Solar Decathlon India

Accidental Engineers
Single-Family Housing

Fr. C. Rodrigues Institute of Technology
Terna Engineering College
Dr. D. Y. Patil College of Architecture

Final Design Report - April 2022

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3. Executive Summary

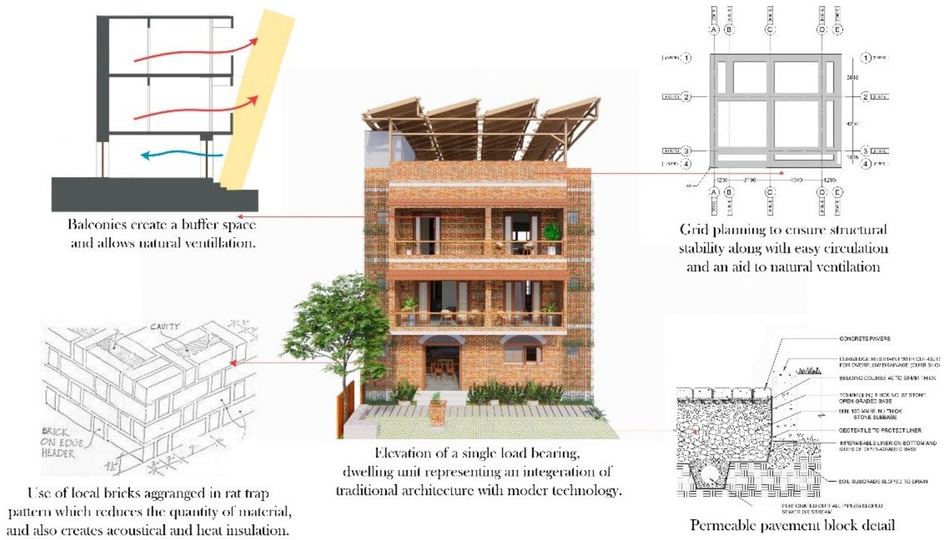
Buildings account for almost 40% of today’s energy demands. With climate change having reached a stage where it is felt by the citizens of earth rather than just measured by some laboratories, it is now more than ever imperative to improve how we consume energy and going net-zero is the most likely way to bring this transition to reality.

Samyukta means conjoin. Our project aims to couple a traditional oriented and environmentally integrated, spacious and open dwelling that the residents call home. Navi Mumbai is a modern city in all senses where the residents live in a concrete jungle by the sea. We want the residents to have an organic experience, and hence, we aim to conjoin a traditionally styled green home with modern city life to give the residents an oasis in the midst of a progressively growing concrete jungle.

Our design emphasis on reducing the ecological impact a building creates on the land that it has been built upon. The net zero performance is achieved through innovative planning and integration of modern technology with traditional wisdom. The main design features incorporated in our project are:

- Achieve comfort with natural ventilation and assisted natural ventilation by creating buffers using balcony, thus taking the micro-environmental aspects of the site location and the user experience into account.
- Being in the coastal region, the humidity is consistently high. Use of comprehensive energy simulations help us validate the level to which our strategies of ventilation provide comfort by modelling the micro-climate and integrating dehumidifiers into our system.
- Adapting to passive design strategies like use of local material, eliminate as much concrete as possible, orientation of the layout according to the wind path and sun direction, rainwater harvesting and use of energy efficient appliances, etc.

The main architectural feature is a clean spacious plan constructed in grids. In cities like Mumbai, space is a primary restraint. In line with our initial goal of providing an organic traditional user experience, we have laid the main focus on simplifying the layout and giving spacious unobstructed user spaces to lead to an overall fulfilling user experience.



Balconies create a buffer space and allows natural ventilation.

Grid planning to ensure structural stability along with easy circulation and an aid to natural ventilation

Use of local bricks aggranged in rat trap pattern which reduces the quantity of material, and also creates acoustical and heat insulation.

Elevation of a single load bearing, dwelling unit representing an integration of traditional architecture with moder technology.

Permeable pavement block detail

Figure 1 Design Features

4. Team Summary

4.1. Team Name: Accidental Engineers

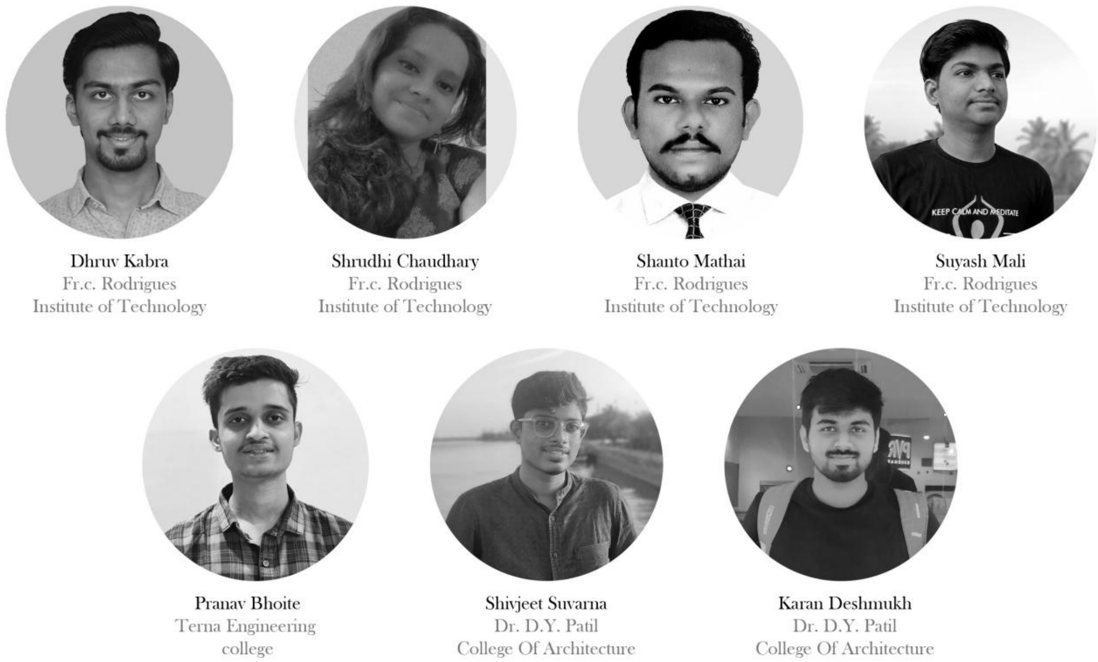
4.2. Division: Single-Family Housing

4.3. Institutions:

a. Fr. C. Rodrigues Institute of Technology, Vashi
b. Dr. D. Y. Patil College of Architecture, Nerul
c. Terna Engineering College, Nerul

4.4. Team Members:

Team Accidental Engineers is a multidisciplinary team consisting of students from different domains, including BE Mechanical, BE Electronics & Telecommunication, BE Civil, and B.ARCH. The team members include



4.5. Design Management Process:

The team is divided into nine overlapping divisions based on the domains of interest. The domains are Energy Performance (EPI, energy calculations, energy-efficient applications, and appliances); Health & Well Being (human comfort, HVAC, natural cooling and ventilation); Cost Analysis (budgeting, affordability, scalability, market potential); Documentation (inclusive of communication); Water Performance; Resilience Design Considerations; Innovation Materials & Research; Engineering and Operations; and Architectural Design. This approach allows for workload sharing whilst maintaining a thorough approach. Our team mainly used Discord for communication. Since the number of team members are low, each team member has taken up around 3 of the above listed domains.
The team's main aim is to make the project sustainable, energy-efficient, water-efficient, affordable, and modular. We plan to use green energy alternatives to achieve net-zero housing facilities and maximize the use of naturally available ambient light and natural ventilation to reduce power consumption further.

4.6. Lead Institution:

The lead institution, Fr. C. Rodrigues Institute of Technology, is a private engineering college affiliated with the University of Mumbai. It was established in 1994 and is in Vashi, Navi Mumbai. The motto of the institute is "Love Your Neighbour as Yourself."
The institute offers a B.E. degree in Mechanical, Computer Science, IT, Electronics & Telecommunication, and Electrical branches. Various coursework offered in a few of these branches include Refrigeration & Air-Conditioning, Thermodynamics, Energy Audit, Disaster Management, Power System Operation & Control, and High Voltage Transmission

4.7. Faculty Lead & Advisor:

The team is guided by a faculty lead and a faculty advisor, both from the lead institute, Fr. C. Rodrigues Institute of Technology.
Faculty Lead - Prof. Nilesh Varkute
Assistant Professor, ME
With a teaching experience of 11 years, his areas of interest include Energy Management, Heat Transfer, and CFD.
Faculty Guide - Prof. Badal Kudachi
Assistant Professor, ME
With a teaching experience of 7 years, his areas of interest include Thermodynamics, Fluid Flow, CFD, and Renewable Energy.

4.8. Industry Partner:

Green Jams
Site: https://www.greenjams.org/
Key Individual: Tarun Jami (Founder)

5. Project Summary

5.1. Project Name: Samyukta

5.2. Project Partner:

- Name of Organisation: Samyukta Co-operative Housing Society Limited
- Background: Samyukta CHS is a society with ten-row houses situated in Vashi, Navi Mumbai.
- Key Individual: Mr. Abhay Kabra (Secretary)

5.3. Brief Description of Project:

The project Samyukta is a redevelopment project for a cooperative housing society in Navi Mumbai. The project is in its pre-design phase. The site has a warm-humid type of climatic zone. Since the houses are single-family dwellings, we expect all-around demography from young kids to experienced grandparents. The operation schedule of different zones varies over the 24 hours and seven days of the week.

Figure 2 Existing Site

5.4. Site Details:

- Site Area = 1740 m^2
- Permissible Built-up Area = 3480 m^2 (for 10 row houses)
- Permissible Ground Coverage = 2
- Proposed/Estimated Built-up Area = 240 m^2 (for 1 row house)

5.5. Energy Performance Index:

EPI Goal = 15 kWh/m^2 per year

5.6. Preliminary estimate of on-site renewable energy generation potential:

Wind Energy Generation Potential = 5000 kWh per year
Solar PV Potential = 13200 kWh per year per house
An 8.8kW plant is feasible per house. For the domestic wind turbine, a wind speed of 6 m/s for a rotor diameter of 7 m is considered.

5.7. Preliminary Construction Budget:

The project partner hasn't constricted us on a budget. However, the preliminary estimate is as follows (Table2):

Table 1 Preliminary Construction Budget Estimation

Sr	Particulars		Baseline Estimate		Proposed Design Estimate	
			%	Amount (in Lakhs)	%	Amount (in Lakhs)
1	Land		0	0	0%	0
2	Civil Work		50%	42.75		
		Excavation			3%	2.565
		Footing and Foundation			12%	10.26
		Brickwork and Plastering			17%	14.535
		R.C.C. Works			10%	8.55
		Roofing Slab			13%	11.115
3	Interior Finishes		27%	23.085		0
		Flooring and Tiling			10%	8.55
		Wood Works			8%	6.84
		Painting			6%	5.13
		Furnishing			5.50%	4.7025
4	MEP		12.25%	10.47375		0
		Water supply and Plumbing			5%	4.275
		Electric Wiring			8%	6.84
		Automation and IBMS			2.50%	2.1375
						0
5	Contingencies		5%	4.275	5%	4.275
	Hard Costs			80.58375		89.775
6	Pre-Operative expenses					
		Building Design and Approval	2.50%	2.1375	2.50%	2.1375
		Site Establishment	2%	1.71	2%	1.71
7	Consultants		1.25%	1.06875	1.25%	1.06875
						0
	TOTAL		100	85.5	110.75	94.69125

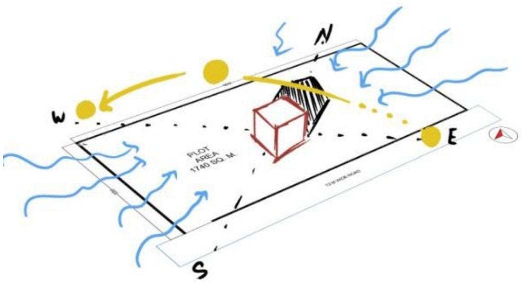
5.8. Special Requirements and Goals of the Project Partner:

The project partner hasn't specified any specific requirements, constraints, or goals. We aim to design a practically ready-to-implement solution and make an actual values-based sustainable design rather than an ideal design.

6. Goals

Table 2 Goals & Strategies

SR. NO.		GOALS	STRATEGIES
1.	Resilience	To create disaster and pandemic resilient accommodation Using the society's amenities to strengthen the community physically and mentally. To withstand extreme climatic conditions.	Natural cross ventilation in maximum spaces in the design, thus maintaining the indoor air quality. Design involving nature and spaces promoting physical and mental fitness. Double glazing, jali wall, chajjas, etc., to combat extreme climatic conditions.
2.	Affordability	Easy to afford and cost-effective design Made up of reusable materials Low operational cost due to usage of sustainable resources	Use of local materials Use of cost effective (about 50%) carbon negative building construction materials like hemp blocks from Green Jams. Faster construction due to the use of sustainable materials.
3.	Energy Performance	The team aims to create energy-efficient housing to minimize total energy consumption using various effective techniques. EPI Target = 10 kWh/m^2 per year	Use of solar panels Domestic windmill Maximizing the use of available daylight Minimizing the need for air conditioning in the building
4.	Architectural Design	Disaster resilient and sustainable architectural design Creating good design amalgamating sustainability with healthy open spaces will help improve physical and mental health and form a community.	Designing the building to maximize the utilization of natural light and ventilation and minimize energy wastage. Construction using minimum available resources. Creating balconies, voids, recreational spaces, etc., to create more interaction.
5.	Water Performance	To recharge the groundwater table. To reduce water consumption. To minimize the water discharge.	To implement a comprehensive rainwater harvesting facility to enhance the water performance by about 40%. Treating and using the wastewater from washbasins to water the plants in the CHS.
6.	Sustainability	To create sustainable accommodation aiding environmental conservation.	Use of locally available materials and modern prefabricated construction Use of sustainable materials like stone and bamboo for resource-efficient construction.
7.	Innovation	To create a climate-responsive and energy-efficient design. To create a self-sustainable design.	Incorporating various innovative technologies such as IoT, VRV, etc., for moving towards a better and sustainable lifestyle.
8.	Health & Wellbeing	Design promoting mental and physical fitness. Design efficiently to create healthy open green spaces.	Design incorporating findings on psychological and behavioral studies. Use of green paints, low VOC paints, carpet tiles.
9.	Engineering & Operation	To design a structurally sound plan with minimal obstruction to user space in structural elements like beams and columns. To design an efficient HVAC system suitable for the use case.	Use of highly efficient BLDC fans and dehumidifiers to employ assisted natural ventilation. Effective use of micro-environment by means of natural ventilation and night flushing.
10.	Scalability & Market Potential	To create a flexible self-sustaining design. Adaptable in use.	Use of various innovative technologies. To use locally available materials. To create a modular design pattern. Modular design that can be extended to more than 5 CHSs on the street.



7. Performance Specifications

7.1. Climate Zone

Navi Mumbai lies in the hot and humid climate type. Particularly, the site is in close proximity to two lakes, a strait and mangrove forests. Vashigaon Chowpaty (an artificial lake) and Vashi holding lake are both at a distance of about 400 m from the site. The site is less than a kilometer away from a strait. Moreover, there is a wide mangrove cover near these water bodies. The micro-climate has evident impacts as assessed through user experiences.

7.2. Site Analysis

Vashi is a node in Navi Mumbai, Maharashtra, across the Thane Creek of the Arabian Sea on the outskirts of Mumbai. The site is plot number 14 of sector 10, Vashi. It has good connectivity to other nodes of Navi Mumbai and Mumbai through local trains, buses, and auto-rickshaws with tar approach roads and cement travel roads. The terrain is flat, with rock formation derived from Deccan Basalt and granites, gneisses, and laterite. The soil is calcareous, neutral to alkaline in reaction (pH 7.5 to 8.5), clayey, with high water holding capacity (200-250mm/m)

The site is in an urban setting. The approach is from the connecting road. The main road is 150 m from the site. The nearest bus stop is also 150 m from the local railway station, 2.5 km from the site. There are hospitals and schools in a 1-kilometer radius.

The location of the site is prime in the sense of approachability, hospitals, and schools nearby and bus and railway stop in close vicinity. The project caters to the redevelopment of the site. However, the new construction is also to cater to the ten families only. No expansion is planned. So, we know the end-users that the project caters to.

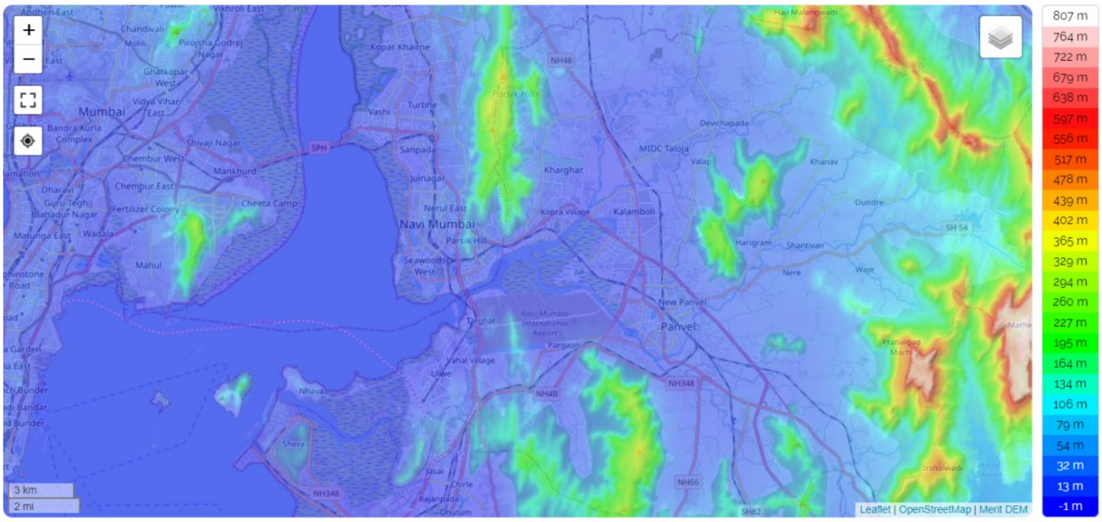
7.3. Performance Specifications

BUILDING ENVELOPE		
WALL-EXTERNAL	(0.6SRI Paint + Agrocrete(200) + Aircavity(25)+Rockwool(50)+Plaster (10))	U=1.226
ROOF	Insulated Roof (0.3SRI Chinamosaic(25)+PCC Screed(50)+PUFF Insulation +Vapour Barrrier +water Proofing+ Hollow Core (100)+ Plaster(10)	
WINDOW	Double Glazing Dbl Clr 6mm air gap 13mm	Vlt=0.781 U=2.665 Shgc=0.703
HVAC		
TYPE	VRF Dehumidifier and Air Conditioning System	
MODEL	**Company -:** Daiken VRV VI **Model-:** VRV RXYTQ8U7YF **Tonnage-:** 5.4 **Power -:** 380- 415V/50 Hz	
RENEWABLE ENERGY		
TYPE	**Roof mounted Solar PVs** **POWER= 8KW** **Efficiency =18%**	

8. Design Documentation

8.1. Energy Performance

Navi Mumbai (also known by its former name New Bombay), is a planned city off the west coast of the Indian state of Maharashtra in Konkan division. Navi Mumbai has a Tropical Climate. There is significantly less rainfall in the winter than in the summer. Navi Mumbai has an average yearly temperature of 26.6 °C | 79.9 °F. The annual rainfall is approximately 1915 mm | 75.4 inch. July is the month with the highest relative humidity (88.90 percent). December is the month with the lowest relative humidity (56.23 percent).July is the month with the greatest number of rainy days (29.00 days). March is the month with the fewest number of rainy days (0.17 days).
The summers in Navi Mumbai are easy to recognise because they are in the midst of the city.



Navi Mumbai, Thane, Maharashtra, 400706, India (19.03083 73.01985)

Name: Navi Mumbai topographic map, elevation, relief.

Coordinates: 18.87083 72.85985 19.19083 73.17985

Minimum elevation: -3 m

8.1.1. Reduction of Loads

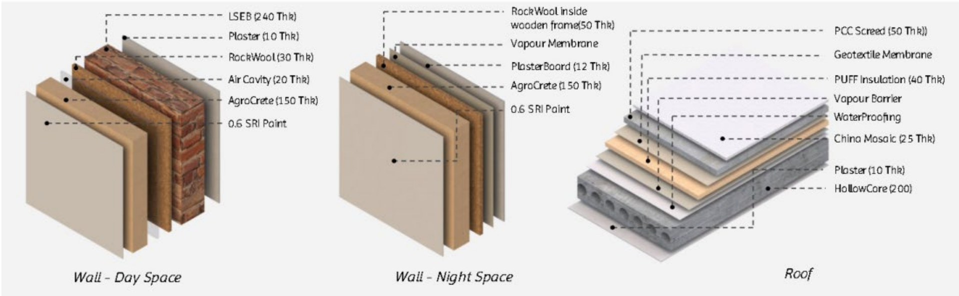
Building Form:
In sites located in cities like Navi Mumbai with tight plots, it is essential to analyze the site along with the climate in the early design phase itself as the space constraints can lead to limitations in the form. Since our main focus was natural ventilation, we tried to create an open ziz-zag orientation with more open facades to enhance natural ventilation. Even though such building forms had an appeal, they led to lower ground coverage and caused us to expand the house upwards. We weighed the pros and cons and decided to go with design iterations with greater ground coverage and a lower number of floors and very efficient use of the site area.

Building Envelope:
Concrete is a fundamental construction material, but it has a detrimental impact on the environment. We wanted to use materials that are in line with our design philosophy of providing the residents with an organic living environment. So instead of contributing to the concrete jungle, we chose to employ carbon negative construction material. However,

not only is the Agrocrete material that we have chosen carbon negative, but it also has a better thermal performance. Coupled with the rat trap bond construction technique by Laurie Baker, we eliminate the need for extra insulation. We have balconies for all the 4 bedrooms and a jail wall for the living room opening using single or double glazing for most windows. The window to wall ratio is shown in table.

Table 3 WWR

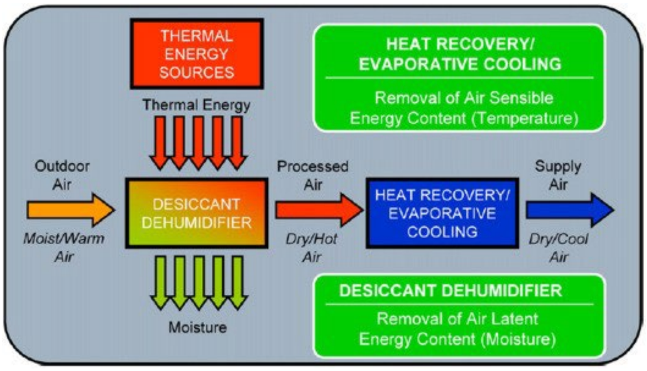
	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	395.92	108.79	86.44	101.20	99.48
Above Ground Wall Area [m2]	395.92	108.79	86.44	101.20	99.48
Window Opening Area [m2]	96.92	34.12	14.77	33.26	14.77
Gross Window-Wall Ratio [%]	24.48	31.36	17.08	32.86	14.85
Above Ground Window-Wall Ratio [%]	24.48	31.36	17.08	32.86	14.85



8.1.2. INTEGRATION OF LOW ENERGY COMFORT SYSTEMS

Dehumidifiers

A desiccant is a substance, either solid or liquid, which absorbs water molecules from air and dehumidifies it. The desiccant, initially used to absorb moisture from the air, is later regenerated by heating the desiccant so that it releases the absorbed moisture. This phase change cycle is a continuous process that drives the operation of desiccant systems. Desiccant cooling systems are heat-driven cooling units and they can be used as an alternative to the conventional vapor compression and absorption cooling systems. The operation of a desiccant cooling system is based on the use of a rotary dehumidifier (desiccant wheel) in which air is dehumidified. The resulting dry air is somewhat cooled in a sensible heat exchanger (rotary regenerator), and then further cooled by an evaporative cooler. The resulting cool air is directed into a room. The system may be operated in a closed cycle or more commonly in an open cycle in ventilation or recirculation modes.



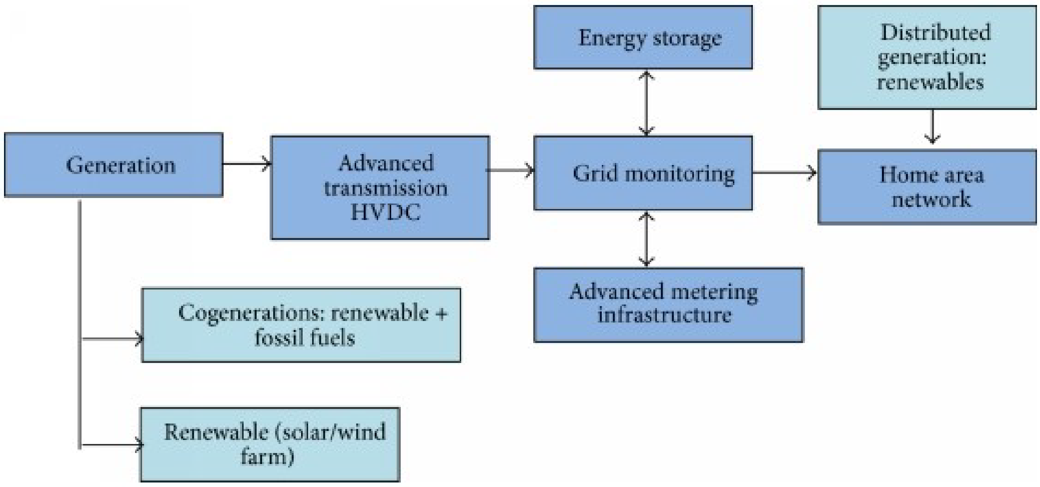
Advantages : Highest low dew point supply air CMH/kW of regeneration: High Performance Efficiency/Energy Efficient

Unlike conventional vapor compression refrigerators, desiccant cooling systems are free from hazardous substances. Therefore they can be considered an environmentally friendly air-conditioning technology.

Unit Construction: robust, durable, > 20 years life

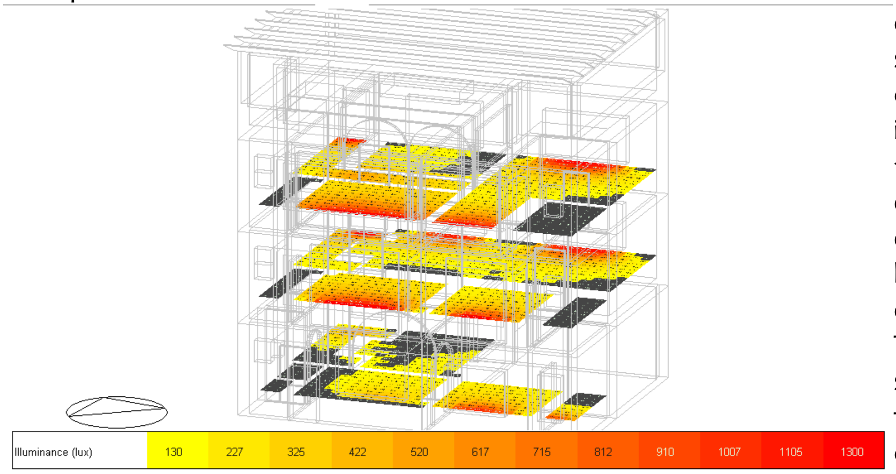
8.1.3. SUFFICIENT RENEWABLE ENERGY GENERATION WITH SMART GRID CAPABILITIES

A smart grid is the solution to the modernization of the electrical energy system and infrastructure to present a more intelligent and reliable electricity grid. Smart grids provide many benefits over conventional grid. Smart grids improve both the physical and economic operations of the grid system, increasing reliability and sustainability



8.1.4. Lighting Optimization:

In accordance with our objective of providing the users with an organic experience, we have designed the spaces to incorporate daylighting as an integral design strategy. However, since we are employing natural ventilation as the primary design strategy, appropriate shading and finding a balance between daylight and glare becomes imperative because we do not want the residents to close the windows. We ran



daylighting simulations considering an illuminance range of 130 to 1300 lux and optimized our openings to find a balance between daylight and glare. The daylight simulation results for overcast conditions are shown in the following photos.

Figure 3 Illuminance

8.1.5. Lighting Optimization:

The building has its main windows facing north-west and south-east. So for a climate-specific shading, the timetable plot for dry-bulb temperature was analyzed with the help of Climate consultant. The observation from the data was that the building requires strict shading in summer.

Hence, the idea was to provide balconies that create buffer to control the sunlight

Figure 4 Ground Floor Illuminance

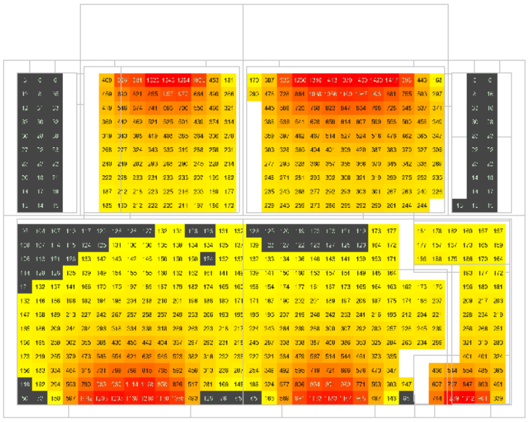
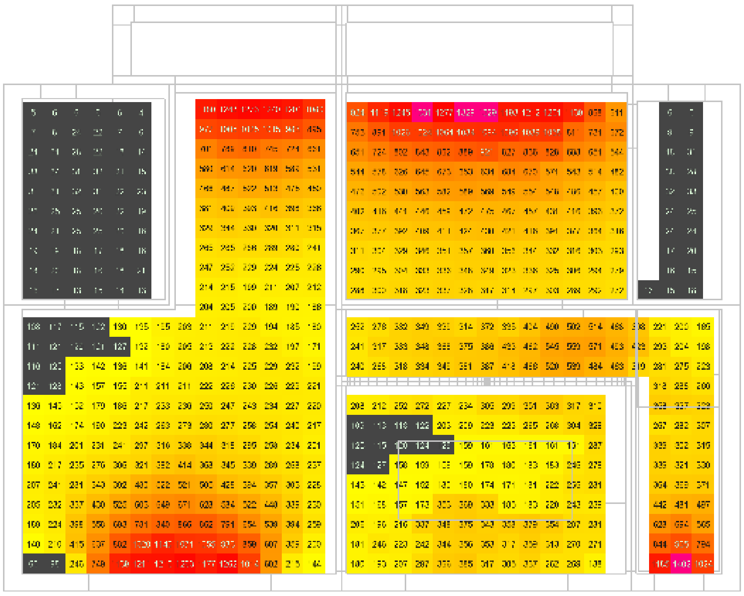
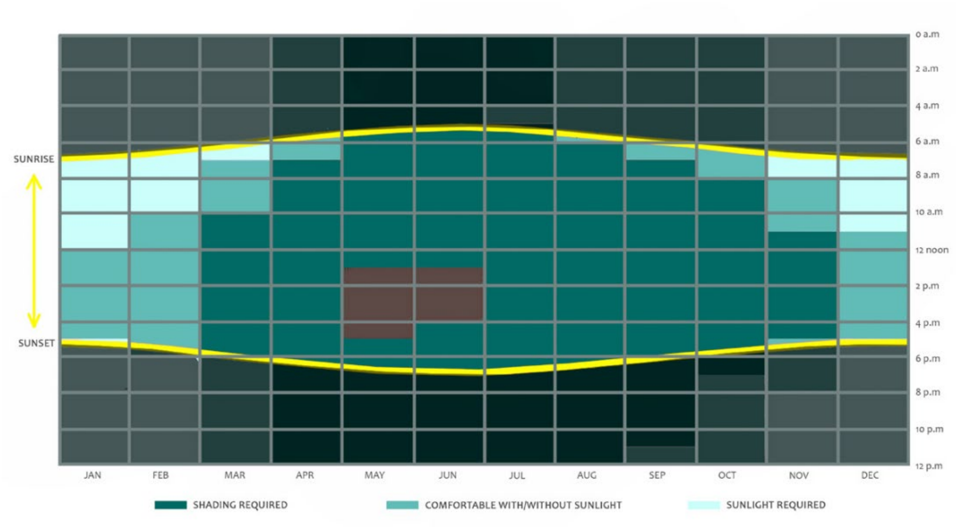


Figure 5 First Floor Illuminance



entering the space and hence providing thermal comfort inside.



8.1.6. ENERGY ANALYSIS

The HVAC system consumes the majority of electricity in the lifetime of a building. Keeping in mind the micro-environmental aspects, the comfort band, user experience and our design philosophy, we plan to employ natural ventilation as our primary design strategy. Firstly, through climate analysis, we were able to determine a layout that assisted natural ventilation using the westerly winds. Next, we planned low-energy high performance BLDC fans to assist the ventilation. In further iterations, we may provide additional assisted ventilation ducts to provide comfort mainly during the peak summer months of April and May.
Most of the cooling load is accounted for by latent loads in coastal regions like Mumbai. Moreover, the microclimate leads to a cooler environment but increases humidity further. Using an air conditioner to counter the latent loads is an inefficient way of achieving comfort. Hence, we tried to look for more direct solutions to manage the latent loads.

Using TRNSYS simulation software, temperature and specific humidity fluctuations at crucial state points of a solar-assisted solid desiccant cooling system are investigated for the ventilation and recirculation modes. The COP for the recirculation mode appears to be slightly greater than that in the recirculation mode. In addition, the regeneration temperature required for dehumidifier desorption is lower in the recirculation mode. As a result of the lower thermal energy required for reactivation and consequently higher COP, the recirculation cycle appears to be superior and more efficient than the ventilation mode.

Simulation:
EPI = 15 kWh/m^2 per year

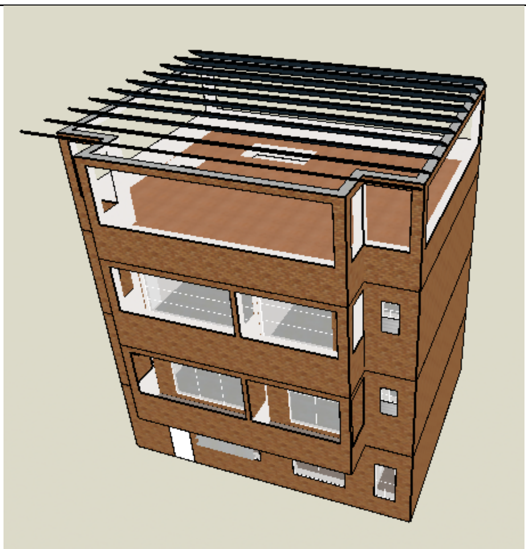


Figure 6 Design Builder Model – View 2

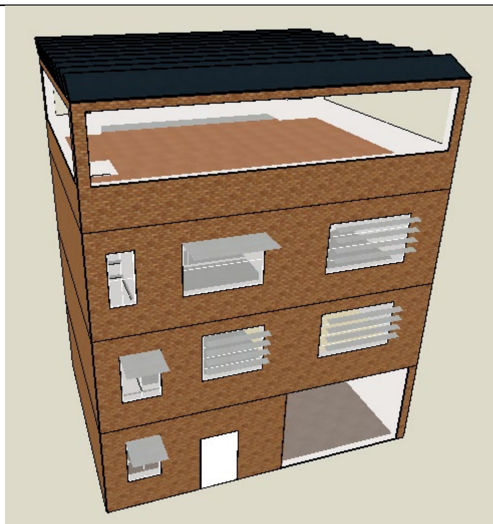


Figure 7 Design Builder Model – View 2

Table 4 Zero Performance Summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Above Ground Gross Wall Area [m2]	Underground Gross Wall Area [m2]	Window Glass Area [m2]	Opening Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
GROUNDFLOOR:DINING	11.75	Yes	Yes	35.24	1.00	12.12	0.00	2.87	3.15	7.5000	59.11	3.0600
GROUNDFLOOR:DININGWASH	1.82	No	Yes	5.45	1.00	5.07	0.00	0.00	0.00	5.0000	41.12	1.6100
GROUNDFLOOR:SITTING	14.14	No	Yes	42.43	1.00	10.09	0.00	0.00	0.00	7.5000	53.32	3.9000
GROUNDFLOOR:STAIRCASEGF	6.52	No	Yes	19.56	1.00	19.57	0.00	1.31	1.50	5.0000	64.50	1.5700
GROUNDFLOOR:KITCHEN	9.00	Yes	Yes	27.00	1.00	9.57	0.00	2.48	2.74	15.0000	42.19	30.2800
GROUNDFLOOR:T1	1.55	No	Yes	4.65	1.00	9.48	0.00	0.09	0.15	5.0000	41.12	1.6100
GROUNDFLOOR:WASHAREA	3.46	No	Yes	10.37	1.00	14.55	0.00	0.88	1.05	5.0000	41.12	1.6100
FF:BEDROOM2	9.58	Yes	Yes	27.78	1.00	0.00	0.00	0.00	0.00	5.0000	43.59	3.5800
FF:BEDROOM1	12.26	Yes	Yes	35.55	1.00	0.00	0.00	0.00	0.00	5.0000	43.59	3.5800
FF:T2XR1	3.53	No	Yes	10.24	1.00	14.55	0.00	0.17	0.25	7.5000	53.37	1.6700
FF:T3XR2	3.54	No	Yes	10.26	1.00	14.56	0.00	0.17	0.25	7.5000	53.37	1.6700
FF:LIVING	32.45	Yes	Yes	87.88	1.00	37.24	0.00	5.77	6.34	7.5000	53.32	3.9000
FF:STAIRCASEFF	0.18	No	Yes	18.90	1.00	19.54	0.00	1.46	1.66	5.0000	64.50	1.5700
SECONDFLOOR:BALCONYR4	2.30	No	No	5.92	1.00	13.16	0.00	5.41	5.41	0.0000		0.0000
SECONDFLOOR:BALCONYR3	2.99	No	No	7.70	1.00	15.72	0.00	6.70	6.70	0.0000		0.0000
SECONDFLOOR:BEDROOM4	24.89	Yes	Yes	72.18	1.00	27.12	0.00	3.48	3.79	5.0000	43.59	3.5800
SECONDFLOOR:BEDROOM3	12.26	Yes	Yes	35.55	1.00	0.00	0.00	0.00	0.00	5.0000	43.59	3.5800
SECONDFLOOR:T4XR3	3.53	No	Yes	10.24	1.00	14.55	0.00	0.17	0.25	7.5000	53.37	1.6700
SECONDFLOOR:CORRIDOR	3.65	No	Yes	25.82	1.00	17.61	0.00	0.87	1.04	5.0000	64.50	1.5700
SECONDFLOOR:LILYPOOL	11.05	No	Yes	32.03	1.00	12.06	0.00	3.08	3.38	5.0000	64.50	1.5700
SECONDFLOOR:T5XR4	6.03	No	Yes	17.48	1.00	14.56	0.00	0.17	0.25	7.5000	53.37	1.6700
TERRACE:ZONE1	73.04	No	No	200.05	1.00	114.78	0.00	59.03	59.03	0.0000		0.0000
Total	171.18			528.61		252.27	0.00	22.99	25.79	6.6206	49.64	4.5197
Conditioned Total	112.18			321.18		86.05	0.00	14.61	16.03	6.7871	47.26	5.7599
Unconditioned Total	58.99			207.43		166.21	0.00	8.38	9.76	6.3039	54.90	2.1614
Not Part of Total	78.32			213.67		143.66	0.00	71.13	71.13	0.0000		0.0000

8.2. Water Performance

Minimizing the water usage - To implement a comprehensive rainwater harvesting facility to enhance the water performance by about 40% by treating and using the wastewater from washbasins to water the plants in the CHS and by recharging the ground water.

- Water metering

Sufficient use of harvested rainwater - The rainwater collected in the subsurface storage tank is pumped to a second roof-mounted overhead tank. Apart from the taps in the kitchen and a washbasin in the dining area, both toilet flush tanks have exclusive connections to this storage tank. The cost of recharge to the subsurface reservoir is also lower than the surface reservoirs. It helps in reducing the water bills.

Recycled water - Water systems everywhere are being challenged by a confluence of trends. Water supplies are strained, climate and weather patterns are changing, and populations are moving and growing. If we don't change our patterns of water use, millions could be left without adequate potable water. Onsite non-potable water reuse helps tackle and mitigate the effects of these issues before they become crises.

Onsite water systems collect non-potable water which can include wastewater, storm water, rainwater and more and treat it. It can then be reused in a building for non-drinking water needs such as irrigation, toilet flushing and cooling. By using alternative water sources for these needs, onsite reuse reduces the waste of valuable drinking water. In fact, water reuse can account for up to 50 to 95 percent of the water used in residential or commercial buildings.

Treated wastewater returned to a public source - The distance between the septic tank and the home should be at least 10 feet. From the point where the discharge sewer line leaves the home, the tank should be positioned straight out. When both the septic tank and the drain field are near the ground surface, a residential sewage treatment system works well and is easier to maintain. There are several advantages to having the lift pump in the basement. For starters, this allows wastewater from the top level of the house to flow to the septic system via gravity. During a flood or a power outage, this has proven to be useful. Second, a lift station that pumps all a house's wastewater is unnecessary for the homeowner. Finally, a basement sump is only activated when basement fixtures are turned on.

Artificial groundwater recharge technology - Artificial recharge is the process of spreading or impounding water on the land to increase the infiltration through the soil and percolation to the aquifer or of injecting water by wells directly into the aquifer. Surface infiltration systems can be used to recharge unconfined aquifers only.

Artificial recharge can be done using any surplus surface water. When low quality water is used for recharge, the underground formations can act as natural filters to remove many physical, biological, and chemical pollutants from the water as it moves through. Often, the quality improvement of the water is actually the main objective of recharge, and the system is operated specifically using the soil and the aquifer to provide additional treatment to the source water. Systems used in this way are called soil-aquifer treatment (SAT), or geopurification, systems.

Grey Water Treatment

Table 5 Greywater Analysis

Source	Generation activities	Quantity, in Liters	Reuse application after treatment

Bathroom	Hand Basin Shower Bath	45- 60 / person / day	Gardening Toilet Flushing
Laundry Rinse water	Washing Machines / Laundries	100-120 liters per wash	Gardening Toilet Flushing

Bathing and laundry operations in both residential and business establishments produce greywater. Chemical and biological treatment procedures can be used to treat the contamination level in this water. Greywater generated by the sources is collected in a common subterranean tank. The primary function of this tank is to equalize peak flows or surges caused by bathing or bathtub draining operations, as well as to standardize the quality of greywater obtained from other sources such as laundries or washbasins. If there is an excess of flow or the flow is of poor qualit, the flow is automatically routed to the sewage drain. The pump is protected against dry running at low flow conditions by an automatic level sensor mechanism. Disinfectant is added to biologically processed greywater in the disinfection zone level tank for disinfection using chlorine tablets. After being disinfected, greywater is polished further using an activated carbon filter and a tertiary microfiltration system. Finally, the class was addressed. In the Reuse water tank, greywater is stored. It will then be used for the intended purpose. If the amount of produced treated water produced exceeds the amount used, it will be automatically routed to the sewer system to prevent floods.

Rain Water Harvesting

Rooftops are an ideal location for collecting rainwater.

This water, if appropriately diverted, can be used for a variety of purposes, including drinking and household needs, agricultural needs, and recharging bore wells and groundwater levels.

The system is made up of four primary components:

1. A 100-square-meter roof
2. The ceiling and the filter are connected by a down pipe.
3. A rainy filter that filters out any dust particles larger than 200 microns.
4. A 1000-liter underground storage tank

The rainwater collected in the subsurface storage tank is pumped to a second roof-mounted over-head tank. Apart from the taps in the kitchen and a washbasin in the dining area, both toilet flush tanks have exclusive connections to this storage tank. Though our row house has a sufficient municipal water supply connection, the intention is to avoid using such high-quality treated water meant for drinking (treated at a cost of INR 25-30 per kilo liter) for non-consumptive applications such as flushing toilets, cleaning utensils, watering plants, and so on.

Total quantity of water to be collected (cu.m.) = Roof Top Area (Sq.m.) x Average Monsoon Rainfall (m) x 0.8

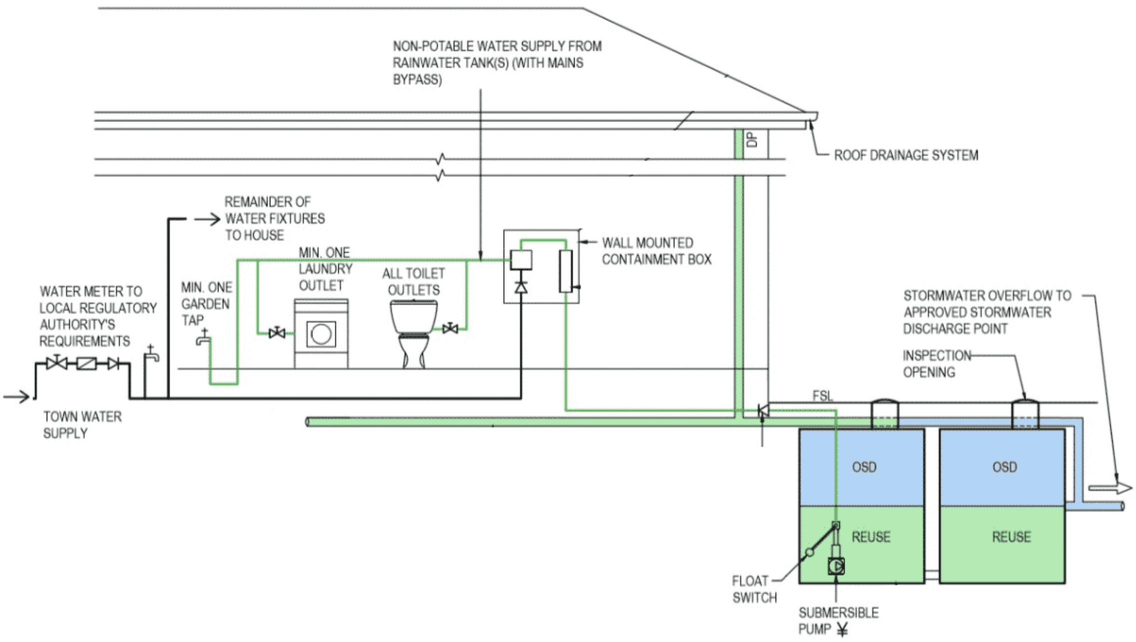
= 100sq.m x 2205.8/1000 x 0.8

= 176.46 cu.m.

1. <u>On-site Storm water Detention:</u>

It is a way of collecting the rain that falls on site known as storm water or surface run-off. Detention tanks store the water temporarily and then releases it slowly so that it does not worsen the downstream flow or flooding.

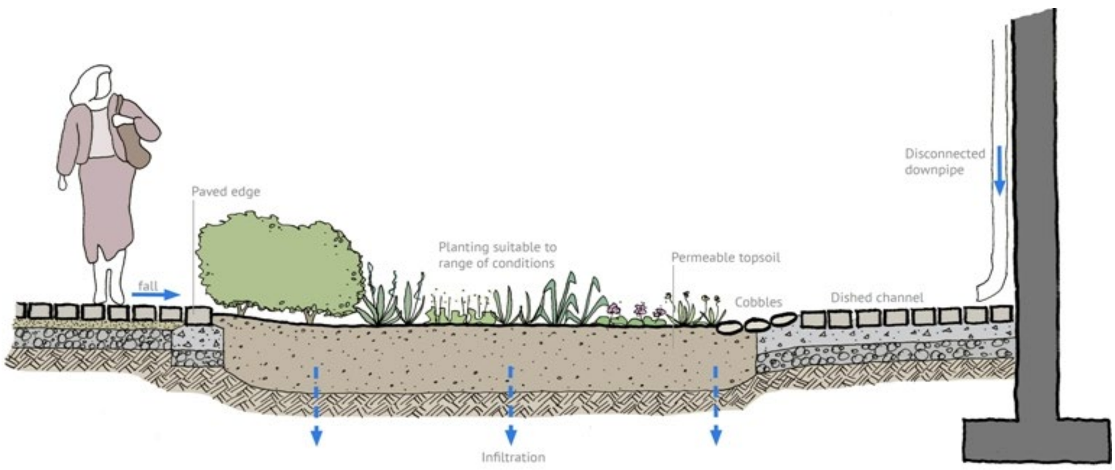
Application: The detention tank is mostly used in urban and residential areas. Therefore, in the project of institute campus, the tank can be retrofitted to hostel block buildings.



1. Infiltration Tanks:

These are shallow excavations that are filled with uniformly crushed stone (similar to soak pits) to create underground reservoirs for storm water runoff. The runoff gradually filters into the subsoil and eventually to the water table. The trench may be designed to include vegetative cover and other features creating a bio-filtration area. This means that inclusion of vegetative cover around the trench will naturally allow water to percolate into the soil and the plants will absorb the water thereby, allowing solid particles to remain above the ground which can be then cleaned manually.

Application: Infiltration tanks can be constructed in the outdoor parking lots or beside streets. In the project, the streets or driveways used for circulation have these tanks on the side of it. Also, the parking area which is not a habitable space can be used to construct these tanks.



Water Consumption Reduction

Table 6 Water Consumption Reduction

Technology Category	Type Detail	Traditional/Existing Standard	High Efficiency	Savings Potential	Comments
Faucets	Lavatory: Private Use	12lpm	6 lpm at 60 psi	6 lpm	Simple and very cost-effective retrofit
	Lavatory: Metering Faucet may be actuated manually or by sensor	2 litres per cycle			A faucet that after actuation dispenses water of a predetermined volume for a predetermined period of time. The volume or cycle duration can be fixed or adjustable.
	Kitchen and other applications	12-19 lpm	8 lpm	4-11 lpm	Simple and very cost-effective retrofit
Showerhead	Wall mount, Handheld	14-19 lpm	8 lpm at 80 psi.	~46 litre/shower	Showerhead flow rate decreases over time due to scale build-up. Flow rate at replacement may be 75% of manufacturer rated flow
Toilets	Gravity Flush Tank	10 litres/flush	5 litres/flush with at least 350-gram waste removal	4-5 litre/flush	New models are engineered for effective flushing
Urinals	Standard Flush	1.5 – 3 litre/flush	0.5 litre/flush	2.5-1 litre/flush	Proven technology in widespread use. Highly efficient (<0.25 litre/flush)

8.3. Resilience

The Navi Mumbai region, or broadly speaking – the Mumbai Region does not lie near any active tectonic plates. Hence there is an extremely low risk of earthquakes or any other seismic hazards.

Some of the potential risks that may be encountered by the residents include waterlogging during monsoons, public health hazards, disruption of water/electricity/food supply during environmental calamities, heat waves, and fire hazards. The measures taken to avoid or reduce the effects of these risks are discussed below.

Natural Disasters and Climate Change:
The region has a warm and humid climate throughout the year and has an average rainfall of 242.2 cm. The only problem faced in the region is due to high rainfall during the peak monsoon months (July-August), with a peak of about 710 mm in July. The Navi Mumbai region has an average elevation of about 4m above sea level and a well-connected network of drainage systems. Hence, despite the high amount of rainfall in the region, there is hardly any waterlogging as opposed to the low-lying central Mumbai region.

Our team primitively came up with a design including a stilt parking system on the ground floor to provide wide parking space and prevent the risk of waterlogging into the accommodations. But the design would have required an additional lighting and ventilation system and increased the overall energy consumption. Moreover, it would have increased the construction cost significantly along with the materials required. Rather, we focused on a more practical and sustainable design providing a sophisticated drainage system for the excess water to seep out easily.

The site utilizes French drains to allow the rainwater to be absorbed into the ground than running off over the ground. The green cover also aids in seepage of water into the ground.

Also, the floor plan of the accommodations is about 10cm elevated from the ground, hence giving an extra clearance against any waterlogging in case of a sudden downpour.

Moreover, the rainwater falling onto the roofs is harvested and filtered for domestic usage by the residents. This further lessens the load on the local drainage system of the construction.

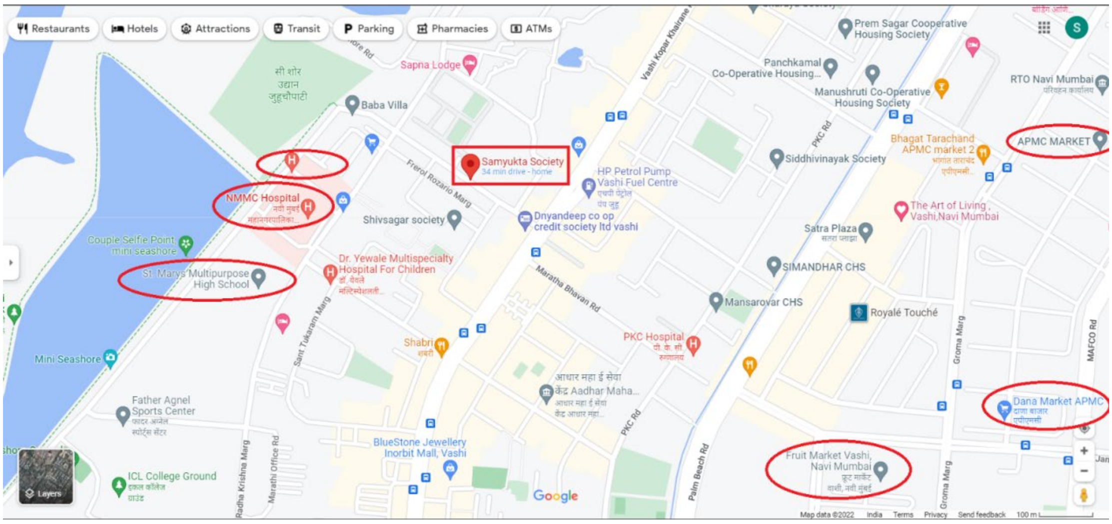
Public Health Hazard:
The premises can also be safeguarded during a biomedical crisis like the recent covid pandemic by ensuring separate or exclusive entrance to the premises. Each household can be quarantined separately hence not posing any threat to the neighboring household members. Moreover, the project site has two major hospitals – Fortis Hospital and NMMC Hospital within a radius of 500m.

Water and Electricity:
There are no major power cuts in the region. Seldomly, in case of any maintenance or emergency cases, only the power supply is disrupted. However, the solar photovoltaic grid provides a backup during such situations. Moreover, domestic wind turbines keep on generating power in the monsoon season when sufficient sunlight is not available.

Also, the area has a 24x7 water supply. However, in case of any disruption, the rainwater harvested serves as a clean and safe alternative for potable water. Moreover, the overhead storage tanks hold sufficient water for 2 days for a normal household of 4-people.

Food Security:
The site is just 2.5km away from the Vashi APMC Market which is a central dana Bazar for the region along with multiple general stores nearby, ensuring stable food security for the residents throughout the year. Moreover, several supermarkets and grocery shops

are located in the vicinity of the site. Further, the area is well connected with a good transport network making the availability of e-commerce services extremely easy.



8.4. Affordability

One of the main aims of the team while designing the layout of the project was optimization of the construction cost and overall cost reduction. Various small yet effective measures are adopted by the team to accomplish these goals.

1. We plan to use the eco-friendly Agrocrete® bricks that are manufactured using crop residues and industrial by-products. Agrocrete®, like Red Bricks and Fly Ash Bricks, can be utilized for load-bearing and non-load-bearing applications. An Agrocrete® Solid Block is nearly 5 times the size of a Red Brick, hence reduces building costs by 30% and allows for faster and easier masonry. Agrocrete® also has a lower thermal conductivity, which means cheaper operating expenses for the building's inhabitants.
The comparison between conventional red bricks and Agrocrete® bricks can be summarized from the following picture.

Parameter	Red Bricks	Agrocrete® Solid Block
Strength	7 MPa	5 - 7.5 MPa
Density	1800 - 2000 kg/m^3	1200 - 1500 kg/m^3
Water Absorption	18-20%	10 - 20%
Durability	75+ yrs.	75+ yrs.
Thermal Conductivity*	0.8 W/mK	0.4 W/mK
Embodied Carbon	0.24 kgCO_2/kg	-0.2kgCO_2/kg
Size of Brick (in mm)	215 x 102.5 x 65	400 x 150 x 130
Cost of Walling per sq.m. (incl. masonry, plastering & mortar joints)	₹ 2245	₹ 1255

* Thermal conductivity tested by TERI
All other values are self-certified.

Figure 8 Comaparison of Agrecretre with Conventional Red Bricks

The construction cost per sq.m. can be reduced by almost 50% by switching to Agrecrete® bricks.

2. No flooring can be more luxurious than fine granite or marble flooring. But the beauty and elegance of granite come at a great economic and environmental cost.

The average flooring cost of granite stones is around Rs. 90-100 per sq.ft. whereas that of the kota flooring is just Rs. 60 per sq. ft. The ko stone is a fine-grained, hard, tough, and homogeneous natural stone. Polished kotata stones look as good as marble or granite flooring.
Moreover, shaded kota stone always remains cool, thus helping in regulating the indoor temperatures as well.

3. Construction cost largely involves the raw materials used. Hence, if we aim to lower the overall construction cost, the ideal way can be reducing the amount and cost of the raw materials used. Moreover, if we can achieve multiple advantages (like insulation of the building from heat while cutting the overall cost and raw materials), it will be a twin advantage as a sustainable design.
The Rat trap bond (or the Jail Wall design), invented in Kerala in the 1970s by famous architect Laurie Baker, is a double-wall technology that dramatically lowers building costs, decreases material and mortar consumption, and aids in increased thermal efficiency without compromising wall strength. Bricks (standard size 230 X 110 X 75 mm) are positioned vertically in Rat-Trap masonry such that the 110mm face is visible from the front elevation rather than the conventional horizontal alignment. The width of the wall, however, stays constant (230mm), resulting in an interior void in place of the 75mm face. This method conserves about 30% of the material (brick and mortar), lowering the entire building cost to around Rs. 300-350/sq.ft.

4. On an average, HVAC accounts for almost 40% of our energy needs in the operational stage. The air conditioning systems are one of the major power consumers in any building. Hence, to reduce the consumption of power and eventually reduce the effective cost, our team came up with solutions to avoid mechanical cooling systems in the buildings by focusing on natural ventilation and assisted natural ventilation by means of fans (to get greater air velocities and ACU) and dehumidifiers (to counter the mainly latent loads). The design aims to eliminate the need fo mechanical cooling. In the long run, this will surely help reduce a considerable amount of operational and maintenance costs.

8.5. Innovation

Rat trap bond, Jail wall:
Construction cost involves the raw materials used. Hence, if we aim to lower the overall construction cost, the ideal way can be reducing the amount and cost of the raw materials used. Moreover, if we can achieve multiple advantages (like insulation of the building from heat while cutting the overall cost and raw materials), it will be twin advantage as a sustainable design.

The Rat-Trap bond (or the Jail Wall design), invented in Kerala in the 1970s by famous architect Laurie Baker, is a double-wall technology that dramatically lowers building costs, decreases material and mortar consumption, and aids in increased thermal efficiency without compromising wall strength. Bricks (standard size 230 X 110 X 75 mm (about 2.95 in)) are positioned vertically in Rat-Trap masonry such that the 110mm face is visible from the front elevation rather than the conventional horizontal alignment. The width of the wall, however, stays constant (230mm), resulting in an interior void in place of the 75mm face. This method conserves about 30% of the material (brick and mortar), lowering the entire building cost to around Rs. 300-350/sq.ft.

Further, as air is an excellent insulator of heat, the air trapped in the void protects the interior of the building from the exterior heat, hence further reducing the load on the cooling systems. Baker's Rat-Trap technique is therefore both an energy-efficient and cost-effective alternative to traditional brick construction.

Figure 9 Rat Trap Bond

Agrocrete:

According to the United Nations Environment Program 2020, the building sector contributed to more than a third of the global carbon emissions in 2019 (Source). This mainly includes the manufacturing of building materials like bricks and cement.

s

Hence, to make the construction eco-friendly and sustainable, our team aimed to avoid the usage of concrete. We came across one of our industrial partners, the GreenJams, who offer the perfect solution for carbon negative and cheaper building materials with the aim of providing products and services that enable their customers to lead a climate-positive lifestyle. The Agrocrete by Green Jams is a “First of its kind” building material made of crop residues and industrial by-products. The Agrocrete solid blocks are a perfect replacement of clay bricks, fly-ash bricks, and concrete masonry units. They are almost 50% cheaper than conventional bricks and 25% more energy efficient. Moreover, they offer 50% higher thermal insulation than conventional clay bricks, require 20% less plaster, and are durable.

Origin Dehumidifiers:

Mumbai has a very humid climate all year long with an average relative humidity of around 75%, varying from 62% during winters and 89% during the monsoon. Due to such high humidity levels, the temperature feels to be much higher than the actual temperature.
Since human skin relies on the air to expel moisture, we are extremely sensitive to humidity. Sweating is our body's way of trying to stay cool and maintain its present temperature. Sweat will not evaporate into the air if the relative humidity is 100 percent. As a result, when the relative humidity is high, we feel hotter than the actual temperature. Conversely, if the relative humidity is low, we feel much cooler than the actual temperature as the sweat evaporates more quickly.

Humidity not only affects the temperature, but also the durability of the interiors of a building. High indoor humidity can condense on cold surfaces and promote microbial growth leading to health hazards for the residents. Condensation onto the interior walls may also damage the plaster and lead to the growth of fungi and moulds on the walls.
Since the air conditioners are used to counter the latent loads, we tried to look for a more direct solution for dehumidification. We found that Origin Dehumidifiers provide domestic dehumidifiers in Mumbai and approached them to form an industry partnership. They have verbally agreed to provide us with technical specifications and technical aid in sizing the system for our application. Dehumidifiers are more commonly used through USA and Europe but have not picked pace in India and hence, are expensive. This is a recent partnership and they haven't formally registered yet. We plan to further analyze the financial aspects of application of a dehumidification system to counter the high latent loads in the coming weeks.

Home Automation and Building Management System:

We have a low people to area ratio as the typical resident strength is just 5 with a range of 2-6 people only. Thus, home automation has tremendous potential for saving costs.

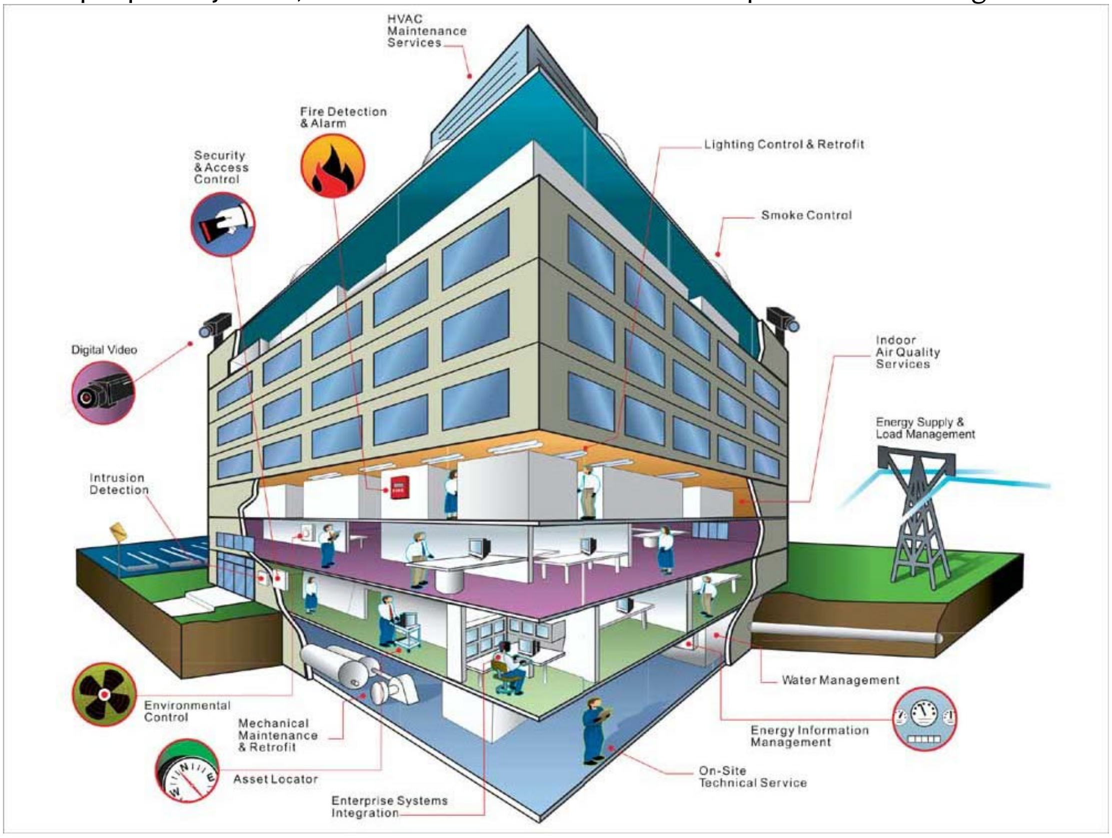


Figure 10– IoT Integrated Automated Building Management System

An IoT provides facility managers with data that they previously did not have access to. These tiny networked sensors can be used in conjunction with automated building systems to increase operational sustainability. For example, based on temperature, weather, and CO_2 data, IoT sensors may dynamically alter the appropriate ventilation and lighting levels inside the structure. The facility manager does not have to keep track of these modifications manually or enter data from various machines. The system specifications are to be worked on in the further design iterations.

8.6. Health and Wellbeing

Thermal Comfort:

The zone-wise distribution of the spaces is shown in table 9.

Micro-climate: As discussed in the site analysis, there are multiple water bodies in close vicinity of the site. Vashigaon Chowpaty (an artificial lake) and Vashi holding lake are both at a distance of about 400 m from the site. The site is less than a kilometer away from a strait. Also, there is a wide mangrove cover near these water bodies. These factors lead to a cooler environment at the site. This observation is validated by the users. A user experience states that a south-west facing room with a WWR of 40% remains comfortable with half drawn curtains without even needing a fan throughout most of the year excepting peak summer months of April and May.

Through preliminary climate analysis, we recognized the possible directions and strategies we could pursue. The IMAC comfort band (Fig.) showed us that the mean monthly outdoor temperatures were in the comfort band throughout the year baring May (over by 0.5°C).

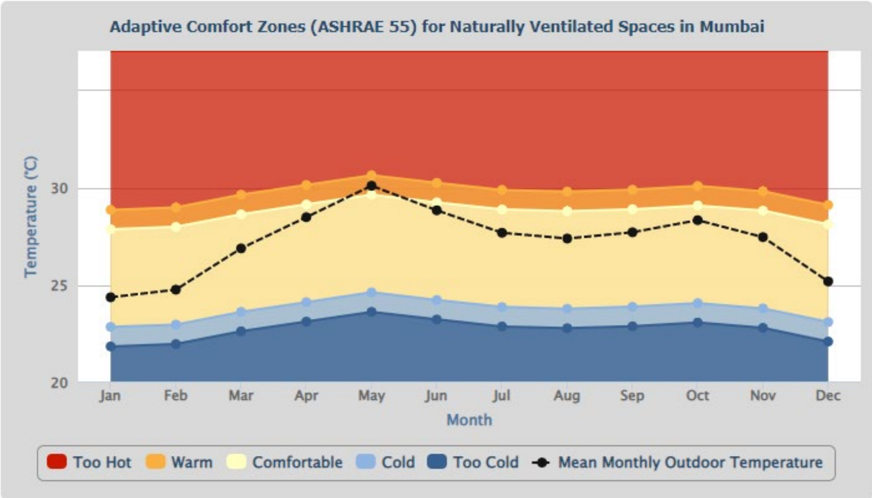


Figure 11 IMAC Comfort Band

Considering the micro-climate, we decided to explore natural ventilation as our primary design strategy.

However, since the mean outdoor temperatures are near the upper threshold of 90% comfort and intermittent nature of wind velocity and direction, we are planning to go for assisted natural ventilation by employing ventilation ducts or domestic dehumidifiers along with high efficiency BLDC fans in the next design iterations. We are in talks with partnering with Origin dehumidifiers for technical assistance on domestic dehumidifiers. Energy analysis for natural ventilation is currently being worked upon. Since the designing of the cooling system is in progress, the annual simulation results are not available at this stage. We plan to incorporate the micro-environmental effects in the simulations in the following design iterations.

Ventilation and Air Quality:

The location of the site is such that it is in the middle of much less travelled connecting road between two main roads. Thus, it has a good approach whilst the road seeing less traffic. The main pollutant in Navi Mumbai is PM2.5. The air can be considered cleaner to that of the weather station readings as it is in close proximity to the mangrove forests lining the creek (within 1km).

A range of indigenous vegetation is planned to counter PM2.5 whilst aiding in natural ventilation. The species of the vegetation and appropriate placement is currently under study and discussion. We plan to determine the specifics in the coming design iteration.

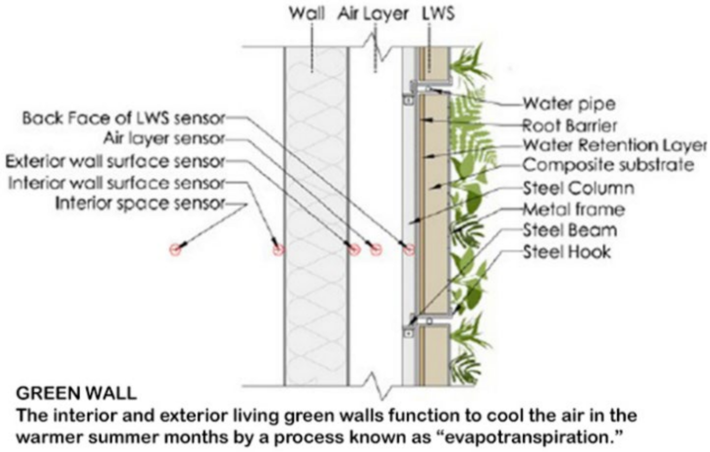
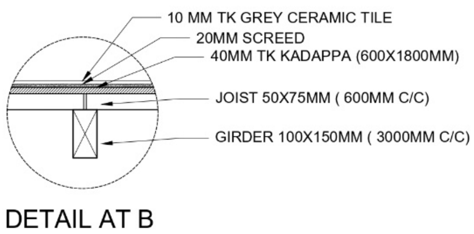


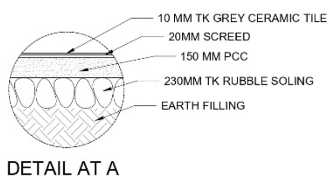
Figure 12 Green Wall

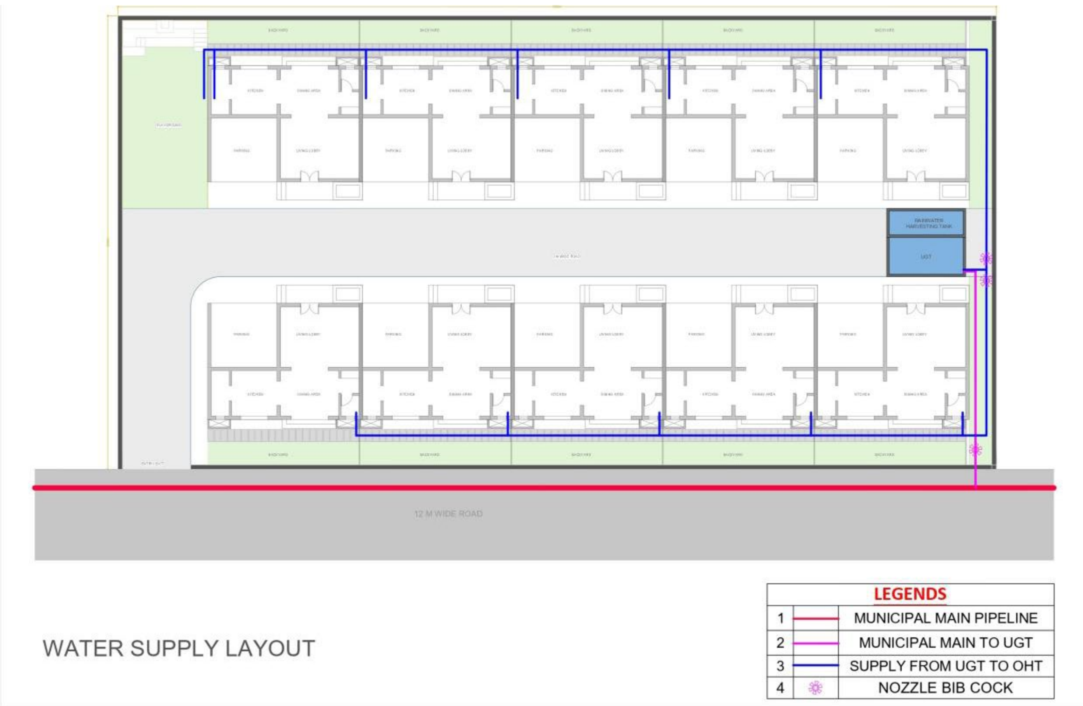
8.7. Engineering and Operations

The third chapter of the annexure contains detailed drawings. We have two external shafts per house. The external shaft is structure based and the structure is covered with climbers to form a green wall.
The layout being symmetrical in pattern creates easy flow of services like plumbing and drainage.
Solar panel roof creates enough equal amount of energy that is consumed by the structure and it also helps in creating a better rain water harvesting system.

Solar panel roof will not only increase the
surface area exposed to direct sunlight but will also help in collecting maximum storm water runoff from the site.
Symmetrical grid layout also allows the use of traditional materials like brick, stones, etc and minimizes the use of RCC in the design.






12 M WIDE ROAD
WATER SUPPLY LAYOUT
LEGENDS
1 MUNICIPAL MAIN PIPELINE
2 MUNICIPAL MAIN TO UGT
3 SUPPLY FROM UGT TO OHT
4 NOZZLE BIB COCK

RAINWATER HARVESTING SYSTEM

LEGENDS		
1		PIPELINE COLLECTING SURFACE RUNNOFF
2		SUPPLY PIPELINE
3		PIPELINE TO RELEASE EXCESS WATER
4		NOZZLE BIB COCK
5		INFILTERATION TANK

ELECTRICAL LAYOUT

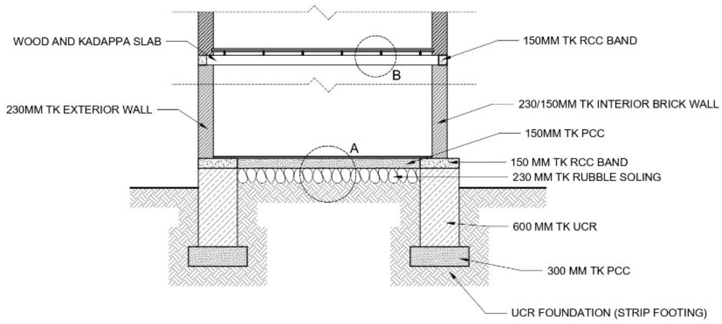
LEGENDS		
1		MUNICIPAL MAIN
2		FEEDER CABLE
3		SUPPLY CABLE
4		METER BOX

Space wise Distribution:

Table 7 Zone-Wise Space Distribution

Floor	Rooms	Cooling System
Ground Floor	Garage	Un-Conditioned
	Sitting	Conditioned
	Dining	Conditioned
	Kitchen	Conditioned
	Kitchen Wash Area	Un-Conditioned
	Dining Wash Area	Un-Conditioned
	Toilet 1	Un-Conditioned
	Staircase	Un-Conditioned
First Floor	Living Room	Conditioned
	Bedroom 1	Conditioned
	Bedroom 2	Conditioned
	Balcony 1	Un-Conditioned
	Balcony 2	Un-Conditioned
	Toilet 2	Un-Conditioned
	Toilet 3	Un-Conditioned
	Staircase	Un-Conditioned
Second Floor	Bedroom 3	Conditioned
	Bedroom 4	Conditioned
	Balcony 3	Un-Conditioned
	Balcony 4	Un-Conditioned

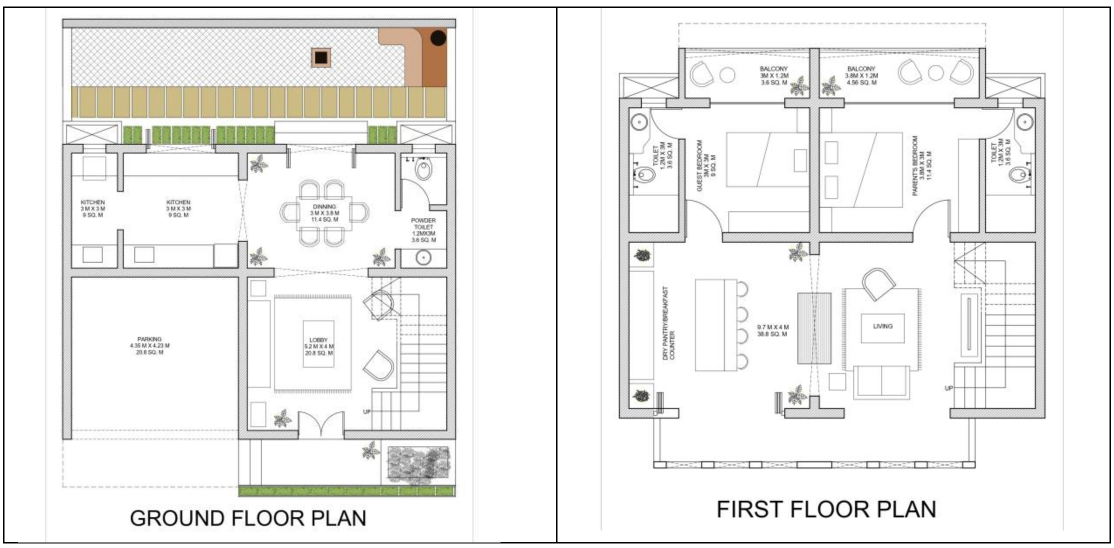
	Toilet 4	Un-Conditioned
	Toilet 5	Un-Conditioned
	Corridor	Un-Conditioned
	Lillypool	Un-Conditioned
Terrace	-	Un-Conditioned

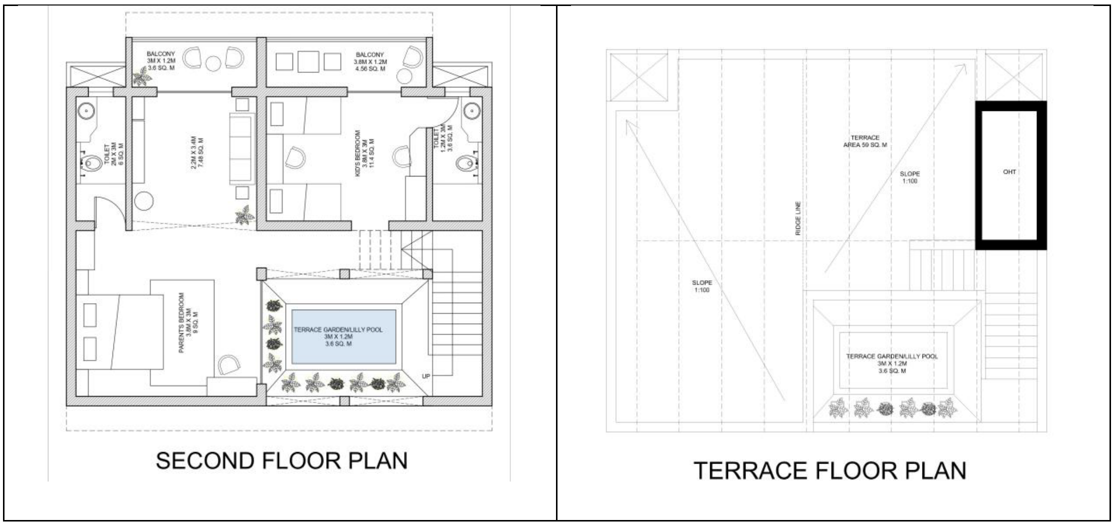


CONSTRUCTION DETAILS

8.8. Architectural Design

Figure 23 – Layout R





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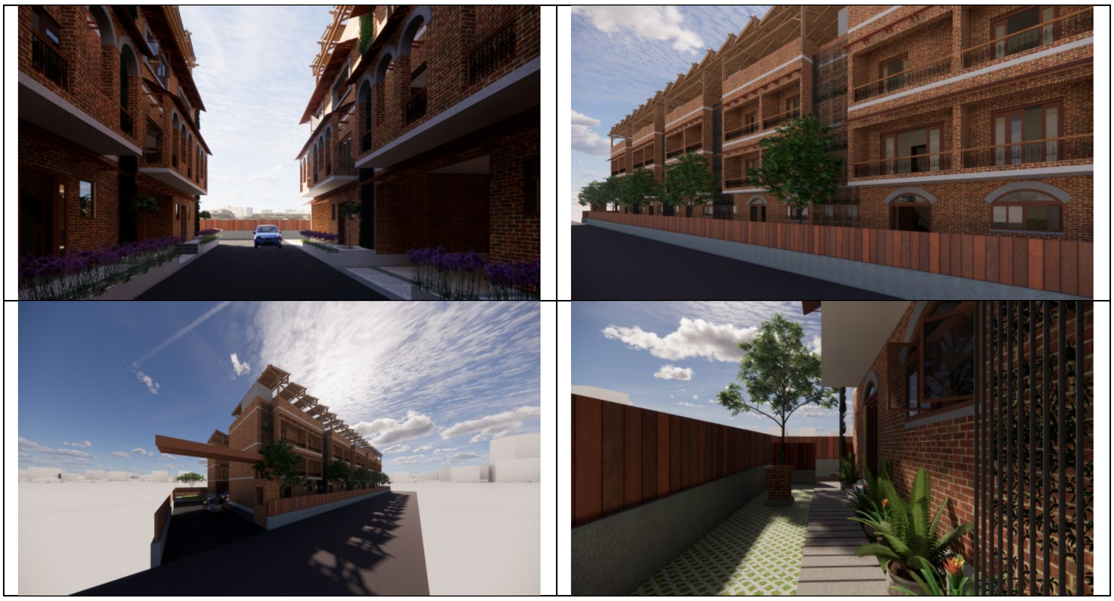

The main architectural feature is a clean spacious plan constructed in grids. In cities like Mumbai, space is a primary restraint. In line with our initial goal of providing an organic traditional user experience, we have laid the main focus on simplifying the layout and giving spacious unobstructed user spaces to lead to an overall fulfilling user experience.

We have given each house its own backyard and a balcony for each of the 4 bedrooms. The form allows for daylighting and natura ventilation inline with our design philosophy of creating an organic user experience with traditionally oriented spaces. Designed according to the traditional courtyard concept of Indian houses, with every house having its own backyard thus making the inside and the outside equally engaging.

Figure 13 Site Elevation

Figure 14. Site Elevation

We have employed extensive usage of arches along with designing in a grid to give an overall clean unobstructed spacious user experience with a traditional feel.

The design spaces are more vernacular with the integration of carbon negative environment friendly materials. We have minimized the use of RCC in our design and shifted the perspective towards sustainable building materials for a sustainable home in accordance with our design objectives.

8.9. Scalability and Market Potential

Analysis identifying the size of the target market:

Row Houses are a suitable alternative for many modern-day buyers who feels apartments are too packed. The format of row houses suits everybody and is among the premium offering in the market. The price ranging is from affordable to premium on basis of land availability. unlike high-density apartments thriving in Indian cities, row houses offer breathing space.

There are more than 5 similar CHS on the street which are going to be redeveloped in the near future. Our design can be directly replicated for them making improvements from the practical inferences from the current design. We further aim to keep our design modular so as to enable the other CHS's to follow suit and form an inclusive oasis in the midst of the concrete jungles of today. Our target audience is people seeking spacious housing integrated into the environment as against closed apartment living areas. The current residents form the first set of customers.

8.10. Communication

For engaging with the public, we have formed a three-pronged strategy:

- Our team plans to record the entire design process and publish it on Linked-In and other social media accounts for creating awareness about effective and sustainable designing approaches. This will help interested people in gaining some insights about various technical aspects related to efficient design process.
- Publishing white papers regarding the integration of technologies provided by the industry partners is also being explored. We are also considering documenting our design process to form a case study that can be used by our project and industry partners. This will help spread the recognition of Solar Decathlon India by showcasing the project.

- Further we also plan to collaborate with the ISHRAE Mumbai Chapter and broadcast our journey through ISHRAE for spreading awareness. Currently we are communicating with the ISHRAE Institute Chairperson regarding the same and expect a positive response soon.
- Currently, posts have been made on LinkedIn by FCRIT (Institute handle and the handle of Department of Mechanical Engineering). Also, posts have been made by ISHRAE Student Chapter (LinkedIn and Instagram).

9. References

Standard Documents:

1. NBC - National Building Code of India - Volume 1 and Volume 2
2. Energy Conservation Building Code - User guide
3. Energy Conservation Building Code - as a tool for energy efficiency
4. IGBC Green Homes Rating System - Version 3.0 - For Residential Units

- https://carbse.org/net-zero-energy-building/
- https://cept.ac.in/library/online-journals