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The Journal of SUSTAINABLE BUILDING DESIGNS

Multi-dwelling housing

UN-HABITAT
FOR A BETTER URBAN FUTURE

The Journal of Sustainable Building Design

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The Journal of SUSTAINABLE BUILDING DESIGN

Multi-dwelling housing

UN HABITAT

Contents

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Introduction

Buildings have a strong potential to impact positively or negatively two important elements of everyday life: our 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 buildings are designed in relation to the local climate and site-specific characteristics.

This journal calls for change in the way we build. It promotes creative ways to produce buildings which achieve optimum conditions for their inhabitants whilst making minimum demands on fossil-based energy. The first step in creating comfort and thermal delight in buildings is to understand the relationship between the local climate and our need for shelter. Buildings should vary with climate and thus with location.

Designing an energy efficient built environment involves minimising the wastage of energy resources while maximising the use of passive design options and renewable energy sources.

The design of energy efficient buildings and homes depends on, solar path and solar radiation, rainfall, humidity, prevailing wind, and ambient temperature of a particular place among others. Design parameters of buildings and homes, therefore, vary with different climatic zones. Therefore, to achieve sustainable housing, it is important to build conssidering the prevailing climatic conditions.

Poor climatic design of buildings, all too often seen in 'modern' architecture, causes many buildings to overheat, even in temperate or cold climates where such problems were never faced before the advent of modern architecture. The influence of the sun should be understood and respected by designers of passive solar buildings in which the sun's free energy is used for natural lighting, heating and drying out but will not interfere with the occupants' comfort. Well-designed buildings with environmentally friendly solutions use less energy. They require lower maintenance compared to ordinary buildings and are more comfortable spaces to live in.

Designing an energy efficient built environment involves minimising the wastage of energy resources while maximising the use of passive design options and renewable energy sources. The green building (or sustainable building) is a result of a holistic approach. It is designed, constructed, and operated in an environmentally responsible way; it is resource efficient (land, water, energy, material, waste) throughout the building's life-cycle.

This journal acts as a guideline in providing applicable passive design principles for different climatic conditions that should be taken into consideration when designing in the different climates. These include:

- Site analysis
- Building orientation
- Natural ventilation
- Day lighting
- Solar shading
- Building materials
- Window sizes
- Window location
- Location of building services

Whereas sustainable buildings are directly related to local climate and site conditions, this journal is not intended to provide generic templates replicable in any part of the East African region. It aims to discuss examples and guide the user on how best to explore local climatic conditions.

2

Prevailing Wind Analysis

Wind is the movement of air masses caused by the difference in atmospheric pressure related to land, water and air temperature gradients. They can be:

- Regional winds: occur at macro-territorial level (between one geographical region and another
- Local winds: occur at a local scale (waterfront, lakeside area, valleys)

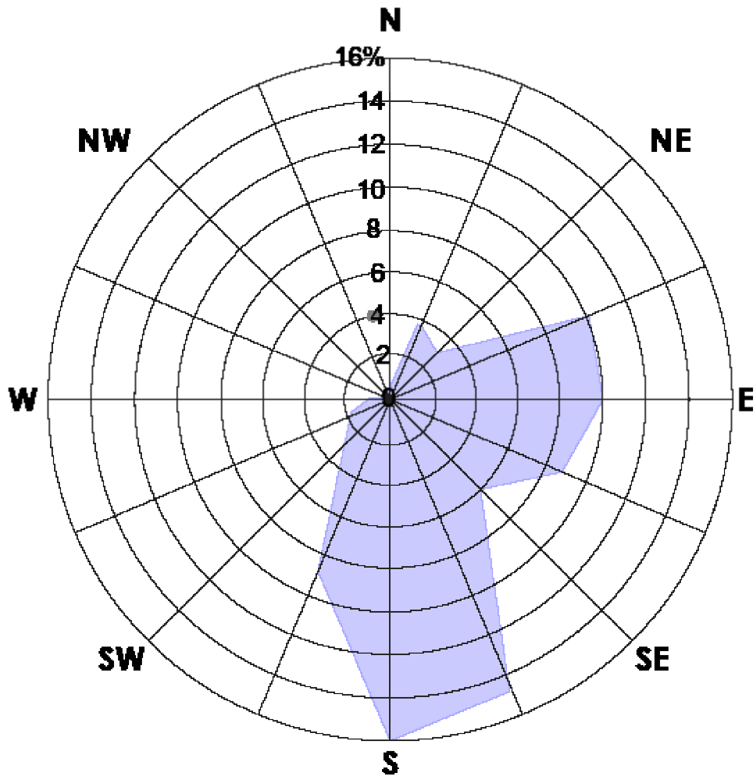
Winds are characterized by the following parameters:

- Speed
- Direction from which it flows
- Frequency

Understanding the prevailing wind patterns of a site can be useful in designing ways to take advantage of natural ventilation or to protect the occupants from uncomfortable windy conditions.

Wind Rose: It is a diagram that shows wind speed and direction for a particular location and analyses the wind characteristics by indicating its strength and frequency over a specified period of time (month, season and year).

Figure 1: Average wind speed wind rose for Mombasa, Latitute 4° South



The longest spoke on the wind rose represents the greatest frequency of winds blowing from that particular direction.

Reading different types of wind rose diagrams:

The wind rose is divided into a number of spokes. The length of each 'spoke' around the circle represents the wind frequency and direction from which it blows while each concentric circle represents different frequencies, starting from zero at the centre to increasing frequencies at the outer circles as illustrated in Fig. 1 above.

1. Determine the location the wind rose represents. A wind rose will indicate statistics for only one location or region.
2. Note the time period represented by the wind rose – month, years etc.
3. The typical orientation of a wind rose is due North at the top.
4. Relate the colours/thickness of the bars/spokes to the legend. They usually represent wind speed in Knots, Meters/Sec, or Km/Hr.
5. Labels on the concentric circles denote frequency in percentages.

3 Natural Ventilation

Thermal comfort of the built environment is affected by air temperature and air movement. Ventilation, which is simply the removal of stale indoor air from a building and its replacement with fresh outside air, has an impact on the thermal comfort.

Adequate ventilation provision is vital in providing pleasant, comfortable internal conditions with suitable air quality in both domestic and non-domestic buildings and also for the provision of cooling in buildings which are overheating. This is essential for the well-being of the occupants and the fabric of the building itself.

Natural Ventilation is used to describe ventilation systems which make use of existing thermodynamic forces within a building to draw in fresh air and discharge waste air without the assistance of energy powered equipment. Air movement is a major factor that influences the indoor climate and should be considered when planning, designing and constructing buildings. It should be incorporated in the design concept. Properly designed and installed natural ventilation systems are considered to be the most energy efficient and healthy solution. They are economic, efficient and require minimum maintenance to provide ventilation at low or zero running costs.

Given the increased awareness of the cost and environmental impact associated with mechanical ventilation, natural ventilation is the best method for reducing energy use and cost in addition, it provides a comfortable, healthy and productive indoor environmental quality. It saves significant amounts of fossil fuel-based energy by reducing the need for mechanical ventilation and air conditioning which in turn reduces greenhouse gases released into the atmosphere from electricity generating plants that produce the energy used for cooling buildings and from air conditioning plants.

Figure 2: Section showing cross and stack effect ventilation

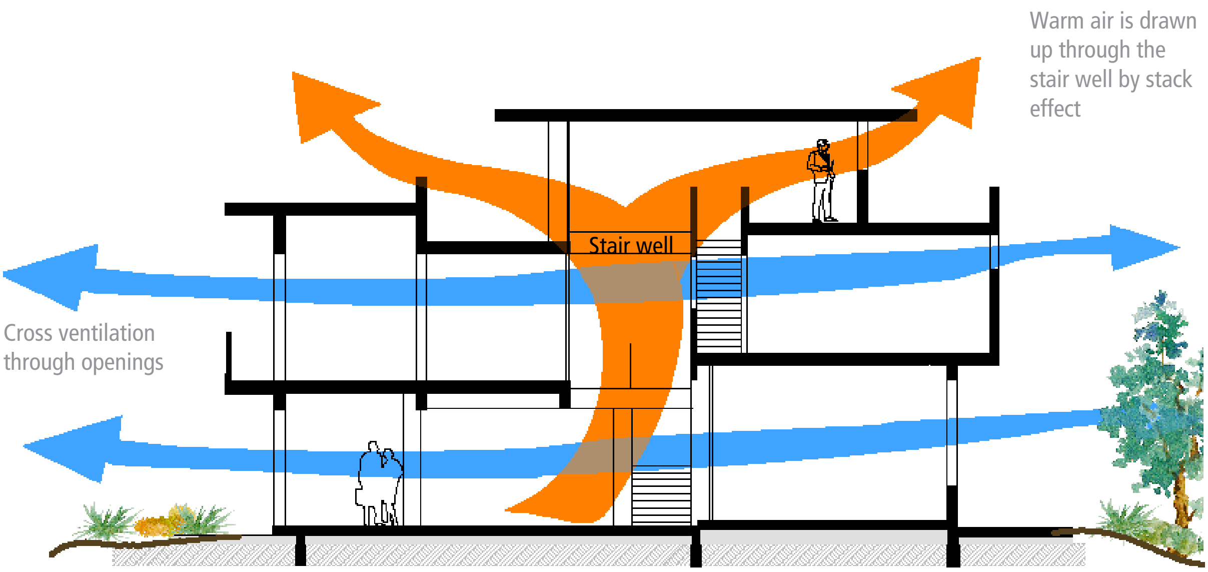
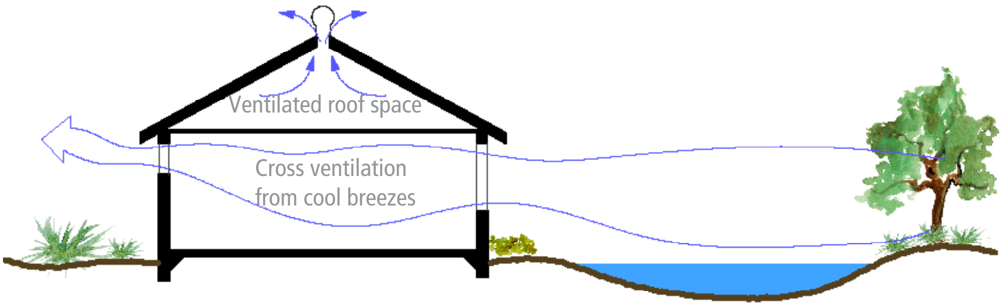


Figure 3: Evaporative cooling ventilation



Use of ponds, pools and water features immediately outside windows or in courtyards pre-cools the air entering the house.

Categories of natural ventilation

Cross ventilation:

In order to achieve reliable air circulation, buildings must be designed for cross-ventilation. Incorrectly designed interior partitions impede cross ventilation by changing the air direction and speed.

Stack Effect:

The stack effect occurs when there is a difference between the inside and outside temperatures. It is brought about by warm air rising up to be exhausted through high-level outlets and drawing in colder, heavier air from outside at the lower levels.

- The "stack effect" can also be induced by placing openings near the floor and near the ceiling. It can be regulated by window shutters to obtain the desired cooling effect.

Evaporative cooling ventilation:

This is an effective method of controlling the internal temperatures, especially in hot arid climates. It can be direct where the air to be cooled is passed over water, and cooled by evaporation then supplied directly into the building (e.g. use of pools, fountains etc.) or indirect where evaporation is separated from the air which is delivered into the space (e.g. use of water spray over external walls, roof pools etc.).

Natural ventilation provides and maintains a comfortable, healthy and productive acceptable indoor environmental quality while reducing energy use and cost.

4 Case Studies

Frequent replacement of used indoor air with fresh air is necessary to improve indoor comfort and hygiene.

CLIMATIC ZONE 1:
Hot and Humid climate

Multi dwelling housing

Climatic Zone 1: Hot and Humid climate	
Location	Dar es Salaam, Tanzania
Latitude	6°48'S
Longitude	39°17'E
Altitude	53 m above sea level
Temperature	Min average temp 21.9°C; Max average temp 29.6°C
Annual Rainfall	Average 1,100 mm
Humidity	Average relative humidity is 79%
Prevalent Wind Direction	Southerly monsoon winds (April - October) and Northerly monsoon winds (November - March) prevailing winds

Figure 4: DAR ES SALAAM (Hours of Sunshine / Temperature)

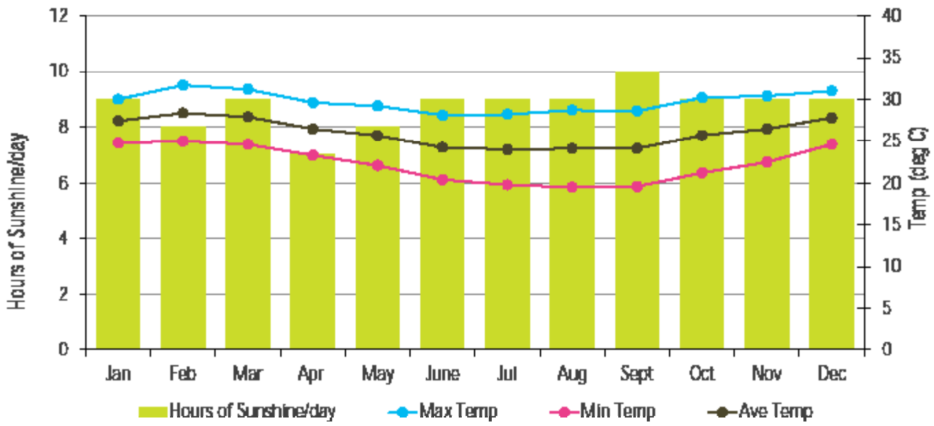


Figure 5: DAR ES SALAAM (Relative Humidity / Rainfall)

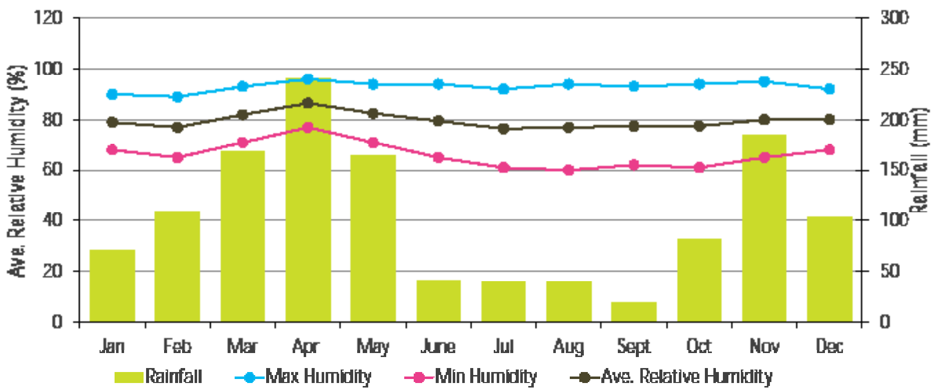


Figure 6: Prevailing wind direction

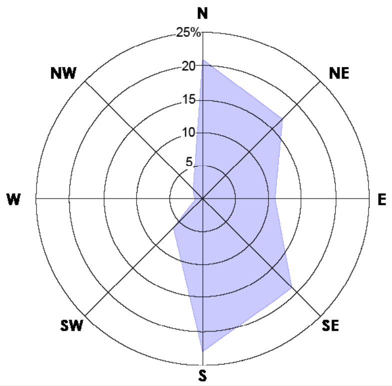


Figure 7: Sun path Diagram for Latitude 6° South

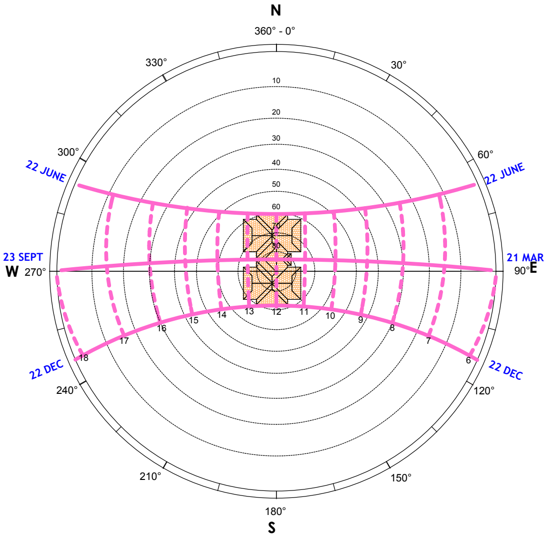
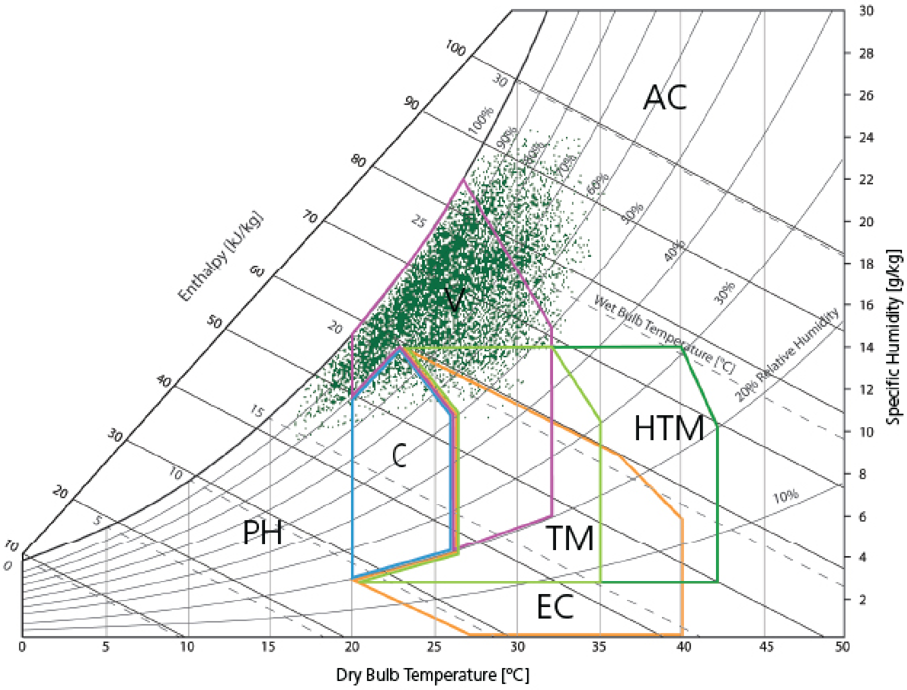
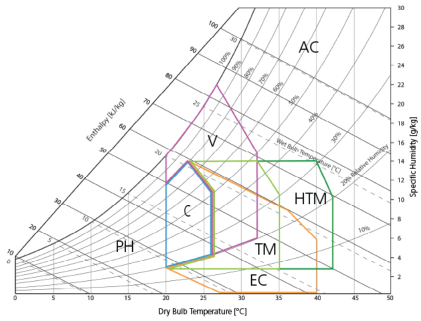


Figure 8: Psychrometric Chart with weather data for Dar es Salaam





LEGEND

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

INTERPRETATION

- Both day and night temperatures in this zone are high. The humidity levels are equally high throughout the year.
- The prime design objective for this zone is to provide free air movement through the house while preventing internal surface temperatures from rising above the outdoor shade temperature protecting all the facades from solar radiation.
- Natural ventilation and solar radiation are the most effective passive design strategies for improving thermal comfort.
- Cross ventilation strategies should be adopted to improve the indoor thermal comfort. Open buildings are preferable.
- Buildings should be lightweight with minimum possible thermal storage capabilities. They should be oriented with the long axis running east-west to provide effective shading.
- Air conditioning may be necessary to provide comfortable indoor conditions by cooling the air during high day temperatures and humidity levels during certain periods of the year.

CLIMATIC ZONE 1:
Hot and Humid climate

Multi dwelling housing

Figure 9: Site Plan

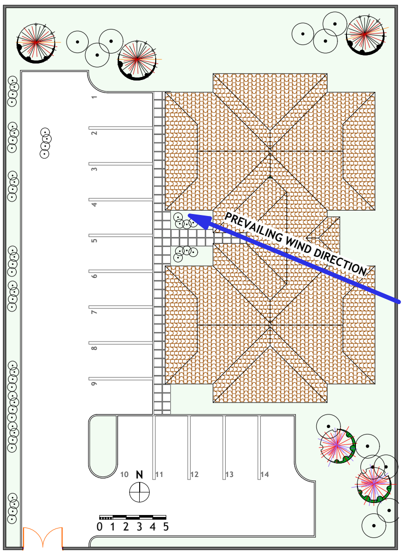


Figure 10:Typical Floor Plan

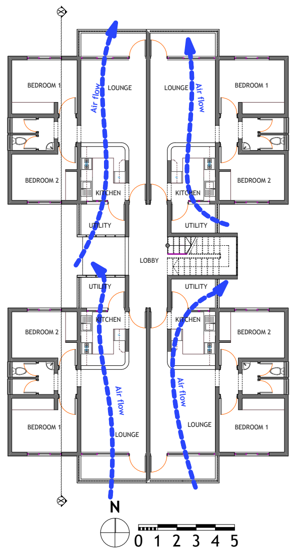


Figure 11: Position of the Sun at different times during the equinox

December 22nd at 9.00 a.m.

The low morning sun strikes the east facing walls that have minimum openings located at ancillary spaces (bathrooms).

December 22nd at 12.00 p.m.

The balconies, horizontal and roof overhangs are instrumental in proving shade to the south facing openings against the mid-day sun.

December 22nd at 3.00 p.m.

At this time of the year, the sun sets due south of west. Windows along the west-facing walls are limited to secondary spaces (e.g. bathrooms) and act as buffer zones against the afternoon sun.

Figure 12: South Elevation

Figure 13: West Elevation

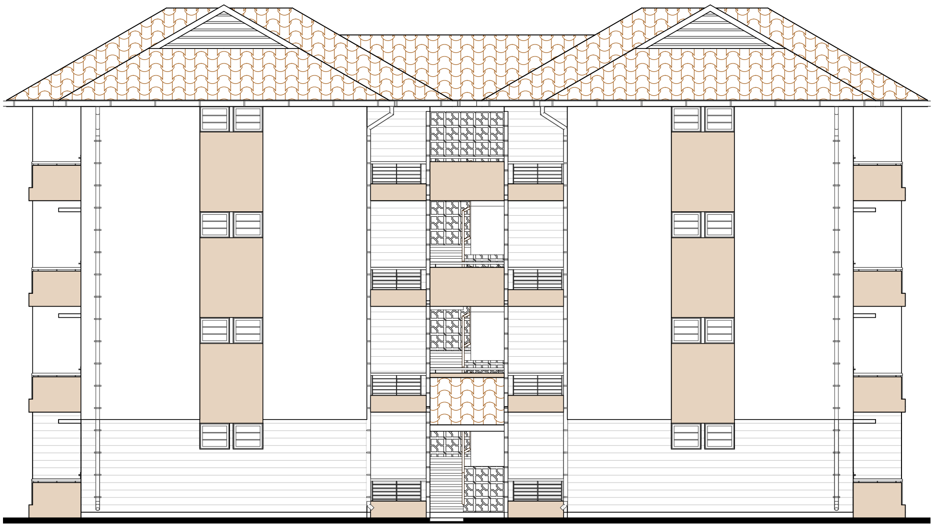
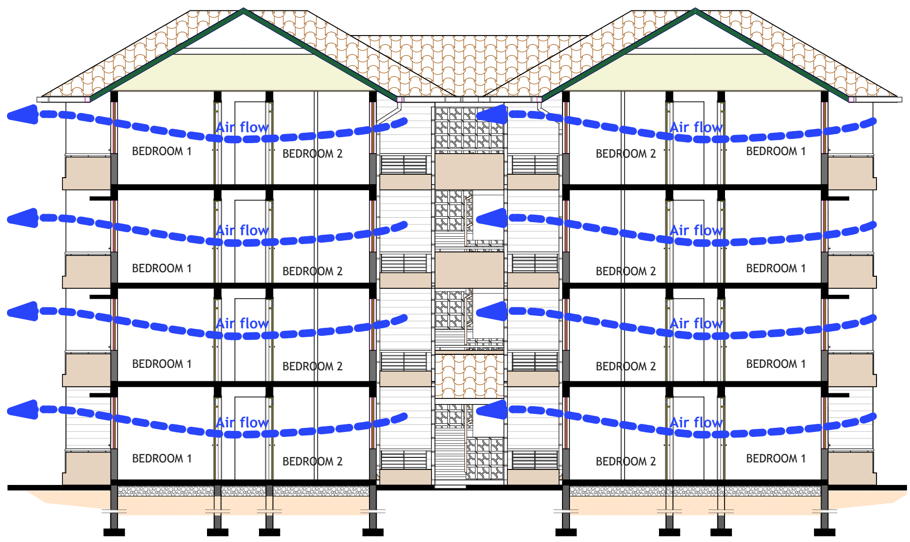


Figure 14: Section X-X showing cross ventilation



DESIGN RESPONSES

1 Orientation - Each unit in the apartment is optimally oriented with the major opening along the North-South facing façades direction.

2 Ventilation - To achieve cross ventilation, louvred windows have been provided in all rooms. Permanent ventilation vents have been provided at every door's transom to maximize on cross ventilation. In addition, there are openings in the roofs to provide ventilation of accumulated hot air in the roof space. The open plan of the living space aids in cross ventilation.

3 Daylighting - Provision of large windows (20 per cent of respective elevation area) in the major spaces ensures that the rooms are adequately lit naturally during the day.

4 Sun shading - Windows on the North and South facing façades are provided with deep balconies to generate mid-day shade to the respective rooms and to provide cool outdoor living spaces. The upper floor windows have been shaded by 800 mm deep roof eaves. Other major windows on the north and south facing walls have been shaded by horizontal overhangs. Major windows have been avoided on the western and eastern facing walls.

5 Building materials - Lightweight walls and roof with external reflective surfaces have been used to allow internal heat to quickly dissipate to the outside and to reflect unwanted solar radiation.

CLIMATIC ZONE 2:
Hot semi-arid / Savannah climate

CASE STUDY 2

Multi dwelling housing

Climatic Zone 2: Hot semi-arid / Savannah climate

Location	Dodoma, Tanzania
Latitude	6°10’S
Longitude	35°44’E
Altitude	1120 m above sea level
Temperature	Min average temp 16°C; Max average temp 29°C
Annual Rainfall	Average 570 mm
Humidity	Average relative humidity is recorded at 65.5%
Prevalent Wind Direction	East prevailing winds

Figure 15: DODOMA (Hours of Sunshine / Temperature)

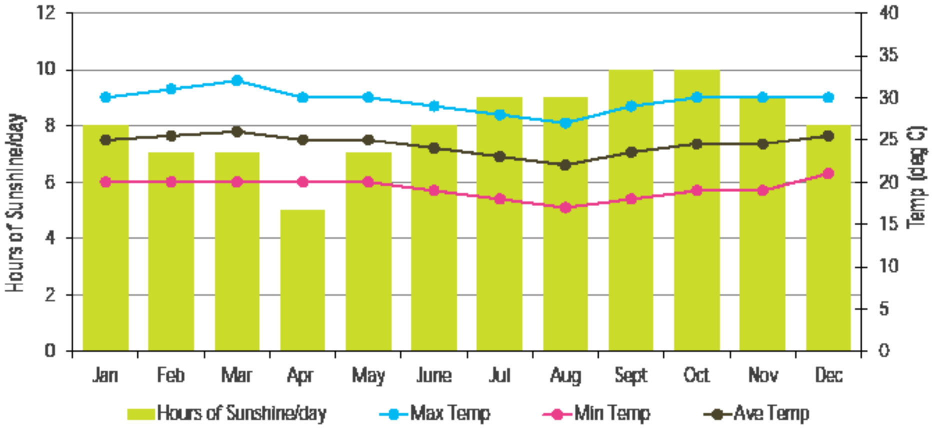


Figure 16: DODOMA (Relative Humidity / Rainfall)

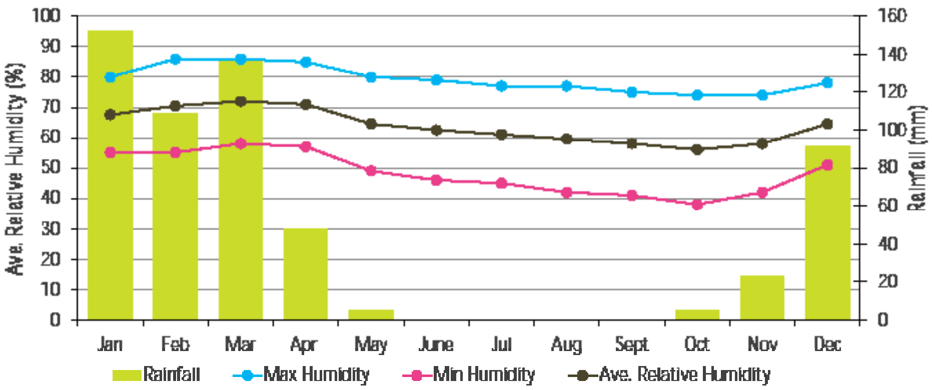


Figure 17: Prevailing Wind Analysis

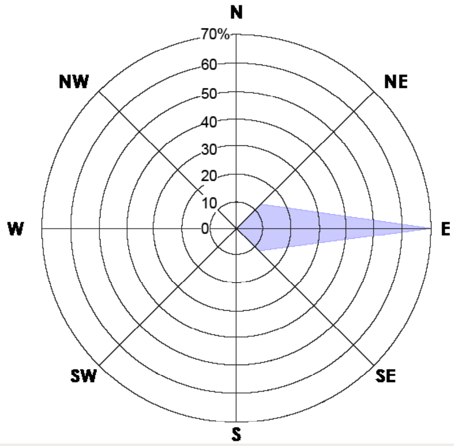


Figure 18: Sun path Diagram for Latitude 6° South

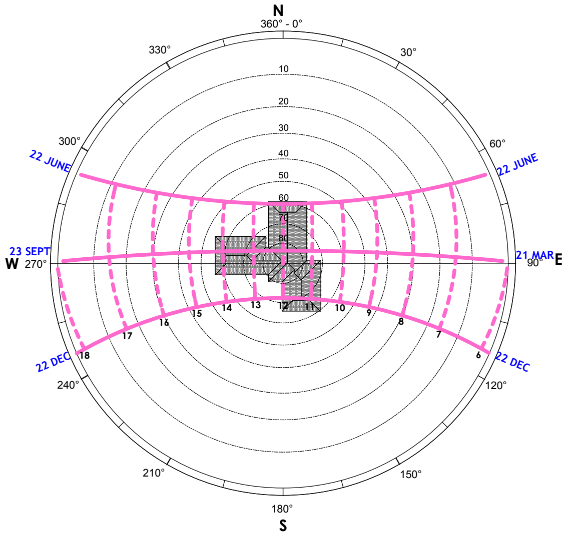
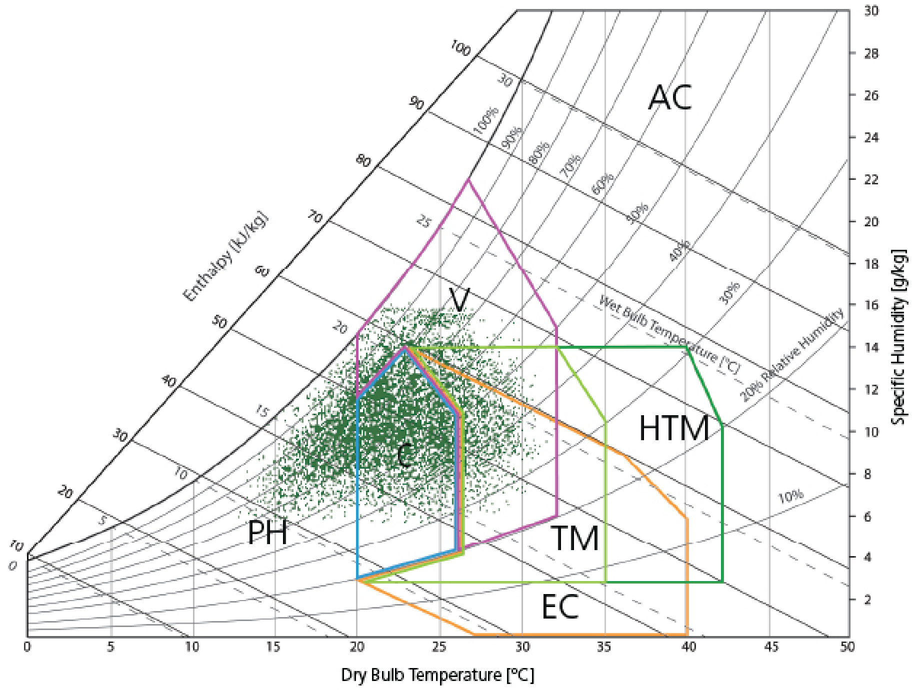
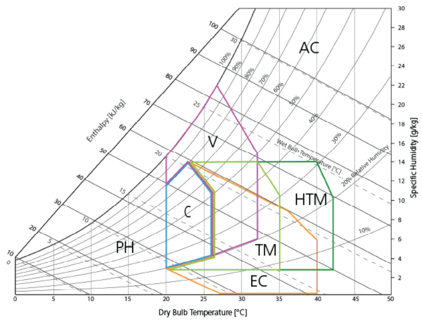


Figure 19: Psychrometric Chart with weather data for Dodoma





LEGEND

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

INTERPRETATION

- Both temperature and humidity levels fall within the comfort zone for most periods of the year.
- Natural ventilation (night ventilation), high thermal mass and solar shading are the most effective passive design strategies for improving thermal comfort.
- Medium or heavy weight walls are preferable in this zone since they are subjected to greater heating by day and faster cooling at night.
- Passive heating through thermal mass assisted with ventilation is an appropriate way to maintain thermal comfort inside the building.
- Compact buildings are suitable for this type of climate to reduce the facade exposed to solar radiation, thus solar heat gains.
- Buildings should be oriented with the long axis running east-west to provide effective shading.

CLIMATIC ZONE 2:
Hot semi-arid / Savannah climate

CASE STUDY 2

Multi dwelling housing

Figure 20: Site Plan

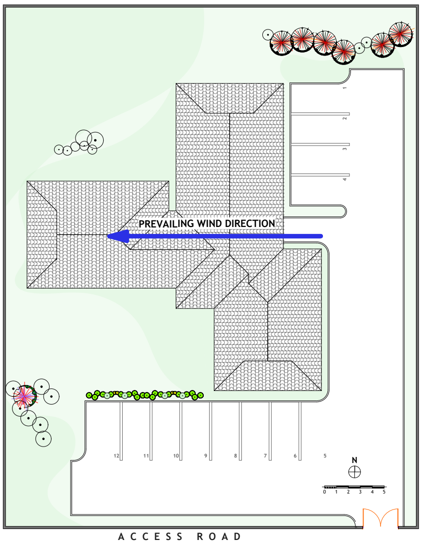


Figure 21: Typical Floor Plan

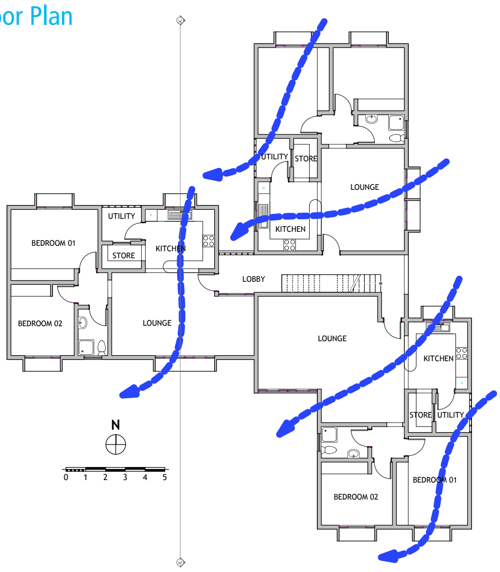
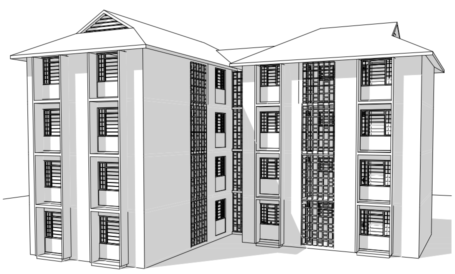


Figure 22: Position of the Sun at different times during the winter solstice

June 22nd at 9.00 a.m.

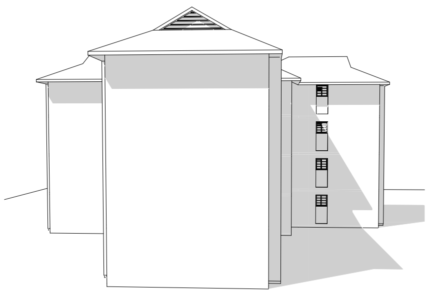
Vertical shading elements and horizontal overhangs are provided to shade the major windows on the east-facing walls.

June 22nd at 12.00 p.m.



North- and south-facing windows are protected from the high mid-day sun by the provision of horizontal window overhangs and roof overhangs.

June 22nd at 3.00 p.m.



The west-facing walls are devoid of any major openings. This minimizes unwanted heat gains from the intense afternoon sun.

Figure 23: North Elevation

Figure 24: West Elevation

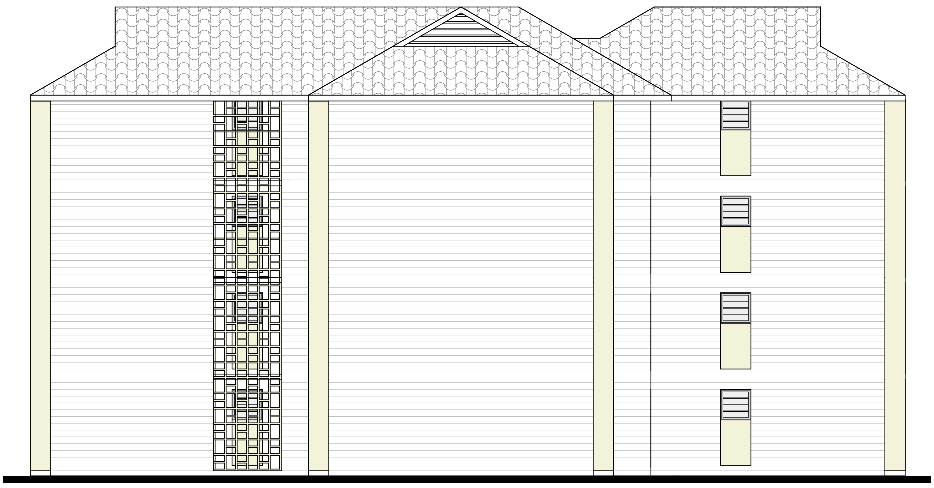
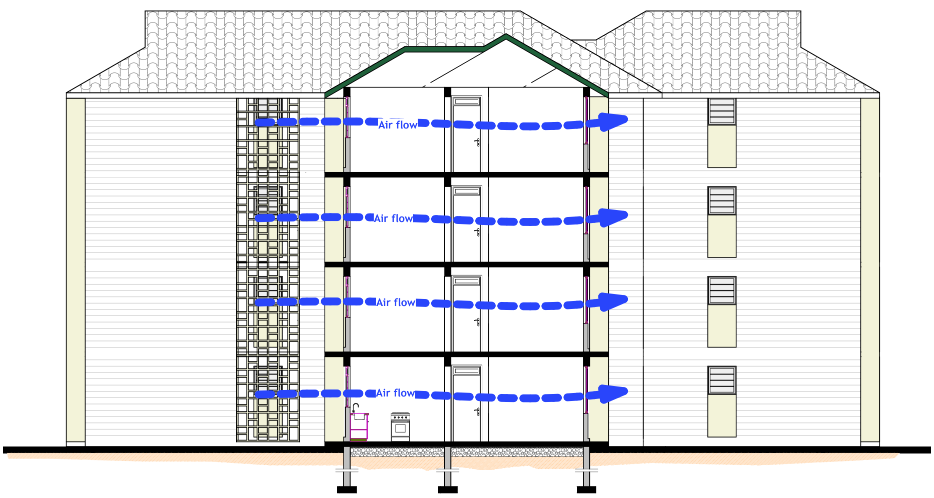


Figure 25: Section X-X showing cross ventilation



DESIGN RESPONSES

1 **Orientation** - The building's major axis is optimally oriented along the east-west axis with all the major openings facing north and south.

2 **Ventilation** - All the rooms are naturally ventilated through the windows and the permanent ventilation provided at the roof level through timber louvres.

- The lobby and staircase external walling is made of hollow concrete vent blocks which guarantee optimum ventilation and natural lighting.

- Roof vents enable air movement and heat release by stack ventilation.

3 **Daylighting** - All the rooms are naturally lit during the day through the windows. This eliminates artificial lighting and during the daytime and thus reduces energy consumption.

4 **Sun shading** - North- and south-facing windows are protected from the high mid-day sun by the provision of balconies, horizontal sun shading elements and roof overhangs at the top level.

- Windows on the East-and West-facing windows are minimized and vertical sun shading elements are provided to avoid unwanted solar gains by the early morning and late afternoon sun during the hot months.

5 **Building materials** - Passive heating through high thermal mass construction materials is desired in this type of climate.

CLIMATIC ZONE 3:
Hot arid climate

Multi dwelling housing

Climatic Zone 3: Hot arid climate

Location	Garissa, Kenya
Latitude	0°26'S
Longitude	39°38'E
Altitude	147 m above sea level
Temperature	Min av. temp 22.81°C; Max av. temp 35.84°C
Rainfall	Average 415 mm
Humidity	Average relative humidity is 62%
Prevalent Wind Direction	South prevailing winds

Figure 26: GARISSA (Hours of Sunshine / Temperature)

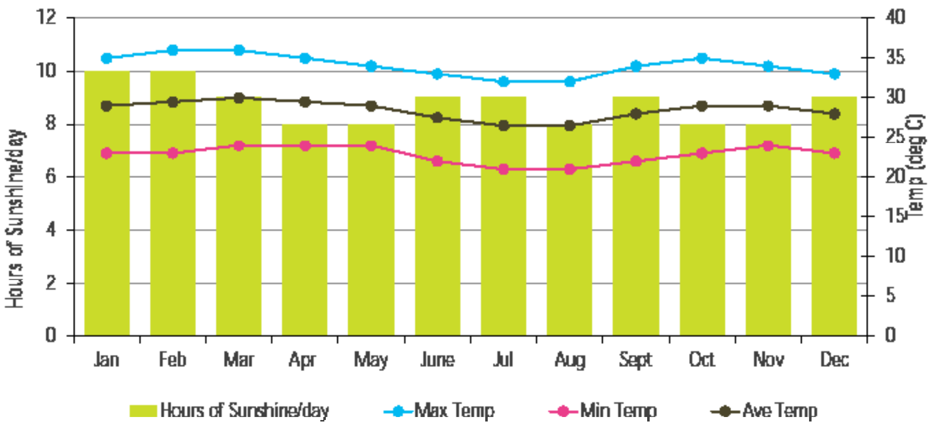


Figure 27: GARISSA (Relative Humidity / Rainfall)

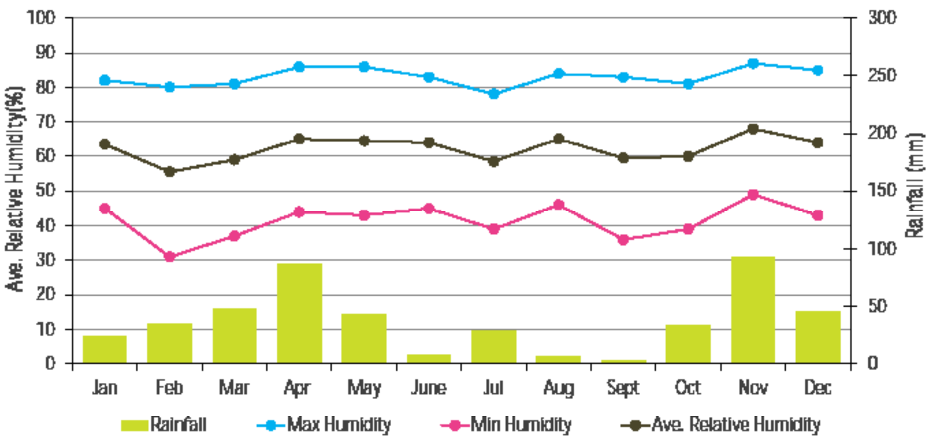


Figure 28: Prevailing Wind Analysis

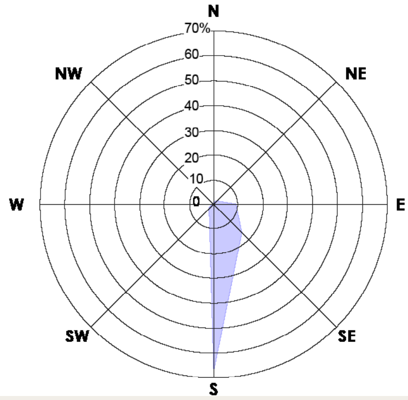


Figure 29: Sun path Diagram for Latitude 0° South

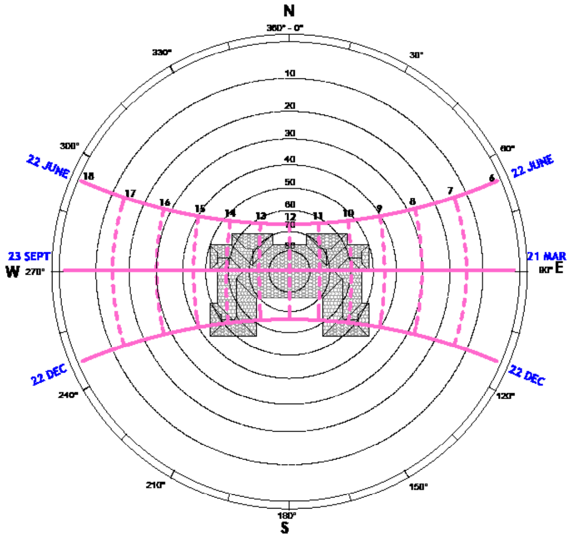
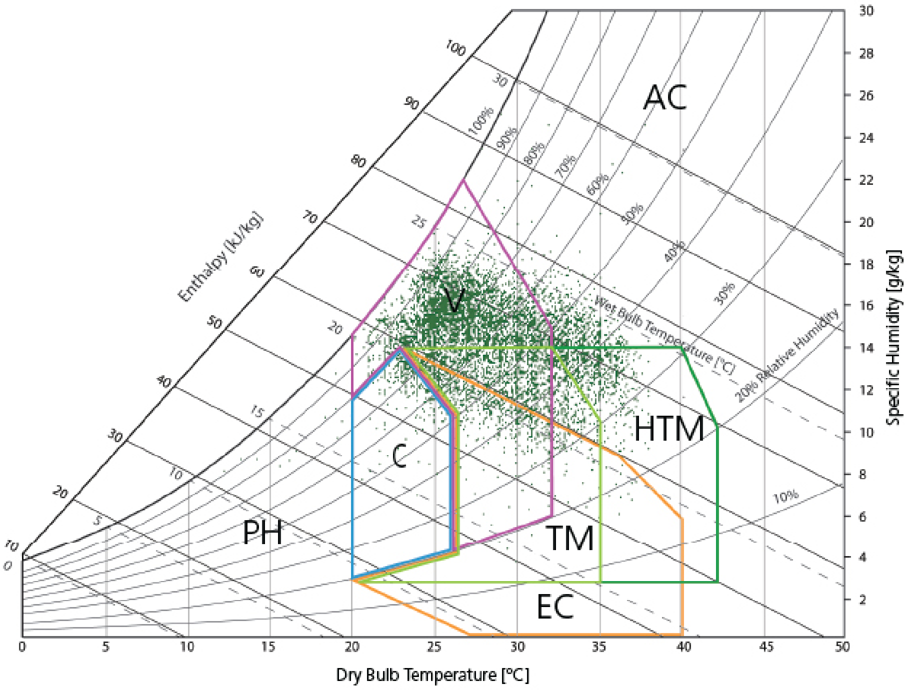
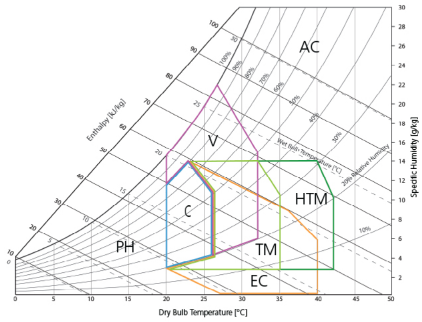


Figure 30: Psychrometric Chart with weather data for Garissa





LEGEND

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

INTERPRETATION

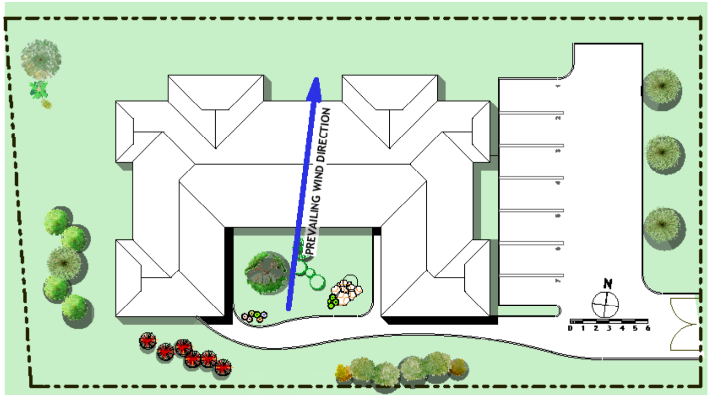
- Days in this zone are invariably hot. High daytime temperatures are accompanied by moderate to low humidity levels.
- Due to the high daily temperature variation or diurnal range, it is best to keep heat out during the day and ventilate during the night i.e. night ventilation.
- Natural ventilation (night ventilation), high thermal mass, solar shading and evaporative cooling are the most effective passive design strategies for improving thermal comfort.
- The maximum temperatures in some months are outside the high thermal mass area, thus additional air conditioning means may be required to provide adequate thermal comfort indoors during the day.
- High thermal mass for walls and roofs prevents overheating during daytime while natural ventilation combined with evaporative cooling relieves heat delivered by the heavy structures at night.
- Buildings should be compact and oriented with the long axis running East-West to provide effective sun shading.

CLIMATIC ZONE 3:
Hot arid climate

CASE STUDY 3

Multi dwelling housing

Figure 31: Site plan



A courtyard (with plants and or a water feature) allows for protection against hot, dry winds, reduces radiation and acts as a cooling well that creates a microclimate enhanced by evaporative cooling.

Figure 32: Typical floor plan

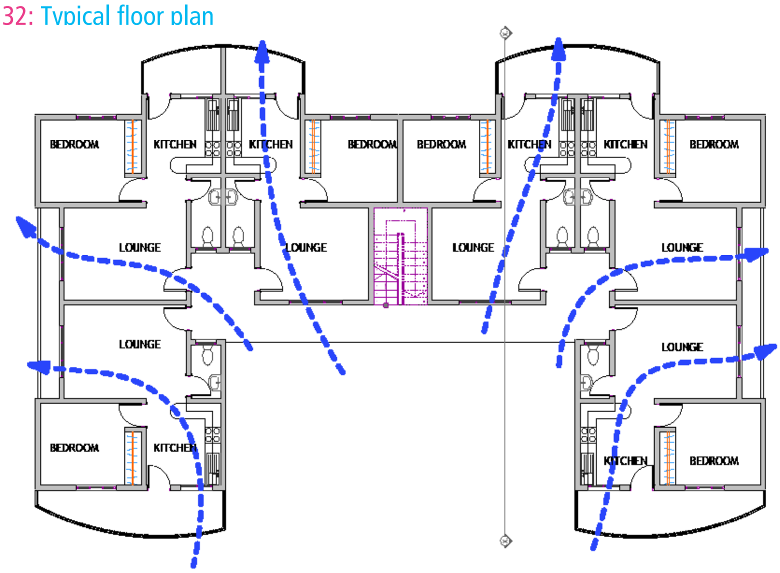
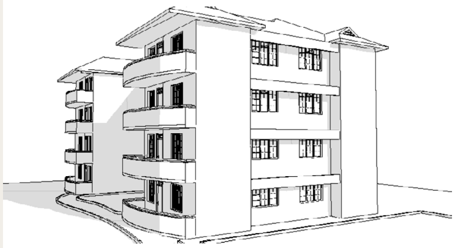


Figure 33: Position of the Sun at different times when the sun is in the Northern hemisphere

June 22nd at 9.00 a.m.



At this time of the year, the sun rises due north of east. The south facing walls are shaded by balconies against the overhead sun.

June 22nd at 12.00 p.m.

The south facing walls are not exposed to direct solar radiation at this time of the year.

June 22nd at 3.00 p.m.

The sun sets due north of west exposing the north-west and west facing walls exposed to the sun. Balconies and horizontal window overhangs provide shade against the afternoon solar radiation.

Figure 34: South Elevation

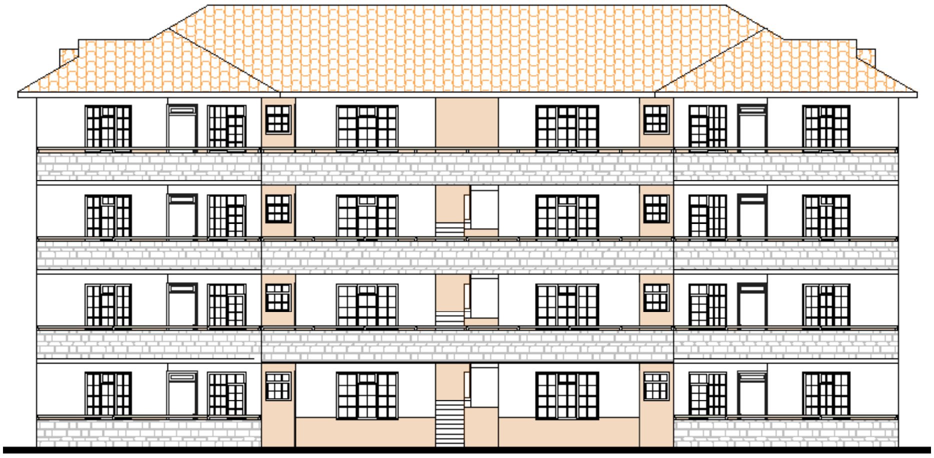
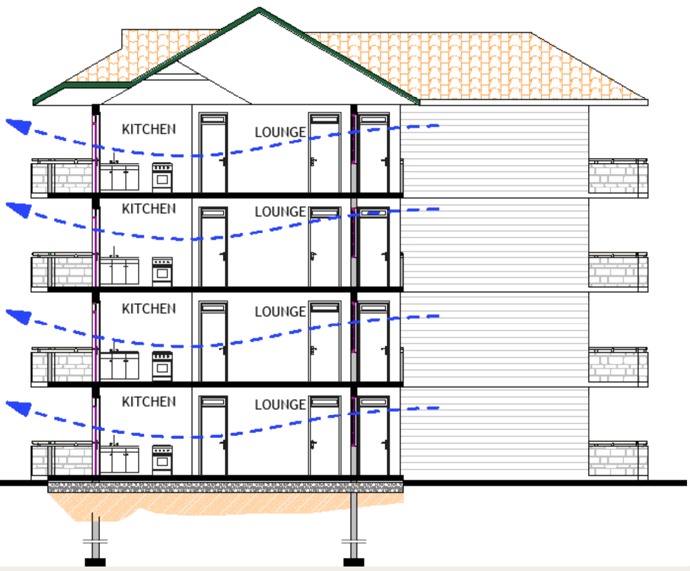


Figure 35: West Elevation

Figure 36: Section X-X showing cross ventilation



DESIGN RESPONSES

1 Orientation - This one bedroomed compact apartment block is oriented along the East-West axis with most of its major openings along the north and south facing walls.

- Coupled with the compact design, this design ensures heat gain is minimized.

2 Ventilation - Openings have been aligned to take advantage of the prevailing winds and thus aid in cross ventilation. Vents at the roof prevent the build-up of hot air within the roof space and encourage thermal air movement. This is important especially at night.

3 Day lighting - The East-West orientation of this block exposes the major openings to the North-South direction thus minimizing on the heat gain and at the same time due to the narrow North-South axis, maximizing on daylighting.

4 Sun shading - Walls and openings on the North-South facing facades are shaded by balconies, large roof and horizontal overhangs so designed to exclude the high mid-day sun.

-Main openings located on east and west facing walls are shaded using vertical shading device against the early morning and late afternoon sun respectively.

5 Building materials - This climate experiences high where the daily (diurnal) temperature range and thus construction materials with high thermal mass are recommended. These absorb heat during the day and thus reduce internal temperature resulting in comfortable temperatures without the need for supplementary cooling.

CLIMATIC ZONE 4:
Highland climate

CASE STUDY 4

Multi dwelling housing

Climatic Zone 4: Highland climate

Location	Kigali, Rwanda
Latitude	1°57'S
Longitude	30°04'E
Altitude	1490 m above sea level
Temperature	Min av. temp 15.7 °C; Max av. temp 26.9°C
Annual Rainfall	Average 1,095 mm
Humidity	Average relative humidity is 68.1%
Prevalent Wind Direction	Predominantly South and North East prevailing winds

Figure 37: KIGALI (Hours of Sunshine / Temperature)

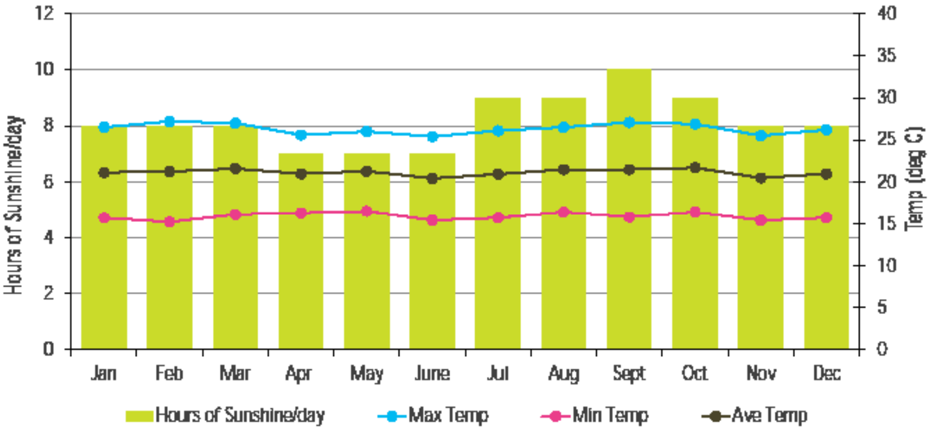


Figure 38: KIGALI (Relative Humidity / Rainfall)

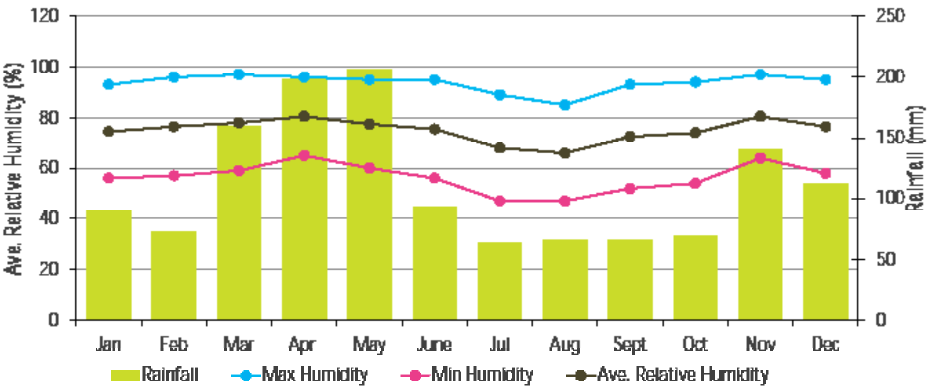


Figure 39: Prevailing wind direction

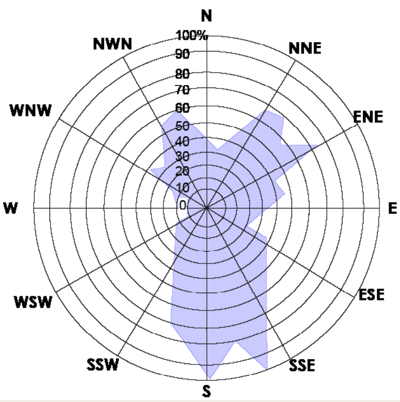


Figure 40: Sun path Diagram for Latitude 1° South

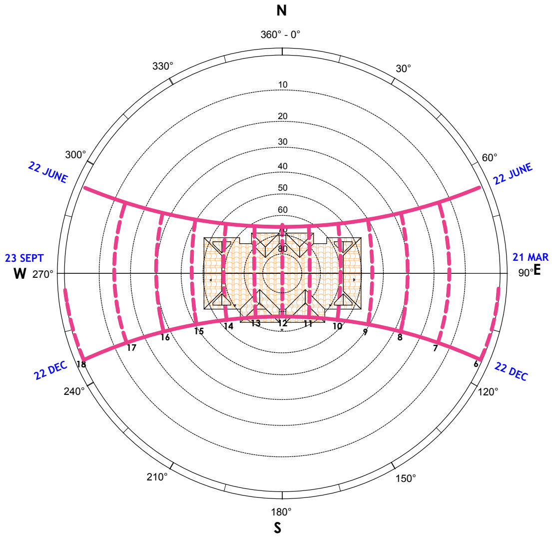
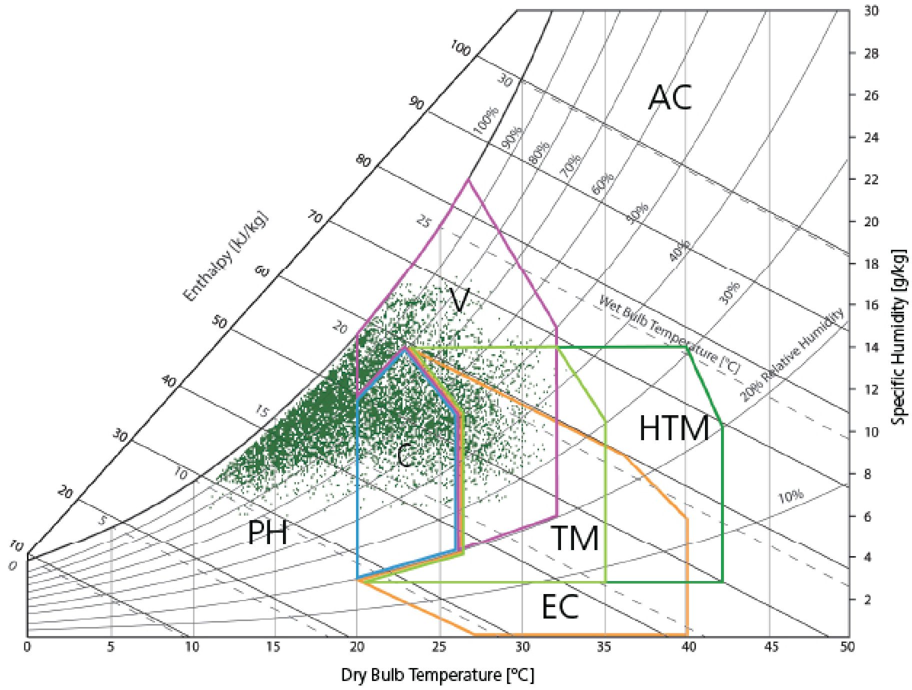
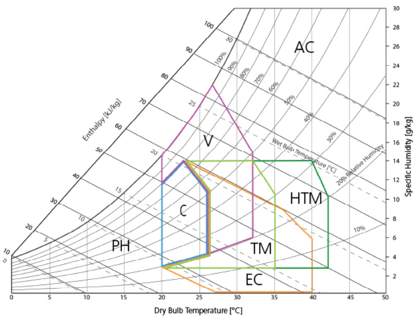


Figure 41: Psychrometric Chart with weather data for Kigali





LEGEND

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

INTERPRETATION

- This zone has its mean temperatures falling within the comfort zone. However, its maximum temperatures rise above the upper limits while the minimum temperatures drop below the lower limits throughout the year.
- Passive heating and medium thermal mass are the most effective design strategies for improving on the thermal comfort.
- Due to low temperatures, some passive heating (e.g. by sunshine) is welcome during the cool period of the year.
- Natural ventilation is important for indoor comfort. Nevertheless, air temperature rarely exceeds the upper limit of the comfort zone
- Thick walled structures are recommended in order to limit the heat admitted to interiors during hours of strong sunshine and to store some of the day's heat so it may be re-emitted to interiors during the cold nights.
- Buildings should be oriented with the long axis running East-West to minimise exposure to the sun as it moves from sunrise to sunset.

CLIMATIC ZONE 4:
Highland climate

Multi dwelling housing

Figure 42: Site plan

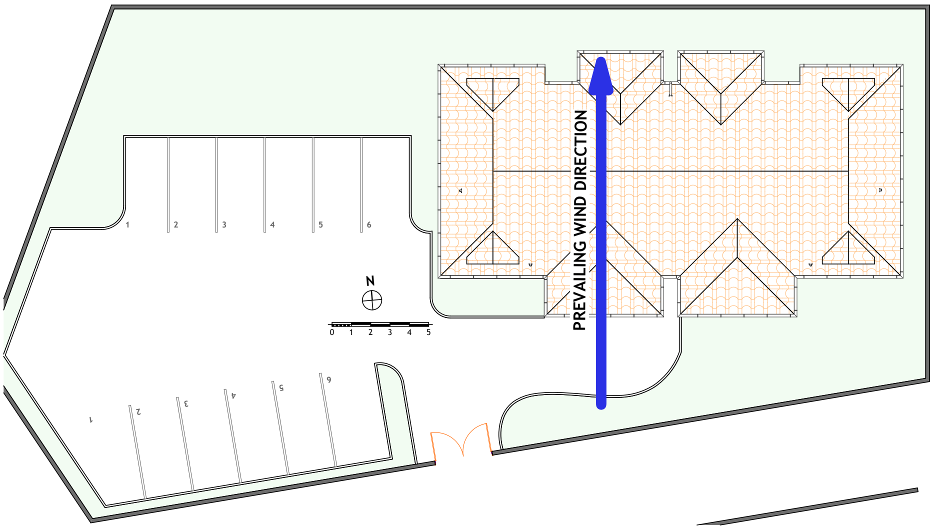


Figure 43: Typical Floor plan

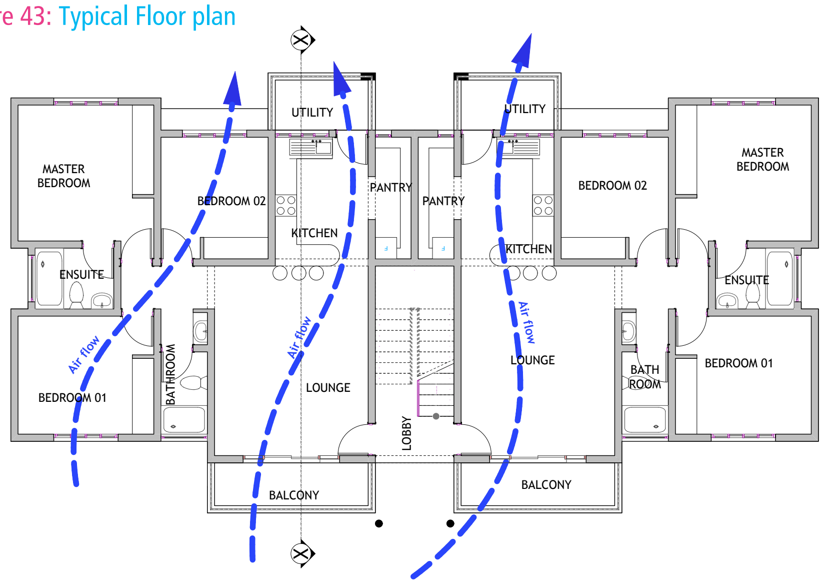


Figure 44: Position of the Sun at different times during the equinox

September 23rd at 9.00 a.m.

The low morning sun strikes the east facing walls that have minimum openings located at ancillary spaces (bathrooms).

September 23rd at 12.00 p.m.

At noon, the sun is overhead. The roof eaves provide shading to windows on the top floor while horizontal overhangs and balconies provide shade to south and north facing window against the noon sun.

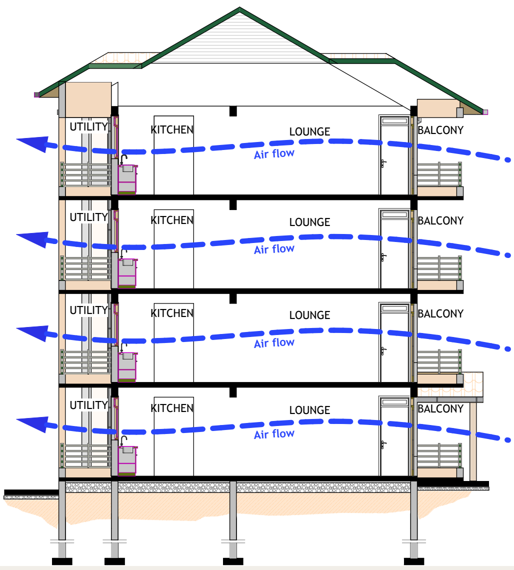
September 23rd at 3.00 p.m.

To minimize solar radiation into the house, there are few openings on the western walls located at secondary spaces (bathrooms) where comfort needs are not a priority.

Figure 45: South Elevation

Figure 46: East Elevation

Figure 47: Section X-X showing cross ventilation



DESIGN RESPONSES

1 Orientation - The block of apartments has its individual units oriented with their main elevations facing North and South so that solar heat gains can be minimized.

2 Ventilation - Windows openings are used to achieve cross ventilation. The open plan design aids in cross ventilation in the living space. Permanent ventilation vents have been provided at all openings. In addition, there are openings in the roofs to provide the exit of accumulated hot air in the roof space.

3 Daylighting - Provision of large windows in the major spaces ensures that the rooms are adequately lit naturally during the day.

4 Sun shading - Roof and horizontal overhangs (600 mm deep) have been used to generate shade to the North and South facing walls eliminating solar penetration of interiors at midday during the hot months. Openings have been minimized on the East and West elevations to avoid the early morning and late afternoon sun respectively. This minimizes unwanted solar gains.

5 Building materials - Natural stone has been used for the building envelope walling which stores the sun's heat and release it back into the buildings at night during the cold months. During the hot season, this absorbs excess heat during the day, therefore, lowering the internal temperature.

- Light coloured roofs are desirable to reflect unwanted solar radiation.

CLIMATIC ZONE 5:
Lake region climate

Multi dwelling housing

Climatic Zone 5: Lake region climate

Location	Kampala, Uganda
Latitude	0°19'N
Longitude	32°34'E
Altitude	1140 m above sea level
Temperature	Min average temp 17.7°C; Max average temp 27.8°C
Annual Rainfall	Average 1,369 mm
Humidity	Average relative humidity is 68.1%
Prevailing Wind Direction	Predominantly South prevailing winds

Figure 48: KAMPALA (Hours of Sunshine / Temperature)

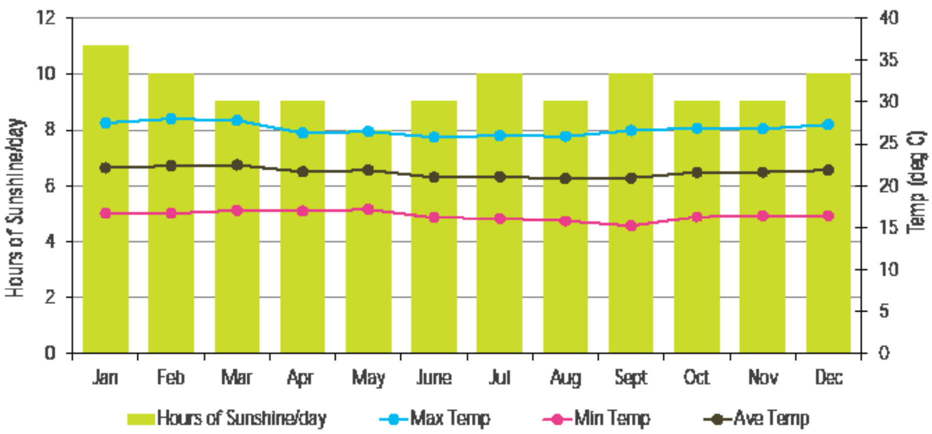


Figure 49: KAMPALA (Relative Humidity / Rainfall)

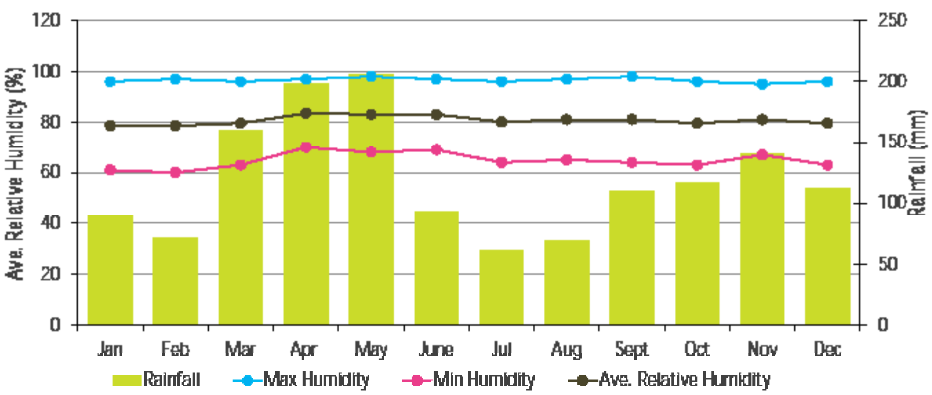


Figure 50: Prevailing wind direction

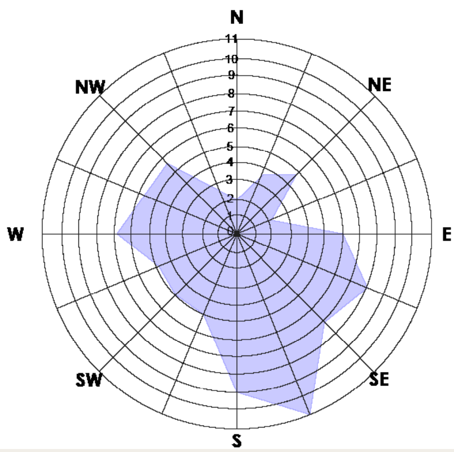


Figure 51: Sun path Diagram for Latitude 0° North

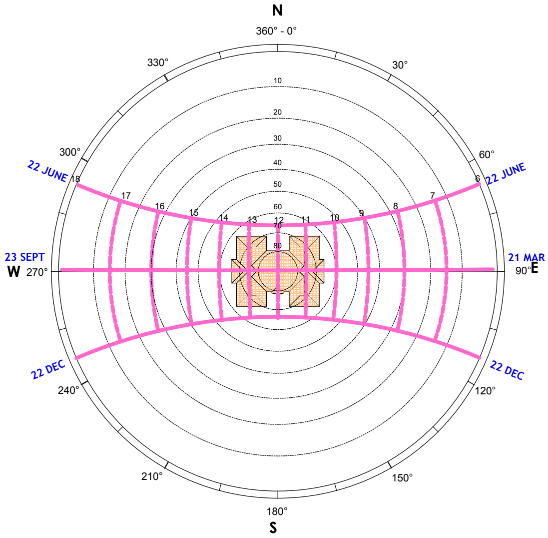
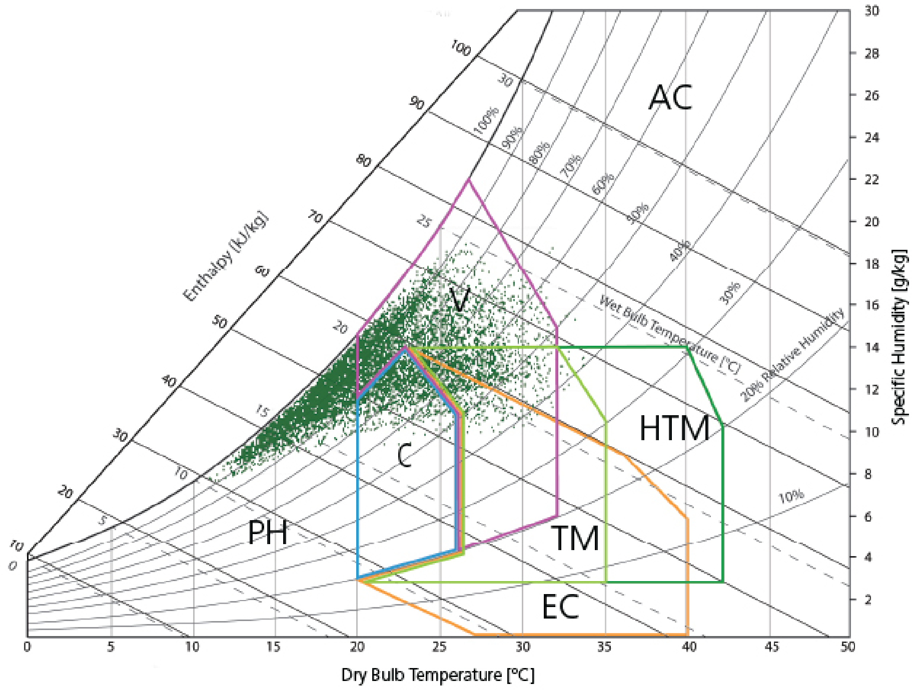
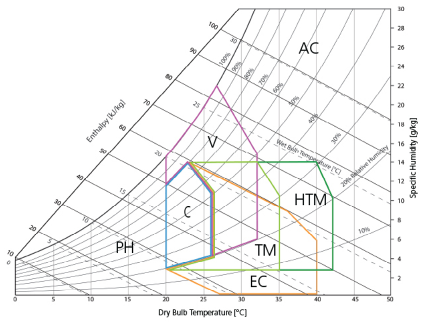


Figure 52: Psychrometric Chart with weather data for Kampala





LEGEND

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

INTERPRETATION

- This zone experiences high daytime temperatures and low nighttime temperatures for some periods of the year.
- Natural ventilation, passive heating through thermal mass during the day, and solar shading are the most effective strategies for improving thermal comfort.
- The most critical climatic requirements of buildings in this zone are the needs for cool indoor spaces during the high day temperatures and, warm interiors during the night. High thermal mass walls are therefore recommended to even out the indoor temperatures.
- Cross ventilation should be achieved in all habitable rooms by having openings on both external and internal walls and by having permanent openings that admit air but not direct sunlight to interiors.
- Buildings should be oriented with the long axis running east-west.
- All window openings should be fully sun shaded throughout the daytime.

CLIMATIC ZONE 5:
Lake region climate

Multi dwelling housing

Figure 53: Site plan

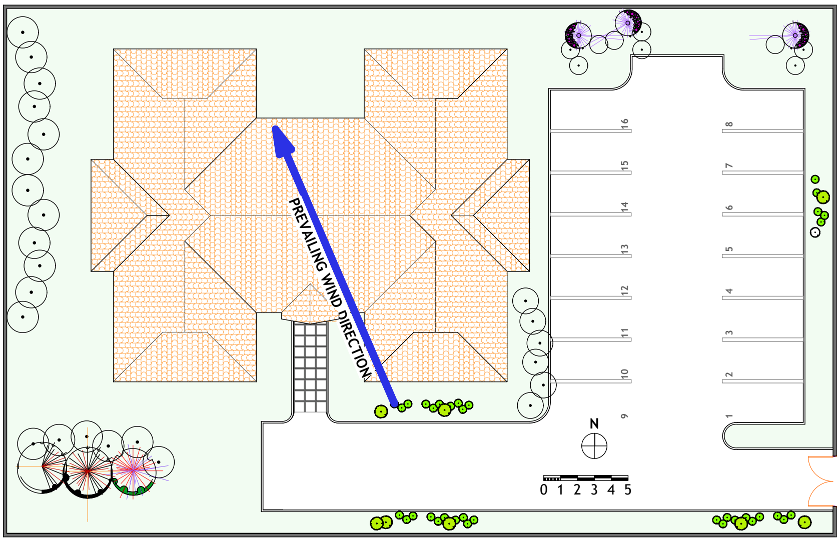


Figure 54: Typical floor plan

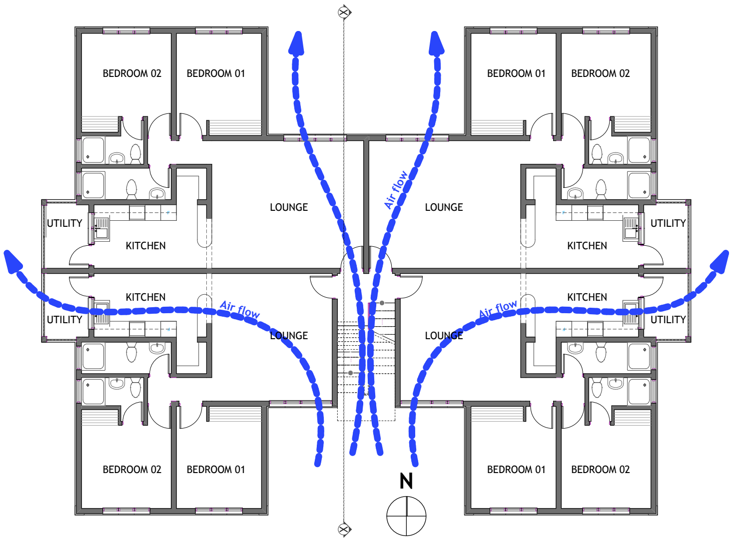


Figure 55: Position of the Sun at different times during the summer solstice

March 21st at 9.00 a.m.

Minimal windows on the east facing walls minimizes exposure to the morning solar radiation.

March 21st at 12.00 p.m.

Roof and window overhangs shade the south facing openings against solar radiation at noon.

March 21st at 3.00 p.m.

Openings to ancillary spaces are exposed to the afternoon solar radiation. The balcony provides adequate shading to the kitchen against solar radiation.

Figure 56: South Elevation

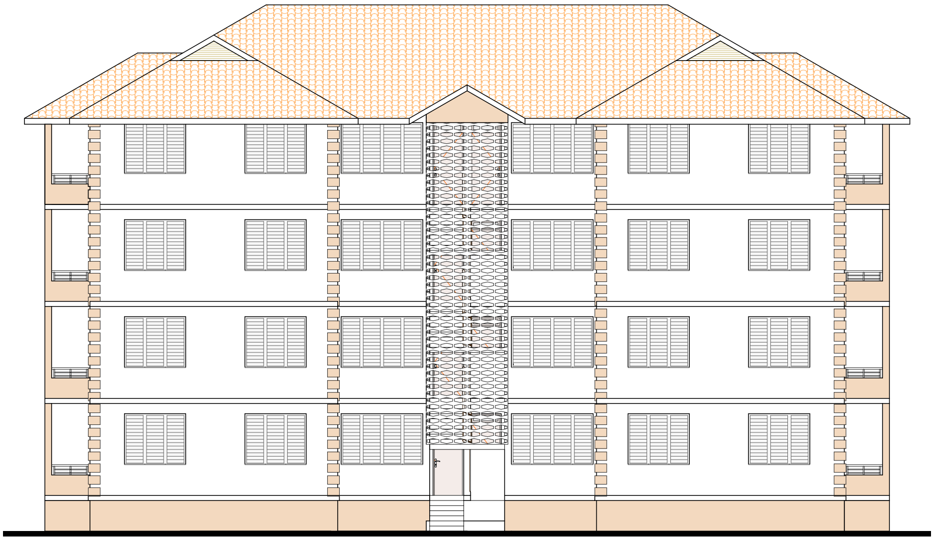


Figure 57: West Elevation

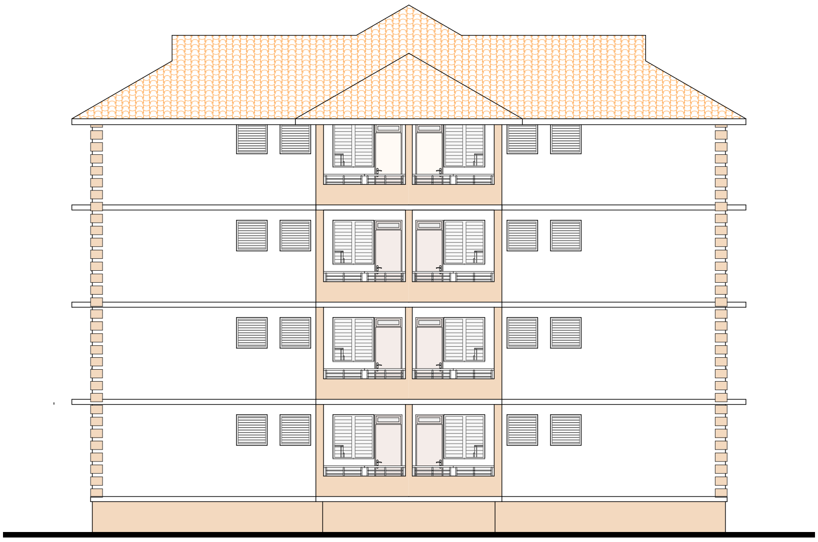
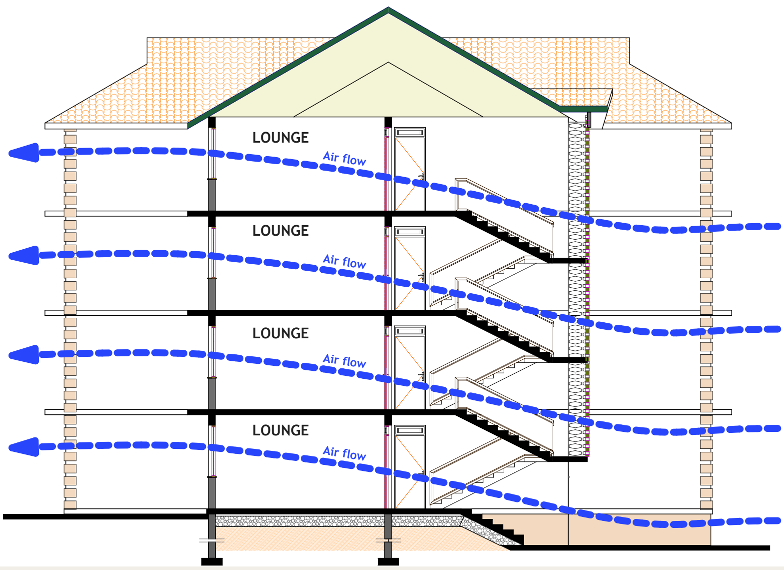


Figure 58: Section X-X showing cross ventilation



DESIGN RESPONSES

1 **Orientation** - The block is optimally oriented along an East-West axis with all major openings located along North and South facing walls minimizing the exposure of the rooms to direct solar radiation.

2 **Ventilation** - All the spaces are naturally ventilated through the windows, doors and the permanent vents provided at the roof level using timber louvres and above the openings.

- Adjustable louvres are appropriate for this zone for directing the incoming air towards any desired level within a room.

- The open stairwell acts as a solar chimney. Hot air rises through the open space and exits at the top through the permanent vent louvres at the roof.

- The living, dining and kitchen are designed as open plan as part of the block's natural ventilation through cross ventilation. This eliminates heat build-up during the hot season.

3 **Daylighting** - Natural lighting is allowed to penetrate all the rooms through the windows and thus prevent the use of artificial lighting during daytime.

4 **Sun shading** - The use of slab and roof overhangs (600 mm deep) have been included to cut out unwanted direct solar radiation from the mid-day sun on the North and South facing façades.

- Windows have been minimized on the West facing façades to reduce solar gains from the afternoon sun.

5 **Building materials** - High thermal mass are used as construction material for the building envelope. This helps to reduce the diurnal temperature swings. Light coloured walls and roofs have been used to reflect heat away during the hot months.

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