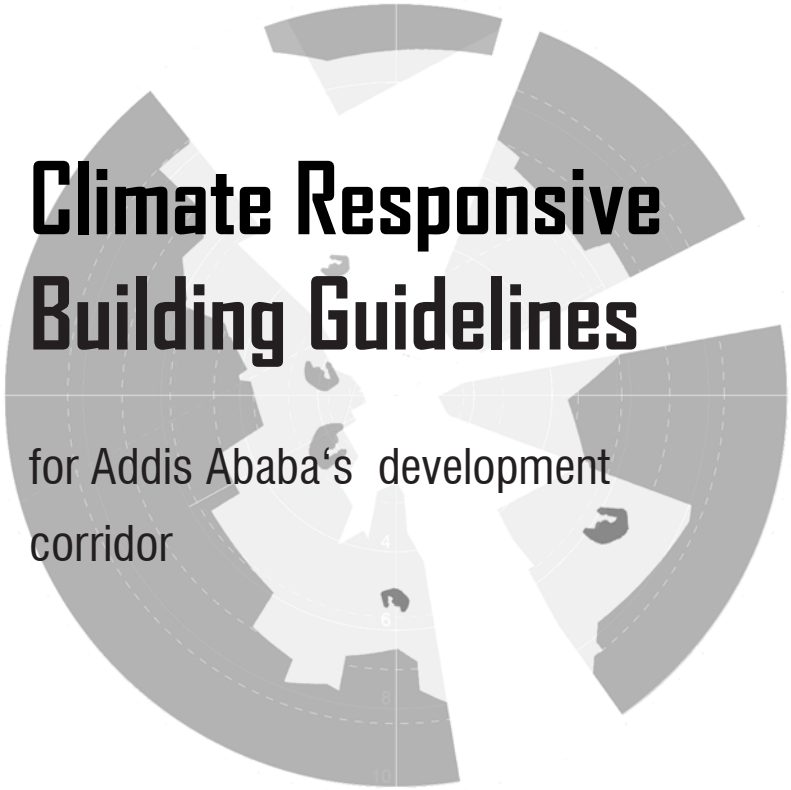


Climate Responsive Building Guidelines

for Addis Ababa's development corridor

Alpha Yacob

Advisers
Jan Mehnert
Tobias Fiedler

September 2014

Gaps are observed between the **actual climatic and environmental context** of the city and **current codes and regulations.**

The goal of this study is to **come up with recommendations** to improve existing regulations as well as present **general building guidelines** in two major scales:

Gaps are observed between the actual climatic and environmental context of the city and current codes and regulations.

This study identifies and analyzes these gaps to **come up with recommendations** to improve existing regulations as well as present **general building guidelines** in two major scales:

OUTDOOR SPACES

01
Climatic Context

02
Building Massing

INDOOR SPACES

03
Natural Daylighting

04
Natural Ventilation

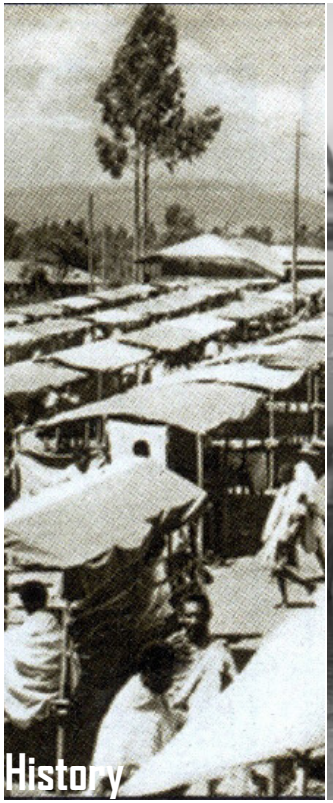
05
Thermal Comfort

Area 357,021 square kilometres
Population 80.3 million,
Density: 225 inhabitants/km2

Area 1,100,000 square kilometres
Poulation 91 million
Density: 83 inhabitants/ km2

CAPITAL CITY OF
ETHIOPIA
ADDIS ABABA

2400m above sea level
Latitude of 9.1°N
Longitude of 38.44°E.


History


Urban Fabric


‚Non Formal'


Tradition


Culture

01

Climatic Context

02
Building Massing

03
Natural Daylighting

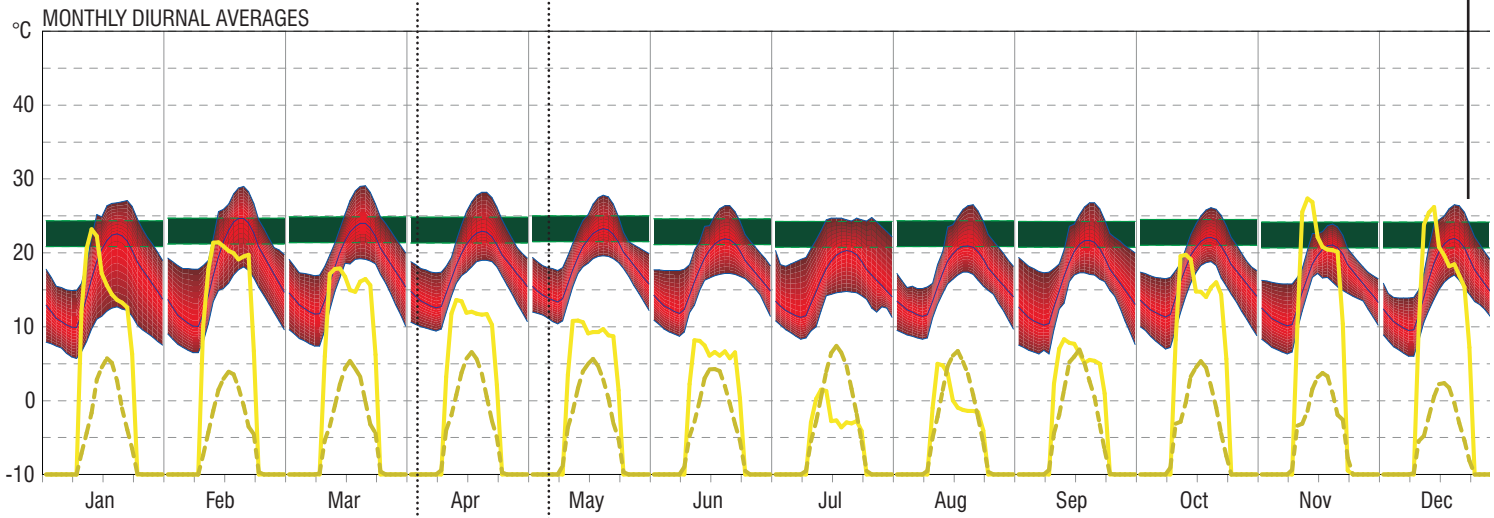
04
Natural Ventilation

05
Thermal Comfort

01 CLIMATIC CONTEXT

Direct Radiation:
Relatively low in wet season

Outside Temperature
Low duirnal fluctuation during wet season



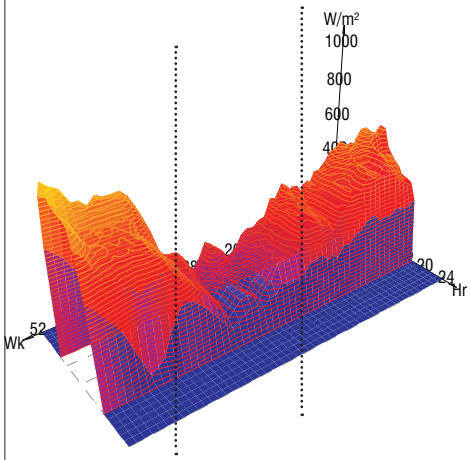
Direct Solar Radiation
Diffuse Solar Radiation
Montly Diurnal Averages

Horizontal Radiation:
2034 kWh/m²/a

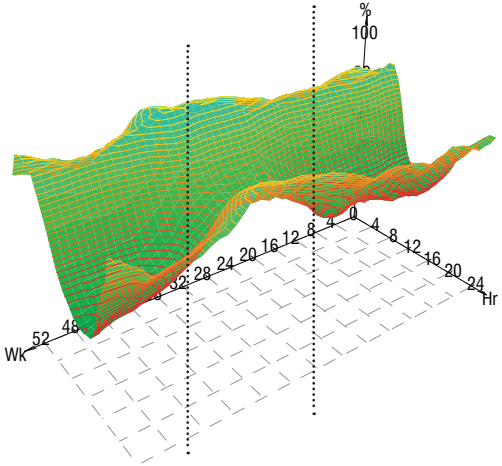
Outside Temperature
Maximum: **27.5 °C**
Average Minimum: **5°C**
Yearly Mean: **16.2 °C**

Wet Season - June, July, August

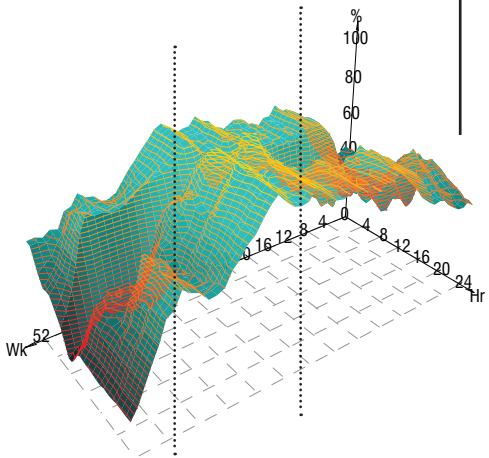
- Relatively high air humidity
- High cloude cover



Direct Solar Radiation



Relative Humidity



Average Cloud Cover

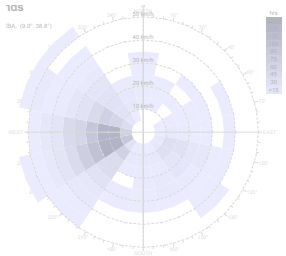
Outdoor Comfort

Average wind speed 3.9 m/s.

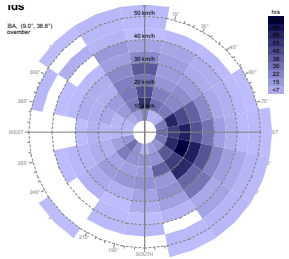
Most windy days are in October.

Least windy days are in January.

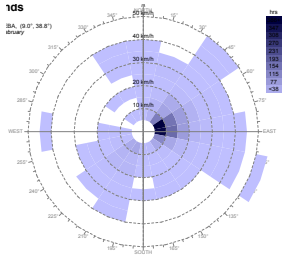
June, July, Aug



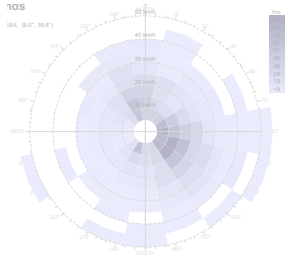
Sept, Oct, Nov



Dec, Jan, Feb



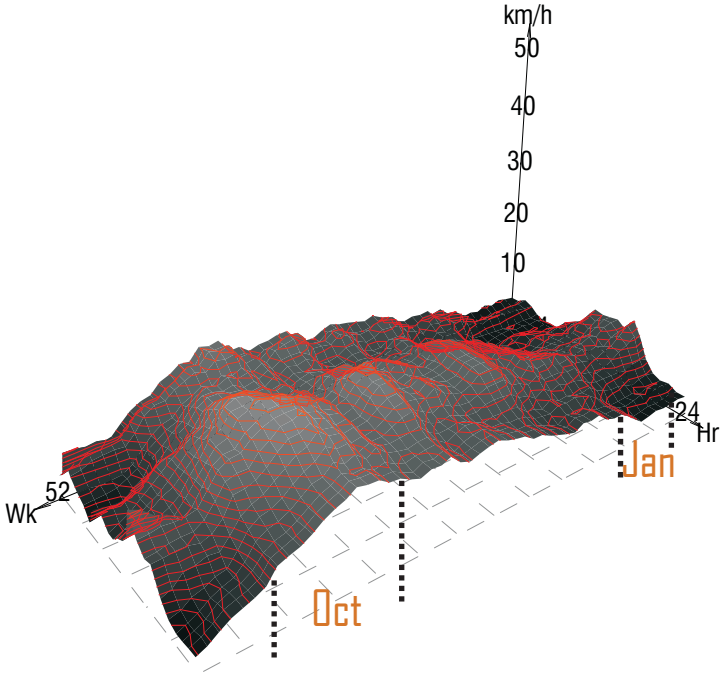
March, April, May



Wind Frequency

>9 hrs — <100 hrs

Annual Average Wind Speed



Outdoor Comfort

Average wind speed 3.9 m/s.

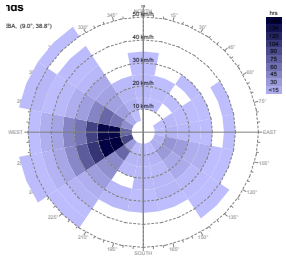
Most windy days are in October.

Least windy days are in January.

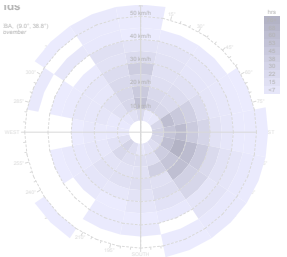
Most prevailing wind direction is from East to West.

Wet Season: wind direction is from West to East.

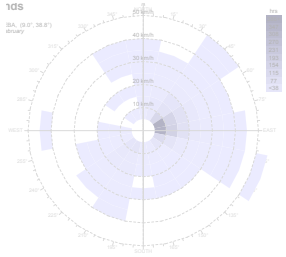
June, July, Aug



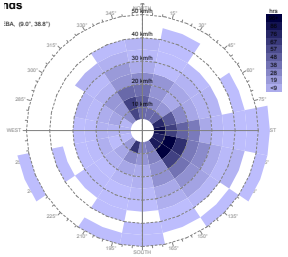
Sept, Oct, Nov



Dec, Jan, Feb



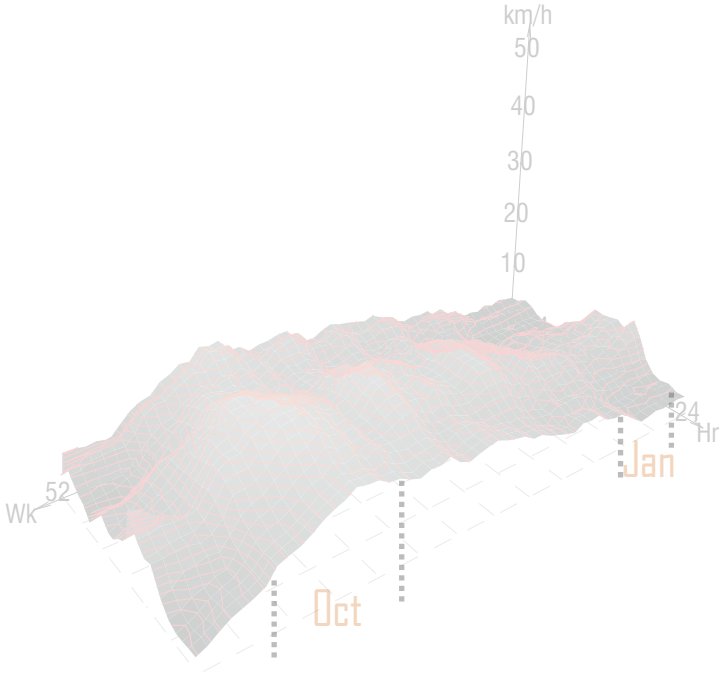
March, April, May



Wind Frequency

>9 hrs — <100 hrs

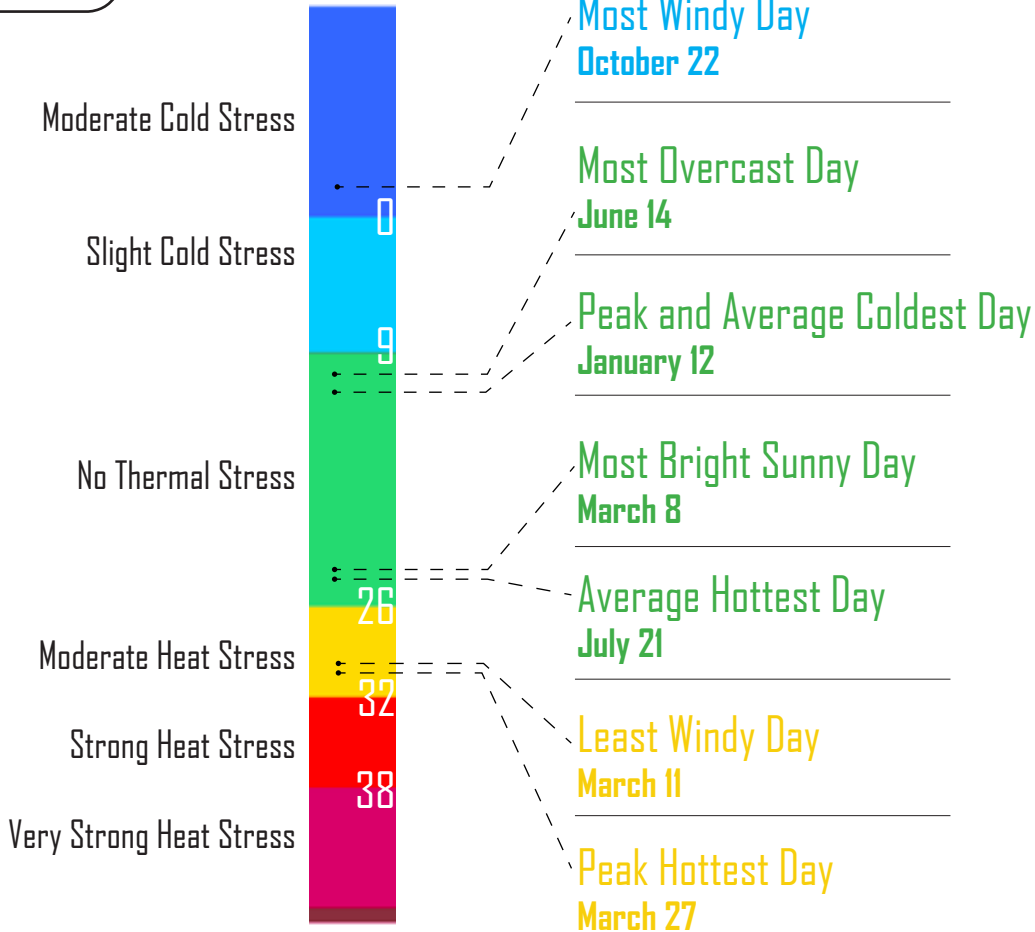
Annual Average Wind Speed

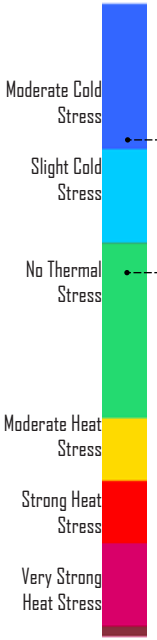


Outdoor Comfort Critical Days

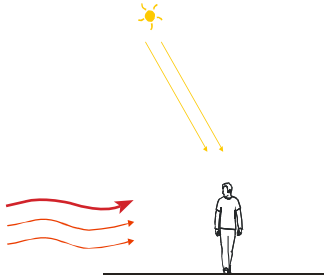
Main challenge of outdoor comfort is direct solar radiation.

With simple strategies of shading good comfort can be achieved.



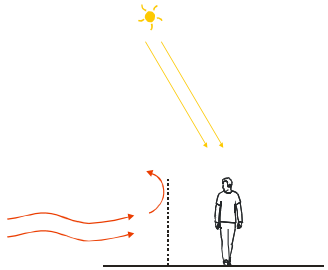


Base Case

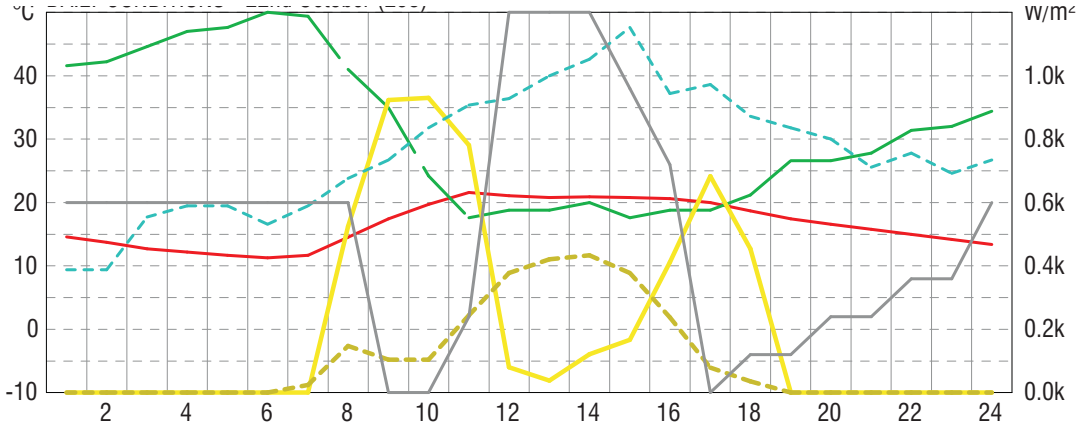


Improved Case

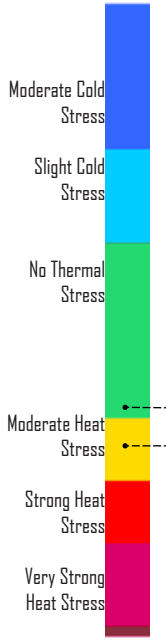
Strategy: Wind Protection



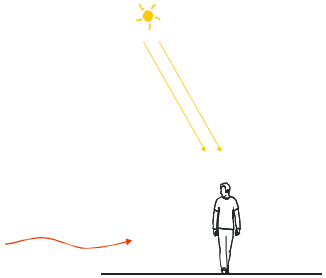
Most Windy Day
October 22



Direct Solar Radiation
Diffuse Solar Radiation
Temprature Monthly Diurnal Averages
Humidity
Wind Speed
Cloud Cover

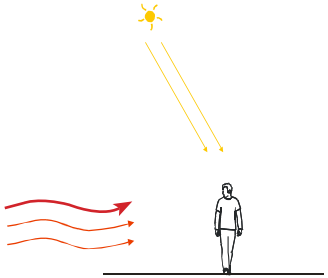


Base Case

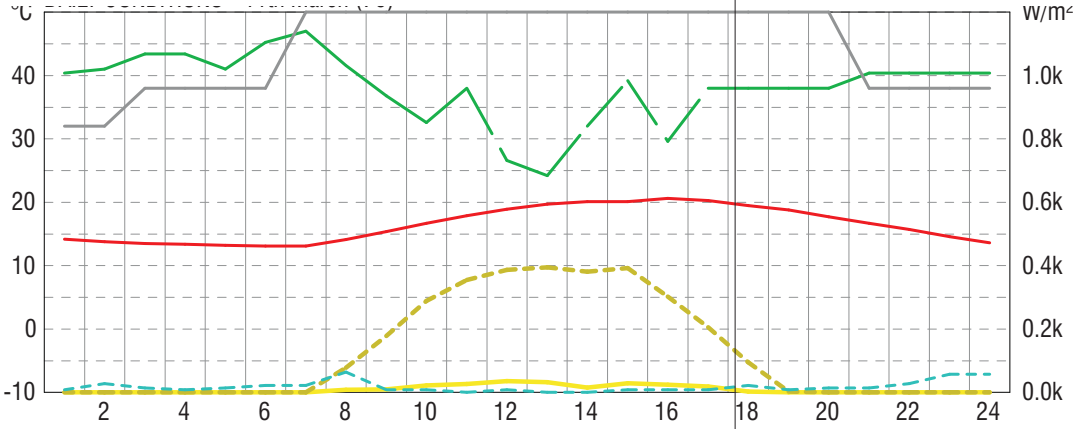


Improved Case

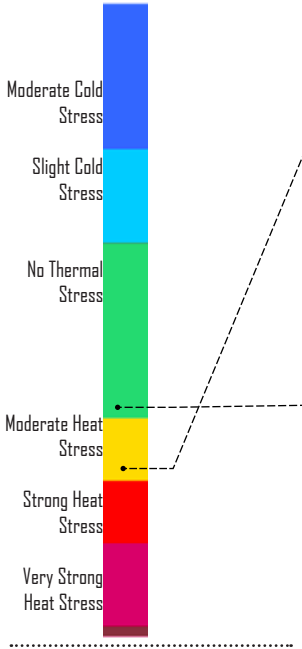
Strategy: Enhance Wind



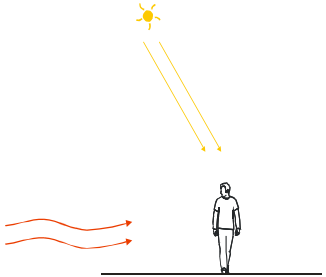
Least Windy Day
March 11



Direct Solar Radiation
Diffuse Solar Radiation
Temprature Monthly Diurnal Averages
Humidity
Wind Speed
Cloud Cover

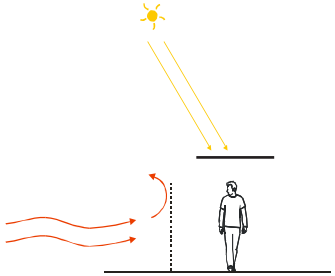


Base Case

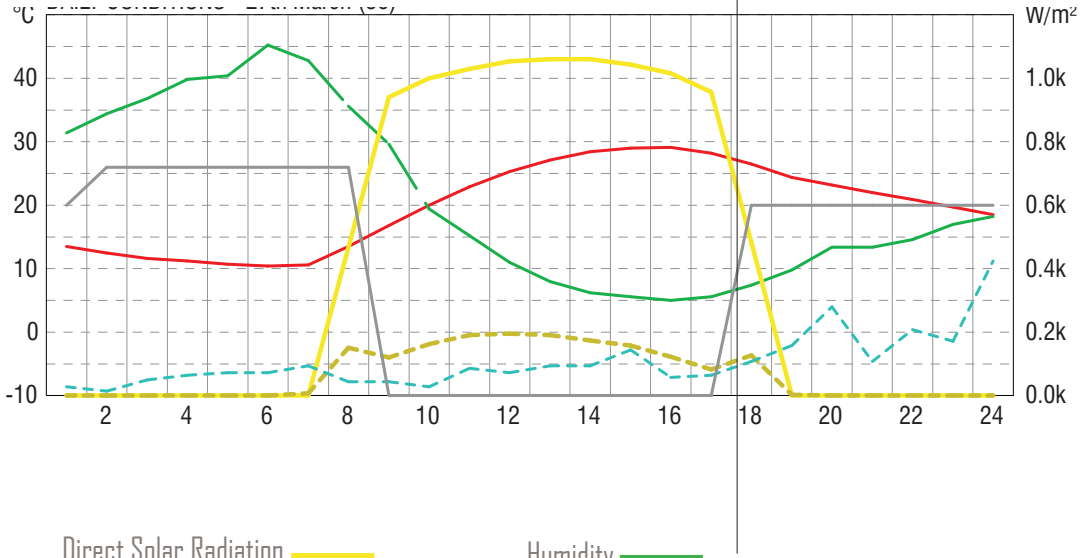


Improved Case

Strategy: Shading and Wind Protection



Peak Hottest Day
March 27

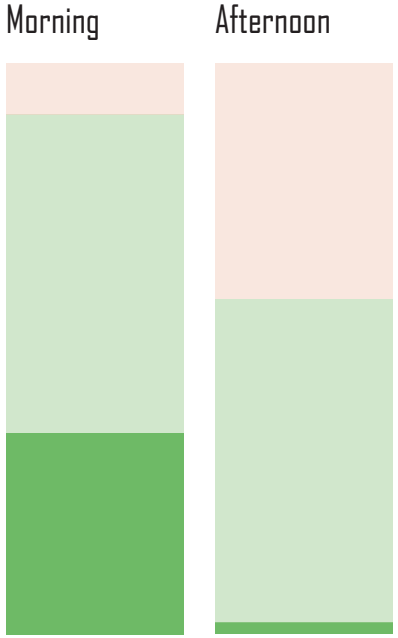


Outdoor Comfort

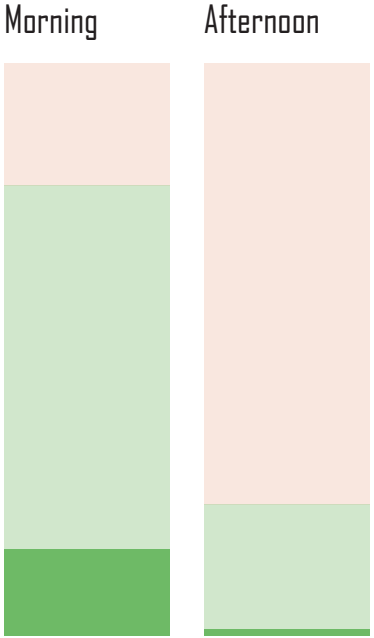
Morning hours have UTCI less than 20 for approximately 90% of the time.

March, April and May 80% afternoon hours have UTCI morethan 20.

June, July, August



March, April, May



UTCI > 20
16 <= UTCI <= 20
UTCI < 16

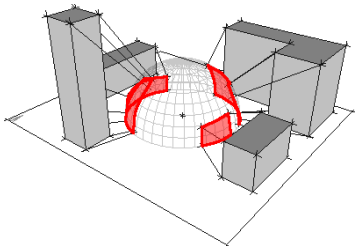
Using UTCI model, two major comfort ranges are identified during morning and afternoon hours.

Outdoor Comfort

Main challenge of outdoor comfort is **direct solar radiation.**

Shading is key strategy for good comfort.

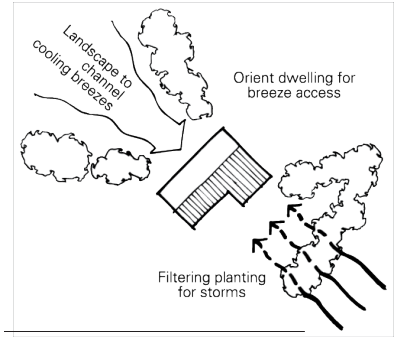
Solar Radiation



Shading afternoon hours in March, April, May.

Maximize **solar exposure** during morning hours in June, July, August.

Wind Movement

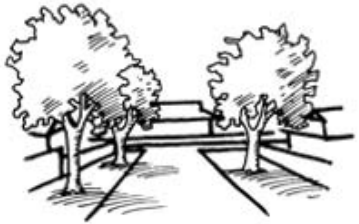


Depending on proposed functions:

March: improving wind movement.

Oct and Nov: wind protection strategies

Micro Climates with Additional Site Features



Water bodies and fountains
Trees
Landscaping elements

02
Building Massing

01
Climatic Context

03
Natural Daylighting

04
Natural Ventilation

05
Thermal Comfort

Overview on Building Regulations

1. **EBCS-** Ethiopian Building Code Standards
2. Ethiopian Building **Proclamation**
3. Ethiopian Building **Directives**
4. Council of Ministers **Building Regulation**
5. Building **Height** Regulation

Overview on Building Regulations

1. **EBCS-** Ethiopian Building Code Standards
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5. Building **Height** Regulation

Drawbacks of Current Regulations

References Used date back to 1980's.

Regualtions from hot climates are used as references.

Climatic conditions of the city are not sufficiently considered.

No provisions for thermal comfort, water utilization and energy consumption of buildings.

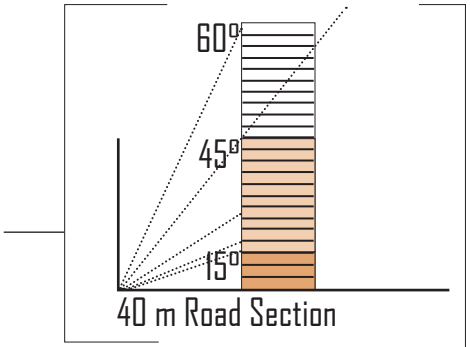
Building Height Regulation

Minimum Economic Height

Maximum Infrastructure Height

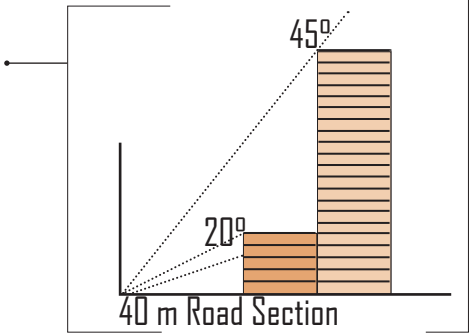
Aesthetic Height

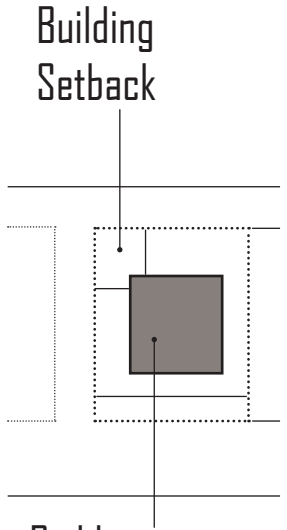
Building Enclosure



Building Scale:

Intimate Scale
Podium Tower
Combiantion





Building Height Regulation

Drawbacks

- Climatic Context is not incorporated
- The date considered is not critical day!
- The study is not exhaustive and detailed to come up with conclusions!

Climatic Height?

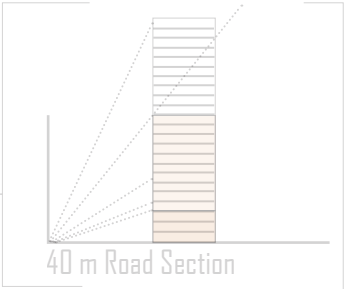
„ . . . A simple calculation made on the basis of having **two hours shade (11 am-1pm) for the month of June** (which is the most critical) on both sides of the East West axis. Result was not economically and esthetically feasible. . . . "

Minimum Economic Height

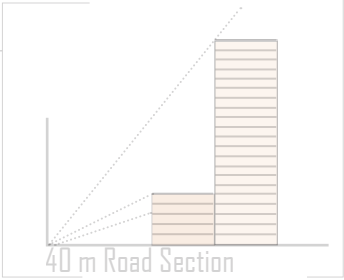
Maximum Infrastructure Height

Aesthetic Heigh

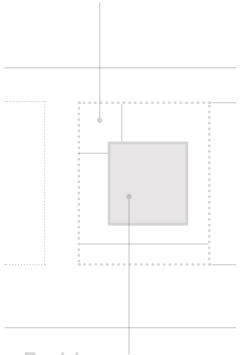
Building Enclosure



Building Scale:
Intimate Scale
Podium Tower
Combiantion



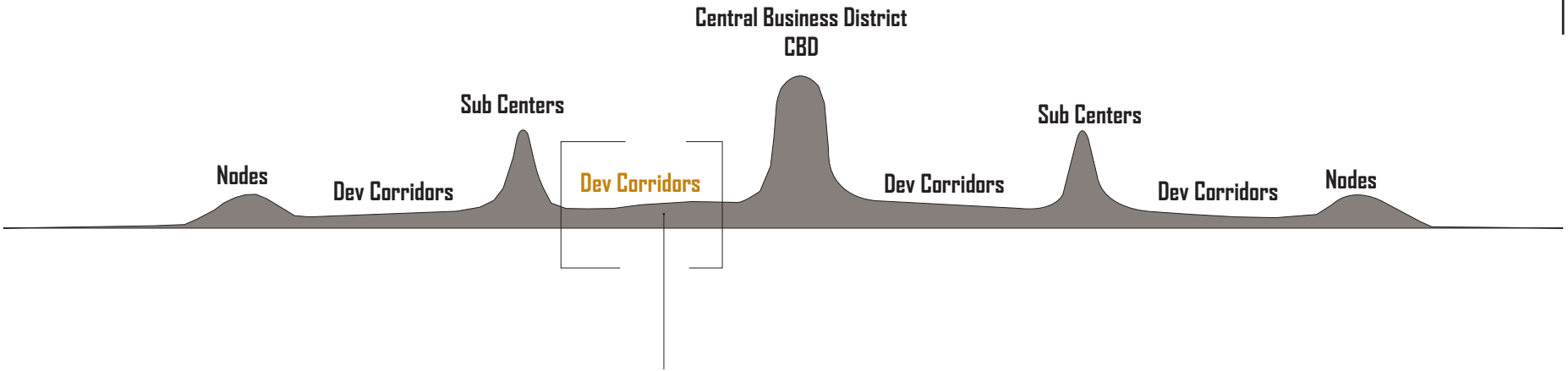
Building Setback



Building Footprint

Resultant Structure as per Current Regulation

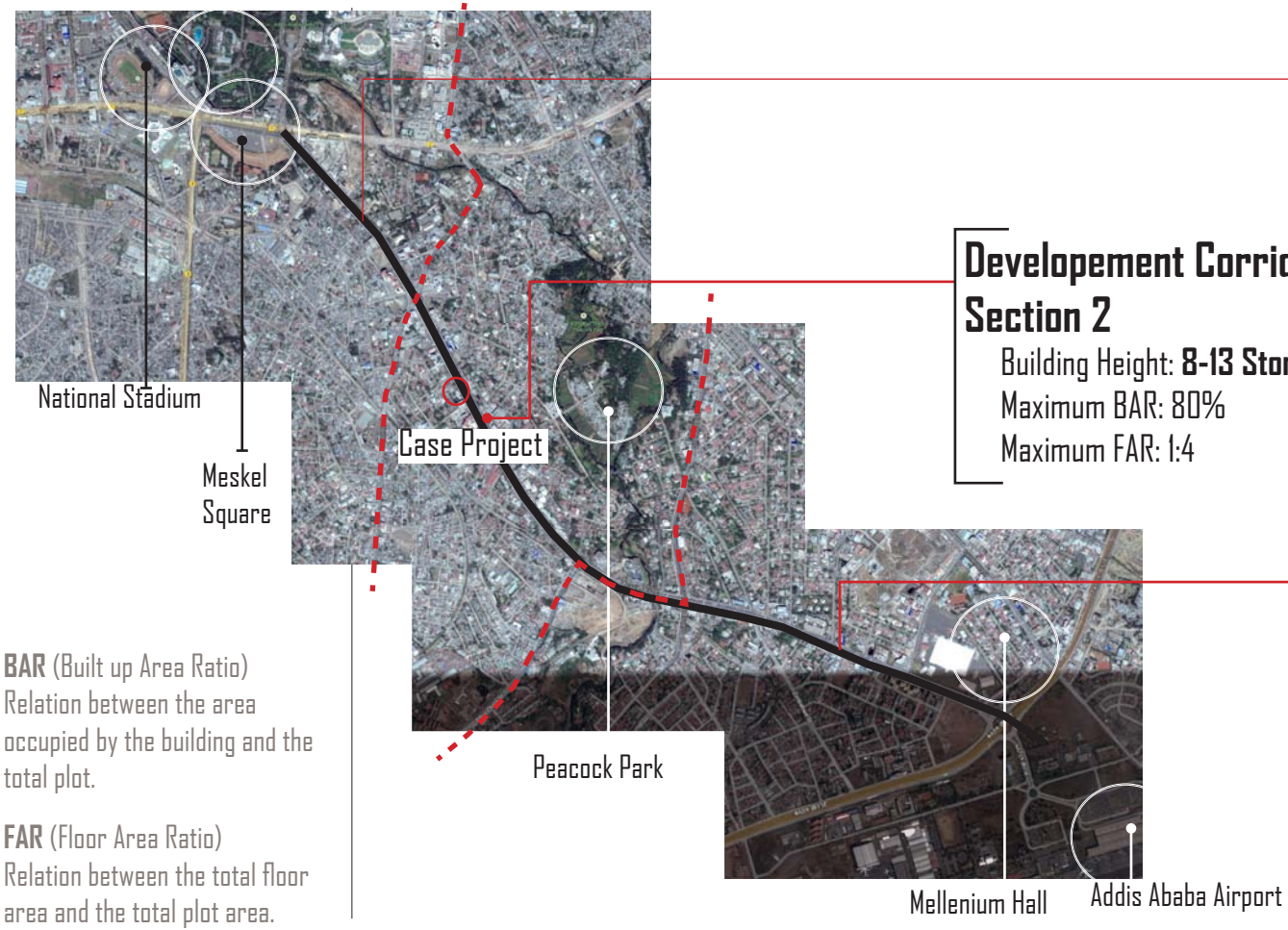
The poly-centric or multi-nucleated city structure



CASE PROJECT LOCATION

How does this city structure respond to context?

02 BUILDING MASSING



Developement Corridor Section 1

Building Height: **13-21 Stories**
Maximum BAR: 80%
Maximum FAR: 1:5 - 1:7

Developement Corridor Section 2

Building Height: **8-13 Stories**
Maximum BAR: 80%
Maximum FAR: 1:4

Developement Corridor Section 3

Building Height: **5-10 Stories**
Maximum BAR: 80%
Maximum FAR: 1:4

BAR (Built up Area Ratio)
Relation between the area occupied by the building and the total plot.

FAR (Floor Area Ratio)
Relation between the total floor area and the total plot area.

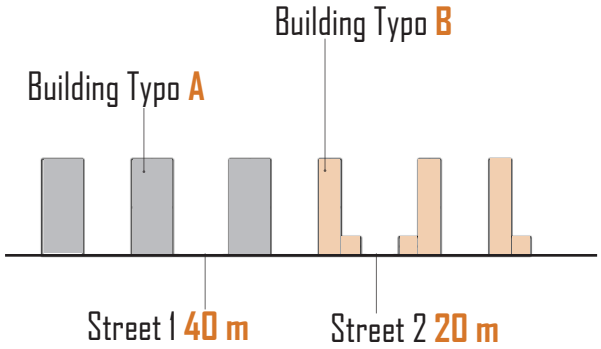
02 BUILDING MASSING

Four Building Typologies

Factors considered for developing typologies

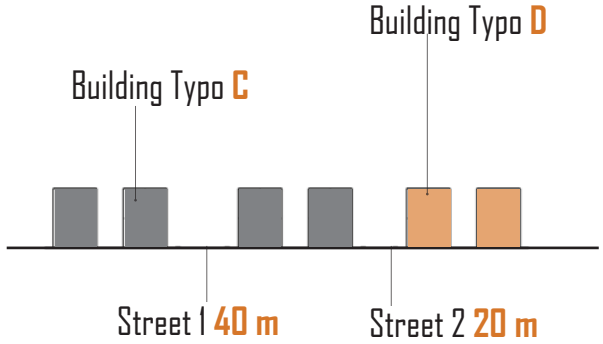
- Provisions of Regulation
- Huge Spatial and Investment Demand

21 Story Building

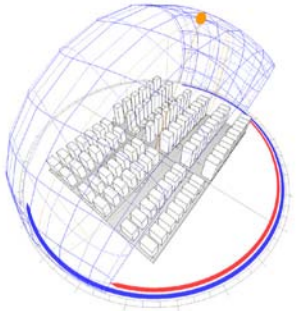


Plot: 37.5 m by 48 m
Block base area 600 m2
Block Size: 20 m * 30 m
Total Area: 12,600 m2
Enclosure- 1:1.73

13 Story Building



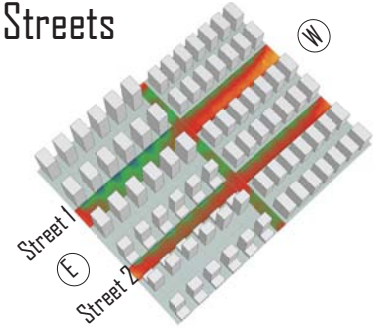
Plot: 30 m by 48 m
Block base area 576 m2
Block dimension 18 m * 32 m
Total Area: 7,488 m2
Enclosure- 1:1



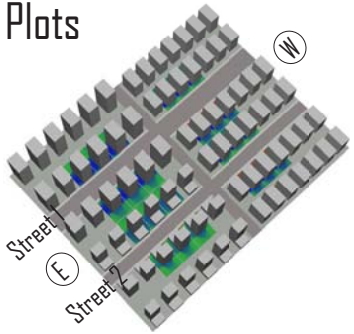
E-W
Main Streets

Radiation
kWh/m2
0
500
1000
1500
2000

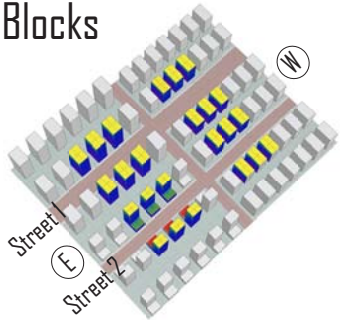
Streets



Plots



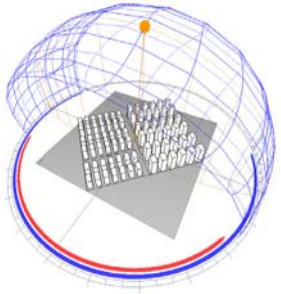
Blocks



02 BUILDING MASSING

E-W

Main Streets



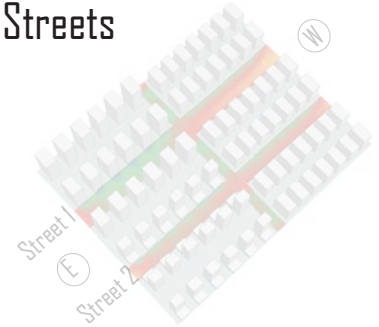
NE to SW

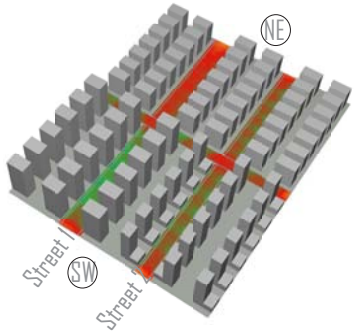
Main Streets

Radiation
kWh/m2

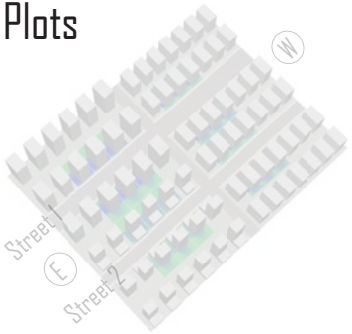
0
500
1000
1500
2000

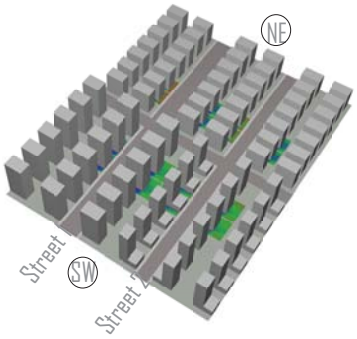
Streets



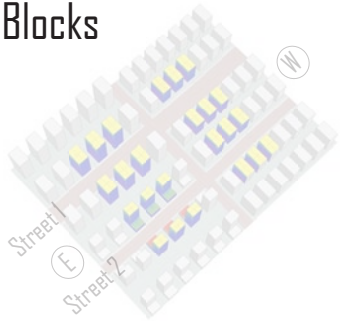


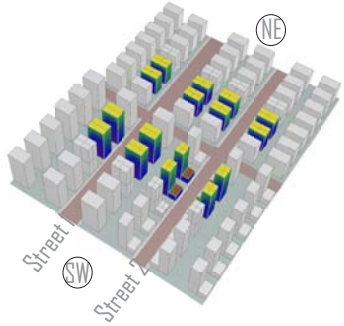
Plots





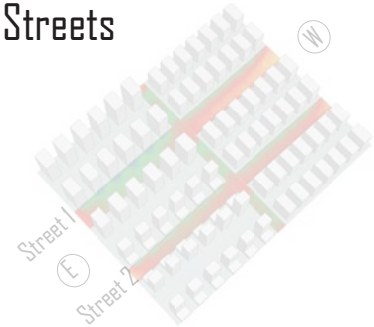
Blocks

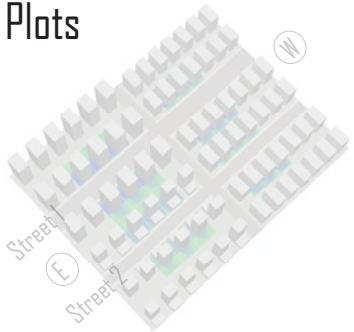


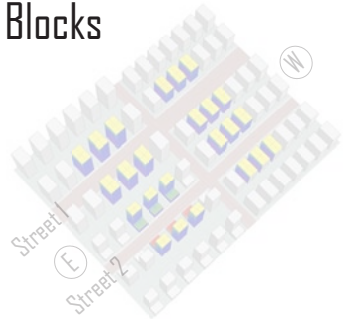


02 BUILDING MASSING

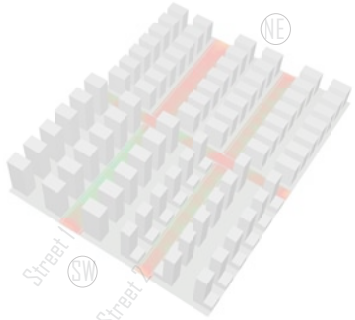
E-W
Main Streets

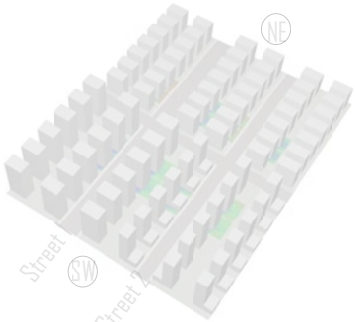


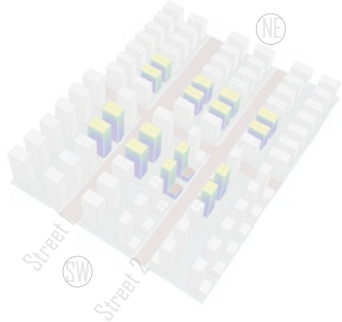


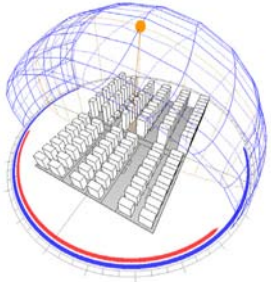


NE to SW
Main Streets



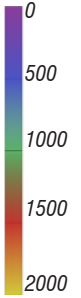


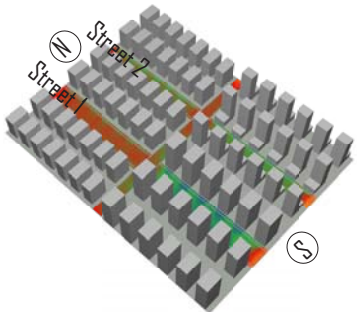


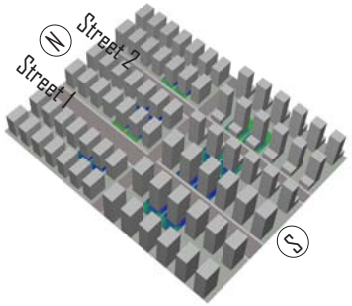


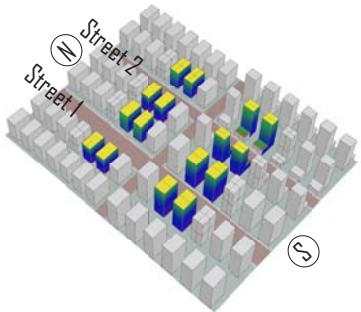
N-S
Main Streets

Radiation kWh/m2









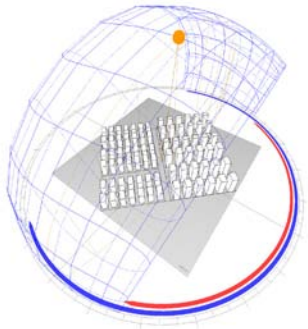
Streets

Plots

Blocks

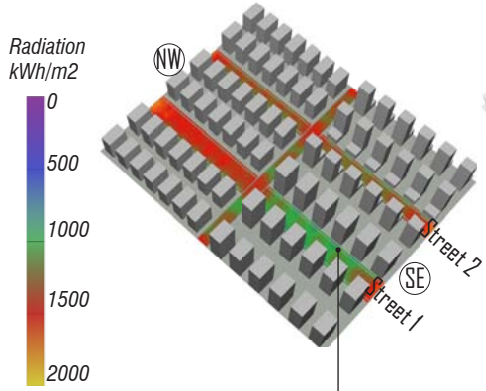
02 BUILDING MASSING

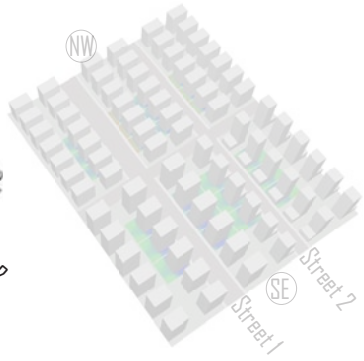
Streets Plots Blocks

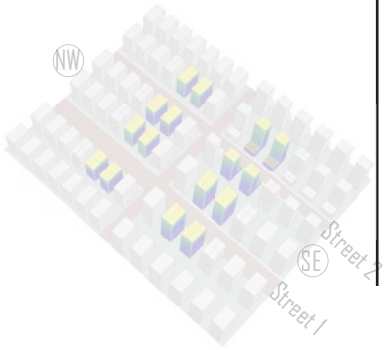


NW to SE

Main Streets

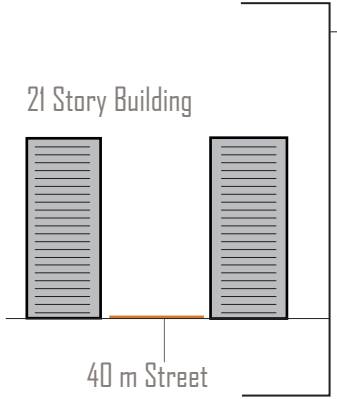


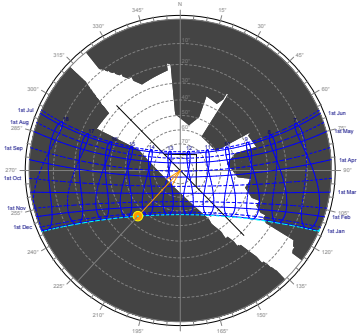




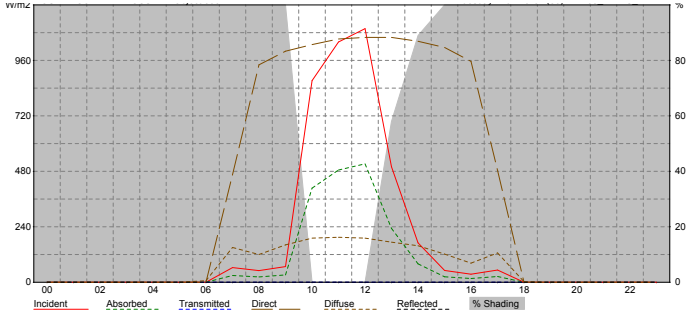
Most Shaded Street

- Exposed to solar radiation during hottest day.
- Needs additional shading strategies.



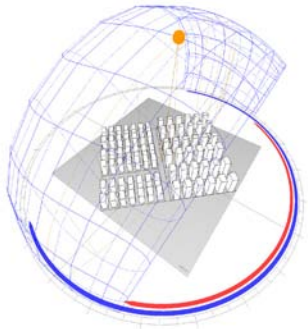


Annual Shading



March 27, Hottest day Hourly Solar Exposure

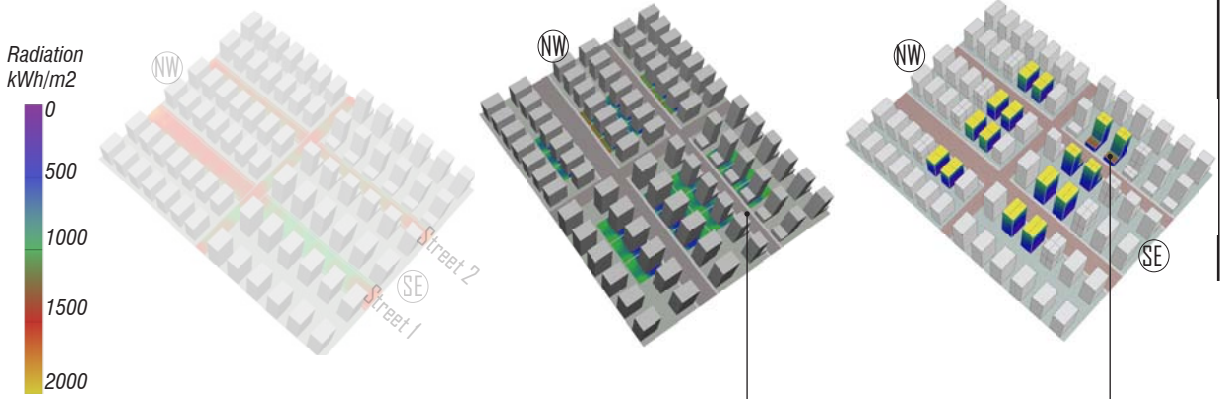
02 BUILDING MASSING



NW to SE

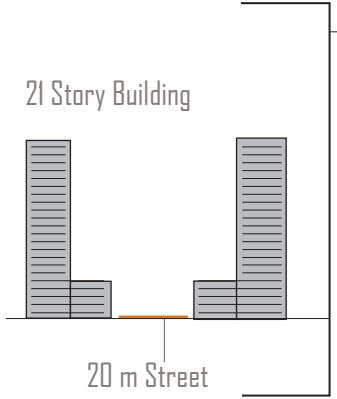
Main Streets

Streets | Plots | Blocks

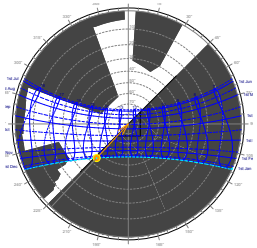


Most Radiation on Plot and Building

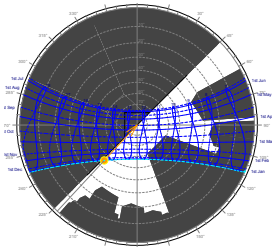
- S and W: exposed to direct radaition during afternoon
- N and E: shaded from direct radiation during afternoon



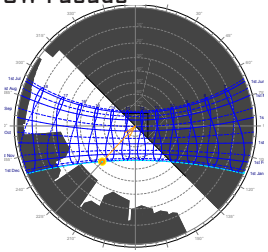
NW Facade



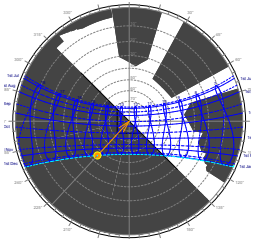
SE Facade



SW Facade



NE Facade



Annual Shading

Massing Strategies

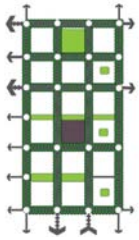
Defining:

- Orientation
- Size of Streets
- Building Height
- Block Size
- Building Setbacks

Streets' Orientation

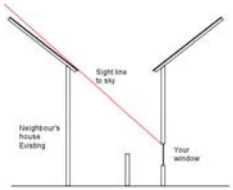
NS streets can be well shaded.
EW streets are most exposed.

Blocks' Orientation



N Facades recieve least annual radiation.
E and W Facades receive most annual radiation.

Right-to-Light



Keeping **sight line** to sky shall be studied based on position of the sun (altitude and azimuth).

Indoor Space Illumination

Sufficient daylighting during **overcast days (Wet Season)** shall be studied.

03

Natural Daylight

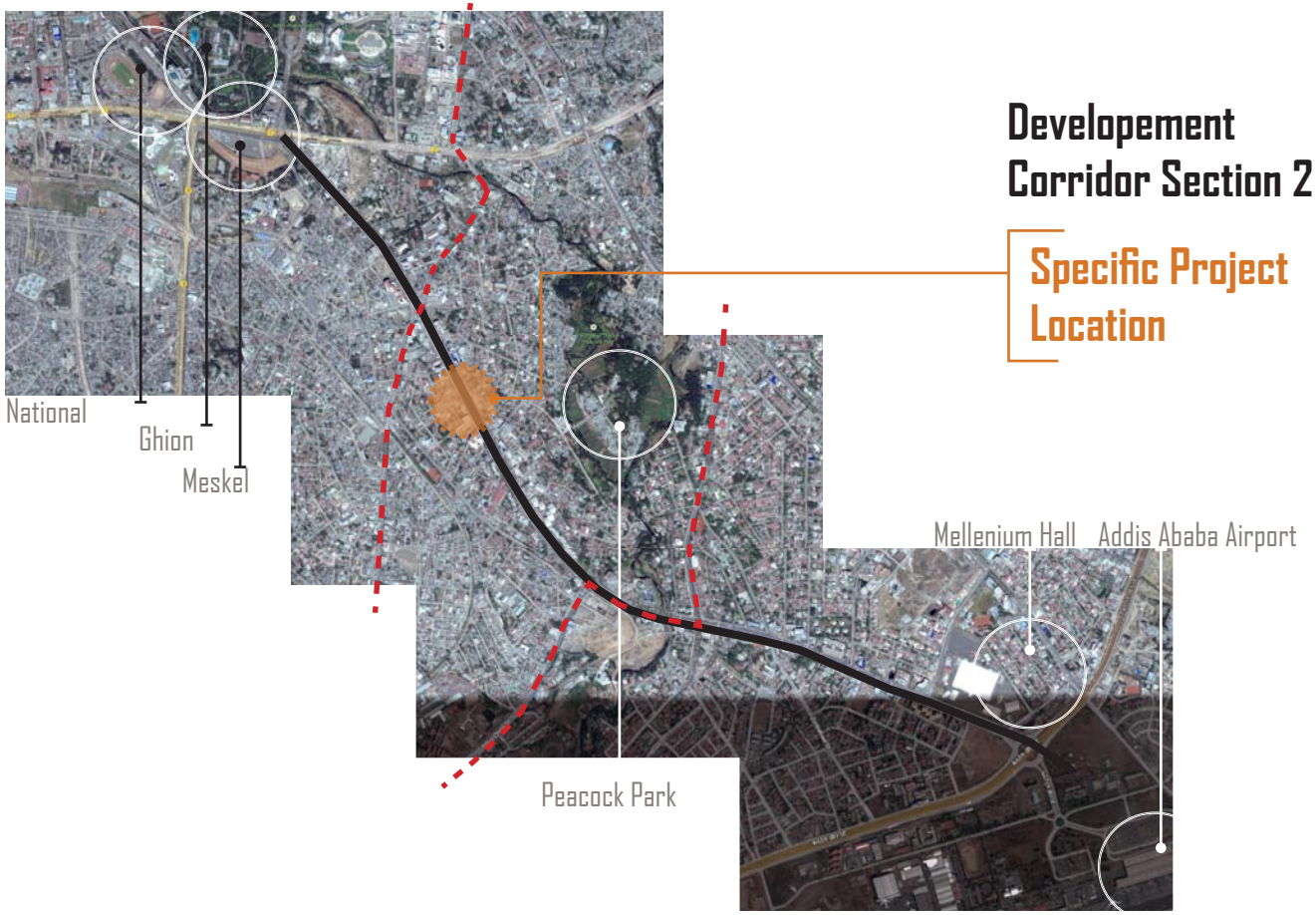
01
Climatic Context

02
Building Massing

04
Natural Ventilation

05
Thermal Comfort

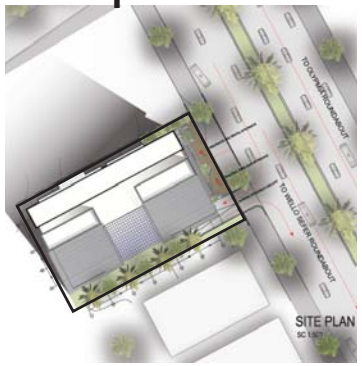
Case Project Description

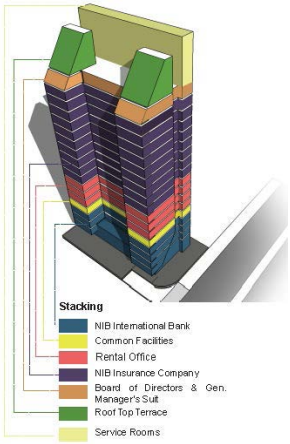


Developement Corridor Section 2

Specific Project Location

Case Project Description





Size of the site/plot: 1436 m2
Gross Floor Area: **17,946 m2**

BAR (Built up Area Ratio):
78% of the plot is built up.

In total for the **17 floors**, 1020 people can be accommodated.

Area per person (working area + circulation space) is 13m2.

Major Function:
Office

Day Light Study of Different Levels

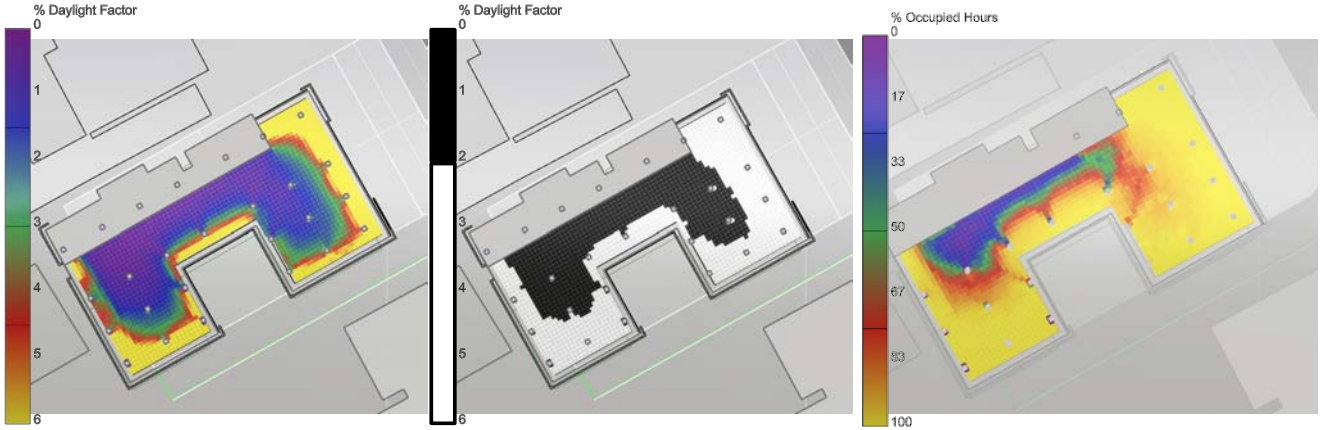
Providing good daylighting in all areas of the floor is challenging.

Day Light Autonomy

0 %
25 %
50 %
75 %
100 %

16th Floor

1st Floor



Day Light Study of Typical Level

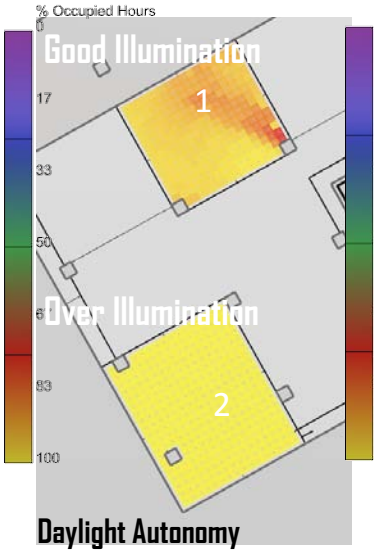
Two extrem cases are present:

- Under illumination
- Over illumination

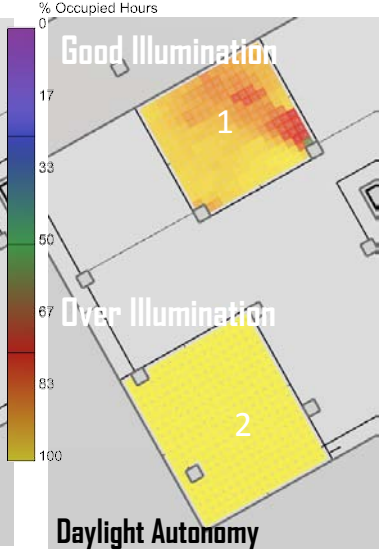
Day Light Study of Typical Level

Investigating the two extreme cases with various glazing proportions showed the position of the core should be adjusted.

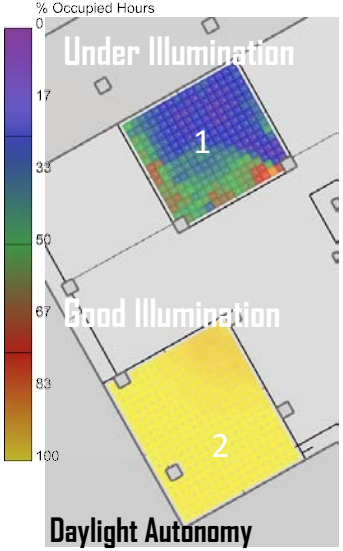
WWR
80% Glazing, 20%SolidWall



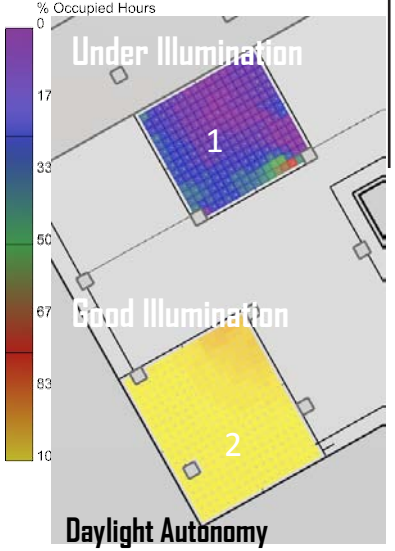
WWR
60% Glazing, 40%SolidWall



WWR
40% Glazing, 60%SolidWall



WWR
20% Glazing, 80%SolidWall



Day Light Study of Typical Level

Two extrem cases are present:

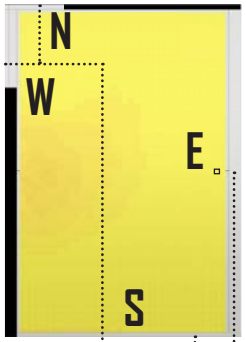
- Under illumination
- Over illumination

Day Light Study of Typical Level

Recommendation

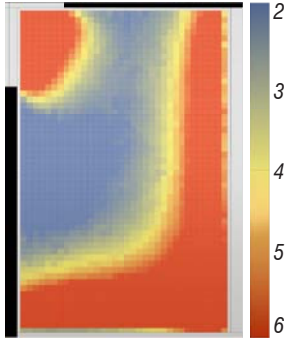
For large spaces, providing openings in different orientations improves illumination.

Daylight Autonomy

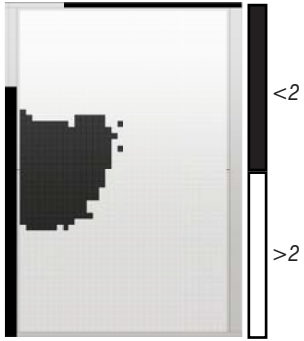


DA 100%

Daylight Factor

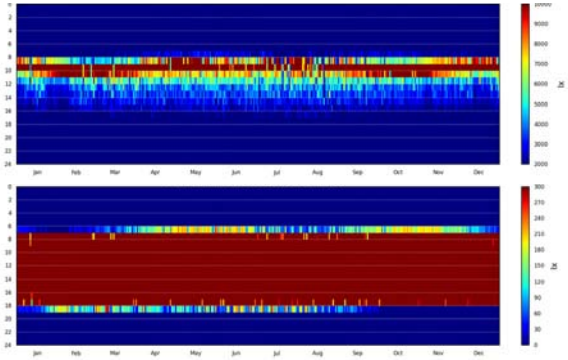


2<DF<6 52%

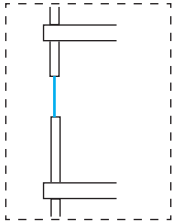


DF<2 13%

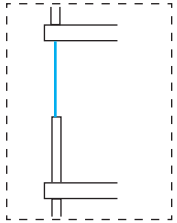
Annula Illumination



Good illumination



50% Glazing



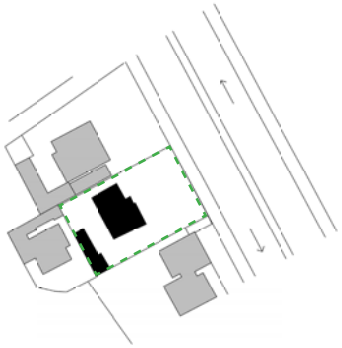
50% Glazing

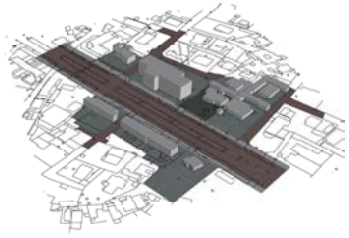
BACK TO BUILDING MASS STUDY . . . .

WHAT ARE THE ALTERNATIVE BUILDING LAYOUTS?

03 NATURAL DAYLIGHTING

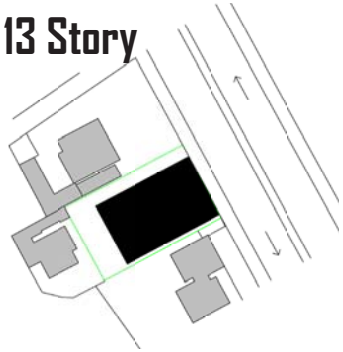
Base Case:
Original Plot

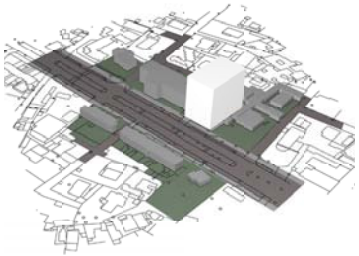




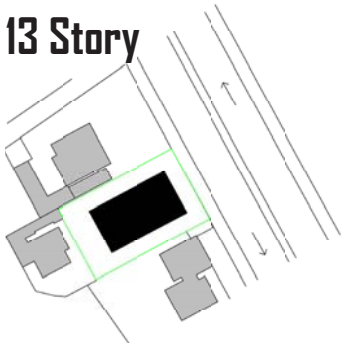
Possible Building Volumes as per the Regulation

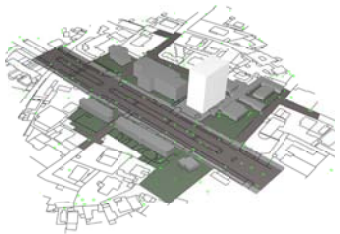
Case 1
13 Story



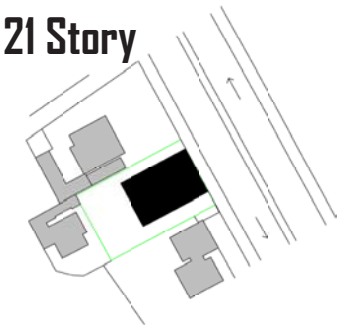


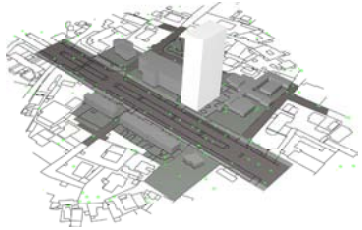
Case 2
13 Story



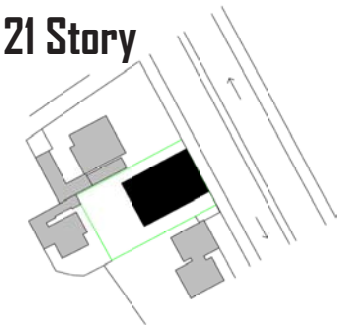


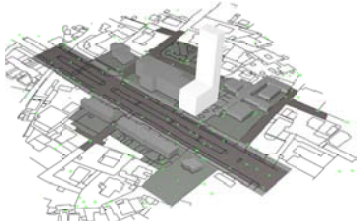
Case 3
21 Story





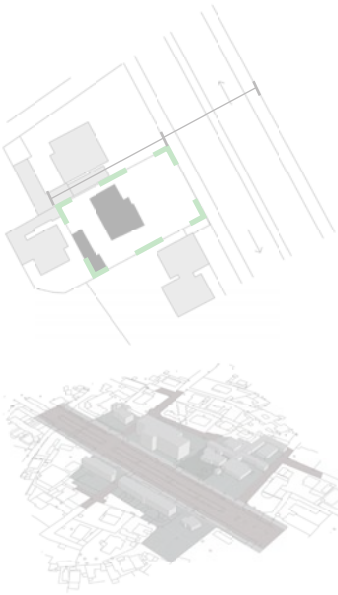
Case 4
21 Story





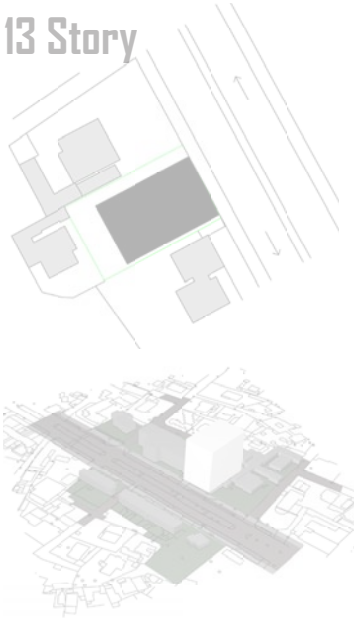
03 NATURAL DAYLIGHTING

Base Case:
Original Plot

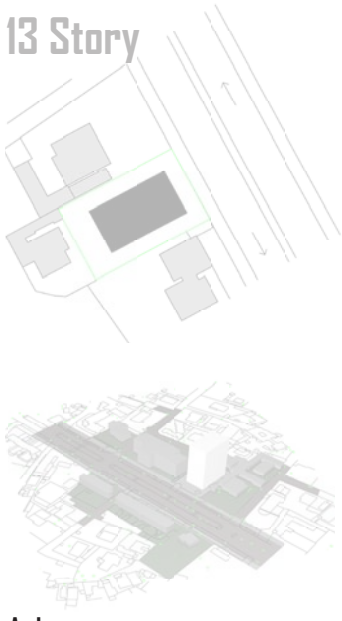


Possible Building Volumes as per the Regulation

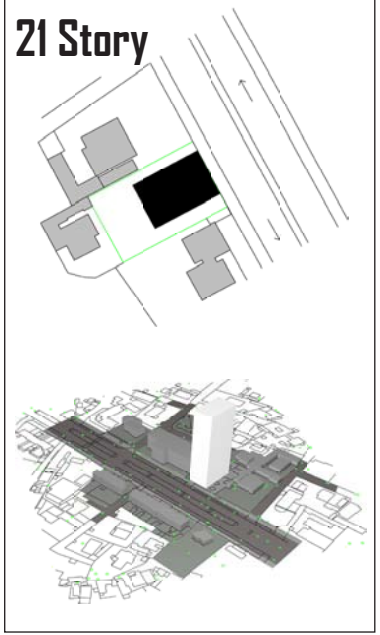
Case 1
13 Story



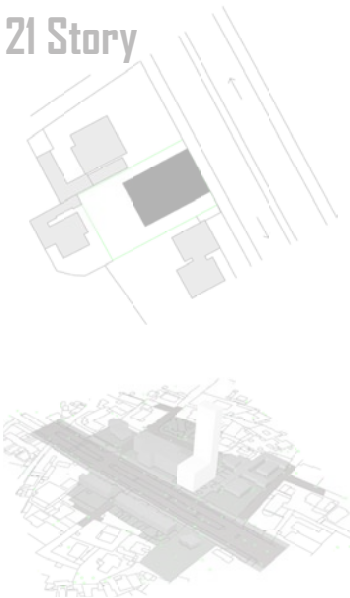
Case 2
13 Story



Case 3
21 Story



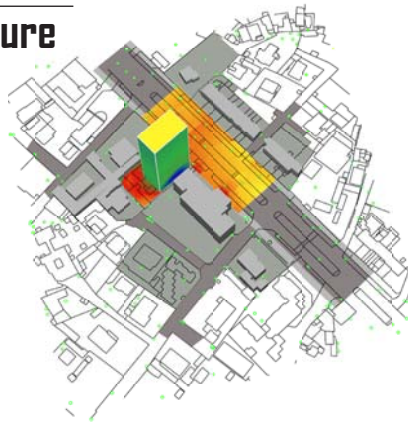
Case 4
21 Story



Advantages:

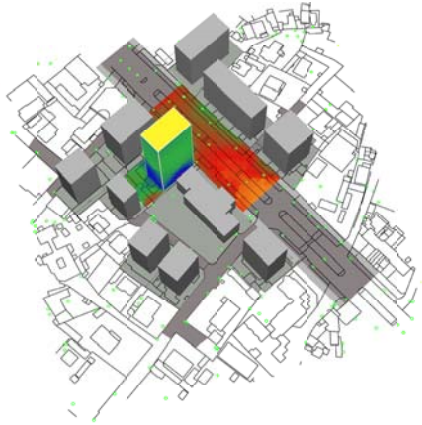
- **Provides the possibility to balance street shading and ideal solar exposure of building facade and plot.**
- **Increased floor area**

Building Impact
Current and Future Development

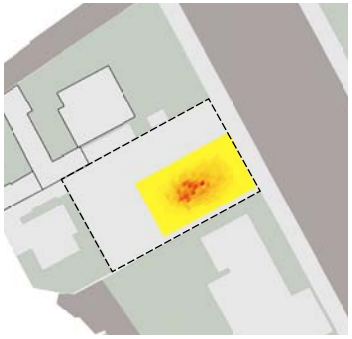


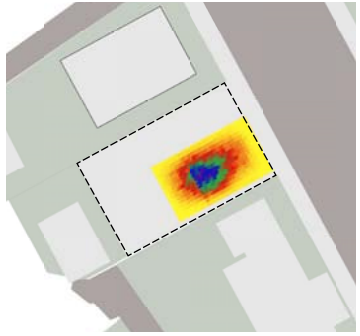
Current Development

Future Development

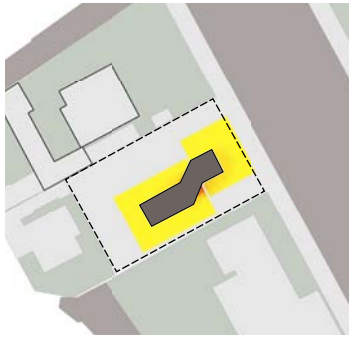


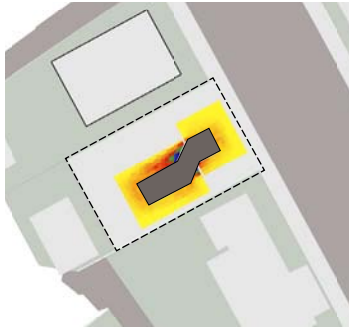
Ground Level



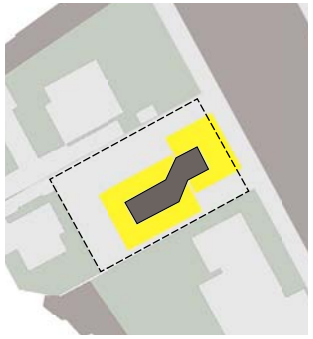


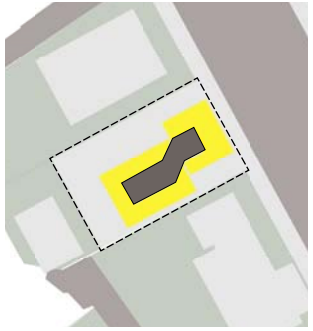
Ground Level





16th Level





FINDINGS OF NATURAL DAYLIGHTING STUDY . . . .

WHAT IS MISSING IN THE ETHIOPIAN BUIDING REGULATION?

WAHT IS MISSING IN DESIGN RULES OF THUMB?

Regulation on Natural Daylighting

„. . . For general offices illuminance of 500.0 lx and for drawing offices illuminance of 750.0 lx shall be provided."

„. . . Where local lighting is used, the ratio of illuminance between task area and the surrounding area shall not exceed 3: 1."

„. . . Demand for office: 50 W/m2 . . ."

Recommendations

Detailed stipulations for Natural DayLighting shall be provided.

Illuminance

As per DIN 5034, natural lighing illuminace requirment dictates that 60% of artificial light lux requirements shall be met.

Glare

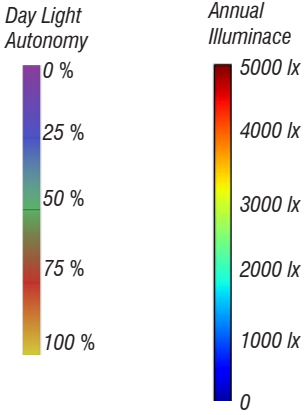
Shall be separately stated for natural lighting and spaces close to windows. As per DIN 5034 ratio as high as 1:10 is evaluated. Glare studies shall incorporate size of light source.

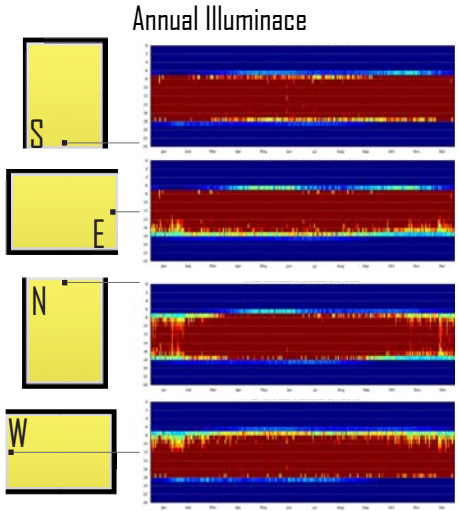
Demand

As per Faustformel Gebäudetechnikfür Architekten Power demand for lighting is 10-15 W/m2.

Rule of Thumb on Natural Daylighting

„Window to Floor Area Ratio of 40% for good lighting“



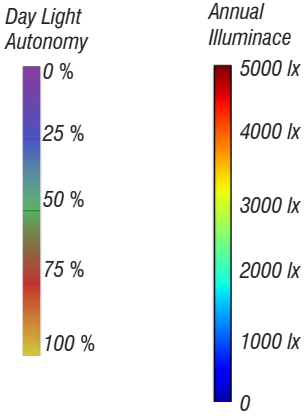


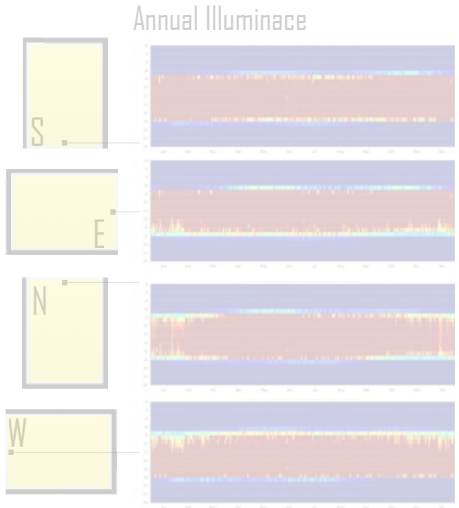
Window to Floor Area Ratio: **43%**

Window to Wall Ratio: **100%**

Rule of Thumb on Natural Daylighting

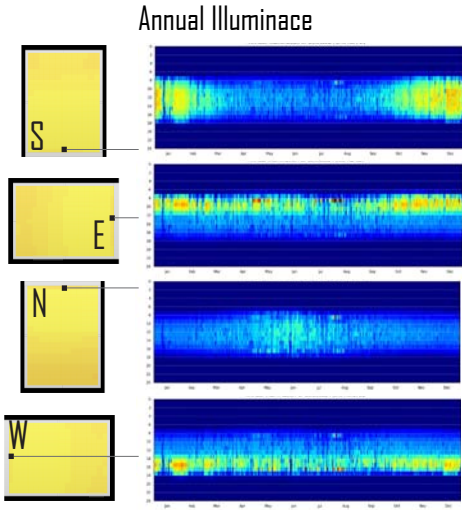
Using 40% of Floor Area to desing glazing size is limiting and less accurate.





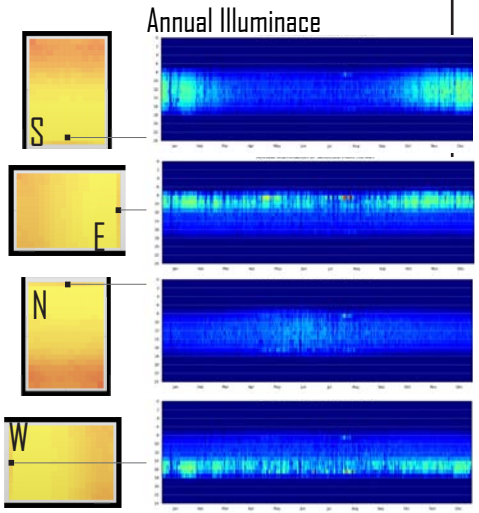
Window to Floor Area Ratio: **43%**

Window to Wall Ratio: **100%**



Window to Floor Area Ratio: **25%**

Window to Wall Ratio: **60%**



Window to Floor Area Ratio: **17%**

Window to Wall Ratio: **40%**

04

Natural Ventilation

01
Climatic Context

02
Building Massing

03
Natural Daylight

05
Thermal Comfort

Potential for Natural Ventiation

Good Potential for night flushing during hot times of the year.

Wind Temprature

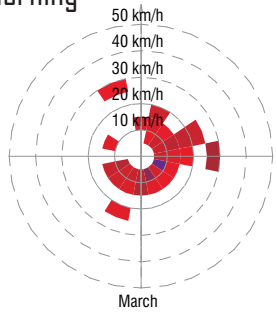
°C
45+
40
35
30
25
20
15
10
5
<0

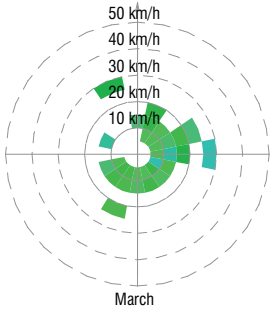
Wind Relative Humidity

%
95+
85
75
65
55
45
35
25
15
<5

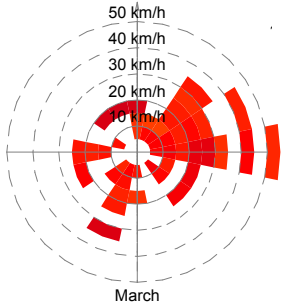
March

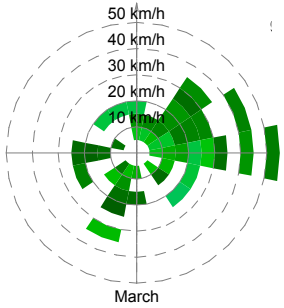
Morning



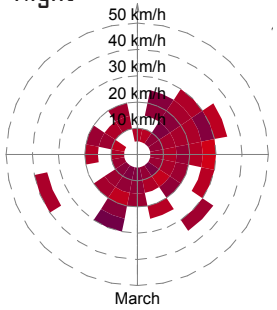


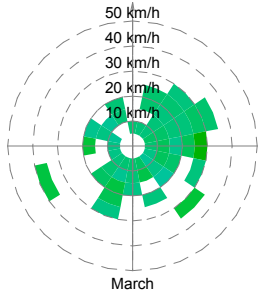
Afternoon





Night





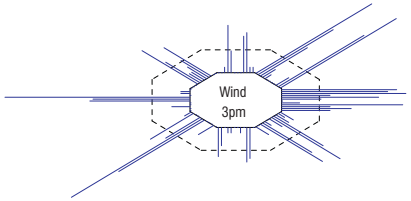
Potential for Natural Ventiation

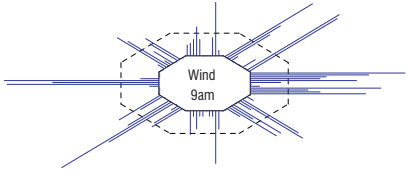
Good Potential for night flushing during hot times of the year.

- **E Facade:** good natural ventilation potential
- **N and S Facade:** least natural ventilation potential for majority of the year.
- **W Facade:** good natural ventilation potential during wet season.

March

Annual Wind
Different Facade Orientations





DESPITE HUGE POTENTIAL FOR NATURAL VENTILATION . . . .

WHAT IS MISSING IN THE ETHIOPIAN BUIDING REGULATION?

DESPITE HUGE POTENTIAL FOR NATURAL VENTILATION . . . .

WHAT IS MISSING IN THE ETHIOPIAN BUIDING REGULATION?

Ethiopian Building Code of Standards

- Detailed guidelines for **natural ventilation** are missing.
- Numbers provided persent ambiguity
  - ◊ Opening part of window is specified not to be less than **1/12th of floor area** regardless of orientation and context.
  - ◊ Requested minimum ventilation is **7ACH (to be achieved with a combination of natural and mechanical)**

05

Thermal Comfort

01
Climatic Context

02
Building Massing

03
Natural Daylight

04
Natural Ventilation

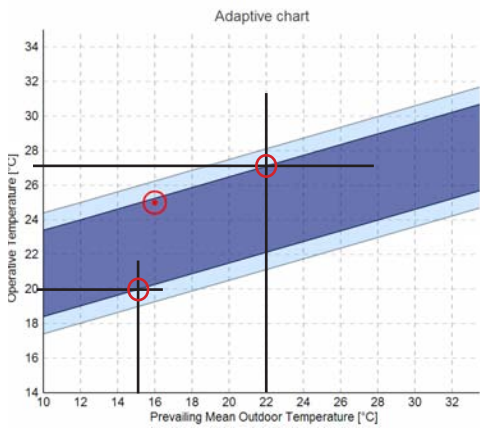
Ethiopian Code of Standards

States requirement when air-conditioning system is used:
Operative temprature between 23 °C and 25 °C.

THERMAL COMFORT IS NOT DISCUSSED FOR NATURALLY VENTILATED SPACES.

Ethiopian Code of Standards
States requirement when air-conditioning system is used:
Operative temprature between 23 °C and 25 °C.

THERMAL COMFORT IS NOT DISCUSSED FOR NATURALLY VENTILATED SPACES.



ASHREA 55: Adaptive Chart

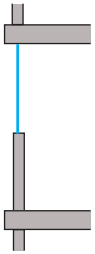
Operative Temperature
90% Acceptability Range
Between 20 °C and 27 °C

05 THERMAL COMFORT

Window to Wall Ratio

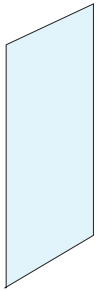
Full Glazing

50% Glazing

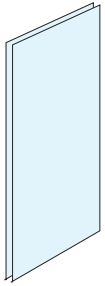


Glazing

Single



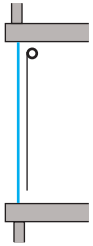
Double



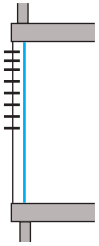
Shading

No

Internal

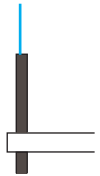


Extrenal

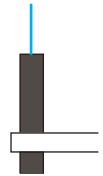


Thermal

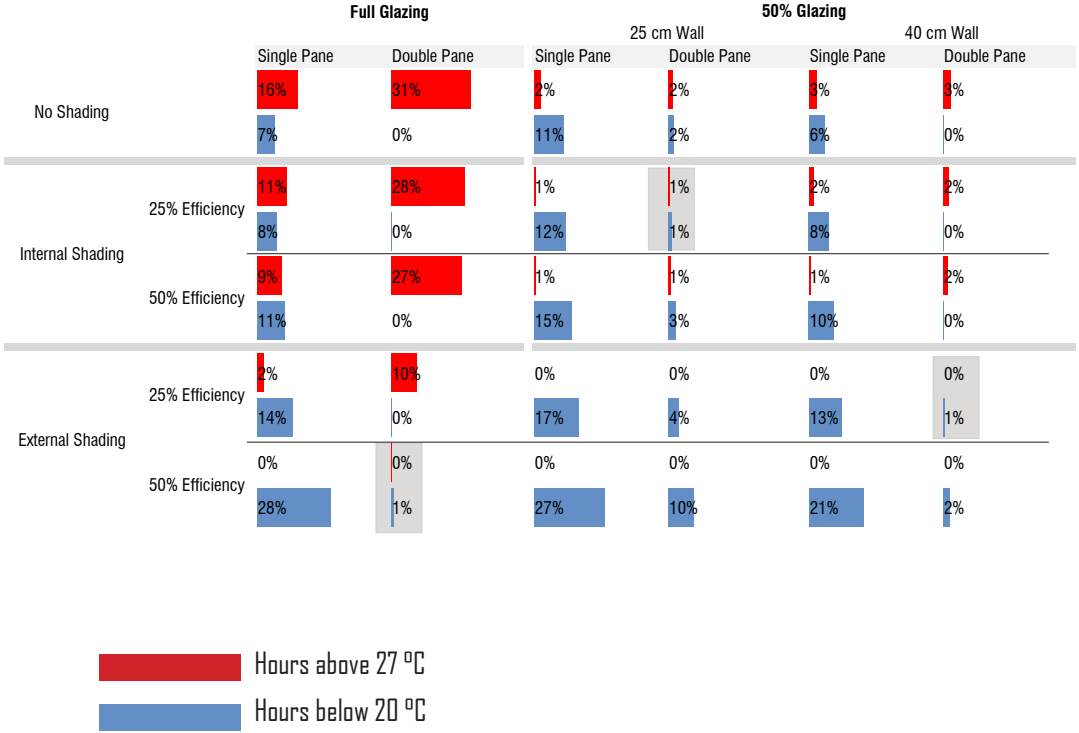
20 cm Wall



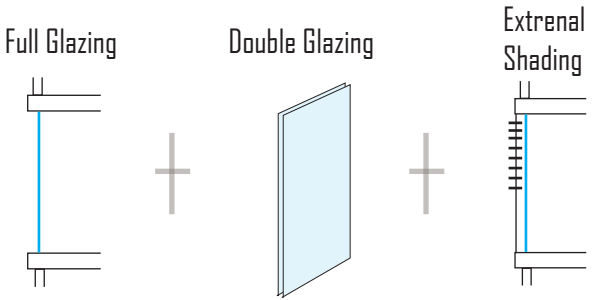
40 cm Wall

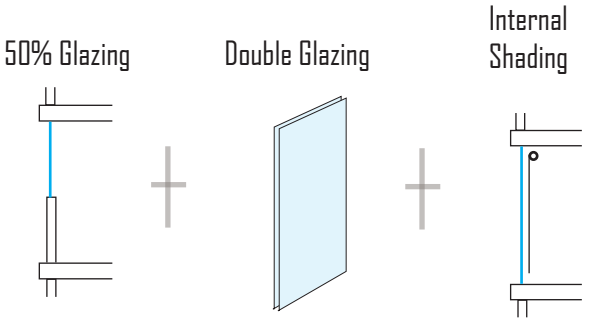


South

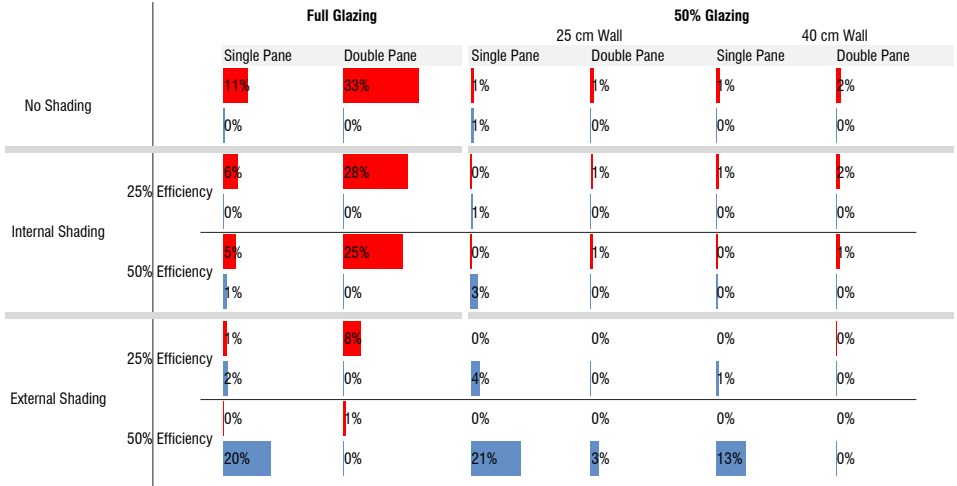


Good Comfort

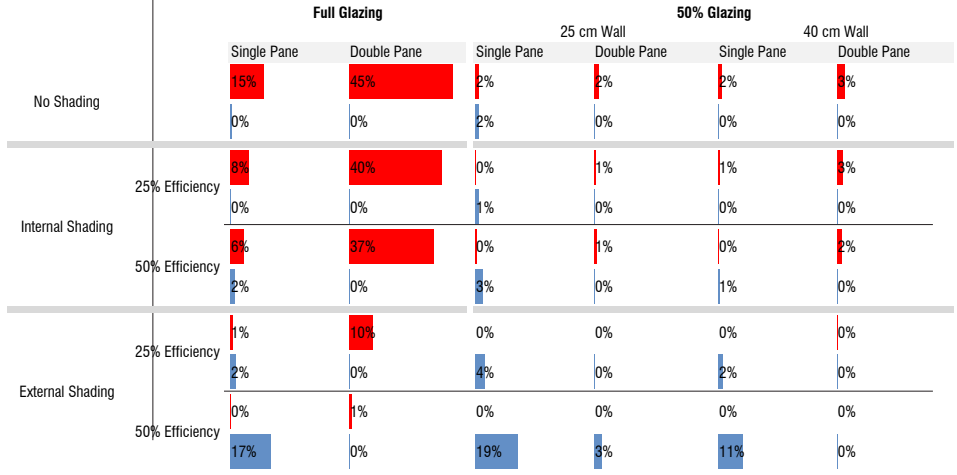




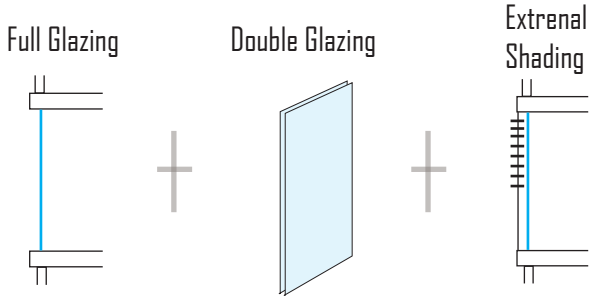
West

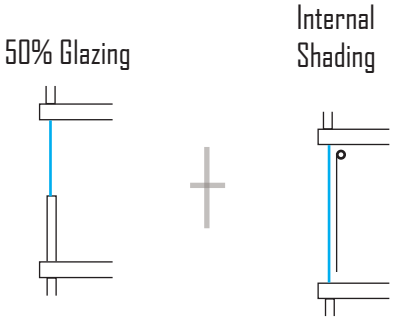


East



Good Comfort

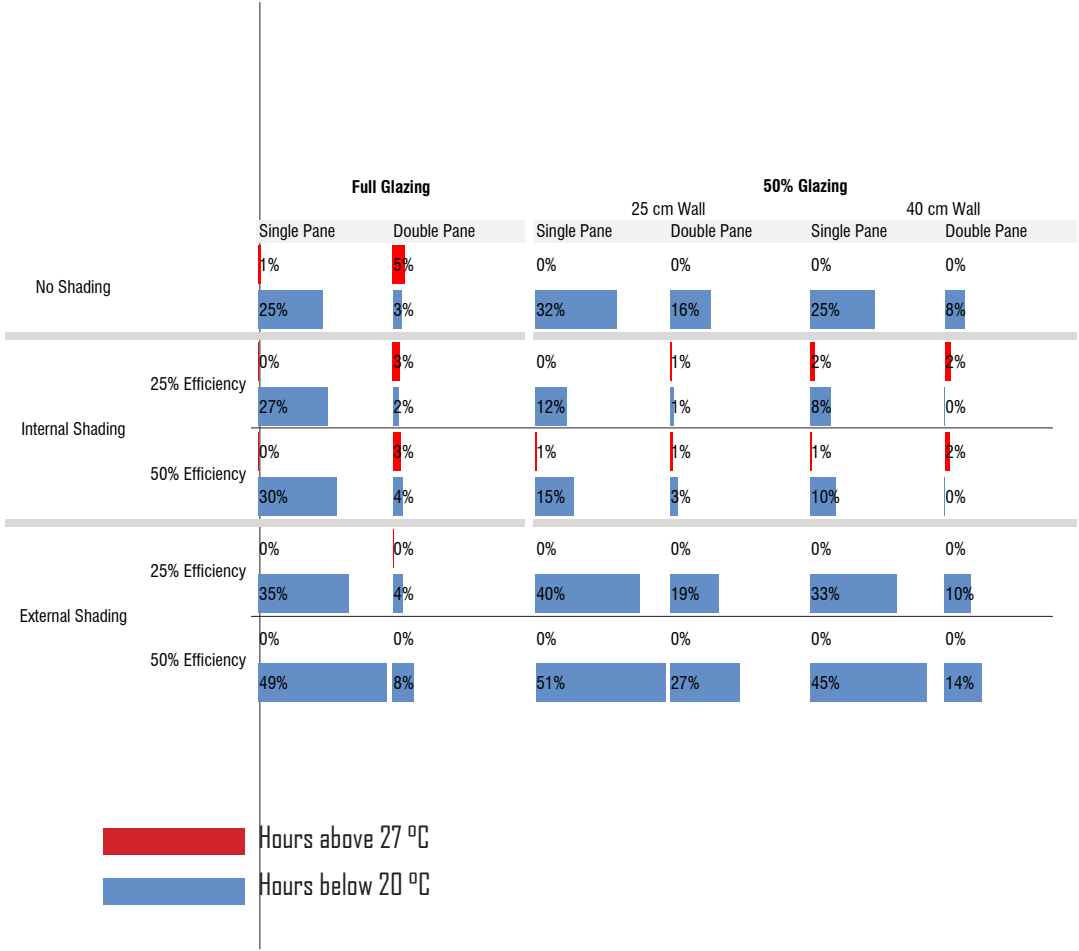




Important note: **Double pane should not be used for full glazed windows without external shading.**

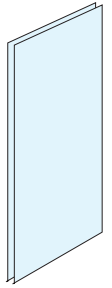
05 THERMAL COMFORT

North

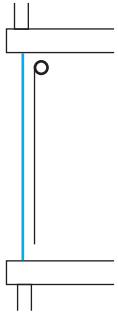


Good Comfort

Double Glazing



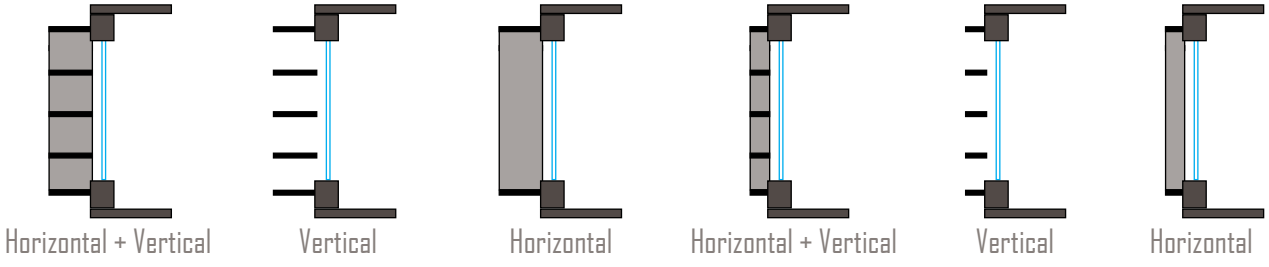
Internal Shading



Important note: **External Shading shall be reduced as much as possible.**

Facade Shading Study

Horizontal Sections of Glazed Surface



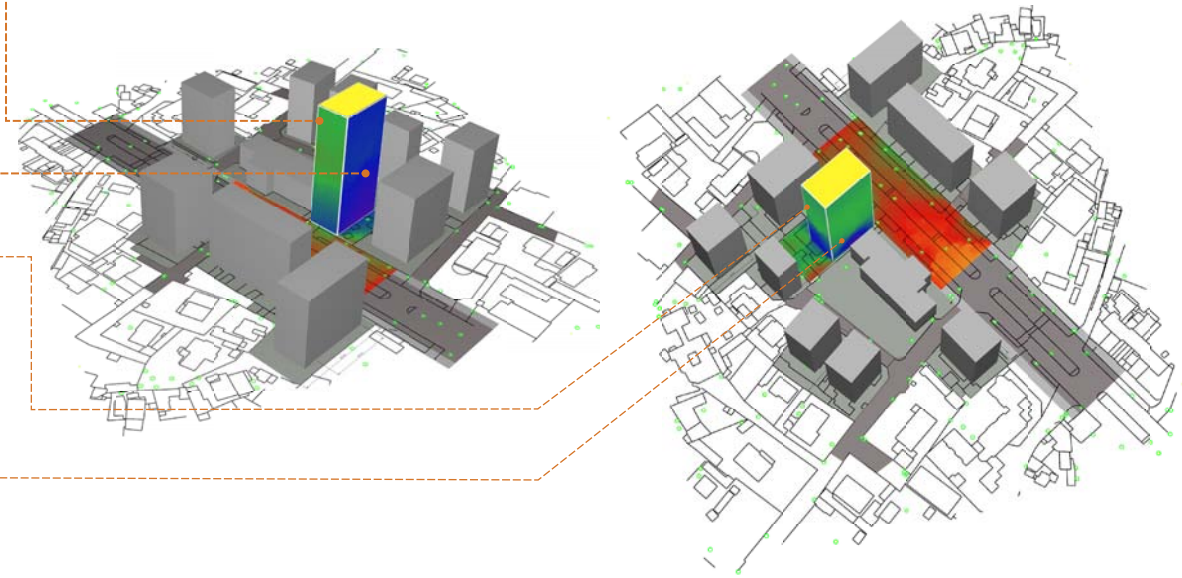
Consideration for future developement.

NE Facade

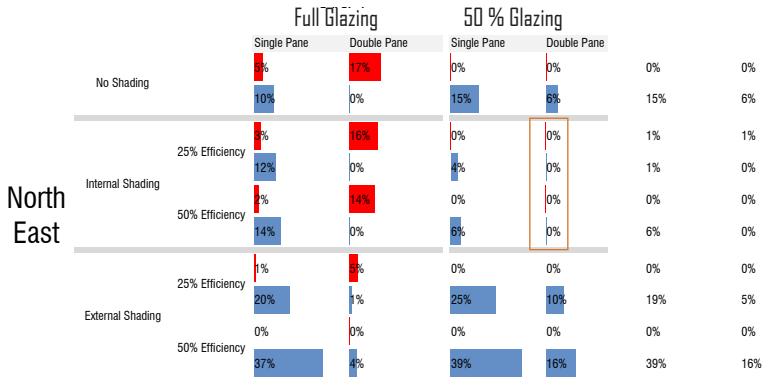
SE Facade

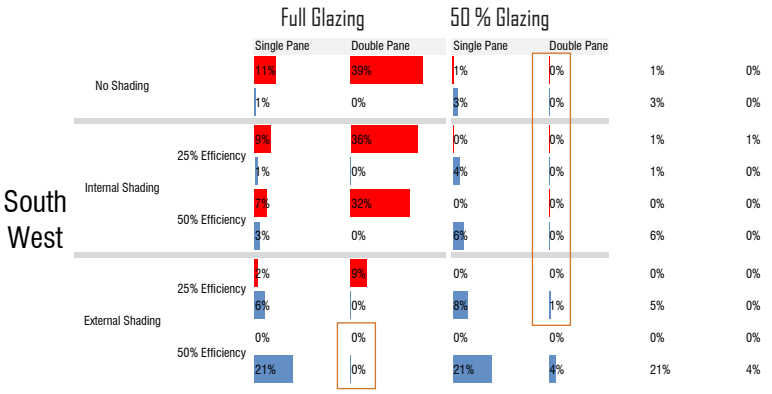
SW Facade

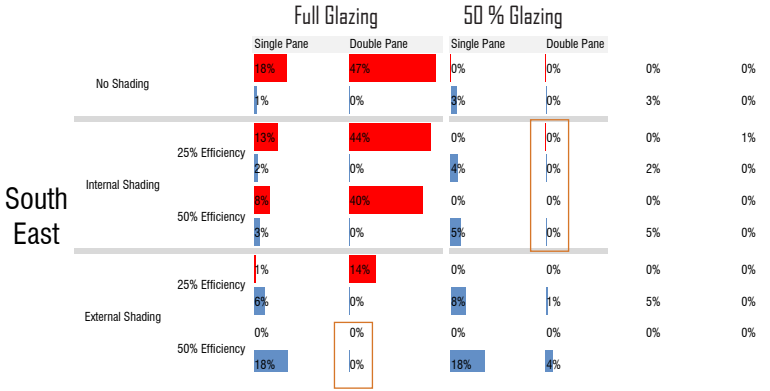
NW Facade

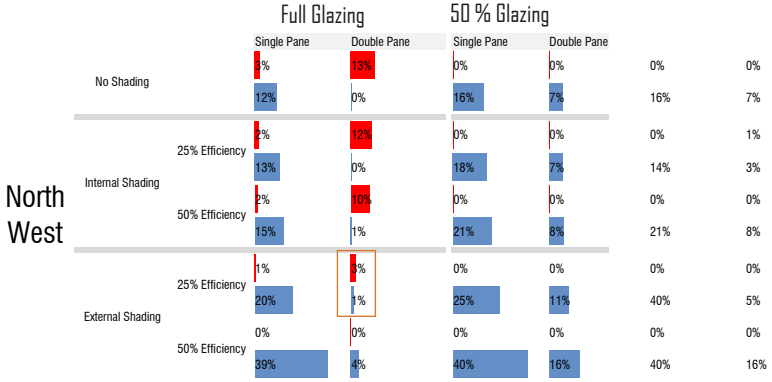


05 THERMAL COMFORT







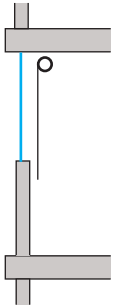


Hours above 27 °C

Hours below 20 °C

05 THERMAL COMFORT

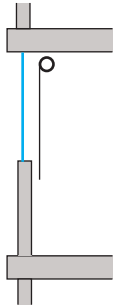
NORTH EAST



50% Glazing

Internal Shading

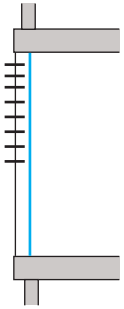
NORTH WEST



50% Glazing

Internal Shading

SOUTH EAST

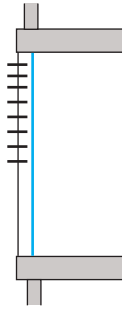


Full Glazing

Extrenal Shading

50 % Efficient

SOUTH WEST



Full Glazing

Extrenal Shading

25 % Efficient

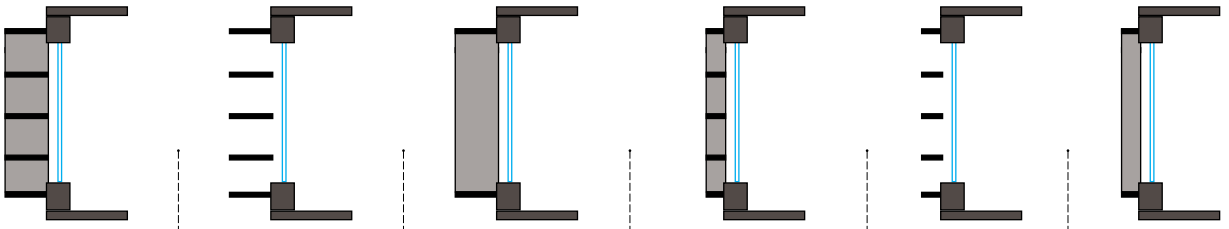
Facade Shading Study

Shading:

Visual Comfort

- Good illumination
- Glare protection

Thermal Comfort



	Horizontal + Vertical	Vertical	Horizontal	Horizontal + Vertical	Vertical	Horizontal
NE Facade	312 kWh/m2 59.3%	583 kWh/m2 24.0%	396 kWh/m2 48.4%	439 kWh/m2 42.8%	705 kWh/m2 8.1%	475 kWh/m2 38.1%
SE Facade	297 kWh/m2 66.1%	633 kWh/m2 27.8%	394 kWh/m2 55.1%	436 kWh/m2 50.3%	812 kWh/m2 7.4%	492 kWh/m2 43.9%
SW Facade	305 kWh/m2 65.9%	736 kWh/m2 17.7%	598 kWh/m2 33.1%	491 kWh/m2 44.0%	856 kWh/m2 2.4%	571 kWh/m2 34.9%
NW Facade	385 kWh/m2 45.5%	417 kWh/m2 19.3%	522 kWh/m2 12.2%	383 kWh/m2 25.9%	478 kWh/m2 7.5%	454 kWh/m2 1.3%

--- kWh/m2 Annual Radiation on Glazing

-----% Facade Shading Efficiency

Gaps are observed between the **actual climatic and environmental context** of the Addis Ababa and **current building codes and regulations** in both **urban and building scale.**

Improvements shall be considered by exhaustively investigating:

- Climatic Context
- Outdoor Comfort
- Natural Daylighting
- Natural Ventilation
- Thermal Comfort

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"Ameseginalehu"