

COURTYARD AS A MICROCLIMATIC MODIFIER IN WARM AND HUMID CLIMATE – IN CASE OF LEARNING ENVIRONMENT

A Thesis

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

by

K. MADHUMITHA (39890009)



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

SATHYABAMA

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

Accredited with Grade “A” by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

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DEPARTMENT OF ARCHITECTURE

BONAFIDE CERTIFICATE

This is to certify that this Report is the bonafide work of **K. MADHUMITHA (39890009)** who carried out the Thesis entitled "**COURTYARD AS A MICROCLIMATIC MODIFIER IN WARM AND HUMID CLIMATE – IN CASE OF LEARNING ENVIRONMENT**" under our supervision from January 2021 to May 2021.

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ABSTRACT

Thermal comfort is one of the most important constituent in providing a complete learning environment. This element resonates at a higher level in an alternate schooling environment. This study focuses on courtyard and analyses its role as a microclimate modifier in warm and humid climate. Courtyard as an element helps to balance the comfort level of user in a building through various factors like ventilation, and lighting. Ventilation plays a vital role in high relative humidity. Introduction of courtyard significantly helps improve the overall airflow in the given area so that user experience is improved to an ideal thermal comfort. Courtyard helps in providing visual comfort by providing pathway for natural light to enter into a building. In today's scenario indoor air quality is one of the most important factors affecting the physical and mental health of any individual. This study aims to investigate various ways to enhance the indoor air quality through means of providing suitable courtyard in a building. The paper further explores how design variants of the courtyard like the form and aspect ratio, orientation and other physical features will affect thermal comfort of an alternate learning school in Warm and Humid climate.

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CHAPTER 1

INTRODUCTION

1.1.1. INTRODUCTION

A school is an educational institution designed to provide learning spaces and learning environments for the teaching of students under the direction of teachers. Most countries have systems of formal education, which is sometimes compulsory. In these systems, students' progress through a series of schools before they are ready to face the real world challenges. The names for these schools vary by country but generally include primary school for young children and secondary school for teenagers who have completed primary education. An institution where higher education is taught, is commonly called a university college or university. In line with that traditional schools, there is available an alternative school is an educational establishment with a curriculum and methods that are nontraditional. Such schools offer a wide range of philosophies and teaching methods; some have strong political, scholarly, or philosophical orientations, while others are more ad hoc assemblies of teachers and students dissatisfied with some aspect of mainstream or traditional education. Be it the traditional or an alternate school, it is very important that the spaces are very well lit and ventilated. Ineffective ventilation and inadequate light in a teaching space can impact attendance, comfort, performance, school equipment and most importantly health. Poor air quality can cause headaches, fatigue, shortness of breath, sinus congestion and irritation of the eyes nose and throat. These health impacts can affect the productivity of teachers and students, resulting in them not having the best out of education.

This stud involves in understanding how we can use courtyard as a microclimatic modifier. A courtyard or court is a circumscribed area, often surrounded by a building or complex, that is open to the sky. Courtyards are common elements in both Western and Eastern building patterns and have been used by both ancient and contemporary architects as a typical and traditional building feature. Courtyards are enclosed outdoor spaces but are normally open to the elements at their top; "An unroofed area that is completely or partially enclosed by walls or buildings, typically one forming part of a castle or large house." (Lea & Runcie, 2002). The courtyard is a form of construction that have a presence since the humans started to build their houses. (Bridson, 2012). Generally, this design familiar in the arid climate of the Middle East, gradually courtyards transformed as more and more of its area covered, so that activities that once took place outdoors begin to take place indoors.

1.1.2. EVOLUTION OF COURTYARD:

As one of the most primeval typology in architecture, courtyards have been seen in all types of buildings, be it commercial, residential, institutional, recreational or industrial; however, they have been most prominent in residential dwellings. They serve as source of air flow,

illumination and provide thermal comfort to a residence by acting as a heat radiator in summers and absorber in winters.

A courtyard traditionally served as a place for family gathering and living, a comfortable and cool place for sleeping during the hot summers, a safe area for the children to play, a source of day light and natural ventilation for the surrounding rooms and a circulation core of the house linking all the spaces in a controlled manner. Despite all these advantages, the courtyard house has been neglected and ignored in the development of contemporary housing projects in the Indian-subcontinent. Observing newer construction today, this typology has faded away in most of our country's metropolitan/developing cities and only gives a vague notion of its origin. Change in social, climatic and cultural patterns have all contributed to the above mentioned statement. Moreover, the change in family structure, housing policies, reorientation of the house to the street and the individualization of rooms has made the introduction of a courtyard space a difficult task.

The idea of courtyards as a plan configuration goes back thousands of years to Neolithic settlements. The historical evolution of courtyard form across the world showed in ancient civilization from excavated at Kahun in Egypt, which back to 5000 years. Courtyard became popular in warm and humid climate as it was a great passive cooling technique for buildings and also helped in enhancing the social and culture of people.

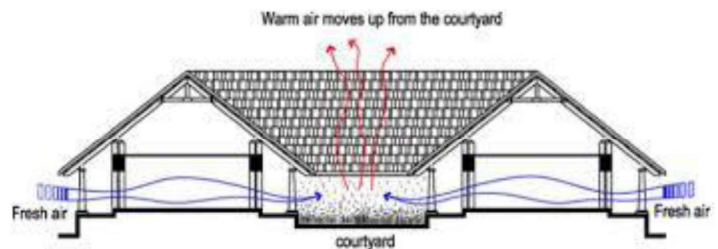


Fig 1.1 Types of Courtyards

Evolution of the a troglodyte village in Matmatas of Southern Tunisia the most primeval and homogeneous society to build courtyard houses, according to Schoenauer and Seeman "Each dwelling-unit is built around a carter open to the sky

with slope wall and flat bottom". Another example that reveals in archeological survey found at Ur on the Euphrates River in Mesopotamia in 2 000 B.C. The plan showed a square courtyard that surrounded by rooms in Ground floor, and the second floor of the house open to courtyard, the building material in that era mainly from fired brick . In China, primary houses have significant influenced by religion and the philosophy of Yin and Yan, the purpose was different the courtyard used for privacy and meditation. Even the form has another attribute from the first example at Ur. Instead of surrounded by rooms, the Chinese courtyard surrounded by individual houses, which belong to different people. Garden and water features were two signs for the courtyard, thus it used as a cooling tool in warm climate in Southern area.

The developer of courtyard takes another kind of design at 700 B.C; in Italy. The atrium house design has had a small courtyard surrounded by rooms, with a container in the center of the courtyard to gathering the rainwater to drink. The main purpose of this design, which is an open to the sky is to provide a private outdoor space. Around 275 B.C., Roman architecture became mix features inherited from the Etruscans and the Greek, after occupied of Southern Italy by Roman. The atrium house met up with Greek pre-style, when people started to build a big house contained two styles (atrium pre-style), any one of these styles has had their location in design, atrium near to street and pre-style in the back of the house.

After the fall of Roman Empire by A.D. 476, the courtyard type dwelling suffered relapses, and found in Italian Cortile and monastic cloisters. During Christian architecture era, the atrium became common in early Christian churches as the main entrance; it was used as a meeting place in the center of the colonnaded open court there was a fountain or well used by worshiper to wash their hand before entering the church. In some Islamic countries North Africa and Middle East, the courtyard in the Dar follows the philosophy "privacy and seclusion with a minimal display of the occupant's social status to the outside world". Private courtyard offers isolated space for women to relax with sheltered courtyard tress, a pool and outdoor furniture. Another element in the design of the courtyard appeared in Mesopotamian region, this room used as a re-treat cool air to the house. According to eminent professor Das, there are two Courtyards in northern area around the Mediterranean Sea, particularly in Spain that influenced by the Roman atrium, the courtyard design in the north of Spain more solid than the Southern, which used the court for more outdoor activities that help in evolution of the courtyard dwellingtype. Lately, patio design method entered to Latin America by Spanish colonists Figure-7 presents dwelling house in Spain and the entered one in Mexico.

In Asia, particularly in Malaysia, the traditional Malay house serves citizen in rural area of Peninsular. The house design provided Malay needs, culture and environment. Many attributes appear in the old Malay house design, such as fully shaded vegetation as buffer zone. The history of the beginning of the use of the plants in landscape design in South Asia return to 14th century In Europe, single storey courtyard houses became widespread. That type of courtyard is requested by low-income class. In addition, he cited that the first courtyard built in the South by Hugo Haring in 1928, his design

modification later into L shape plan, which became popular in England and Germany during 1960s

In the modern era, the courtyard first entered to the West Coast of North America, and revealed in the Southern California due to the influence of Spanish colonial. Whereas another opinion mentioned that, the reason of the different building's style of Los Angeles influence by the movie set and film industry observed the regained of tourists to settle down in California between 1880 and 1930 created need to high accommodation that, changed the form of courtyard houses in that region. Lately, the courtyard type transferred across the United State to the East Coast when the idea of use courtyard to separate between the sleeping area from living area.

1.1.3. COURTYARD IN INDIA

The origin of traditional Indian courtyards can be traced back to the Indus Valley civilization. Climate and culture have always influenced the construction of different kinds of buildings in the passage of time. Buildings with internal courtyards are considered to be the most appropriate in warm regions. Courtyard architecture originated as far back as 3000 BC in Egypt, Iran and China. The first courtyard houses, according to historical evidence, appeared to have originated in India probably around 6500-6000 BC. When we meticulously assess different cultures, we can understand that the courtyard buildings were an integral part of the Chinese, Japanese, Spanish societies. With the shaping of various cultures, there occurred a transition from the public court to the private one. The entry of the Islamic rulers (14th century) to the northern parts of India brought the key issue of treating the open space in buildings in such a way as to respond to the harsh realities of the weather in the region. The advent of the British led to a remarkable change in the architectural style and the concept concept of the courtyard (18th century).

Courtyards in India were not just an architecture style. They, it seems, were a way of life. Courtyards reflected the society of the time and controlled the character and atmosphere within the house. Courtyards exercised an authoritative or dominating influence over the environment inside the house. They helped people adjust to the extremes of summers and the freezing winters of the Indian subcontinent. Courtyards have different names like nalukettu (the central courtyard surrounded with set of rooms) of Kerala, haveli of Rajasthan, wada houses of Gujarat, houses in pols of Ahmedabad, traditional houses of Goa, etc. The lay-out of the traditional (tharavadu) houses in Kerala was simple and designed to cater to a large number of people who lived in the joint family system. Ettukettu (a duplication of the nalukettu with four courtyards) and pathinarukettu (a duplication of the ettukettu with four courtyards) were elaborate forms of the same architecture. Every structure has provisions for sufficient sunlight and in some well designed nalukettus, there was excellent ventilation. Temperature even in the heat of summer would be remarkably lower. The architecture of the traditional tharavadu suited many people living under one roof and enjoying the commonly owned comforts of the homestead. The courtyards in the traditional homes of Kerala set apart a prominent place for the sacred thulasithara (a raised platform for tulsi). Houses in Central India have many courtyards. The first courtyard is

known as the baithak (the sitting place). Another is near the women's area called the inner courtyard. These courtyards have beautiful facades and rich variations in decor elements. What's fascinating is that these courtyards not only define the perfect spatial organisation of those times, but also act as centres for rituals, marriages, festivals and social gatherings. By looking at various houses in India, this shows that the courtyard houses evolve from a concept of creating a home around a large space.

1.1.4. COURTYARD IN WARM AND HUMID CLIMATE

The inclusion of an internal courtyard in building design in warm and humid climate is attributed to the optimization of natural ventilation in order to minimize indoor overheating conditions. The effect of design variables of courtyard buildings, such as shape, orientation and shading devices of the courtyard, on thermal performance in warm and humid climate. It is found that choosing appropriate shape of courtyard, taking the orientation into account and using good shading device can enhance the thermal performance in internal courtyard adjacent areas. In term of courtyard shape, central-close squared and U-shaped rectangular courtyards provide the optimum thermal performance compared with closed rectangular and U-shaped square courtyards, respectively. The courtyard orientation impact depends on the season, where during summer northern direction gives the optimum thermal performance due to high shading and wind speed, while during winter courtyard recommended to be oriented with an angle of 30° with respect to east to achieve high sunlit area. Last but not least, the shading tools have a positive impact on thermal performance where using trees and vegetation show better performance compared with other types of roofing. However, having space between the roof of the courtyard and its opening level highly effect on the thermal performance. Further investigation on the effect courtyard walls material, size and number of openings, and material of courtyard roof shading on thermal comfort and energy consumption need be considered in future. However, the efficiency of this strategy greatly depends on the design details of the building composition in providing appropriate airflow pattern to the courtyard. From the results of thermal measurements, a significant correlation between wall surface temperatures and indoor air temperatures is evident. A reduction of indoor air temperature below the levels of ambient is seen as a function of heat exchange between the indoor air and high thermal mass of the building fabric. However, this behavior is affected by indoor airflow patterns, which are controlled through the composition between envelope openings and the courtyard of the building. From a computational analysis, several airflow patterns are identified. A relatively better indoor thermal modification is seen when the courtyard acts as an air funnel discharging indoor air into the sky, than the courtyard acts as a suction zone inducing air from its sky opening. The earlier pattern is promoted when the courtyard is ventilated through openings found in the building envelope.

1.2. AIM

To propose a suitable design of a learning space ,which will include courtyard planning and green initiatives to provide a good learning environment.

1.3. OBJECTIVE

The objective of the thesis is to identify, evaluate and access the significant differences in thermal comfort of users by proving courtyard in warm and humid climate. The same is split into below for collating empirical evidences as below.

1. Importance of courtyard in the learning space
2. Impact of interactive learning environment for students, lecturers and other users.
3. To systematically understand the criticality of the space and role of the environment in the learning process.
4. To demonstrate via design various green initiatives and create a holistic learning built environment.

1.4. SCOPE

1. To provide an alternate learning environment for the targeted community
2. To study the impact of various parameters of courtyard in a Learning environment.
3. To study how the green design principles will transform the views and experience of the people by the economic and social merits of the proposed learning environment.

1.5. LIMITATION OF THE STUDY

The limitation of the study is as follows.

1. Measuring the impact of economic and social benefits through a green building with considerable Level of Significance using appropriate tools.
2. Impact due to building materials on indoor thermal comfort is assumed to be uniform.
3. Seasonal variations of weather and its impact on Indoor thermal comfort is not studied through out the year. i.e. study is subjected to a summer solstice.
4. Cost limitation for project execution due to limited investor interest.

CHAPTER 2

LITERATURE REVIEW

2.1.1 INTRODUCTION

Courtyard is one of the traditional architectural forms that contributed in determining climatic environment, physical and psychological in the courtyard house. In my literature review I have traced the evolution of courtyards to how it evolved over a period of time. Many researched I understand that that the courtyard design had been used since the Neolithic settlements and was extensively used from China to Morocco. One of the primary roles of courtyard spaces is to protect the occupants from the harsh outdoor conditions and provide environmental functions such as natural lighting and ventilation. The courtyard form was generally influenced by the climatic conditions of the region. In one of the studies published by Professor Knapp he explains that in China, the size of the courtyard reduced from northern (cold climates) to southern regions (warm climates). The northern region has larger and shallower courtyards to receive more solar radiation, whereas the southern region adopts smaller and deeper courtyards to prevent the solar heat gain. In general, the size and design of the courtyard's enclosure make a significant impact on its performance.

In a research published by Hyde, he highlighted that the courtyard can be divided into three major types which are: 1) Fully enclosed courtyard, 2) Semi-enclosed courtyard and 3) Semi-open courtyard. Each of the courtyard has its characteristic and the appropriate function. For instance, a fully enclosed courtyard is suitable for elongated buildings, because the natural lighting, ventilation and also comfortable spaces could be introduced to the core of the buildings through the courtyards. In addition, the environmental performance of courtyards can be optimized by considering the building shape and the heat gain control devices. Proper building and courtyard designs in consideration of the local climatic conditions would enable indoor spaces to be thermally comfortable

2.2 DESIGN VARIABLES CONSIDERATION ON THERMAL PERFORMANCE OF COURTYARD IN HOT HUMID CLIMATE

Building design is the most important factor influences the internal thermal of the buildings. The building's shape, arrangement, composition and spacing impact on the solar and wind factors. For hot climates, the most important environmental design considerations for courtyards in residential buildings are considered to be shading and ventilation effects. Shading effects of courtyards are commonly determined by the building orientations, height, and their exposure to the sky. On the other hand, the ventilation effects by courtyards mainly depend on the outdoor wind conditions or the indoor temperature difference for the stack effects. Various design consideration for Courtyard in Hot and Humid climate can be viewed in Fig 2.2.1

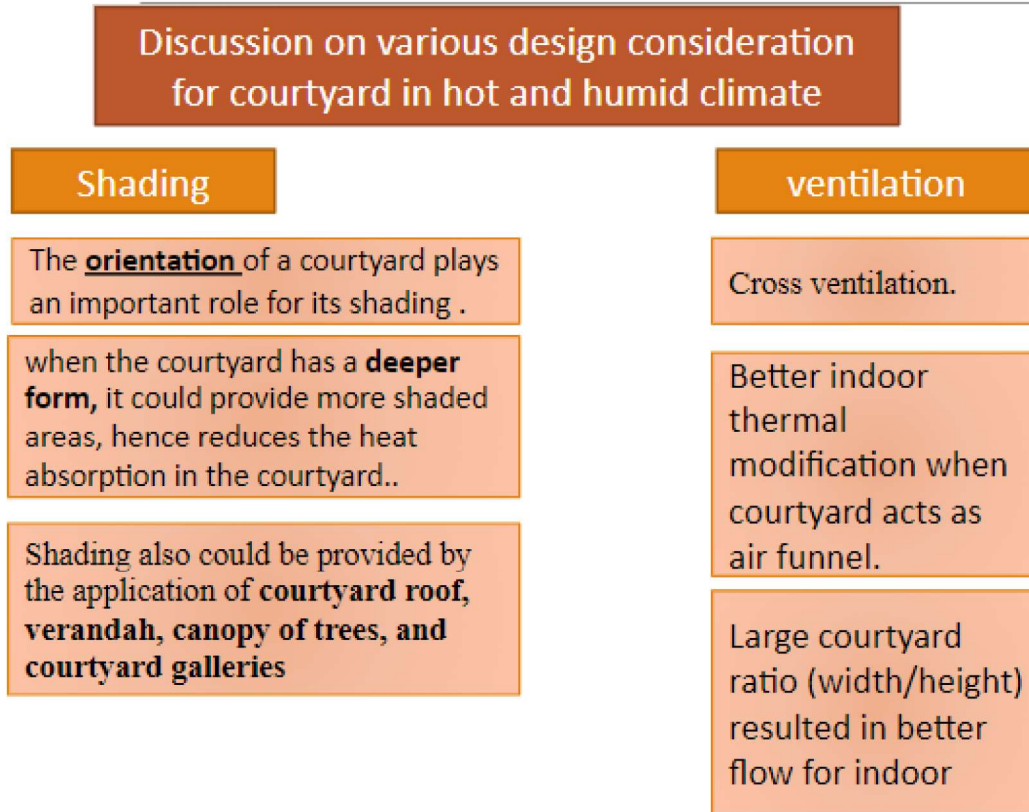


Fig 2.2.1 Design consideration for Courtyard in Hot and Humid climate

2.3 IMPACT OF COURTYARD GEOMETRICAL CONFIGURATION ON ENERGY PERFORMANCE OF BUILDINGS

The importance of courtyards is due to their location in centralized focal areas of the building or urban setting. Design variants like arcades, colonnades for producing shading enhances the thermal and visual comfort within the courtyards while integration of landscapes with water bodies, various plants, shade and light, play a fundamental role in the optimization of the environmental performance of these spaces plus improving the social interactions, productivity, working life and ultimately, well-being. Reviewing recent studies published by various scholars like J. Rodríguez, 2018; Acosta, Navarro, & Sendra, 2013; Kim, Yang, & Kang, 2014, it is deduced that the design of courtyards could be highly influential in providing thermal, visual and acoustic protections, alongside their potentials for promoting social activities. Hence, to provide the optimum level of comfort, and enhanced environmental performance, this study draws attention to the consideration of assessing geometrical configurations of courtyards and versatile alternatives and scenarios during the

early design stage passive cooling system is predominantly an inherent part of courtyards for enhancement of the environmental performances. In this regard, the impacts and interrelations of various aspects such as ventilation, spatial features solar heat and shading, thermal comfort, energy efficiency and geometrical configuration must be fully taken into consideration prior to any practical implementations. Further, Courtyards have a definite role as an environmental modifier, particularly in the context of tropical climate. Still, the quality of environmental performance can be affected by modifying the design variants of courtyards including size, enclosed wall envelope, orientation, and exposure As shown in Fig 2.3.

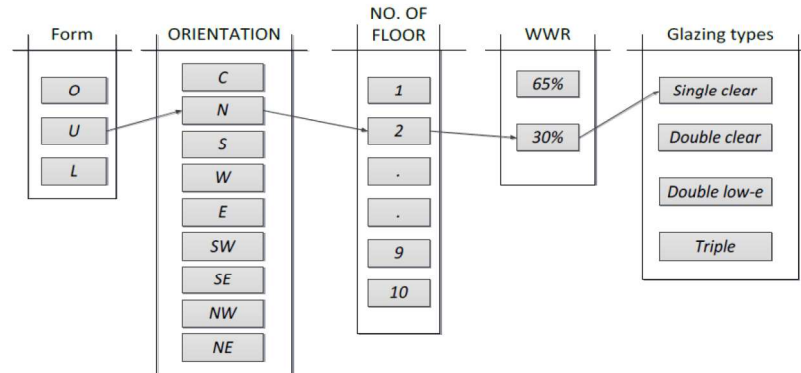


Fig 2.3.1 COURTYARD GEOMETRICAL CONFIGURATION ON ENERGY PERFORMANCE OF BUILDINGS

2.4 CFD SIMULATIONS FOR EXAMINING NATURAL VENTILATION IN THE LEARNING SPACES OF AN EDUCATIONAL BUILDING WITH COURTYARDS IN MADURAI

The aim of this paper was to investigate the potential of courtyards in optimizing natural ventilation and improving comfort levels in the learning spaces of a naturally ventilated educational institution with courtyards in the warm-humid climatic region of Madurai.

The methodology that was adopted to analyses the process was Field measurements and experimental studies were carried out to predict the indoor and outdoor environmental conditions. The numerical study was carried out using computational fluid dynamics-based simulations using Ansys Fluent as the solver. The main aim of the simulation is to understand the airflow pattern and air velocity fields inside the classrooms surrounding the courtyards for different wind directions. The study proves that courtyards are crucial elements of design for fresh air supply in the naturally ventilated buildings in warm-humid climatic conditions.

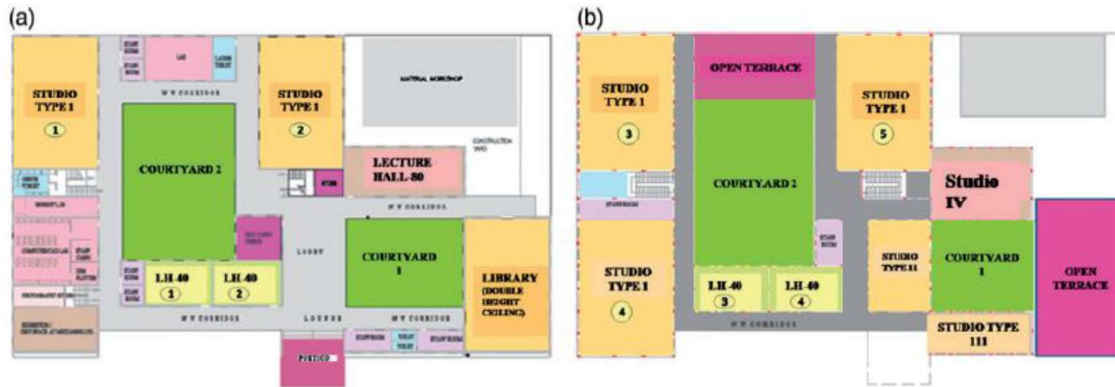


Fig 2.4.1. – THIAGARAJAR COLLEGE OF ENGINEERING

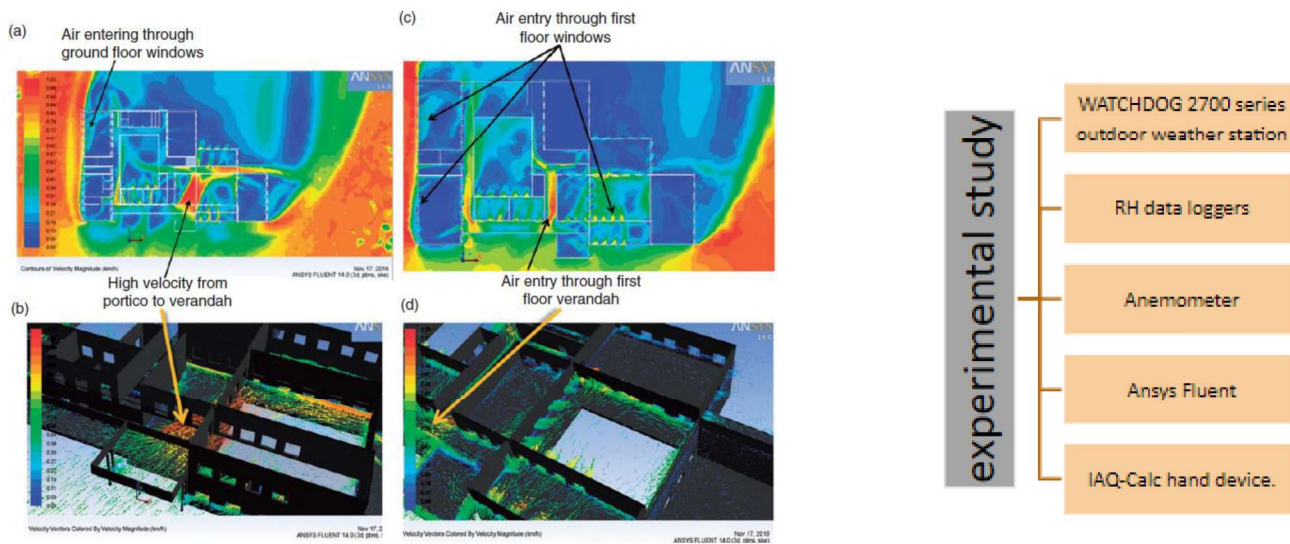


Fig 2.4.2. – ANALYSIS PROCESS OF COURTYARD –ANSYS

Paper	Climate classification	Parameter	Conclusion
CFD simulations for examining natural ventilation in the learning spaces of an educational building with courtyards in Madurai	Hot and humid	Shade	promoting natural ventilation, courtyards also provide mutual shading, thereby reducing heat gain through walls.
		Orientation	the longer axis of the courtyard should be oriented in the north-south direction to achieve better thermal comfort.
		Size	length of the courtyard should be less than 3X

This shows that usage of fans becomes mandatory in these spaces due to insufficient air movement. Fans offer an important adaptive opportunity for users at high indoor temperatures usually experienced in India. It is also noticed that the corridors act as tunnels for movement of air and help in channelizing the wind across the building. The influence of courtyard in cooling the air can be well noticed in both the cases.

2.5 A study on different natural ventilation approaches at a residential college building with the internal courtyard arrangement

This aims at studying Dyasari RC, which is an old low-rise multi residential building established in the year 1966 and is located in the University of Malaya (UM) campus in the capital city of Kuala Lumpur. This building was designed with the internal courtyard that allows numerous implementations of bioclimatic design strategies, especially in regard of natural ventilation. Eight unoccupied student rooms were selected to represent ten different scenarios, where two from eight selected rooms had been chosen to represent two different scenarios. The scenarios are concerned with the level of radiation and penetration of sunlight that influence the values of temperature and relative humidity. Different natural ventilation approaches were introduced simultaneously in all selected rooms for four weeks. Initially, the effectiveness of different ventilation approaches is obviously influenced by the position/floor level rather than the orientation of the selected rooms. The night ventilation is the most effective approach due to the lower mean temperature and higher relative humidity values. The recorded mean temperature values were below than 30 °C with the relative humidity values exceeding 70%. Other ventilation approaches namely; daytime, full-day, and no ventilation, were more than 30 °C and had exceeded 32 °C at certain rooms. The ranking of the effectiveness of the ventilation approaches was in the following order; night ventilation>daytime ventilation>full-day ventilation>no ventilation.

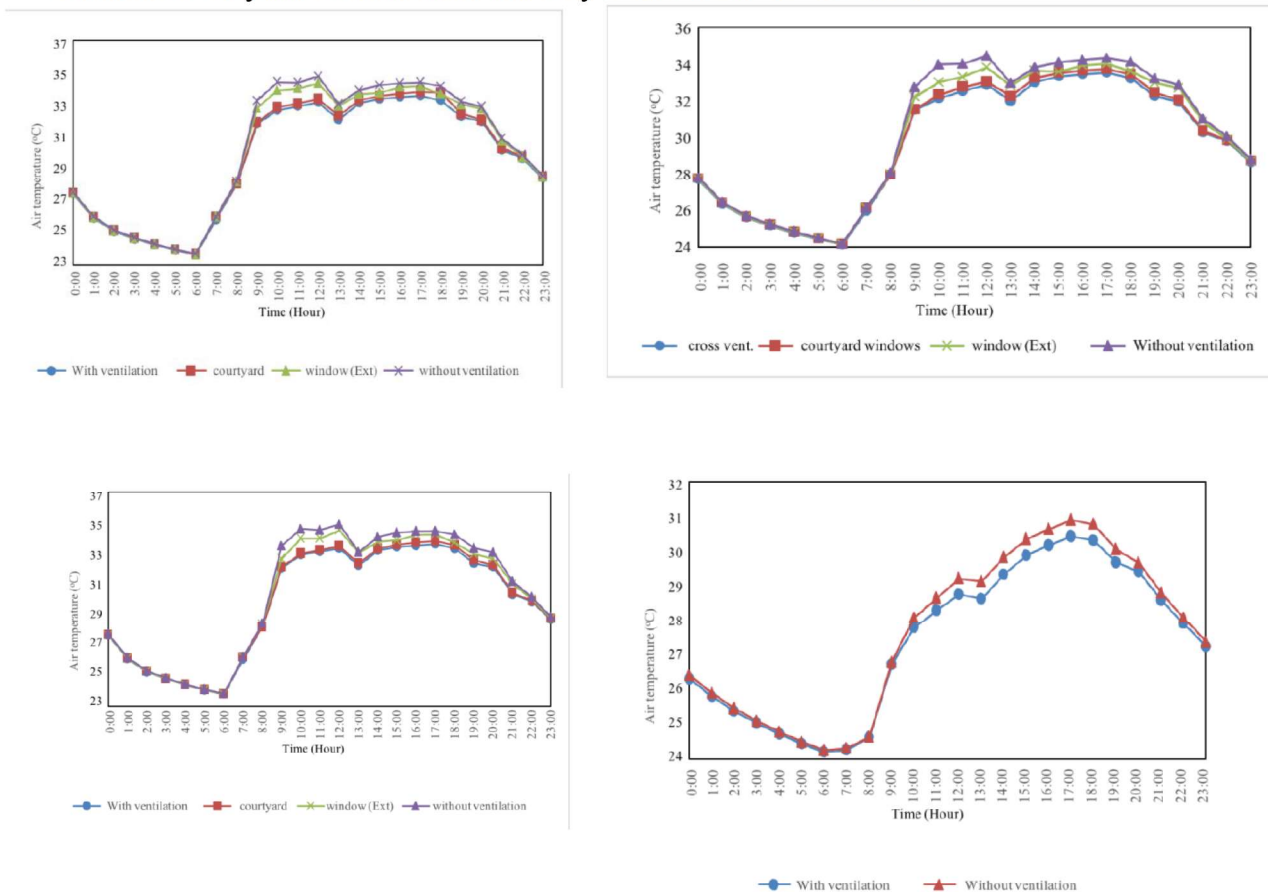


Fig 2.5.1 – ANALYSIS OF DESIGN IN PROVIDING VENTILATION

2.6 STUDY OF VIDHYA MANDIR SCHOOL

Vidya Mandir is a branch of Vidya Mandir, Mylapore. It is affiliated to the CBSE. The focus is on the wholesome development of the child at his/her own pace. The KG follows the play-way method and activities form a major part of the day in this section. Estancia Township is one of the popular residential developments in Guduvanchery, neighborhood of Chennai. Spread over an area of 82 acres, Estancia is a totally integrated township for discerning professionals to work and live. The school building for one of the leading educational institutions of Chennai, is set on a 2 acre site in the periphery of Chennai. It faces West and is adjoining an open space to the South that is used as a play area for the school. It is situated inside the Estancia Township on GST Road, Vallanchery. It is spread over two sprawling campuses on either side of the private road inside the Estancia Township. Classes LKG to 5 operate in the old campus and classes 6 to 12 operate in the new campus. Both buildings house airy, spacious classrooms and several courts and areas for free play. The total built up area is 1,40,000 sq ft.

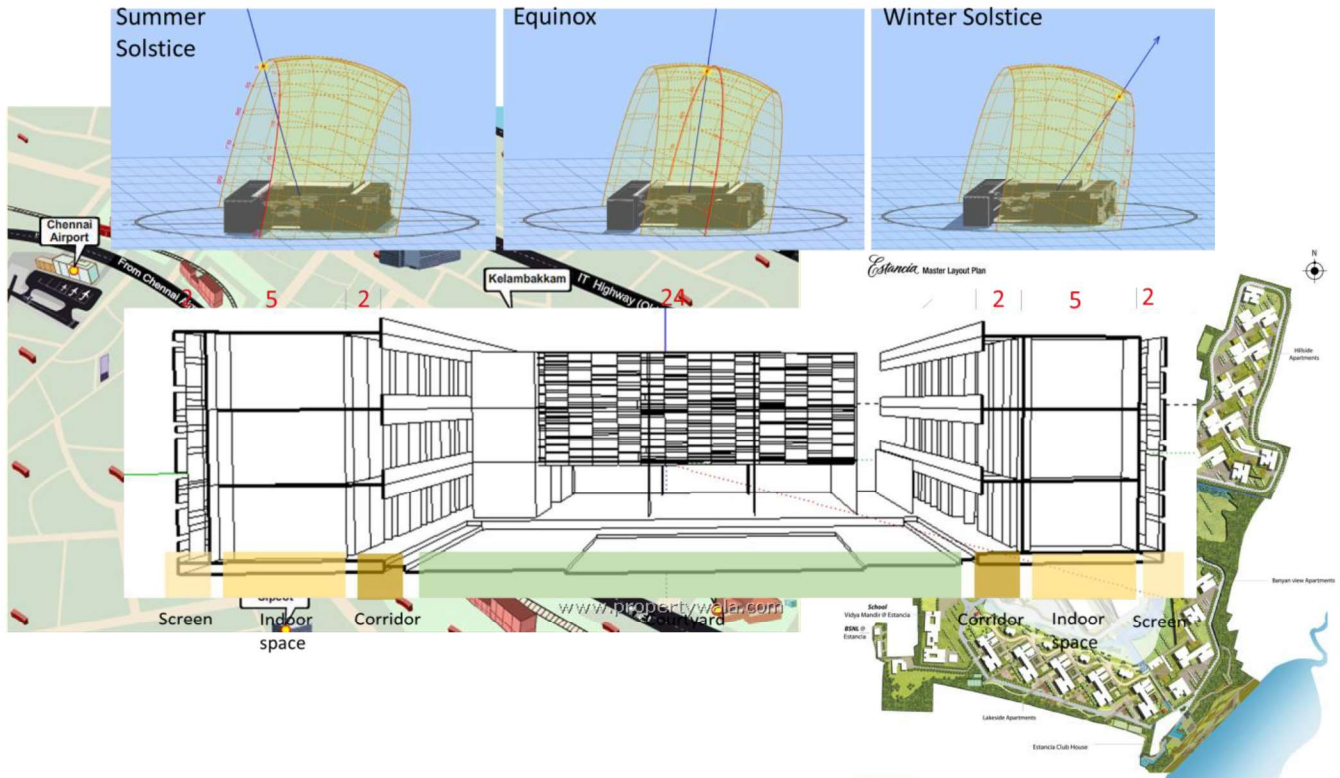


Fig 2.6.1 – PLAN, LOCATION, COURTYARD POSITIONING OF VIDHYAMANIR SCHOOL.

2.7 STUDY OF NANDHANAM KINDERGARDEN

Nandanam is a kindergarten for children between 3 to 6 years of age, and is a project that is very close to the Studio's heart. The Kindergarten is located in the Centrefield Area in Auroville. The geological structure of the area reveals that the topsoil is hard laterite on a bed of clay of varying depths. The soil is not suitable for productive agriculture with traditional methods. The area also falls in the cyclonic belt. All the classrooms and activity rooms are arranged around this through common semi covered space which forms a continuous band of activities like an internal street. The open courtyard is the constant reference and shaded by existing Neem tree, it is indeed the calm anchor that holds the entire composition together.

Pondicherry :

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	24.5	25.2	27.2	29.6	31.7	32.1	30.8	30	29.6	27.9	25.9	24.7
Min. Temperature (°C)	20.7	21	22.9	25.7	27.1	27.1	26.1	25.4	25.1	24.2	22.7	21.3
Max. Temperature (°C)	28.3	29.5	31.5	33.5	36.4	37.1	35.5	34.7	34.1	31.7	29.2	28.1
Avg. Temperature (°F)	76.1	77.4	81.0	85.3	89.1	89.8	87.4	86.0	85.3	82.2	78.6	76.5
Min. Temperature (°F)	69.3	69.8	73.2	78.3	80.8	80.8	79.0	77.7	77.2	75.6	72.9	70.3
Max. Temperature (°F)	82.9	85.1	88.7	92.3	97.5	98.8	95.9	94.5	93.4	89.1	84.6	82.6
Precipitation / Rainfall (mm)	32	9	9	18	50	45	82	154	114	229	285	144

Auroville :

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	24.3	25.1	27.1	29.5	31.6	31.8	30.5	29.8	29.4	27.8	25.7	24.4
Min. Temperature (°C)	20.4	20.7	22.6	25.5	26.9	26.8	25.9	25.2	24.9	24	22.4	21
Max. Temperature (°C)	28.2	29.5	31.6	33.5	36.4	36.9	35.2	34.5	33.9	31.6	29	27.9
Avg. Temperature (°F)	75.7	77.2	80.8	85.1	88.9	89.2	86.9	85.6	84.9	82.0	78.3	75.9
Min. Temperature (°F)	68.7	69.3	72.7	77.9	80.4	80.2	78.6	77.4	76.8	75.2	72.3	69.8
Max. Temperature (°F)	82.8	85.1	88.9	92.3	97.5	98.4	95.4	94.1	93.0	89.9	84.2	82.2
Precipitation / Rainfall (mm)	29	9	8	18	48	45	81	150	115	230	274	134

The variation in the precipitation between the driest and wettest months is 266 mm | 10 inch. The variation in temperatures throughout the year is 7.5 °C | 45.5 °F.

Table 2.7.1 TEMPERATURE COMPARISON CHART PONDICHERRY VS AUROVILLE

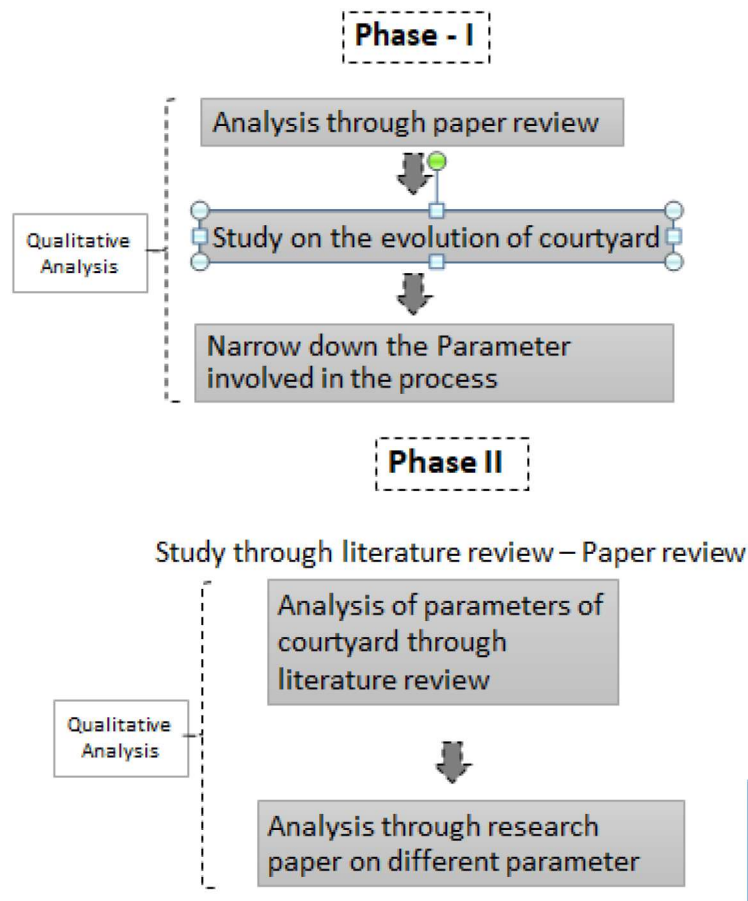


Fig 2.7.1 – PLACEMENT OF COURTYARD AND VENTILATION PLAN

CHAPTER 3 METHODOLOGY

The methodology we have deployed for the hypothesis under study is

- Multi method analysis is followed in this thesis in order to arrive at an empirical backed up conclusion.
- A thorough Investigation through literature review is conducted.
- Based on the Secondary research, the premise of the Primary Research is formed.
- Systematically data is collected through simple random sampling through scientifically framed questionnaire.
- The collated data is critically analyzed through computer aided simulation and other scientific tools to check how courtyard impacts thermal comfort in Hot and Humid climate.
- The research is concluded for significant difference if any on thermal comfort by providing courtyard in Hot and Humid climate.
- Overall approach has been split into 4 phases as seen below.



Phase III

Analysis through research paper on literature case study

Phase IV

Location under warm and humid climate

ANTALYA
KUALAUMPUR
CANTANIA

Conclusion on parameters of the courtyard with respect to the location.

Mode of Analysis for above location

Literature study

Simulation –
IESVE , Shade dat

Conclusion on parameters for respective location was simulated in Chennai

FINDINGS

CHAPTER 4 ANALYSIS AND RESULTS

4.1 ANALYSIS

The analysis of this work involves in assessing Chennai's climatic zone as the project site under study is based out of Chennai. We have various site classifications in warm and humid climate and the analysis progresses based on that. We then further progressed with concluding various parameters of the courtyard in connection with its influence over thermal comfort. It then followed by various studies and hands on simulation using tools like IESVE and Shade dat.

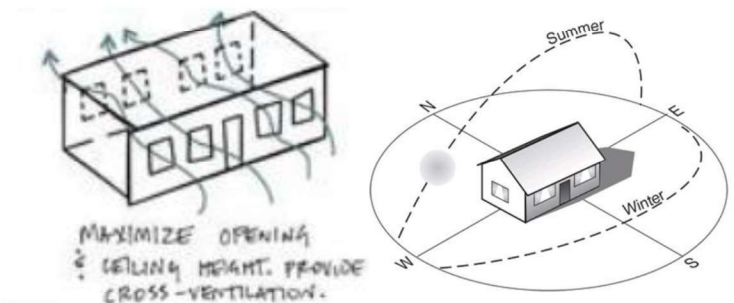
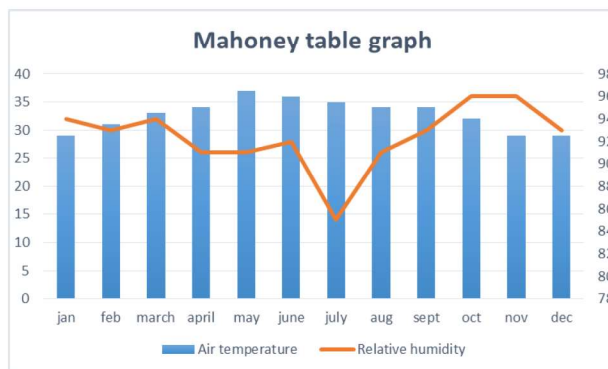
4.2.1 CHENNAI CLIMATE ANALYSIS

The Mahoney table graph displays for temperature and relative humidity in Chennai. The max. temperature reaches 40°C and RH in the month of may. The max. temperature and min RH is observed in the months of may and June. Similarly min. Temperature and max. RH is observed in the months of November and December. In the month of September the maximum temperature is 36.2 and RH 63%. Our Observation was carried in the month of September and October 2019.

Air Temperature														
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	high	AMT
Air temperature Monthl	31	32.6	34.5	35.3	39.1	38.3	36	35.2	36.2	33.6	30.6	29.5	39.1	28
monthly mean min.	16.9	18.9	22.3	23.9	24.9	24.4	24	23.4	24.3	23.2	21.8	19.7	16.9	22.2
Monthly mean range	14.1	11	12.2	12	14.2	13	12	14	11.9	15	8.8	16	low	AMR

RELATIVE HUMIDITY %													
	jan	feb	march	april	may	june	july	aug	sept	oct	nov	dec	
Monthly mean max. a.m	72	68	72	64	59	57	68	66	67	76	81	72	
monthly mean min. p.m	58	53	66	61	55	52	60	56	59	70	72	63	
Average Relative Humic	65	60.5	69	62.5	57	54.5	64	61	63	73	76.5	67.5	
Humidity group	4	3	4	4	3	3	3	4	4	4	4	4	

Table 4.1.1 Annual Air Temperature and Humidity .



S.No	Design Parameters	Design Recommendation as per MAHONEY table
1	Layout	Orientation North and South, Long axis E-W
2	Spacing	Open spaces for wind penetration
3	Air movement	Rooms single banked, permanent provision for air movement
4	Openings	Minimum opening of 25% – 40%
5	Position of openings	In windward side
6	walls	Heavy walls, over 8 hrs time lag
7	Roofs	Heavy roofs, over 8 hrs time lag
8	Rain protection	Protection necessary for heavy rain
9	External features	Space for outdoor activities

Table 4.1.2 Mahoney table graph- Design Parameters.

Plotting the overheated period shows that only in the month of Jan, Feb, March and Dec we experience comfort temperature

OVERHEATED PERIOD												
month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
a.m time of heating	9:40	9:15	8.15	H	H	H	H	H	H	H	8:25	9:25
p.m time of cooling	7:40	9:00	H	H	H	H	H	H	H	H	H	8:00

Table 4.1.3 Overheated Period – Annual comparison.

LOCATION: Chennai-Madras, Tamil Nadu, IND
Latitude/Longitude: 13.0° North, 80.18° East, Time Zone from Greenwich 5
Data Source: ISHRAE 432790 WMO Station Number, Elevation 16 m

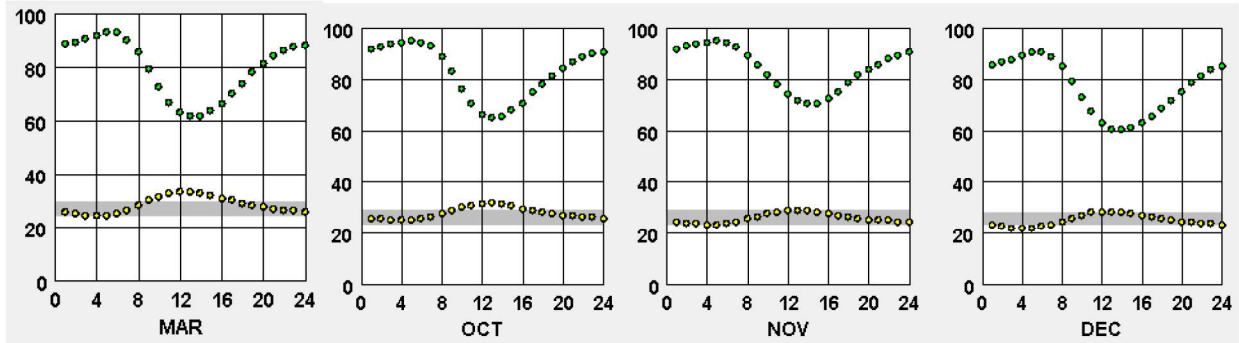


Fig 4.2.1 Chennai Weather graph-ISHRAE

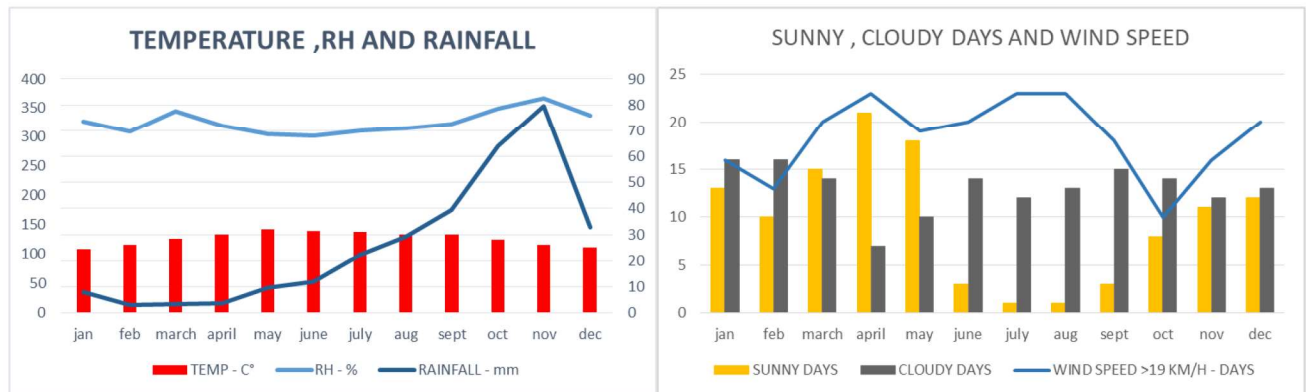


Fig 4.2.2 Temperature, RH and Wind speed Graph

Relative humidity gradually starts to increase from the month of September. Rainfall in Chennai starts from the month of Sept and there is a gradual decrease in clear sky where as in in month of April, July and Aug is clear sky.

The parameters i.e. temperature , RH and rainfall plotted together we infer that the critical months April to July where the temperature is high with no rain ,whereas the end of the year i.e. from September to November rainfall is high which brings relative humidity also to the

higher level. Prevailing winds in Chennai are usually southwesterly between April and October and north-easterly during the rest of the year.

The comparative analysis of sunny days ,cloudy and wind speed infers that even when the temperature is high that is month of April and may we have good wind speed and again the month of Nov – Dec during monsoon time

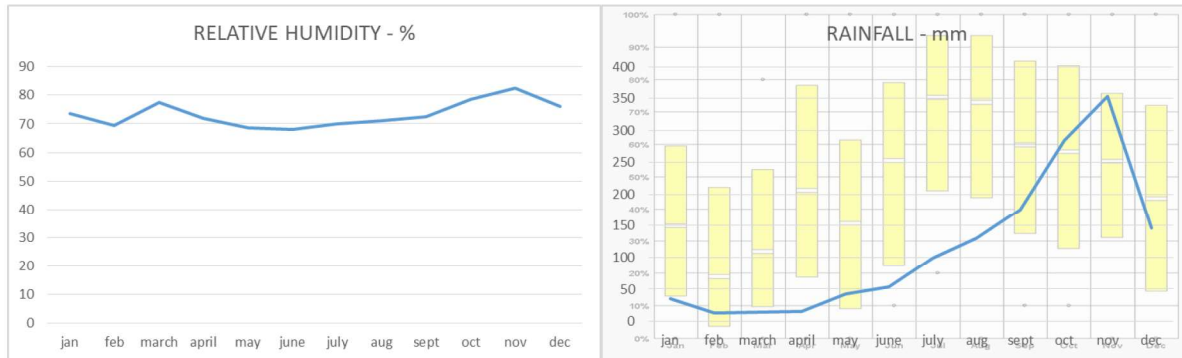


Fig 4.2.3 Relative Humidity and Rainfall Chart

Solstice and Equinox review reveals that in the month of June temperature is in the higher side and there is also traces of rainfall. In month of September there is a decrease in temperature comparatively and monsoon starts in the early of October. In the month of December it's a comfortable month were all the climatic parameters are in the comfortable level.

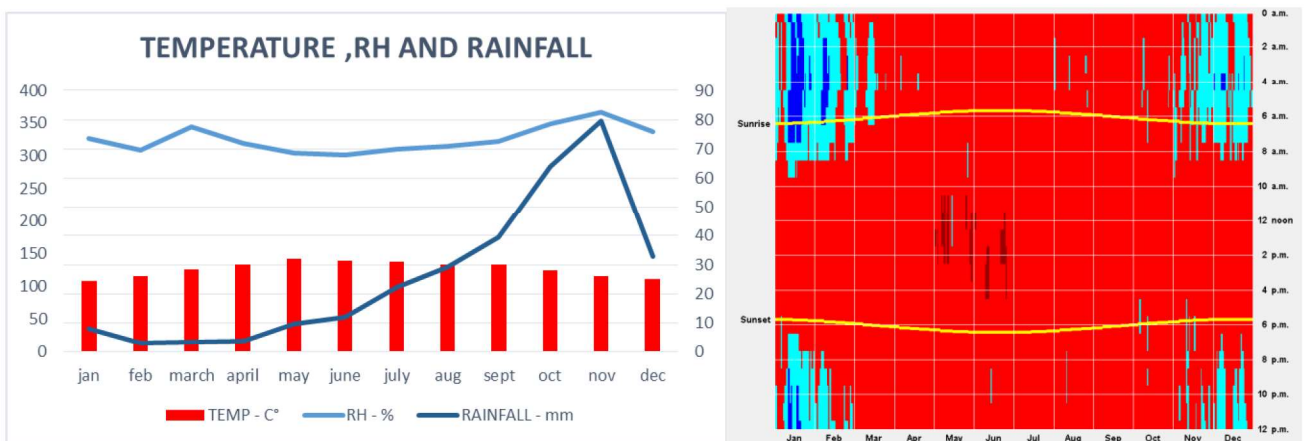


Fig 4.2.4 Temperature and Humidity – Solistice and Equinox

Air Temperature												
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Air temperature Monthl	31	32.6	34.5	35.3	39.1	38.3	36	35.2	36.2	33.6	30.6	29.5
monthly mean min.	16.9	18.9	22.3	23.9	24.9	24.4	24	23.4	24.3	23.2	21.8	19.7

Orientation

Designing acc. to the wind movement

Proposing opening in the envelope for better comfort

Courtyard as a element will also help to enhance the thermal comfort

Wind movement

Cross-ventilation

Introducing buffers to cut through direct solar radiation

The timetable shows that user occupancy starts from 8:00am to evening 4:00pm

According to the user occupancy time we can design our shading device accordingly.

Climate analysis

Orientation - windward, south & south west

Orientation of the blocks can be according to the windward side which will enhance the comfort.

20

4.3 STANDARDS

Various standards we had referred in this project are TSS- SCHOOL, NBC and GRIHA. Important analysis was a based on the below mentioned benchmarks.

Sl.No.	Description	Continuous Building Areas	Other areas
1	2	3	4
A.	Minimum road width	7.20m	Minimum 7.2m for schools upto higher secondary level and industrial training institutes. For others, min. 9 m
B.	Maximum Height	18.30m.	
C.	Normally Permissible FSI	2.0	
D.	Minimum Setbacks	Where Street Alignment/new road is prescribed, it shall be from that street alignment/narrow line. In the case of others, it shall be from the property boundary.	
(i)	Front Setback	6m	6m
(ii)	Side Setback	Nil For schools - 2m	6m
(iii)	Rear Setback	Nil For schools - 2m	6m
E.	a) Structures permissible in the minimum prescribed Front set back, Side setback and Rear set back are given in the rule 28 b) In addition, Gate pillars, gopurams, and incidental structures (with height not exceeding 4m) such as servant room, cloak room, and watch man booth, cycle stand, Kitchen and toilets are permissible in these minimum prescribed setback spaces.		

Note:

- In Continuous Building Area (CBA), there shall be atleast 1m wide internal passage from rear to front in ground level or ground floor, directly accessible to road.
- In the case of schools, the development shall conform to the additional safety standards stated in the Annexure - XV.
- The maximum height of the building shall not exceed 18.30 metres provided water tanks, chimneys, Architectural features such as flag masts, gopurams, minarets, steeples and other ornamental structures which are not intended for human habitation may be permitted subject to a ceiling of 30.5 metres from ground level.

F.	Parking spaces shall be provided within the site conforming to standards prescribed in the Annexure - IV.
G.	Rainwater harvesting provisions as prescribed in the Annexure - XXII.
H.	The minimum width of corridor shall be as given in rule 42
I.	Special regulations for physically disabled stated in the rule 43 shall be adhered to.
J.	The applicant not being a government department or agency shall deposit a sum at the rate of 50% of the infrastructure and amenity charges as a refundable non-interest earning security and earnest deposit. The deposit shall be refunded on completion of development as per the approved plan as certified by Competent Authority; if not, it would be forfeited.
K.	The reservation of Land for community recreational purposes such as park or play ground required in these regulations shall be as given in the rule 41.

(13) Educational Institutions

(a) Government Schools or Local Body schools

(A) Corporation/ Municipal Areas

1 car space for every 500sq.m of class room area or part thereof and 1 two wheeler space for every 50sq.m of class room or part thereof and one cycle space for every 10sq.m of class room area or part thereof.

(B) Panchayat Areas

1 two-wheeler space for every 50sq.m of class room area or part thereof and one cycle space for every 5sq.m of class room area or part thereof.

(b) Private Schools

(A) Corporation or Municipal Areas

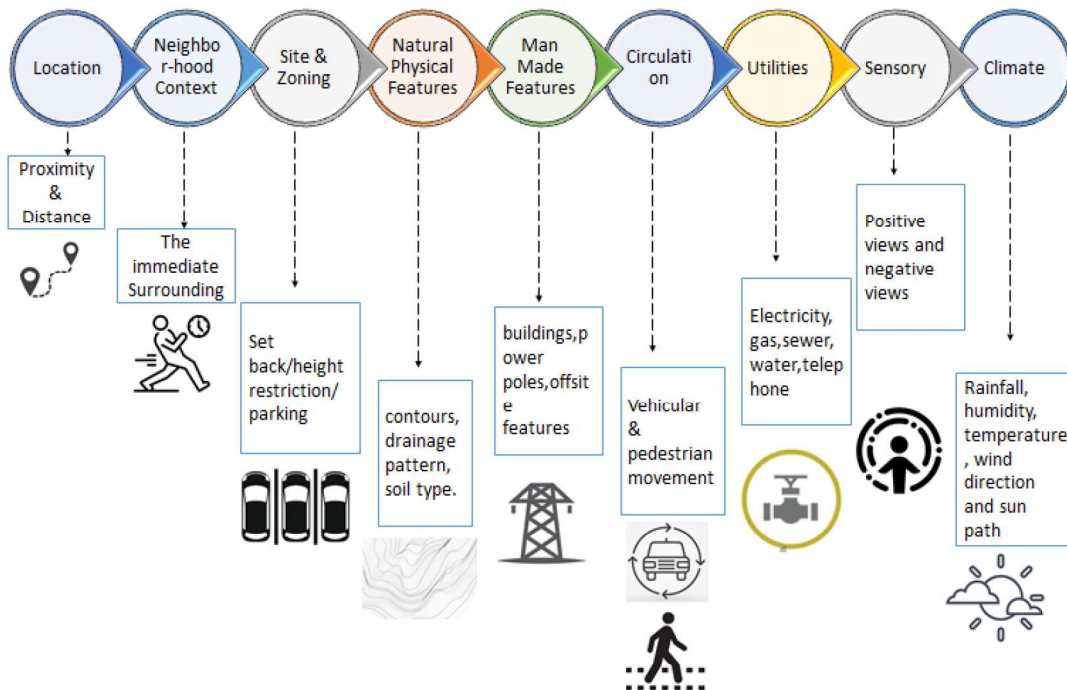
1 car space for every 100sq.m of class room area or part thereof and 1 two wheeler space for every 50sq.m of class room or part thereof and one cycle space for every 10sq.m of class room area or part thereof.

(B) Panchayat Areas

1 car space for every 300sq.m of class room area or part thereof and 1 two-wheeler space for every 50sq.m of class room area or part thereof and one cycle space for every 5sq.m. of class room area or part thereof.

Note: 50% of the car spaces specified above shall be provided in the front area abutting the road so as to act as a recessed parking area for the vehicles coming for drop/pick up for students.

42. Corridor / Verandah Width.— The minimum width of corridor or verandah within buildings shall be as given below.



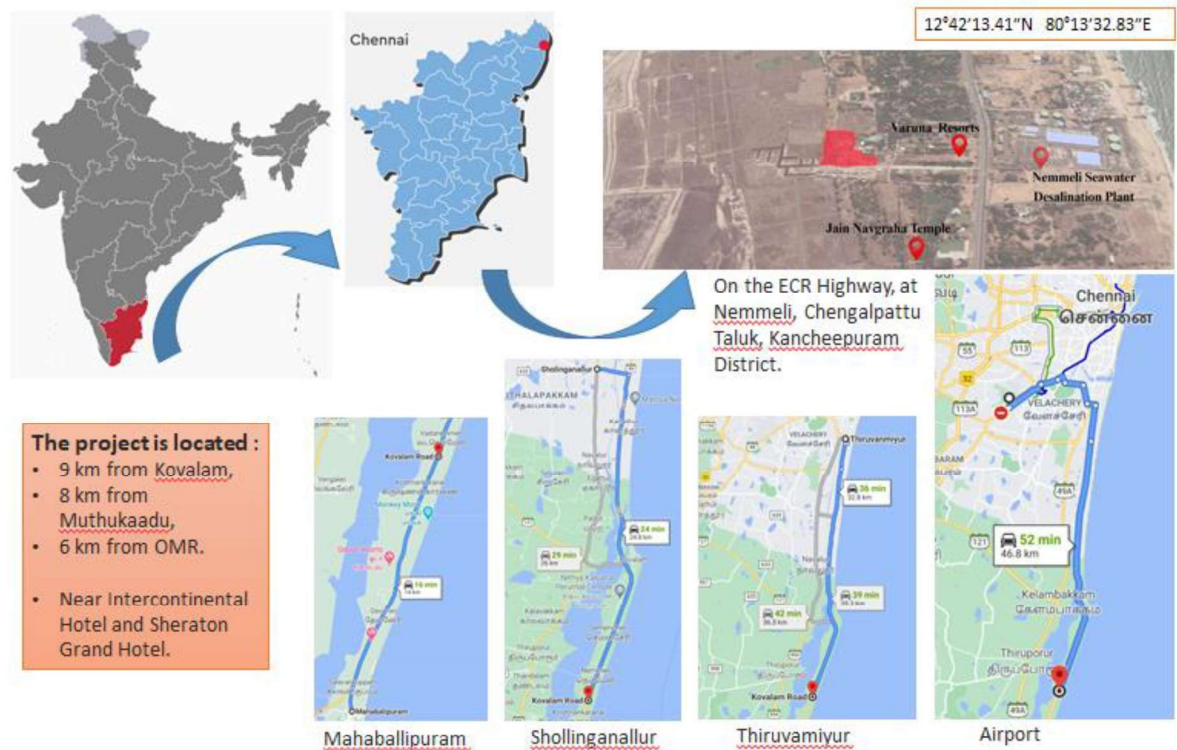
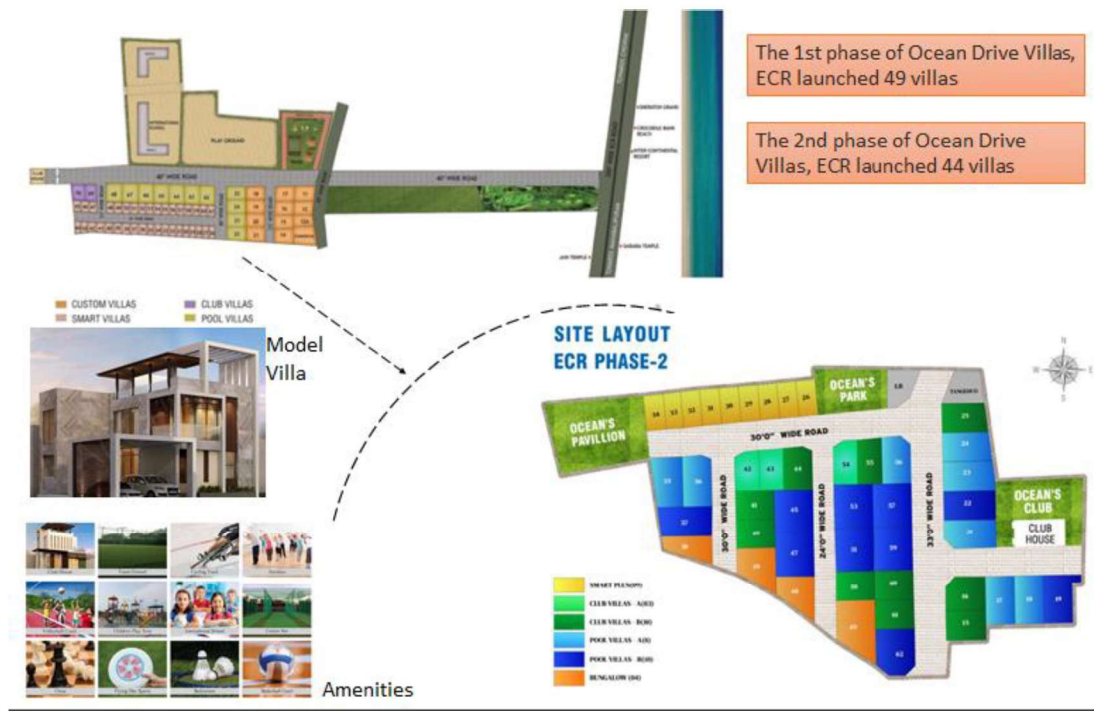


FIG 4.3.1 Project Site Location and Layout

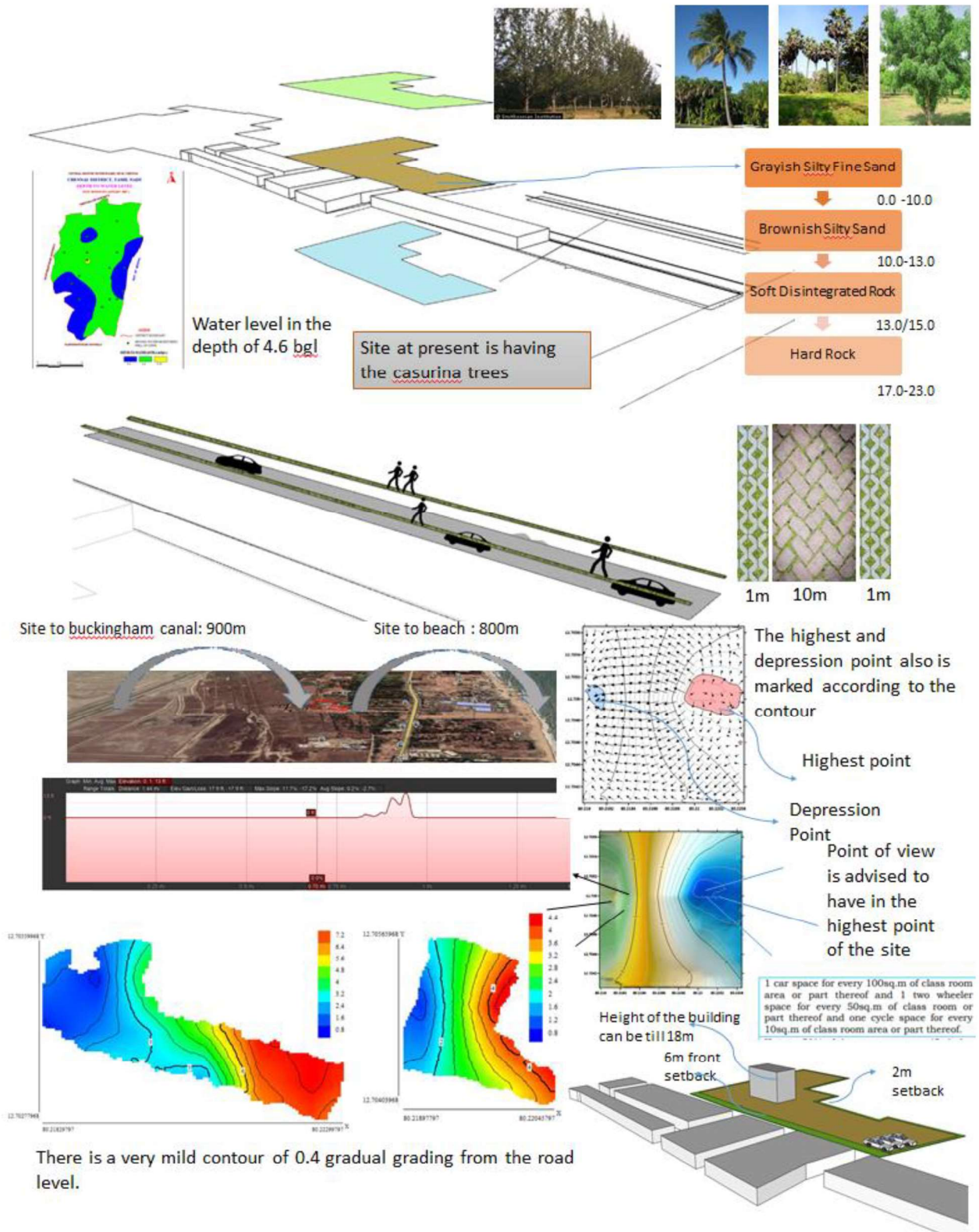
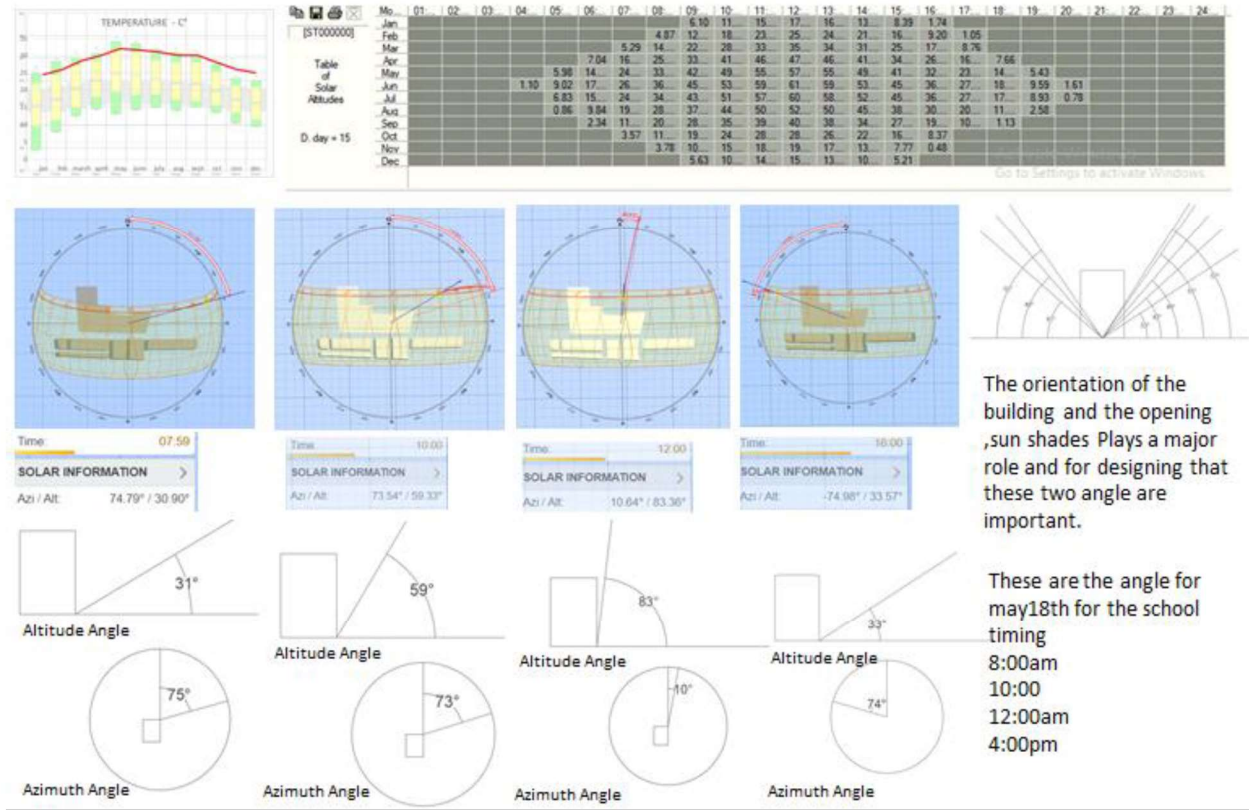


Fig 4.2.3 Neighborhood Analysis

The orientation of the building and the opening ,sun shades Plays a major role and for designing that these two angle are important.



The above figure gives us the angles for may18th for the school timing as listed below

- 8:00am
- 10:00
- 12:00am
- 4:00pm

The art of learning starts right from the womb

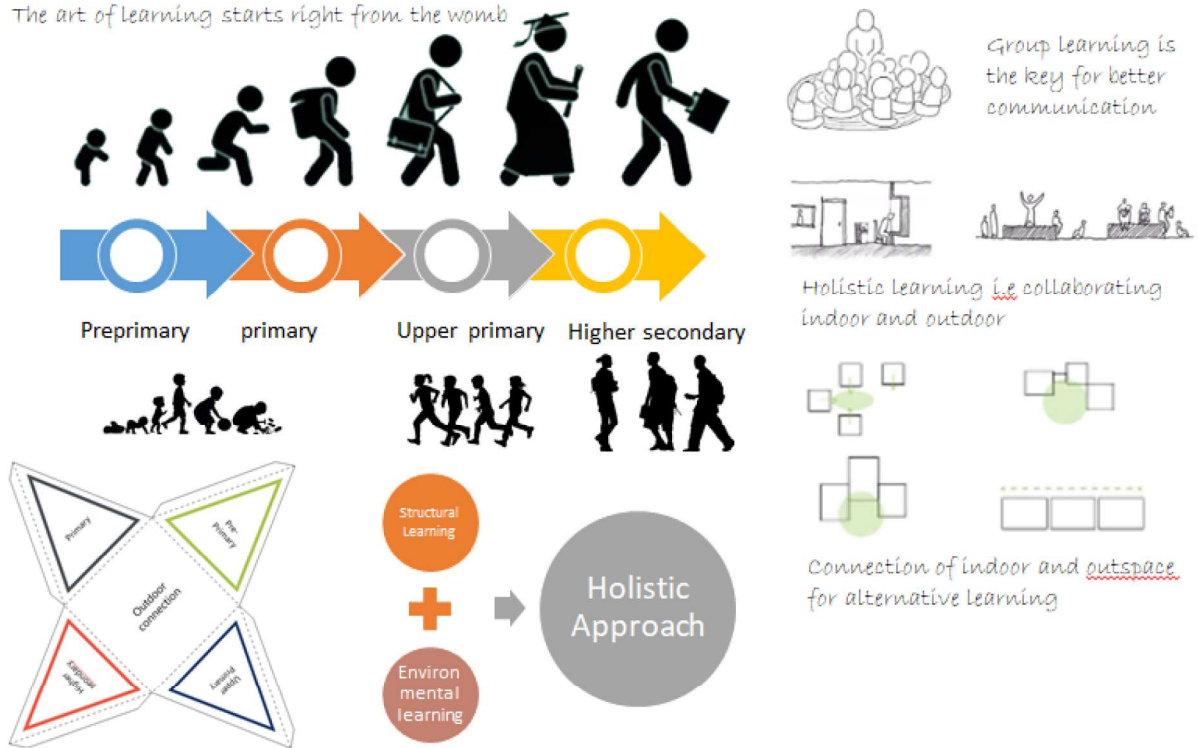
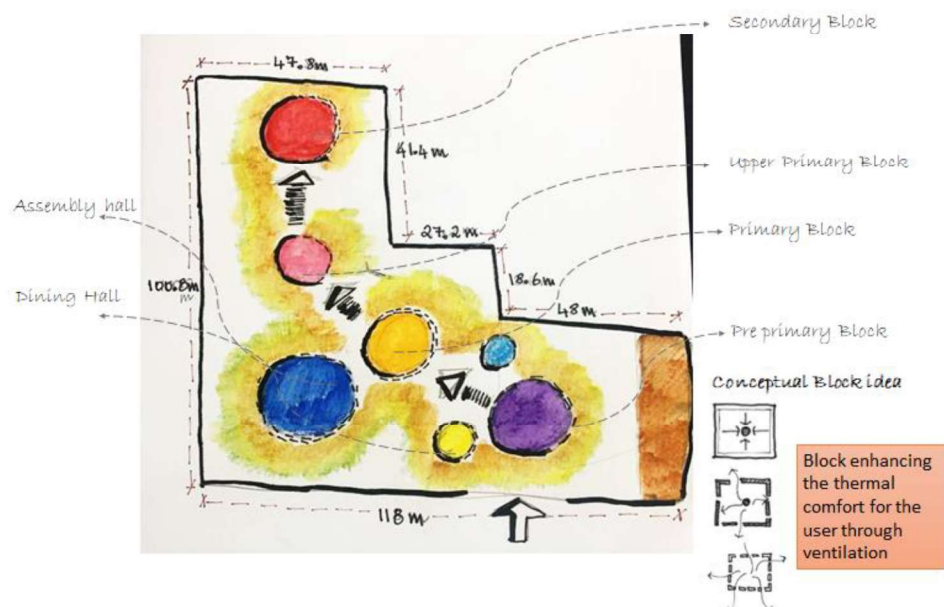


Fig 4.2.3 Holistic learning approach

The way how blocks are placed also impacts the thermal comfort through ventilation



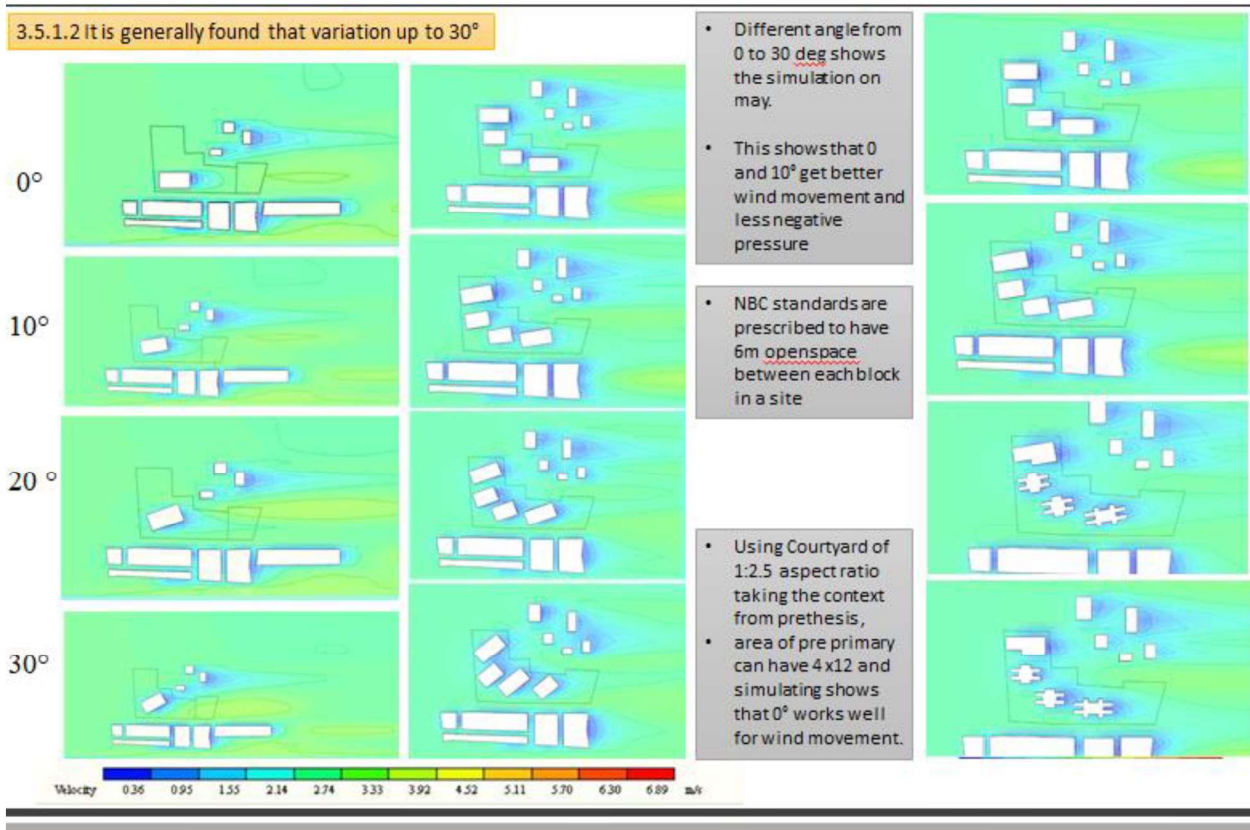
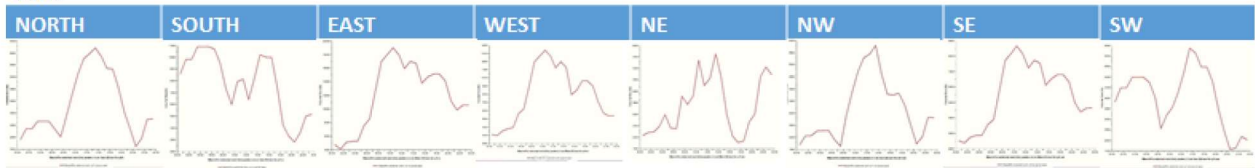


Fig 4.2.3 Simulation – Angle approach

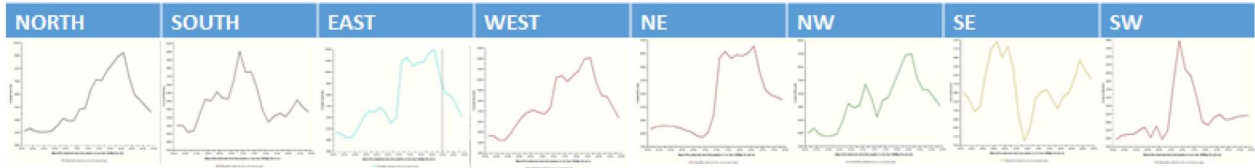
Above figure reveals that Different angle from 0 to 30 deg. shows the simulation on May. This shows that 0 and 10° get better wind movement and less negative pressure. NBC standards are prescribed to have 6m open space between each block in a site. Using Courtyard of 1:2.5 aspect ratio taking the context from pre-thesis, area of pre primary can have 4 x 12 and simulating shows that 0° works well for wind movement.

From the below depicted analysis, With respect to the month of December E, NW and S works well constant through out the day that users are using the space that is from morning 8:00am to evening 4:00pm. SE and E are having constant wind movement from 8:00 in June.

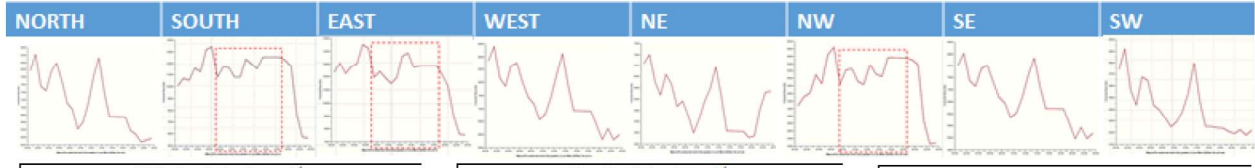
JUNE



MAY



DEC



	8:00	10:00	12:00	14:00	16:00	18:00
N	2.8	4.6	5.8	5.9	5.4	4
S	8.2	7.8	7	9	9.8	9.8
E	14.4	18	16	16.2	14	14.2
W	10.5	11.5	11.5	11.2	8	9
NE	3.6	4.6	4.2	5	2.5	1.8
NW	2.2	4.4	4.5	5.4	3.8	3.5
SE	6.5	8.2	7.2	7.2	6	6.5
SW	3.2	3.4	4.5	6	5.4	4.3

	8:00	10:00	12:00	14:00	16:00	18:00
N	4	4.5	5.5	7	8	8.5
S	6.8	6.5	8.5	9.5	10.5	11.5
E	6.2	5.8	7	10.8	10.8	11.8
W	3.9	4.1	4.6	4.2	3.4	3.4
NE	2	1.8	3.4	4.8	4.7	5
NW	3.4	4	3.6	3.8	4.5	4.5
SE	3.2	2.5	2.2	2.5	2.6	2.6
SW	2.3	3	4.2	3.4	2.5	2.7

	8:00	10:00	12:00	14:00	16:00	18:00
N	7	6.5	7.5	7.7	6.7	6.7
S	7.3	6.5	7.8	8.2	6.8	6.9
E	12.3	11.9	13	13.1	12.8	12.8
W	11	10.2	11.5	11.3	12.2	12.2
NE	4.6	3.8	5.1	5.6	3.5	3.5
NW	4.9	5	5.5	5	5.45	5.45
SE	6.5	5.8	7.2	7.5	6.2	6.2
SW	3.4	3.3	3.45	3.55	3.22	3.2

Fig 4.2.4 Ventilation Rate

4.4.1 PRE PRIMARY BLOCK VENTILATION ANALYSIS

	AREA	No. of Students	NO.	SQ.M.	
1	Pre-kg	25	1	80	80
2	LKG	25	1	80	80
3	UKG	25	1	80	80
4	Library	50	1	150	150
5	Activity room/Dinnig	60	1	150	150
6	staffroom	6	1	60	60
7	Toilet hall		1	80	80

Volume flow for pre-primary block

Acc. to ASHRAE no. of air exchange in school should be between 5-6 (per hour)

$$\text{Ventilation rate (V)} = \frac{N \times \text{room volume}}{3600} \text{ m}^3/\text{s}$$

number of air changes per hour (N)
3600 is the number of seconds in an hour

$$\text{Ventilation rate (V)} = 4 \text{ m}^3/\text{s}$$

This is respect to the over all Pre primary block

	8:00	10:00	12:00	14:00	16:00	18:00
N	4	4.5	5.5	7	8	8.5
S	6.8	6.5	8.5	9.5	10.5	11.5
E	6.2	5.8	7	10.8	10.8	11.8
W	3.9	4.1	4.6	4.2	3.4	3.4
NE	2	1.8	3.4	4.8	4.7	5
NW	3.4	4	3.6	3.8	4.5	4.5
SE	3.2	2.5	2.2	2.5	2.6	2.6
SW	2.3	3	4.2	3.4	2.5	2.7

	8:00	10:00	12:00	14:00	16:00	18:00
N	7	6.5	7.5	7.7	6.7	6.7
S	7.3	6.5	7.8	8.2	6.8	6.9
E	12.3	11.9	13	13.1	12.8	12.8
W	11	10.2	11.5	11.3	12.2	12.2
NE	4.6	3.8	5.1	5.6	3.5	3.5
NW	4.9	5	5.5	5	5.45	5.45
SE	6.5	5.8	7.2	7.5	6.2	6.2
SW	3.4	3.3	3.45	3.55	3.22	3.2

	8:00	10:00	12:00	14:00	16:00	18:00
N	2.8	4.6	5.8	5.9	5.4	4
S	8.2	7.8	7	9	9.8	9.8
E	14.4	18	16	16.2	14	14.2
W	10.5	11.5	11.5	11.2	8	9
NE	3.6	4.6	4.2	5	2.5	1.8
NW	2.2	4.4	4.5	5.4	3.8	3.5
SE	6.5	8.2	7.2	7.2	6	6.5
SW	3.2	3.4	4.5	6	5.4	4.3

4.4.2 PRIMARY BLOCK VENTILATION ANALYSIS

PRIMARY BLOCK :900				
AREA	No. of Students	NO.	SQ.M.	
Classroom (1to5)	25	5	80	400
Activity room	50	1	100	100
Activity room	25	3	50	150
Staff room		1	80	80
Toilet		1	80	80

Volume flow for primary block

Acc. to ASHRAE no.of air exchange in school should be between 5-6 (per hour)

$$\text{Ventilation rate (V)} = \frac{N \times \text{room volume}}{3600} \text{ m}^3/\text{s}$$

number of air changes per hour (N)
3600 is the number of seconds in an hour

$$\text{Ventilation rate (V)} : 6 \text{ m}^3/\text{s}$$

This is respect to the over all primary block

UPPER PRIMARY BLOCK : 600				
AREA	No. of Students	NO.	SQ.M.	
Classroom (6to8)	25	3	80	240
Activity room	50	1	100	100
Lab	25	1	50	50
Staff room		1	80	80
Toilet		1	80	80

Volume flow for Upper primary block

Acc. to ASHRAE no.of air exchange in school should be between 5-6 (per hour)

$$\text{Ventilation rate (V)} = \frac{N \times \text{room volume}}{3600} \text{ m}^3/\text{s}$$

number of air changes per hour (N)
3600 is the number of seconds in an hour

$$\text{Ventilation rate (V)} : 4 \text{ m}^3/\text{s}$$

This is respect to the over all Upper primary block

May - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	4	4.5	5.5	7	8	8.5
S	6.8	6.5	8.5	9.5	10.5	11.5
E	6.2	5.8	7	10.8	10.8	11.8
W	3.9	4.1	4.6	4.2	3.4	3.4
NE	2	1.8	3.4	4.8	4.7	5
NW	3.4	4	3.6	3.8	4.5	4.5
SE	3.2	2.5	2.2	2.5	2.6	2.6
SW	2.3	3	4.2	3.4	2.5	2.7

DEC - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	7	6.5	7.5	7.7	6.7	6.7
S	7.3	6.5	7.8	8.2	6.8	6.9
E	12.3	11.9	13	13.1	12.8	12.8
W	11	10.2	11.5	11.3	12.2	12.2
NE	4.6	3.8	5.1	5.6	3.5	3.5
NW	4.9	5	5.5	5	5.45	5.45
SE	6.5	5.8	7.2	7.5	6.2	6.2
SW	3.4	3.3	3.45	3.55	3.22	3.2

JUNE - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	2.8	4.6	5.8	5.9	5.4	4
S	8.2	7.8	7	9	9.8	9.8
E	14.4	18	16	16.2	14	14.2
W	10.5	11.5	11.5	11.2	8	9
NE	3.6	4.6	4.2	5	2.5	1.8
NW	2.2	4.4	5.4	5.4	3.8	3.5
SE	6.5	8.2	7.2	7.2	6	6.5
SW	3.2	3.4	4.5	6	5.4	4.3

May - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	4	4.5	5.5	7	8	8.5
S	6.8	6.5	8.5	9.5	10.5	11.5
E	6.2	5.8	7	10.8	10.8	11.8
W	3.9	4.1	4.6	4.2	3.4	3.4
NE	2	1.8	3.4	4.8	4.7	5
NW	3.4	4	3.6	3.8	4.5	4.5
SE	3.2	2.5	2.2	2.5	2.6	2.6
SW	2.3	3	4.2	3.4	2.5	2.7

DEC - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	7	6.5	7.5	7.7	6.7	6.7
S	7.3	6.5	7.8	8.2	6.8	6.9
E	12.3	11.9	13	13.1	12.8	12.8
W	11	10.2	11.5	11.3	12.2	12.2
NE	4.6	3.8	5.1	5.6	3.5	3.5
NW	4.9	5	5.5	5	5.45	5.45
SE	6.5	5.8	7.2	7.5	6.2	6.2
SW	3.4	3.3	3.45	3.55	3.22	3.2

JUNE - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	2.8	4.6	5.8	5.9	5.4	4
S	8.2	7.8	7	9	9.8	9.8
E	14.4	18	16	16.2	14	14.2
W	10.5	11.5	11.5	11.2	8	9
NE	3.6	4.6	4.2	5	2.5	1.8
NW	2.2	4.4	5.4	5.4	3.8	3.5
SE	6.5	8.2	7.2	7.2	6	6.5
SW	3.2	3.4	4.5	6	5.4	4.3

4.4.3 SECONDARY BLOCK VENTILATION ANALYSIS

SECONDARY BLOCK :900				
AREA	No. of Students	NO.	SQ.M.	
Classroom (9to12)	25	4	80	320
Activity room	50	1	100	100
Lab	25	3	80	240
Staff room		1	80	80
Toilet		1	80	80

Volume flow for Secondary block

Acc. to ASHRAE no. of air exchange in school should be between 5-6 (per hour)

$$\text{Ventilation rate (V)} = \frac{N \times \text{room volume}}{3600} \quad \text{m}^3/\text{s}$$

number of air changes per hour (N)
3600 is the number of seconds in an hour

$$\text{Ventilation rate (V)} : 6 \text{ m}^3/\text{s}$$

This is respect to the over all secondary block

May - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	4	4.5	5.5	7	8	8.5
S	6.8	6.5	8.5	9.5	10.5	11.5
E	6.2	5.8	7	10.8	10.8	11.8
W	3.9	4.1	4.6	4.2	3.4	3.4
NE	2	1.8	3.4	4.8	4.7	5
NW	3.4	4	3.6	3.8	4.5	4.5
SE	3.2	2.5	2.2	2.5	2.6	2.6
SW	2.3	3	4.2	3.4	2.5	2.7

DEC - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	7	6.5	7.5	7.7	6.7	6.7
S	7.3	6.5	7.8	8.2	6.8	6.9
E	12.3	11.9	13	13.1	12.8	12.8
W	11	10.2	11.5	11.3	12.2	12.2
NE	4.6	3.8	5.1	5.6	3.5	3.5
NW	4.9	5	5.5	5	5.45	5.45
SE	6.5	5.8	7.2	7.5	6.2	6.2
SW	3.4	3.3	3.45	3.55	3.22	3.2

JUNE - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	2.8	4.6	5.8	5.9	5.4	4
S	8.2	7.8	7	9	9.8	9.8
E	14.4	18	16	16.2	14	14.2
W	10.5	11.5	11.5	11.2	8	9
NE	3.6	4.6	4.2	5	2.5	1.8
NW	2.2	4.4	5.4	5.4	3.8	3.5
SE	6.5	8.2	7.2	7.2	6	6.5
SW	3.2	3.4	4.5	6	5.4	4.3

In the below table we can infer that in May, June and December NW and SW addresses the mentioned ventilation rate. In the months of May, June and December SE addresses the mentioned ventilation rate.

600m2 block : 4 m³/s

May - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	4	4.5	5.5	7	8	8.5
S	6.8	6.5	8.5	9.5	10.5	11.5
E	6.2	5.8	7	10.8	10.8	11.8
W	3.9	4.1	4.6	4.2	3.4	3.4
NE	2	1.8	3.4	4.8	4.7	5
NW	3.4	4	3.6	3.8	4.5	4.5
SE	3.2	2.5	2.2	2.5	2.6	2.6
SW	2.3	3	4.2	3.4	2.5	2.7

DEC - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	7	6.5	7.5	7.7	6.7	6.7
S	7.3	6.5	7.8	8.2	6.8	6.9
E	12.3	11.9	13	13.1	12.8	12.8
W	11	10.2	11.5	11.3	12.2	12.2
NE	4.6	3.8	5.1	5.6	3.5	3.5
NW	4.9	5	5.5	5	5.45	5.45
SE	6.5	5.8	7.2	7.5	6.2	6.2
SW	3.4	3.3	3.45	3.55	3.22	3.2

JUNE - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	2.8	4.6	5.8	5.9	5.4	4
S	8.2	7.8	7	9	9.8	9.8
E	14.4	18	16	16.2	14	14.2
W	10.5	11.5	11.5	11.2	8	9
NE	3.6	4.6	4.2	5	2.5	1.8
NW	2.2	4.4	5.4	5.4	3.8	3.5
SE	6.5	8.2	7.2	7.2	6	6.5
SW	3.2	3.4	4.5	6	5.4	4.3

900 m2 block : 6 m³/s

May - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	4	4.5	5.5	7	8	8.5
S	6.8	6.5	8.5	9.5	10.5	11.5
E	6.2	5.8	7	10.8	10.8	11.8
W	3.9	4.1	4.6	4.2	3.4	3.4
NE	2	1.8	3.4	4.8	4.7	5
NW	3.4	4	3.6	3.8	4.5	4.5
SE	3.2	2.5	2.2	2.5	2.6	2.6
SW	2.3	3	4.2	3.4	2.5	2.7

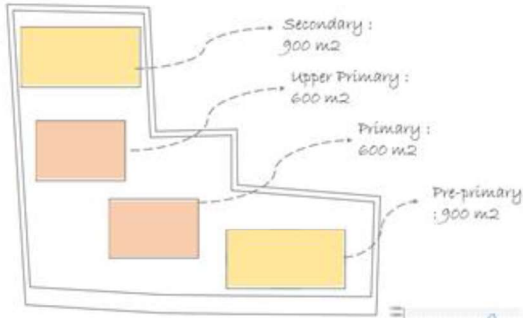
DEC - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	7	6.5	7.5	7.7	6.7	6.7
S	7.3	6.5	7.8	8.2	6.8	6.9
E	12.3	11.9	13	13.1	12.8	12.8
W	11	10.2	11.5	11.3	12.2	12.2
NE	4.6	3.8	5.1	5.6	3.5	3.5
NW	4.9	5	5.5	5	5.45	5.45
SE	6.5	5.8	7.2	7.5	6.2	6.2
SW	3.4	3.3	3.45	3.55	3.22	3.2

JUNE - Ventilation Rate m ³ /s						
	8:00	10:00	12:00	14:00	16:00	18:00
N	2.8	4.6	5.8	5.9	5.4	4
S	8.2	7.8	7	9	9.8	9.8
E	14.4	18	16	16.2	14	14.2
W	10.5	11.5	11.5	11.2	8	9
NE	3.6	4.6	4.2	5	2.5	1.8
NW	2.2	4.4	5.4	5.4	3.8	3.5
SE	6.5	8.2	7.2	7.2	6	6.5
SW	3.2	3.4	4.5	6	5.4	4.3

4.4.3. Monthly Ventilation Rate

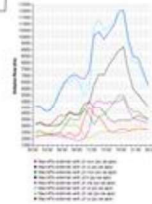
Pre-primary, primary, upper primary and secondary

AREA	SIZE	ASPECT RATIO	ORIENTATION
144	4 x 4	1:1; 1:2; 1:2.5	N-E
800	6X6X6		South and S-E-S-W
920	6X8X6		
1040	6X12X6		
1148	6X15X6		
800			
400			



Pre primary block are iterated with 4x10 m courtyard size of aspect ratio of 1:2.5

West orientation shows the ventilation rate between 4 to 4.5 m3/s

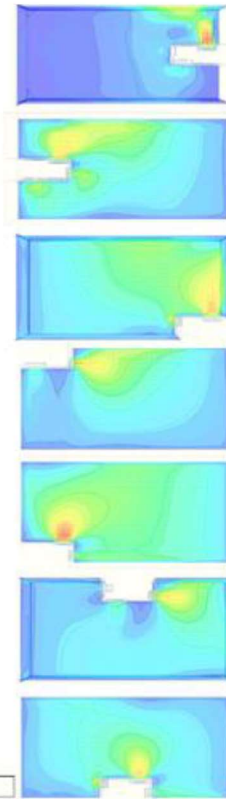
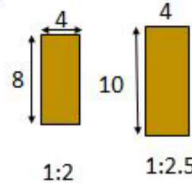


Pre-primary : 900 m2



From prethesis we can infer that Built space between 144 to 900 m2 courtyard size can be between 4 to 6 in 1:2.5 aspect ratio

Taking 4 as the base size for the courtyard and placing that in aspect ratio of 1:2 and 1:2.5



Temperature

MONTHS	Temp	RH
Jan	25.15	83
Feb	26.35	80
March	29.2	76
April	31.5	71
May	33.8	63
June	32.15	59
July	31.15	67
August	30.3	71
September	29.75	74
October	29.5	81
November	27.15	83
December	26.05	82

Wind speed for achieving thermal comfort should be 3 m/s

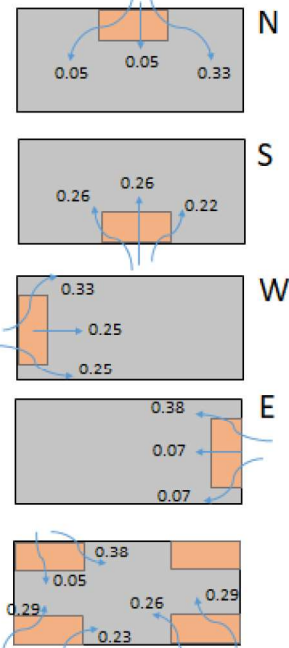
Wind speed for achieving the acceptable condition for the critical month i.e. month of may 0.60 m/s

Table 9 Desirable Wind Speeds (m/s) for Thermal Comfort Conditions
(Clause 5.2.3.1)

Dry Bulb Temperature, °C (1)	Relative Humidity (Percentage)							
	30 (2)	40 (3)	50 (4)	60 (5)	70 (6)	80 (7)	90 (8)	
28	*	*	*	*	*	*	*	
29	*	*	*	*	*	0.06	0.19	
30	*	*	*	0.06	0.24	0.53	0.85	
31	*	0.06	0.24	0.53	1.04	1.47	2.10	
32	0.20	0.46	0.94	1.59	2.26	3.04	**	
33	0.77	1.36	2.12	3.60	**	**	**	
34	1.85	2.72	**	**	**	**	**	
35	3.20	**	**	**	**	**	**	

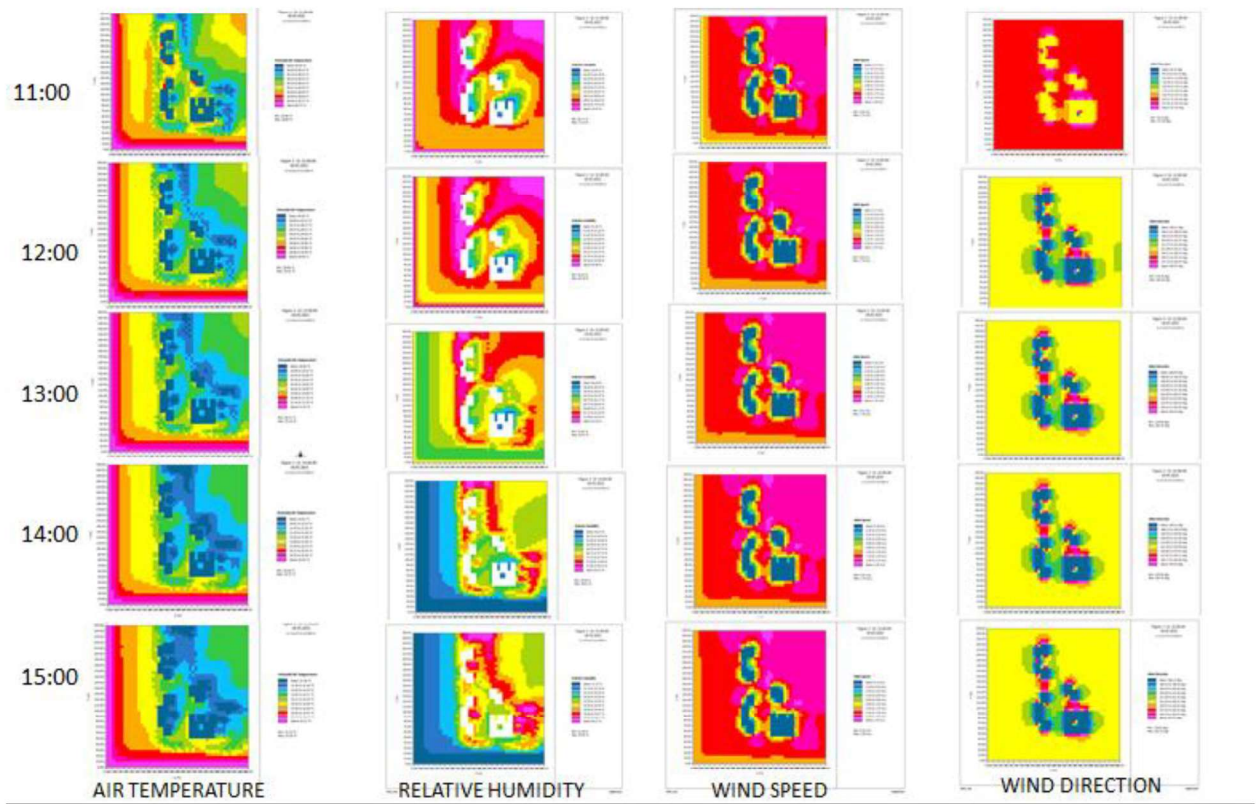
Table 10 Minimum Wind Speeds (m/s) for Just Acceptable Warm Conditions
(Clause 5.2.3.1)

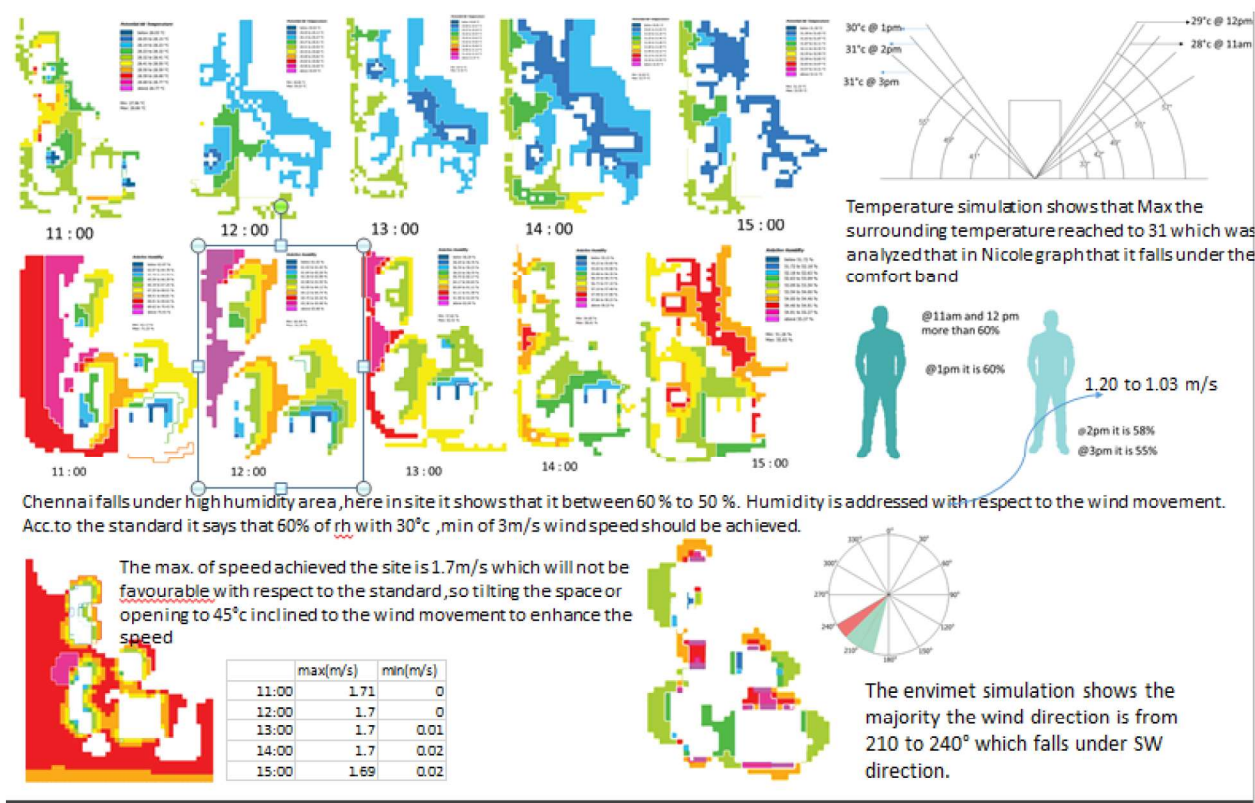
Dry Bulb Temperature, °C (1)	Relative Humidity (Percentage)							
	30 (2)	40 (3)	50 (4)	60 (5)	70 (6)	80 (7)	90 (8)	
28	*	*	*	*	*	*	*	
29	*	*	*	*	*	*	*	
30	*	*	*	*	*	*	*	
31	*	*	*	*	*	0.06	0.23	
32	*	*	*	0.09	0.29	0.60	0.94	
33	*	0.04	0.24	0.60	1.04	1.85	2.10	
34	0.15	0.46	0.94	1.60	2.26	3.05	**	
35	0.68	1.36	2.10	3.05	**	**	**	
36	1.72	2.70	**	**	**	**	**	



Windspeed in the critical month of may shows courtyard in orientation of S, W and SW get more wind speed comparative to other orientation

From prethesis we can infer that Built space between 144 to 900 m² courtyard size can be between 4 to 6 in 1:2.5 aspect ratio. Taking 4 as the base size for the courtyard and placing that in aspect ratio of 1:2 and 1:2.5. Moreover, one can infer that Windspeed in the critical month of May shows courtyard in orientation of S ,W and SW get more wind speed comparative to other orientation.





Temperature simulation shows that Max the surrounding temperature reached to 31 which was analyzed that in Nicole graph that it falls under the comfort band. Chennai falls under high humidity area, here in site it shows that it between 60% to 50%. Humidity is addressed with respect to the wind movement. According to the standard it says that 60% of rh with 30°C, min of 3m/s wind speed should be achieved. The envimet simulation shows the majority the wind direction is from 210 to 240° which falls under SW direction.

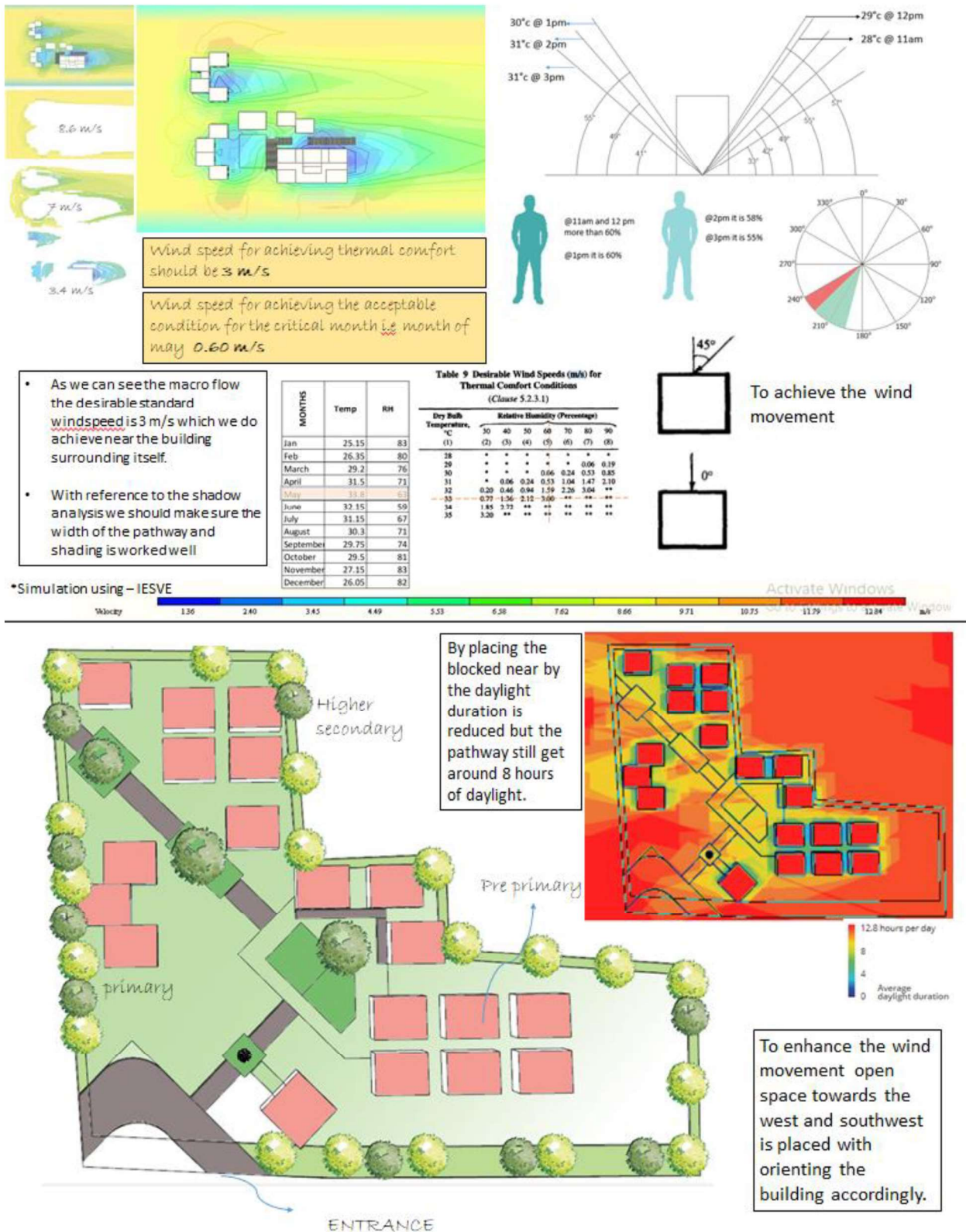
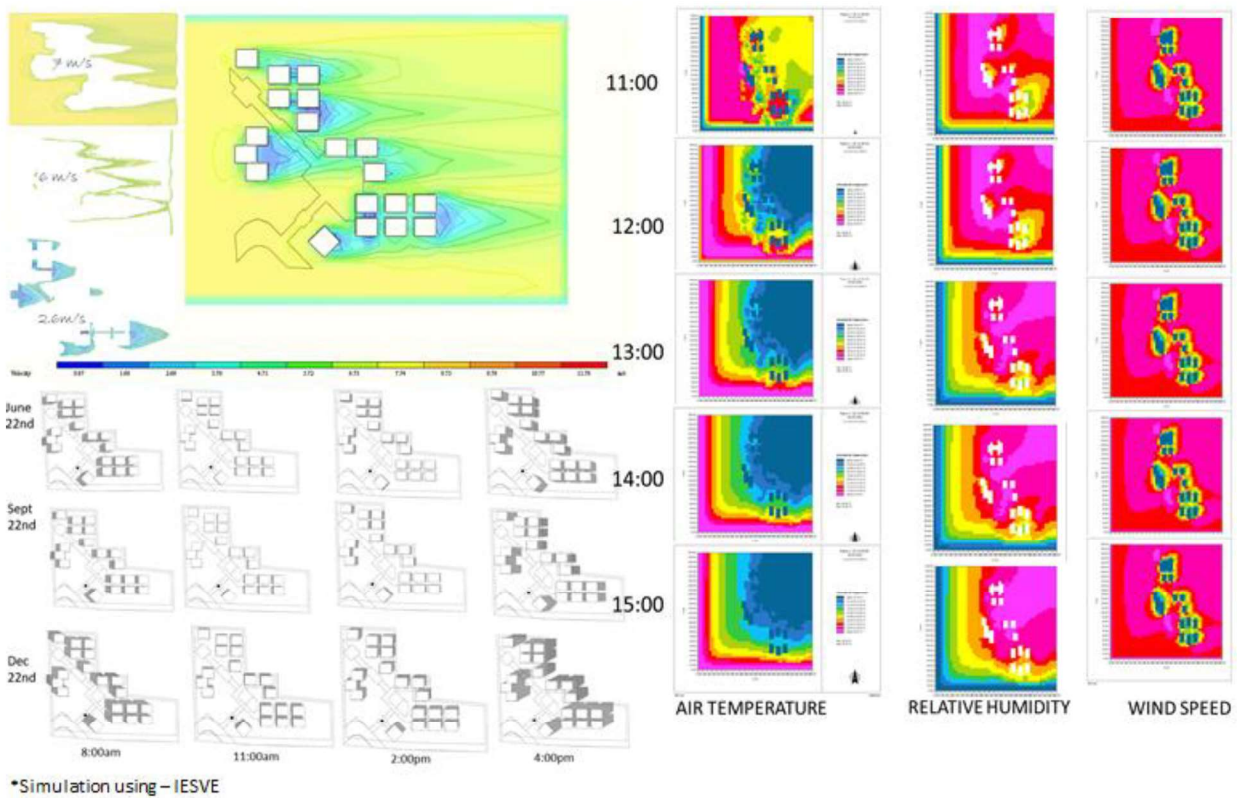


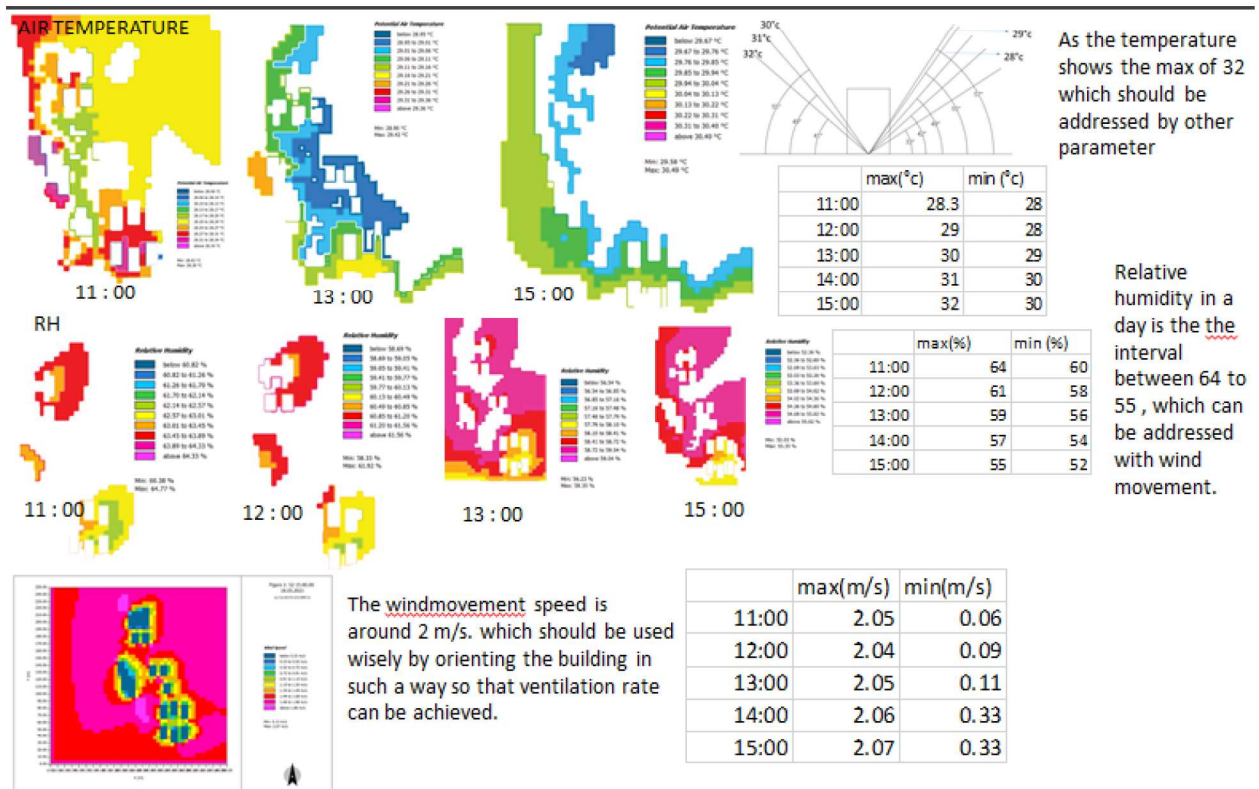
FIG 4.4. Wind Analysis

As we can see the macro flow the desirable standard wind speed is 3 m/s which we do achieve near the building surrounding itself. With reference to the shadow analysis we should make sure the width of the pathway and shading is worked well. By placing the blocked near by the daylight duration is reduced but the pathway still get around 8 hours of daylight. To enhance the wind movement open space towards the west and southwest is placed with orienting the building accordingly.

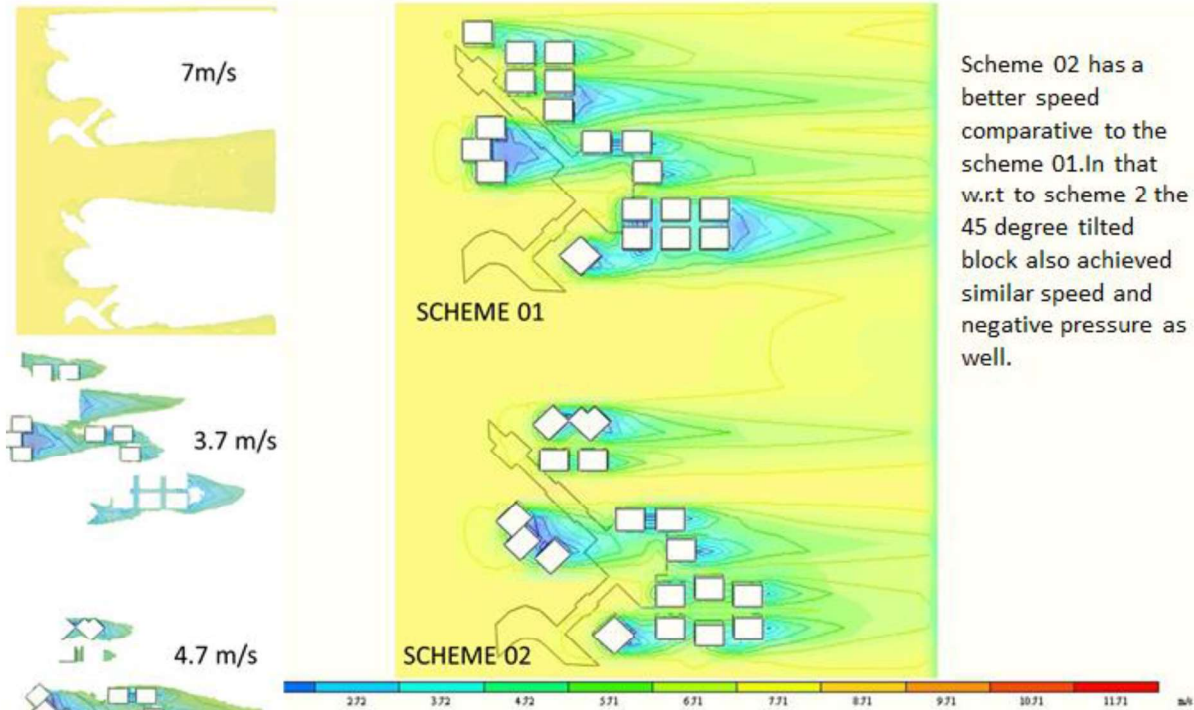


4.4.2 Wind Analysis -2

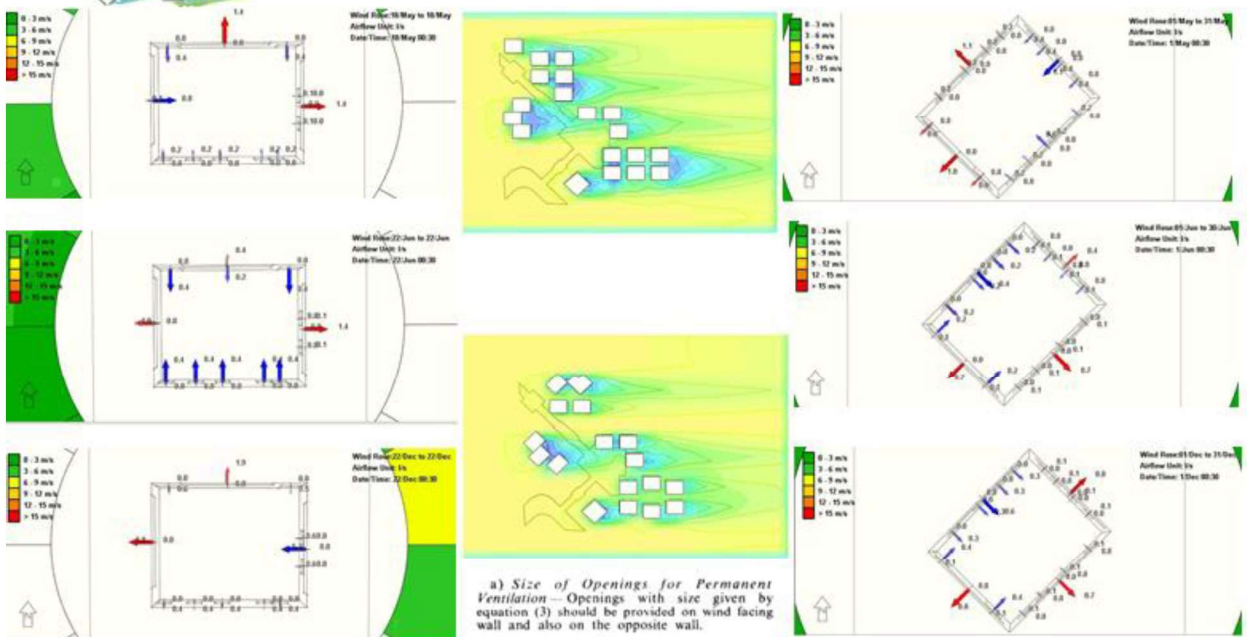
The wind movement speed is around 2 m/s. which should be used wisely by orienting the building in such a way so that ventilation rate can be achieved. Relative humidity in a day is the interval between 64 to 55 , which can be addressed with wind movement. As the temperature shows the max of 32 which should be addressed by other parameter



4.4.3 Wind Analysis -3



Scheme 02 has a better speed comparative to the scheme 01. In that w.r.t to scheme 2 the 45 degree tilted block also achieved similar speed and negative pressure as well.



a) Size of Openings for Permanent Ventilation — Openings with size given by equation (3) should be provided on wind facing wall and also on the opposite wall.

$$A = \frac{Q}{KV} \quad \dots (3)$$

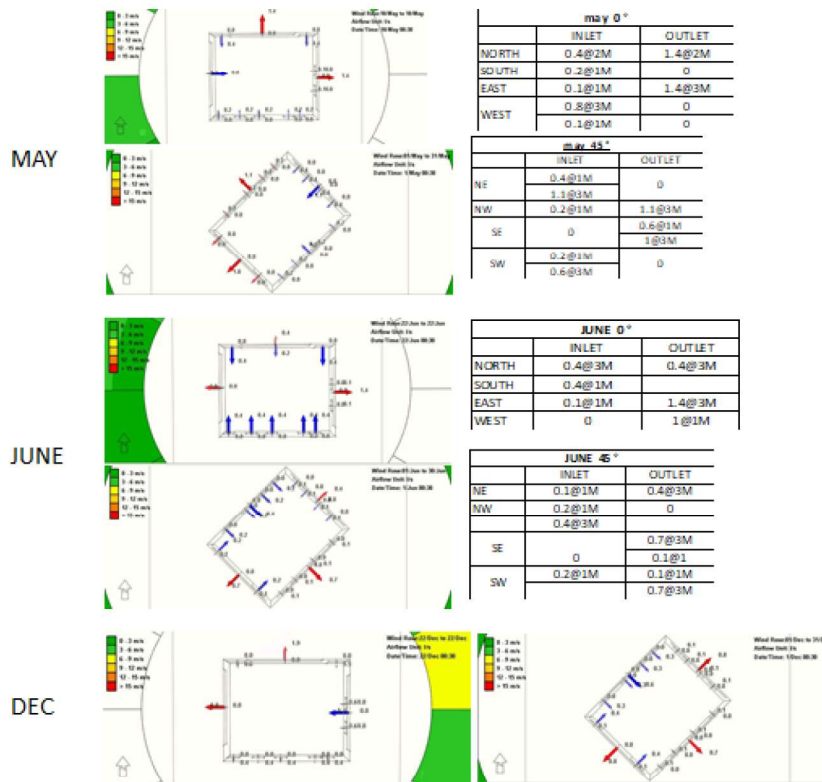
where

A = area of openings provided on wall (assumed equal for each wall) in m^2 ,
 Q = desired rate of air flow in m^3/h ,
 V = prevailing outdoor wind speed in m/h , and
 K = the coefficient of flow which may be taken as 0.6 for wind perpendicular to the

Area : 0.5 for 80 msq

4.4.4 Wind Analysis -4

From the above analysis, We can infer that Scheme 02 has a better speed comparative to the scheme 01. In that w.r.t to scheme 2 the 45 degree tilted block also achieved similar speed and negative pressure as well.



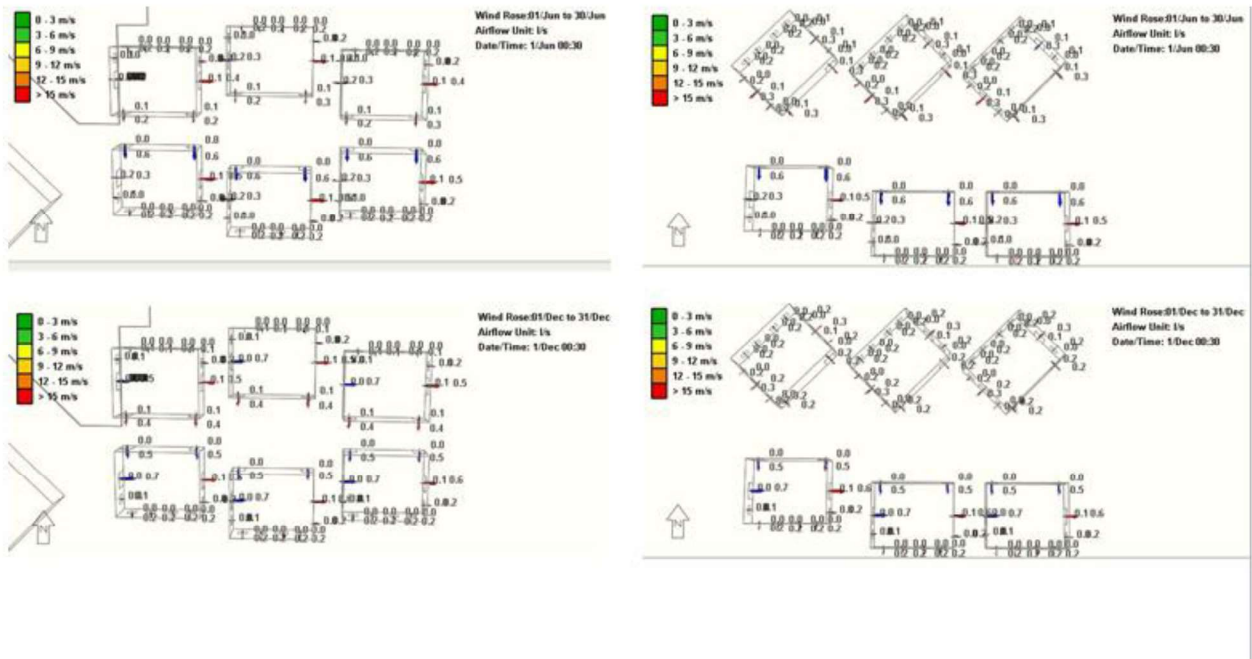
The south west wind speed remain the same in both 0 and 45 degree tilt. Where as the outlet in 0 deg is 1.4 and in 45 deg is 1.1

The inlet from the east in 45 shows 1.1, where as in 0 degree it shows as 0.8

Tilted shows outlet from sw where as in 0 degree it shows the inlet as 0.4 m/s

The inlet in 45 degree happens from the north east side in December where as in 0 deg the performance is very less.

4.4.5 Wind Analysis -5



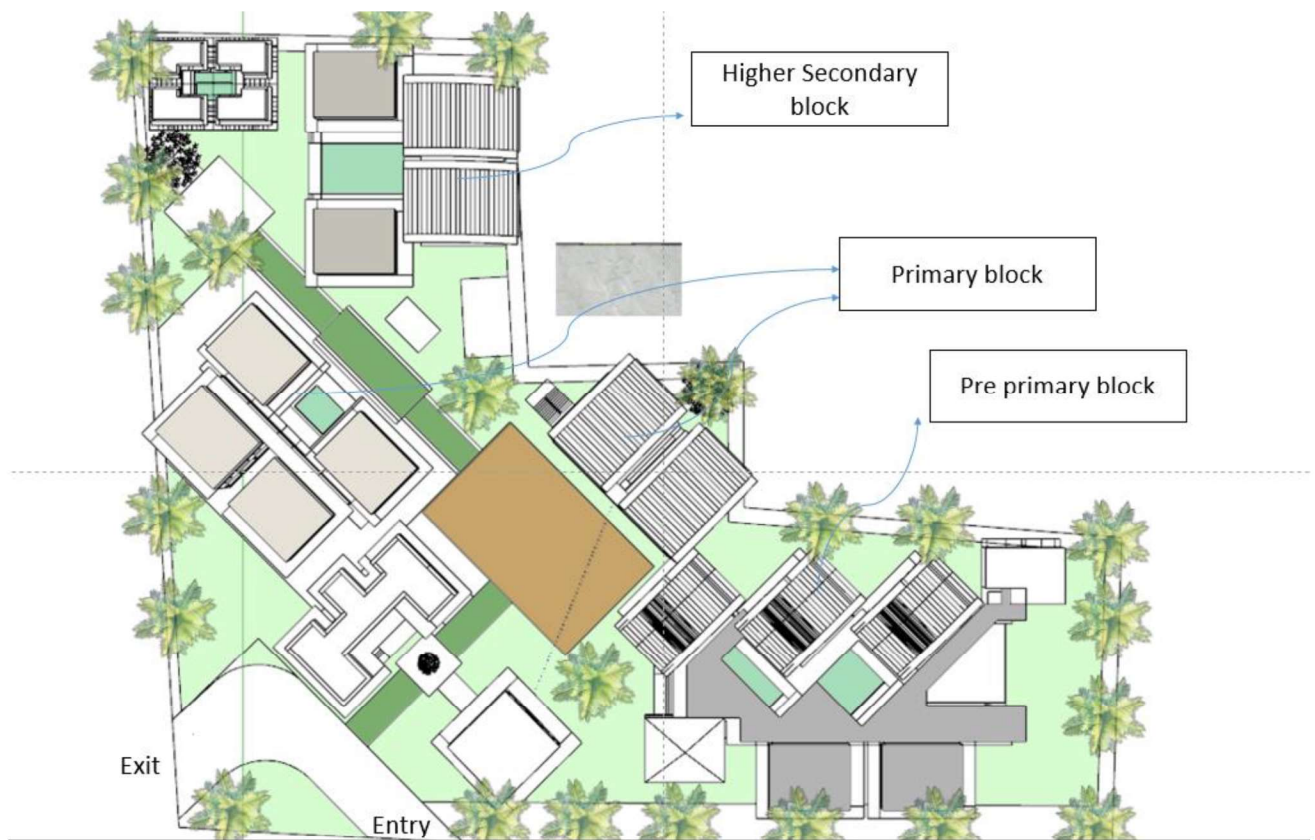
4.4.6 Wind Analysis -6

The south west wind speed remain the same in both 0 and 45 degree tilt. Where as the outlet in 0 deg is 1.4 and in 45 deg is 1.1. The inlet from the east in 45 shows 1.1 , where as is 0 degree it shows as 0.8. Tilted shows outlet from sw where as in 0 degree it shows the inlet as 0.4 m/s. The inlet in 45 degree happens from the north east side in December where as in 0 deg the performance is very less.

From all these analysis one can come to a conclusion that well placed courtroom and well ventilated design directly reflects to attribute towards the thermal comfort of the user thereby ensuring the best experience of learning.

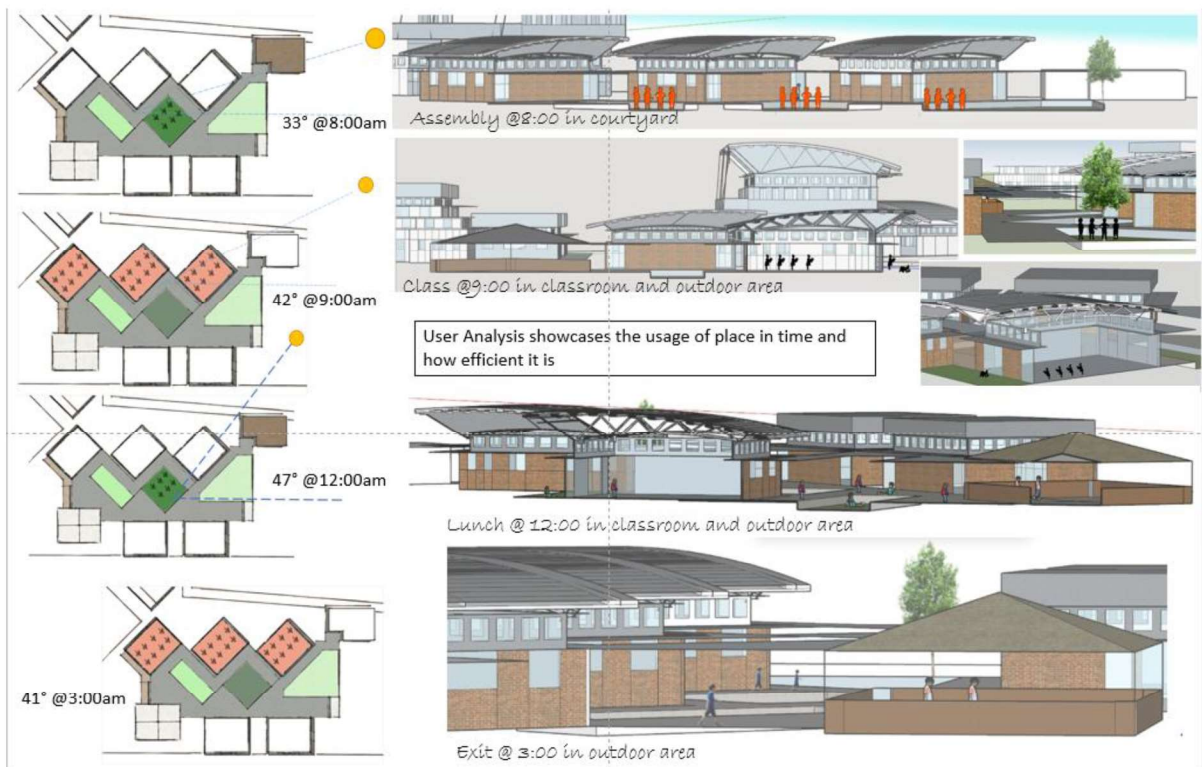
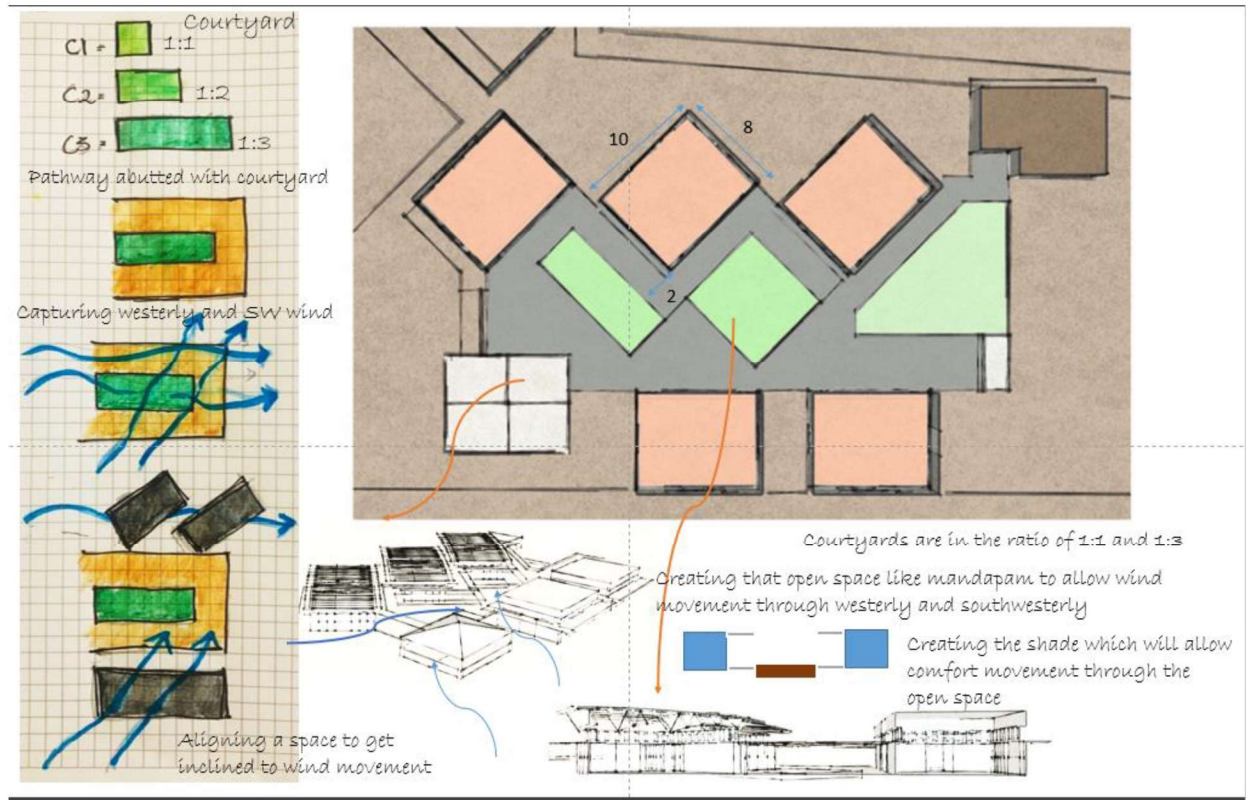
4.5 DESIGN

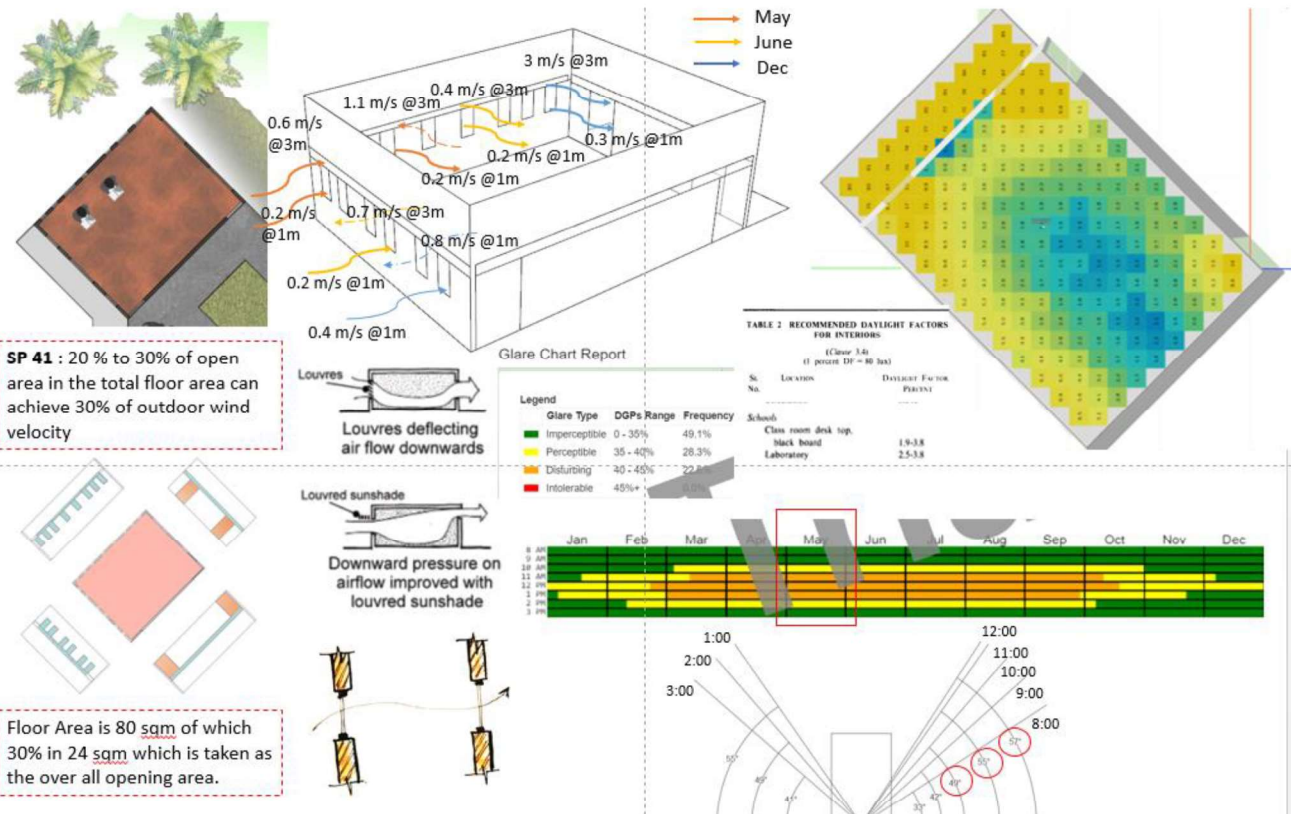
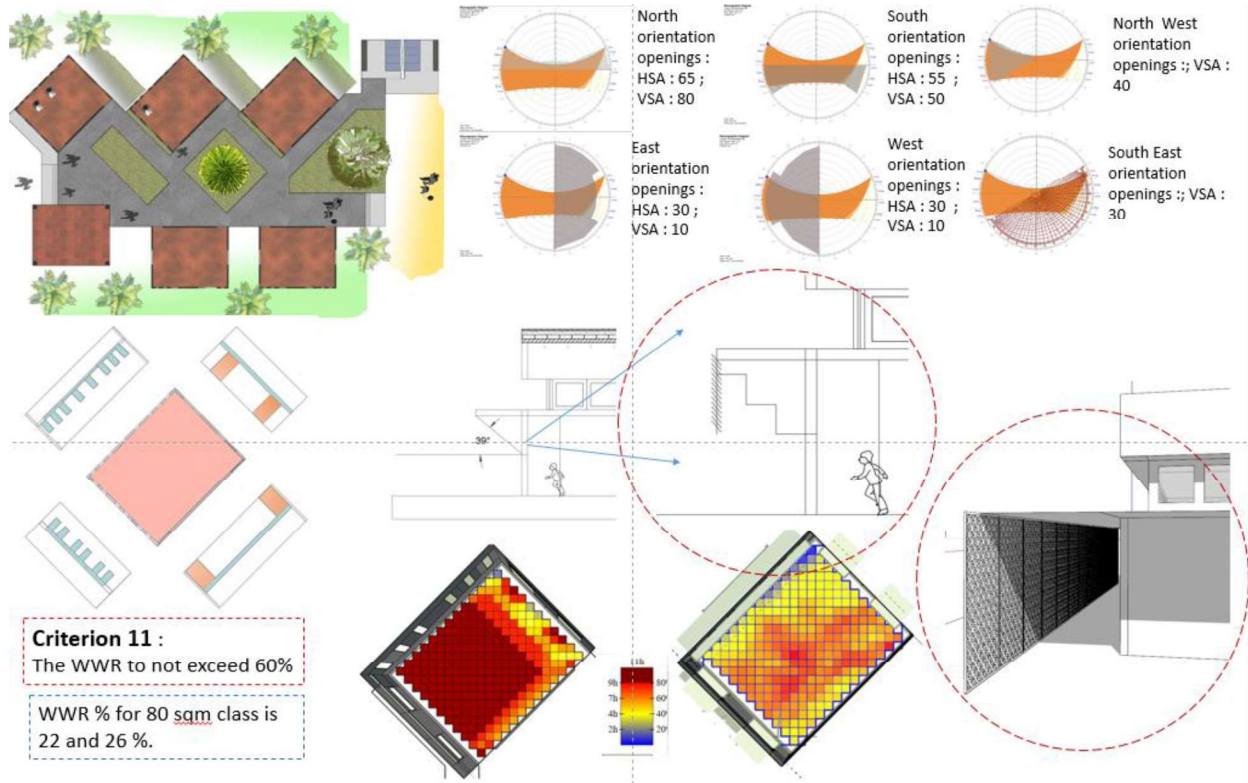
The design elements and considerations for the learning space has been carefully chosen based on various analysis and simulation. At every step, thermal comfort of the users across the year has been considered and optimal solution has been provided through the design elements incorporated in various forms.



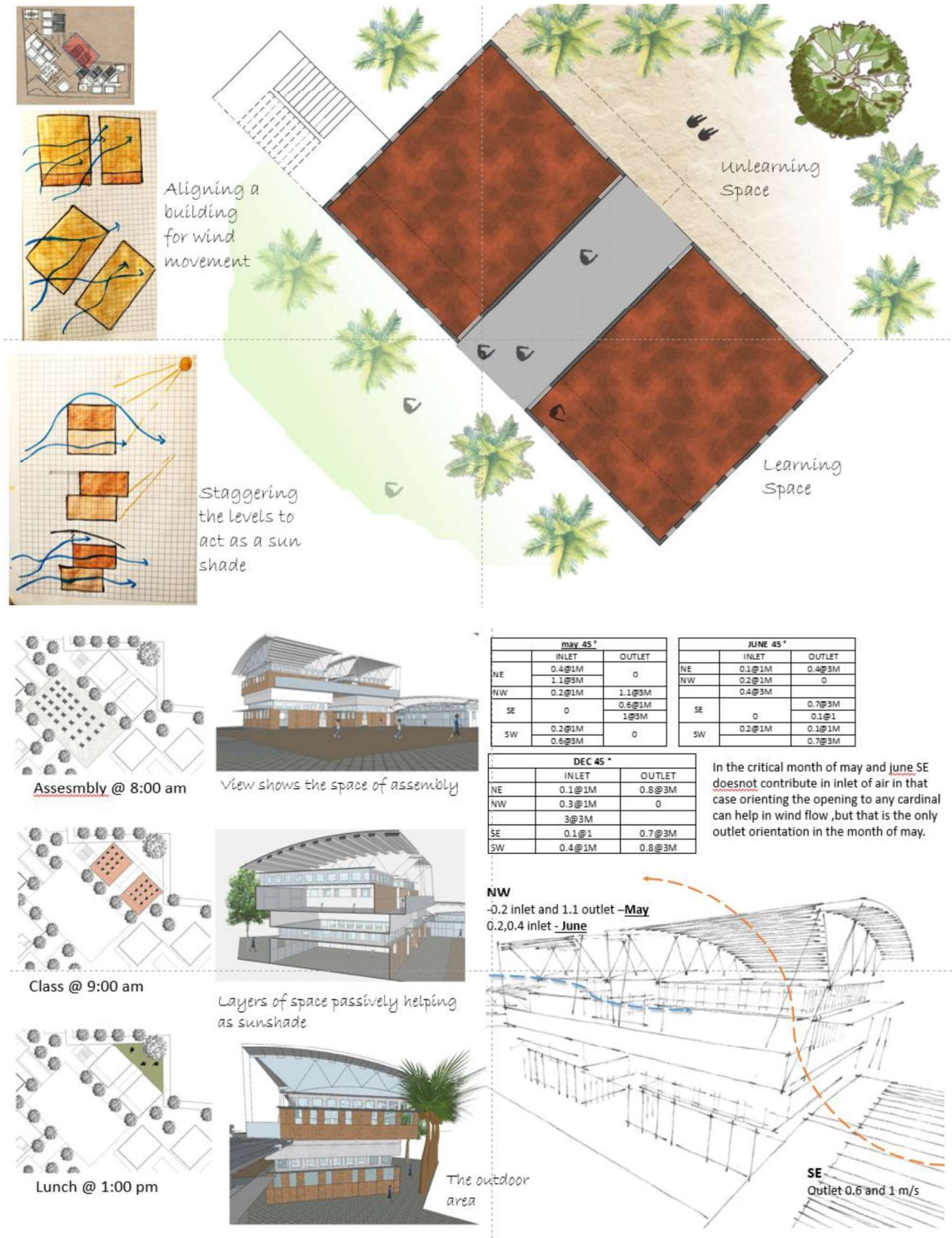
The above figure depicts the site plan for the project and minimalistic approach has been followed.

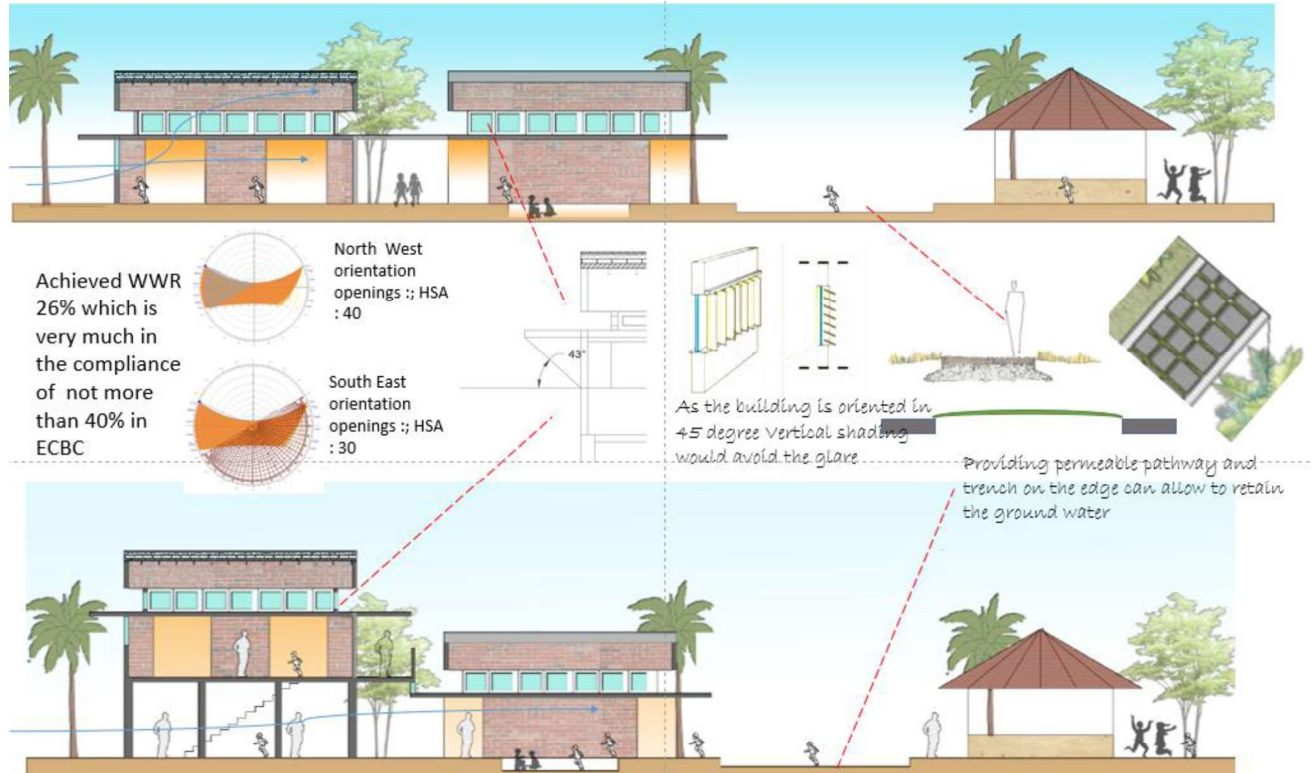
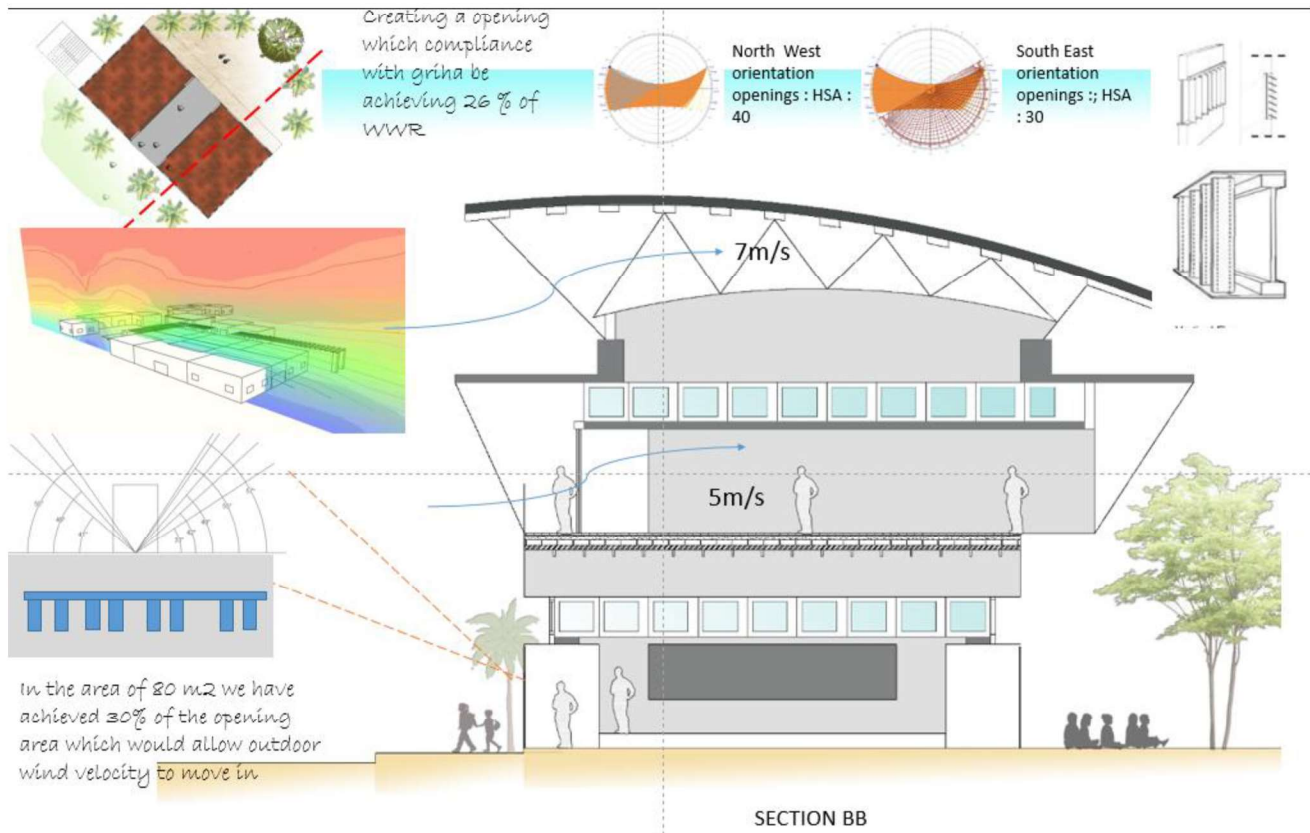
The courtyard has been designed in the preprimary block follows a 1:1 and 1:3 ratio. It follows a mandapam style and allows northerly through westerly winds.



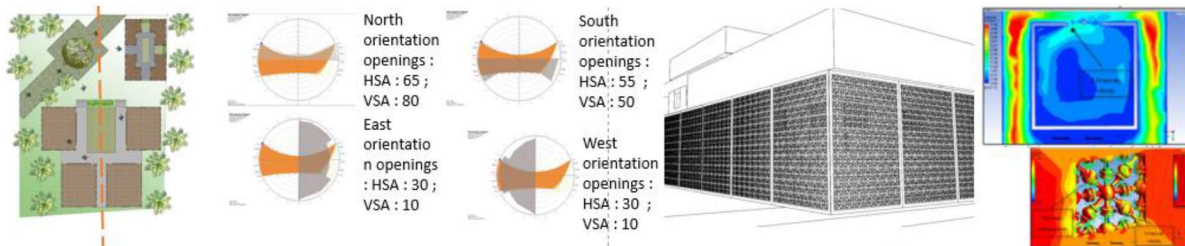


Primary block has been designed with proper alignment to wind movement and has staggering levels to act as a sun shade.

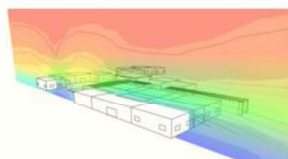




The design in the secondary school section allows equal wind movement in all the sections. It also has provisions in the roof to capture more wind. The entire design is optimized for maximum ventilation throughout the year.



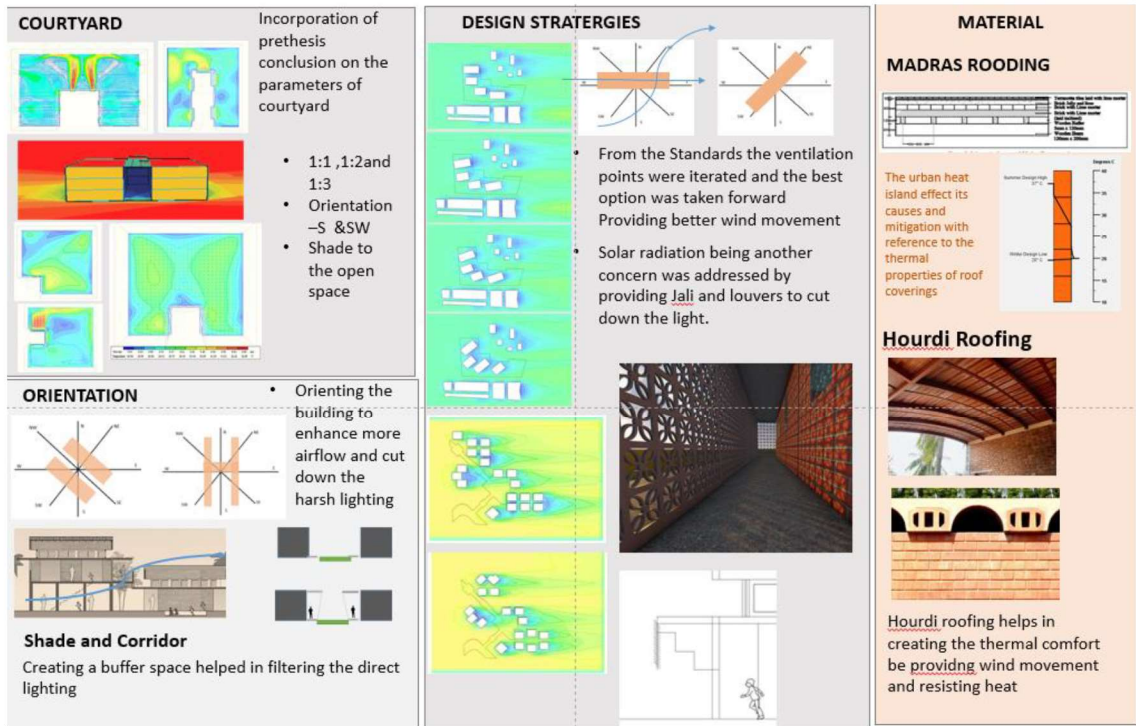
As we can see wind movement is predominant in westerly side @ 1m where as outlet is minimum only on north and east @ 3m which should be optimized for good cross ventilation



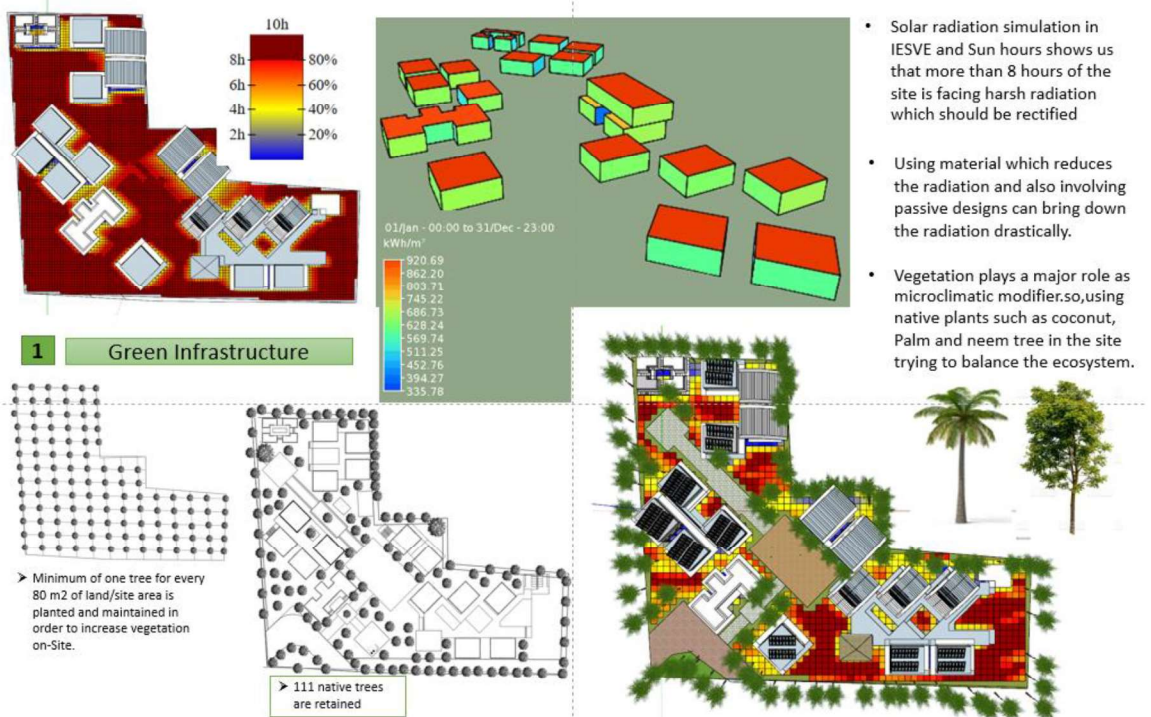
may 0°		
	INLET	OUTLET
NORTH	0.4@2M	1.4@2M
SOUTH	0.2@1M	0
EAST	0.1@1M	1.4@3M
WEST	0.8@3M	0
	0.1@1M	0

4.5.1 PASSIVE DESIGN STRATEGIES

Passive design strategies incorporated here varies from various design dimensions of courtyard to orientation, creating shared and buffer spaces to provide better ventilation. Solar radiation issue has been encountered by providing Jali and Louvers. Madras roofing and Hourdi roofing helps in providing better thermal comfort.

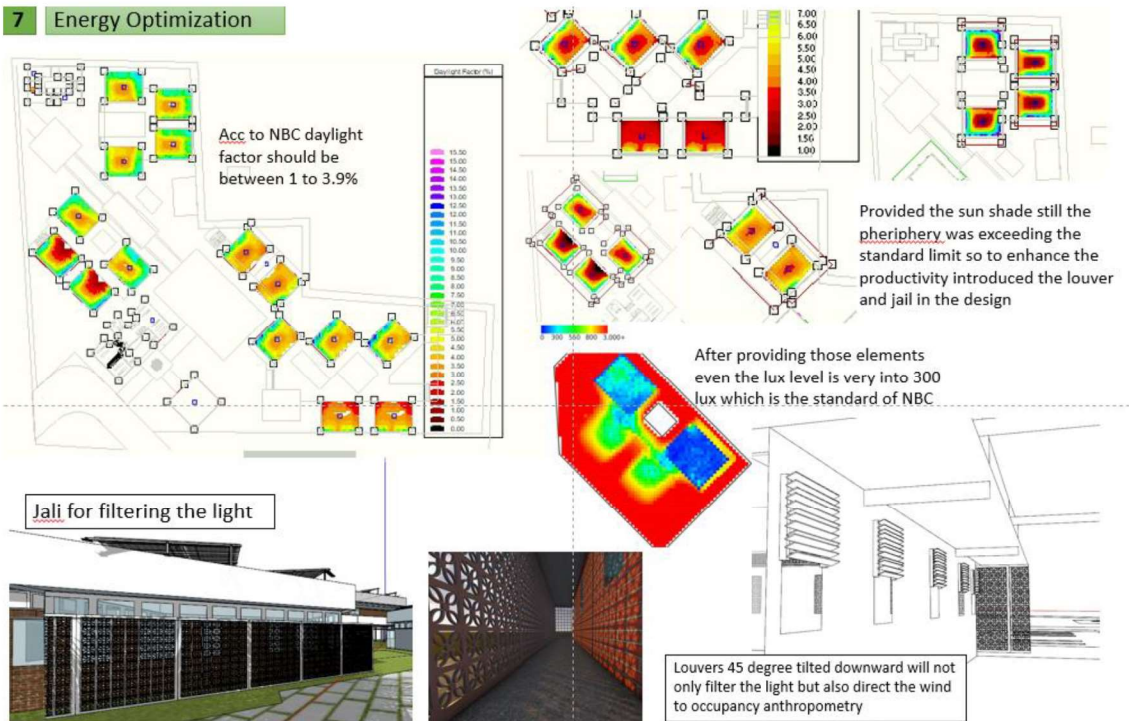


Providing green infrastructure helps as a shade and regulates both wind and light.



As per GRIHA standards, Energy optimization, Waste water management and Waste management has been integrated into the design element. Energy optimization can be achieved through various design elements including introduction of Louvers and Jali.

7 Energy Optimization



Water Management

Rainwater Harvesting Calculations		
Surface Type	Surface run off (in Liters)	
Roof	= 3060 X 900 X 0.7	24, 78, 600
Non Roof (Road and Pavement)	= 1700 X 900 X 0.95	14, 53, 500
Non Roof (Open grid grass / Parking)	= 4790 X 900 X 0.5	21, 60, 000
Vegetation on Ground	= 12,510 X 900 X 0.2	22, 51, 800
Total Rain water run off		2, 14, 13, 900

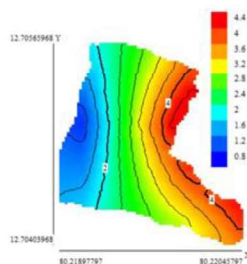
The ground water level (2 to 5m) pertaining in the site helps in achieving the water capita through out the year, in addition to this, the rain water harvesting system adopted in the school helps in non dependency of Ground water / share the excess water stored to the gated community.

Per Capita Water requirement Calculation for the School

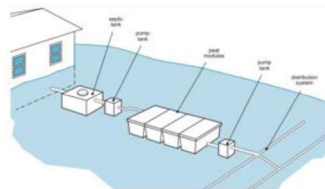
Population: 500
Per Capita for School: 45 lphd
No of days: 305 days

Water Demand for the school =
500 X 45 X 305

68, 62, 500 Liters per year



Waste Water Management



Waste water can be managed through peat treatment, as it's a day school not much of water usage is going to be there the amount of waste water is 3.66l for which this method would be apt.

Waste Management



Providing colored bins which gives the awareness about the reuse and recycle to the students as well

The entire design aims at providing the best thermal comfort to the users while conforming to various standards so that learning becomes sustainable.

2 SUMMARY AND CONCLUSION

The study which is aimed at analyzing various design parameters of a courtyard that effect the Indoor air quality and thermal comfort in a hot and humid climate for a learning environment was successfully concluded that there is a significant effect of inducting a courtyard on thermal comfort in a learning space. We did a thorough investigation of various ways to enhance the indoor air quality through means of providing suitable courtyard in a building. The paper further explored how design variants of the courtyard like the form and aspect ratio, orientation and other physical features will affect thermal comfort of a building in Warm and Humid climate. We also understood that providing good ventilation in a building enhances the contribution of a courtyard towards providing a better thermal comfort. The same has been established through several simulations and the output received from the same. The proposed design also supports the initial assumptions and tentative conclusion through a series of empirical evidence. Overall, the design recommendations are aimed at fulfilling the user comfort and the analysis clearly shows that providing courtyard helps in enhancing thermal comfort of the user. The design , while conforming to various standards provided best in class thermal comfort to the users making the learning space sustainable for the times to come.

References

- 1) Impacts of Courtyard Geometrical Configurations on Energy Performance of Buildings
- 2) IMPACT OF INNER COURTYARD FORM ON HUMAN SENSATIONAL PERCEPTION
- 3) Shading simulation of the courtyard form in different climatic regions Courtyard as Passive Design Solution for School Buildings in Hot Area
- 4) CFD simulations for examining natural ventilation in the learning
- 5) Spaces of an educational building with courtyards in Madurai.