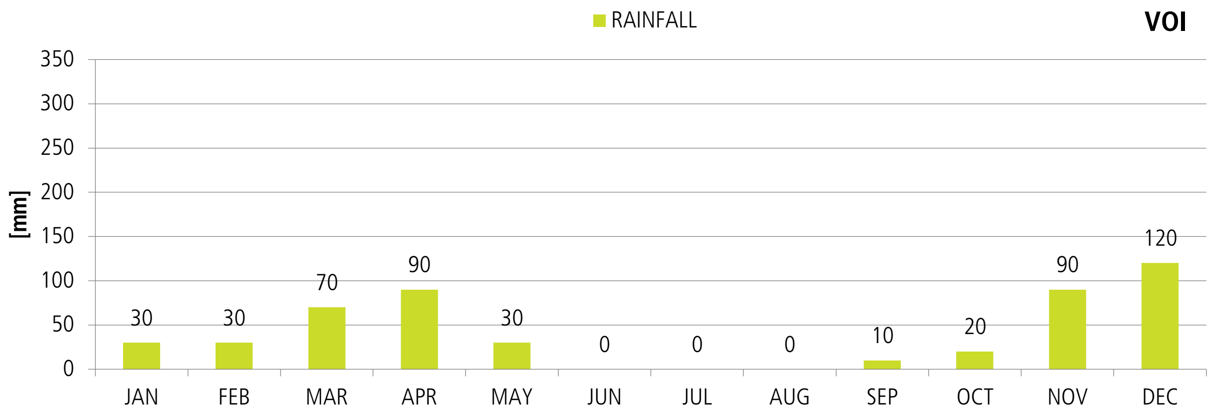


FIGURE 206 **POLAR SUN PATH DIAGRAM FOR LATITUDE 3° SOUTH**

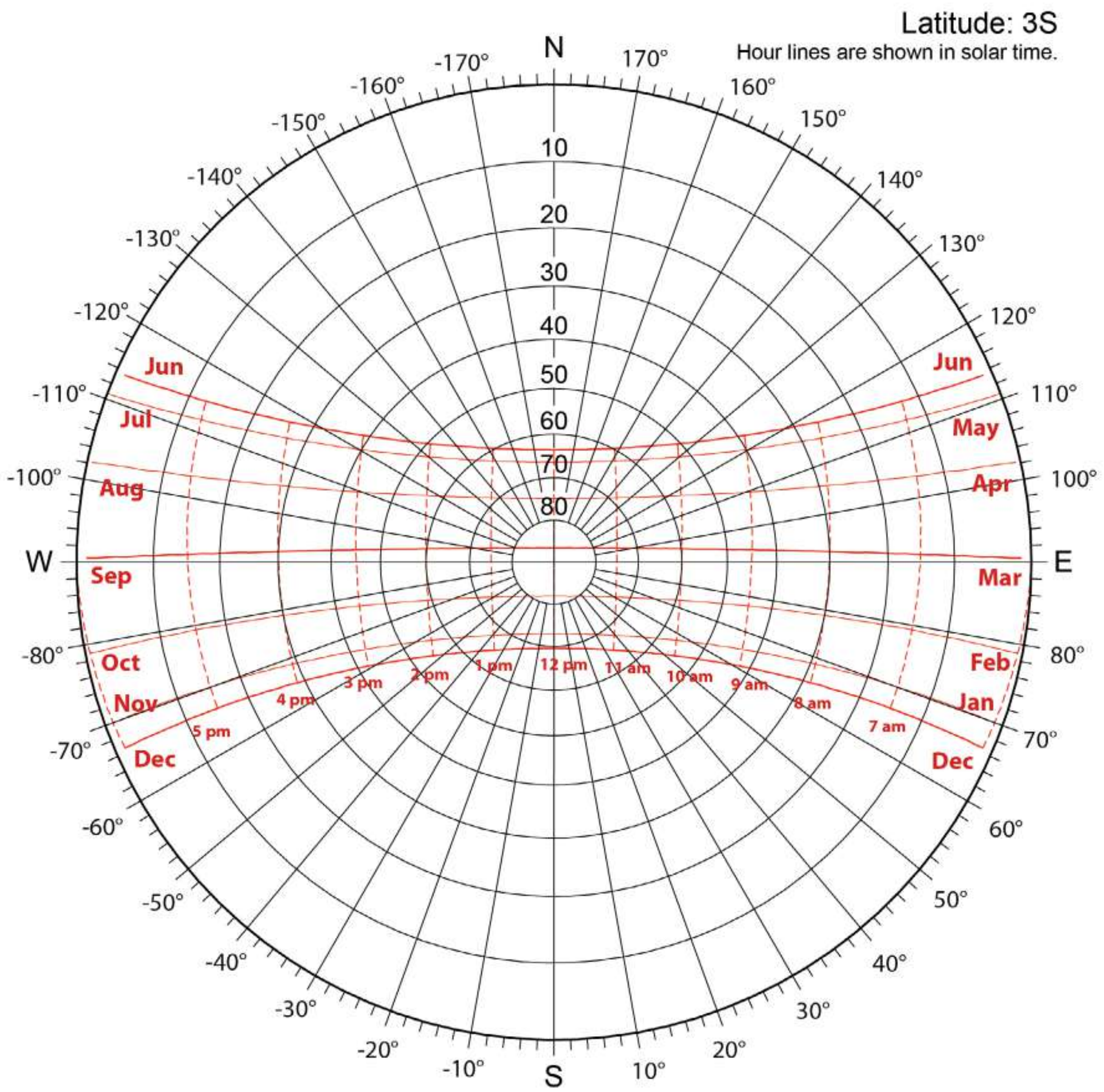


FIGURE 207 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN VOI**

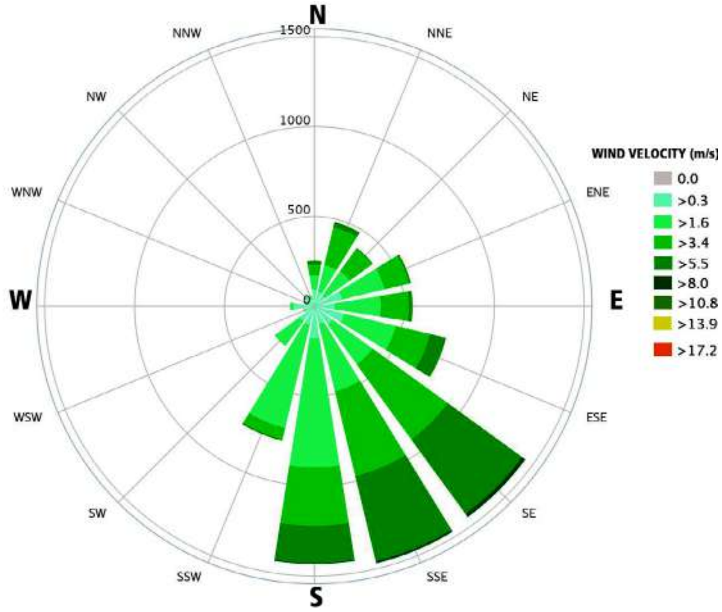
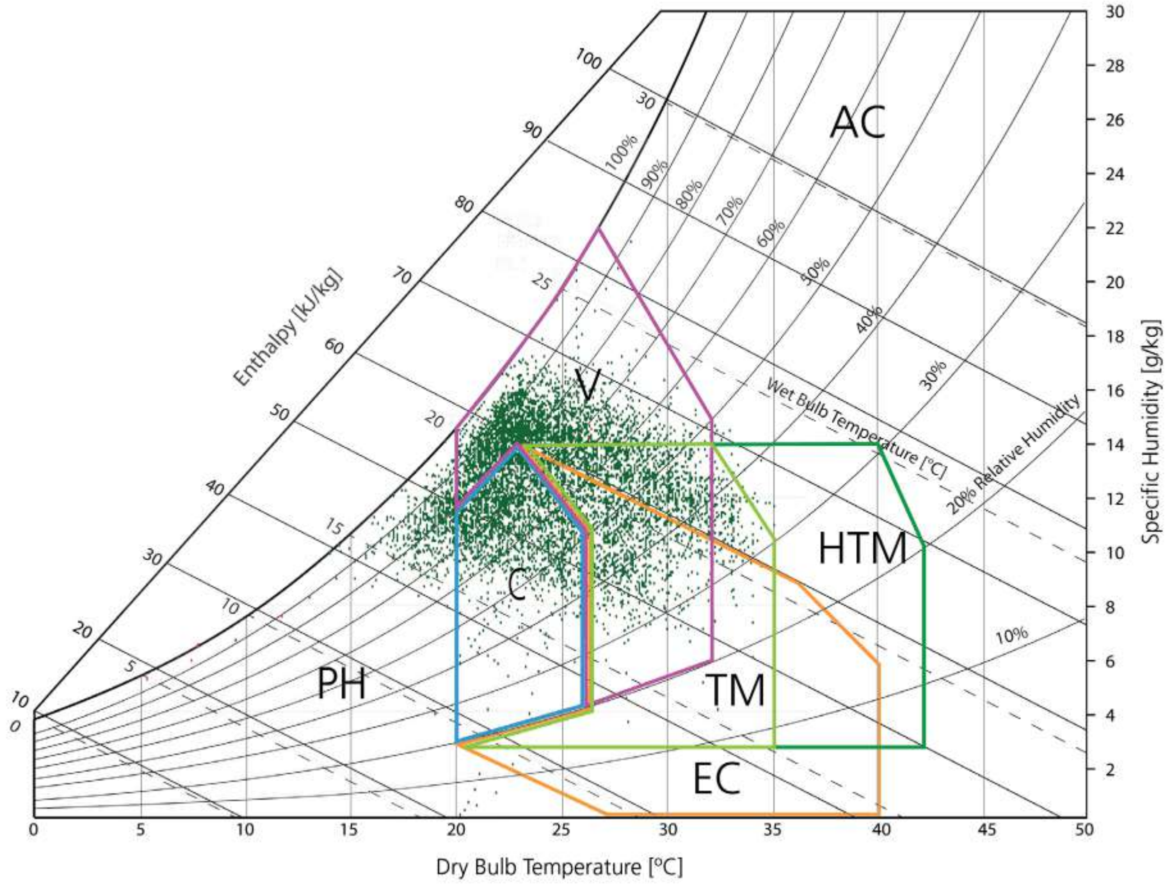


FIGURE 208 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR VOI**



C Comfort Zone	EC Evaporative Cooling
V Natural Ventilation	PH Passive Heating
TM Thermal Mass	AC Air Conditioning
HTM High Thermal Mass	

INTERPRETATION

Voi experiences both hot and cold conditions that fall above and below the comfort zone respectively as seen in Figure 208. Based on the psychrometric chart, a combined effect of natural ventilation, high thermal mass (along with night ventilation) are the most effective strategies to improve thermal comfort during the overheated period. In the case of the under heated period, passive heating through direct solar heat gain and thermal mass are effective in expanding the comfort zone when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

- In Voi, the design objective should be to balance the conflicting needs of the cold and hot periods to provide comfort. The following design strategies are recommended:

a. To reduce effects of intense solar radiation

- Compact layout of buildings is recommended to provide mutual shading and minimise exposure to solar radiation.
- Courtyard design of buildings minimises the impact of solar radiation on the outer walls as well as provide cool spaces with the buildings / building layout.
- Buildings should be oriented along the east – west axis with the longer sides facing north and south to prevent solar heat gains. The building's surface area exposed to the east and west should be minimised.
- Openings should be located on the north and south. Small openings that are located high on the walls are recommended to facilitate natural ventilation as well as reduce glare from light reflected from the ground or surrounding buildings.
- Appropriate shading devices are necessary on all openings to decrease heat gain from solar radiation. Use of vegetation, verandas, covered walkways, pergolas etc. is recommended to provide shade to walls, openings and outdoor spaces.
- Use of reflective surfaces (roof) and light coloured external walls are effective in reflecting solar radiation thus minimising solar heat gains and consequently minimising internal daytime temperatures.

b. To balance diurnal temperature range

- Medium weight building materials with high thermal capacity are recommended to balance temperature variations between day and night. These materials absorb heat during daytime keeping indoor temperatures lower than outdoor temperature. The stored heat is later dissipated at night thereby providing indoor thermal comfort when the outdoor temperatures fall below the comfort zone.

c. To ensure air circulation

- Openings should be located to take advantage of prevailing winds and allow for cross-ventilation.
- Ventilation through windows should be kept at a minimum during the daytime to keep hot and dusty air out. However, at night, windows may be opened to provide adequate ventilation for dissipation of heat accumulated during the day by walls and the roof to prevent overheating of the interior space.
- Other ventilation strategies include use of wind catchers, wind towers, solar chimneys, roof-mounted exhaust fans etc.

d. To minimise problems associated with dust

- Vegetation can be used to filter dust from the air before it gets into the building.
- Closing windows during daytime prevents dust from getting into the building on windy days. Windows should be tight-fitting as possible to prevent dust from infiltrating.

6.2 TANZANIA

FIGURE 209 **MAP OF AFRICA SHOWING THE LOCATION OF TANZANIA**

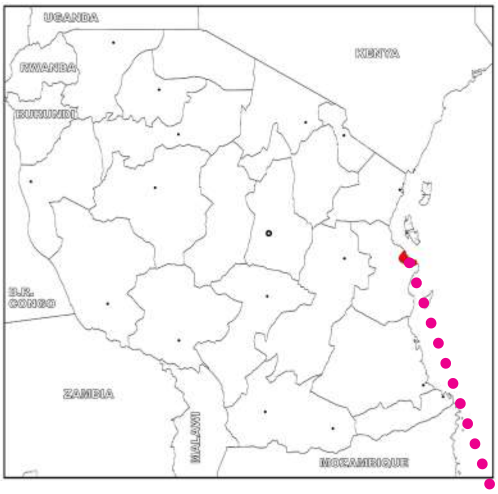
Source: *http://www.d-maps.com/*

TABLE 23 **REPRESENTATIVE TOWNS IN KENYA**

CITY/TOWN	ALTITUDE (M)	LATITUDE	LONGITUDE	CLIMATE ZONE
Arusha	1,400 m	3°32′ S	36° 40′ E	Zone 5 – Upland
Bukoba	1,200 m	1° 20′ S	31° 49′ E	Zone 4 – Great Lakes
Dar es Salaam	55 m	6° 48′ S	39° 17′ E	Zone 1 – Hot and humid
Dodoma	1,120 m	6° 10′ S	35° 45′ E	Zone 3 – Hot semi-arid / Savannah
Iringa	1,600 m	7° 46′ S	35° 41′ E	Zone 5 – Upland
Kasulu	1,500 m	4° 34′ S	30° 06′ E	Zone 5 – Upland
Mbeya	1,800 m	8° 56′ S	33° 28′ E	Zone 5 – Upland
Mwanza	1,140 m	2° 28′ S	32° 54′ E	Zone 4 – Great Lakes
Tabora	1,190 m	5° 04′ S	32° 50′ E	Zone 3 – Hot semi-arid / Savannah
Tanga	35 m	5° 04′ S	39° 05′ E	Zone 1 – Hot and humid
Zanzibar	15 m	6° 13′ S	39° 12′ E	Zone 1 – Hot and humid

DAR ES SALAAM

FIGURE 210 **LOCATION OF DAR ES SALAAM**



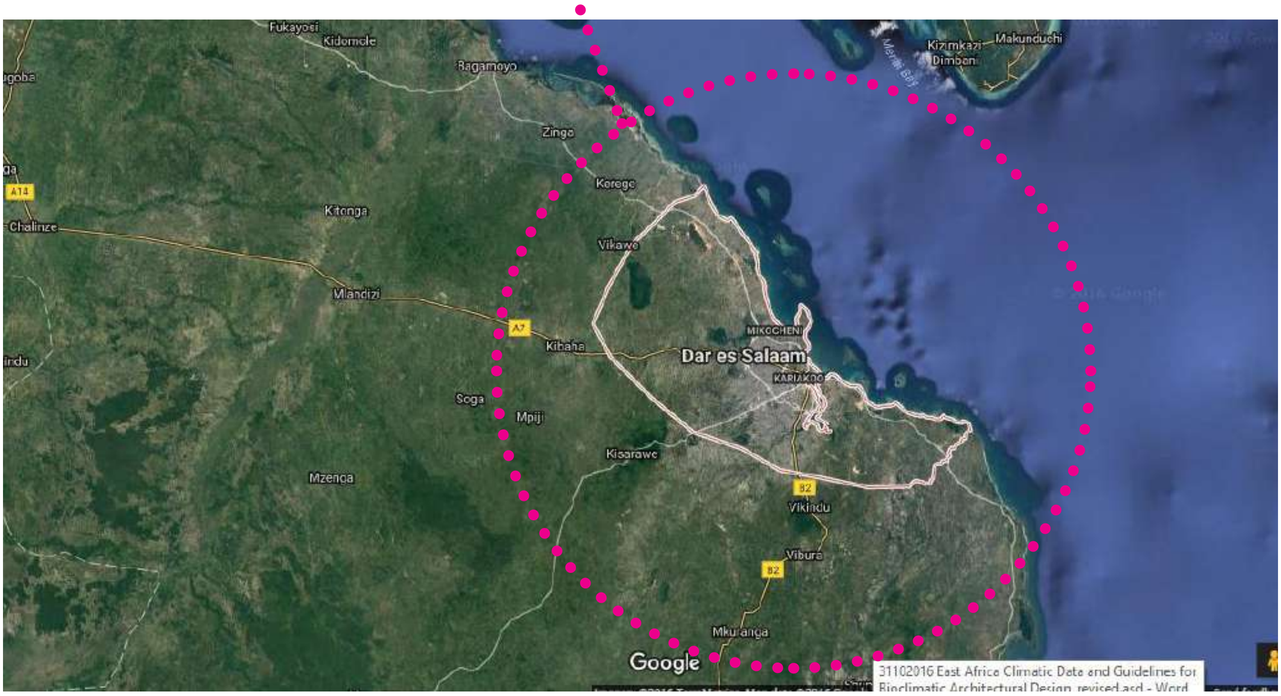
Source: *http://www.d-maps.com/*

Climatic Zone	HOT AND HUMID
Latitude	06° 48’ S
Longitude	39° 17’ E
Altitude	55 m

FIGURE 211 **AERIAL VIEW OF DAR ES SALAAM**

Source: *© Chen HUALIN*

FIGURE 212 **LOCATION OF DAR ES SALAAM CITY**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Dar es Salaam, situated along the Indian Ocean, is the largest city in Tanzania and is located at geographic coordinates of 06° 48′ S, 39° 17′ E and at an elevation of 55 m above sea level. It enjoys a hot and humid climate with high temperatures throughout the year (average of 26 °C) as well as high relative humidity (annual mean of 80.3%). The hottest month on average is February while the coolest period occurs in July and August. The average amount of rainfall recorded annually is 990 mm with the highest recorded amount in April and the least amount in July to September. High wind velocity is recorded annually at an average of 3.9 m/s with the predominant wind direction being South South East (SSE). The annual average global solar radiation in Dar es Salaam is 4.8 kWh/m².

TABLE 24 **DAR ES SALAAM MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	27.8	80.0	4.1	5.1	3.1	2.9	70
FEB	28.2	77.0	4.1	5.2	3.1	2.9	60
MAR	27.8	83.0	4.1	4.7	2.4	3.0	120
APR	26.3	87.0	3.1	3.9	2.0	2.5	260
MAY	25.5	83.0	3.6	4.4	3.1	2.4	180
JUN	24.1	81.0	4.1	4.4	3.6	2.1	30
JUL	23.9	77.0	3.6	4.4	3.4	2.3	20
AUG	23.9	77.0	3.6	4.8	3.4	2.5	20
SEP	24.1	79.0	4.1	4.9	3.3	2.6	20
OCT	25.7	78.0	4.1	5.3	3.9	2.5	40
NOV	26.3	81.0	4.1	5.8	4.5	2.6	80
DEC	27.8	81.0	4.6	5.3	3.7	2.7	90

FIGURE 213 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR DAR ES SALAAM**

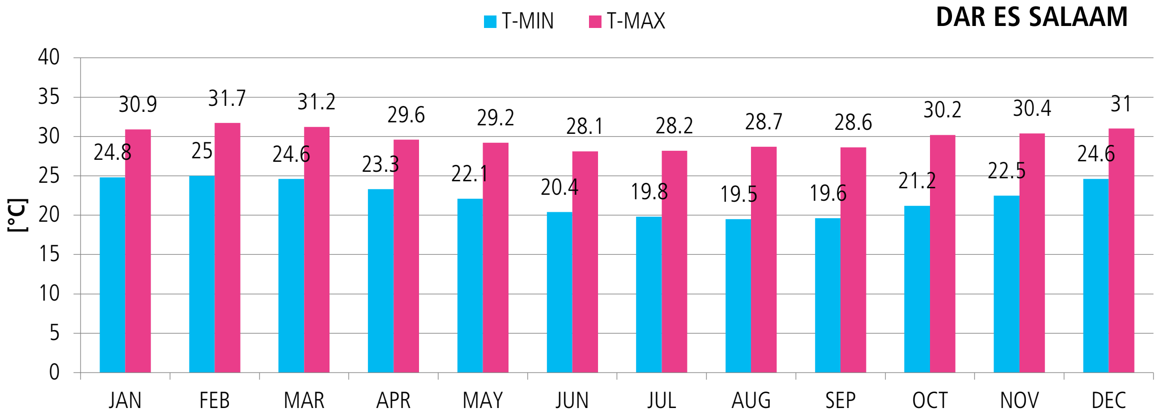


FIGURE 214 **MONTHLY MEAN RELATIVE HUMIDITY FOR DAR ES SALAAM**

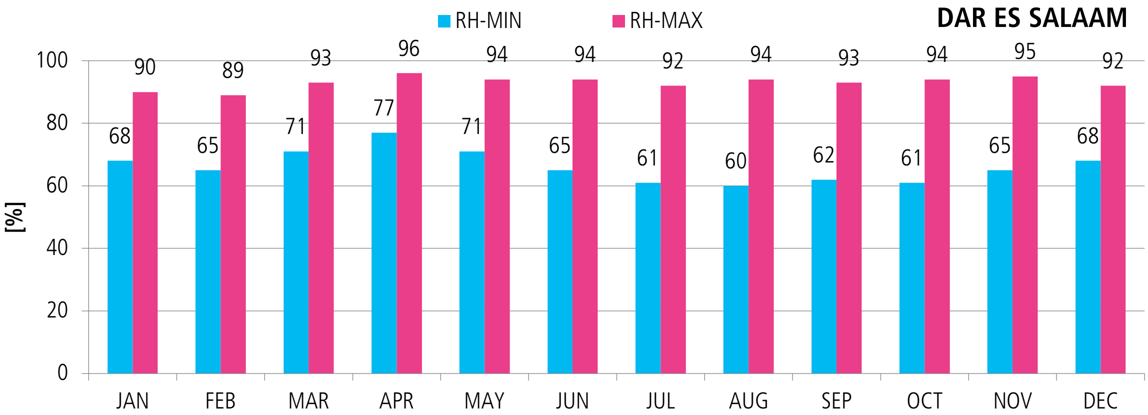


FIGURE 215 **MONTHLY AVERAGE RAINFALL FOR DAR ES SALAAM**

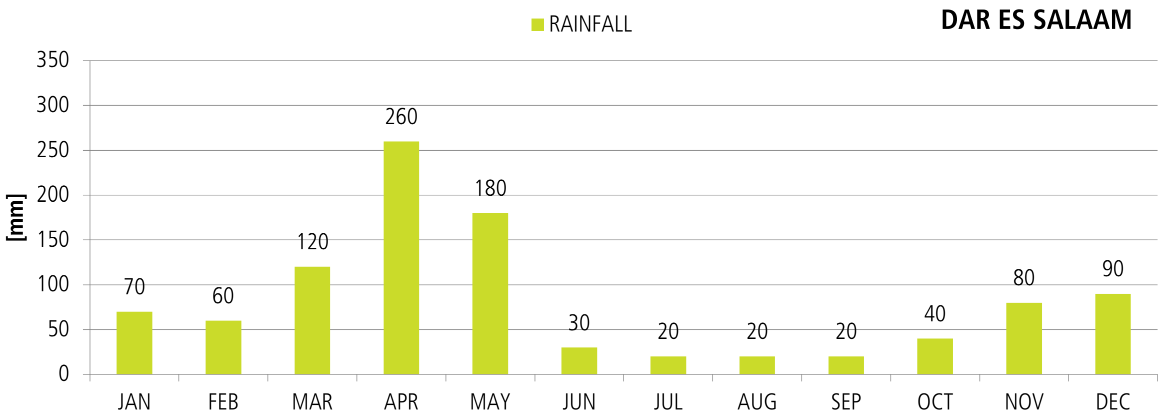


FIGURE 216 **POLAR SUN PATH DIAGRAM FOR LATITUDE 6° SOUTH**

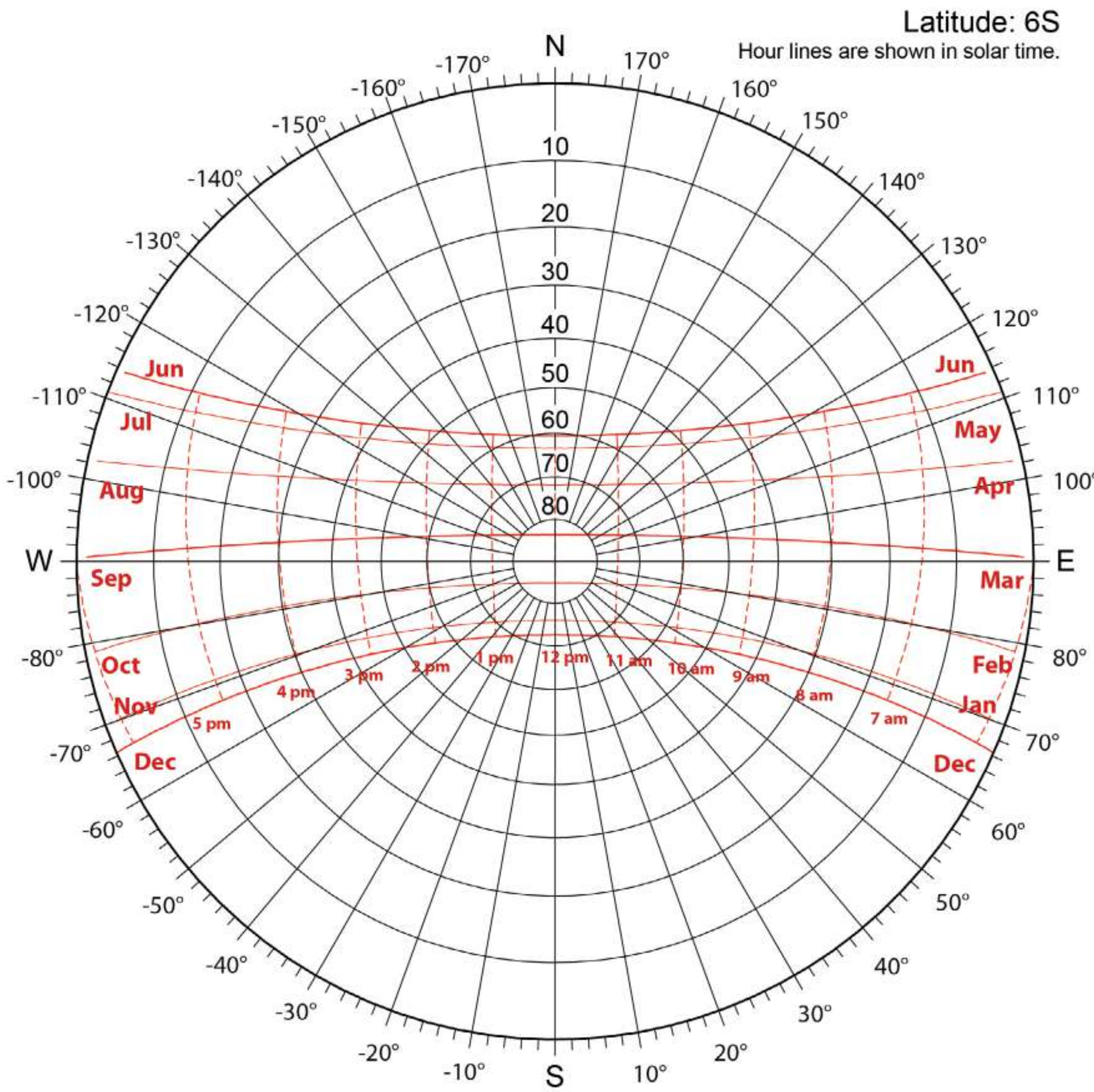


FIGURE 217 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN DAR ES SALAAM**

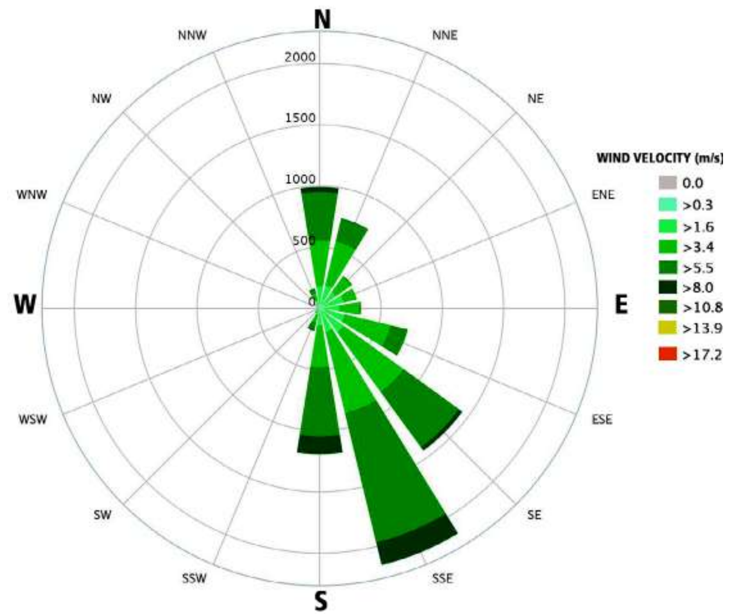
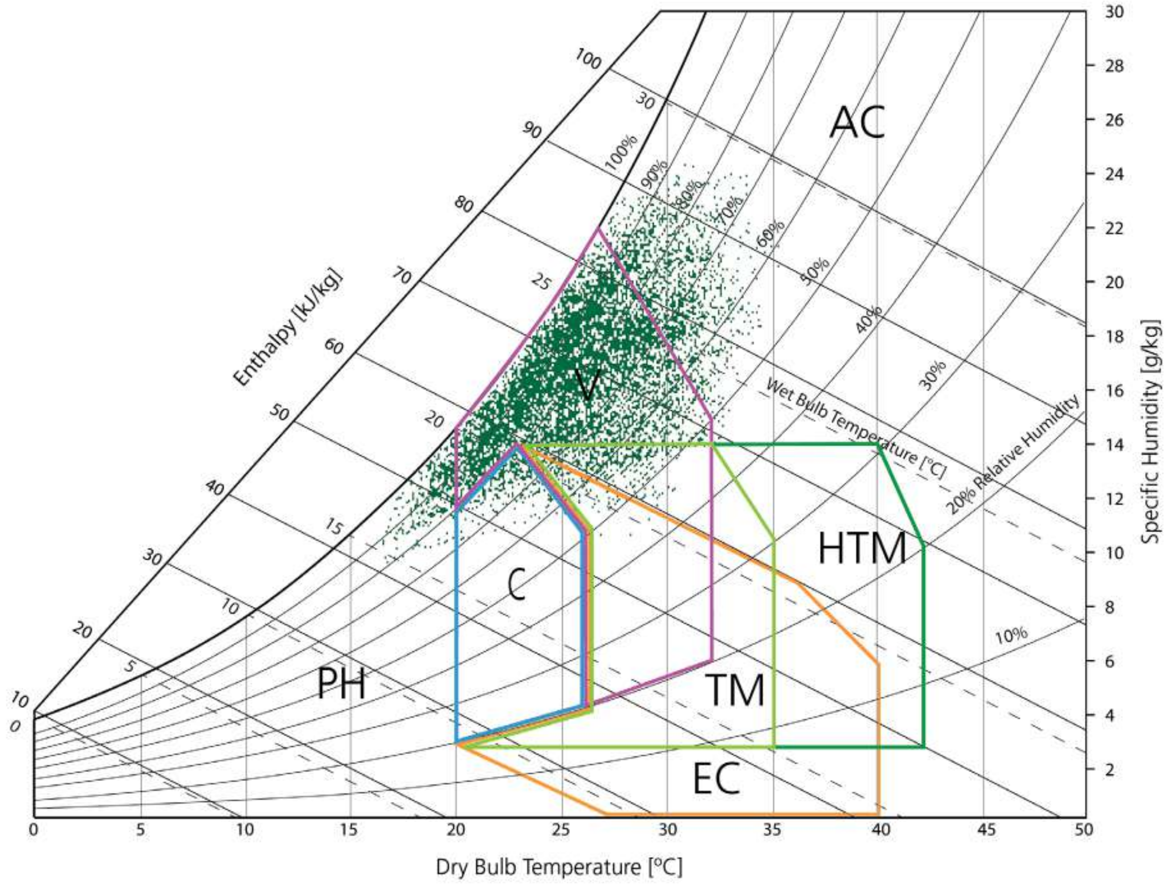


FIGURE 218 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR DAR ES SALAAM**



C Comfort Zone

V Natural Ventilation

TM Thermal Mass

HTM High Thermal Mass

EC Evaporative Cooling

PH Passive Heating

AC Air Conditioning

INTERPRETATION

The outdoor hourly dry bulb temperatures and relative humidity data points indicate that Dar es Salaam is out of the comfort zone. The resulting combination of high temperatures and high relative humidity causes discomfort in the region throughout the year. Thermal comfort can however be achieved passively through natural ventilation for temperatures below 33 °C but beyond the comfort zone. This makes it the most appropriate strategy to extend the comfort zone. However, Figure 218 indicates that artificial cooling using fans or air conditioners will be necessary for periods where temperatures are above 33 °C.

BIOCLIMATIC RECOMMENDATIONS

The design objectives and responses for a hot and humid climate like Dar es Salaam's should be to address issues due to high temperatures, high relative humidity and high solar radiation levels. The following passive design strategies may be used to address the cooling requirements that result from the above climatic characteristics:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading.
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, covered verandas and porches etc.
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and reduce heat gains.
- Lightweight building materials with low thermal capacity are recommended for walls, floors and roofs to allow rapid cooling at night.

b. To promote maximum ventilation

- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings.
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum ventilation.
- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.
- Openings should be located on opposite sides of walls to allow for proper cross-ventilations. Internal walls should also have openings for airflow through the internal space.
- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement.
- Ventilated double roofs enhance ventilation of the roof minimising overheating.

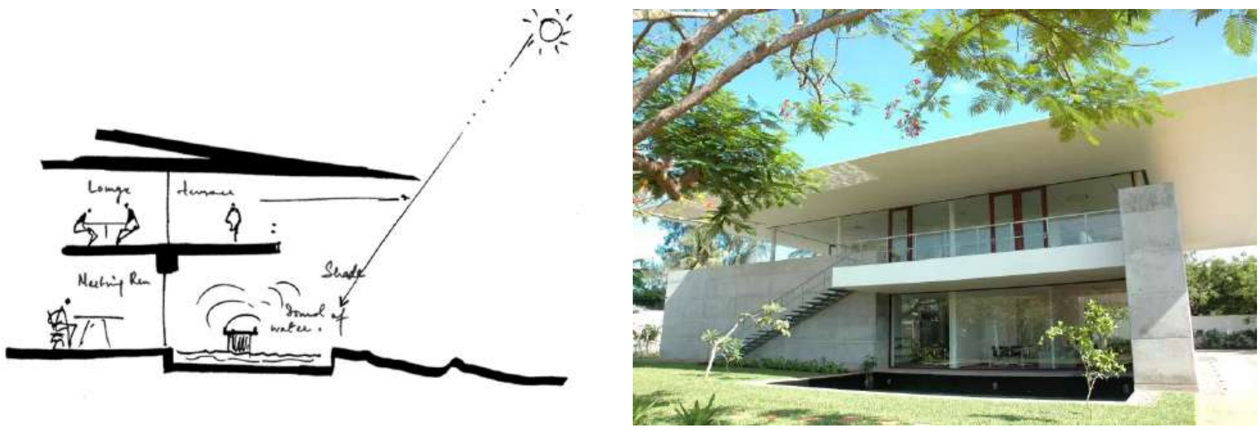
FIGURE 219 **NARROW CROSS SECTION OF THE TOWER ALLOWS FOR MAXIMUM DAYLIGHT PENETRATION ELIMINATING THE NEED FOR ARTIFICIAL LIGHTING DURING THE DAYTIME**

Exim Tower, Dar es Salaam
Source: *http://www.spasmindia.com/ © Spasm Design Architects*

FIGURE 220 **EXTENSIVE BALCONIES ON EVERY FLOOR CREATE SHADED TERRACES THAT OFFER COMFORTABLE OUTDOOR SPACES (TOP). GLAZED SURFACES OF THE BUILDINGS ARE SHADED BY A STAINLESS-STEEL MESH THAT REFLECTS SOLAR RADIATION MINIMISING HEAT GAIN (BOTTOM).**

Exim Tower, Dar es Salaam
Source: *http://www.spasmindia.com/ © Spasm Design Architects*

FIGURE 221 **LARGE OVERHANGS PROVIDE SUN SHADING OF THE LARGE WINDOWS MINIMISING UNWANTED SOLAR RADIATION. THE ALSO OFFER PROTECTION FROM DRIVING RAIN AND PREVENTS GLARE FROM THE SKY. LARGE OPERABLE WINDOWS ALLOW FRESH COOL BREEZE TO PENETRATE THE BUILDING ENABLING CROSS VENTILATION, THEREBY REDUCING ENERGY LOADS ASSOCIATED WITH COOLING.**



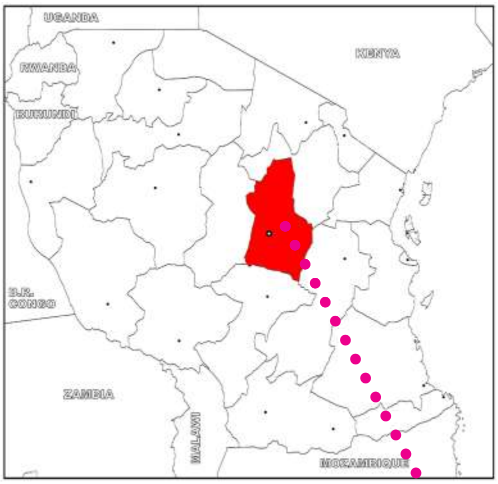
AON Insurance Headquarters, Dar es Salaam
Source: *http://www.spasmindia.com/ © Spasm Design Architects*

FIGURE 222 **PROVISION OF A FLOATING SUN SOLAR ROOF, EXTERNAL SHADING LOUVRES AND USE OF LIGHT-COLOURED EXTERNAL SURFACE PREVENT HEAT GAIN BY REFLECTING UNWANTED SOLAR RADIATION**

Umoja House, Dar es Salaam
Source: *http://www.bdp.com/en/projects/p-z/Umoja-House/*

DODOMA

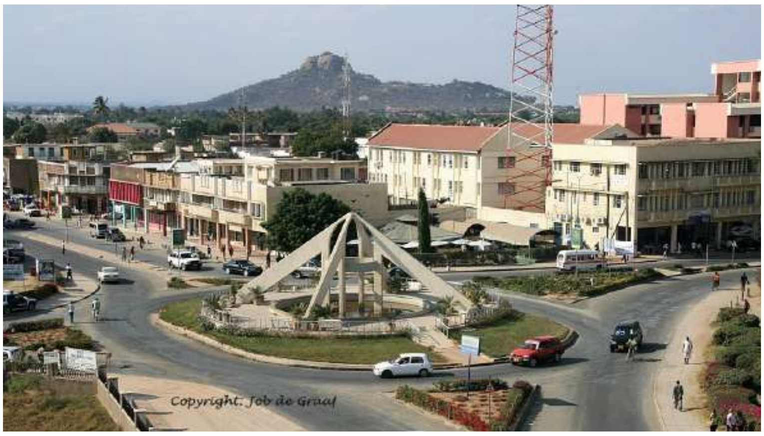
FIGURE 223 **LOCATION OF DODOMA**



Source: *http://www.d-maps.com/*

Climatic Zone	HOT SEMI-ARID / SAVANNAH
Latitude	06° 10′ S
Longitude	35° 45′ E
Altitude	1,120 m

FIGURE 224 **VIEW OF DODOMA CITY CENTRE**



Source: *https://www.flickr.com/photos/kiliweb/4792484428/ © Job de Graaf*

FIGURE 225 **LOCATION OF DODOMA CITY**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Dodoma is the national capital of Tanzania located at geographic coordinates 6° 10′ S, 35° 45′ E and at an altitude of 1,120 m above sea level. Its climate is categorised as savannah characterised by mean annual temperatures of 22.6 °C and low amounts of rainfall (annual average of 540 mm). The warmest months on average are November and December while the coolest month on average is July. January is recorded as the month with the most amount of rainfall at an average of 150 mm. Relative humidity ranges 55 – 71% while the wind velocity averages 3.4 m/s with the predominant wind direction being East. The annual average global solar radiation in Dodoma is 5.6 kWh/m^2.

TABLE 25 **DODOMA MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m^2 day]	Direct normal solar radiation [kWh/m^2 day]	Diffuse solar radiation [kWh/m^2 day]	Rainfall [mm]
JAN	23.9	68.0	3.5	5.4	4.2	2.5	150
FEB	23.0	70.0	3.5	5.6	4.4	2.6	100
MAR	23.3	71.0	3.5	5.6	4.2	2.6	130
APR	22.5	71.0	2.7	5.1	4.2	2.3	50
MAY	22.0	65.0	3.1	5.3	5.0	2.1	0
JUN	21.1	63.0	3.5	5.2	5.4	1.8	0
JUL	19.7	61.0	3.1	5.4	5.6	1.8	0
AUG	20.6	60.0	3.1	5.6	5.3	2.0	0
SEP	21.9	58.0	3.5	6.1	5.5	2.2	0
OCT	24.0	55.0	3.5	6.4	5.4	2.4	0
NOV	24.7	58.0	3.5	6.3	5.2	2.5	20
DEC	24.7	65.0	3.9	5.8	4.9	2.4	90

FIGURE 226 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR DODOMA**

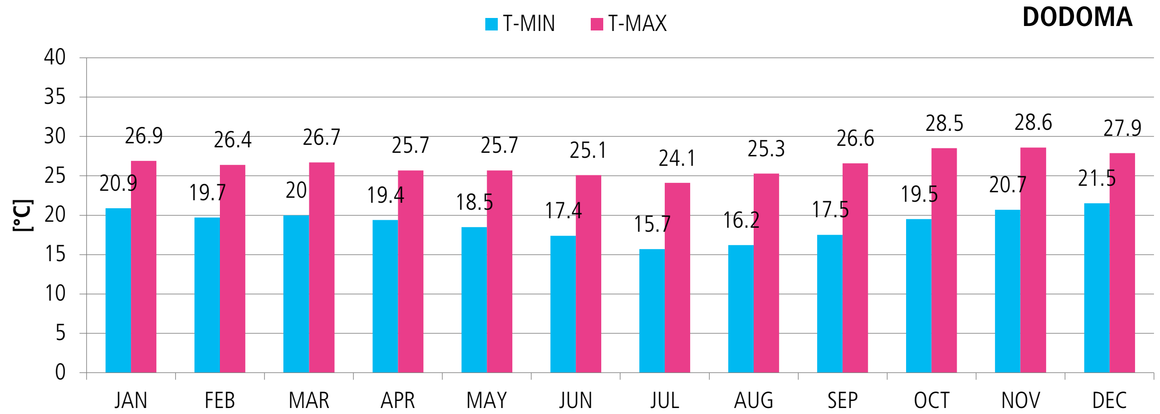


FIGURE 227 **MONTHLY MEAN RELATIVE HUMIDITY FOR DODOMA**

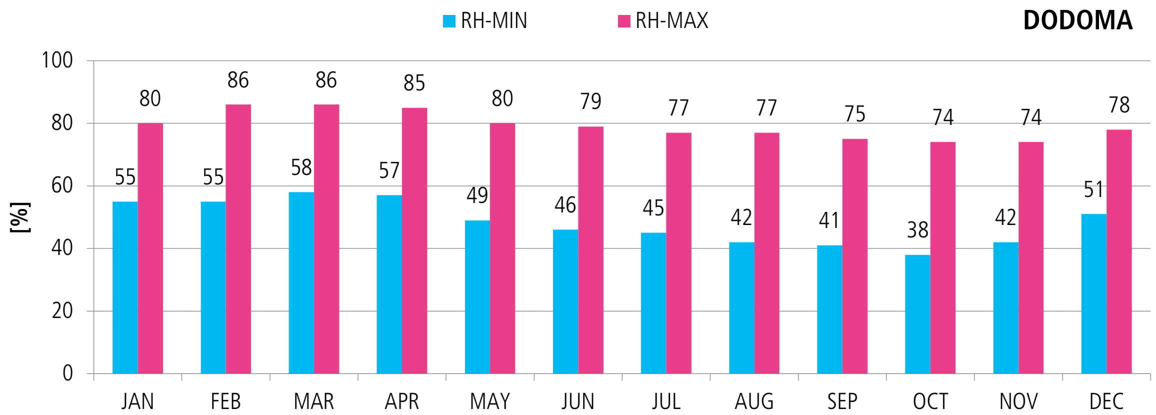


FIGURE 228 **MONTHLY AVERAGE RAINFALL FOR DODOMA**

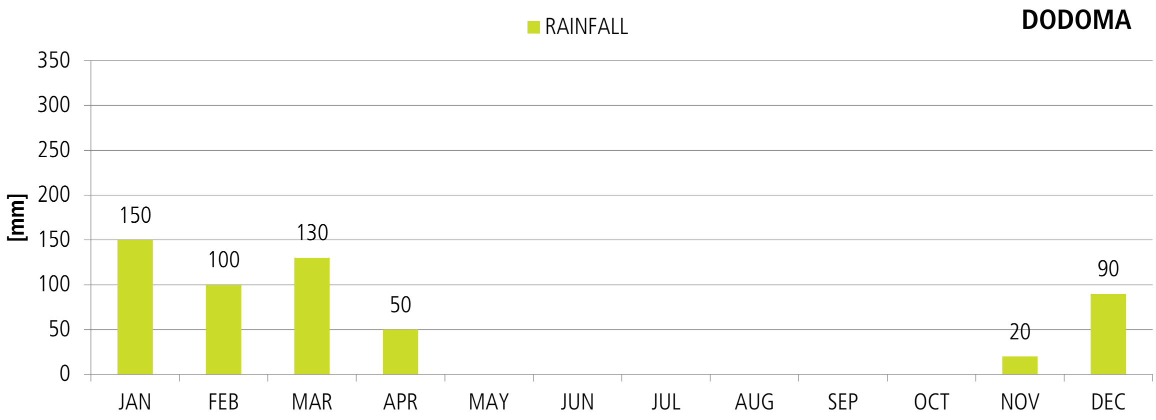


FIGURE 229 **POLAR SUN PATH DIAGRAM FOR LATITUDE 6° SOUTH**

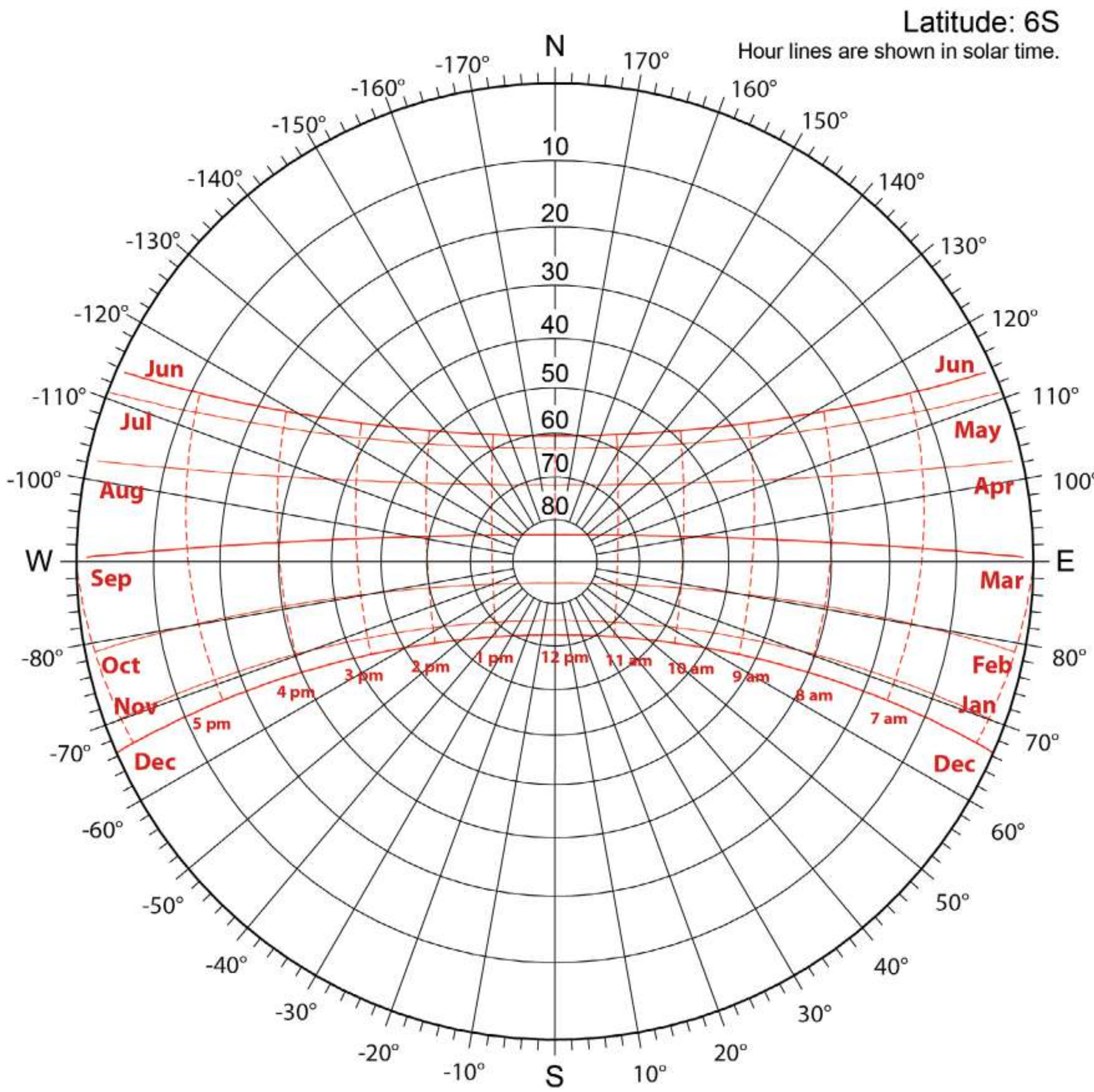


FIGURE 230 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN DODOMA**

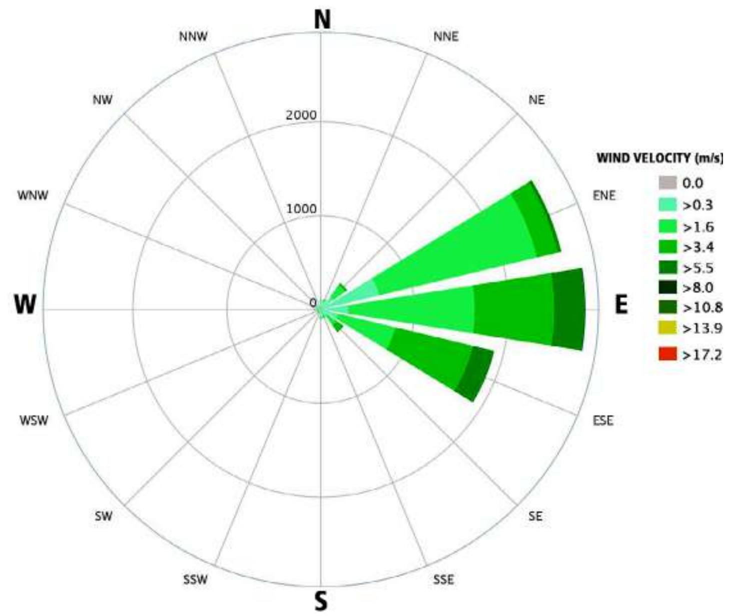
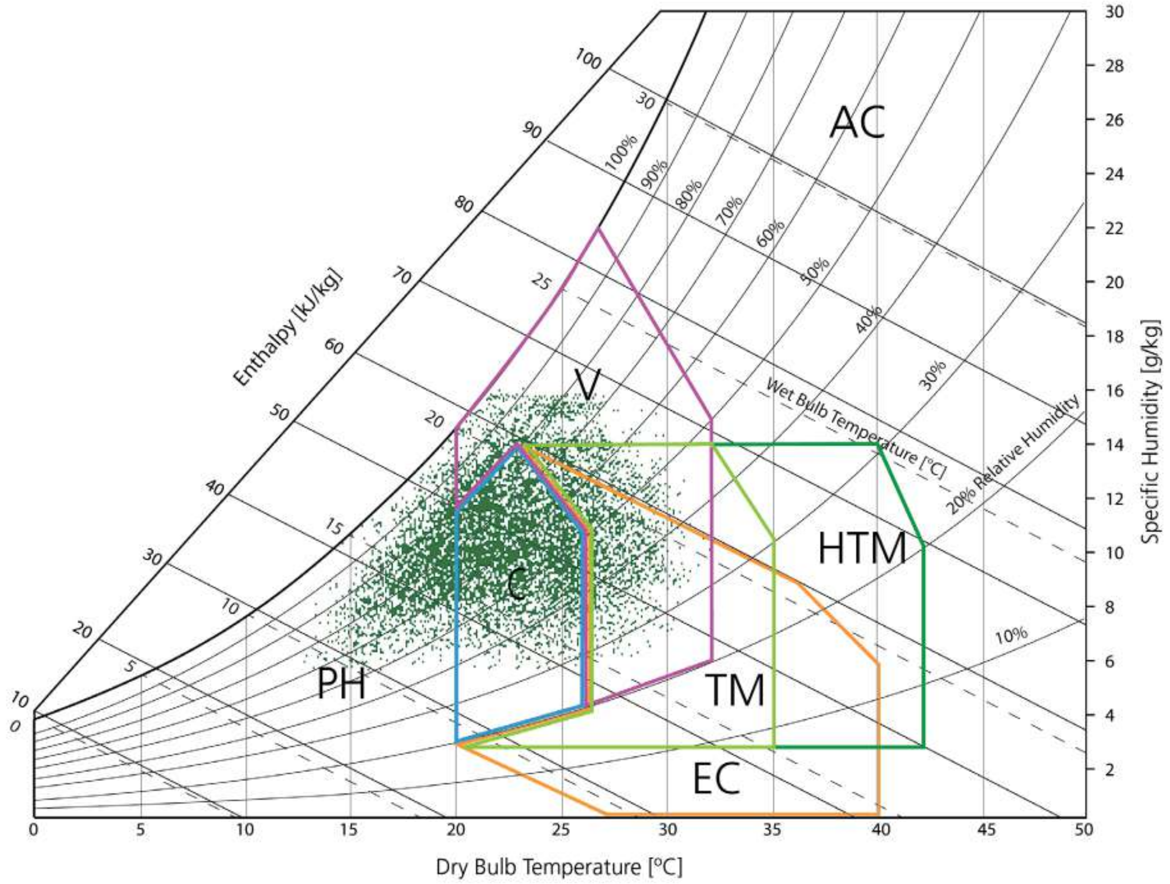


FIGURE 231 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR DODOMA**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

Dodoma experiences both hot and cold conditions that fall above and below the comfort zone respectively as seen in Figure 230. Based on the psychrometric chart, a combined effect of natural ventilation, high thermal mass (along with night ventilation) are the most effective strategies to improve thermal comfort during the overheated period. In the case of the under heated period, passive heating through direct solar heat gain and thermal mass are effective in expanding the comfort zone when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

In Dodoma, the design objective should be to balance the conflicting needs of the cold and hot periods to provide comfort. The following design strategies are recommended for:

a. To reduce effects of intense solar radiation

- Compact layout of buildings is recommended to provide mutual shading and minimise exposure to solar radiation.
- Courtyard design of buildings minimises the impact of solar radiation on the outer walls as well as provide cool spaces with the buildings / building layout.
- Buildings should be oriented along the east – west axis with the longer sides facing north and south in order to prevent solar heat gains. The building's surface area exposed to the east and west should be minimised.
- Openings should be located on the north and south. Small openings that are located high on the walls are recommended to facilitate natural ventilation as well as reduce glare from light reflected from the ground or surrounding buildings.
- Appropriate shading devices are necessary on all openings to decrease heat gain from solar radiation. Use of vegetation, verandas, covered walkways, pergolas etc. is recommended to provide shade to walls, openings and outdoor spaces.
- Use of reflective surfaces (roof) and light coloured external walls are effective in reflecting solar radiation thus minimising solar heat gains and consequently minimising internal daytime temperatures.

b. To balance diurnal temperature range

- Medium weight building materials with high thermal capacity are recommended to balance temperature variations between day and night. These materials absorb heat during daytime keeping indoor temperatures lower than outdoor temperature. The stored heat is later dissipated at night thereby providing indoor thermal comfort when the outdoor temperatures fall below the comfort zone.

c. To ensure air circulation

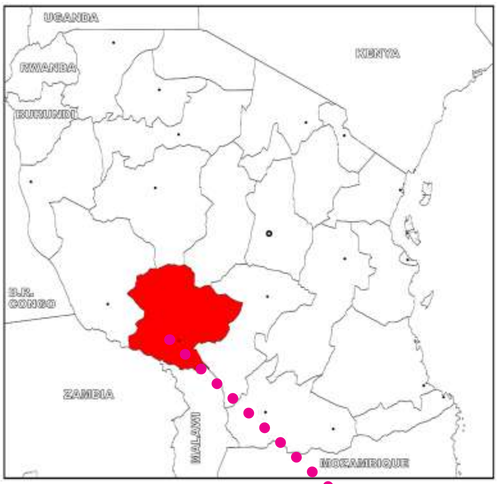
- Openings should be located to take advantage of prevailing winds and allow for cross-ventilation.
- Ventilation through windows should be kept at a minimum during the daytime to keep hot and dusty air out. However, at night, windows may be opened to provide adequate ventilation for dissipation of heat accumulated during the day by walls and the roof to prevent overheating of the interior space.
- Other ventilation strategies include use of wind catchers, wind towers, solar chimneys, roof-mounted exhaust fans etc.

FIGURE 232 **USE OF LIGHT-COLOURED SURFACES AND SHADING SCREEN TO MINIMISE HEAT GAINS**

CCM Conference centre, Dodoma © UN-Habitat / Jerusha NGUNGUI

MBEYA

FIGURE 233 **LOCATION OF MBEYA**



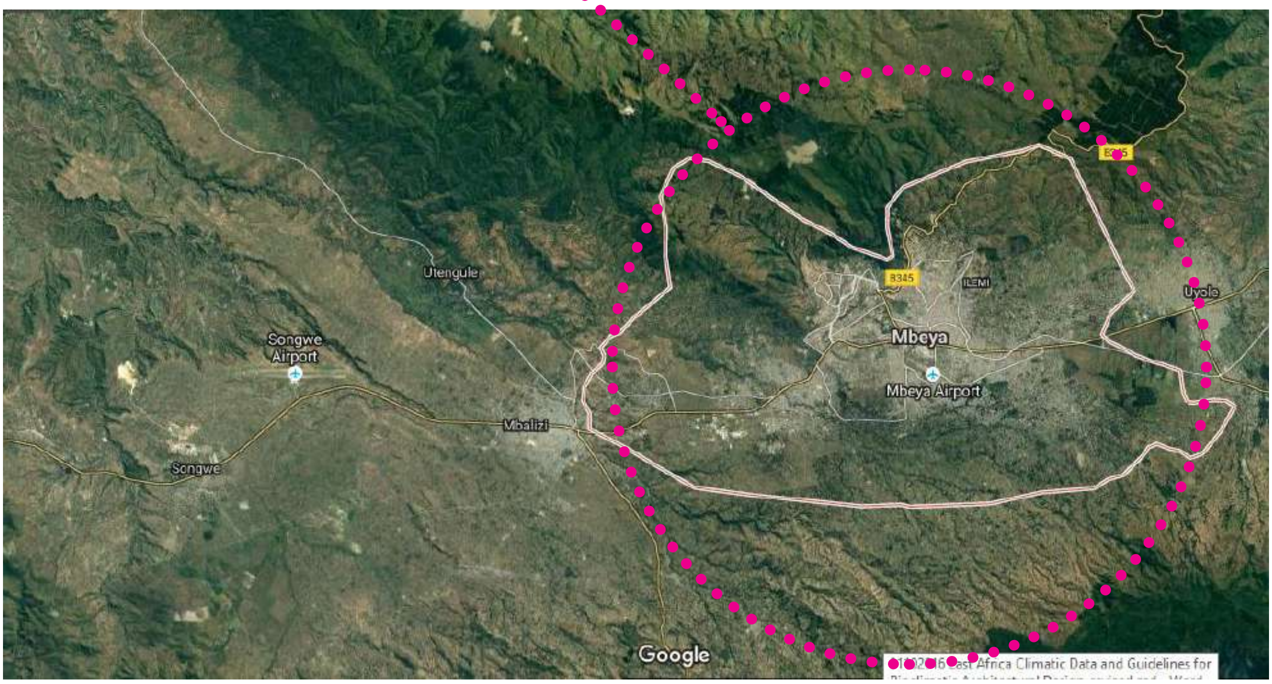
Source: *http://www.d-maps.com/*

Climatic Zone	UPLAND
Latitude	08° 56' S
Longitude	33° 28' E
Altitude	1,707 m

FIGURE 234 **VIEW OF MBEYA TOWN**

Source: *http://www.panoramio.com/photo/3778759 © Martin TLUSTOS*

FIGURE 235 **LOCATION OF MBEYA TOWN**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Mbeya town, at the southwestern part of Tanzania and surrounded by mountains, is located at geographic coordinates of 08° 56′ S, 33° 28′ E. At an altitude of 1,707 m above sea level, it enjoys an upland climate characterised by cool temperatures (annual mean of 19.1 °C) with the coolest months being June and July while the warmest month on average being October. Average rainfall per year is 800 mm with the heaviest rainy period occurring between December to April. Between May and November, there is little to no rainfall. Relative humidity averages at 60.8% annually while the wind velocity ranges 1.8 – 5.4 m/s with the predominant wind direction being South East. The annual average global solar radiation in this town is 6.2 kWh/m².

TABLE 26 **MBEYA MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	19.3	72.0	1.8	5.5	4.7	2.3	190
FEB	19.2	74.0	2.2	6.1	4.9	2.7	150
MAR	19.5	73.0	3.3	5.6	4.4	2.6	150
APR	19.2	70.0	5.0	5.9	5.5	2.2	110
MAY	18.4	65.0	5.3	6.4	7.8	1.5	10
JUN	16.7	59.0	5.4	6.4	8.3	1.1	0
JUL	16.9	52.0	5.4	6.3	7.4	1.4	0
AUG	18.2	53.0	5.1	6.5	7.2	1.7	0
SEP	20.1	48.0	4.9	6.8	6.9	1.9	0
OCT	21.5	46.0	4.0	7.1	6.9	2.0	10
NOV	20.3	54.0	2.7	6.3	5.3	2.4	50
DEC	19.6	64.0	1.8	5.4	4.1	2.4	130

FIGURE 236 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR MBEYA**

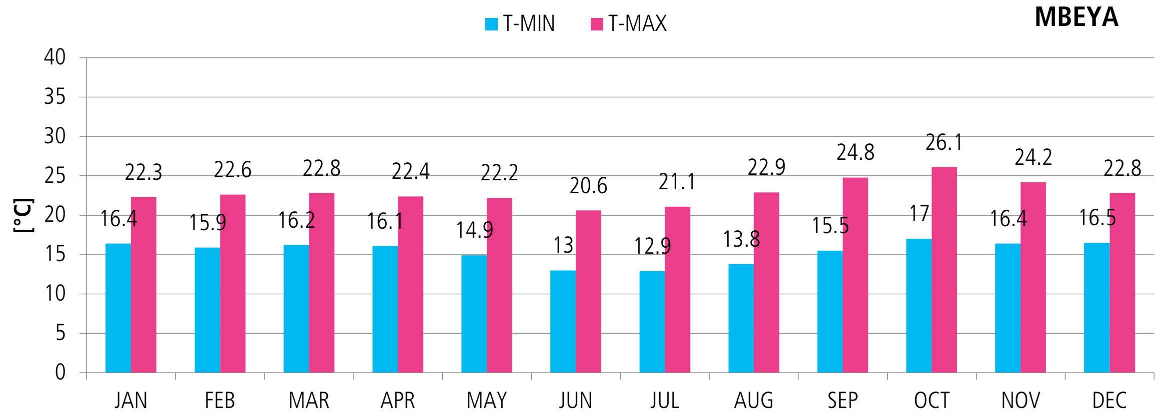


FIGURE 237 **MONTHLY MEAN RELATIVE HUMIDITY FOR MBEYA**

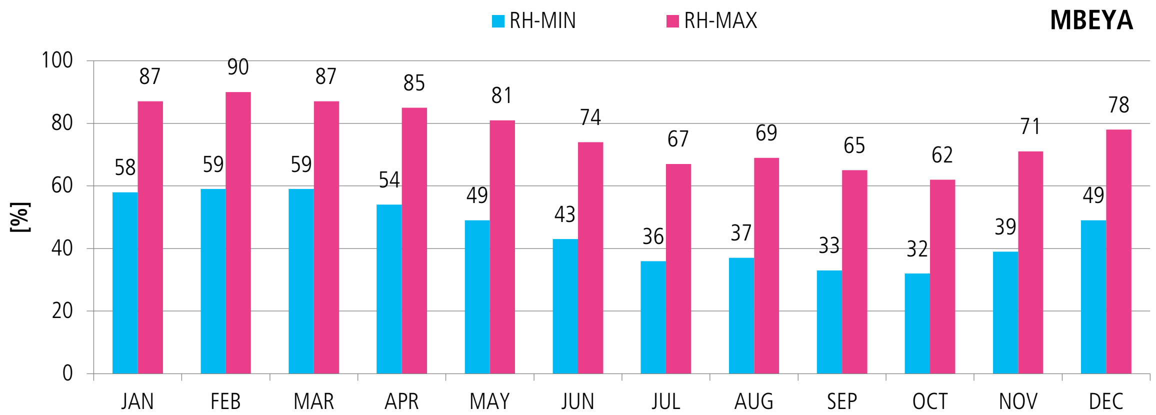


FIGURE 238 **MONTHLY AVERAGE RAINFALL FOR MBEYA**

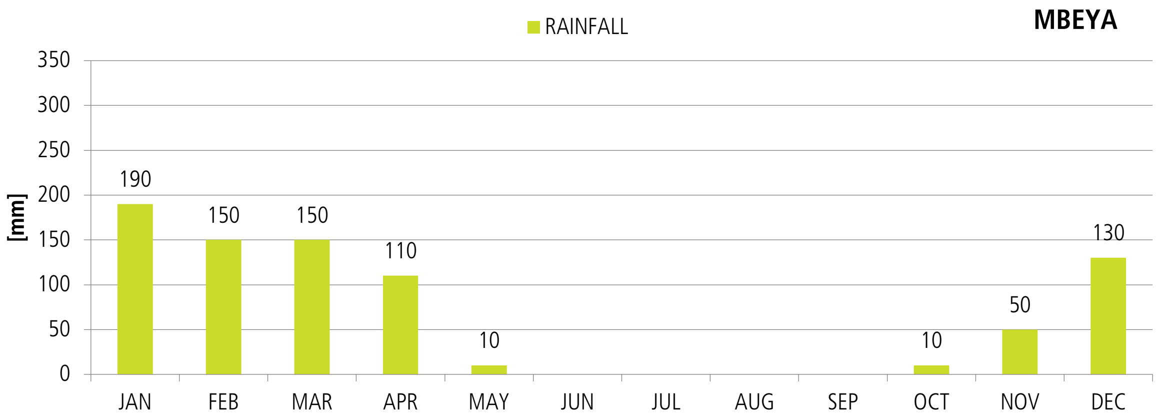


FIGURE 239 **POLAR SUN PATH DIAGRAM FOR LATITUDE 8° SOUTH**

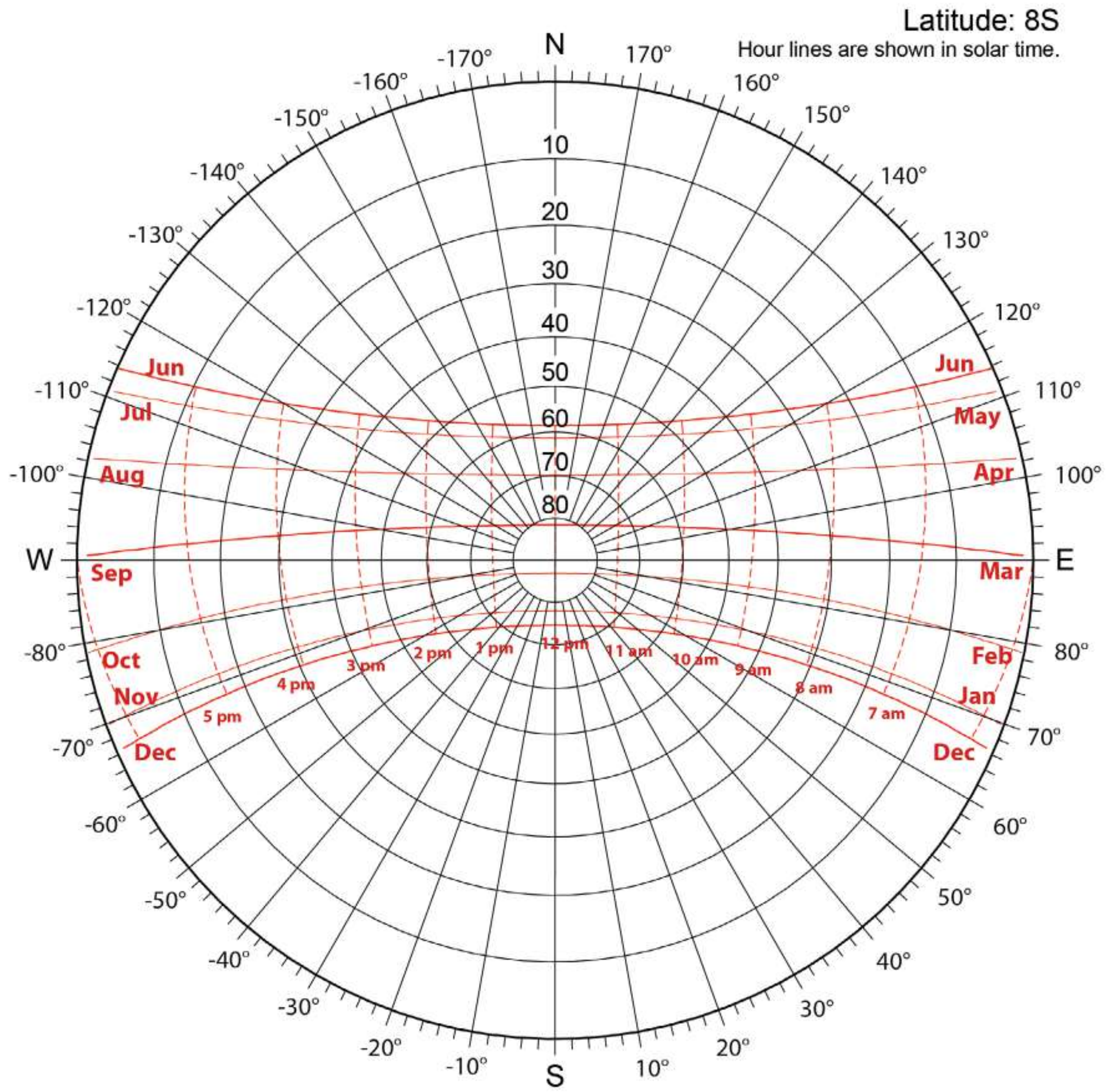


FIGURE 240 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN MBEYA**

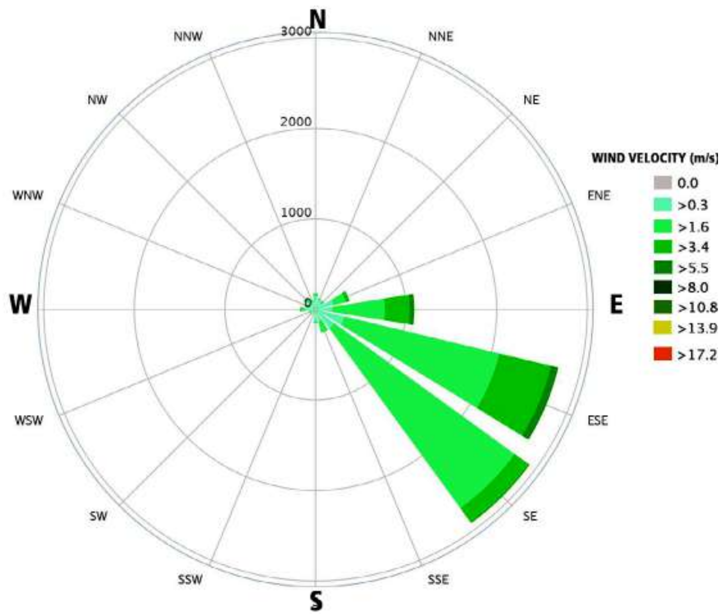
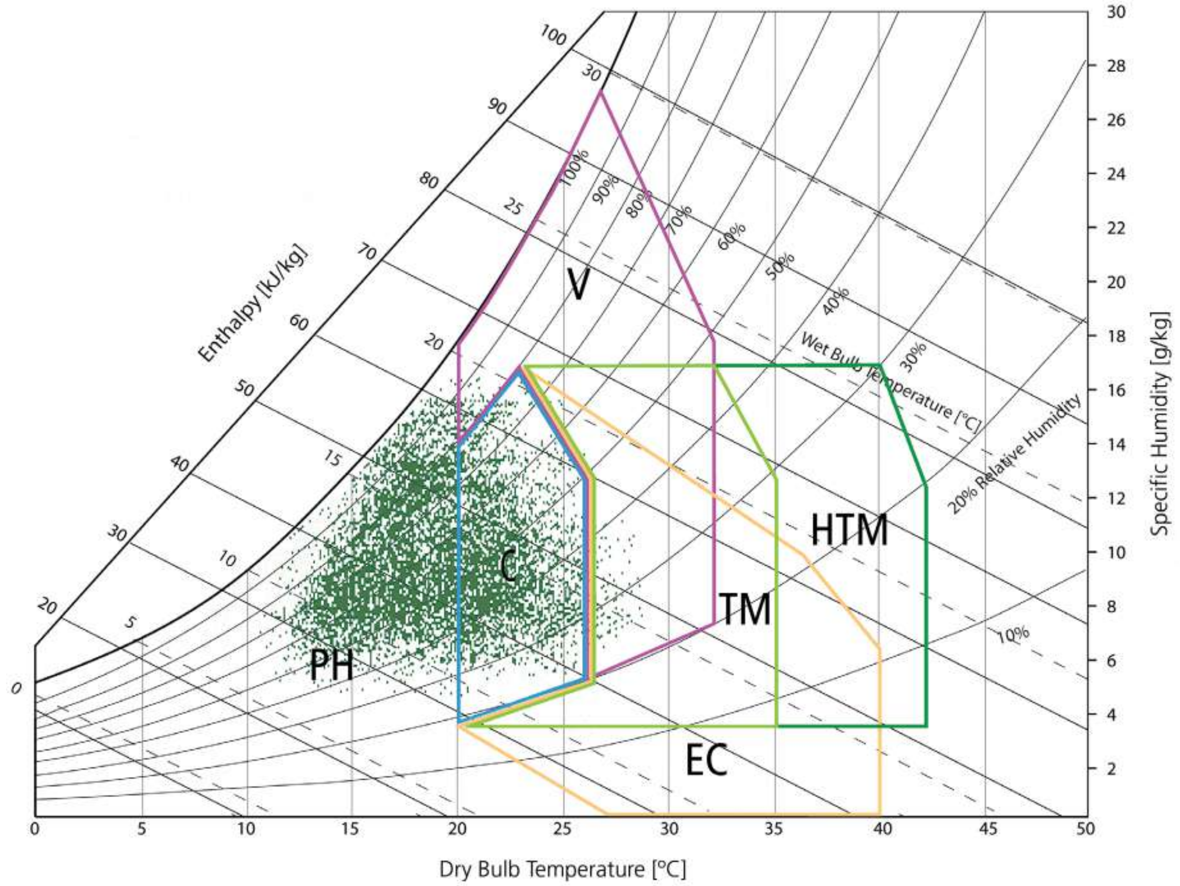


FIGURE 241 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR MBEYA**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

In Mbeya, most of the hourly points of outdoor dry bulb temperature and relative humidity fall within the comfort zone. However, a substantial portion falls below the comfort zone as seen in Figure 241. This means that during that period, space heating is necessary in order to extend the limit of comfort zone. This can be done through passive heating through direct solar heat gain and thermal mass. Further, internal heat gain from equipment, lights and occupants are also helpful in extending the thermal comfort and reducing heading heating demand.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Mbeya, the following design strategies are recommended for:

a. Enabling passive heating

- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate into daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.
- Additional heating systems such as fireplaces can be incorporated in the design.
- Internal heat gains from occupants, equipment and lights will greatly reduce heating needs.

b. Protection against heat gain in the hot period

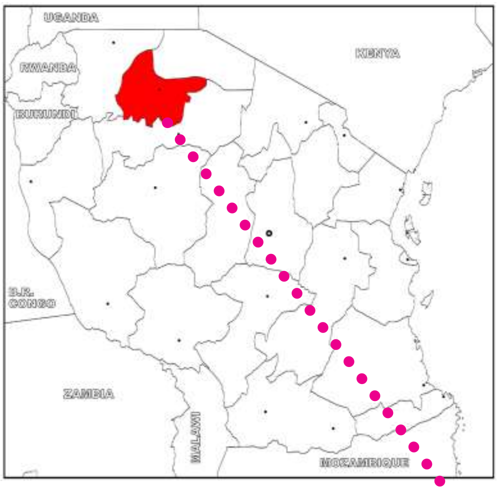
- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

FIGURE 242 **SUNSHADING**

Mbeya University of Science and Technology, Tanzania
Source: *http://www.mbeya.go.tz/*

MWANZA

FIGURE 243 **LOCATION OF MWANZA**



Source: *http://www.d-maps.com/*

Climatic Zone	GREAT LAKES
Latitude	02° 28’ S
Longitude	32° 54’ E
Altitude	1,140 m

FIGURE 244 **AERIAL VIEW OF MWANZA TOWN**

Source: *http://bestplacestotravel.info/page/mwanza/tanzania/default.html*

FIGURE 245 **LOCATION OF MWANZA TOWN**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Mwanza, a port-town situated on the shores of Lake Victoria, is the second largest city in Tanzania after Dar es Salaam. It is located at geographic coordinates of 02° 28′ S, 32° 54′ E and at an altitude of 1,140 m above sea level. Its climate is characterised by rainfall being recorded throughout the year with an average amount of 930 mm. The most amount occurs in March while the least amount occurs from June to August. The average annual temperature is 23.3 °C with the warmest period on average occurring in October while the coolest is July. Relative humidity averages at 66.5% annually while high wind velocity is recorded throughout the year at an average of 5.1 m/s and the predominant wind direction being North West and South East. The annual average global solar radiation in Mwanza is 5.4 kWh/m².

TABLE 27 **MWANZA MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	23.5	71.0	6.2	5.3	4.3	2.4	90
FEB	23.0	74.0	6.2	5.4	4.5	2.3	100
MAR	23.6	73.0	6.2	5.8	4.9	2.3	150
APR	23.0	74.0	5.1	5.4	4.2	2.5	140
MAY	23.3	70.0	4.1	5.3	5.0	2.0	90
JUN	22.7	64.0	3.6	5.6	5.6	1.9	10
JUL	22.5	58.0	3.1	5.6	5.5	2.0	10
AUG	23.1	56.0	3.6	5.8	5.1	2.2	10
SEP	23.3	60.0	5.1	5.5	4.5	2.4	40
OCT	24.2	59.0	5.7	5.6	4.1	2.6	40
NOV	23.6	68.0	5.7	5.3	3.6	2.8	110
DEC	23.2	71.0	6.2	4.7	3.2	2.5	140

FIGURE 246 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR MWANZA**

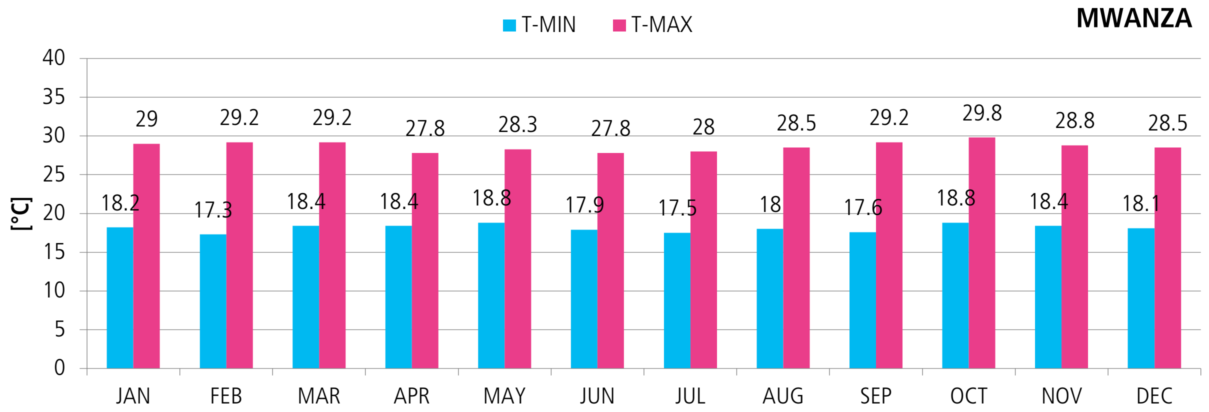


FIGURE 247 **MONTHLY MEAN RELATIVE HUMIDITY FOR MWANZA**

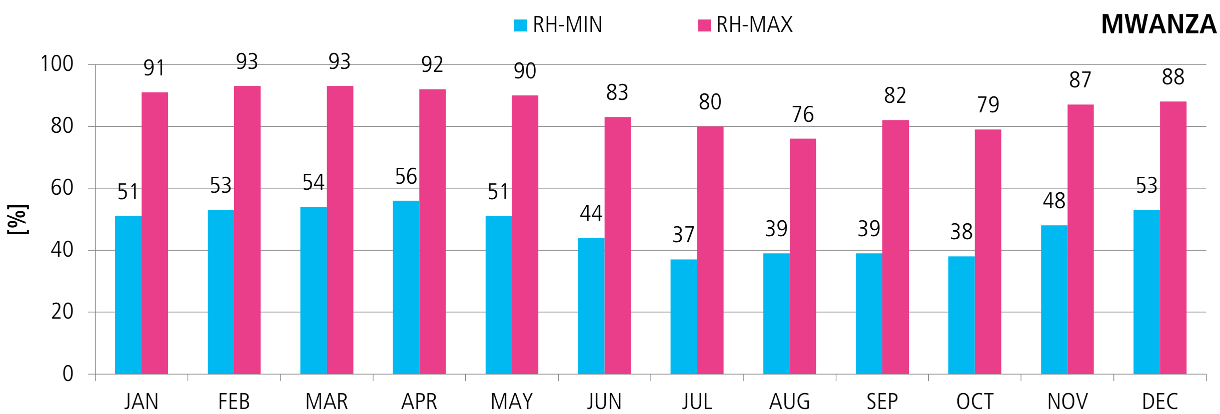


FIGURE 248 **MONTHLY AVERAGE RAINFALL FOR MWANZA**

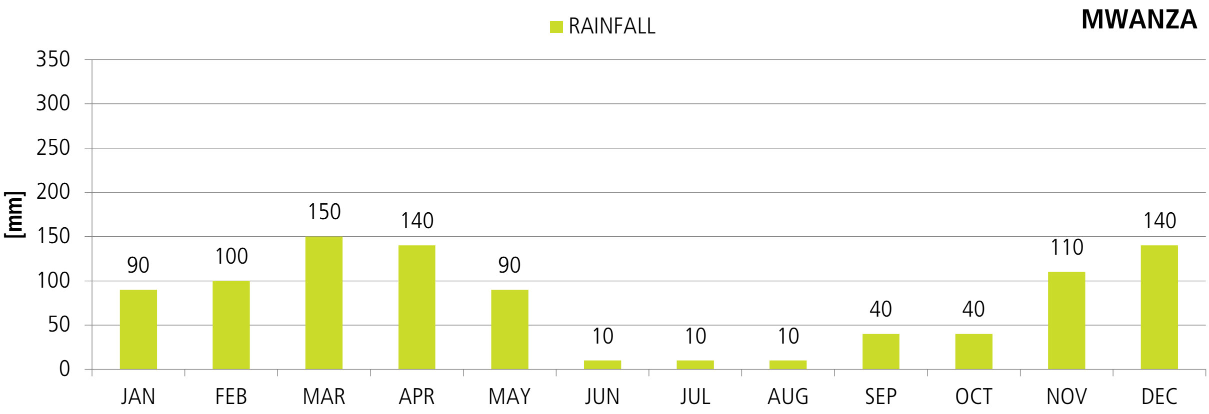


FIGURE 249 **POLAR SUN PATH DIAGRAM FOR LATITUDE 2° SOUTH**

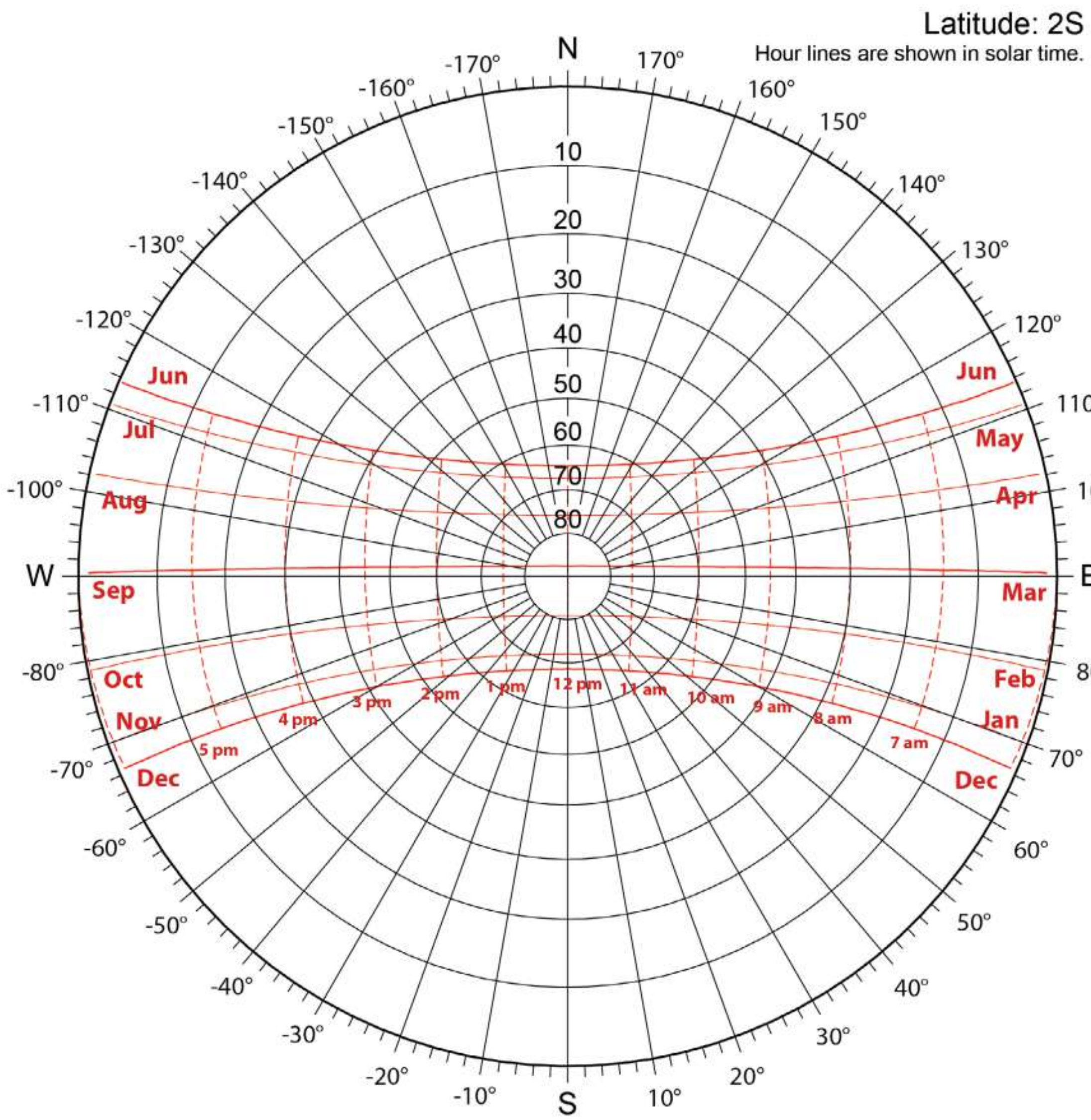


FIGURE 250 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN MWANZA**

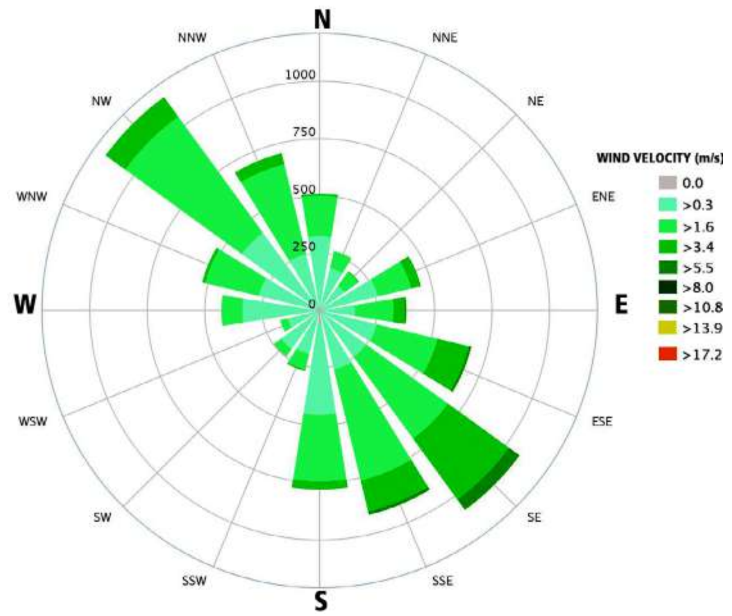
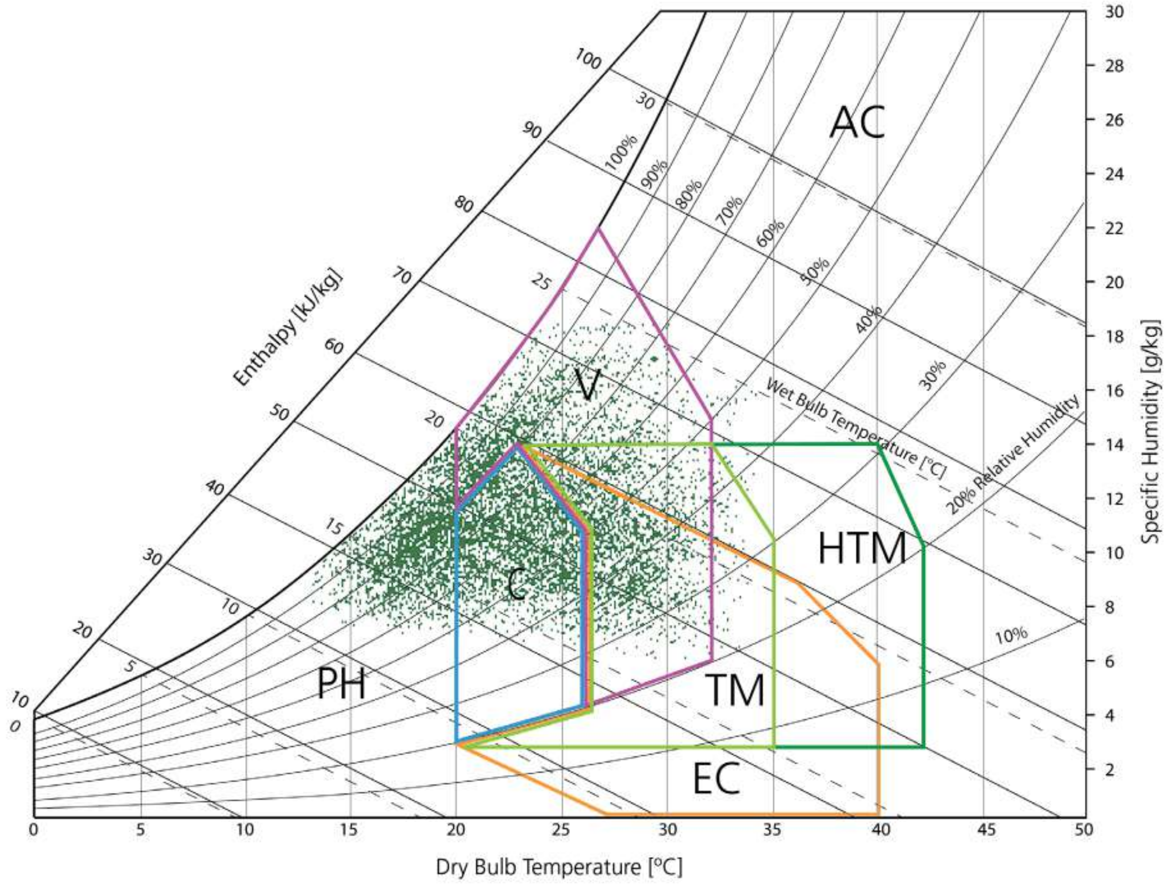


FIGURE 251 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR MWANZA**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

Most of the outdoor hourly dry bulb temperature and relative humidity data point fall within the comfort zone. However, the area experiences under heated periods with temperatures falling below the comfort zone to 15 °C as well as overheated periods with temperatures rising to 32 °C. Based on the psychrometric chart (see Figure 251), a combined effect of natural ventilation, high thermal mass (along with night ventilation) are the most effective strategies to improve thermal comfort during the overheated period. In the case of the under heated period, passive heating through direct solar heat gain and thermal mass are effective in expanding the comfort zone when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

In Mwanza, the design objective should be to balance the conflicting needs of the cold and hot periods to provide comfort. The following passive design strategies may be used to address the cooling and heating requirements that result from the above climatic characteristics:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading.
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, vertical fins, covered verandas and porches etc. (Figure 252).
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and minimise heat gains.

b. To promote maximum ventilation

- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings.
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum airflow through them.
- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.

FIGURE 252 **BALCONIES AND ROOF OVERHANGS ACT AS SUN SHADING ELEMENTS THUS MINIMISING SOLAR HEAT GAIN**

Mwanza Train Station
Source: *http://www.wikiwand.com/en/Mwanza*

- Openings should be located on opposite sides of walls to allow for proper cross-ventilations. Internal walls should also have openings for airflow through the internal space.

- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement.

- Ventilated double roofs enhance ventilation of the roof minimising overheating.

c. To enabling passive heating

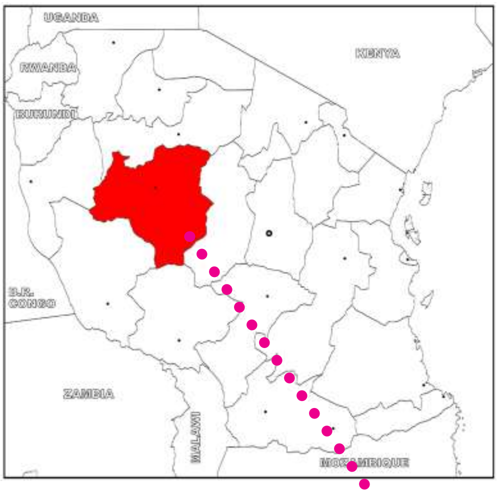
- Medium weight walls, floors and ceilings are recommended to explore passive solar gains by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.

- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.

- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone.

TABORA

FIGURE 253 **LOCATION OF TABORA**



Source: *http://www.d-maps.com/*

Climatic Zone	HOT SEMI-ARID / SAVANNAH
Latitude	05° 04' S
Longitude	32° 50' E
Altitude	1,190 m

FIGURE 254 **A STREET IN TABORA TOWN**

Source: *https://www.odysseysafaris.com/tag/adventure/page/24/*

FIGURE 255 **LOCATION OF TABORA**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Tabora town is located at geographic coordinates of 05° 04' S, 32° 50' E and at an altitude of 1,190 m above sea level. The town has savannah climate with annual temperatures averaging 23.1 °C. The warmest month of the year is October while June and July present the months with the lowest average temperatures of the whole year. About 820 mm of rain falls annually with most of it occurring from November through to April. The most amount is seen in December, at an average of 170 mm. June to September present the driest months with no rainfall at all. Relative humidity averages at 60.5% while the predominant wind direction being East South East (ESE). The annual average global solar radiation in Tabora is 5.6 kWh/m².

TABLE 28 **TABORA MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	22.6	72.0	0.4	5.4	4.8	2.3	120
FEB	22.8	74.0	0.4	5.5	4.6	2.4	120
MAR	23.2	75.0	0.4	5.8	5.2	2.1	160
APR	22.3	72.0	0.4	5.3	4.4	2.3	130
MAY	22.6	63.0	0.4	5.6	5.4	2.1	20
JUN	21.5	57.0	0.6	5.8	6.4	1.6	0
JUL	21.5	51.0	0.6	5.7	5.5	1.9	0
AUG	22.7	48.0	0.6	6.1	6.0	1.9	0
SEP	24.2	46.0	0.6	5.7	4.5	2.5	0
OCT	25.7	44.0	0.6	6.0	4.9	2.4	10
NOV	24.7	55.0	0.6	5.4	4.0	2.5	90
DEC	23.2	69.0	0.4	4.9	3.6	2.5	170

FIGURE 256 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR TABORA**

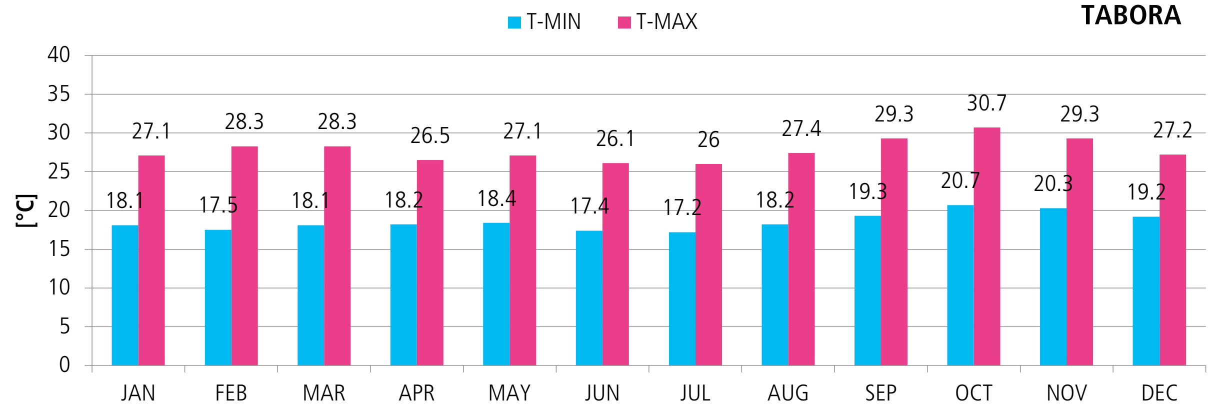


FIGURE 257 **MONTHLY MEAN RELATIVE HUMIDITY FOR TABORA**

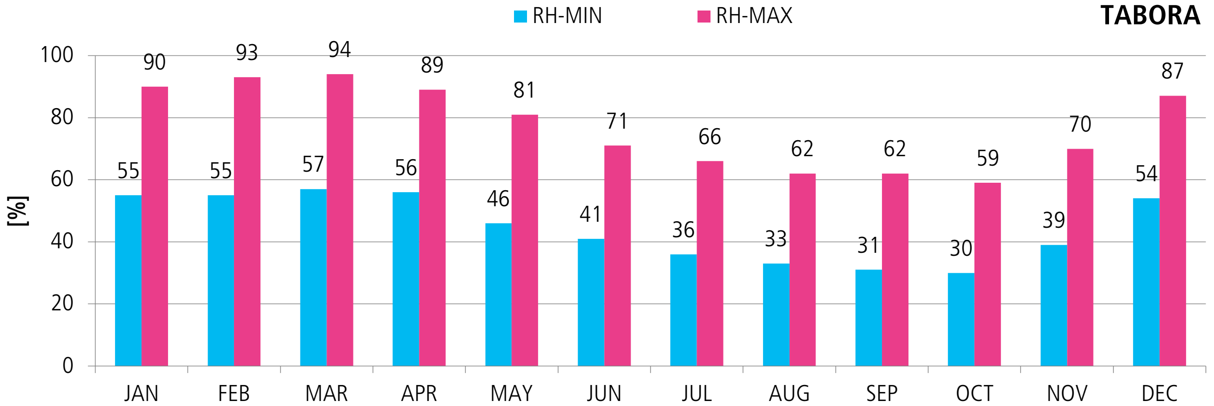


FIGURE 258 **MONTHLY AVERAGE RAINFALL FOR TABORA**

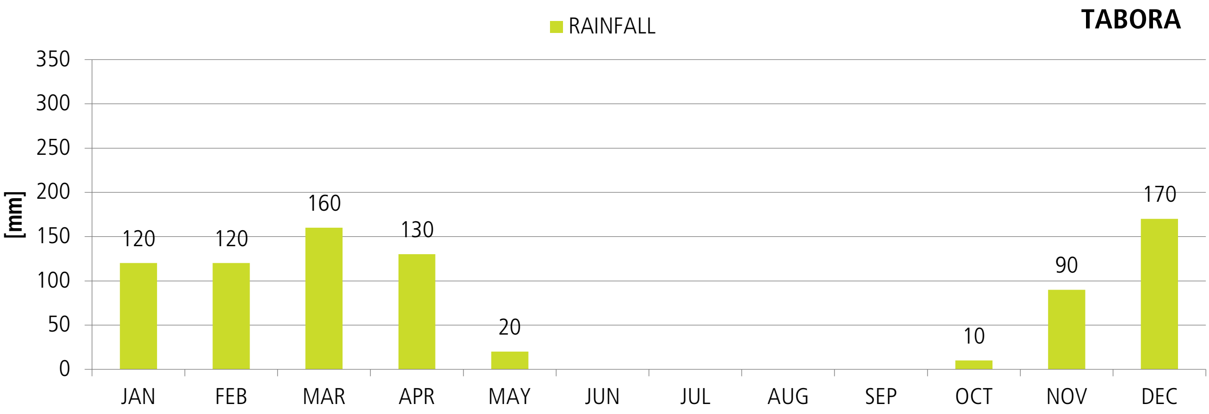


FIGURE 259 **POLAR SUN PATH DIAGRAM FOR LATITUDE 5° SOUTH**

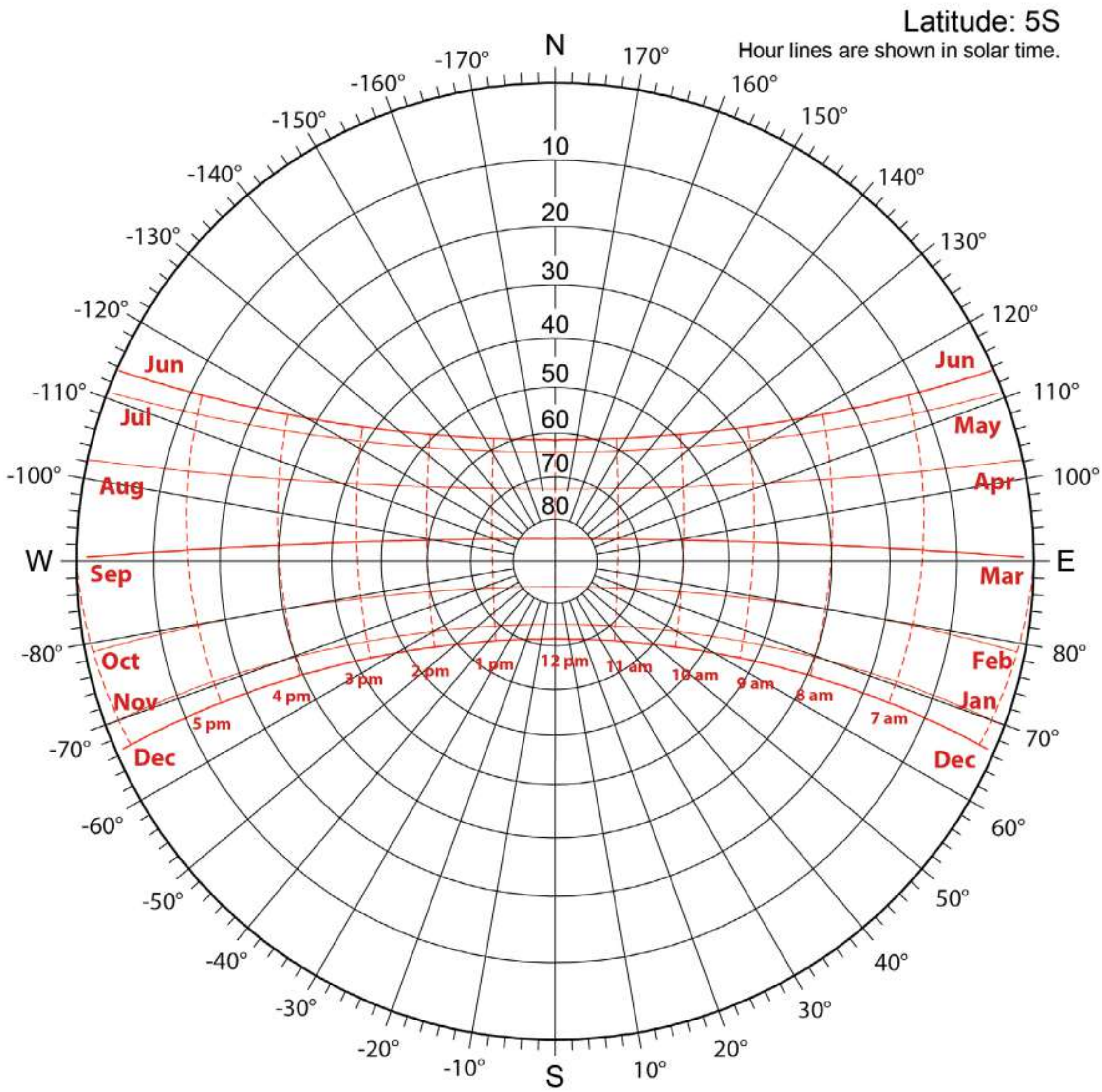


FIGURE 260 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN TABORA**

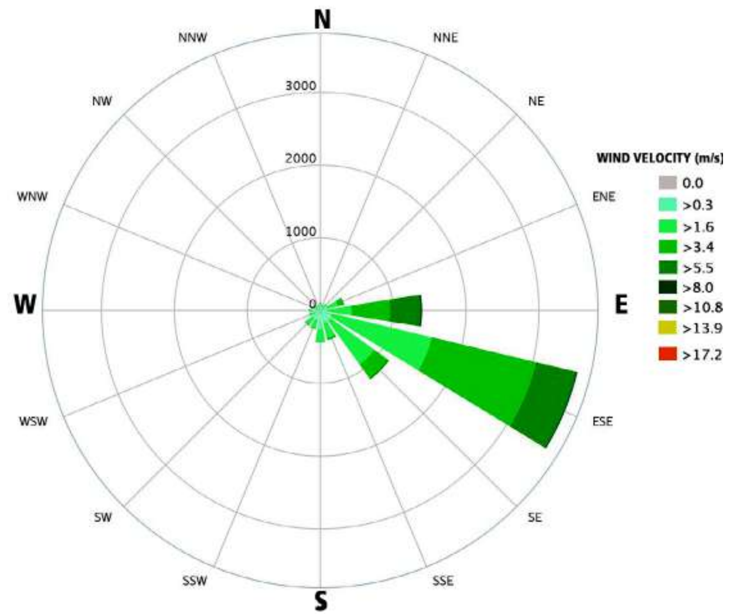
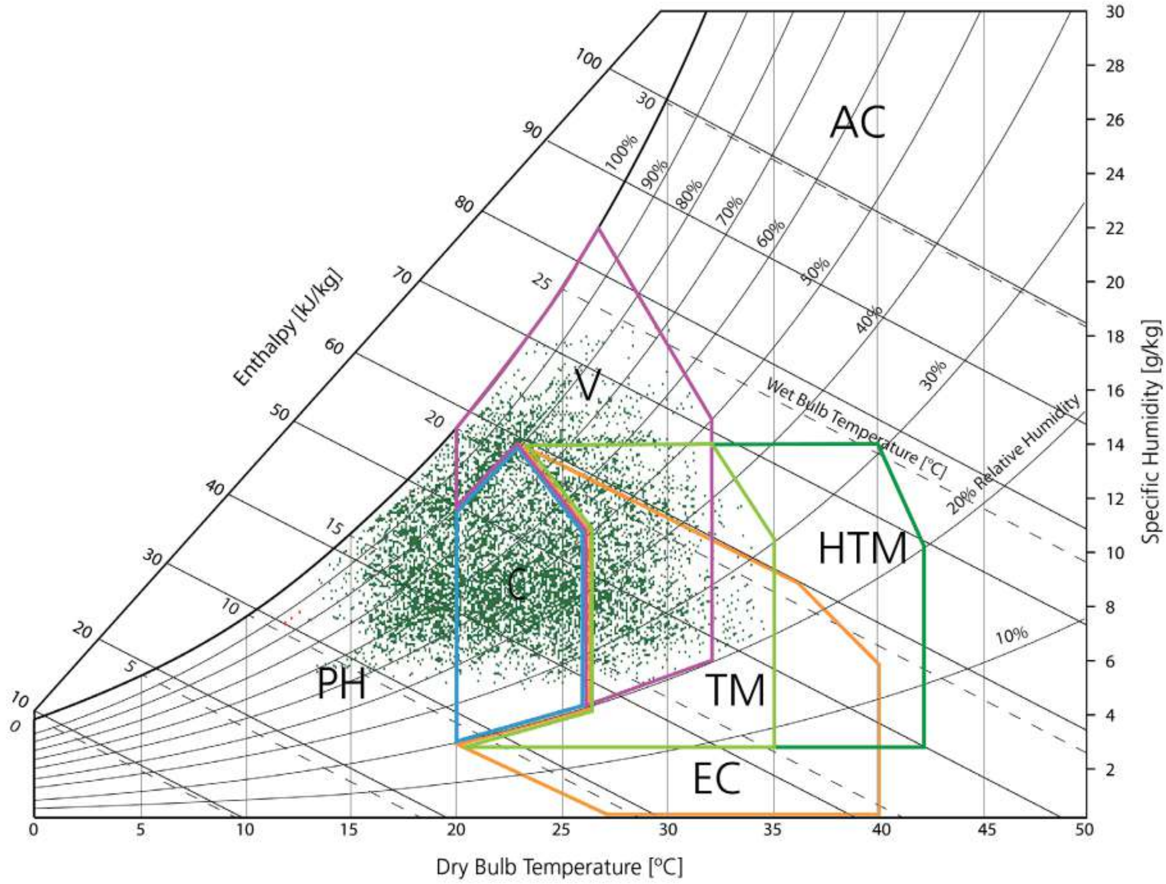


FIGURE 261 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR TABORA**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

Tabora experiences both hot and cold conditions that fall above and below the comfort zone respectively as seen in Figure 261. Based on the psychrometric chart, a combined effect of natural ventilation and thermal mass (along with night ventilation) are the most effective strategies to improve thermal comfort during the overheated period. In the case of the under heated period, passive heating through direct solar heat gain and thermal mass are effective in expanding the comfort zone when the temperatures fall below the comfort zone.

BIOCLIMATIC RECOMMENDATIONS

In Tabora, the design objective should be to balance the conflicting needs of the cold and hot periods to provide comfort. The following design strategies are recommended for:

a. To reduce effects of intense solar radiation

- Compact layout of buildings is recommended to provide mutual shading and minimise exposure to solar radiation.
- Courtyard design of buildings minimises the impact of solar radiation on the outer walls as well as provide cool spaces with the buildings / building layout.
- Buildings should be oriented along the east – west axis with the longer sides facing north and south to prevent solar heat gains. The building's surface area exposed to the east and west should be minimised.
- Openings should be located on the north and south. Small openings that are located high on the walls are recommended to facilitate natural ventilation as well as reduce glare from light reflected from the ground or surrounding buildings.
- Appropriate shading devices are necessary on all openings to decrease heat gain from solar radiation. Use of vegetation, verandas, covered walkways, pergolas etc. is recommended to provide shade to walls, openings and outdoor spaces.
- Use of reflective surfaces (roof) and light coloured external walls are effective in reflecting solar radiation thus minimising solar heat gains and consequently minimising internal daytime temperatures.

b. To balance diurnal temperature range

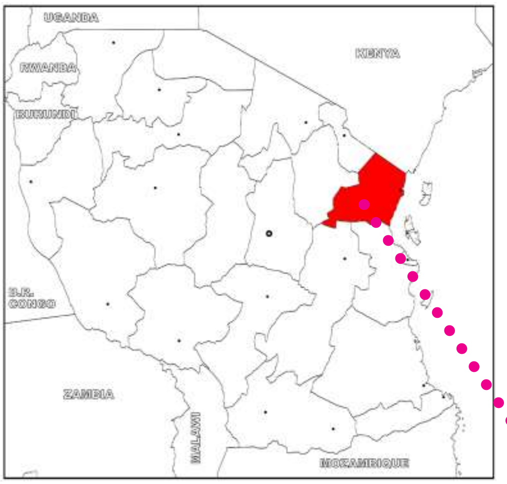
- Medium weight building materials with high thermal capacity are recommended to balance temperature variations between day and night. These materials absorb heat during daytime keeping indoor temperatures lower than outdoor temperature. The stored heat is later dissipated at night thereby providing indoor thermal comfort when the outdoor temperatures fall below the comfort zone.

c. To ensure air circulation

- Openings should be located to take advantage of prevailing winds and allow for cross-ventilation.
- Ventilation through windows should be kept at a minimum during the daytime to keep hot and dusty air out. However, at night, windows may be opened to provide adequate ventilation for dissipation of heat accumulated during the day by walls and the roof to prevent overheating of the interior space.
- Other ventilation strategies include use of wind catchers, wind towers, solar chimneys, roof-mounted exhaust fans etc.

TANGA

FIGURE 262 **LOCATION OF TANGA**



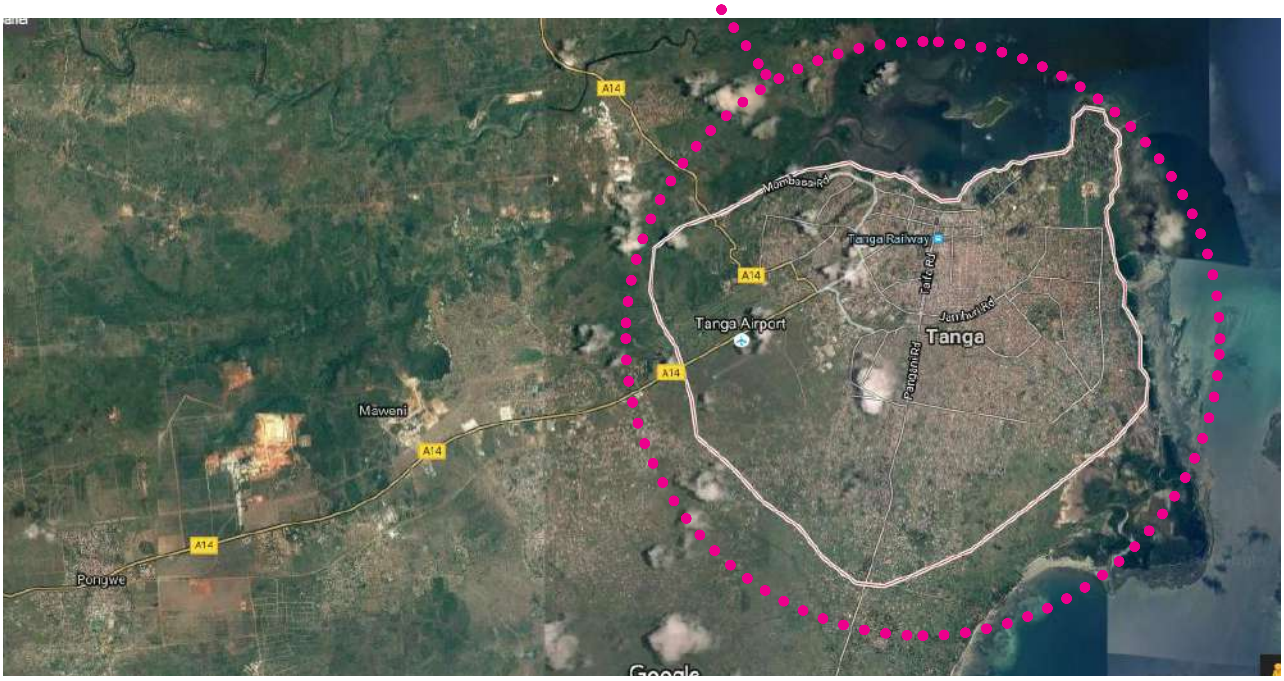
Source: *http://www.d-maps.com/*

Climatic Zone	HOT AND HUMID
Latitude	05° 04' S
Longitude	39° 05' E
Altitude	35 m

FIGURE 263 **A SECTION OF TANGA TOWN**

Source: *https://static.panoramio.com.storage.googleapis.com/photos/original/121372289.jpg*

FIGURE 264 **LOCATION OF TANGA TOWN**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Tanga, the headquarters of Tanga region and one of the sea port cities of Tanzania, is situated along the Indian Ocean coast of Tanzania. It is located at geographic coordinates of 05° 04′ S, 39° 05′ E at an altitude of 35 m above sea level. It enjoys a hot and humid climate characterised by high relative humidity (annual mean of 80.9%) and high temperatures throughout the year (average of 26.4 °C). The warmest month of the year is March. The lowest average temperatures of the year are in July making it the coolest month. The average amount of rainfall recorded annually is 1,290 mm with the highest recorded amount in May and the least amount in January. High wind velocity is recorded annually at an average of 4.5 m/s with the predominant wind direction being South. The annual average global solar radiation in Tanga is 5.0 kWh/m².

TABLE 29 **TANGA MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	27.9	77.0	4.9	5.3	3.5	2.8	30
FEB	28.2	77.0	5.4	5.5	3.5	3.0	40
MAR	28.4	80.0	4.5	5.4	3.6	2.7	120
APR	27.0	85.0	4.3	4.7	2.8	2.7	220
MAY	26.1	84.0	4.8	4.5	3.2	2.4	320
JUN	24.6	83.0	4.9	4.6	3.7	2.2	70
JUL	24.3	81.0	4.8	4.7	3.5	2.4	50
AUG	24.5	80.0	4.4	4.9	3.5	2.4	70
SEP	24.7	81.0	4.1	5.0	3.7	2.4	80
OCT	26.0	79.0	3.7	5.4	3.7	2.7	110
NOV	26.9	83.0	4.1	5.3	3.5	2.8	100
DEC	27.6	81.0	4.6	5.3	3.8	2.6	80

FIGURE 265 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR TANGA**

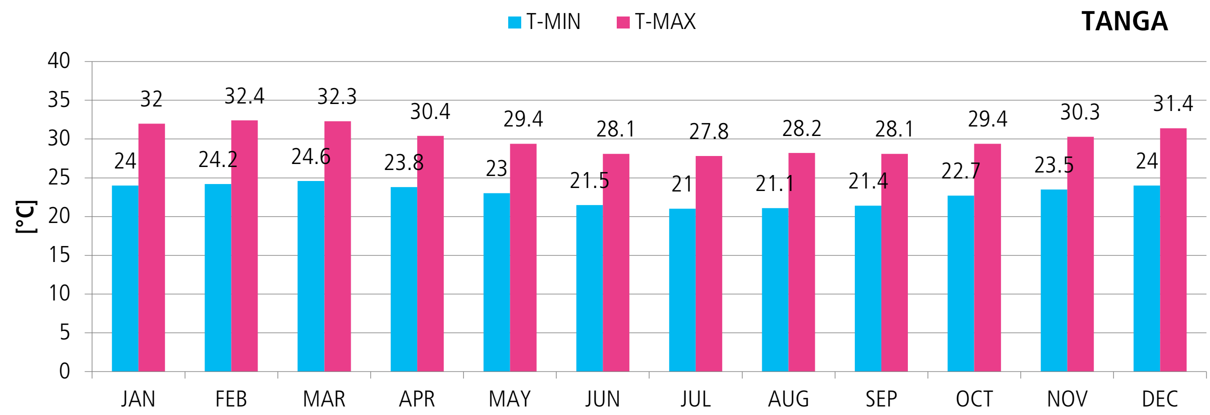


FIGURE 266 **MONTHLY MEAN RELATIVE HUMIDITY FOR TANGA**

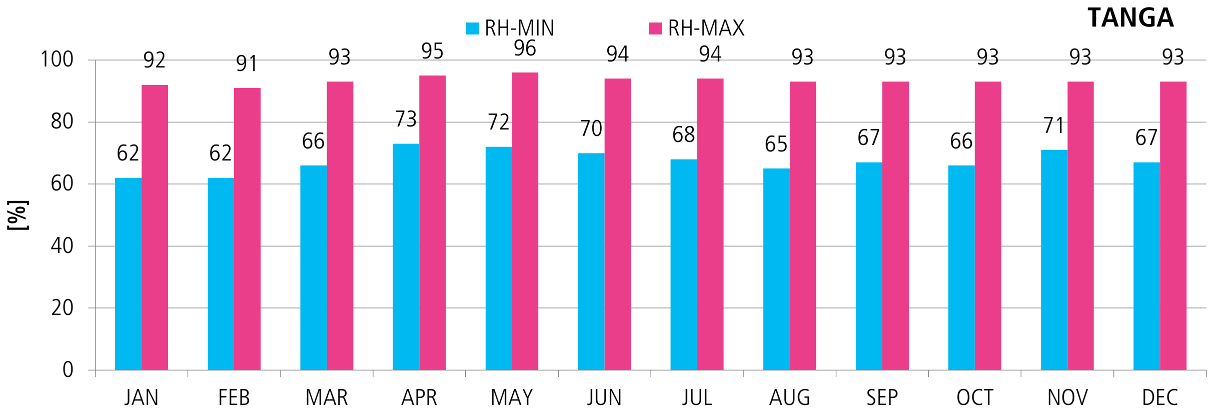


FIGURE 267 **MONTHLY AVERAGE RAINFALL FOR TANGA**

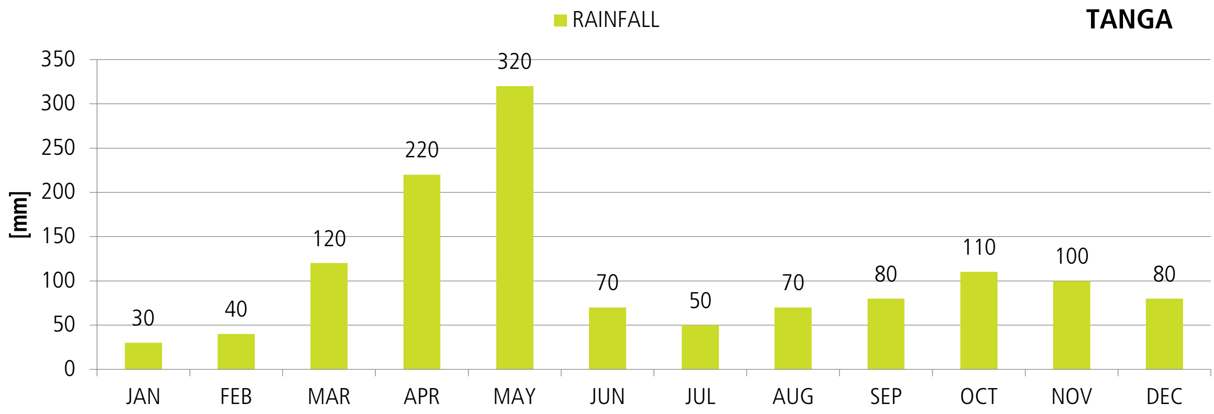


FIGURE 268 **POLAR SUN PATH DIAGRAM FOR LATITUDE 5° SOUTH**

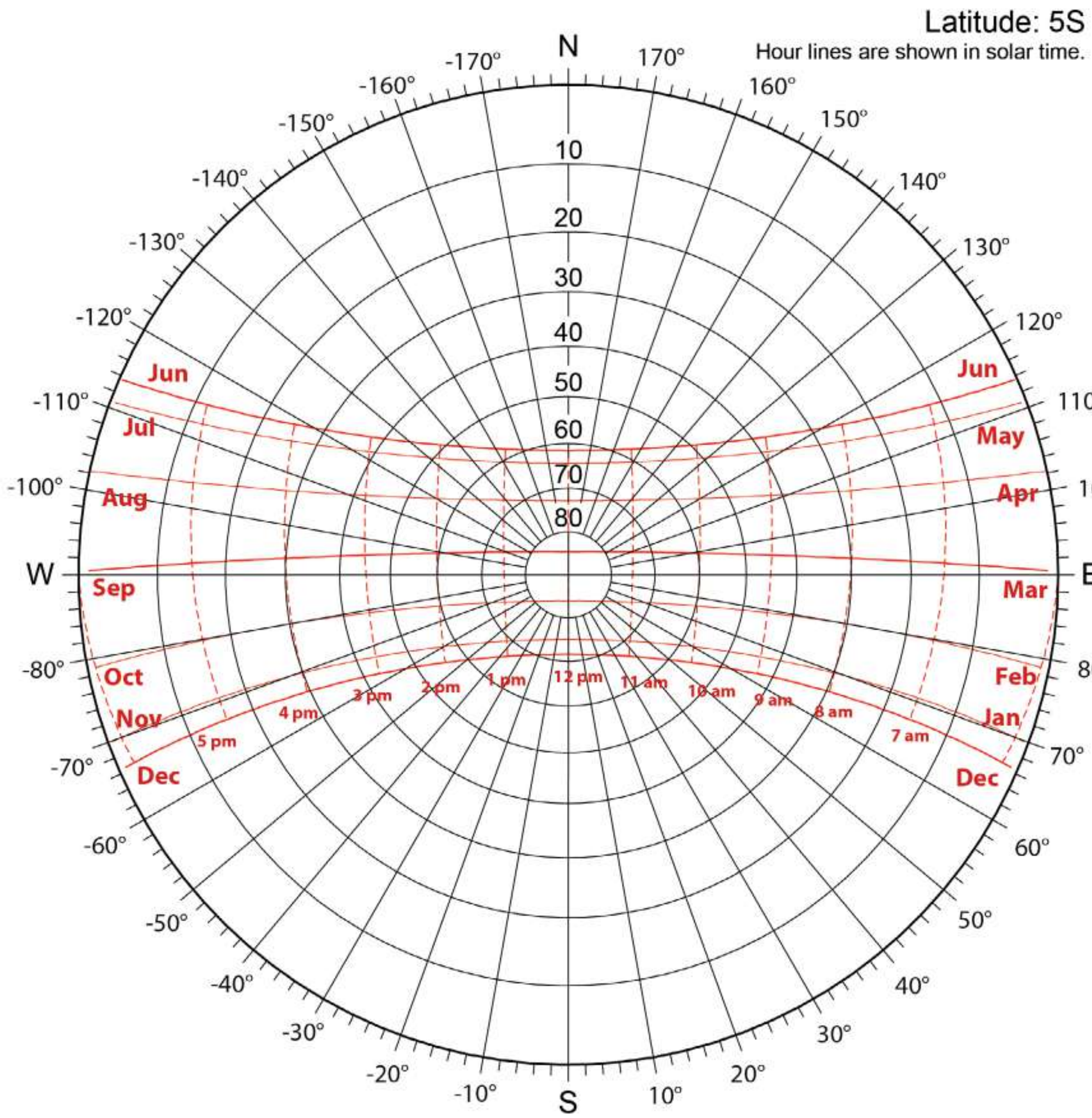


FIGURE 269 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN TANGA**

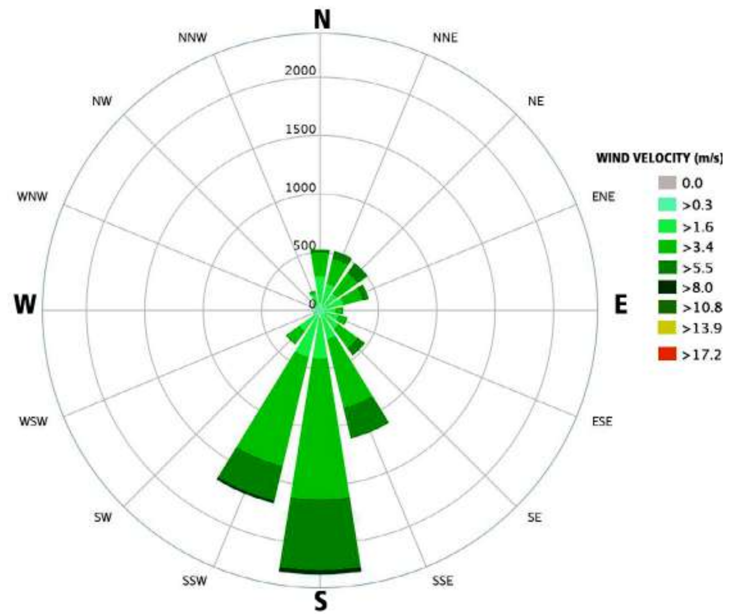
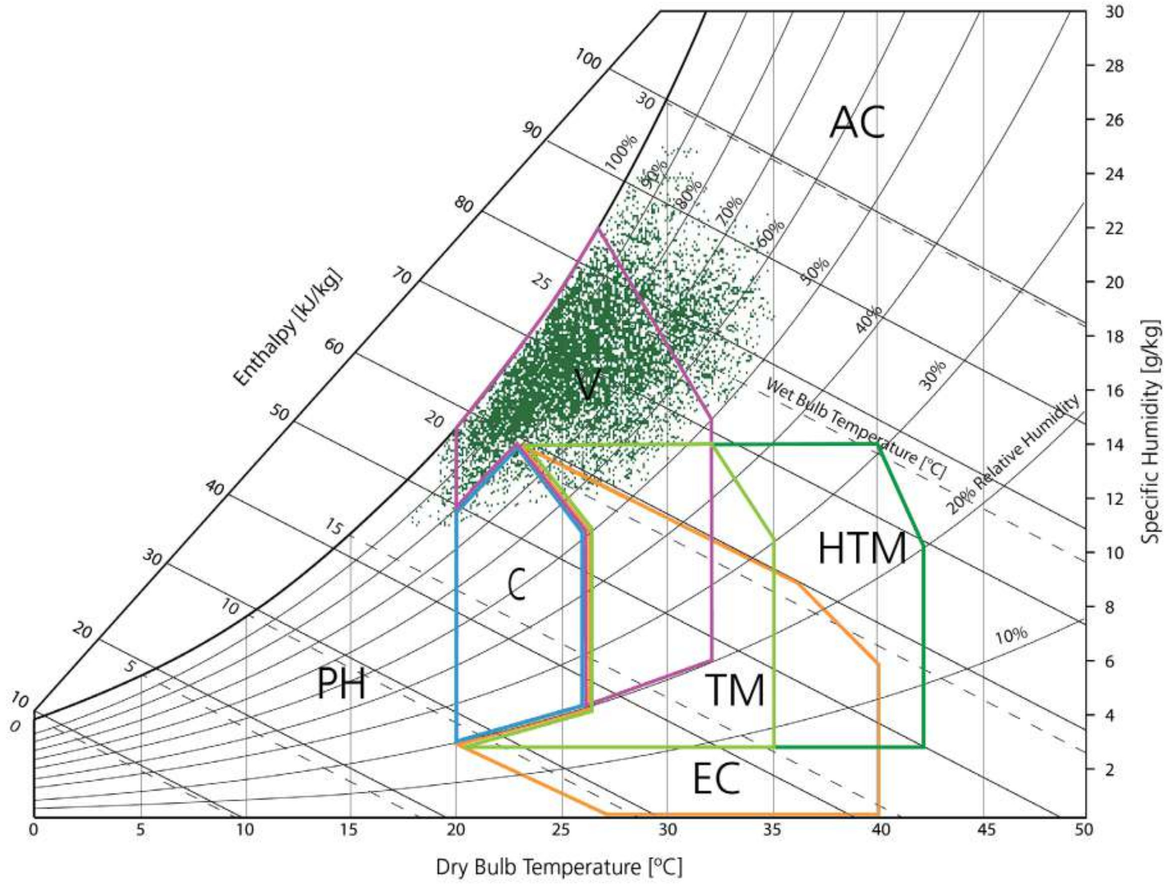


FIGURE 270 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR TANGA**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

Figure 270 shows that Tanga lies outside the comfort zone throughout the year. The resulting combination of high hourly outdoor dry bulb temperatures and relative humidity causes discomfort. In order to improve thermal comfort, natural ventilation is the most appropriate strategy to adopt.

However, at certain times of the year, temperature go above the natural ventilation zone and mechanical cooling may be necessary to provide thermal comfort.

BIOCLIMATIC RECOMMENDATIONS

The design objectives and responses for a hot and humid climate like Tanga's should be to address issues due to high temperatures, high relative humidity and high solar radiation levels. The following passive design strategies may be used to address the cooling requirements that result from the above climatic characteristics:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading.
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, covered verandas and porches etc.
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and reduce heat gains.
- Lightweight building materials with low thermal capacity are recommended for walls, floors and roofs to allow rapid cooling at night.

b. To promote maximum ventilation

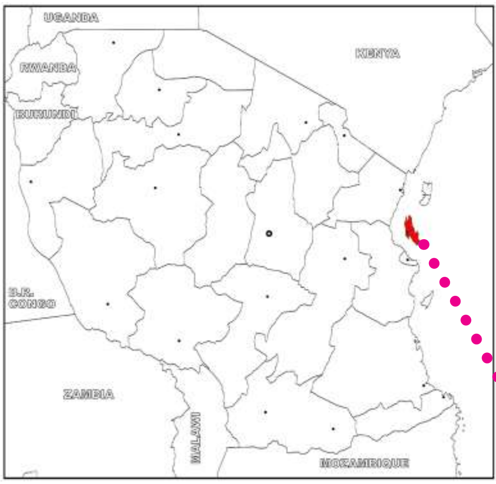
- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings.
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum ventilation.
- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.
- Openings should be located on opposite sides of walls to allow for proper cross-ventilations. Internal walls should also have openings for airflow through the internal space.
- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement.
- Ventilated double roofs enhance ventilation of the roof minimising overheating.

FIGURE 271 **LIGHTWEIGHT MATERIALS SUCH AS BAMBOO, SHADE NETS AND TIMBER HAVE BEEN USED IN THE BUILDING'S FAÇADES ALLOWING FOR CROSS VENTILATION THROUGH THE OPENINGS IN THESE PERMEABLE MATERIALS. RAISED FLOORS MINIMISE HEAT GAIN FROM THE GROUND WHILE OPEN EAVES AND OPEN WINDOWS COVERED WITH WIRE AND MOSQUITO MESH MAXIMISE NATURAL VENTILATION BY PROMOTING AIR FLOW THUS PROVIDING THERMAL COMFORT.**

The Magoda Project, Tanga
Source: *http://ingvartsen.dk/ © Ingvartsen Architects / Konstantin IKONOMIDIS*

ZANZIBAR

FIGURE 272 **LOCATION OF ZANZIBAR**



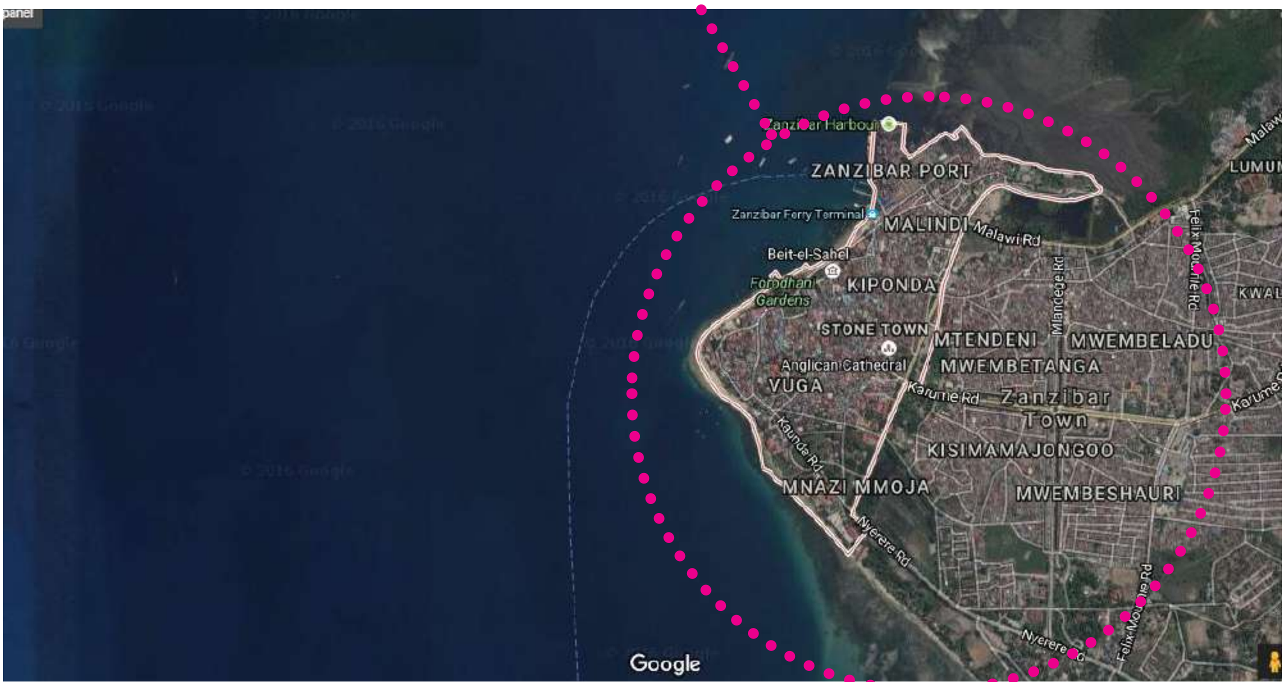
Source: *http://www.d-maps.com/*

Climatic Zone	HOT AND HUMID
Latitude	06° 13' 6
Longitude	39° 12' E
Altitude	15 m

FIGURE 273 **AERIAL VIEW OF ZANZIBAR TOWN**

Source: *http://networkutazasiiroda.network.hu/*

FIGURE 274 **LOCATION OF ZANZIBAR TOWN ON ZANZIBAR ISLAND**



Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Zanzibar city is found in Zanzibar, the main and largest island of the Zanzibar Archipelago that lies off the off the coast of East Africa in the Indian Ocean. It is located at geographic coordinates of 06° 13′ S, 39° 12′ E at an altitude of 15 m above sea level. It enjoys a hot and humid climate characterised by high relative humidity (annual mean of 80%) and high temperatures throughout the year (average of 26.9 °C). The warmest month of the year is March. The lowest average temperatures of the year are in July making it the coolest month. The average amount of rainfall recorded annually is 1,350 mm with the highest recorded amount in April and the least amount in July. High wind velocity is recorded annually at an average of 4.9 m/s with the predominant wind direction being South and South East. The annual average global solar radiation in Zanzibar is 4.9 kWh/m².

TABLE 30 **ZANZIBAR MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	28.4	75.0	5.1	5.0	3.2	2.7	50
FEB	28.6	75.0	5.1	5.2	3.3	2.7	60
MAR	29.0	80.0	5.1	4.9	2.9	2.8	140
APR	27.2	87.0	4.1	4.4	2.6	2.5	320
MAY	26.4	85.0	4.6	4.6	3.7	2.2	280
JUN	25.5	82.0	5.1	4.8	4.0	2.2	50
JUL	25.1	80.0	4.6	4.9	4.3	2.1	20
AUG	25.4	78.0	4.6	5.2	3.8	2.5	30
SEP	25.3	79.0	5.1	5.2	3.6	2.6	40
OCT	26.5	78.0	5.1	5.4	3.7	2.7	60
NOV	27.5	81.0	5.1	5.0	3.2	2.8	170
DEC	28.1	79.0	5.6	4.8	2.7	2.9	130

FIGURE 275 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR ZANZIBAR**

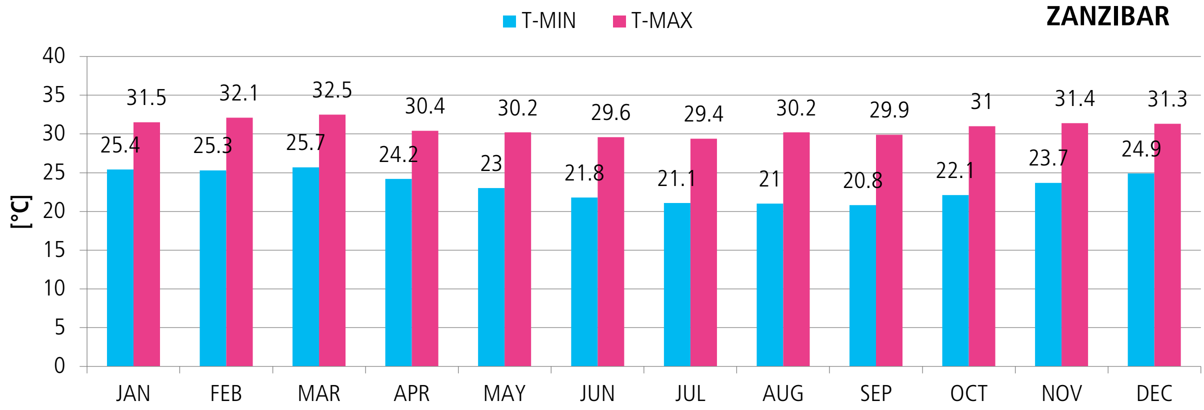


FIGURE 276 **MONTHLY MEAN RELATIVE HUMIDITY FOR ZANZIBAR**

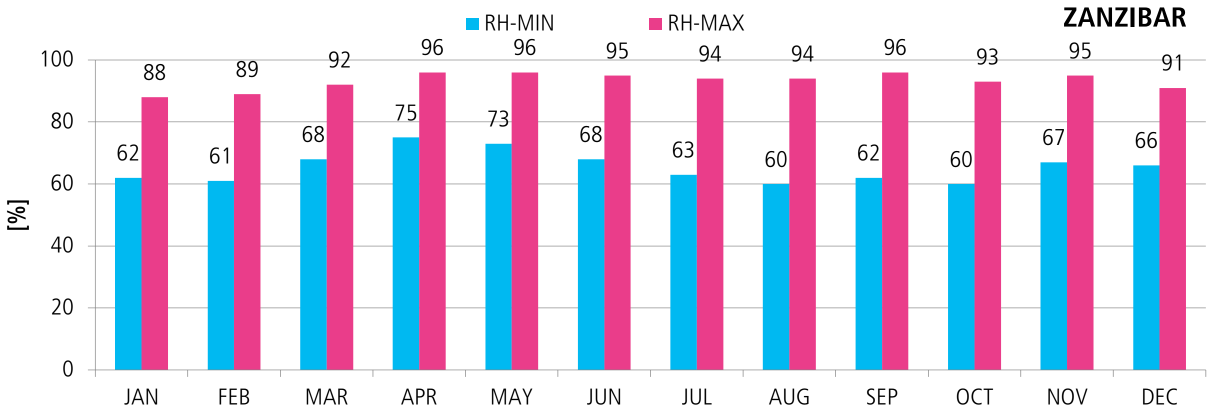


FIGURE 277 **MONTHLY AVERAGE RAINFALL FOR ZANZIBAR**

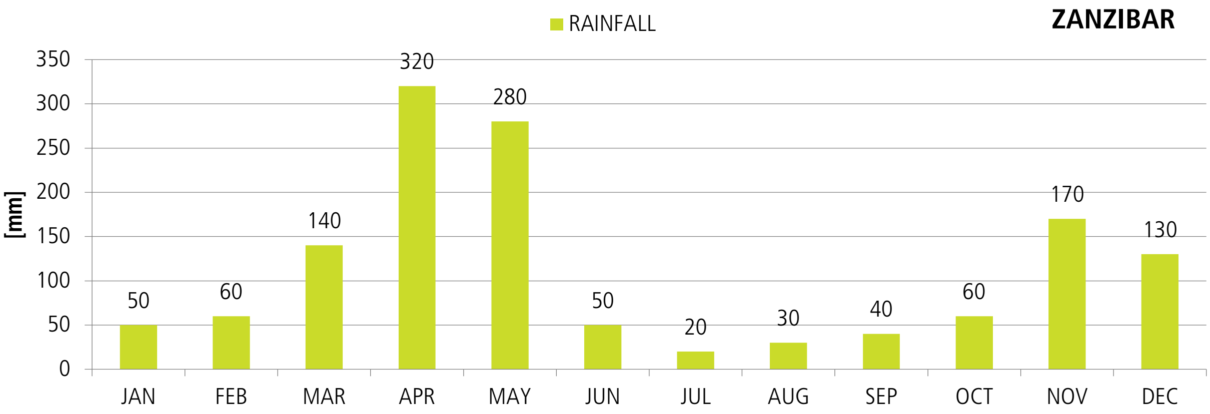


FIGURE 278 **POLAR SUN PATH DIAGRAM FOR LATITUDE 6° SOUTH**

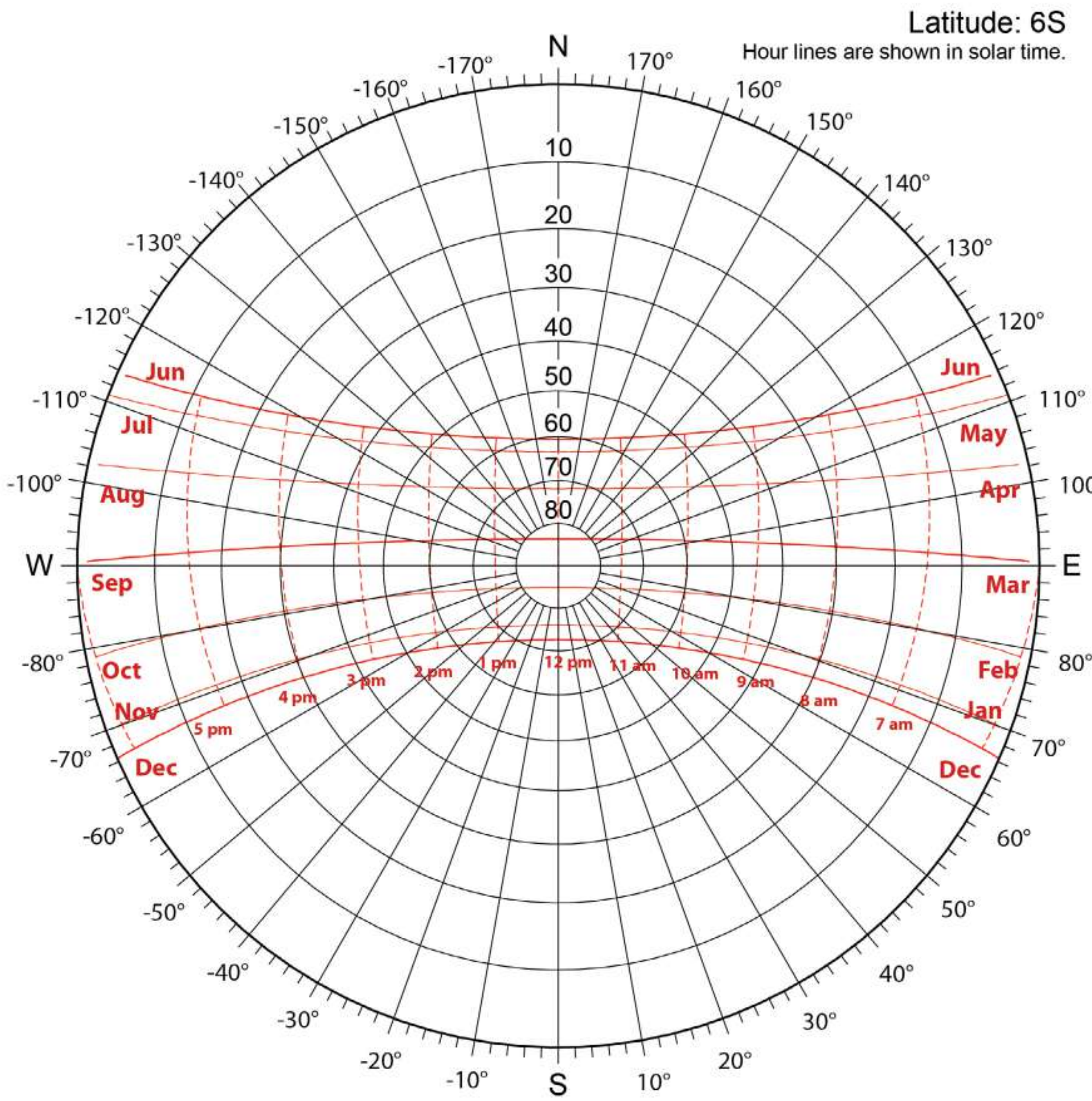


FIGURE 279 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN ZANZIBAR**

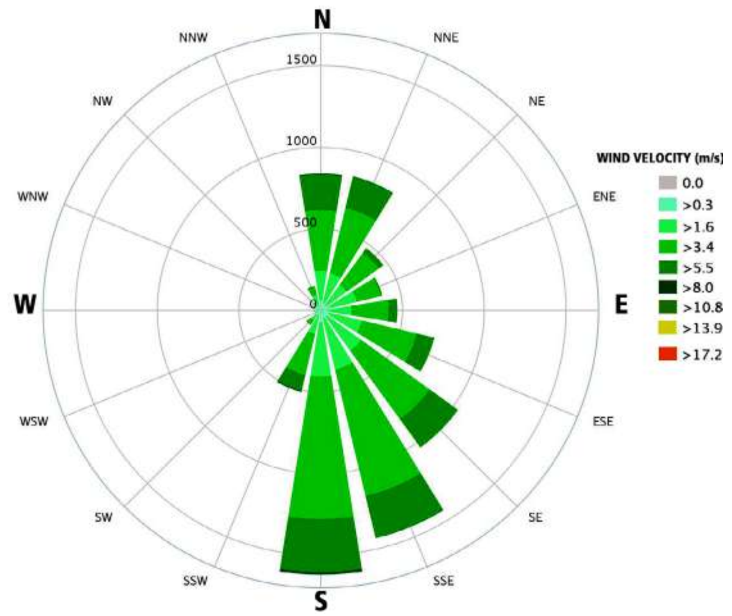
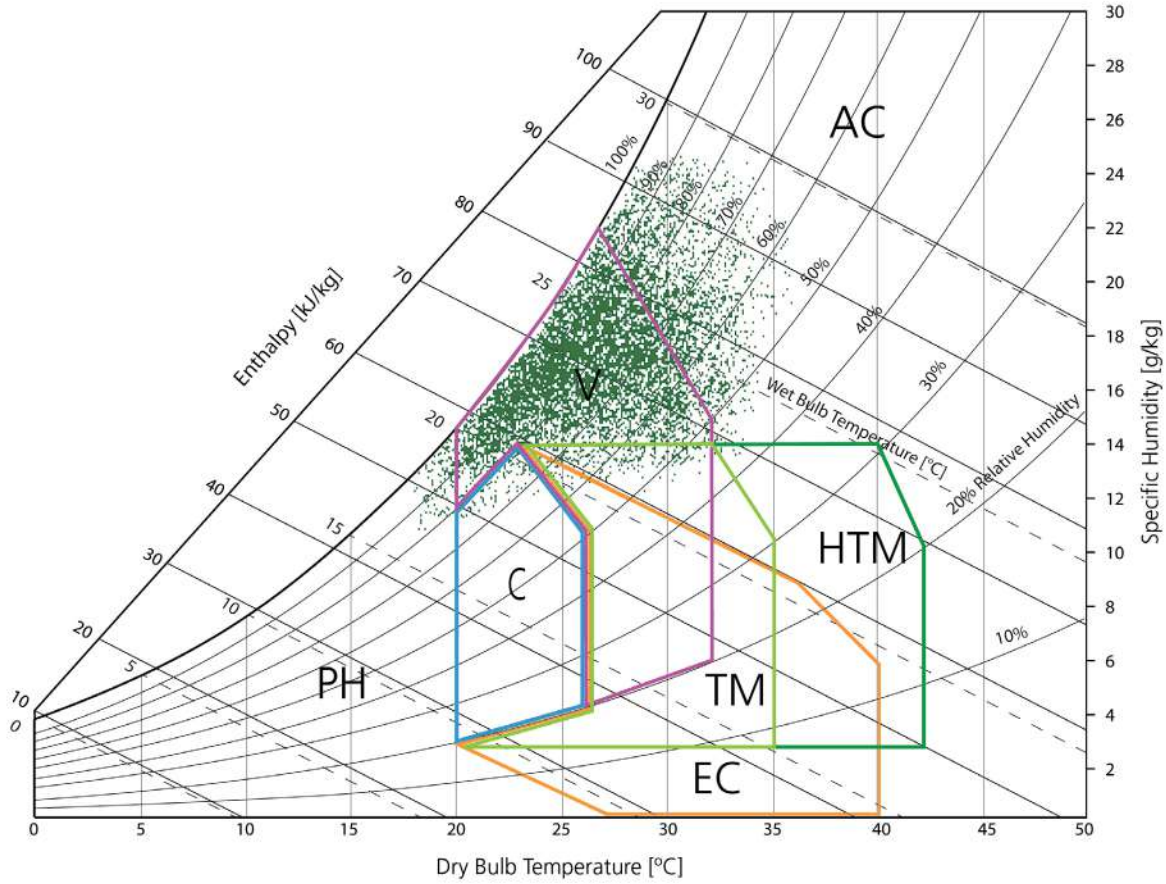


FIGURE 280 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR ZANZIBAR**



C Comfort Zone
V Natural Ventilation
TM Thermal Mass
HTM High Thermal Mass
EC Evaporative Cooling
PH Passive Heating
AC Air Conditioning

INTERPRETATION

Figure 280 shows that Zanzibar has its hourly outdoor dry bulb temperatures and relative humidity data points out of the comfort zone. The resulting combination of high temperatures and relative humidity causes discomfort. According to the psychrometric chart, thermal comfort can be achieved through natural ventilation for temperatures below 33 °C making it the most appropriate design strategy to extend the comfort zone.

However, at certain periods, outdoor dry bulb temperature and relative humidity fall outside the limits of natural ventilation, thereby necessitating the use of mechanical cooling and dehumidification to improve thermal comfort.

BIOCLIMATIC RECOMMENDATIONS

The design objectives and responses for a hot and humid climate like Zanzibar's should be to address issues due to high temperatures, high relative humidity and high solar radiation levels. The following passive design strategies may be used to address the cooling requirements that result from the above climatic characteristics:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading.
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, covered verandas and porches etc.
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and reduce heat gains.
- Lightweight building materials with low thermal capacity are recommended for walls, floors and roofs to allow rapid cooling at night.

b. To promote maximum ventilation

- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings.
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum ventilation.
- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.
- Openings should be located on opposite sides of walls to allow for proper cross-ventilations. Internal walls should also have openings for airflow through the internal space.
- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement.
- Ventilated double roofs enhance ventilation of the roof minimising overheating.

6.3 UGANDA

FIGURE 281 **MAP OF AFRICA SHOWING THE LOCATION OF UGANDA**

Source: *http://www.d-maps.com/*

TABLE 31 **REPRESENTATIVE TOWNS IN KENYA**

CITY/TOWN	ALTITUDE (M)	LATITUDE	LONGITUDE	CLIMATE ZONE
Arua	1,200 m	3° 02′ N	30° 54′ E	Zone 3 – Hot semi-arid / Savannah
Fort Portal	1,480 m	0° 39′ N	30° 16′ E	Zone 5 – Upland
Gulu	1,100 m	2° 46′ N	32° 17′ E	Zone 3 – Hot semi-arid / Savannah
Hoima	1,120 m	1° 25′ N	31° 21′ E	Zone 3 – Hot semi-arid / Savannah
Iganga	1,120 m	0° 36′ N	33° 29′ E	Zone 3 – Hot semi-arid / Savannah
Jinja	1,200 m	0° 25′ N	33° 12′ E	Zone 4 – Great Lakes
Kabale	1,800 m	1° 15′ S	29° 59′ E	Zone 5 – Upland
Kampala	1,190 m	0° 19′ N	32° 34′ E	Zone 4 – Great Lakes
Kasese	1,000 m	0° 11′ N	30° 05′ E	Zone 3 – Hot semi-arid / Savannah
Lira	1,080 m	2° 14′ N	32° 54′ E	Zone 3 – Hot semi-arid / Savannah
Mbale	1,143 m	1° 04′ N	34° 10′ E	Zone 5 – Upland
Soroti	1,080 m	1° 42′ N	33° 36′ E	Zone 3 – Hot semi-arid / Savannah
Tororo	1,185 m	0° 41′ N	34° 10′ E	Zone 5 – Upland

KAMPALA

FIGURE 282 **LOCATION OF KAMPALA**

Source: *http://www.d-maps.com/*

Climatic Zone	GREAT LAKES
Latitude	00° 19’ N
Longitude	32° 34’ E
Altitude	1,190 m

FIGURE 283 **VIEW OF KAMPALA CITY**

Source: *http://www.enjoyuganda.info/wp-content/uploads/2011/11/Kampala003.jpg*

FIGURE 284 **LOCATION OF KAMPALA CITY**

Source: *https://maps.google.co.ke Map data © 2016 Google*

GEOGRAPHY AND BIOCLIMATIC DATA

Kampala, the capital and largest city of Uganda, is located at geographic coordinates 0° 19′ N, 32° 34′ E at an altitude of 1,190 m above sea level. Its climate is characterised by rainfall being recorded throughout the year with an average amount of 1,211 mm. The most amount occurs in April while the least amount occurs in July. The average annual temperature is 21.5 °C with the warmest period on average occurring between February and March while the coolest months on average being August and September. The city experiences high relative humidity throughout the year at an average of 82.1%. High wind velocity is recorded throughout the year at an average of 5.1 m/s and the predominant wind direction being South. The annual average global solar radiation in Kampala is 4.8 kWh/m².

TABLE 32 **KAMPALA MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	22.0	80.0	6.2	4.9	4.0	2.2	58
FEB	22.0	80.0	6.2	5.0	3.9	2.2	61
MAR	22.3	81.0	6.2	5.1	4.1	2.2	122
APR	21.5	85.0	5.1	4.8	3.4	2.4	179
MAY	21.8	84.0	4.1	4.8	3.9	2.1	132
JUN	20.9	85.0	3.6	4.4	3.3	2.3	66
JUL	20.9	81.0	3.1	4.3	3.0	2.3	53
AUG	20.7	82.0	3.6	4.6	3.0	2.5	88
SEP	20.7	83.0	5.1	5.1	3.7	2.5	101
OCT	21.5	81.0	5.7	4.8	3.3	2.5	118
NOV	21.5	82.0	5.7	4.9	3.5	2.4	139
DEC	21.7	81.0	6.2	5.0	4.1	2.3	94

FIGURE 285 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR KAMPALA**

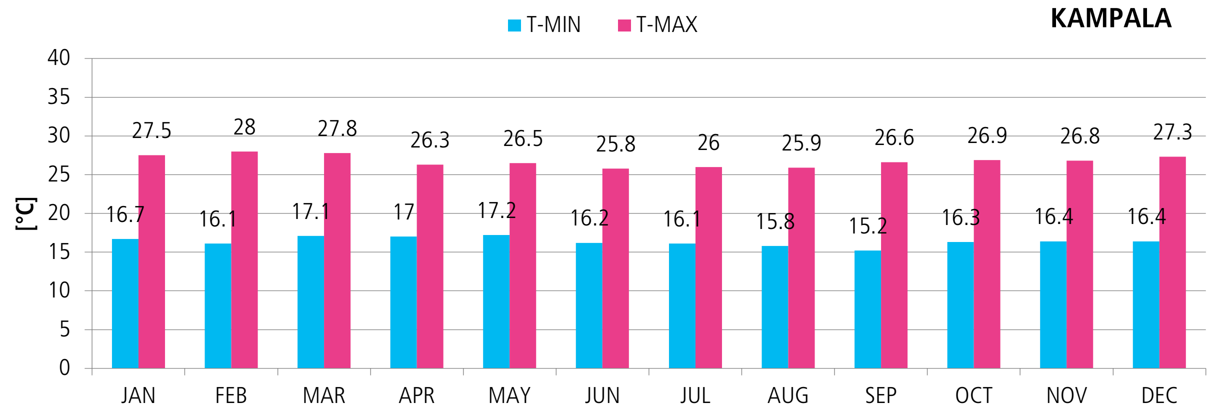


FIGURE 286 **MONTHLY MEAN RELATIVE HUMIDITY FOR KAMPALA**

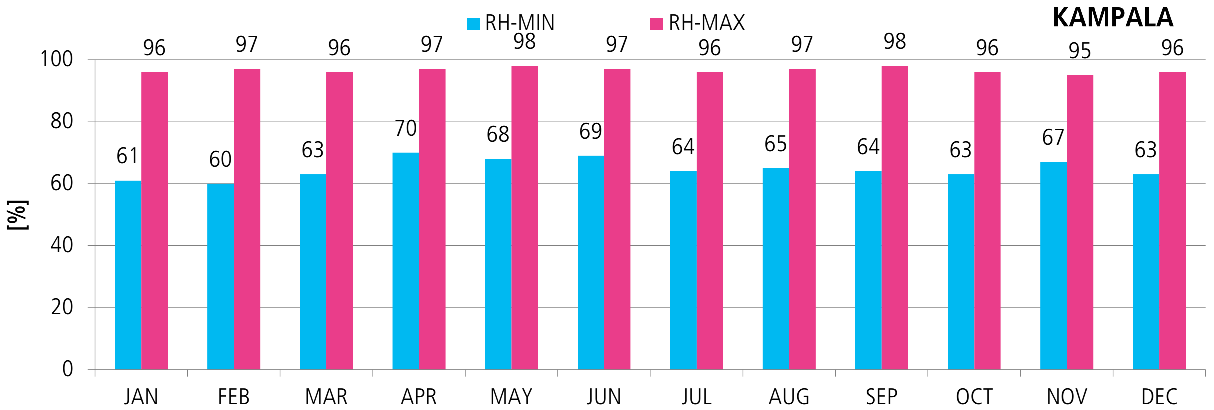


FIGURE 287 **MONTHLY AVERAGE RAINFALL FOR KAMPALA**

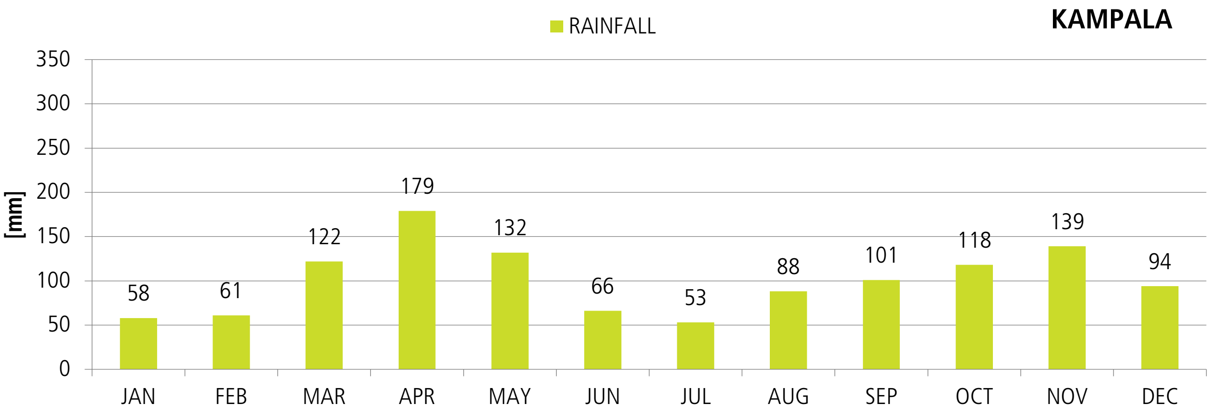


FIGURE 288 **POLAR SUN PATH DIAGRAM FOR LATITUDE 0° (EQUATOR)**

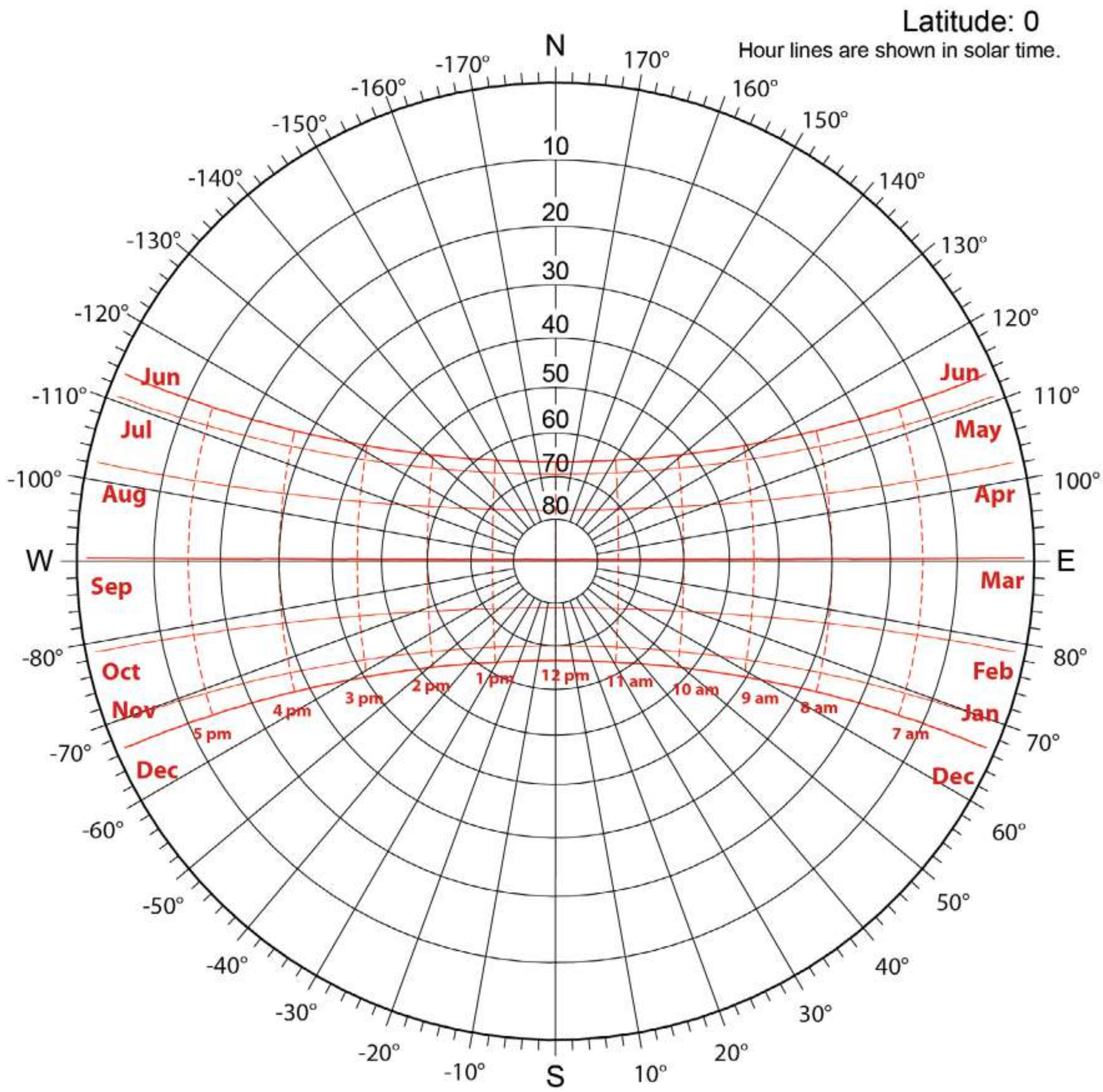


FIGURE 289 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN KAMPALA**

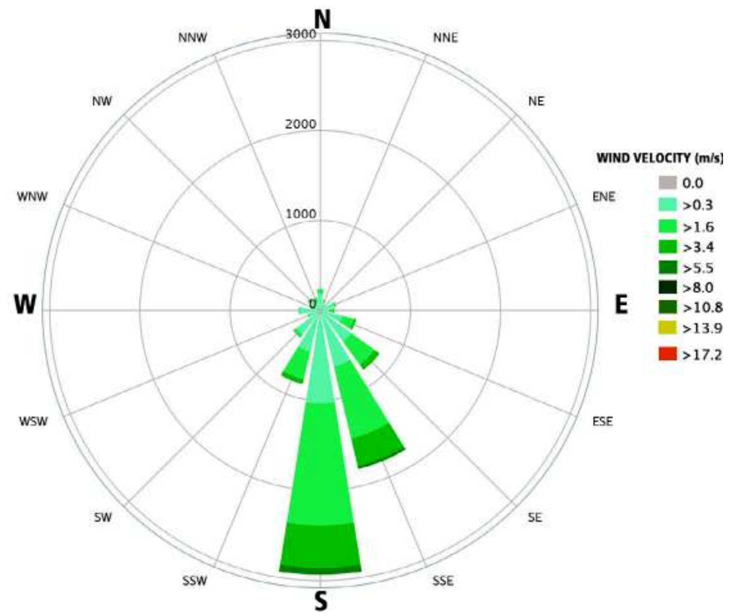
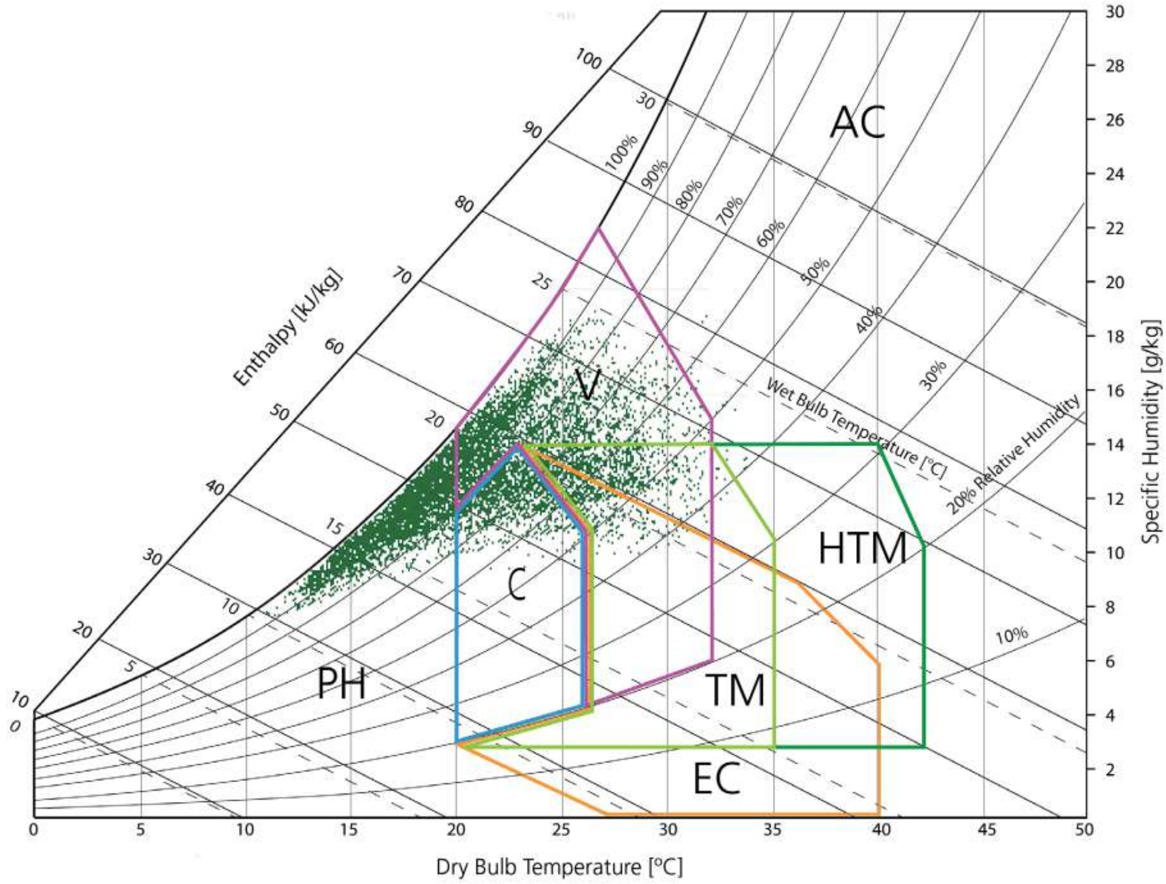


FIGURE 290 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR KAMPALA**



C	Comfort Zone	EC	Evaporative Cooling
V	Natural Ventilation	PH	Passive Heating
TM	Thermal Mass	AC	Air Conditioning
HTM	High Thermal Mass		

INTERPRETATION

The psychrometric chart Figure 290 shows that the Great Lake climate of Kisumu experiences a few hours of thermal comfort with most of the hourly data points of outdoor dry bulb temperature and relative humidity falling beyond the comfort zone thus experiencing high temperature and humidity. Certain periods of the year have the outside conditions falling below the comfort zone. The chart therefore suggests that natural ventilation, passive heating through direct solar heat gain and solar shading are the most effective strategies for improving thermal comfort.

BIOCLIMATIC RECOMMENDATIONS

The design objectives and responses for Great Lakes climate like Kampala's should be to address issues due to high daily temperatures variation, high relative humidity and high solar radiation levels. The following passive design strategies may be used to address the cooling and heating requirements that result from the above climatic characteristics:

a. To provide maximum protection against direct and indirect solar radiation

- Buildings should be oriented with their long axis running east – west to provide effective shading.
- Openings should be located on the north and south facing façades and avoided on the east and west facing façades to reduce heat gain from the low early morning and late afternoon sun.
- Appropriate shading devices should be located on all openings. These can be in form of extended roof eaves, vertical fins, covered verandas and porches etc. (Figure 291).
- Additional solar radiation protection may be provided by shade-providing vegetation within the space surrounding the building.
- Reflective roof surfaces and light coloured external finishes are appropriate to reflect solar radiation and minimise heat gains.

b. To promote maximum ventilation

- Building layout should be widely spaced to avoid obstruction of the wind and allow maximum ventilation around and inside buildings.
- Long and narrow buildings (shallow floor plans) are more suited to this climate as they provide maximum ventilation.
- North and south facing walls should have large and fully openable openings. These openings should preferably be oriented to take advantage of the prevailing breezes to facilitate natural airflow. Openings at body level are more effective.
- Openings should be located on opposite sides of walls to allow for proper cross-ventilations. Internal walls should also have openings for airflow through the internal space.
- It is advisable to have permanent vents / openings close to the ceiling / roof to prevent the built up of hot air and encourage thermal air movement.
- Ventilated double roofs enhance ventilation of the roof minimising overheating.

c. Enabling passive heating

- Medium weight walls, floors and ceilings are recommended to explore passive solar gains by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot period as well as lead to extensive heat loss at night or during the cold periods.
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone.

FIGURE 291 **PROVISION OF PERFORATED SCREEN WALLS AND OPENABLE WINDOWS AID IN CROSS VENTILATION. WINDOWS ARE SHADED KEEPING OUT SOLAR RADIATION THUS PROVIDING COOL INTERIORS.**

British High Commission building in Kampala
Source: *https://www.kilburnnightingale.com / © Richard NIGHTINGALE*

6.3 RWANDA

FIGURE 292 **MAP OF AFRICA SHOWING THE LOCATION OF RWANDA**

Source: *http://www.d-maps.com/*

TABLE 33 **REPRESENTATIVE TOWNS IN RWANDA**

CITY/TOWN	ALTITUDE (M)	LATITUDE	LONGITUDE	CLIMATE ZONE
Butare	1,768 m	2° 36′ S	29° 45′ E	Zone 5 – Upland
Gisenyi	1,481 m	1° 41′ S	29° 15′ E	Zone 5 – Upland
Kigali	1,567 m	1° 56′ S	30° 03′ E	Zone 5 – Upland
Kibuye	1,500 m	2° 03′ S	30° 04′ E	Zone 5 – Upland
Ruhengeri	1,860 m	1° 30′ S	29° 63′ E	Zone 5 – Upland
Rwamagana	1,528 m	1° 57′ S	30° 26′ E	Zone 5 – Upland

KIGALI

FIGURE 293 **LOCATION OF KIGALI**

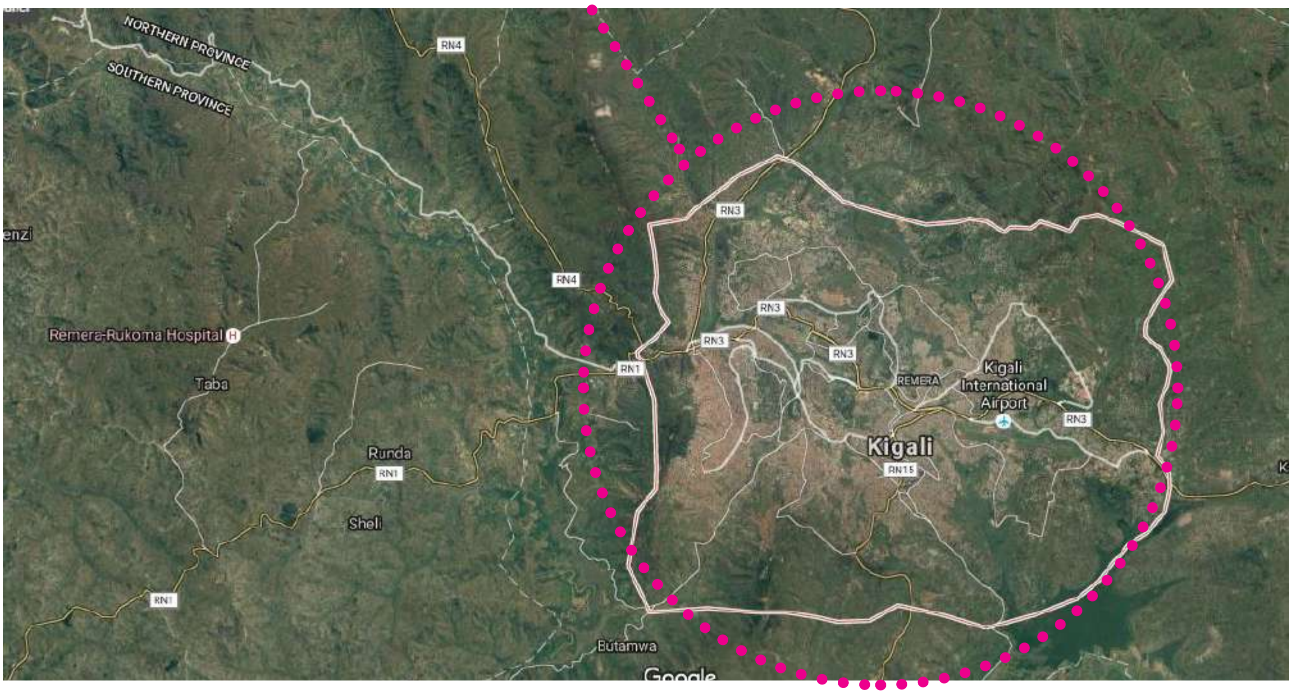
Source: http://www.d-maps.com/

Climatic Zone	UPLAND
Latitude	01° 56' S
Longitude	30° 03' E
Altitude	1,567 m

FIGURE 294 **AERIAL VIEW OF KIGALI CITY**

Source: © Thabiso MAKELO

FIGURE 295 **LOCATION OF KIGALI CITY**



Source: https://maps.google.co.ke Map data © 2016 Google

GEOGRAPHY AND BIOCLIMATIC DATA

Kigali, the capital and largest city in Rwanda, is located at geographic coordinates 01° 56′ S, 30° 03′ E. At an altitude of 1,567 m above sea level, the city enjoys a pleasant upland climate with annual average temperature of 21 °C. March and October are the warmest months on average while June is the coolest month. The average annual rainfall is recorded at 951 mm with the highest amount occurring in April. Relative humidity ranges at 67 – 81% throughout the year while the wind velocity averages at 5.1 m/s with the predominant wind direction being South East. The annual average global solar radiation in Kigali is 5.0 kWh/m².

TABLE 34 **KIGALI MONTHLY MEAN CLIMATIC DATA TABLE**

Month	Dry bulb temp [°C]	Relative humidity [%]	Wind velocity [m/s]	Global solar radiation [kWh/m² day]	Direct normal solar radiation [kWh/m² day]	Diffuse solar radiation [kWh/m² day]	Rainfall [mm]
JAN	21.1	75.0	6.2	4.9	3.7	2.5	76.9
FEB	21.2	77.0	6.2	5.0	3.6	2.5	91
MAR	21.4	78.0	6.2	5.1	3.7	2.5	114.2
APR	20.9	81.0	5.1	4.9	3.5	2.4	154.2
MAY	21.1	78.0	4.1	4.9	3.9	2.3	88.1
JUN	20.3	75.0	3.6	5.1	4.4	2.0	18.6
JUL	20.8	67.0	3.1	5.2	5.0	1.9	11.4
AUG	21.3	67.0	3.6	5.1	4.3	2.1	31.1
SEP	21.3	73.0	5.1	5.0	3.4	2.5	69.6
OCT	21.5	75.0	5.7	4.9	3.6	2.3	105.7
NOV	20.4	81.0	5.7	4.8	3.3	2.5	112.7
DEC	20.8	78.0	6.2	4.7	3.5	2.5	77.4

FIGURE 296 **MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURE FOR KIGALI**

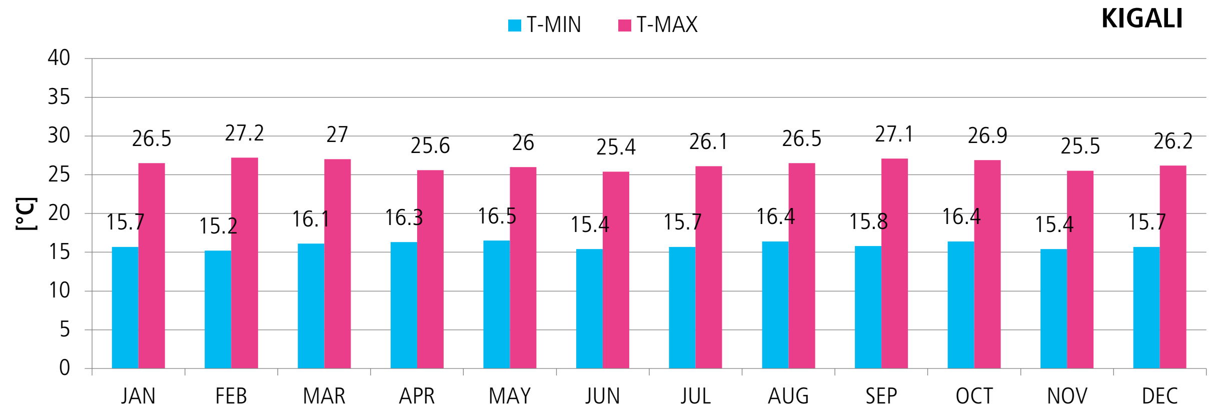


FIGURE 297 **MONTHLY MEAN RELATIVE HUMIDITY FOR KIGALI**

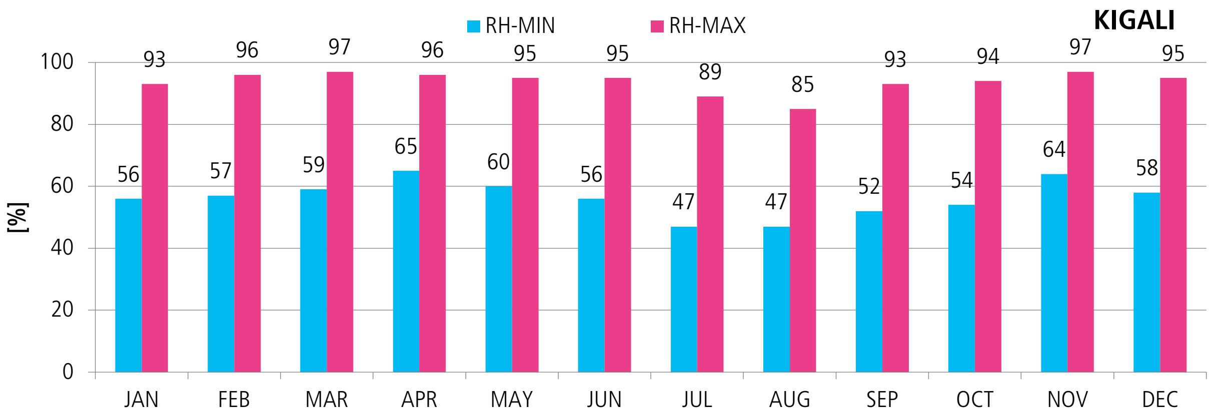


FIGURE 298 **MONTHLY AVERAGE RAINFALL FOR KIGALI**

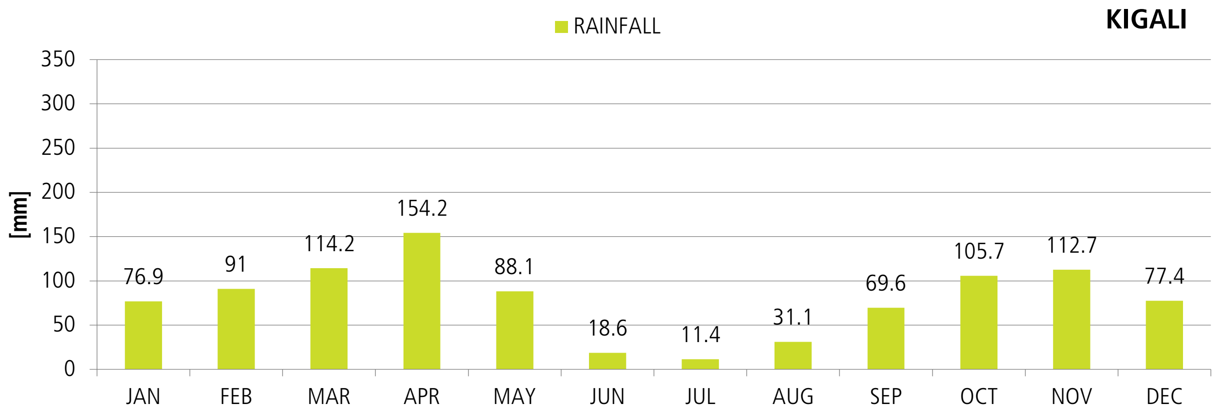


FIGURE 299 **POLAR SUN PATH DIAGRAM FOR LATITUDE 1° SOUTH**

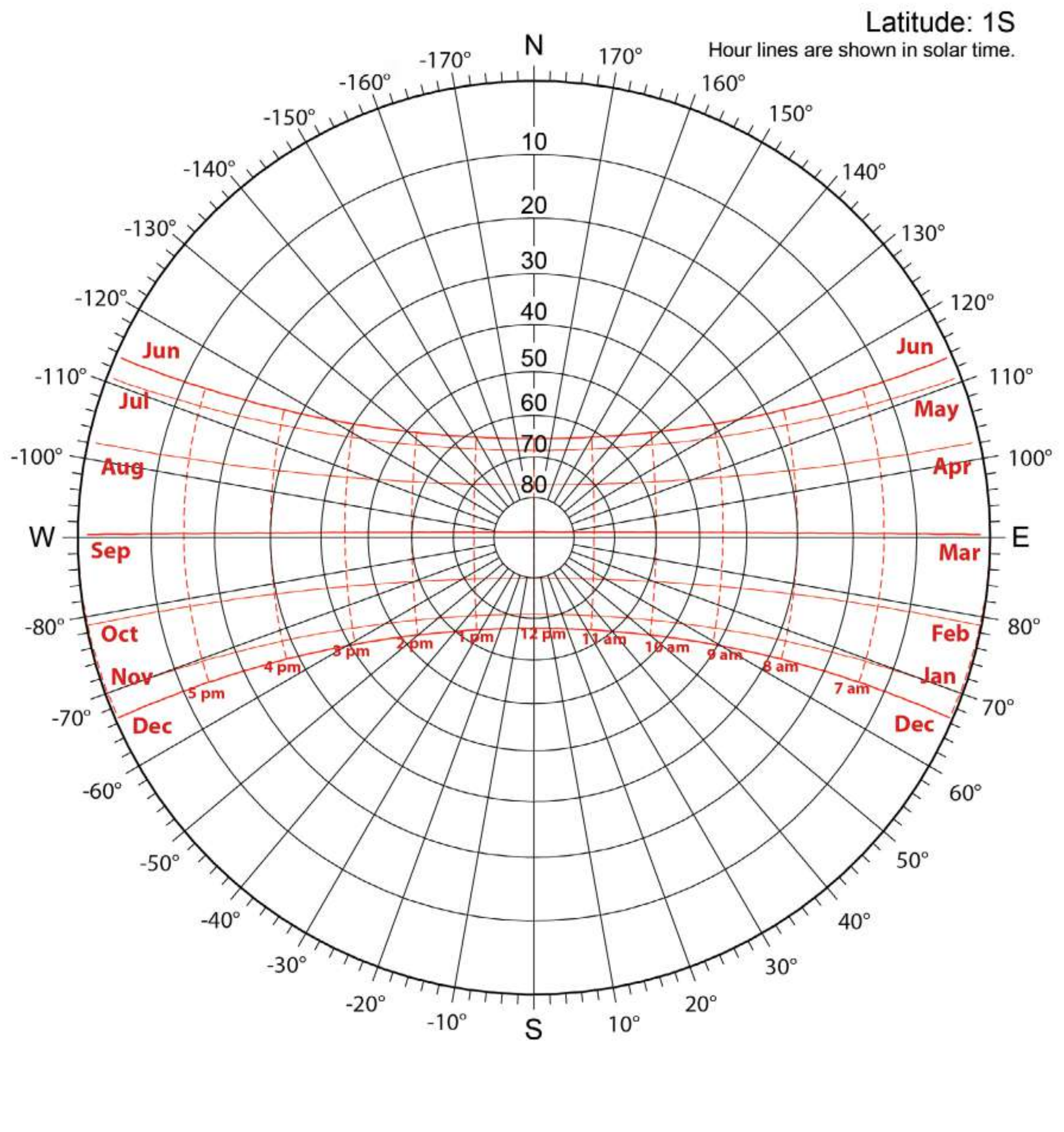


FIGURE 300 **WIND ROSE DIAGRAM SHOWING THE PREVAILING WIND DIRECTION IN KIGALI**

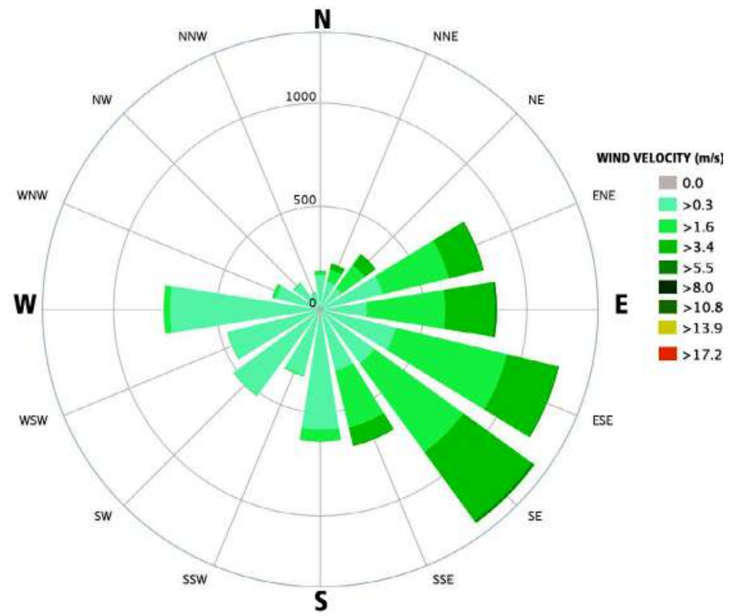
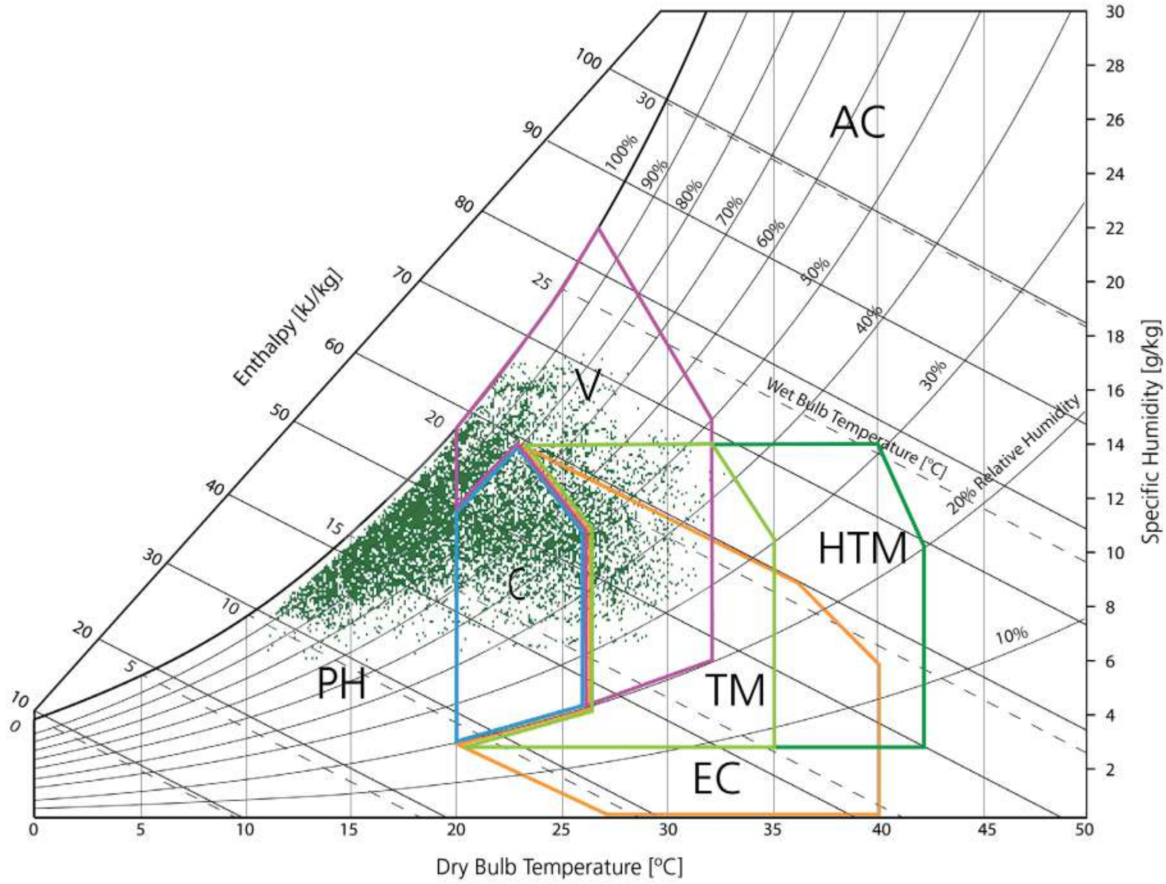


FIGURE 301 **PSYCHROMETRIC CHART WITH PASSIVE DESIGN STRATEGIES OVERLAYS FOR KIGALI**



C Comfort Zone	EC Evaporative Cooling
V Natural Ventilation	PH Passive Heating
TM Thermal Mass	AC Air Conditioning
HTM High Thermal Mass	

INTERPRETATION

In Kigali, most of the hourly points of outdoor dry bulb temperature and relative humidity fall within the comfort zone. However, a substantial portion falls below the comfort zone as seen in Figure 301. This means that during that period, space heating is necessary to extend the limit of comfort zone. This can be done through passive heating through direct solar heat gain and thermal mass. Further, internal heat gain from equipment, lights and occupants are also helpful in extending the thermal comfort and reducing heating demand. However, during certain times of the year, the hourly data points (outdoor dry bulb temperature and relative humidity) fall beyond the comfort zone. Thermal mass is effective in extending the comfort zone by absorbing and storing daytime solar heat for release at night when the temperatures fall below the comfort zone. Natural ventilation is also effective in creating thermal comfort in periods of high temperature and high relative humidity.

BIOCLIMATIC RECOMMENDATIONS

According to the climatic data for Kigali, the following design strategies are recommended for:

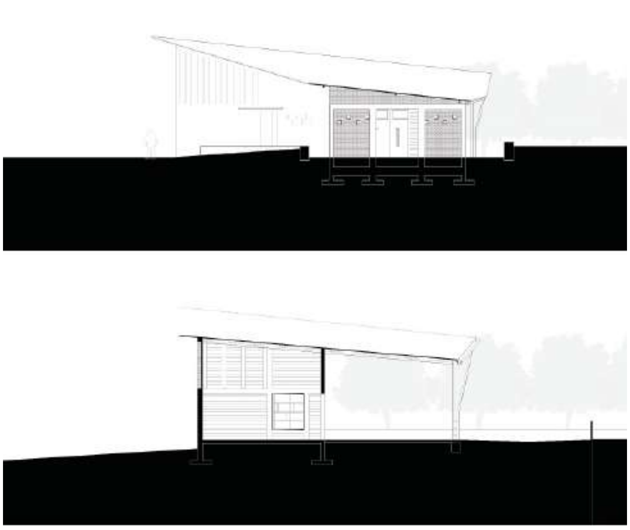
a. Protection against heat gain in the hot period

- Buildings should be oriented with the main glazed windows facing north and south for easier sun control and to minimise overheating during the hot periods.
- Large windows should be avoided on the east and west facing façades.
- Appropriate sun shading devices should be incorporated to keep out the solar radiation and glare during certain hours of the day during the hot periods.

b. Enabling passive heating

- Careful orientation of buildings with main rooms facing north east is appropriate to allow a certain amount of solar radiation to penetrate for passive heating during the cold periods.
- The floor plan should be organised such that it allows the sun to penetrate daytime spaces during the cold periods.
- Compact forms reduce heat gains during the hot periods and minimise heat losses during the cold periods.
- Medium weight walls, floors and ceilings are recommended to explore passive heating by storing heat accumulated during the day (avoiding overheating) to balance the night time low temperatures to keep them at comfort level.
- Excessive glazing should be avoided as it can lead to overheating during the hot

FIGURE 302 **DEEP OVERHANGS TO THE NORTH AND SOUTH PROVIDE SHADING AGAINST SOLAR RADIATION IN TURN ASSISTING IN COOLING OF THE INTERIOR SPACES. THESE OVERHANGS ALSO PROVIDE SHADING TO OUTDOOR SPACES.**



Kimisagara Football for Hope Centre, Kigali
Source: *http://www.archdaily.com/267440/kimisagara-football-for-hope-centre-kdap / Architectural Field Office with Architecture for Humanity © Killian DOHERTY*

- period as well as lead to extensive heat loss at night or during the cold periods.
- All windows should be airtight to prevent heat losses when the outdoor temperatures are below the comfort zone and they should be located on opposite walls to allow for cross-ventilation.
- Additional heating systems such as fireplac incorporated in the design.
- Internal heat gains from occupants, equip lights will greatly reduce heating needs.

FIGURE 303 **HIGH LEVEL OPENINGS HAVE BEEN INCORPORATED TO FACILITATE NATURAL CROSS VENTIL OF ROOMS AS WELL AS PROVISION OF DAYLIGHTING.**

Kimisagara Football for Hope Centre, Kigali
Source: *http://www.archdaily.com/267440/kimisagara-football-for-hope-centre-kdap / Architectural Field Office with Architecture for Humanity © Killian DOHERTY*

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APPENDIX 01- MAHONEY TABLES*

TABLE 1: DATA COLLECTION

Location | Latitude

Longitude | Altitude

AIR TEMPERATURE ⁰C	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	High	AMT
Monthly mean max.														
Monthly mean min.														
Monthly mean range													Low	AMR

RELATIVE HUMIDITY %												
Monthly mean max. (am)												
Monthly mean min (pm)												
Average												
Humidity group												

Note	Humidity group	1	If average RH - below	30%
		2		30- 50%
		3		50- 70%
		4		Above 70%

RAIN AND WIND	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	Total
Rainfall, mm													
Wind, prevailing													
Wind, secondary													

AMT = Annual Mean Temperature AMR = Annual Mean Range

TABLE 2: TEMPERATURE AND HUMIDITY DIAGNOSIS

		AMT over 20⁰C		AMT 15- 20⁰C		AMT below 20⁰C	
Comfort limit		Day	Night	Day	Night	Day	Night
Humidity group	1	26-34	17-25	23-32	14-23	21-30	12-21
	2	25-31	17-24	22-30	14-22	20-27	12-20
	3	23-29	17-23	21-28	14-21	19-26	12-19
	4	22-27	17-21	20-25	14-20	18-24	12-18

RAIN AND WIND		**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	AMT
Monthly mean. max. ⁰C														
Day comfort	Upper													
	Lower													
Monthly mean. min. ⁰C														
Night comfort	Upper													
	Lower													
Thermal stress	Day													value O,H,C
	Night													

** The Mahoney tables presented in this section are adopted from a reproduction by Anh Tuan NGUYEN (2013) – University of Liege Belgium.*

***Source:** http://www.mediafire.com/file/85jh7lhq56coqsw/Mahoney+Tables.xlsx*

H (hot): if mean is above comfort limits

O (comfort): if mean is within comfort limits

C (cold): if mean is below comfort limits

INDICATORS						
Applicable when:	Indicator	Thermal Stress		Rainfall	Humidity group	Monthly mean range AMR
Meaning		**Day**	**Night**			
Air movement essential	H1	H			4	
		H			2,3	Less than 10⁰C
Air movement desirable	H2	O			4	
Rain protection neccessary	H3			Over 200mm		
Thermal capacity necessary	A1				1,2,3	More than 10⁰C
Outdoor sleeping desirable	A2		H		1,2	
		H	O		1,2	More than 10⁰C
Protection from cold	A3	C				

INDICATORS		**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	Total
Humid:	**H1**													
	H2													
	H3													
Arid	**A1**													
	A2													
	A3													

TABLE 3: RECOMMENDED SPECIFICATIONS

Indicator totals from Table 2								
H1	H2	H3	A1	A2	A3			
								Layout
			0- 1				**1**	Orientation North and South (long axis East- West)
			11,12		5- 12			
					0- 4		**2**	Compact courtyard planning
								Spacing
11,12							**3**	Opening spacing for breeze penetration
2- 10							**4**	
0,1							**5**	Compact courtyard planning
								Air movement
3- 12							**6**	Room single banked, permanent provision of air movement
1,2			0- 5					
			6- 12				**7**	Double banked room, temporary provision for air movement
0	2- 12							
	0- 1						**8**	No air movement
								Openings
			0,1		0		**9**	Large openings, 40- 80%
			11,12		0,1		**10**	Very small openings, 10- 20%
Any other conditions							**11**	Medium openings, 20- 40%

								Walls
			0- 2		0		**12**	Light walls, short time lag
			3- 12		0,1		**13**	Heavy external and internal walls
								Roofs
			0- 5				**14**	Light, insulated roofs
			6- 12				**15**	Heavy roofs, over 8h time lag
								Outdoor sleeping
				2- 12			**16**	Space for outdoor sleeping required
								Rain protection
		3 - 12					**17**	Protection from heavy rain necessary

TABLE 4: DETAIL RECOMMENDATIONS

Indicator totals from Table 2

H1	H2	H3	A1	A2	A3

								Size of openings
			0,1		0		1	Large 40- 80%
					1- 12		2	Medium 25- 40%
			2- 5					
			6- 10				3	Small 15- 25%
			11,12		0- 3		4	Very small 10-20%
					4- 12		5	Medium 25- 40%
								Position of openings
3- 12							6	In North and South walls at body height on windwad
1- 2			0- 5					
			6- 12				7	As above, openings also in internal walls
0	2- 12							
								Protection of openings
					0- 2		8	Exclude direct sunlight
		2- 12					9	Provide protection from rain
								Walls and floors
			0- 2				10	Light, low thermal capacity
			2- 12				11	Heavy, over 8h time lag
								Roofs
10- 12			0- 2				12	Light, reflective surface, capacity
			3- 12				13	Light, well insulated
0- 9			0- 5					
			6- 12				14	Heavy, over 8h time lag
								External surfaces
				1- 12			15	Space for outdoor sleeping
		1- 12					16	Adequate rainwater drainage

The project **"Promoting Energy Efficiency in Buildings in East Africa"** is an initiative of UN-Habitat in collaboration with the United Nations Environment Programme (UNEP), the Global Environment Facility (GEF) and the governments of Kenya, Uganda, Tanzania, Rwanda and Burundi.

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