

NATURAL VENTILATION IN HIGH RISE RESIDENTIAL BUILDING

A Thesis

Submitted in partial fulfillment of the requirements for the award
of
Master of Architecture degree in Sustainable Architecture

by

RUDHRAA SHREE S.K (40890013)



**DEPARTMENT OF ARCHITECTURE
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAACJEPPIAAR
NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

MAY 2022



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited with Grade "A" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

www.sathyabama.ac.in



DEPARTMENT OF ARCHITECTURE BONAFIDE CERTIFICATE

This is to certify that this Report is the bonafide work of **RUDHRAA SHREE S.K (40890013)** who carried out the Thesis entitled "**NATURAL VENTILATION IN HIGH RISE BUILDING**" under our supervision from January 2022 to May 2022.

Internal guide
(Ar.CATHERINE)

INTERNAL PANEL MEMBER
(Ar. SHEETAL AMRAOTKAR)

External guide
(Ar.BALAMURUGAN)

DR. DEVYANI GANGOPADHYAY
Dean, School of Building and Environment
Head of Department

Submitted for Viva voce Examination held on 06-05-2022

Internal Examiner

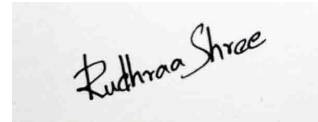
External Examiner

DECLARATION

I **RUDHRAA SHREE S.K** hereby declare that the Thesis Report entitled “**NATURAL VENTILATION IN HIGH RISE BUILDING**” is done by me under the guidance of **AR.CATHERINE** (Internal) and **AR.BALAMURUGAN** (External) at Sathyabama Institute of Science and Technology is submitted in partial fulfillment of the requirements for the award of Master of Architecture degree in Sustainable Architecture

DATE:

PLACE:

A rectangular box containing a handwritten signature in black ink. The signature is written in a cursive style and reads "Rudhraa Shree".

SIGNATURE OF THE CANDIDATE

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to the Board of Management of **SATHYABAMA** for their kind encouragement in doing this Pre-Thesis project and for completing it successfully. I am grateful to them.

I convey my thanks to **Dr. Devyani Gangopadhyay, Dean and Head of the department, Dept. of Architecture, School of Building and Environment**, for providing me necessary support and details at the right time during the progressive reviews.

My special thanks to **Dr. Suresh Kuppusamy**, our Design chair and **Ar.Balamurugan**, (External guide) and **Ar. Sheetal Amraotkar** (Thesis Coordinator) for their valuable comments and guidance during the project work.

I would like to express my sincere and deep sense of gratitude to my Project Guide **Ar. Catherine** for her valuable guidance, suggestions and constant encouragement which paved the way for the successful completion of my project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Architecture who were helpful in many ways for the completion of this Thesis.

ABSTRACT

Natural ventilation is a traditional but effective way in buildings to adjust the indoor environment. It has also been proved to be effective in today's design, if applied appropriately. At the same time, there is a growing trend that higher and higher buildings are constructed in the crowded city area. Air velocity, temperature and other factors have already been found to change with height, and the difference in thermal comfort can also affect the architectural design. Therefore, we do need to know the thermal comfort distribution in high rise buildings. The aim of this thesis is to investigate the thermal comfort distribution in a naturally ventilated high rise residential building, and find out if the suitable solutions can be implemented to improve it.

TABLE OF CONTENTS

CHAPTER No.	TITLE	PAGE No.
	ABSTRACT	v
	LIST OF TABLES	xii
	LIST OF FIGURES	xiii

TABLE OF CONTENTS

CHAPTER No.	TITLE	PAGE No.
	ABSTRACT	v
	LIST OF TABLES	xii
	LIST OF FIGURES	xiii
1	INTRODUCTION	1
	INTRODUCTION	1
	AIM 1	
	RESEARCH QUESTIONS	2
	OBJECTIVE	2
	NEED FOR THE STUDY	2
	SCOPE AND LIMITATIONS FOR THE STUDY	2
2	LITERATURE REVIEW	3
	INTRODUCTION	3

NATURAL VENTILATION	3
NEED FOR NATURAL VENTILATION	3
VENTILATION FUNCTION & EQUIPMENT	4
BENEFITS OF NATURAL VENTILATION	5
3 LITERATURE STUDY	6
INTRODUCTION	6
NATURAL VENTILATION STRATEGIES	6
The Physical mechanism in tall building	6
Wind induced ventilation	6
Buoyancy induced ventilation	7
The combined effect of wind and thermal force	7
NATURAL VENTILATION PRINCIPLES	7
Single sided ventilation	8
Cross ventilation	8
Stack ventilation	8
DESIGN FACTOR AFFECTING NATURAL VENTILATION	8
Built form & orientation	8
Window opening orientation	9
Window size	9
Effect of verandahs, balconies, terrace garden	9
Relationship of the building to the ground	9

4	CASE STUDIES	10
	KANCHANJUNGA APARTMENT	10
	VERTICAL COURTYARD APARTMENT	14
	INTERLACE – SINGAPORE	16
	ISHATVAM 9	22
	SKY HABITAT	26
	COMPARATIVE ANALYSIS	28
	RESEARCH ANALYSIS	29
5	SITE STUDY AND ZONING	34
6	ANALYSIS AND RESILT	42
	REFERENCES	51
	APPENDICES	52

LIST OF TABLES

TABLE No.	TITLE	PAGE No.
-----------	-------	----------

LIST OF FIGURES

FIGURE No.	TITLE	PAGE No.
4.1.1	Organization of space & natural sources	10
4.1.2	Kanchenjunga section	11
4.1.3	Concepts of stacking units	11
4.1.4	Floor plan	12
4.1.5	Elevation	12
4.1.6	Units	13
4.1.7	Floor plate	13
4.2.1	Master plan	14
4.2.2	Section	14
4.2.3	Section of courtyard	15
4.2.4	Floor plan of vertical courtyard	15
4.3.1	Interlace Singapore – Master plan	16
4.3.2	Interlace – design concept	16
4.3.4	DESIGN FEATURE & FLOOR PLAN	17
4.3.5	Sustainable features – Interlace	19

LIST OF SYMBOLS AND ABBREVIATIONS

UDI	-	Useful daylight Illuminance
DF	-	Daylight factor
Lux	-	Unit of illumination
ADF	-	Average daylighting factor
DA	-	Daylight autonomy

CHAPTER 1

INTRODUCTION

INTRODUCTION

High rise building is a growing trend in many big cities all over the world, especially in Asia. In 2014, 3 high rise buildings more than 200m were built in Europe and the trend will keep growing. Though lots of high rise buildings spring up in the world every year, most of them are very similar in the huge amount of energy consumption and little access to nature.

Due to the high wind velocity at high altitude, mechanical ventilation systems are usually applied in most high rise buildings. Though mechanical systems can provide an acceptable temperature and humidity during most of the time, they do not guarantee a good indoor environment. According to research by Seppanen, the prevalence of the Sick Building Syndrome (SBS) in mechanically ventilated buildings is typically higher by roughly 30% to 200% than in naturally ventilated ones

Comfort is also an important issue in residential buildings. More than 40% of the users of high rise buildings want to have an operable window to permit fresh air or some other access to the outside . A naturally ventilated building can largely increase satisfaction and provide a healthier indoor environment, which is also related to productivity. Residents in a naturally ventilated building tend to work more efficiently than those who work in a mechanically ventilated building . Although productivity for residential buildings is less important than for office buildings, it is likely that the users will appreciate the contact with the external climate, which could increase the value of the property.

Energy is another main issue when choosing between natural ventilation and mechanical systems. Based on related research, natural ventilation systems can help to reduce around 40% of the energy consumption in residential buildings, compared with mechanically ventilated ones. Natural ventilation can be a very effective way to improve the thermal comfort level and decrease energy consumption. However, we still need to do more research about the thermal comfort in high rise buildings, before we can really make “climate design”.

Aim

To design a High-Rise residence, with adequate natural ventilation in a warm and humid climate.

Research question

- What are natural ventilation strategy need to address in high-rise residential building

- What are design factors affecting the natural ventilation in warm and humid climates?
- How do wind can induced natural ventilation be utilized in high-rise residential building.
- What are the building design parameters which affect the natural ventilation in High rise residential buildings ?
- What are the ventilation standards & requirements for high rise residential buildings according to NBC.

Objective

- To understand the natural ventilation strategy adopted from the case study, which enhance design guidelines for High-rise Residential building.
- To identify the parameter, which determines whether a high-rise residential building entirely depends on natural ventilation based on warm and humid climate.
- To evaluate the impact of natural ventilation in high-rise residential buildings in warm and humid climates.

Need for natural ventilation

- Natural ventilation has emerged as the cost effective and energy efficient approach to provide a healthy indoor environment in recent times as compared to high-cost and energy consuming mechanical and manageable as compared to mechanical ventilation.
- Natural ventilation includes many ways in which external air can be used for occupant's benefits of building. It can be used to enhance the comfort level of occupants for a healthy atmosphere and even for building cooling. All these can be achieved from air change, air movement, airflow rate, and wind velocity. Same as ventilation has two needs, to increase the level of thermal comfort and removal of moisture and contaminated air. Reasonable organization of natural ventilation is both energy and cost effective.
- Energy consumption can be reduced by almost 50%, if air conditioning is replaced by natural ventilation as well as it also reduces the emission of carbon dioxide and other harmful gasses in mechanical ventilation systems. Meanwhile, it decreases the dependency of that equipment, which is used by mechanical ventilation and air conditioning to ensure a healthy building environment. High rise buildings have much longer organization of natural ventilation in high rise buildings and are more difficult and challenging.

1.5 Limitation

The Study focuses on ventilation in high rise apartment in warm and humid climate

CHAPTER 2

LITERATURE STUDY

Introduction

The process of replacing air in one place to provide the same but with better quality. However for architects the word air includes moisture, odor, smoke, dust and so on. Ventilation neither means the supply of oxygen nor to get rid of carbon dioxide to the occupants in the building. The two primary reasons for ventilation of occupied spaces in buildings are to provide acceptable IAQ and based on supply of fresh air and removal of indoor pollution concentration and to provide thermal comfort to the occupants in the building.

“Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment”

When the term ventilation is used for a building then there are two options for the same. One is natural ventilation and the other is mechanical ventilation. If we peep into the history of architecture, we will never find the presence of mechanical systems for the purpose of ventilation in historic buildings.

Natural ventilation, unlike the fan forced ventilation, uses natural forces of wind and buoyancy to deliver fresh air into the building.

NATURAL VENTILATION

Natural ventilation is the international flow of outdoor air through an enclosure under the influence of wind and thermal pressure through controlled openings. It can effectively control both temperature and contaminants, particularly in mild climates. Temperature control by natural ventilation is often the only means of providing cooling when mechanical air conditioning is not available.

The arrangement, location, and control of ventilation is driven by pressure difference across the openings caused by ambient pressure and temperature difference between different openings within a unit.

Need for natural ventilation

Natural ventilation has emerged as the cost effective and energy efficient approach to provide a healthy indoor environment in recent times as compared to high-cost and energy consuming mechanical and manageable as compared to mechanical ventilation.

Natural ventilation includes many ways in which external air can be used for occupant's benefits of building. It can be used to enhance the comfort level of occupants for a healthy atmosphere and even for building cooling. All these can be achieved from air change, air movement, airflow rate, and wind velocity. Same as ventilation has two needs, to increase the level of thermal comfort and removal of moisture and contaminated air. Reasonable organization of natural ventilation is both energy and cost effective.

Energy consumption can be reduced by almost 50%, if air conditioning is replaced by natural ventilation as well as it also reduces the emission of carbon dioxide and other harmful gasses in mechanical ventilation systems. Meanwhile, it decreases the dependency of that equipment, which is used by mechanical ventilation and air conditioning to ensure a healthy building environment. High rise buildings have much longer organization of natural ventilation in high rise buildings and are more difficult and challenging.

Ventilation function and equipments

Ventilation serves three distinct function such as:

Health ventilation in all climatic conditions maintains the quality of the indoor air above a certain minimum level by replacing indoor air, vitiated in the process of living and occupancy, by outdoor fresh air. It is to provide the necessary amount of oxygen for breathing, cooking etc to prevent the unduly high levels of carbon dioxide and odors

Thermal comfort ventilation is to provide thermal comfort by increasing the heat loss from the human's body and preventing discomfort due to feelings of warmth and skin wetness. High speed of indoor air movement in the occupied area would be the best solution to provide thermal comfort.

Structural cooling ventilation cools the thermal mass when the indoor temperature is above its outdoor temperature. Air has a very low heat capacity in an unventilated space; indoor air temperature attains its outdoor surrounding temperature and fluctuates about the average outdoor surface temperature

Comfortable temperature can be achieved by permanent ventilation or night ventilation.

The relative importance of each function depends on different levels of airflow through building in relation to climate.

- Maintain acceptable indoor air quality by replacing the outdoor fresh air, which is needed for every climate but it's of interest in cold climates and in air conditioning building in all climates.
- By providing a high rate of airspeed over the body, thermal comfort can be achieved by increasing convective heat loss from the body and prevents discomfort from excessively moist skin in a humid climate.
- Cooling the building mass during night through night ventilation and utilizing it as a heat sink during the following daytime in order to achieve thermal comfort, this is mostly for desert climate.

The most important and universal thing is to maintain air quality through ventilation, which depends on the number of people per unit volume in a habitable place, their lifestyle and sensitivity. So a ventilation rate of 0.5 air change per hour can be suggested as the minimum health ventilation rate for an occupied residential building.

Minimum and optimum ventilation requirements depend on type of climate and seasons. Maintenance of minimum ventilation rate is more challenging in humid climates. In hot and humid regions, the main function of ventilation is to provide thermal comfort by air movement near the body for fast sweat evaporation. Air movement can be achieved by adjusting design details and the provision should be made to get indoor air indoor air velocity of up to 2m/sec to achieve thermal comfort.

BENEFITS OF NATURAL VENTILATION

Comfortable thermal conditions for occupant and good indoor air quality are among the other advantages of a well integrated natural ventilation system apart from energy saving and positive impact on the environment. In addition, problems associated with mechanical HVAC systems like noise and health problems like sick building syndromes are unemployed, providing a healthier and more comfortable environment, which enhances the productivity of occupants.

The use of natural ventilation reduces the capital, maintenance and operational costs of mechanical

Equipment and the space requirement for them.

HVAC systems can take up to 2 to 3 intermediate floors in tall buildings to house mechanical plant equipment. Each building type requires a specific amount of fresh air to dilute the internal pollution to achieve a good indoor air quality. According to Allard, the air that is free of pollutants that cause irritation, discomfort or ill health in the occupants is optimum quality of air.

He also states that the pollution level decreases with the increase in airflow rate and at the same time the occupants' behaviors like opening and closing of windows and doors have a great impact on energy consumption in a building.

CHAPTER 3

LITERATURE STUDY

INTRODUCTION

High rise structure is generally defined as multi-story structure between 35-100 meters tall, or a building of unknown height from 12 – 39 floors. NBC defines a high-rise as all buildings 15m or above in height.

More than half of the world's 7.8 billion population live in cities and urban areas, and 2.5 billion more are expected to join them within the next 20-25 years. High-rise buildings, particularly residential ones, have proved to be beneficial in densely-populated cities where vacant plots are almost impossible to find. Natural ventilation is used as a passive strategy in high-rise buildings to provide the air quality and thermal comfort at the same time saving energy.

NATURAL VENTILATION STRATEGIES

Design for minimizing cooling requirement such as by orientation and spatial organization, use of shading devices, ventilation cooling by wind or buoyancy or both wind and buoyancy, material, color and texture, thermal mass, radiant cooling, indirect evaporative cooling such as of roof pond, roof spray and roof garden and dehumidification technique especially in humid climate are some of strategies could be used to achieve indoor thermal comfort.

The physical mechanism in tall building

Pressure difference across a building interior and exterior induce airflow through the building by wind force and thermal force.

Wind induced ventilation

Pressure differences are created across a building when wind blows against it – pressure on walls facing the wind is elevated whereas the pressure on the leeward side is reduced which induces air flow from high pressure to low pressure zone. These zones are also known as pressure zones and suction zones respectively. When wind direction is at right angles to a rectangle building, the front wall acts as a pressure zone and the sides rear act as suction zones. When the direction is oblique, two upwind sides are pressure zones and the rest are suction zones. Roof in all cases acts as a suction zone. From the center of the pressure zone the pressure diminishes outwards on the windward surfaces. For a perpendicularly blowing wind, the pressure variation across the walls is smaller as compared to a wind blowing in an oblique direction.

There is a drastic drop in pressure from windward to leeward corners in case of oblique direction. At a 45 degree incidence angle, pressure on the downward corners is almost zero whereas at a lesser angle, a suction zone develops. An air pressure variation in suction zones is greater as compared to that in the pressure zones. For instance, with a perpendicular wind, on the sidewalls, the suction is greater

upwind and at the rear wall, it reduces from center to peripheral zone. With an oblique wind the suction magnitude on the side and the roof diminishes downwind.

Buoyancy induced ventilation

Changes in average air temperature inside and outside a building create a difference in air density and vertical pressure gradients on the inside and outside of doors. If there a single aperture at a certain level in a building, air pressure on either side of its equalizes with time and there no air flow after this even though there may be thermal difference, at certain height of the building, the indoor pressure and the outdoor pressure are equal to each other, causing air stagnation known as the neutral plane.

The combined effect of wind and thermal force

The combined effect of wind and thermal forces results in the effective airflow in a building. For a given opening, the gradient is a sum of pressure differences by each force separately.

The resultant airflow is proportional to the square root of combined pressure gradients. Thus, even both the forces work in the same direction; the resultant airflow will be only slightly higher than it would be with the greater force alone.

Thermal force of ventilation is dependent on temperature gradient and height of opening, it is important only when either of these have a high value. For residential buildings the height of the ventilation path is very small so the deciding factor becomes temperature difference in interior and exterior, which is only existent in cold regions in winter whereas wind will typically be the dominating driving force on windy hot days.

The thermal force however can induce airflow only by pressure difference. If two rows of openings are placed on a wall at different heights and airflow is induced by thermal force only, air will enter through the lower set of openings and leave through the upper set of openings in case indoor temperature is higher. However in case of air flow induced force of the incoming air mass, hence can be controlled by detailed design of the inlet openings. For the same quantity of air moved, such airflow may produce velocity owing to turbulence than the one induced by thermal pressure.

Natural ventilation principles

The introduction of air into the building and the extraction of the same out of the building is a ventilation strategy. There are 3 main categories of ventilating strategies,

- Single – sided ventilation
- Cross ventilation
- Stack ventilation

Single –sided ventilation

Here only one side of the building is on one side only. This is an effective way to summer for a room of depth at least 2.5 times of the height. Wind is the main driving force in this case. If there is a significant difference between the inside and outside temperature and the openings are on heights for ventilation then buoyancy effect can also aid single-sided ventilation.

CROSS VENTILATION

This depends on flow of air between two sides of the building's envelope due to difference in pressure as air moves from windward to leeward side. Cross ventilation is effective for a room of depth, maximum five times of the height. Cross ventilation is facilitated when a room has apertures at both pressure and suction zones.

Stack ventilation

Incident wind on external wall. There is a flow of air along and parallel to the length of the wall resulting in a pressure gradient and inducing airflow from a low pressure area. This pressure difference can be used to better the ventilation condition in a room by providing two lateral windows at upwind and downwind sides as compared to a single window of the same area. However, since pressure gradients are not that significant, the resultant airflow may not be high. However, according to experiments, it was determined that by creating artificial pressure and suction zones along the external wall, ventilation conditions could be improved to a good extent in the case of rooms with a single vertical projection from the internal side.

Design factor affecting natural ventilation

In hot humid climates of lower latitude, verandahs, overhangs work well with movable horizontal louvers. However, in extremely hot low latitude climates, east and west should completely be windowless due to intense solar gain. To overcome this extreme situation, the ideas and examples for natural ventilation and passive cooling strategy should be taken from the vernacular architecture.

Built form and orientation

For ventilation, favorable conditions are not only perpendicular wind direction but when wind is incident at an angle 30 degree to 120 degree and 45 degree to 105 degree to the wall and especially if the openings in windward and leeward side can provide an effective amount of airflow into the space. Orientation of a room is the direction to which its external elevation faces and the main problem of building orientation is primarily related to long blocks.

The choice of the orientation is subjected to much consideration such as nature of climate, topography, accessible roads to the site and view in different directions. Based on climatic consideration it affects the indoor climate in two different aspects such as:

- Heating effect of solar radiation on different facades of the building.
- Ventilation problem associated with the direction of the prevailing wind with respect to its orientation

By considering these two factors the design may lead to a contradictory but finding an optimum solution for any particular situation can be possible with a proper design consideration based on microclimate condition. Airflow pattern in a room is affected by pressure distribution around the building and the inertial force of the moving air. Irrespective of window position in either windward or leeward walls, average indoor pressure always equals itself to the outdoor pressure. When windows are positioned both on windward and leeward walls airflow suffers friction and is directed towards a low pressure openings.

WINDOW OPENING ORIENTATION WITH RESPECT TO PREVAILING WIND

Contrary to the assumption that inlet window should directly face the inward wind to provide maximum indoor air flow, recent studies have demonstrated that when inlet window are positioned at an oblique angle to incoming wind more air flow and circulation occur inside the room all across as compared to a situation when the inlet window is placed directly at the wind in which case air just passes through the inlet and outlet with little or no impact on the side walls. However when it is incident at a right angle than the one where wind hits at an oblique angle.

Window Size

In a room where windows are positioned on only one wall, the size of the window will have minimal effect on the overall ventilation condition and internal air velocity as compared to a room with a window on opposite walls. Vertical location of windows, windows – position and methods of opening.

Effect of verandahs, balconies and terrace garden

- Porches, verandahs, and balconies should be placed in between rooms, especially in east & west façade
- Choice of material
- Wall
- Roof

Relationship of the building to the ground (vertical green)

In urban cities where high rise buildings are predominant, vertical landscaping can reduce the solar gain and provide indoor thermal comfort to the occupants living in higher floors. Vertical greenery systems can provide excellent thermal protection to the wall and the surface temperature of hard surfaces can be reduced up to about 15 degrees especially on east and west façade which are protected by dense trees.

CHAPTER 4 CASE STUDIES AND RESEARCH PAPER STUDY

KANCHANJUNGA APARTMENT

Architect - Charles Correa
Location - Mumbai
Climate - Warm Humid
Height - 84m
No. of Floors - 28
No. of Apartment - 32

CONTEXT

- Bombay climate and location presents a contradictory situation – East West axis affords the best views of Arabian sea and harbor and catches all sea breezes but also brings the hot afternoon sun and hard monsoon rains.
- Correa decided to use the organization of a bungalow wrapping around the main living spaces using a protective verandah.
- Variation to this is to convert them into a garden which not only protects the interior from sun and rain but also thrives on them.
- Configuration of interlocking units facing east and west.

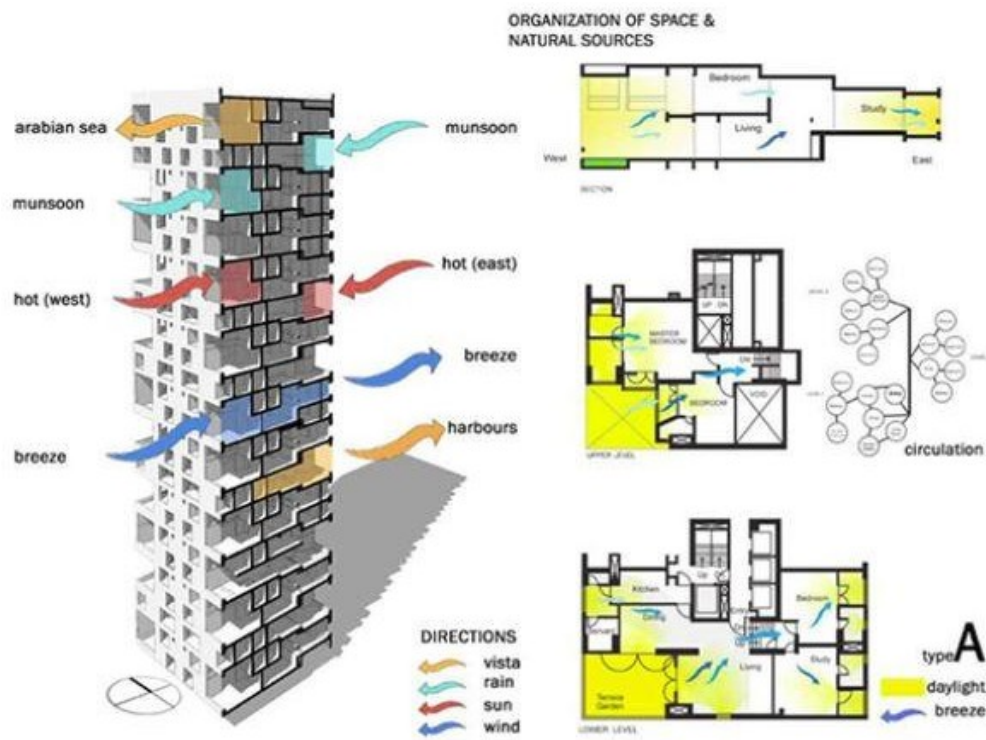


fig 4.1.1 Organization of space & natural sources

Sketches Showing the principle used for the units as a variation of the bungalow plan

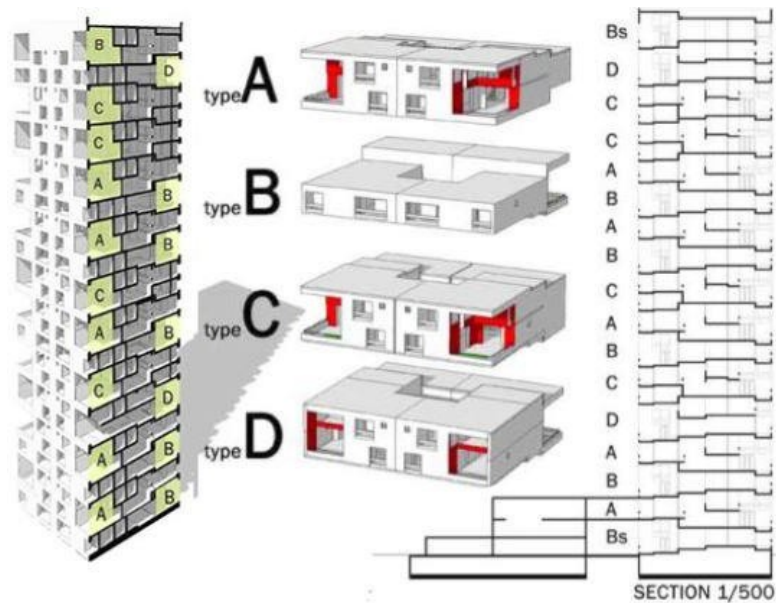


fig 4.1.2 Kanchanjunga Section

Concept of stacking units or interlocking units

Transparency

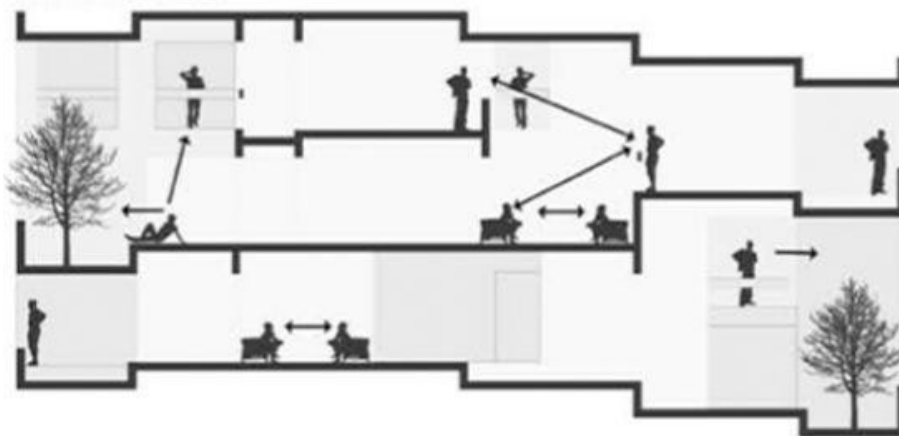


fig 4.1.3 Concepts of stacking Units

Great deal of transparency has been achieved by the use of large openings and terrace gardens on every floor.

- The garden terrace is a modern interpretation of a features of the traditional indian bungalow, the varendah wraps the main living area, whole structure is made of reinforced concrete. the building is 32 storeyed reinforced concrete structure with 6.3m cantilevered open terrace.
- the central core house lifts and other services also provided the main structural element for resisting lateral loads.
- Transparency has been achieved by the use of large opening and terrace garden on every floor. Type occur at the top and ground floor are little bit chanced because of the postion.

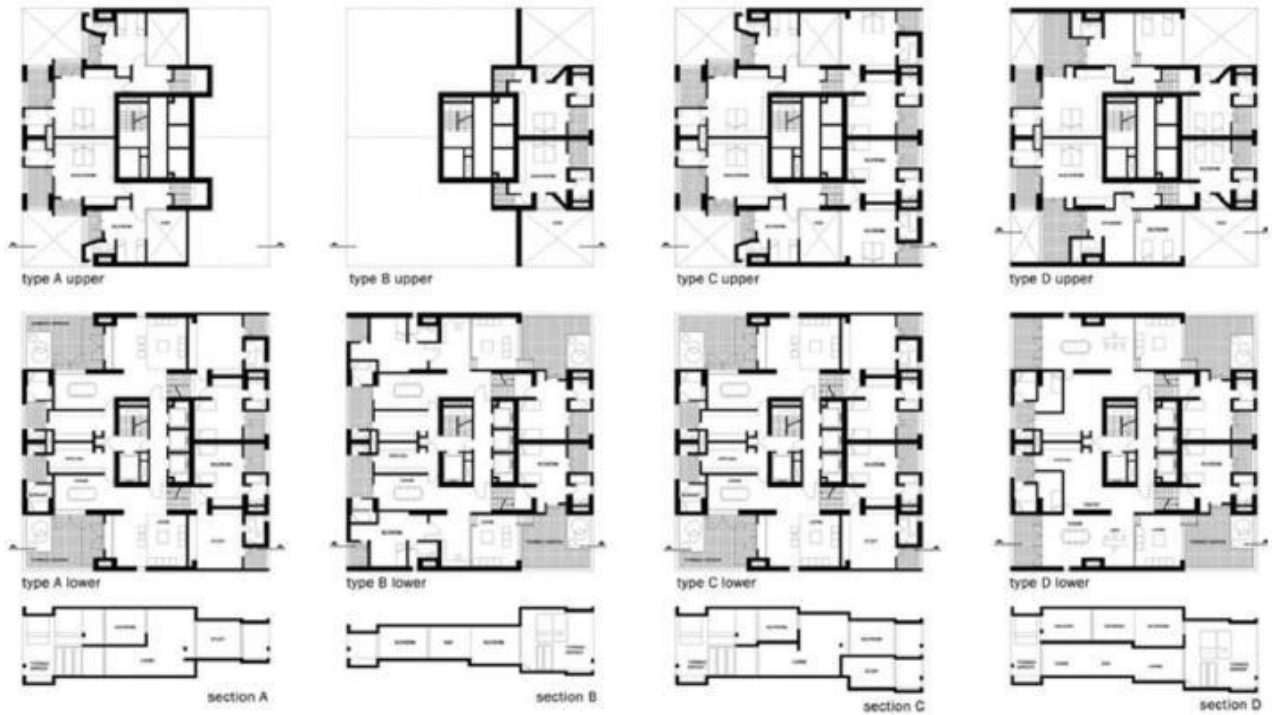


fig 4.1.4 Floor plan

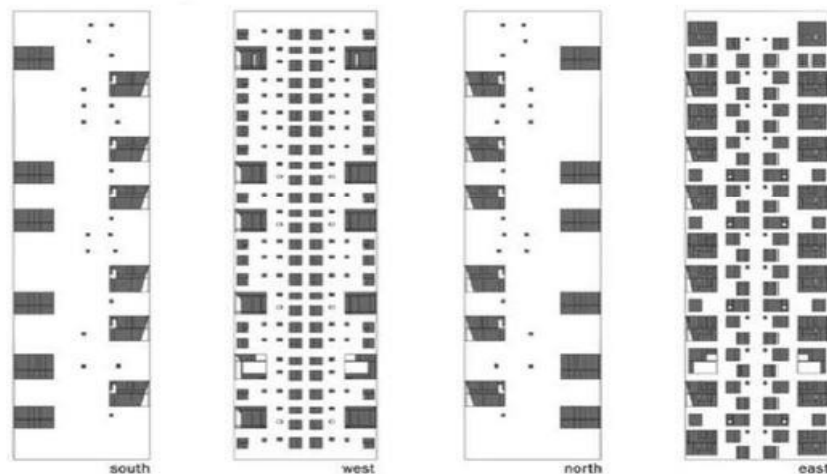


fig 4.1.5 Elevation

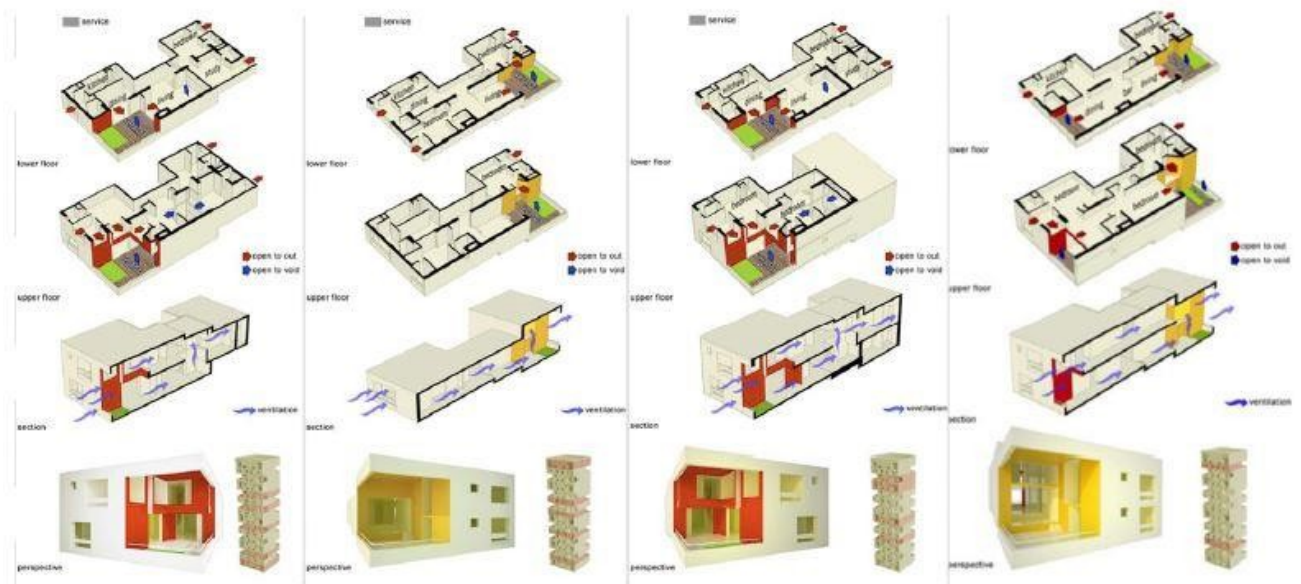


fig 4.1.6 units



fig 4.1.7 Floor plate

VERTICAL COURTYARD APARTMENT

Location - south china
Climate - Warm Humid
Height - 100m
No.of Floors - 9
No. of. Apartment - 80



fig 4.2.1 Master plan

There are six nearly one hundred meter high buildings, for eight hundred residents. Each second floor there is a double high “courtyard” in the sky. The elevation of the towers looks as if it was a vertical / horizontal turn of a traditional town in south China. Every resident, no matter on which height will have the chance to enjoy a courtyard of his own and will have the illusion of living on the second floor.

The building as set in a diagonal link across the complex, much like seats in the theatre. opposite to the side of the lake lies a large open public park.

BUILDING TYPOLOGIES

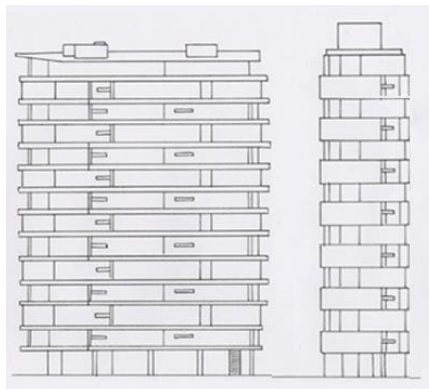


fig 4.2.2 SECTION

There are two main building typologies. one building is made up of a singular stack of units. these building are much narrower and slightly shorter than the second building type. for second type overlayed three of the smaller building to create a longer chain of building

COURTYARD

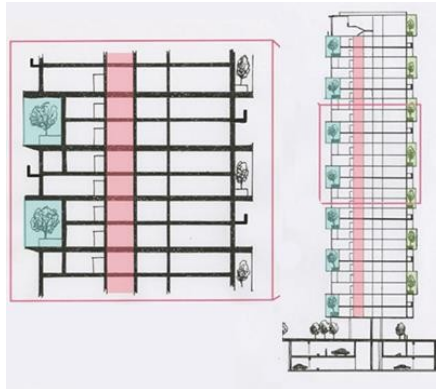


fig 4.2.3 SECTION OF COURTYARD

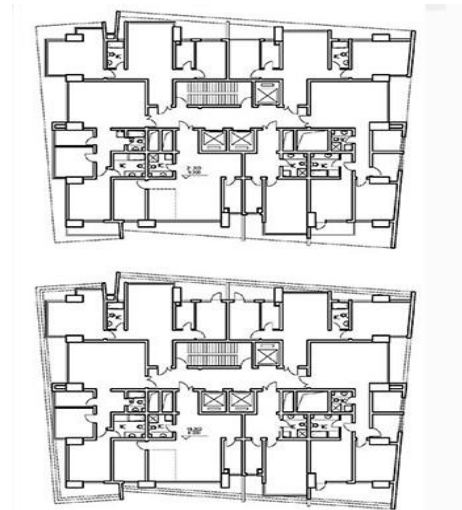
Each level of the building allow for alternating courtyard and balcony spaces. Each unit has one or other. They alternate up the entire height of the building, The extruded envelope that encapsulates the courtyard also provide coverage for the balcony spaces.

Floor plan

The shifting of planes allows for every apartment to have either a covered courtyard or balcony. The shift occurs between the floor plate of one unit and ceiling of another creating a beautiful overlapping detail within the structure.



fig 4.2.4 floor plan



INTERLACE SINGAPORE

Architect - OMA, ole scheeren

Location - Singapore

Gross Floor Area - 1169600 sq.m

Site Area - 8100 sqm

Project Year - 2013

No.of units - 1040 units, 31 apartments blocks, each six storey tall with 8 main courtyard.



fig 4.3.1 Masterplan



fig 4.3.2 views

Design Concept

- New residential typology which breaks away from the cluster of isolating towers.
- Horizontally connected volumes establishing a better connected and less isolated residential environment.
- The interlace incorporates sustainability features through careful environment analysis of sun, wind, microclimate conditions on site and integration of low impact passive energy strategies

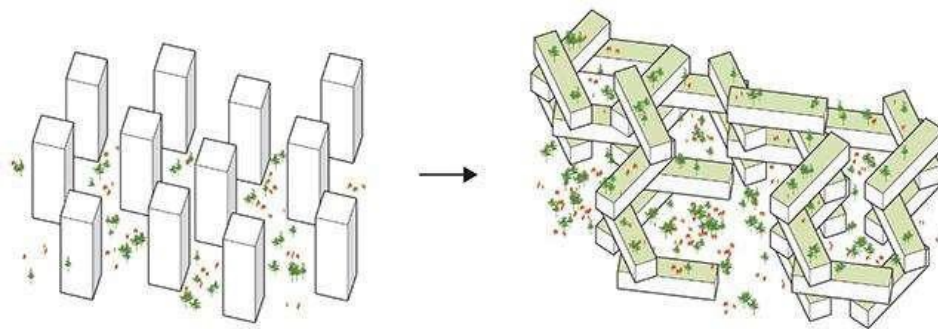


fig 4.3.3 Design concept



fig 4.3.4 Design features

Design Features

- The interlocking blocks form a vertical village with cascading sky garden and both private and public roof terrace.
- Strategic position of water bodies reduce local temperature and improved thermal comfort.
- The number of paths and pedestrian circulation is a response to location and density of residents around each courtyard and core residence.



fig 4.3.5 Floor plans

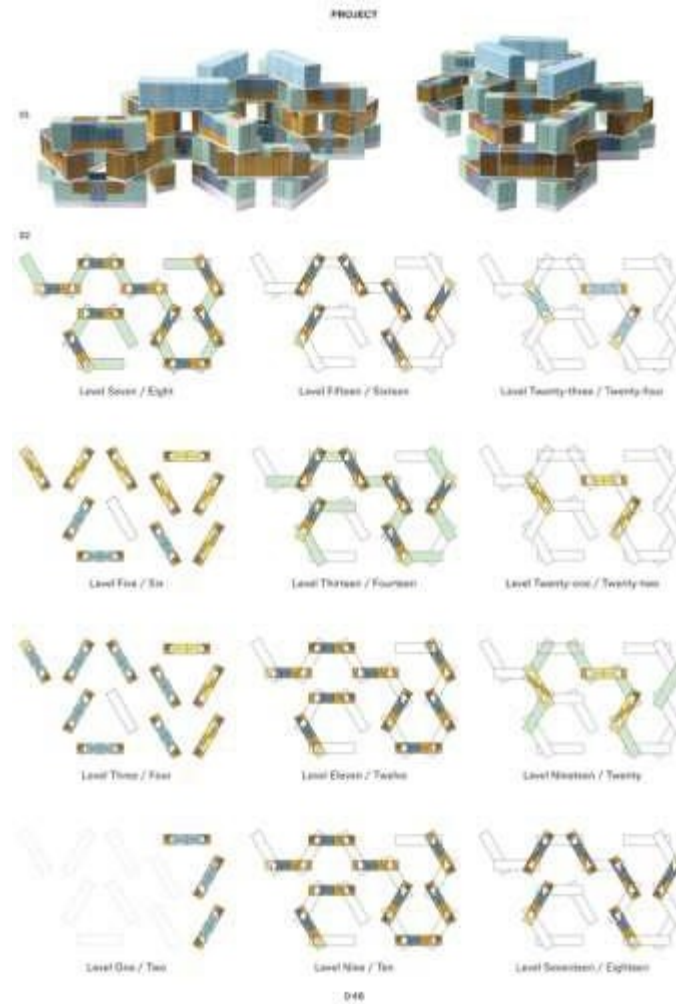


fig 4.3.6 floor plan of staggered effect

COURTYARD AND ACTIVITIES

- Each courtyard has a different character and the orienting device for the residents is not the blocks that they live in, but actually the character of the courtyard. So they navigate and locate where they are living by different courtyard.
- Pathways are designed along the building in the same hexagon grid. There are secondary pathways that are connecting two gardens/ voids through the built mass.

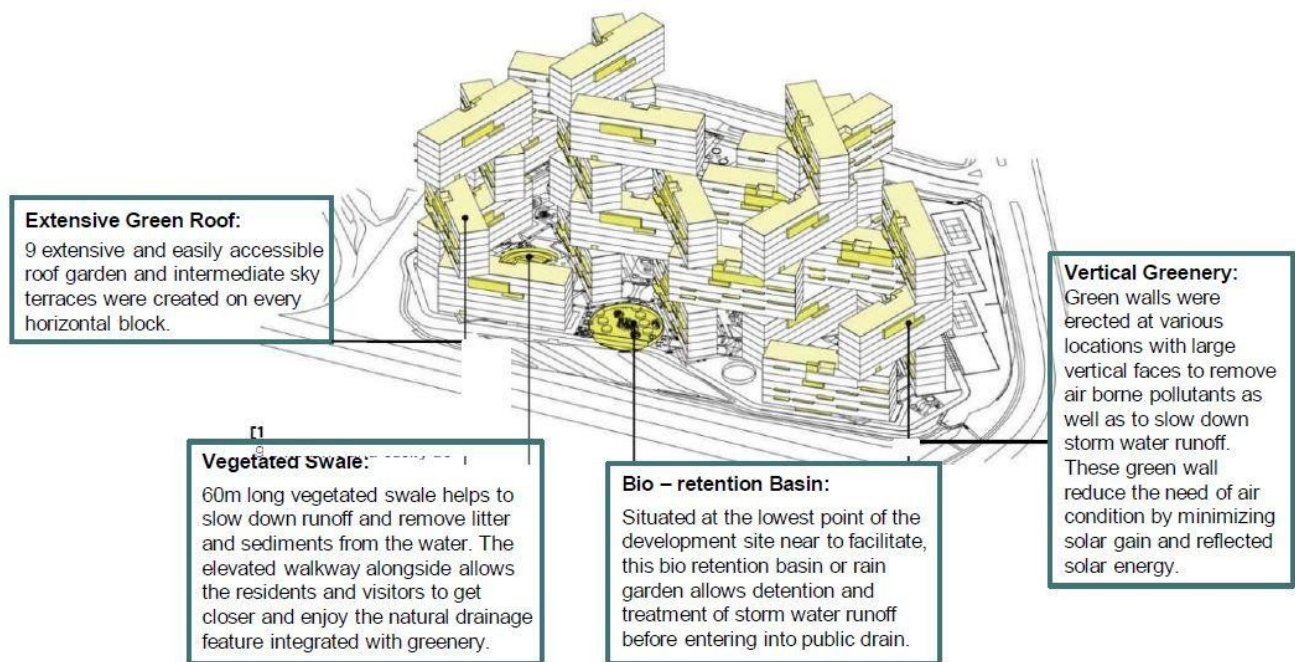


fig 4.3.7 sustainable features

Shadow analysis

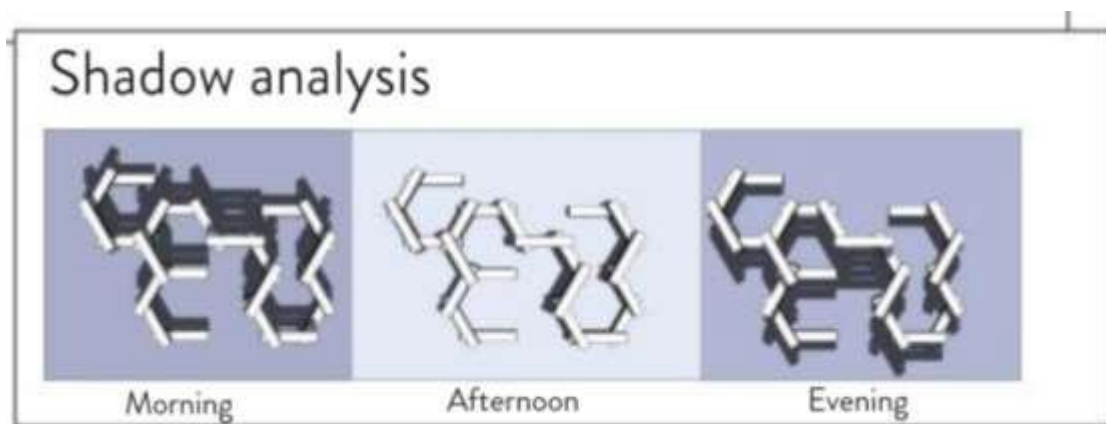
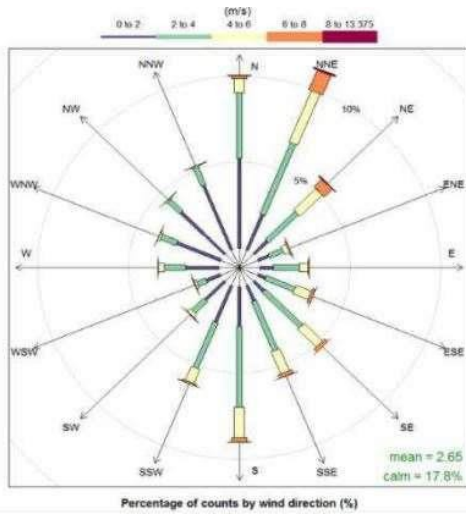


fig 4.3.8 shadow analysis

CFD analysis

The Building Construction Authority has mandated in its Green mark Standards for Residential Buildings that a minimum wind speed result of 0.6 m/s, as per CFD simulations, is required for interior and pedestrian spaces for the Green mark Platinum Building Certification



Beaufort Number	Description	Wind Speed at 1.75 m height (m/s)	Effect
0	Calm	0.0-0.1	No noticeable wind
1	Light air	0.2-1.0	Wind felt on face
2	Light breeze	1.1-2.3	Hair disturbed, clothing flaps, newspaper difficult to read
3	Gentle breeze	2.4-3.8	Raises dust and loose paper, hair disarranged
4	Moderate breeze	3.9-5.5	Force of wind felt on body, danger of stumbling when entering a windy zone
5	Fresh breeze	5.6-7.5	Umbrellas used with difficulty, hair blown straight, difficult to walk steadily, sideways wind force about equal to forwards walking force, wind noise on ears unpleasant
6	Strong breeze	7.6-9.7	Inconvenience felt when walking
7	Near gale	9.8-12.0	Generally impedes progress, great difficulty with balance in gusts
8	Gale	12.1-14.5	People blown over
9	Strong gale	14.6-17.1	

Figure 2 Beaufort Scale for effect of wind flow on humans

fig 4.3.9 Beaufort scale for effect of wind flow on humans

Impact wind flow has on people and it can be inferred that a speed of 0.2 5 m/s does not cause problems

WIND FLOW AROUND SINGLE BUILDING

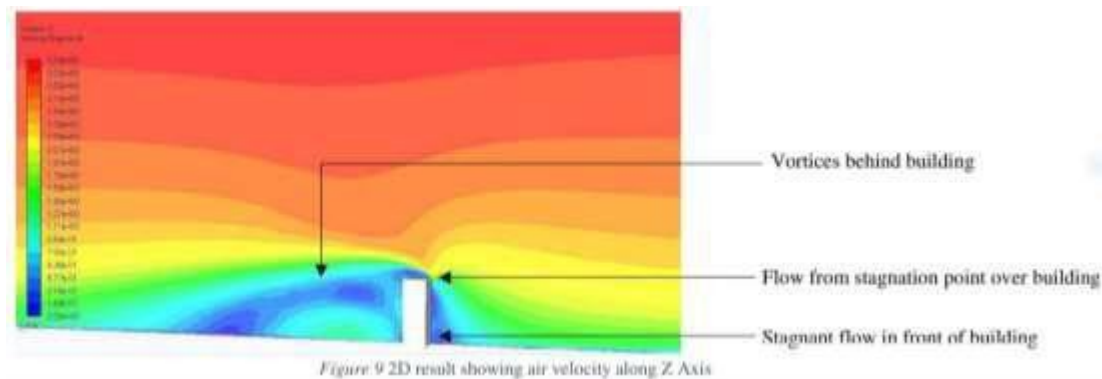


Figure 9 2D result showing air velocity along Z Axis

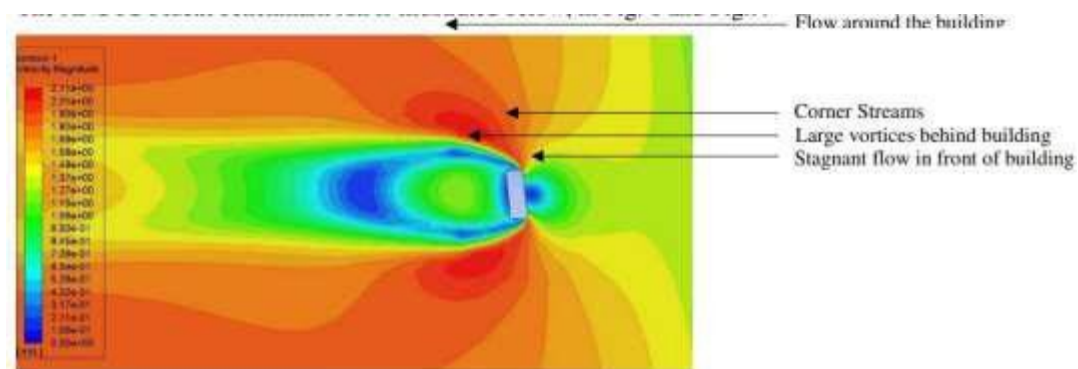


Figure 8 2D result showing air velocity along XY Plane

fig 4.3.10 Air velocity along XY Plane

Two benchmark test cases were run to understand wind flow and pattern behavior in urban spaces.

The Benchmark case studies used are

1. Wind flow over a single building
2. Venturi Effect across diverging buildings placed at 45 longitudinal faces to each other, with variation to Width/Height (w/H) factor.

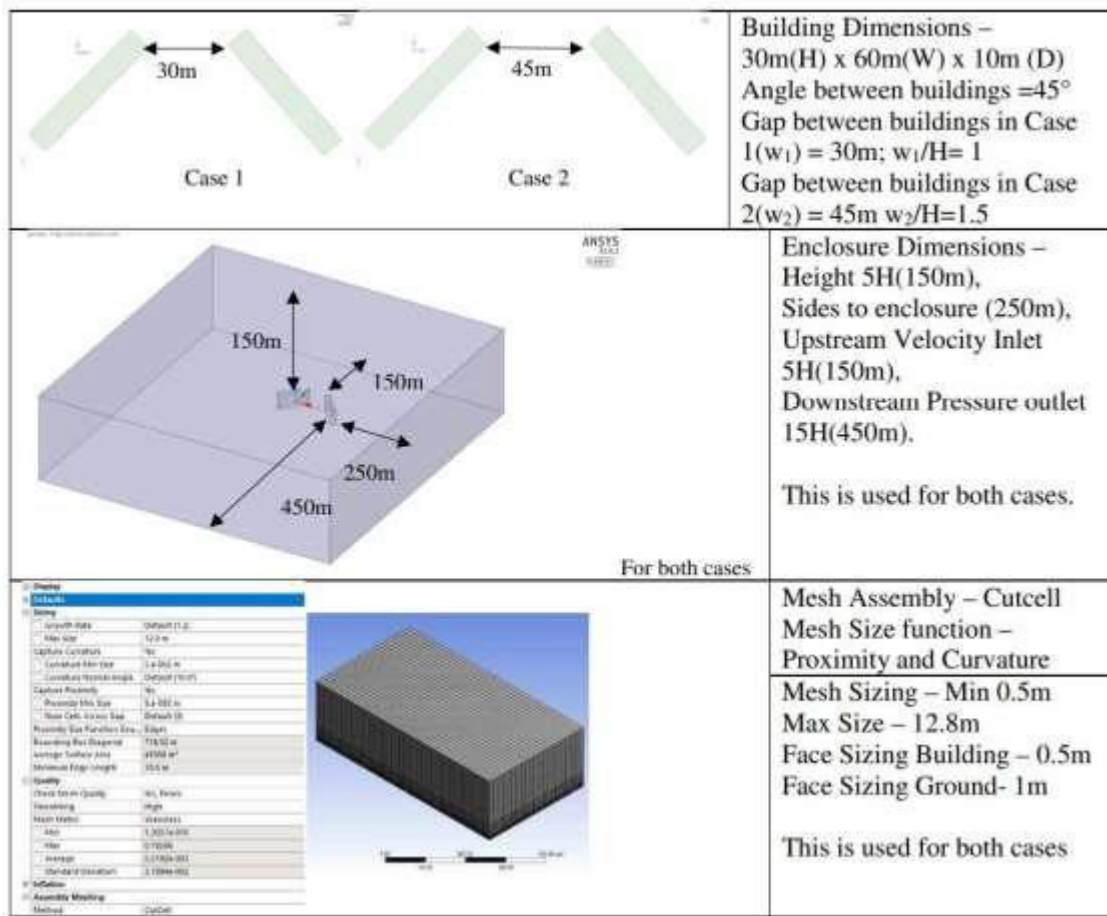


fig 4.3.11 Analysis result of CFD

Inference

Analyze the change in wind flow patterns and optimize wind flow into the targeted courtyards at pedestrian level, to make them both conform to the 0.6 m/s Green mark Standard but also not exceed 2.3m/s for strong breeze that would cause discomfort. This was not observed in the CFD analysis, but it was observed that a more even windflow exists after the changed case. A disclaimer for the large inaccuracy for these simulation studies due to limitations of software meshing quality and wind speed input. Further experiments can be done by modifying the positions further for better results.

Ishatvam 9

Architects : Sanjay Puri Architect

Location : Ranchi

Plot area : 1800 m²

Project Year : 2017

Unit types - 15 units of 4 bhk flats



fig 4.4.1 Insert Location

Design Concept

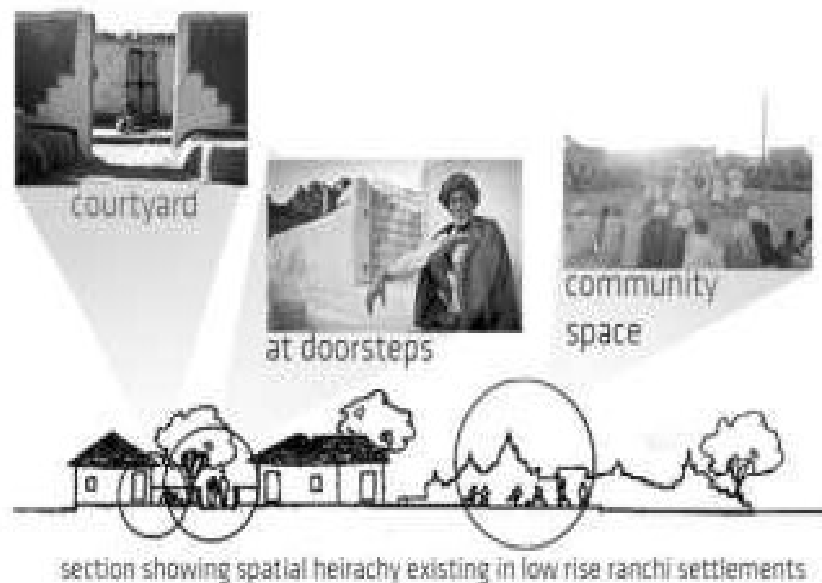


fig 4.4.2 Design concept

- Most of this city has existed with low rise development.
- The layout is done in response to the social habits of the people in the city where 3 generation are generally living together in the same house.
- City inhabitants have been used to living in individual houses with private garden

Climate analysis

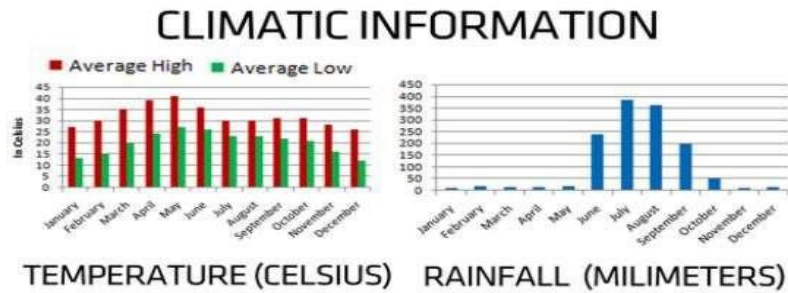


fig 4.4.3 Climatic information

- The climate in Ranchi is composite.
- Hot and dry summer followed by a humid season with monsoon rains. In winter, there is much less rainfall in Ranchi than in summer.
- Use of windows designed to deflect breezes from varying angles.
- Locating window on wall with best exposure to common cooling breezes and design for effective cross flow of air through the building Climate Responsive Open space play an important role in providing thermal
- comfort. Balconies and terrace keeps the interiors cool against the excessive heat.
- Extension of landscape spaces efficiently maximize natural light and cross ventilation.
- Directing airflow at levels suitable for activity proposed for the building.



fig 4.4.4 Master plan

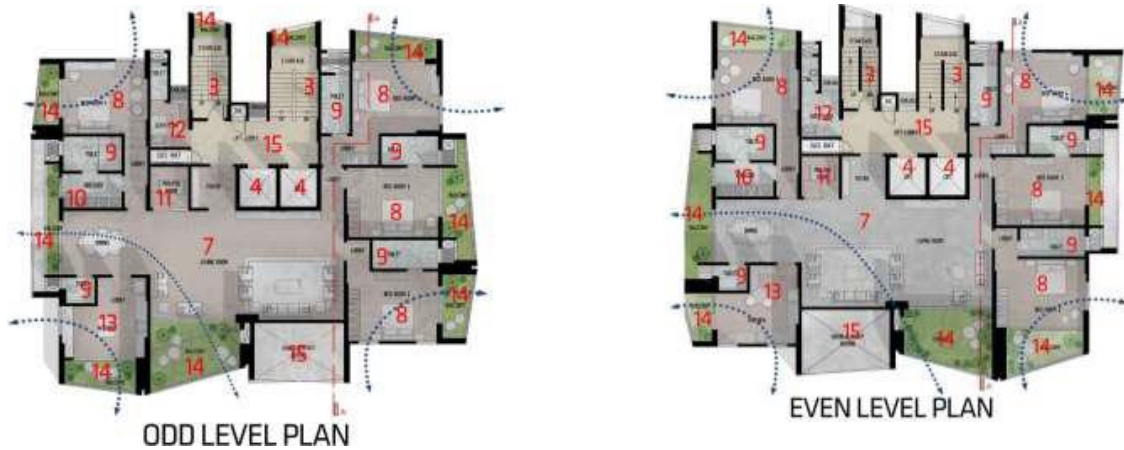


fig 4.4.5 Odd level plan & Even level plan

Floor plans

Each Balcony is partially covered and partially open to sky. This allow the user to sit in the open or in sheltered space depending upon the weather.

Design Features

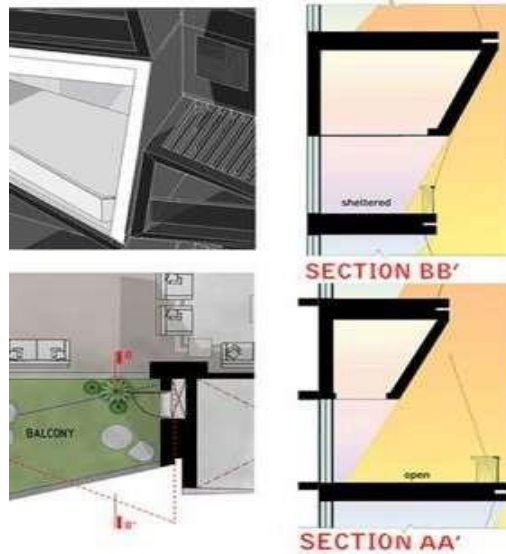


fig 4.4.6 Section of balcony

- Designed with 20 % open area as extension to internal space, maximizing on natural light and air cross ventilation to every room in the house. Each balcony is partially covered and partially open to sky.
- Double height deck and cantilevered bedrooms are carved out of bold geometries. Spayed and twisted walls allow for varying spatial character throughout these spaces

GREEN AREA ACHIEVED THROUGH TERRACING



fig 4.4.7 Green area over the space

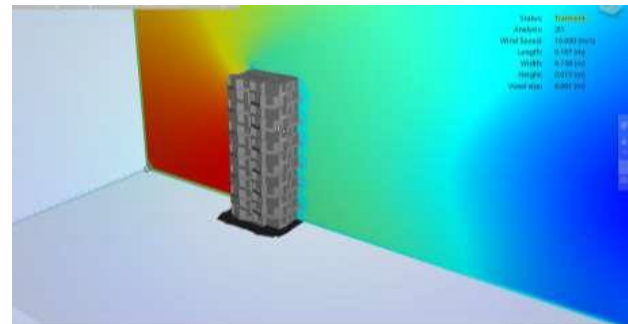
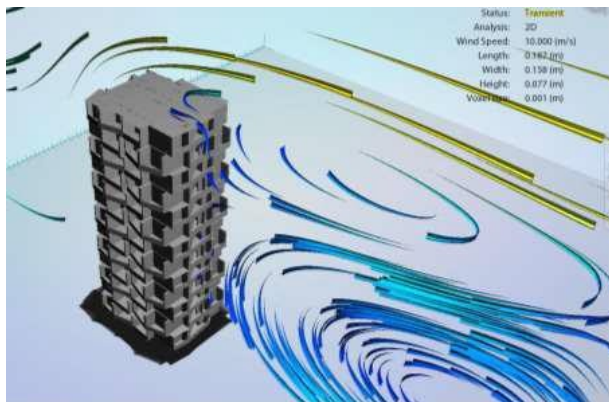


fig 4.4.8 CFD Analysis

CFD analysis

The predominant direction from south and northwest, Four side the balcony is provided and helps in cross ventilation, thermal comfort inside the room.

INFERENCE

- Pros : This modern high rise will allow its user the openness and comfort of the low rise structures they are used to. In keeping with the social pattern of life, providing good cross ventilation.
- Cons: It is designed more from an individual point of view rather than on social cause.

Sky Habitat

Completion date : 2015

Height : 133 meters

Stories : 38

Total Area: 65,000 sq.m

Type: Residential

Architects : Safdie



fig 4.5.1 Sky habitat view

- Sky habitat is a thirty eight storied residential complex Green pockets of landscape and gardens to help warm sun rays play with light.
- The overall mass is porous and open, allowing breezes to flow through and daylight to penetrate deep into the structure."

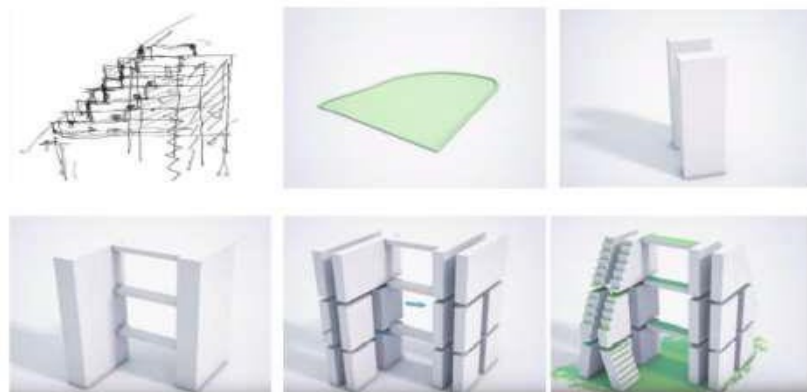


fig 4.5.2 Sky habitat concept



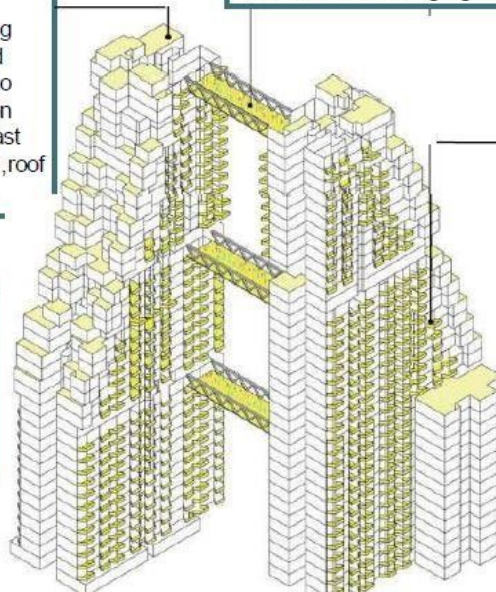
fig 4.5.3 master plan

The sky Habitat consist of several sustainable elements incorporated into its design.

Cross ventilation: In order to maximize air movement in Singapore tropical climate. The structure is highly rationalized, affording cross ventilation and multiple exposures to every unit. In addition many apartment boast individual balconies ,roof terrace and garden.

These bridges boost air-circulation and compel the daylight to penetrate deep within the spill-over spaces. Furthermore, the interconnected street-like bridges contain gardens and terraces to aid public recreation and congregation for interactions.

Multiple orientations relative to the sun, naturally ventilated units



Balcony Design: The faced design help to mitigate the tropical heat. The cantilevered 2m deep balconies play major role in shading the window and cut down on the direct solar radiation. Mounted to the face of each balcony is a custom railing screen, which serve to further shade the structure. The screen is constructed as an aluminum egg crate, providing while allowing air to flow through.

fig 4.5.4 sky habitat sustainable strategy

CFD analysis

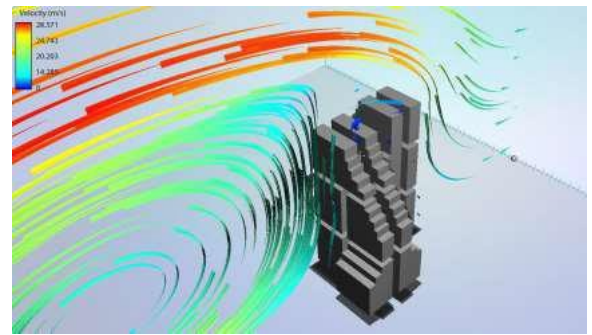
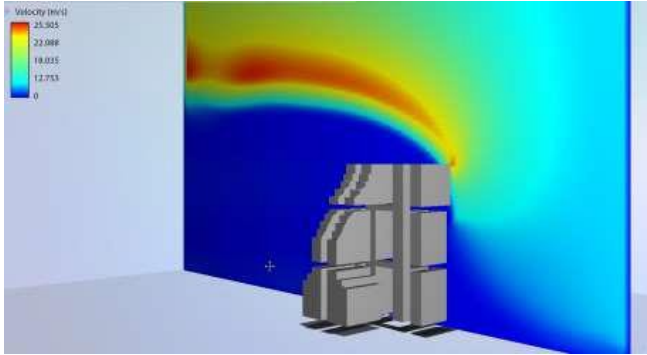


fig 4.5.5 Sky habitat CFD analysis

Inference

The wind is from North and north easterly, openings are provided in north and south side, helps in providing cross ventilation. The sky bridge is located on eastern side, by considering the wind speed, in higher floors.

Comparative analysis

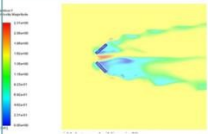
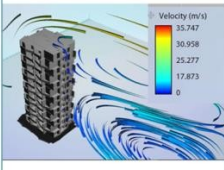
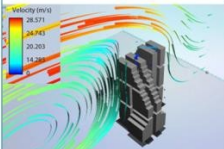
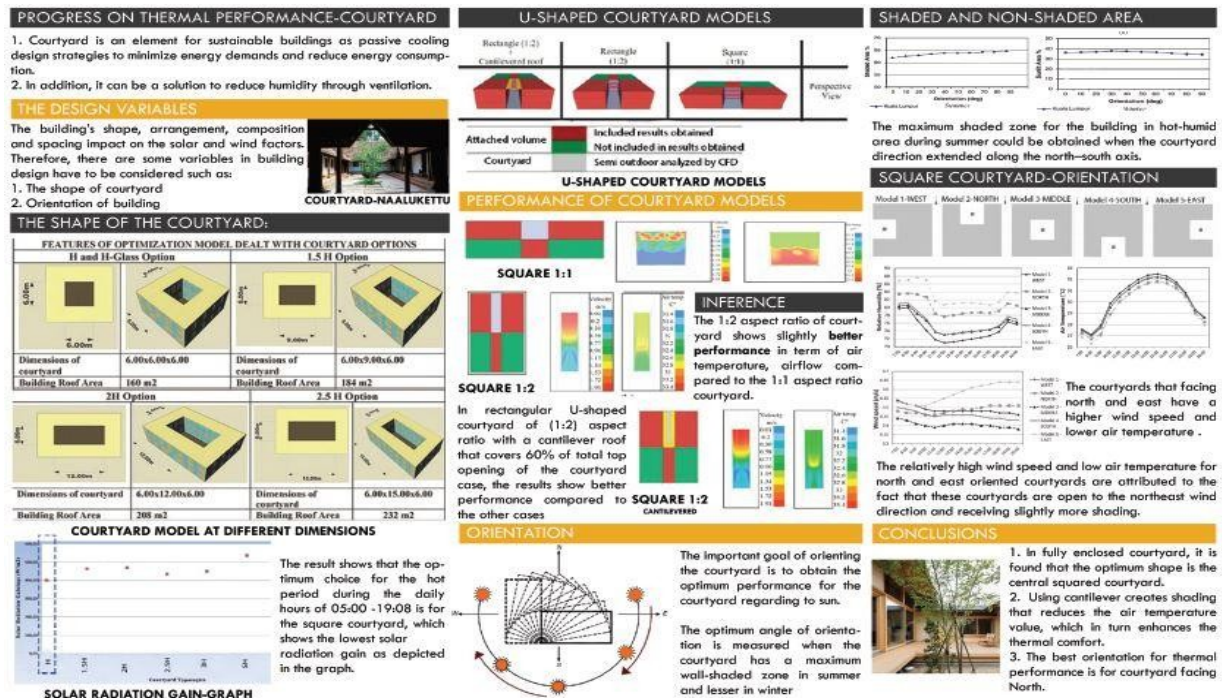
NAME	PROFILE	TEMPERATURE	RELATIVE HUMIDITY	AIR VELOCITY	DAYLIGHTFACTOR	
Interlace singapore		Orientation Buffer space Landscape External shading Roof Garden	Window wall ratio Landscape Inlet and outlet opening	Wind direction Cross ventilation Building height Glazing material wing wall & balconies	Window wall ratio Glazing material wide corridor	
Ishatvam 9 Ranchi		Orientation External shading	Window wall ratio Inlet and outlet opening	Inlet and outlet opening Cross ventilation	Deep opening Window wall ratio Glazing material	
sky habitat singapore		Orientation Buffer space External shading Building geometry	Inlet and outlet opening Window wall ratio Landscape	Building height Inlet and outlet opening Cross ventilation Glazing material wing wall & balconies	Deep opening Window wall ratio Glazing material	

Table 4.6 comparative analysis

Research paper analysis

Topic	Author	Aim	Method	Inference	Gaps in the paper
Thermal Performance of Vertical Courtyard System in Office Buildings Under Typical Hot Days in Hot-Humid Climate Area	Jin Wei Fangsi Yu Haixiu Liang Maohui Luo	Investigates the thermal performance impact of three typical vertical courtyards.	A field case study was conducted in VCSs during two typical extreme hot days under hot-humid climate condition	Study provides empirical evidence for architects to consider the impact of different VCSs on the thermal performance in high-density environments by adjusting the spatial forms and constructed surface materials.	Evaluate and predict the thermal improvement effect of VCS and investigate how it changes under different climate conditions.
Environmental design consideration in hot and humid climate	Mohd Azuan Zakaria Tetsu Kubota	Paper discuss environmental design consideration for courtyard in hot and humid climate through a literature review by contrasting with those in hot and dry climates	Discuss environmental design consideration for courtyard in hot and humid climates through a literature review by contrasting with those in hot dry climate.	Continuous and cross ventilation strategy are appropriate for courtyard building. It is found that the required environmental effect of a courtyard and its design consideration in the case of high thermal mass building in hot humid climate are still uncertain and need to be investigated in future.	effects of sky exposure rate on its cooling effect and ventilation strategies assisted by courtyards in high thermal mass buildings
Progress on thermal performance of the courtyard building in hot humid areas	Esraa Sh Abbaas, Ma Che Munaaim	The effect of design variables of courtyard buildings such as shape, orientation and shading device of the courtyard on thermal performance in hot humid climate	Discuss design variables, namely shape, orientation and shading devices on thermal performance of courtyard in hot and humid climate through literature review	Shape of courtyard optimum shape is the central squared courtyard since it shows the minimum solar radiation gain U- shape courtyard in ratio of 1:2 gives better performance Cantilever creates shading that reduces the air temperature value. Orientation facing north due to minimum air temperature & wind speed.	the future studies must focus on the effect courtyard walls material, size and number of openings, and material of courtyard roof shading on thermal comfort and energy consumption

Research paper 2



Research paper 3

Topic - Thermal comfort in a natural ventilated high rise residential building

Author - Xiangyu Zheng^{1,*}, Stanley Kurvers¹

Aim - to design appropriate ventilation systems for high rise buildings corresponding to the local climate.

Methodology - The field study of a high rise residential building in Delft. the thermal comfort level of the occupants and the thermal conditions in this building were assessed and analyzed.

Reason - To understand various parameters to consider

Inference - The building scale, height and orientation were found to be the crucial parameters in the thermal comfort distribution in a regular high rise residential building, it is important to consider the prevailing wind, glare and other related aspects.

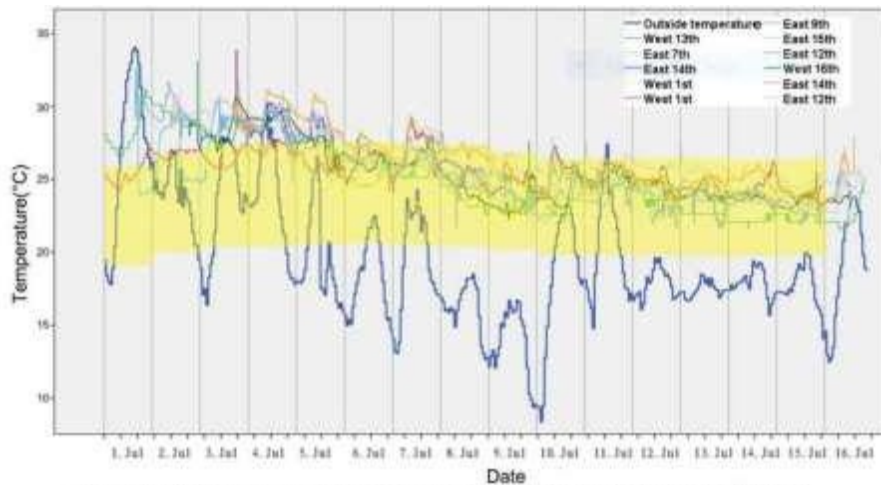


fig 4.7.2.1 Comfort zone & real temperature inside & outside the building



fig 4.7.2.2 The operative temperature comparison on the different floor on west side

Inference

- Two spatial parameters, height and orientation, were found to play an important role in thermal comfort distribution.
- Isolated roof act as thermal insulation on the top of the building
- Adjustable window shading, extra air outlet by means of a mechanical ventilator combined with a new window system to provide sufficient (cooling) ventilation and privacy protection at the same time.

Research paper 4

Topic - Hot and humid climate: prospect for thermal comfort in residential building

Author - Zainazlan Md Zain *, Mohd Nasir Taib , Shahrizam Mohd Shah Baki ,

Aim - This paper describes typical strategies to naturally improve comfort in a climate which is hot and humid without air conditioning.

Methodology - Climate data will be analyzed and typical thermal behavior of buildings was evaluated. The analysis will be compared with the state of thermal comfort for people living in Malaysia.

Reason - To understand various strategies

Inference - effective strategy adopted to reduce the extra heat going into a building. Strategy to flush out the extra heat which will improve thermal comfort consumes energy. For urban areas, thermal comfort can be improved through enough microclimate strategies within the surrounding areas of the building. Else, thermal comfort cannot be achieved through natural ventilation

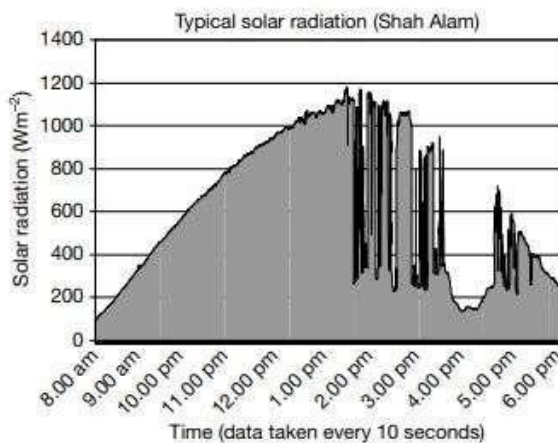


Fig. 2. Solar radiation of 6.05 kWh/m² for a typical day in UiTM Shah Alam (5th May 2003).

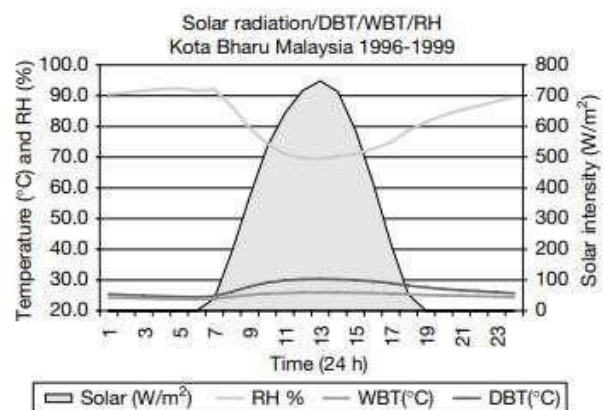


Fig. 4. A typical variation of solar radiation/DBT/RH for a town in Malaysia.

Table 3
Hypothetical influence of air flow

	DBT less than	Air flow (m/s) %		
		0	0.7	1.5
T_n	26.19	0%	0%	100%
$T_n \pm 2.5$	28.69	44.0%	100%	100%
$T_n \pm 3.5$	29.69	100%	100%	100%

Inference

Results Temperature measurements were made at various location of a terrace house, adopting various strategies to facilitate air flow. What was observed is that if there is no air flow, only 44.0% occurrences is below 28.69 C but an air flow of 0.7 m/s will improve the occurrence of thermal comfort to 100%.. An air flow of 0.7 m/s will give rise to comfort while if the air flow is more than 1 .5 m/s, the space will be comfortable throughout. An air flow if less then 0.2 m/ s would not be effective

CHAPTER 5 SITE STUDY AND ZONING

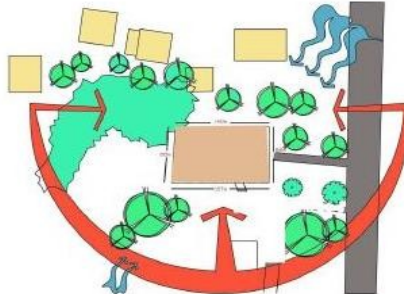
Site analysis

SITE ANALYSIS



Location
The site is located in Mogappair, Chennai with the area of 3.46 acres.
The coordinates are N and S.

Accessibility
The site is accessible from 1 sides. Towards east.



Solid & Void



Latitude - 13.075366974926524,
Longitude - 80.17124386054209

Terrain - Flat Terrain

SITE PHOTO



Vegetation



fig 5.1 Site analysis

PROXIMITY MAP

The Site is located in mogappair , is a residential neighborhood in north-western Chennai, India.

Distance From Airport, railway station & Bus stand

- > Mogappair BusStop - 4Min
- > Thirumangalam Metro Station - 10Min
- > CMBT - 20Min
- > Chennai International Airport - 50 Min

Corporates

- > Indiabulls, Ayanambakkam - 10Min

- > Multinational Companies such as Ambit IT Park, HCL, Tech Mahindra are located in this area

- > The availability of small parks, educational institutions, Hospital, banks, supermarket, well developed residential area in this part of this city.



Which is surrounded by schools, hospitals and proximity to market and has excellent transport facilities.

Mogappair is a very prime residential locality and well connected with the other parts of the city. It is well connected by trains, buses and public transport.

- School /College
- ⊕ Hospital
- ⊖ Bus stop
- ⊕ Park



LANDUSE MAP

Macro climatic analysis

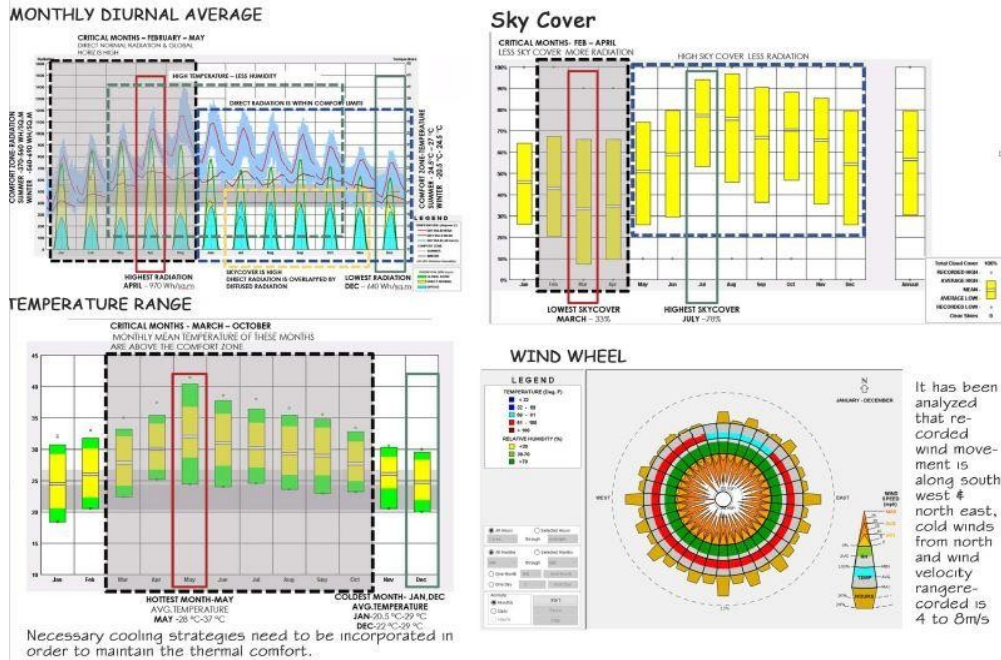
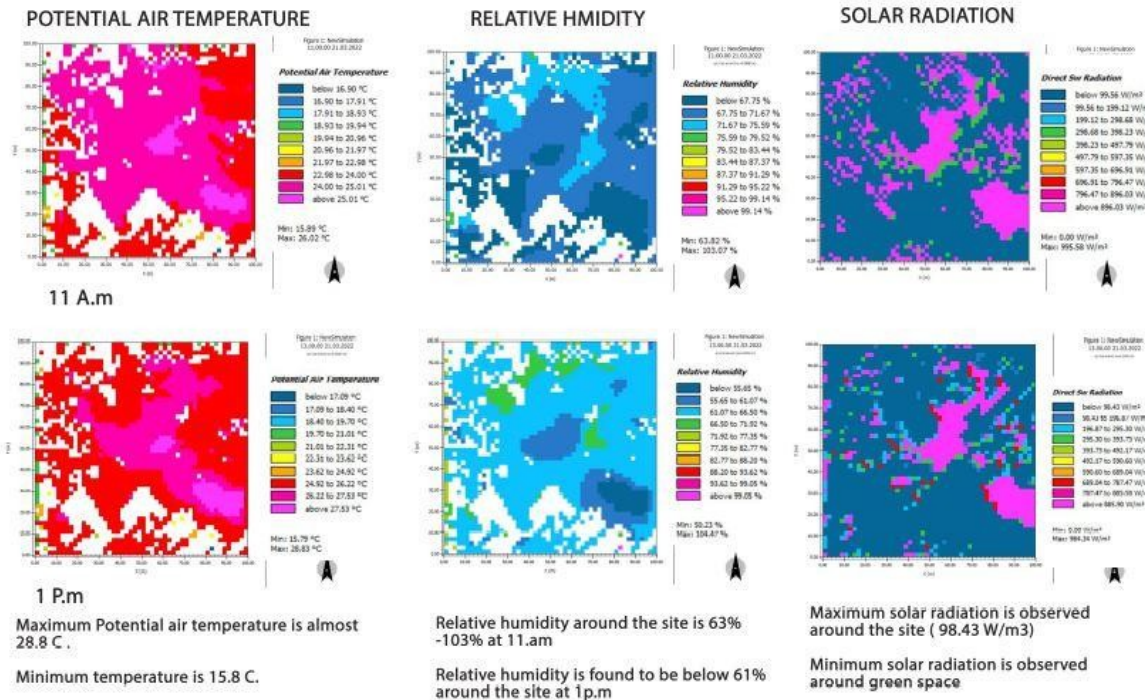


fig 5.2.1 climate consultant – Macro climate analysis

Micro climatic analysis

ENVIMET ANALYSIS



ENVIMET - SITE ANALYSIS

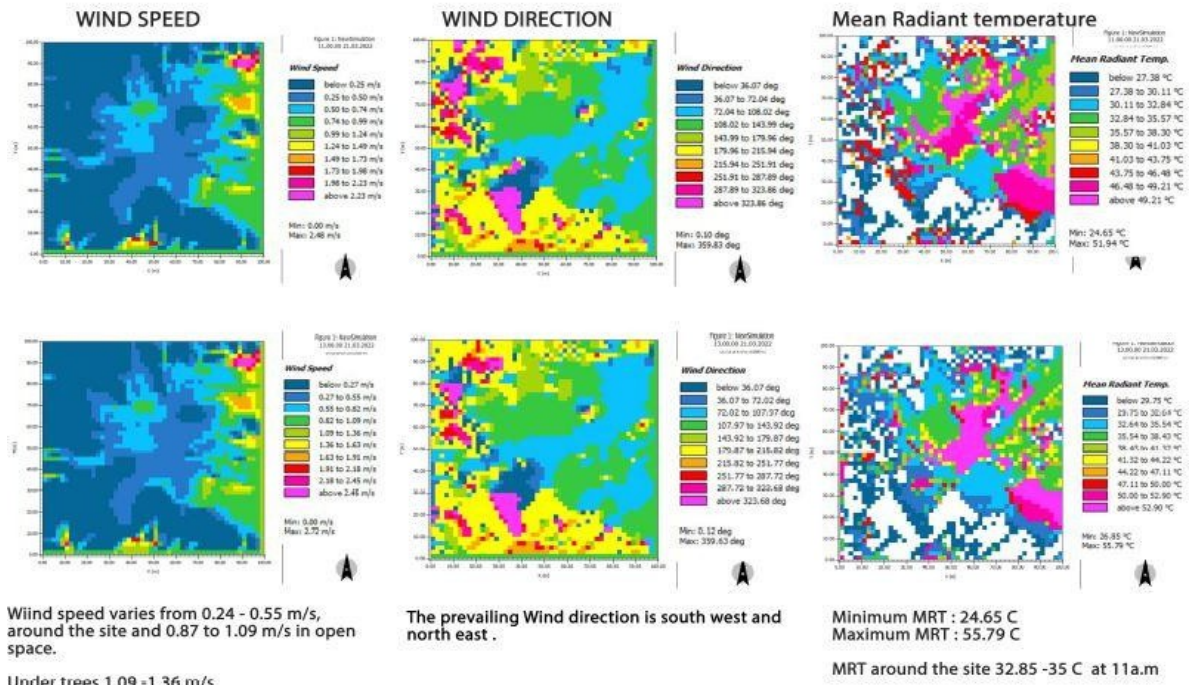
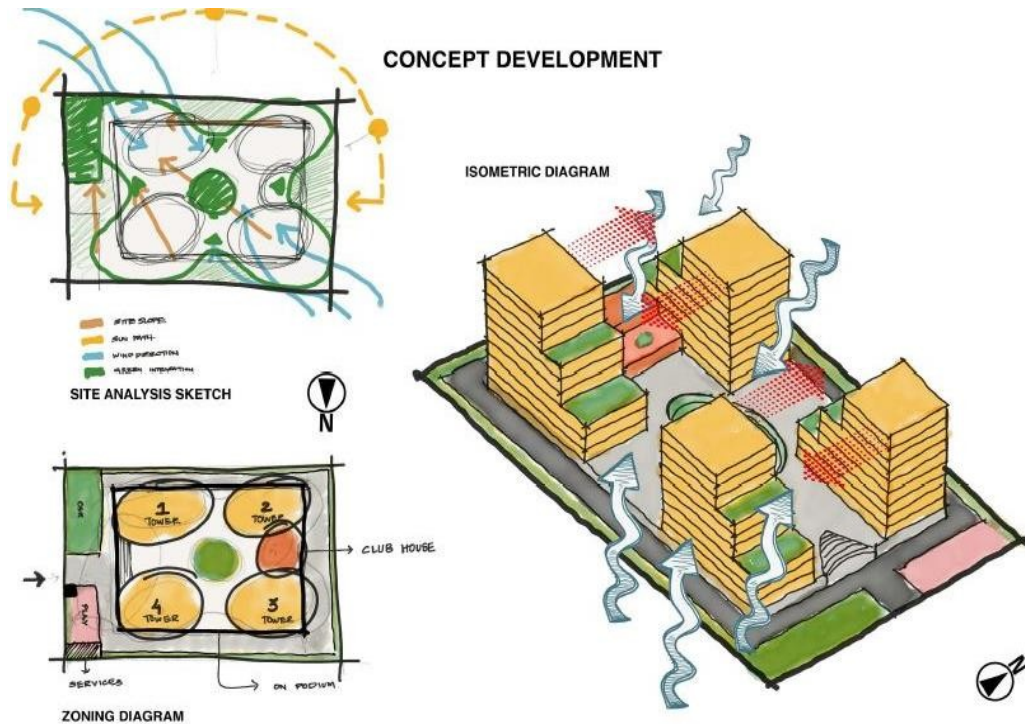
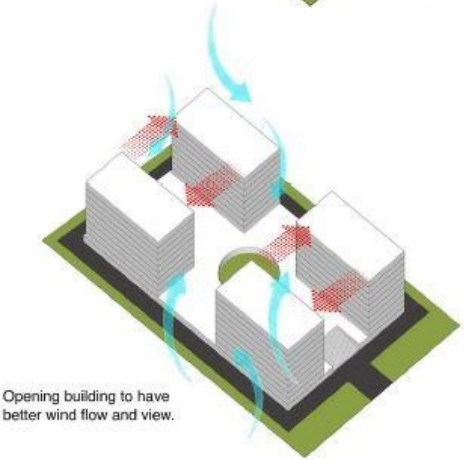
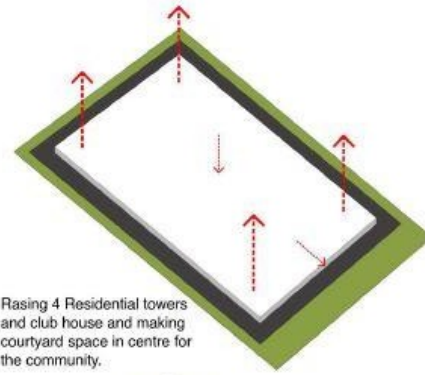
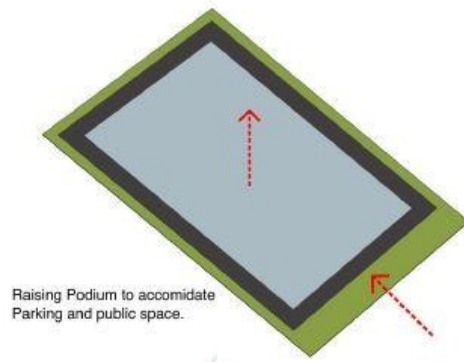


fig 5.3.1 Envimet site analysis

Site zoning 1



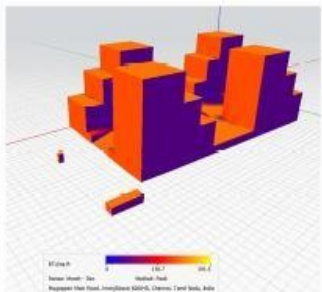
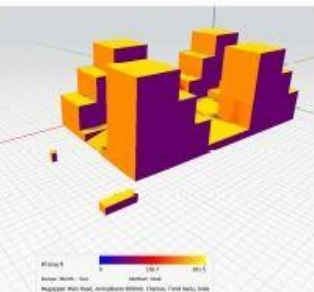
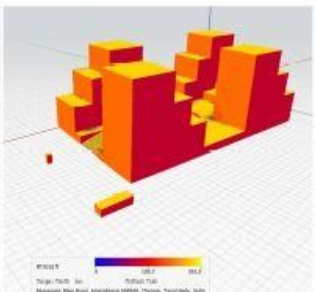
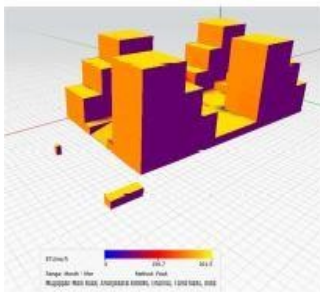
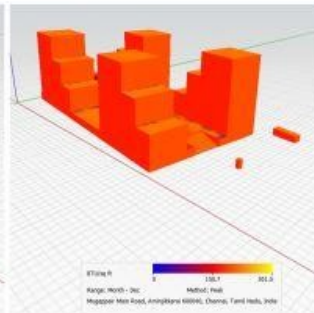
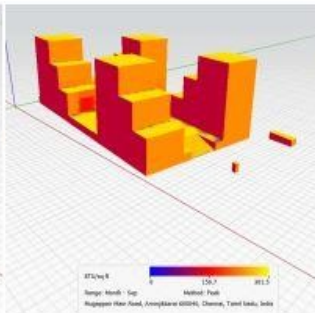
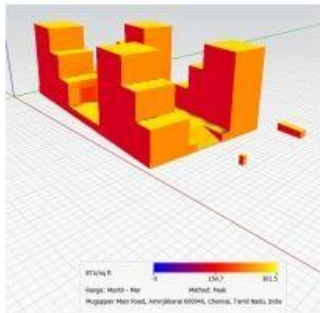


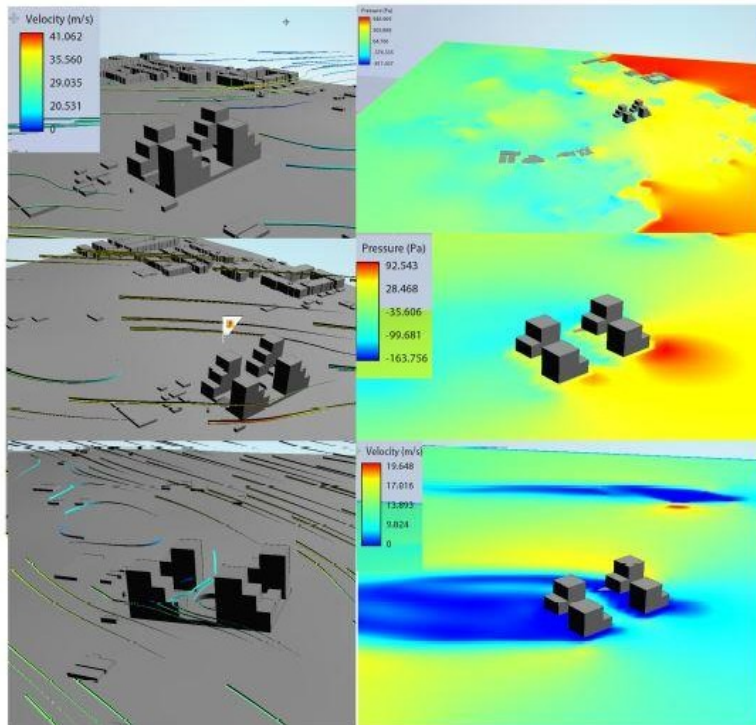
FORMIT ANALYSIS

MARCH

SEPTEMBER

DECEMBER

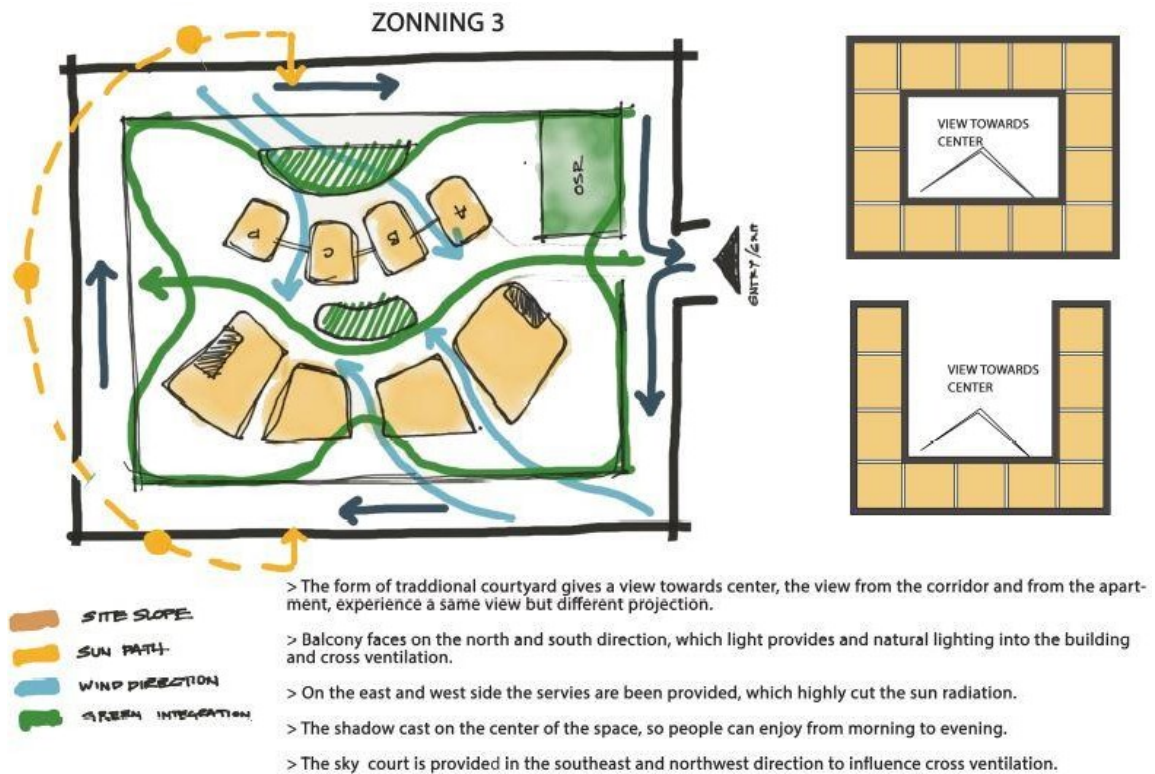




INFERENCE

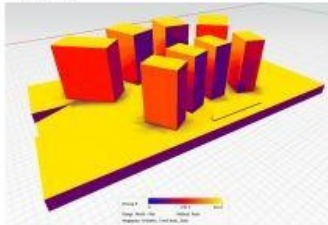
- > The predominant wind direction from south east and northwest wind.
- > The southeast is not blocked by neighbouring building, mainly there is no blockage of wind in all four sides.
- > Towards Northwest, turbulent effect & swirl effect is formed.
- > The building block is acting like a wind block and creates stagnation of wind.
- > The velocity ranges between 5m/s to 0.
- > The pressure difference varies between in the range of 40-50 Pa, on the northwest.
- > Around the site the pressure difference ranges between -99Pa.

Site zoning 2

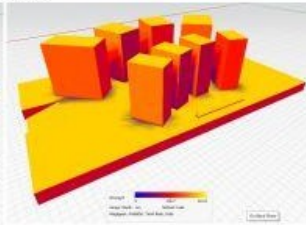


FORMIT ANALYSIS

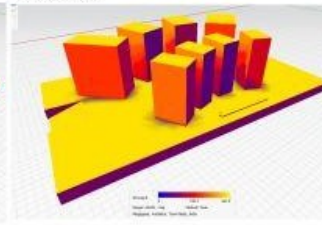
March



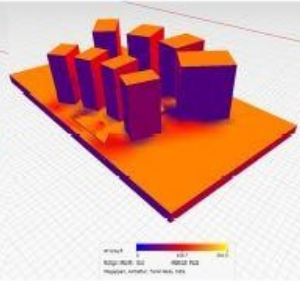
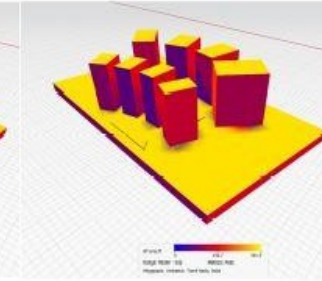
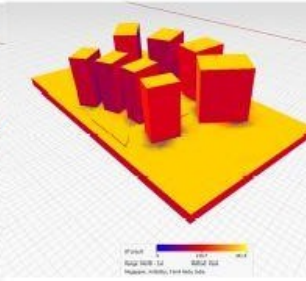
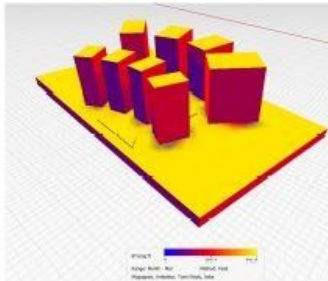
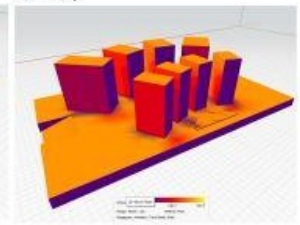
June



September



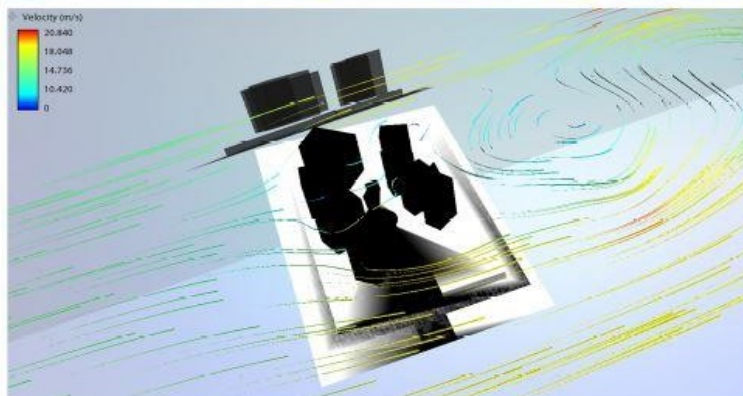
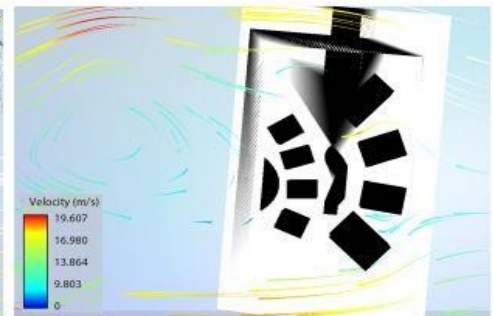
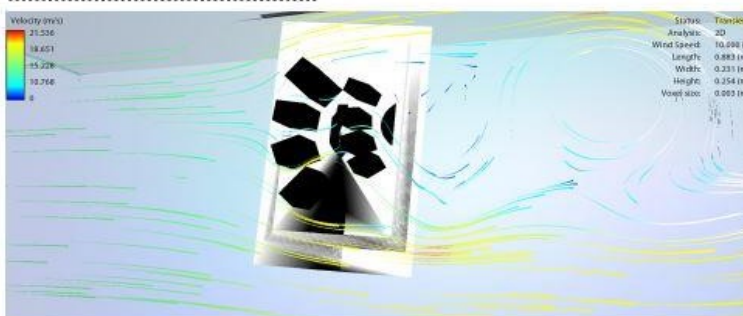
January



INFERENCE:

- > From the thermal analysis we can infer that the hottest facade that receive are south facade.
- > The east and west facade does not get ample amount of solar radiation, due to the placement of the adjacent building.
- > Passive strategy has to implement in the east and west facade to improve indoor thermal comfort.
- > South west facade are shaded by the adjacent blocks

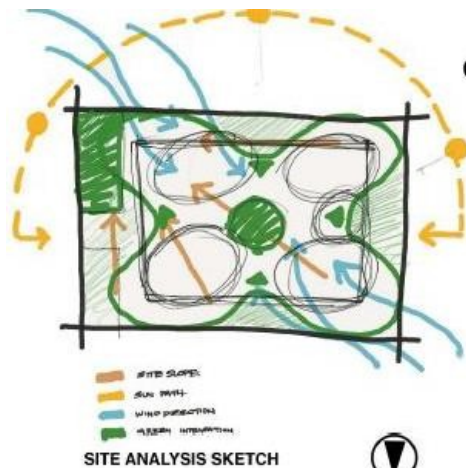
WIND FLOW -Zonning 3



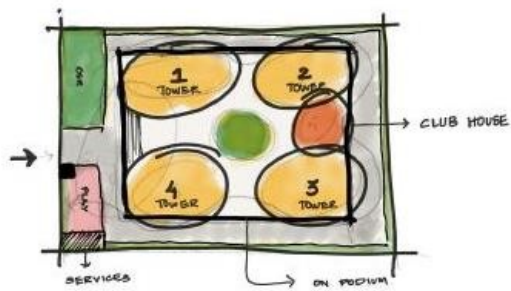
INFERENCE

- > The wind flow from southeast and penetrate through other side of the building, which experience funnel effect.
- > wind shadow is occurred at the north side of the building.
- > Effective ventilation is provided everywhere throughout the building.
- > Narrowing building structure cause accelerated air speed.

Site zoning



SITE ANALYSIS SKETCH

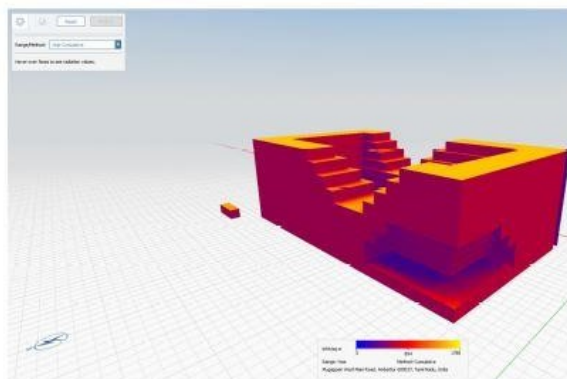
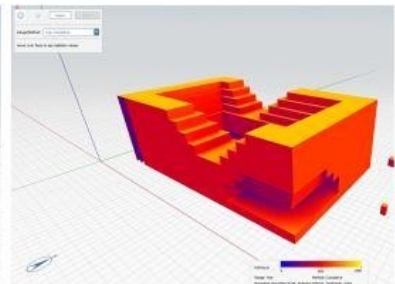
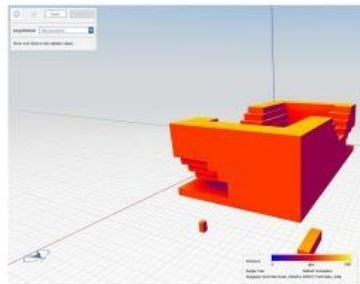
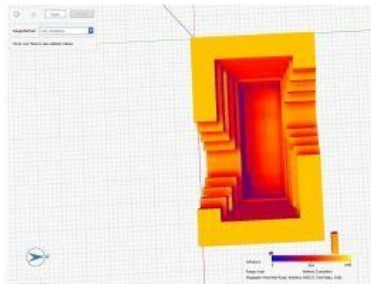
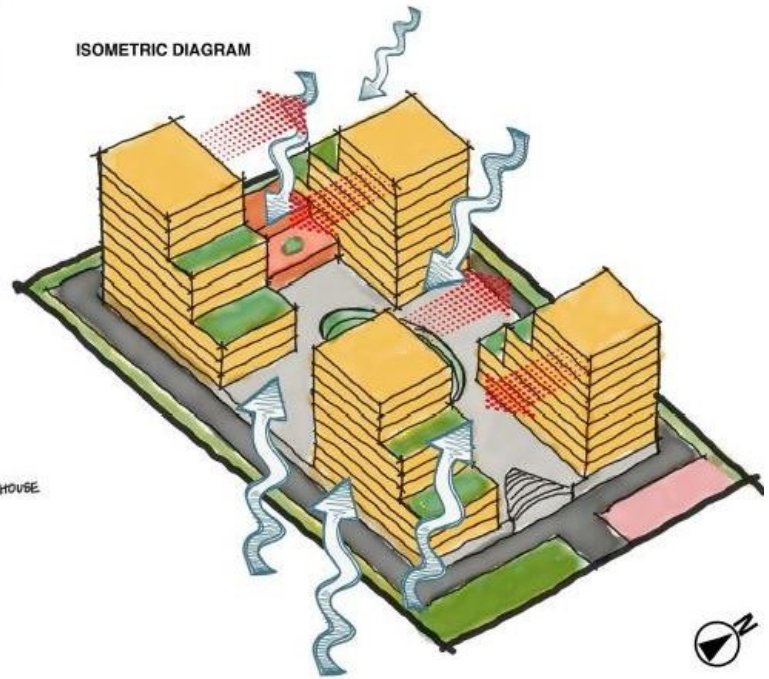


ZONING DIAGRAM

SOLAR RADIATION

CONCEPT DEVELOPMENT

ISOMETRIC DIAGRAM



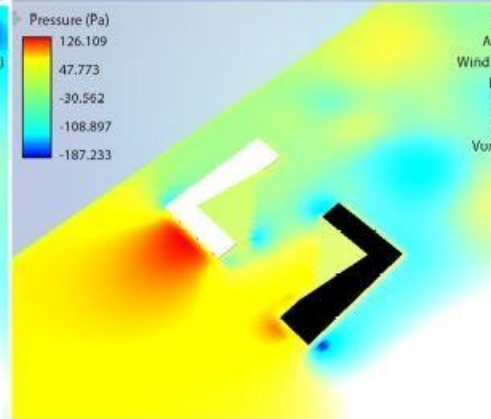
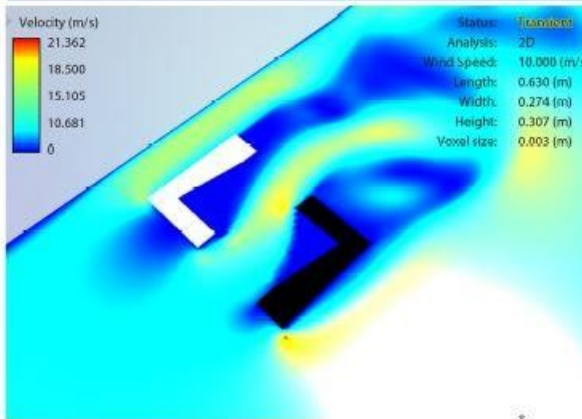
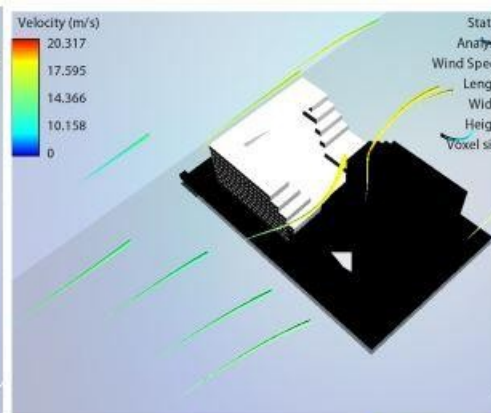
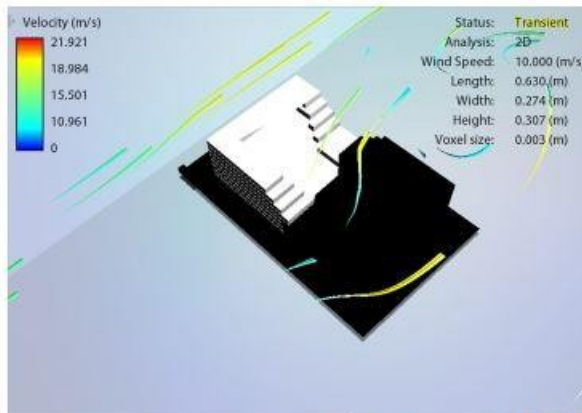
INFERENCE

> The courtyard always experience shadow in the center of the courtyard.

> South facade experience a large amount of solar radiation and west side highly influence more amount of solar radiation, to main that services and the balcony space will be taken in to design .

> The green roof is maintained to reduce the solar radiation.

> Influence solar shading to reduction in solar radiation.



INFERENCE

The wind flow from southwest to northwest, the wind is not blocked by any of the building.

> the wind challenged by the building form which improve high cross ventilation.

> In the southwest the pressure difference is seen highly at the range of 50 pa.

> Around the 15m the area of flow pressure been created.

CHAPTER 6 ANALYSIS & RESULT

Sky court analysis

ANALYSIS

Sky courts come in many distinct designs were each can differ depending on factors such as

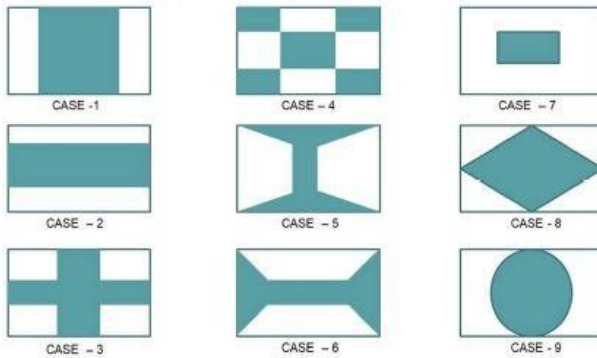
- 1.Design specification,
2. Location,
- 3.Usage and also
- 4.Space availability

The wind comfort Quality is depending on the sky court design and wind flow direction.

The site is in perungudi, which is three sided road, there is no high rise building around 5m of the site.

With a building height of 116m and determined that the building will have 36 floors, floor to floor heights is 3.5m and sky court level 8m.

SKY COURT GEOMETRY DESIGN AND CASES FOR THE SIMULATION

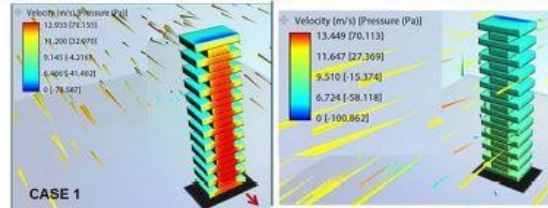


The Lawsonwind comfort criteria

Reference	Threshold wind speed (m/s)	Activity
A	$U > 1.8$ m/s	Sitting long
B	$U > 3.6$ m/s	Sitting short
C	$U > 5.3$ m/s	Strolling
D	$U > 7.6$ m/s	Walking fast
E	$U > 15.1$ m/s	Danger

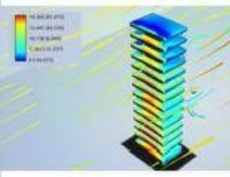
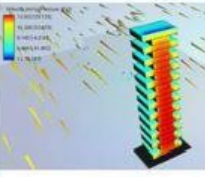
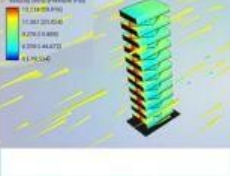
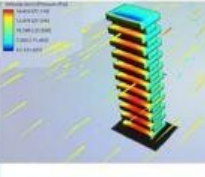
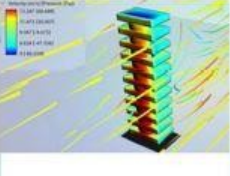
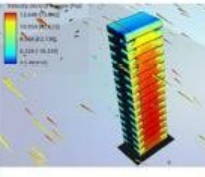
Criteria for wind nuisance according to NEN 8100 (2006a) [31].

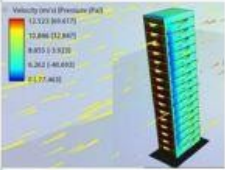
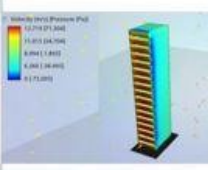
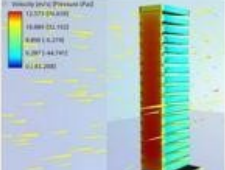
P ($U_{T100} > 5$ m/s in % hours per year)	Grade	Activity		
		Traversing	Strolling	Sitting
< 2.5	A	Good	Good	Good
2.5-5.0	B	Good	Good	Moderate
5.0-10.0	C	Good	Moderate	Poor
10.0-20.0	D	Moderate	Poor	Poor
> 20.0	E	Poor	Poor	Poor



Sky court areas on both side of the building, changes occur to the flow path direction due to certain of eddies, indicating greater fluctuation in velocity with a decrease at the leeward side of the building, within sky court.



CASES	SIMULATION	INFERENCE	CASES	SIMULATION	INFERENCE
 CASE - 7		• Decrease in velocity on the windward side, with areas of reverse flow result in greater amount of area on leeward side with velocity less than 6m/s. • Distribution of pressure coefficient at a height of 2/3H along wind ward side and leeward facades of the building.	 CASE -1		□ Greater velocity along the windward and leeward side. A constant quality class D.
 CASE - 8		□ Which indicates a greater velocity (Quality D) along windward side, and forming a larger region of wind shadow. □ A separation between windward and leeward sides, its illustrates a constant quality class A within leeward side.	 CASE - 2		□ Greater velocity (Quality Class D) along windward side forming larger regions of wind shadow. □ With a separation between leeward and windward sides, a constant Quality Class A within leeward side.
 CASE - 9		□ There is greater wind flow acceleration occur around the corners of the sky court at all the levels. Which is unsafe for occupant. Wind flow condition is in quality E. □ Wind velocity of 14 m/s. Which allowing greater changes in flow direction and more fluctuation in velocity.	 CASE - 3		□ Greater changes in flow direction & more fluctuation in velocity magnitudes. □ Negative pressure coefficient is presented on side and leeward façade with slight variation due to the shape of the sky court design

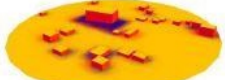
CASES	SIMULATION	INFERENCE	CASES	SIMULATION	INFERENCE
 CASE – 4		- Negative pressure coefficient is presented on to vertical façade on the sides of sky court areas - wind velocity of 10m/s at 5-10m away from the building.	 CASE – 6		- Greater velocity (Quality Class D) along windward side forming larger regions of wind shadow, on leeward side. - In the leeward side the quality comfort A
 CASE – 5		The windward, the positive pressure coefficient is similar. Negative pressure coefficient is presented on side and leeward façade with variation due to the shape of the sky court design.			

CONCLUSION

- 1.Wind comfort criteria, comfort with various sky court were analyzed.
- 2.From the simulation of sky court design (case 4, 5), it is observed that the region of quality class A and class C..
- 3.The quality of wind comfort achieved in higher sky court levels was better with class A.
- 4.The condition within leeward sides of sky court are generally observed as a quality class lower than for the windward region.
- 5.For (case-1,2) it was observed the condition between leeward and windward region were completely different, with leeward side typically within the class A criteria, it result in majority of the occupant stay only on one half of the sky court.
- 6.Based on the simulation result of sky court design (circle) the worst comfort and unsafe, the sky court are usually in cuboids not in cylindrical.
- 9 The result obtained in this work were based on the assumption of a single isolated building. In reality there would be adjacent building and sky court area is used to provide greenery, its varies.

Orientation analysis

Solar Analysis According to form

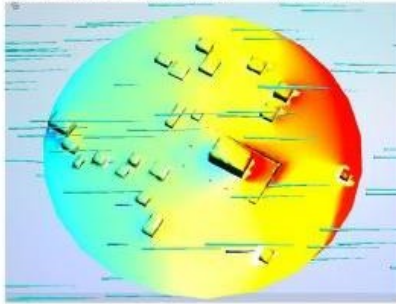
Orientation	Simulation	East	West	North	South	Roof	Cumulative
OPTION 1 0 Degree		1089 KWh/sqm	537.5 KWh/sqm	411.5 KWh/sqm	671.9 KWh/sqm	1577 KWh/sqm	4250.9 KWh/sqm
OPTION 2 15 Degree		1026 KWh/sqm	560 KWh/sqm	361 KWh/sqm	755 KWh/sqm	1577 KWh/sqm	4279 KWh/sqm
OPTION 3 30 Degree		921 KWh/sqm	573 KWh/sq.m	381 KWh/sqm	882 KWh/sqm	1577 KWh/sqm	4337 KWh/sqm
OPTION 4 45 Degree		782 Kwh /sqm	575 KWh/sq.m	418 KWh/sqm	992 KWh/sqm	1577 KWh/sqm	4344 KWh/sqm

INFERENCE:

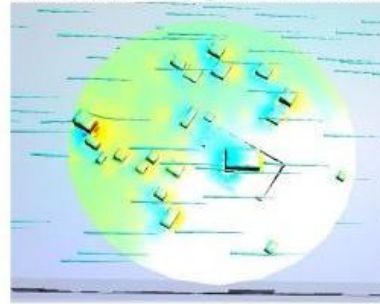
- > Built form is elongated along East & West axis, minimizes the heat exposure on East & West direction
- > when building is slited at 0°, 15°, 30°, 45°, minimum solar exposure is highly seen in 0°

Wind analysis according to orientation

Orientation - 0 Degree **OPTION 1**



Orientation - 15 Degree **OPTION 2**



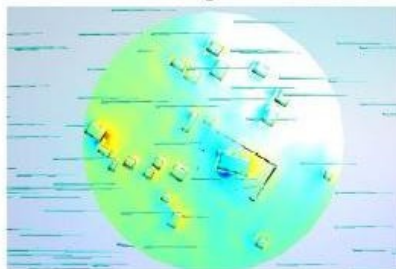
Orientation at 0 degree

- Placed building at 0 degree angle to the direction of wind, which enhance large amount of natural ventilation in to the building.
- 8 m/s of wind is taken into the site when building is oriented at 0 degree.

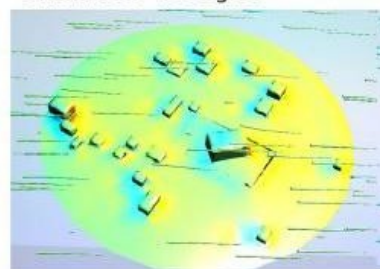
Orientation at 15 degree

- Placed building at 15 degree, which ingress lesser amount of natural ventilation in to the site, and the wind gets deviated at the sides.

Orientation - 30 Degree **OPTION 3**



Orientation - 45 Degree **OPTION 4**

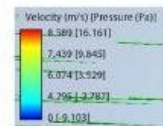


Orientation at 30 degree

- the north corner lower wind pressure is obtained.

Orientation of 45 degree

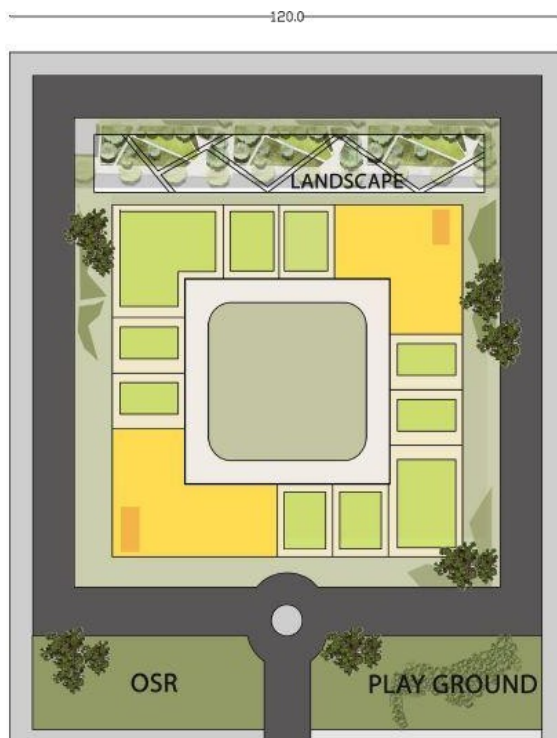
- at the side and leeward side lower



INFERENCE :

- > Place building at a 30 or 45 degree angle to the direction of wind for enhanced ventilation.
- > 0 Degree which enhance more ventilation over the site, compare to all other degree of angle.
- > Orienting longer axis parallel to dominant wind/ Minimize East & West exposure.

Form evolution



Site location

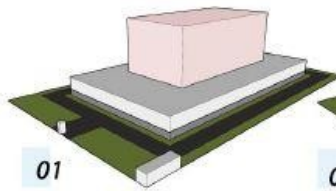
Located in mogappair, which is mixed residential zones

STATIEGIES AT SITE LEVEL :

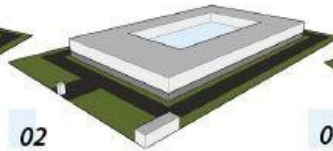
- > Orientation : Longer axis towards North & south
- > Spacing : open placing for natural ventilation
- > Efficient use of prevailing wind in the site
- > Openings : large opening 40 - 80%
- > Walls :Light wall, short timelag
- > Roofs : light insulation roofs
- > Rainwater protection



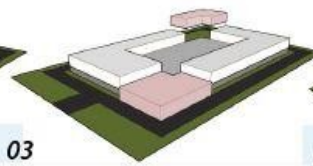
EVOLUTION OF FORM



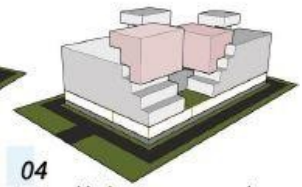
01
Typical Apartment
Arrangement



02
Courtyard Arrangement



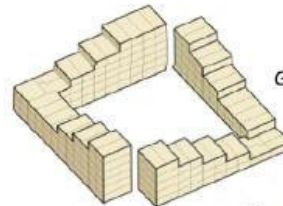
03
Subtraction of SW & NE corner to
ingress natural ventilation



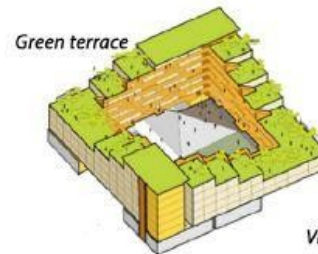
04
Stepped balcony space cut down
the harsh sun from east & west



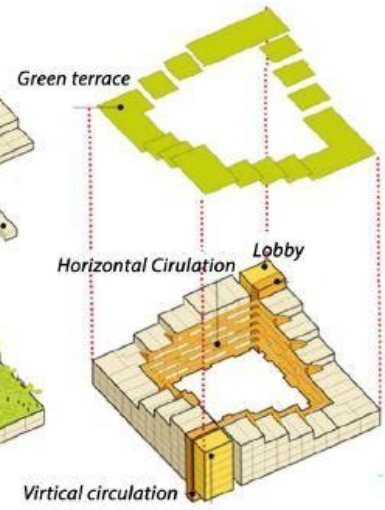
Green Terrace provide on semi
public space for the community people in the block



Typical Apartment



Green terrace

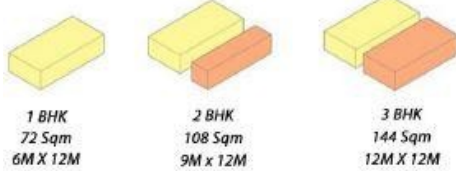


Green terrace

Horizontal Circulation

Vertical circulation

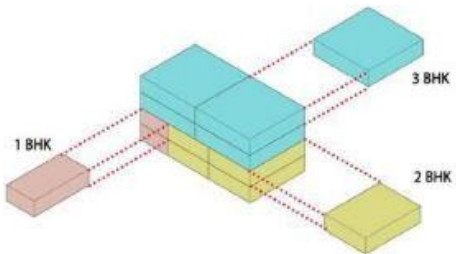
FLOOR PLAN OF UNITS :



1 BHK
72 Sqm
6M X 12M

2 BHK
108 Sqm
9M X 12M

3 BHK
144 Sqm
12M X 12M



Units are arrage in 6m x 6m grid system



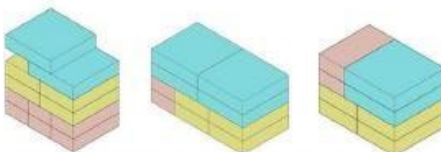
1 BHK MODULE
ISOMETRIC VIEW



2 BHK MODULE
ISOMETRIC VIEW



3 BHK MODULE
ISOMETRIC VIEW

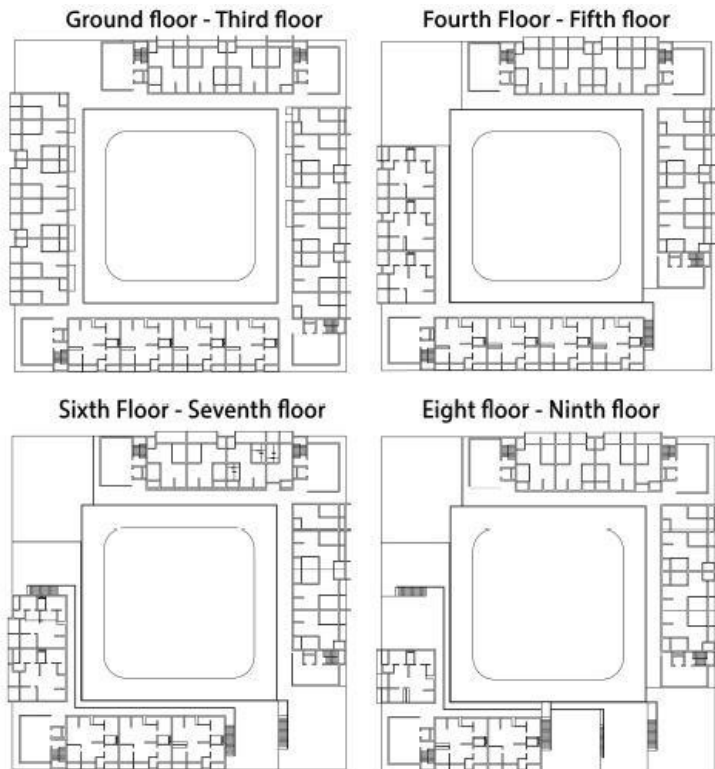


Sustainable features

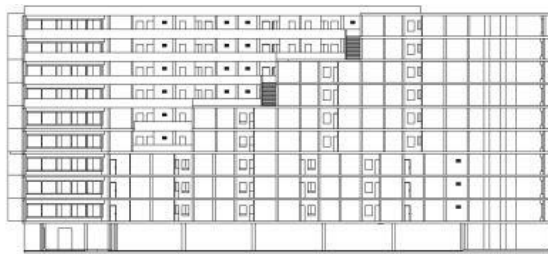


Floor plan

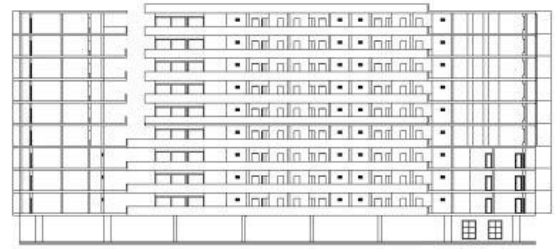
- This block is oriented according to the sunpath and wind direction on the site.
- Courtyard has more effective space to create interaction
- Provide heigher level of privacy and interaction between the user of block and also has sustainable benifits of courtyard in ventilation of air and air into the building.
- Stepped balcony which cuts down the harsh sunlight into the building.
- Green terraces provide an semi public space for the community people in the view from stepped terrace.



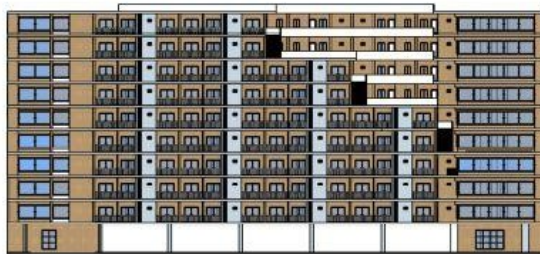
Section and Elevation



SECTION AA



SECTION BB



EAST ELEVATION



WEST ELEVATION

wind analysis

INDOOR WIND SPEED CALCULATION

TABLE 1 DESIRABLE WIND SPEEDS FOR THERMAL COMFORT CONDITIONS
(Clause 4.3.1)

Dry Bulb Temperature °C	Relative Humidity (Percent)					
	30	40	50	60	70	80
	Wind Speed, m/s					
28	*	*	*	*	*	*
29	*	*	*	*	*	*
30	*	*	*	*	*	*
31	*	0.06	0.24	0.53	1.04	1.47
32	0.30	0.46	0.94	1.59	2.26	3.04
33	0.77	1.36	2.12	3.00	+	+
34	1.85	2.72	+	+	+	+
35	3.2	+	+	+	+	+

*None
+Higher than those acceptable in practice.

TABLE 2 MINIMUM WIND SPEEDS FOR JUST ACCEPTABLE WARM CONDITIONS
(Clause 4.3.1)

Dry Bulb Temperature °C	Relative Humidity (Percent)					
	30	40	50	60	70	80
	Wind Speed, m/s					
28	*	*	*	*	*	*
29	*	*	*	*	*	*
30	*	*	*	*	*	*
31	*	*	*	*	*	*
32	*	*	*	0.09	0.29	0.40
33	*	0.04	0.24	0.60	1.04	1.45
34	0.15	0.46	0.94	1.59	2.26	3.05
35	0.68	1.36	2.10	3.05	+	+
36	1.72	2.70	+	+	+	+

SOURCE : Mahoney table, SP41

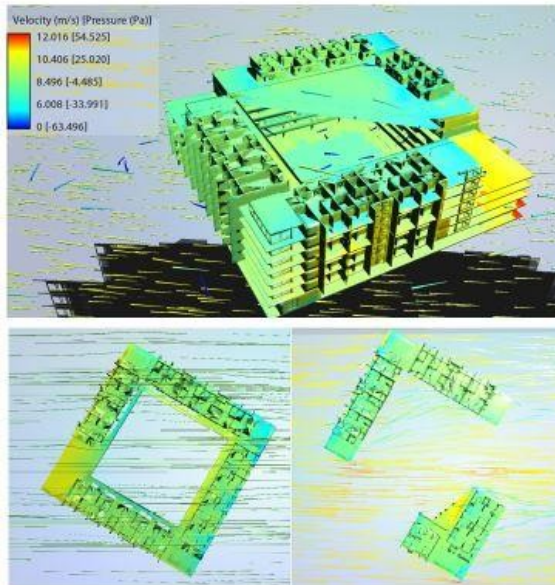
INFERENCE

- Calculations are made as mentioned in the requirement and percentages are recorded some of the spaces have openings more than 30% of the floor area, in that case as mentioned above 40% of the outdoor speed will be relieved in the indoor area.
- The spaces in the design achieves wind speed above 20% so the design satisfies the criteria.

Months	Months Avg Temp	Monthly Avg Humidity	Wind direction	Wind speed
Jan	24.3	74%	E	5.7 m/s
Feb	25.3	73%	E	4.6 m/s
March	27.4	72%	S	4.4 m/s
April	29.6	73%	S	4.1 m/s
May	31.3	66%	S	6.2 m/s
June	30.8	62%	S	6.6 m/s
July	30	63%	W	6.1 m/s
August	29.2	68%	W	6.1 m/s
Sep	28.7	73%	S	5.8 m/s
Oct	27.3	80%	SW	4.7 m/s
Nov	25.7	80%	E	4.9 m/s
Dec	24.6	77%	E	5.4 m/s

VENTILATION CALCULATION

SPACES	FLOOR AREA	Opening - 1	Opening - 2	TOTAL	OPENING % of FLOOR AREA
1 BED ROOM UNIT					
Living	20 sq.m	1.89	2.52	4.41	22
Bed room	10 sq.m	2.5		2.5	25
Kitchen	7 sq.m	1.4		1.4	20
2 BED ROOM UNIT					
Living	22 sq.m	1.89	3.36	5.25	24
Bed room 1	9.2 sq.m	2.03		2.03	23
Bed room 2	11.02 sq.m	2.52		2.52	23
Kitchen / dining	8 sq.m	1.6		1.6	20
3 BED ROOM UNIT					
Living	36.9 sq.m	1.89	3.36	5.25	24
Bedroom 1	10 sq.m	2.03		2.03	20
Bed room 2	12 sq.m	2.52		2.52	21
Bed room 3	13.64 sq.m	2.95		2.95	23
Kitchen / dining	8.2 sq.m	1.7		1.2	21



- > Building are placed at 0 degree , which enhance more ventilation over the site, compare to all other angle.
- > The form which enhance into tunnel effect into the building and ,provide more cross ventilation in to the building and opening are provided at the south and outer side of the envelope.

The Lawsonwind comfort criteria

Reference	Threshold wind speed (m/s)	Activity
A	$U > 1.8 \text{ m/s}$	Sitting long
B	$U > 3.6 \text{ m/s}$	Sitting short
C	$U > 5.3 \text{ m/s}$	Strolling
D	$U > 7.6 \text{ m/s}$	Walking fast
E	$U > 15.1 \text{ m/s}$	Danger

Criteria for wind nuisance according to NEN 8100 (2006a) [31].

P ($U_{\text{max}} > 5 \text{ m/s}$ in % hours per year)	Grade	Activity		
		Traversing	Strolling	Sitting
< 2.5	A	Good	Good	Good
2.5-5.0	B	Good	Good	Moderate
5.0-10.0	C	Good	Moderate	Poor
10.0-20.0	D	Moderate	Poor	Poor
> 20.0	E	Poor	Poor	Poor

On the south west opening space the velocity ranges 10 m/s , which is suitable for walking fast . > wind speeds are highest near the front, in the range of 10 m/s. Speeds are generally lower along the middle of the skygarden and increase towards the sides. On average, the velocity at the occupants' level is 12 m/s, which is significantly higher than the human comfort range. Thus, people will always experience discomfort within the skygarden. Even for intense physical activity, , such high wind speeds will be a cause of distress.

The courtyard that has middle have a higher wind speed and lower air temperature.

The relatively high wind speed and low air temperature for middle oriented courtyard, which attributed to the fact that these courtyard are open to the southwest and northeast wind direction of wind and receiving slightly more shading.

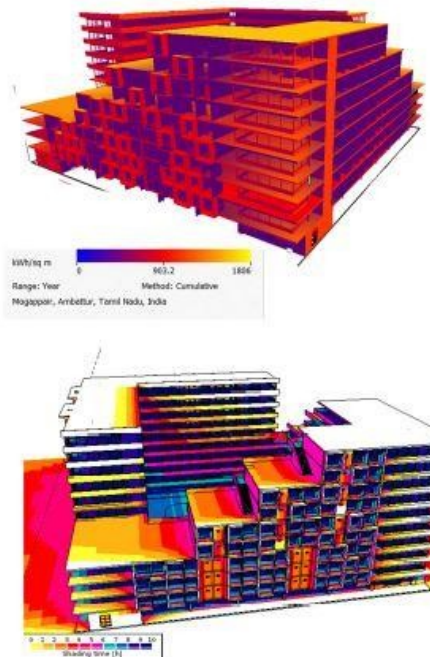


> The railing is modelled as a thin solid wall with a width of 0.05 m and height of 1.5 m and 2 m.

generating a blockage of 13% and 17%

The hedge has a width of 1.5 m and height of 1.5 m and 2 m, generating a blockage of 13% and 17%. Both the railing and hedge are placed at the edge of the skycourt

Shadow analysis



The shadow analysis is done for yearly cumulative period, the court side is affected at the critical time 1.20pm. the courtyard space experience a shade for 7hrs in a day.

Design of shading devices

The shading devices were designed based on the recommendation from sp41

South facade

> Window type 1 : 2m x 1.89m

Horizontal Member

- By Table 10, H (B = 0degree)
- The spacing between the horizontal member is given as 2.75P, where P is the length of the projection.

1. Window Type 1: (2m x 1.89m)

$2.75 \times P = \text{Spacing}$

$P = 189/2.75$

$P = 68.72 \text{ cm}$

Two horizontal shading members of length 34 cm

Vertical member

- By table 10, V (B = 0 degree)
- The spacing between the vertical member is given by 2.75 P, where P is the length of the projection.

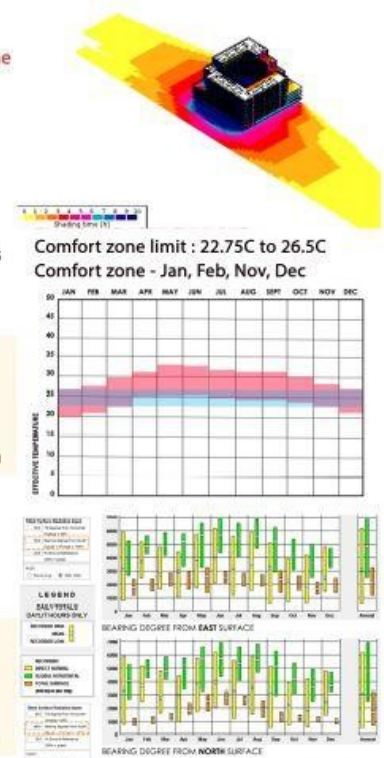
Window Type 1 : (2m x 1.89m)

$2.75 \times P = \text{Spacing}$

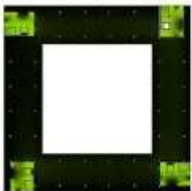
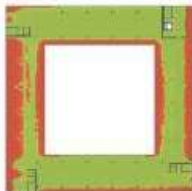
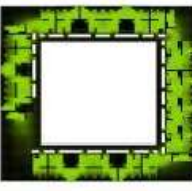
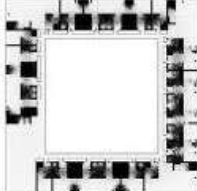
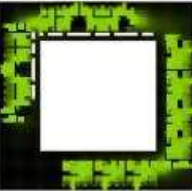
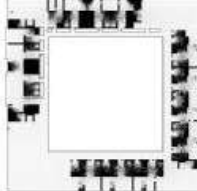
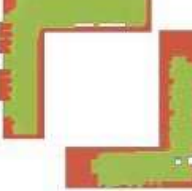
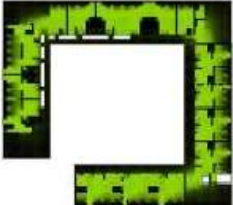
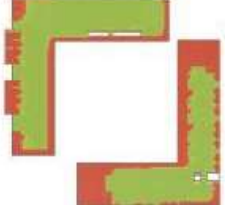
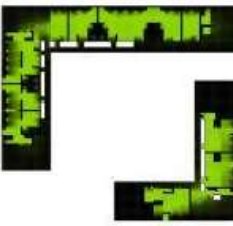
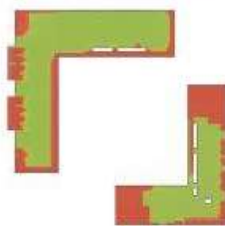
$P = 200/2.75$

$P = 136.98 \text{ cm}$

Two vertical shading of member of length 69 cm



Daylight analysis

FLOOR	Useful daylight Illuminance	Daylight autonomy	Annual Solar Exposure
Ground Floor	 UDI : 84.8%	 DA : 98.6%	 ASE : 32%
1st, 2nd, 3rd Floor	 UDI: 56%	 DA : 67.4%	 ASE : 11.6%
4th & 5th Floor	 UDI : 59%	 DA: 75.4%	 ASE :12%
FLOOR	Useful daylight IlluminanceE	Daylight Autonomy	Annual solar exposure
6th & 7th Floor	 UDI : 59%	 DA: 74.6%	 ASE 16%
8th & 9th Floor	 UDI :57%	 DA : 76.7%	 ASE : 20%

Kitchen (300 lux- 750 lux)
 Bedroom(100-300 lux)
 Bedroom (500 lux -800 lux)
 Bathroom (300 lux)
 Living room(500 lux)
 Family room (300 lux-500 lux)

Laundry -200 lux
 Dining room - 200 lux
 stairway100-500 lux

Views

OAT in Courtyard



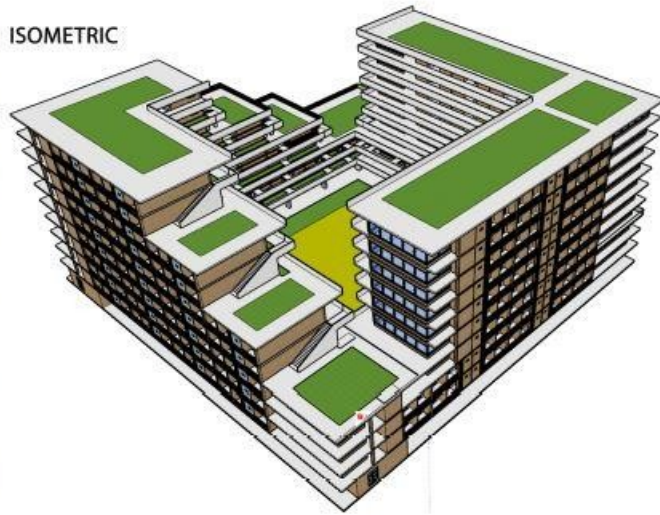
Front view of building



Terrace view



ISOMETRIC



NORTH ELEVATION



WEST ELEVATION



References

1. Heat Island Impacts. EPA United States Environmental Protection Agency. Available online: <https://www.epa.gov/heat-islands/heat-island-impacts> (accessed on 23 June 2020).
2. World Energy Outlook 2018. Available online: <https://www.iea.org/reports/world-energy-outlook-2018> (accessed on 23 June 2020).
3. Krefis, A.C.; Augustin, M.; Schlünzen, K.H.; Oßenbrügge, J.; Augustin, J. How Does the Urban Environment Affect Health and Well-Being? A Systematic Review. *Urban Sci.* **2018**, *2*, 21.
4. Cities in Numbers: How Patterns of Urban Growth Change the World. Available online: <https://www.theguardian.com/cities/2015/nov/23/cities-in-numbers-how-patterns-of-urban-growth-change-the-world> (accessed on 23 June 2020).
5. High Demand for High-Rise: Where will the City Put Its New Skyscrapers? Available online: <https://www.architectsjournal.co.uk/news/high-demand-for-high-rise-where-will-the-city-put-its-new-skyscrapers/8691245.article> (accessed on 23 June 2020).
6. Akristiniy, V.A.; Boriskina, Y.I. Vertical cities-the new form of high-rise construction evolution. In *E3S Web of Conferences*; 2018; Volume 33.
7. Jim, C.Y.; Chan, M.W.H. Urban greenspace delivery in Hong Kong: Spatial-institutional limitations and solutions. *Urban For. Urban Green.* **2016**, *18*, 65–85.
8. Lo, A.; Byrne, J.A.; Jim, C.Y. How climate change perception is reshaping attitudes towards the functional benefits of urban trees and green space: Lessons from Hong Kong. *Urban For. Urban Green.* **2016**, *23*, 74–83.
9. Haaland, C.; van den Bosch, C.K. Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban For. Urban Green.* **2015**, *14*, 760–771.
10. Moss, J.L.; Doick, K.J.; Smith, S.; Shahrestani, M. Influence of evaporative cooling by urban forests on cooling demand in cities. *Urban For. Urban Green.* **2019**, *37*, 65–73.
11. Ow, L.F.; Ghosh, S.; Yusof, M.L.M. Growth of *Samanea saman*: Estimated cooling potential of this tree in an urban environment. *Urban For. Urban Green.* **2019**, *41*, 264–271.
12. Abhijith, K.V.; Kumar, P.; Gallagher, J.; McNabola, A.; Baldauf, R.; Pilla, F.; Broderick, B.; Di Sabatino, S.; Pulvirenti, B. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments-A review. *Atmos. Environ.* **2017**, *162*, 71–86.
13. Wellmann, T.; Schug, F.; Haase, D.; Pflugmacher, D.; van der Linden, S. Green growth? On the relation between population density, land use and vegetation cover fractions in a city using a 30-years Landsat time series. *Landsc. Urban Plan.* **2020**, *202*, 103857.
14. Malys, L.; Musy, M.; Inard, C. Direct and Indirect Impacts of Vegetation on Building Comfort: A Comparative Study of Lawns, Green Walls and Green Roofs. *Energies* **2016**, *9*, 32.
15. Aflaki, A.; Mirmezhad, M.; Ghaffarianhoseini, A.; Ghaffarianhoseini, A.; Omrany, H.; Wang, Z.H.; Akbari, H. Urban heat island mitigation strategies: A state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong. *Cities* **2017**, *62*, 131–14.
16. Hirano, Y.; Ihara, T.; Gomi, K.; Fujita, T. Simulation-Based Evaluation of the Effect of Green Roofs in Office Building Districts on Mitigating the Urban Heat Island Effect and Reducing CO₂ Emissions. *Sustainability* **2019**, *11*, 2055.
17. Gomes, M.G.M.; Silva, C.; Valadas, A.S.; Silva, M. Impact of Vegetation, Substrate, and Irrigation on the Energy Performance of Green Roofs in a Mediterranean Climate. *Water* **2019**, *11*, 2016. [CrossRef]
18. Kang, G.; Kim, J.-J.; Kim, D.-J.; Choi, W.; Park, S.-J. Development of a computational fluid dynamics model with tree drag parameterizations: Application to pedestrian wind comfort in an urban area. *Build. Environ.* **2017**, *124*, 209–218.