Solar™ Decathlon India

Skanders Family

Multifamily Housing

Final Design Report- April 2020

Dhun Jaipur Pvt. Ltd.

School of Planning and Architecture
New Delhi

Chebrolu Engineering College
Andhra Pradesh

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EXECUTIVE SUMMARY

“Humans have to adjust with the planet rather than the planet being adjusted to humans.”

Buildings are not just static architecture. We have to redefine the role of architect and engineer as a trainer, adaptation expert, stakeholder rather than a person who builds for the static condition and not being concerned about the ongoing global scenario.

Building upon the egalitarian and ecology-driven values, team Skander’s Family from the School of Planning and Architecture, New Delhi aims to develop a prototypical housing that can withstand the hazards of a hot and arid climate, through the optimization of demand-supply side management to achieve the desired results.

This paper delivers a net-zero design through the innovative integration of modern technology with traditional wisdom. Various passive strategies including thermal insulation, earth air heat exchanger coupled with solar chimney, and energy-efficient appliances are also used to achieve the net-zero energy performance in the given contemporary lifestyles.

- The final design outcome emerged out of a comparison between a built as usual (BAU) housing block vs three proposed design options, where the reduction in the Energy Use Intensity (EUI) from 38.5Kwh/m2/yr (as given by SDI) to 19.9Kwh/m2/yr for the proposed Housing Design was made possible.
- With this Reduction in EPI, after the use of various energy conservation measures, a 15-20 degrees reduction in temperature at the peak summer day is also carried out. (Refer CFD Analysis under comfort and environment)
- IPCC predicts that water consumption will rise and the groundwater table will go down, as per the climate change report. In that, India is the third-largest country in drawing groundwater, where we draw four times more than the water we replenish. In this project, the strategies for meeting water demand at all stages, starting from construction, are sustainably laid out.

Our aim was not just to provide the propitiatory aspect of assessment and energy needs but even the universal accessibility and social sustainability desired by a person to be living in a safe and secure environment.

Figure 1 : Design features

TEAM SUMMARY

Team - Skanders Family
Institutions - School of Planning and Architecture, New Delhi
Chebrolu Engineering College, Andhra Pradesh.
Division - Multi-Family Housing

TEAM MEMBERS

Our approach towards the design consisted of three main processes: research, problem-identification, and problem-solving, all of which went hand-in-hand during the design exercise. The team was divided into various sub-groups to tackle individual topics and then combined to come up with the final design.
All the members of the team are third-year architecture students from SPA Delhi along with a third-year engineering student Kamma Vamsi Kiran from Chebrolu Engineering College, Andhra Pradesh.

Nanda Kishore K

Adithya M Nair

Akansha Shilpi Kachhap

Devadath Jayakrishnan

Ejas Muhammed

Femi Susan Reji

Sahiba Shukkoor

Kanumala Sai Sri Maneesh Reddy

Shivani Yadav

Sivakrishnan M S

Samyu T M

Yerra Meghana

SCHOOL OF PLANNING AND ARCHITECTURE, DELHI (Est. in 1941)

SPA Delhi is a specialized deemed University, only one of its kind, which exclusively provides training at various levels, in different aspects of human habitat and environment.
The School has lead in introducing academic programs in specialized fields both at the Bachelor's and Master's levels, some of which are even today not available elsewhere in India.

FACULTY LEAD AND FACULTY ADVISORS

Lead Faculty-

Mrs. Vandana Balakrishnan
Assistant Professor, SPA Delhi

Faculty Advisors-

Mr. Prabhjot Singh Sugga
Associate Professor SPA Delhi

Mr. Debashish Majumdar
Visiting faculty , SPA Delhi

Mr. Anand Dhote
Visiting Faculty at SPA, Delhi

Mr. Sachin Rastogi
Visiting Faculty at SPA, Delhi

INDUSTRY PARTNERS

GreenJams

Asahi India Glass Limited

PROJECT INTRODUCTION

PROJECT NAME - ADVAIT DHUN

PROJECT PARTNER - Dhun Jaipur Pvt. Ltd Est. 2017
Dhun Jaipur Private Limited is a non-govt company in Jaipur, Rajasthan, which is involved in renting construction /demolition equipment with an operator.

Project Director
Manvendra Singh Shekhawat
His work is an outcome of a unique way of life, carefully preserving the traditions of the past yet framing them in a modern idiom.

Other Key individuals

Mangal Singh Solanki
Director

Raghvendra Singh
Director

PROJECT DESCRIPTION

The site is located in Phagi tehsil of Jaipur district in a mixed-use project by Dhun Pvt. Ltd. This project aims to create a self-sufficient egalitarian neighborhood that provides all the basic amenities, work opportunities, and social infrastructure to the inhabitants. We aim to design a multi-family housing for the support staff of Dhun in an area of 19000 m2 for 150 families (max.). The entire area is further divided into three zones (50 families each) by an interesting system of swales as in the master plan (provided with respective community amenities).

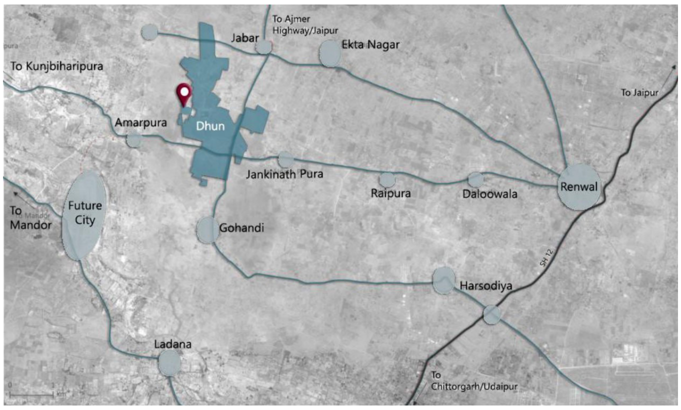


Figure 2 : Jaipur x Dhun

Figure 3 : Dhun x Site

Figure 4 : Zone division plan

The units are a combination of 1BHK and 2BHK units with variations in occupant numbers from 2-4 as described by the project partner. The occupants in the housing are the support staff of the developing township and will be in the vicinity of their workspace.

MARKET POTENTIAL

- Low operational energy and less maintenance housing for the working society of Dhun township.
- Flexibility and adaptiveness to the wide range of user groups that Dhun aspires to.
- A net-zero energy, waste, and water housing prototype that can withstand the varied climatic contrast of Rajasthan.

CLIENT REQUIREMENTS

Some of the client requirements are in line with the solar decathlon requirements and others have been mentioned.

Figure 5 : Client needs

AREA PROGRAMING

Total site area (3 zones) = 4.5 acres
Total site area Zone 1 : 6500 m2(2 Clusters)
1 Cluster : 22 DUs (10 -1 BHK 12 - 2 BHK)

DU Built Up Area :

Type	Space	Area (m²)
1 BHK	Bedroom + Bathroom (17 + 6)	23
	Kitchen	11
	Living Room With Dining	22
Carpet area		**40**
Private Courtyard + Balconies		**11 + 4**
Built Up area (including services)		**71**
2 BHK	Bedroom + Bathroom (16.5 + 17.5 + 5)	39
	Kitchen	10
	Living Room with Dining	22
Carpet area		**51**
Private Courtyard + Balconies		**11 + 4 + 4**
Built Up area (including services)		**90**

Table 1 : Area program

Ground Coverage : 1668 m2 (Building) + 100 m2 (Emergency Parking) = 1768 m2
Softscape area : 3930 m2 (60 %)
Hardscape area : 800 m2 (12.3 %)

Total Built Up Area (two cluster) : 5380 m2
Roof Area (community area shaded by PV panels) : 1274 m2
Conditioned Spaces (Mixed Mode) : 554.2m2

PERFORMANCE AND SPECIFICATIONS

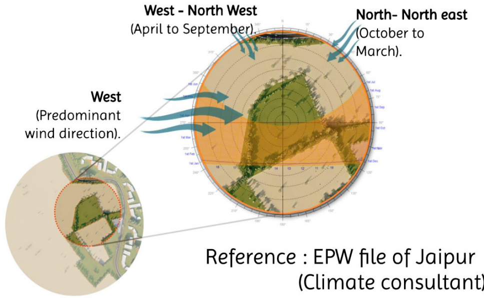


Figure 6 : Site analysis

CLIMATE ZONE

The site, located in Phagi tehsil of Jaipur district, is approx. 40km away from the Jaipur core city. It is a hot and dry region, away from the urban city in a rural context.

PERFORMANCE SPECIFICATION

Keeping in mind the sustainability aspect of building energy performance, energy-efficient equipment and assemblies were chosen for the project.

	BUILDING ENVELOPE ASSEMBLIES (Outside to Inside_in mm)	U-VALUE(W/m2.k)
WALL - DAY SPACE	**Cavity Wall** (0.6 SRI Paint + AgroCrete(150) + AirCavity(20) + RockWool (30) + LSEB(240) + Plaster(10)	0.62
WALL - NIGHT SPACE	Lightweight Envelope (0.6 SRI Paint + AgroCrete(150) + RockWool(50) + Vapour Membrane(0.13) + PlasterBoard(12)	0.61
ROOF	Roof Insulation (0.3 SRI ChinaMosaic(25) + PCC Screed(50) + GeoTextile + PUFF Insulation(40) + VapourBarrier + WaterProofing + HollowCore(200) + Plaster(10)	0.45
WINDOW	**Clear Essence Plus** (UPVC frame with 6 mm Low-E Glass – 12 mm Air Gap – 6 mm Clear Glass) (VLT=71, SHGC=53)	1.81
	HVAC TYPE AND DESCRIPTION	
HVAC TYPE	EATHE System Coupled with AHU-VRV (Combination Model)	
RAHU	*(DAIKIN MODEL)* RAHU-VR2500 (Power - 1.8 KW) Air Flow - 2500 CFM (EC FAN) Total Cooling Capacity - 19KW	
CONDENSOR UNIT	*(DAIKIN MODEL)* VRV IV+ Series _ RXYTQ8U7YF COP - 4.20 (IEER - 22.5 / 27.3) Total Cooling Capacity - 19KW (5.4 TR)	
	ELECTRICAL POWER	**P. DENSITY(W/m2)**
LIGHTING	Average Lighting Power Density of the Cluster	1.64
EQUIPMENTS	Average Equipment Power Density of the Cluster	16.2
	RENEWABLE ENERGY	
TYPE	Roof Mounted Solar PhotoVoltaics (430 Modules)	
SPECIFICATION	PV Generator Capacity - 45 KW Power Rating - 105 W Module Efficiency - 15.14%	
	WATER PUMP SYSTEMS	
POTABLE W.	Kirloskar Water pump 1.75 KL Over-head Water Tank (370W_SuperStar)	
NON-POTABLE W.	Kirloskar Water pump 0.25 KL Over-head Water Tank (180W_Tiny 180)	
SOLAR W. TANK	Openwell Water pump 0.50 KL Over-head Water Tank (92W)	
TALAAB W. SUPPLY	Openwell Submersible Water pump (Talaab Supply) (750W)	

Table 2 : Performance Specification Table

GOALS

Assuring the community's well-being while also striving to be in harmony with nature, we aim at achieving a sustainable and net-zero multi-family housing in Jaipur, Rajasthan, which is suitable for the hot and dry climate of this region. We plan to produce a housing which exceeds the minimum nominal quality standards.

SAFEGUARDING THE VISION OF DHUN

Goal : Designing with an egalitarian approach without compromising the privacy of the user.

- Multi level interaction spaces : following the traditional Rajastani hierarchy of spaces (Public- Semi public - Private).
- Spatial flexibility irrespective of occupants' socio-cultural background.
- Sustainable transport : Pedestrian-oriented , shared electric carts.
- Sustainable material : Precast concrete to reduce construction waste, carbon negative construction materials like agrocrete.
- Equity and local economy : Creating job opportunity for local artisans.

ENERGY PERFORMANCE

Goal : Target energy performance index of 18 kWh/m2/year with net-positive energy design to be achieved . More than 40% energy reduction on common services like water pumps, general lighting in common areas, etc.

- Achieved energy performance index of 19.9 kWh/m2/year with net-positive energy design.
- 32% energy reduction in common services like water pumps, general lighting in common areas, etc.
- Eco-Niwas Samhita (ECBC-R) Compliance for multi-family residential housing.

THERMAL COMFORT

Goal : To achieve adaptive thermal comfort within the IMAC comfort range for 90% acceptability in a mixed-mode building and environmental qualities.

- Achieved adaptive thermal comfort (following IMAC Thermal comfort Model)
- Continuous fresh-air supply through the EAHE system.
- Comfortable community space with less ambient temperature and perpetual shading.
- Environmental comfort : Xeriscaping with native flora and fauna.
- Universal accessibility : Provided handrails, special parking zones, tactile pavings

INNOVATION AND ARCHITECTURE

Goals : Segregation of daytime and nighttime spaces. Effective passive ventilation strategy for both summer and heat gain strategy for winter, integrated with spatial character.

- Carbon negative building envelop maximising use of local materials
- Multi-level open court, as a ventilation strategy in summer and solar gain strategy in winter.
- Use of local materials to reduce embodied energy.
- Innovation in architecture and structural details.

RESILIENCE

Goals : Design to withstand heat waves, extreme temperatures with passive techniques. Wide range adaptability and spatial flexibility for the users.

- Various strategies used at cluster as well as DU level to combat heat waves and extreme temperatures (passive strategies, building envelope optimization, landscaping, wind sheltering etc.)
- Precautions to ongoing pandemics like Covid 19 :
  - > Street overlooking balconies for interaction while staying at home and social distancing.
  - > Fresh air supply through EAHE system maintaining the indoor quality of air.

WASTE AND WATER MANAGEMENT

Goal : Self sustained water system; and aiming at a net zero water and waste system.

Water management at all three project stages : before, during and after construction.

- The water is self-sustained from the premises itself and reduces the depletion of groundwater.
- Water fixture optimization; 85 lpd achieved.
- Proper water treatment system integrated with swales (greywater treatment plant), sewage treatment plant, and rainwater harvesting and sewage is treated to be used as a garden compost.

SCALABILITY

Goal : Wide range adaptability and spatial flexibility for the users.

An innovative design that can be replicated in a similar geo-climatic context and is flexible with respect to the local socio-cultural aspects of the region.

DESIGN PROCESS

PARTICIPATION AND TEAM FORMATION

As part of our third-year studio, we participated in the Solar Decathlon competition, which begins with the basics and progresses to a thorough analysis and research of net-zero electricity, waste, and water designs. The entire design development process was very systematic and definitive, with every member of the team putting in a combined effort to produce a practical net-zero design.

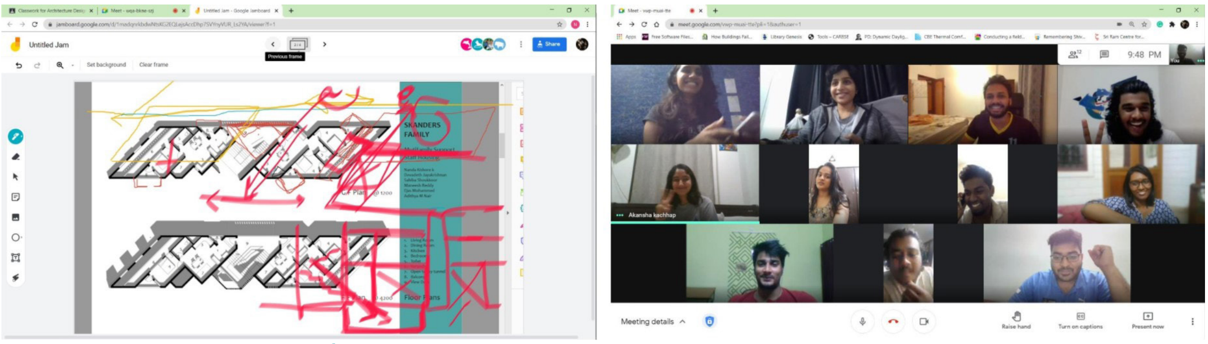


Figure 7 : Group ddiscussion and feedback

GROUP DISCUSSION AND FEEDBACK
SESSION: Meetings were conducted at each stage of design process and the feedbacks were given

WORK SCHEDULE

PHASE 1 (Oct - Sep)	PHASE 2 (Sep - Nov)	PHASE 3 (Nov - Jan)	PHASE 4 (Jan- Mar)	PHASE 5 (Mar - May)
Base Research (SDI Competition)	Meeting with project partner and understanding the projects constraints.	Initial Design development and basic simulations	Meeting with Energy analyst and Industry Partners	Final Calculations and Simulations
Team formation and Typology finalization	Site context analysis, Identification of Challenges	Developing concept and approach to tackle 10 contest of SDI	Final design Development	Deliverable 4 Submission
Understanding associated terminologies, systems for the competition	Case studies, Setting up goals and strategies	Understanding core concepts through SDI Self-learning modules	Meeting with experts and attending external webinars.	Movie making and presentation slides
Deliverable 1 Submission	Deliverable 2 Submission	--------	Deliverable 3 Submission	--------

Figure 8 : Work schedule

DESIGN PROCESS

ANALYSIS AND STUDY : A site visit was not possible due to the pandemic so, a virtual site analysis was done along with a demographic study of the site and the nearby areas.

Basic study was performed to understand the problems in the site and the traditional solutions to tackle the problem.

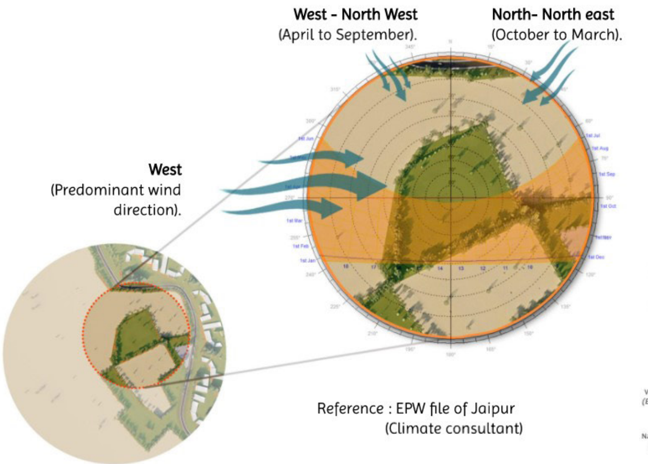


Figure 9 : Site analysis

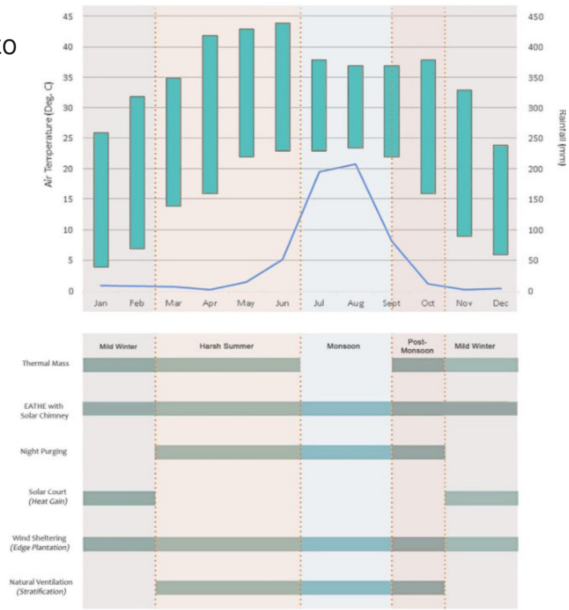


Figure 10 : Proposed Climate Matrix for the site

MAJOR CHALLENGE FACED - Water scarcity

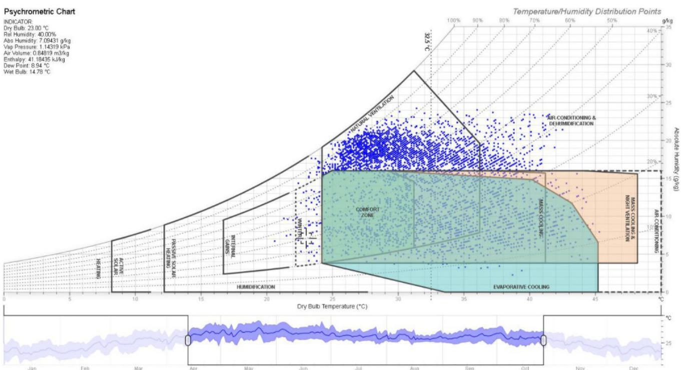


Figure 11 : Psychrometric chart

The approach was to analyze the Psychrometric chart based on comfort parameters and then derive the best possible strategy for summer.

From the Givoni Bioclimatic Chart of Barmer (which was considered to be the Worst case scenario), we can observe that evaporative cooling covers only 10 hrs which is beyond the reach of other passive strategies.

A basic water calculation was performed to analyze the water requirement for evaporative cooling.

	WATER USAGE (L/Tr)	AREA FOR COOLING (m2)	COOLING LOAD THUMB RULE (m2/Tr)	TOTAL WATER REQUIREMNET IN AN HR. FOR A DU (L)
BASE CASE	8.57	70	40	**14.2**
EFFICIENT CASE	5.5	70	60	**6.4**

Table 3 : Water usage

Minimum water required for cooling a cluster for a day = 6.4 x 22 x 12 = 1.6 KL

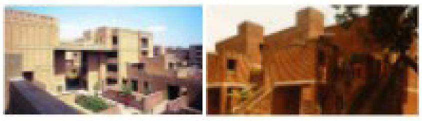
Annual water loss due to evaporative cooling in a Cluster = 1.6 x 5 x 30 = 240 Kl

35% Of the water harvested from the site will be required for cooling, Hence evaporative cooling strategy was not integrated into the project.

RESEARCH AND CASE STUDIES

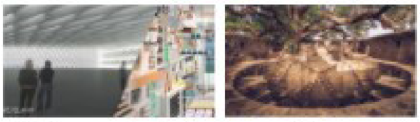
Research was based on a comparative case study approach to **analyse the similarities and differences in the housing projects** based on factors like the climate, context, user group, typologies etc

Typology, spatial Hierarchy



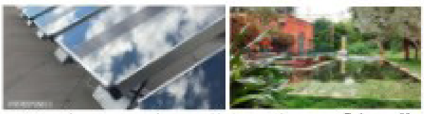
Courtyards integrated with Row Housing was chosen after studying multiple typologies like shared courtyard (sheik sarai housing Delhi), courtyard (Asian games village Delhi), row housing (Atira housing Ahmedabad, French Embassy housing , New Delhi) and affordable housing .

Modern & Traditional space marker

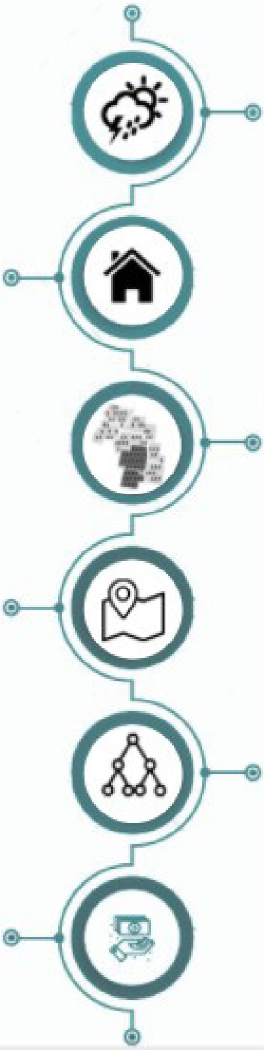


Modern technical and special innovations that redefine the use and functions of traditional landmarks.

Energy, Waste, Water systems



Modern and traditional **eco friendly energy, waste, water systems**



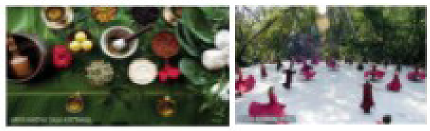
Climate Resilience

IIT jodhpur, Pearl Academy Jaipur Climate resilient design with its **compact cluster arrangements with both sun and wind strategies.**

Regional influence

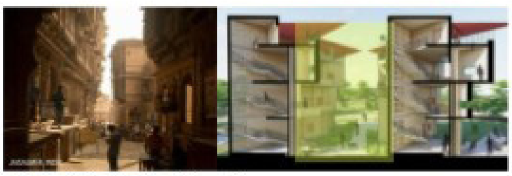
Incorporation of Rajasthani / Jaisalmer architectural features like mutually shaded streets, havalies, Kund, jalli.

Community Wellness



Various case studies were done to understand how to provide safety and security to the inhabitants and maintain their well being.

Energy efficient, Net zero energy ,waste, water, climate resilient housing prototype for this hot and dry region of Rajasthan.



Mutually shaded streets

Our interpretation of Regional identities

Figure 12 : Case study details

Working along with a hot and dry climate was a challenging task that went from learning about local passive strategies to broader contextual references and into a conjunction of two ways of achieving comfort i.e. passive and active strategies working alongside.

The initial concept was to use a traditional solution innovatively to build a climate resilient housing. The main intake from traditional pearls of wisdom are:

In the later stage of the design we have incorporated those strategies as the responses for site challenges. They are:

Shared wall Self and mutual shading Evaporative cooling courtyard	Narrow streets Sandstone jaali Light colour Condensed texture	Multi-level Open Court Segregation of Day and Night spaces Cavity Wall with thermal mass Mutual Shading	EAHE integrated with Solar Chimney Jaali Facade Solar Panel Shading Deciduous tree shading

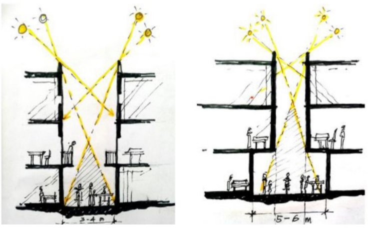


Figure 13 : Initial sketches

Figure 14 : Exploring courtyard typology

Figure 15 : Exploring row housing typology

Figure 16 : Exploring row housing typology

FEEDBACKS AND CRITS

Giving special credits to our guides, SDI TRG members, and mentors (our college faculty) helped us at every step of the way, guiding us with a selfless mindset. Along with that, webinars, self-learning modules and a very interactive resource team provided by the organizers of Solar Decathlon immensely helped us in this journey.

INDUSTRIAL PARTNERS

- Asahi Glass Pvt. Ltd. provided us with various parameters of different glazed units (SHGC, Cost, VLT, etc) that played a vital role in the selection of the glazing.
- GreenJams gave us an insight into AgroCrete and its efficiency as a construction material

SIMULATIONS AND TOOLS USED

For a deeper understanding and realistic approach to the design, simulations were done using various tools and many other tools were also used to help us with our design and report.

INTERACTIVE PLATFORMS

Moreover, the concept of learning by doing helped us in each step. Analyzing, understanding, and working adjacent to each point has brought us to where we stand.

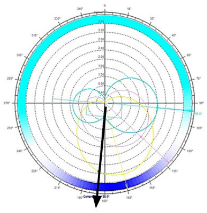
ENERGY PERFORMANCE

DEMAND SIDE MANAGEMENT

ORIENTATION AND BUILDING SHADING

The best orientation for the building was identified with the help of the Andrew Marsh weather tool. Further Shoe-box analysis helped us to Identify the best Aspect-ratio as 1:2.

A series of simulations were then performed in design-builder to understand the effect of other basic strategies in the site energy consumption.



Optimum Orientation
Compromise Angle- 185°
Av. Daily Radiation at -175.0
Entire Year : 1.77 kWh/m2

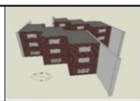
SHOE-BOX ANALYSIS		Percentage Decrease in Total Site Energy	SHOE-BOX ANALYSIS		Percentage Decrease in Total Site Energy
BAU		0%	SELF AND MUTUAL SHADING STRUCTURE		15.82%
NO WINDOWS ON EAST-WEST FACE		12.51%	SOLAR PANEL SHADING		25.54%

Table 4 : Preliminary Shoebox Analysis

ENVELOPE SELECTION

PARAMETRIC OPTIMIZATION

180+ simulations were performed with net site energy use and total building cost as the key deciding factor for the Pareto optimal outcome. Design-builder was used for the Pareto optimization after which XlStat was used to derive the graph.

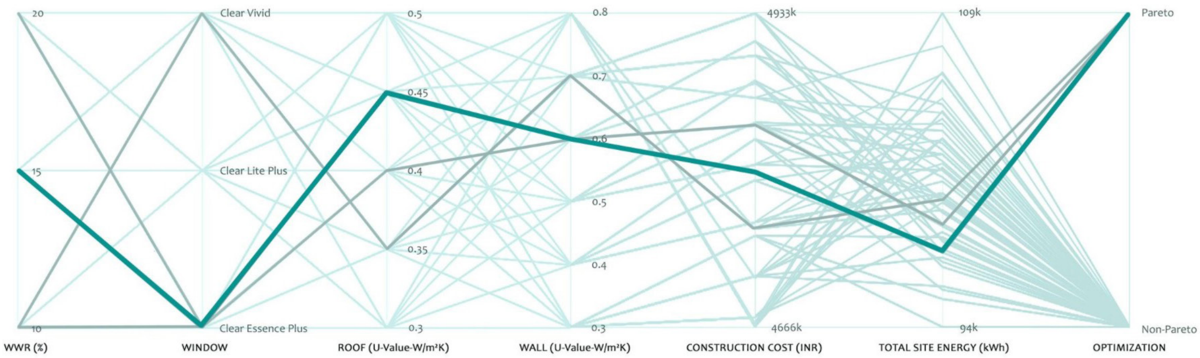


Figure 17 : Parametric optimization for building envelope

From the three Pareto outputs, the thread with WWR 15% was selected, considering the requirement for minimum daylight for space.

The envelope materials were identified by studying the basic parameters of selection, which are local availability, cost, U-value, thermal mass and embodied energy. (Covered under affordability topic)

ENVELOPE SELECTION (contd.)

A series of iterations were performed with cost and U-value as parameters to obtain a building envelope with the desired U-value. Two separate building envelopes were designed based on their use:

- Day Space (has a high thermal mass envelope with the desired U-value)
- Night Space (has a low thermal mass envelope with the desired U-value)

It was to ensure that the night purging strategy doesn't cool the mass rather it cools the space.

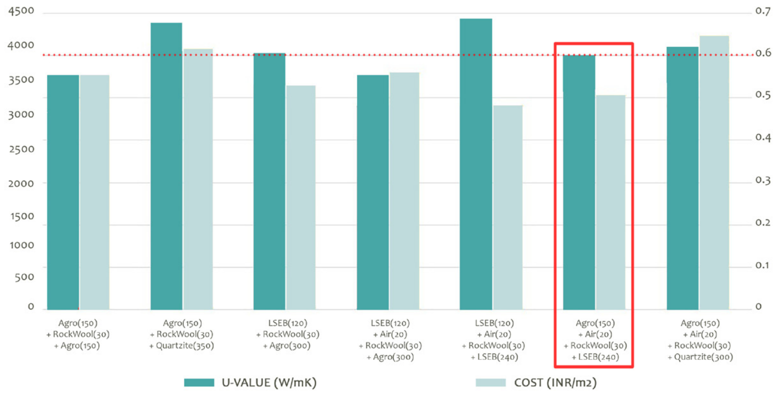


Figure 18 : Iterative study for envelope selection

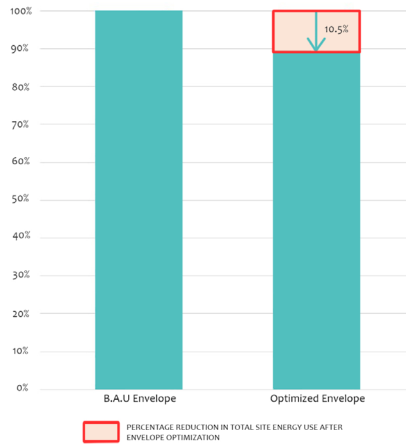


Figure 19 : Impact of optimized envelope on total site energy

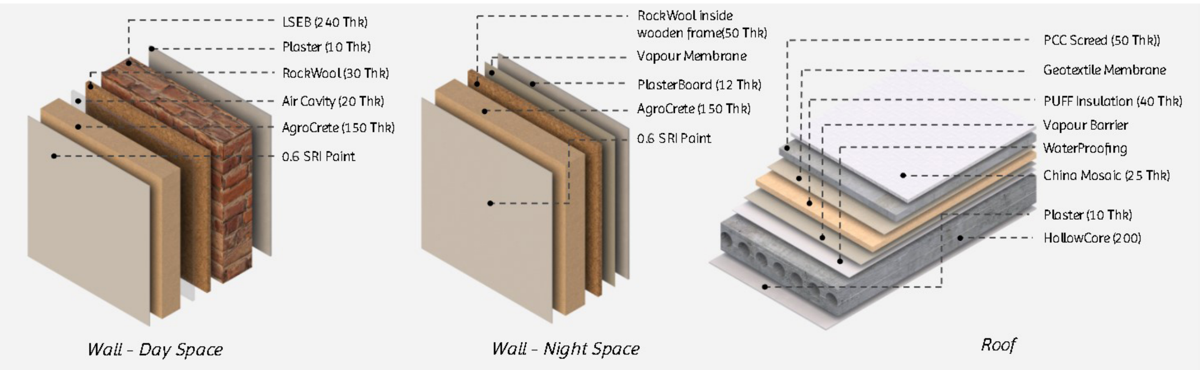


Figure 20 : Envelope details

	BUILDING ENVELOPE ASSEMBLIES (Outside to Inside_in mm)	U-VALUE (W/m2.k)
WALL - DAY SPACE	Cavity Wall *(0.6 SRI Paint + AgroCrete(150) + AirCavity(20) + RockWool(30) + LSEB(240) + Plaster(10)*	0.62
WALL - NIGHT SPACE	Lightweight Envelope *(0.6 SRI Paint + AgroCrete(150) + RockWool(50) + Vapour Membrane(0.13) + PlasterBoard(12)*	0.61
ROOF	Roof Insulation *(0.3 SRI ChinaMosaic(25) + PCC Screed(50) + GeoTextile + PUFF Insulation(40) + VapourBarrier + WaterProofing + HollowCore(200) + Plaster(10)*	0.45
WINDOW	Clear Essence Plus *(UPVC frame with 6 mm Low-E Glass – 12 mm Air Gap – 6 mm Clear Glass) (VLT=71, SHGC=53)*	1.81

Table 5 : Envelope design

SHADING 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.

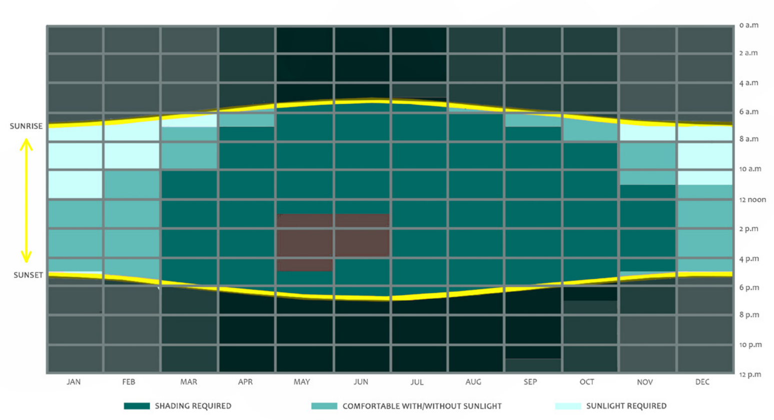


Figure 21 : Timetable plot for D.B.T

The observation from the data was that the building requires strict shading in summer and abundant sunlight in winter.
Hence, the idea was to provide operable bamboo chicks to control the sunlight entering the space.

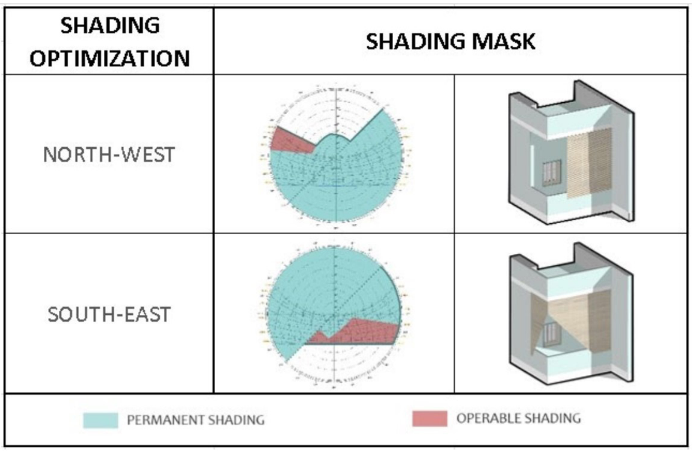


Table 6 : Specific Shading Mask

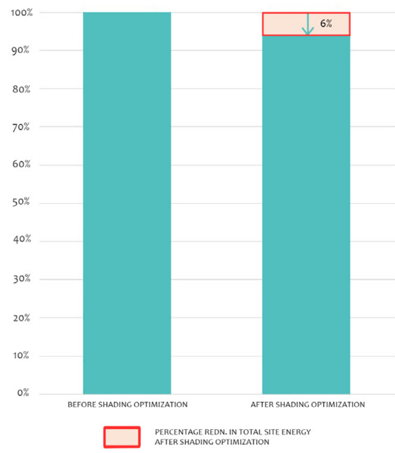


Figure 22 : Impact of Shading on Total Site Energy

Specific orientational shading masks were created in Ecotect Software.

LIGHTING OPTIMIZATION

(a) Daylighting

Daylight analysis for ground floor units was done as they have the least amount of sunlight exposure due to the mutual shading strategy.

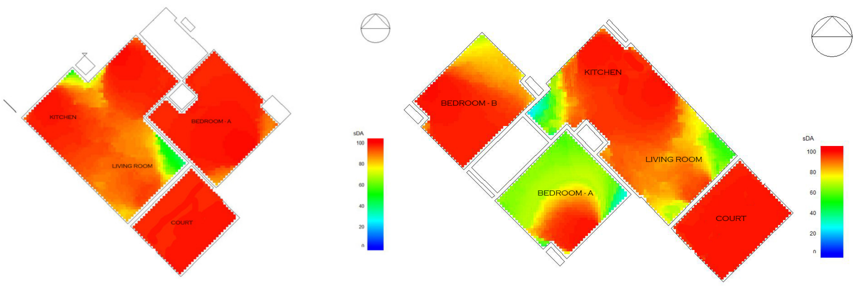


Figure 23 : Spatial Daylight Autonomy for GF Units

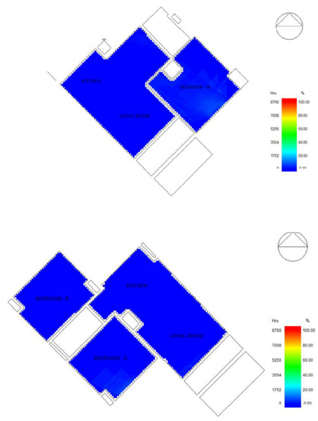


Figure 24 : Annual Sun Exposure

The main idea was to introduce higher albedo surfaces. White colour was maximised in the interior as a strategy for increasing lighting.

SL. No.	SPACE TYPE	TARGET ILLUMINANCE (lux)	sDA (%)	A.S.E(%)
		2-BHK		
1	KITCHEN	150	87.34	0
2	LIVING	100	83.68	0
3	BEDROOM-A	100	72.33	0
4	BEDROOM-B	100	92.26	0
		1-BHK		
1	KITCHEN	150	90.14	0
2	LIVING	100	85.33	0
3	BEDROOM-A	100	95.32	0

Table 7 : Daylight illumination

SIMULATION PARAMETERS

- Working Plane Ht. = 0.8m
- Working Hrs = 8 A.M - 6 P.M
- Ceiling Reflectance = 85%
- FLoor Reflectance = 25%
- Wall Reflectance = 80%
- Ext. Wall Reflectance = 75%

The daylight autonomy result was comparatively less for spaces facing the mutually shaded streets. We traded the daylight for thermal comfort as done in the traditional Rajasthani Havelis. This was due to the reason that energy required for cooling is higher than that of lighting.

(b) Artificial lighting optimization

Artificial lighting placement was done after identifying the tasks performed in various rooms. LED technology opted for several advantages like energy savings, environment friendly, etc.

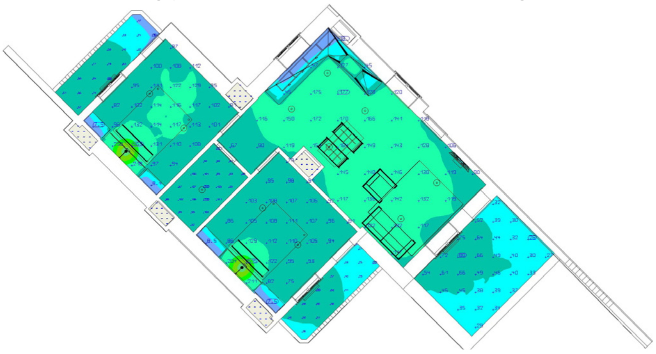


Figure 25 : The Lighting Design Simulation performed in DIaLux Evo.

- Reflectivity of surfaces and specs is same as that of daylight specification.
- The lights have a color temperature range of 5000-6000K i.e. cool white color for a natural look.
- Kitchen counters and bedside tables have been given additional task lights.
- Ceiling mounted lights are provided for ambient lighting.

Space Function	Target illuminance (Lux)	min (lux)	max (lux)	avg (lux)	Luminaire	No. of Luminaires	Power	Total wattage(kW)	Hours per day	Energy per day (kWh)
Living area	100	80	146	120	wall ceiling mounted LED	2	8.5	0.017	8	0.136
Dining area	100	91	170	135	wall ceiling mounted LED	2	8.5	0.017	8	0.136
Court	50	45	80	52	wall ceiling mounted LED	1	8.5	0.0085	1	0.0085
Kitchen	150	119	177	152	wall ceiling mounted LED	2	8.5	0.017	4	0.068
	150				Task lighting under cabinets	2	3	0.006	4	0.024
Bedroom 1	100	82	129	101	wall ceiling mounted LED	2	8.5	0.017	7	0.119
	100				reading light	1	7	0.007	2	0.014
Balcony	50	36	75	50	wall ceiling mounted LED	1	7	0.007	1	0.007
Bedroom 2	100	82	132	107	wall ceiling mounted LED	2	8.5	0.017	7	0.119
	100				reading light	1	7	0.007	2	0.014
Balcony	50	33	83	59	wall ceiling mounted LED	1	7	0.007	1	0.007
Toilet	100	76	110	100	wall ceiling mounted LED	1	8.5	0.0085	5	0.0425
Passage	50	67	90	75	wall ceiling mounted LED	1	7	0.007	10	0.07
Total								**0.112**		**0.765**
Total lighting load of 2BHK = 0.765*365 days/ 74.9 = 3.73 kWhr/m²/year						LPD of 1BHK = 112/48.6 = 2.30 W/m2				
Total lighting load of 1BHK = 0.6165*365 days/48.6 = 4.63 kWhr/m²/year						LPD of 2BHK = 143/74.9 = 1.91 W/m2				
Total lighting load of common area = 0.675*365 days/50 = 4.92 kWhr/m²/year						LPD of Common Area = 0.7 W/m2				
Average lighting load = 3.73 + 4.63 + 4.92/3 = 4.42 kWhr/m2/year						**Average LPD = 2.3 + 1.91 + 0.7/3 = 1.64 W/m2**				

Table 8 : Optimized Artificial Lighting

EQUIPMENT OPTIMIZATION

Appliances were selected based on their rating by BEE energy rating scale. The appliances chosen were the most energy efficient ones with 5 star rating to reduce total equipment load.

S No.	Appliances	Quantity	Wattage	No of hours per day	No of days	Energy consumed annually(kWh)
	1 BHK equipment selection					
1	Havells Ceiling Fan-48" 5 star	3	26	6	260	121.68
2	Exhaust Fan-Havells 150 mm (Bathroom)	1	22	2	365	16.06
4	Exhaust Fan-Havells 150 mm (kitchen)	1	22	4	365	32.12
5	Washing Machine-LG 6.0 Kg 5 Star front load	1	462	0.3	365	50.58
6	LG 32" LED TV	1	45	5	365	82.12
7	Philip dry iron	1	750	1	70	52.51
8	Havells Mixer/juicer	1	500	0.2	365	36.51
9	Refridgerator-LG 5 star 235 L	1	68	8	365	198.56
	TOTAL (kWh)					**590.14**
	Block specifications					
1	Water pump for 1.75kl OHT (Potable)	1	370	1.06	365	143.15
2	Water pump for 0.25 kl OHT (Non-Potable)	1	180	0.42	365	27.39
3	Water pump for 0.5 kl OHT (SWT)	1	92	0.38	120	4.19
4	Water pump (Talaab Water Supply)	1	750	0.41	173	53.19
	TOTAL (kWh)					**227.92**
	Cluster specifications					
5	EATHE Fan (Ambient-air suction)	4	30	9	365	394.21
	TOTAL (kWh)					**394.21**
	Total equipment load of 1 BHK = 645.9/builtup area of 71 m^2 = 9.09 kWh/m2/year					
	Total equipment load of 2 BHK = 686.6/builtup area of 90 m^2 = 7.63kWh/m2/year					

Table 9 : Optimized equipments

The equipment load was kept minimum by defining an operational schedule which was derived from studying a survey of 18 homes. The findings of the survey include no. of individuals, their daily routine, and appliance usage patterns. For washing machine, we chose front load over top load which uses less energy because front load uses less water.

EAHE COUPLED WITH SOLAR POWERED RAHU-VRV SYSTEM

The system being used is an open-loop system, wherein outdoor air is drawn into the tunnel and delivered to the inside of the building. Hot air from inside of the building is exhausted out through the solar chimney.

Considering the site area restrictions and efficiency, the final dimensions were chosen as :
Pipe diameter: 0.6 m
Pipe length: 370 m
No. of pipes: 2

The airflow rate through each pipe: 4200 m3/hr
Total airflow rate: 8400 m3/hr

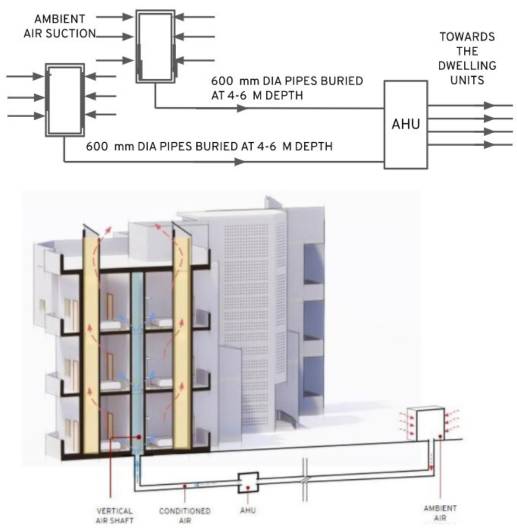


Figure 26 : EAHE system

The efficiency of the earth air tunnel alone is shown in the graph below:

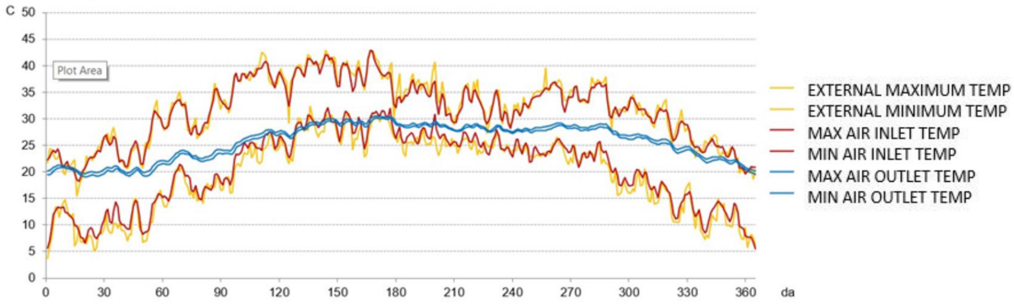


Figure 27 : EAHE system performance

EAHE is designed to operate for approximately 8-9 hours a day, leaving the rest of the day for earth to rejuvenate and avoid saturation. Since EAHE cannot provide the necessary comfort in this time frame, the active system will be set to work for 1505 hours. (For more information on how we arrived at 1505 hrs, see the Comfort Sub-topic.)

HVAC SIZING AND SYSTEM SELECTION

The total Cooling load is sized-up by 1.15 to account for the derating of the equipment. Hence minimum equipment size required is 1.15 x 8.2 = 9.43 TR (Calculation is Shown under Comfort Subtopic on how we arrived at Cooling Load)

DAIKIN VRV IV+ (RXYTQ8U7YF)
Tonnage - 2 x (5.4 TR)
COP - 4.20

Q(Total) = 22893.68 KWh
COP = 4.20
Total Energy use by VRV = Q(Total) / COP = 5450.8KWh
Total Energy use by EAHE (AHUs) = 13122 KWh
Total Built-up area of Cluster = 2689.5m2

Hence EPI for Cooling = 18572/2689 = 6.9 KWh/m2/yr

EPI BREAKDOWN

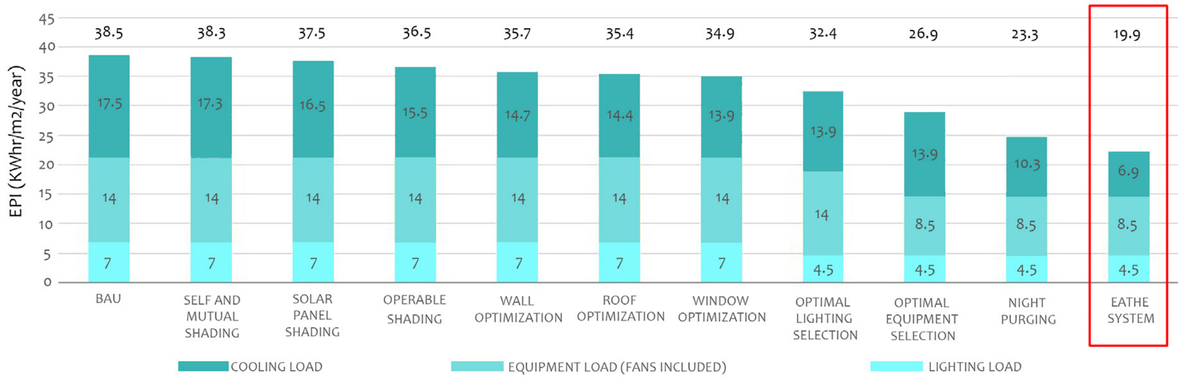
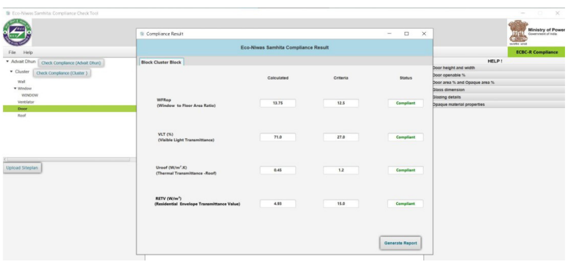


Figure 28 : EPI breakdown Graph

ECO NIWAS COMPLIANCE

The Eco-Niwas Samhita Compliance Check tool, developed by the Indo-Swiss Building Energy Efficiency Project (BEEP), was used to assess the proposed residential building design's code compliance.

The proposed design meets all of the Energy Conservation Building Code (ECBC) - for residential buildings - requirements.



1. ECBC-R Compliance Results

S/No.	REQUIREMENT	CALCULATED	CRITERIA	STATUS
Block-1				
1	WFRop	13.75	12.5	Compliant
2	VLT %	71.0	27.0	Compliant
3	Uroof	0.45	1.2	Compliant
4	RETV	4.93	15.0	Compliant

Figure 29 : Eco niwas compliance report

SUPPLY SIDE MANAGEMENT

SOLAR POTENTIAL

The site receives an ample amount of solar radiation throughout the year, making solar energy a viable option for energy generation. Roof-mounted solar panels are installed on the terrace with a 7° tilt, facing towards the south side. 428 panels have been arranged in two rows, each consisting of 214 panels on the rooftop

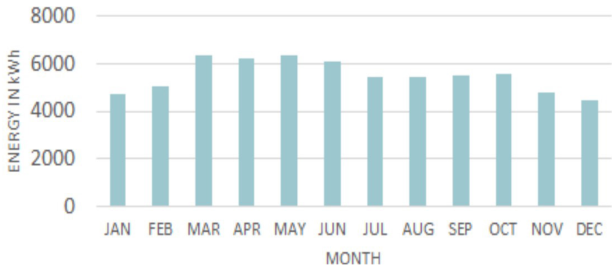


Figure 30 : On site solar energy generation graph

Total Energy Consumed (53,510 Kwh/yr) < Total Energy Generated (65,810 Kwh/yr)

System specifications are as follows :

PV Generator capacity	45 kW
Area covered	300 m²
Number of PV modules	430
Total Yearly Generation	65,810 kWh/yr

Table 10 : System specifications

Module specifications are as follows :

MODULE SPECIFICATION	
Power rating	105 W
Module Efficiency	15.14%
Dimension	1035 x 670 x 34
Weight	8.20 kg

Table 11 : Module specifications

BUSINESS MODEL FOR RENEWABLE SYSTEM

FEASIBILITY OF SOLAR PHOTOVOLTAIC PANELS

At the cluster level, both solar panels and roofs are owned by Dhun private limited (Developer). The rooftop structure framing along with operation and maintenance costs are also taken by the developer (CAPEX model).

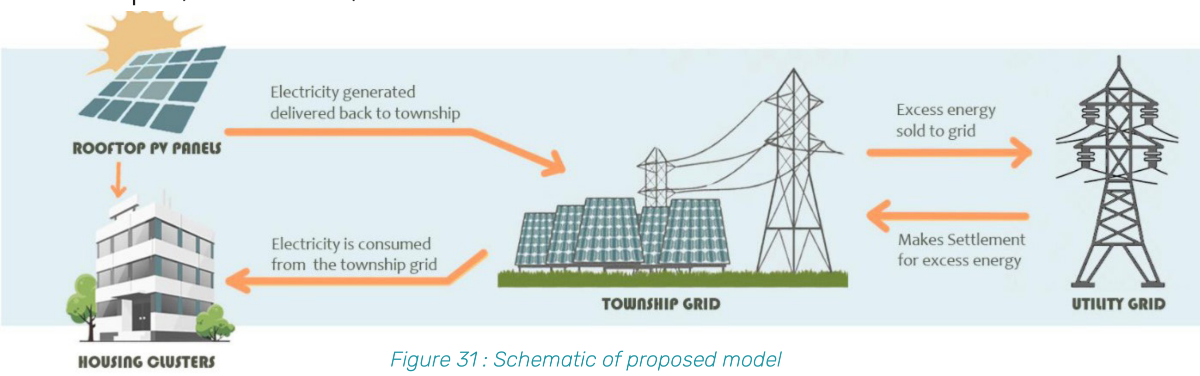


Figure 31 : Schematic of proposed model

Net metering is at the site level. The generated renewable energy is partially consumed at the cluster level, and the additional generation is fed to the grid. At the cluster level, the additional electricity consumed is directly taken from the township grid. The extra electricity generated from the renewable panel is delivered back to the township grid. Thus, making it a net-zero project.

Total Electricity Consumed in a year	KWh	53,510
Total Electricity Generated in a year	KWh	65,810
Degradation of Generation per year	%	1%
Av. Total Electricity Generated in a Year (For 20Yrs) considering degradation of Gen.	KWh	59,558
Extra Electricity to feed into grid	KWh	6,048
Cost of Electricity	INR/KWh	8
Cost of Extra Electricity (Feeding to Grid)	INR/KWh	3.5
Cost saving per year	INR	449248

Table 12 : Specifications of Solar Photovoltaic modules

No. of years	20
Cost of CAPEX (Module)	17,67,300
O and Maintenance Cost	1% of CAPEX
Total Cost	17,84,973
ROI	25%
Payback Period	4 Years

Table 13 : PayBack Period Calculation

COMFORT AND ENVIRONMENTAL QUALITY

IMAC adaptive thermal comfort model of Jaipur is referred, to derive the target indoor operative temperature for a mix-mode building.

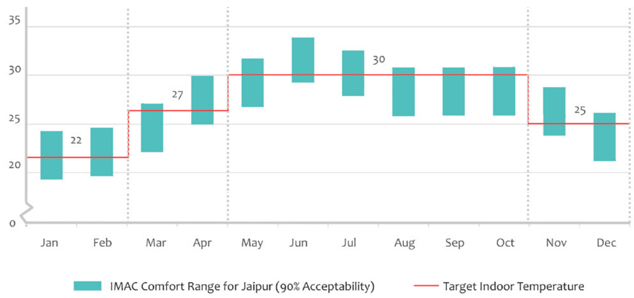


Figure 32 : IMAC Comfort range for Jaipur

The main idea was to utilize the adaptive thermal comfort of the dwellers with passive strategies and then optimize the system just enough to satisfy their comfort needs.

OPTIMIZED COOLING STRATEGY (EAHE + NIGHT PURGE VENTILATION)

CFD analysis was performed for the hottest time of the summer design day to derive the outlet temperature for the given flow rate of 100 l/s. (For living room + dining on the top floor, 2BHK)

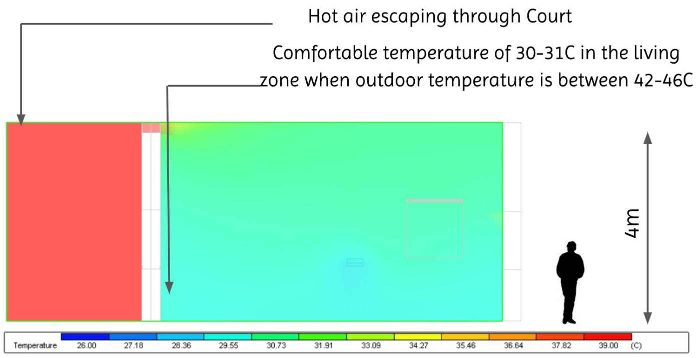


Figure 33 : CFD Analysis for summer design day

Time: 13:00 p.,m, 16th June
Outlet Air Temperature: 27.5C
Air Flow Rate: 100 l/s

INFERENCE: 30-31C is within the comfort range of table 9 section 1 part 8 of the National Building Code of India.

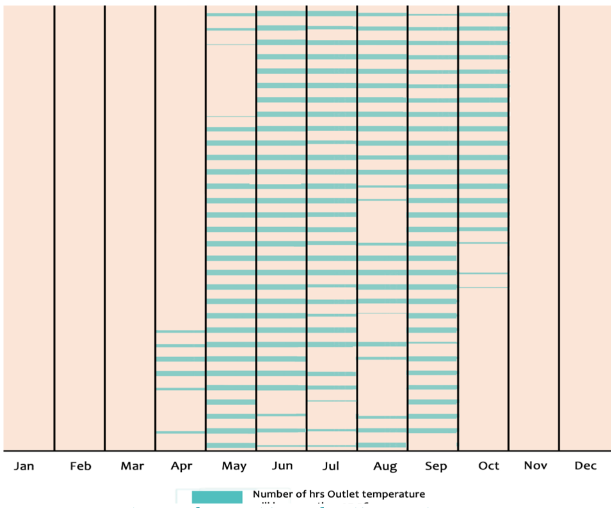


Figure 34 : Heat map for working of active system

The heat map shows us that for almost 1505hours EAHE system will have an outlet temperature of more than 27.5C during its work period. Hence, the active system should work for 1505 hrs at 26.5C to deliver comfort in the morning hrs.

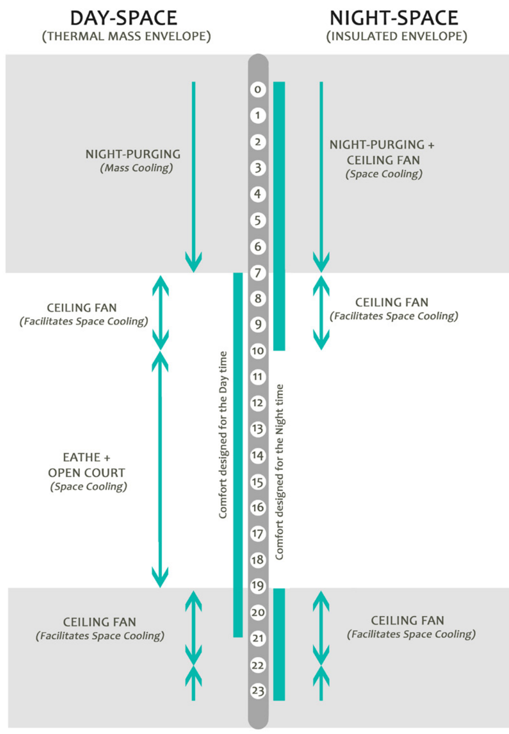


Figure 35 : Cooling design schedule

Q=3.15(CMS)ΔT (In KWh), Derived from Q=1.08(CFM)ΔT (In BTU/hr)
CMS for 1 BHK = 0.04 + 0.10 = 0.14m3/s (Refer Ventilation Strategy Table under Comfort and Environment)
CMS for 2 BHK = 0.04 + 0.04 + 0.11 = 0.19m3/s
The proposed active system only works for Day-space since EAHE system cannot deliver required comfort during day time. Hence, Total CMS for Day Space = 0.11x12 + 0.1x10 = 2.32m3/s
The active system should work at 26.5C to provide an outlet temperature of 27.5C (Refer to CFD analysis under Comfort and env.)

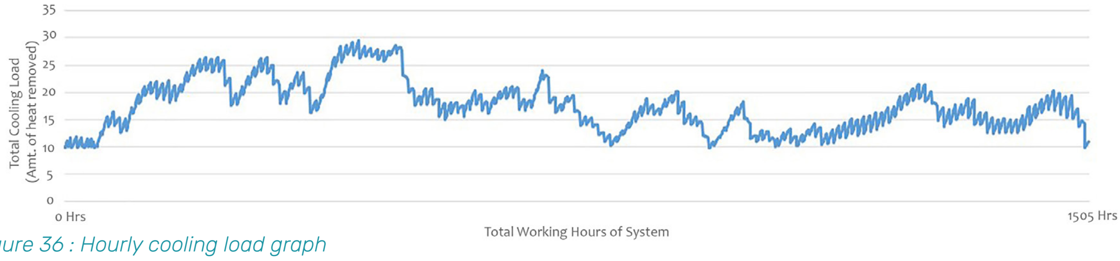


Figure 36 : Hourly cooling load graph

Dynamic Calculation was performed in Excel (for Dynamic ΔT) to arrive at total thermal energy moved for 1505hrs. The total energy after the integration process thus came out to be 22893.68 KWh.

OPTIMIZED HEATING STRATEGY

CFD Analysis was performed for the winter design day to analyze the space heating efficiency of the open court and impact of EAHE on space heating.

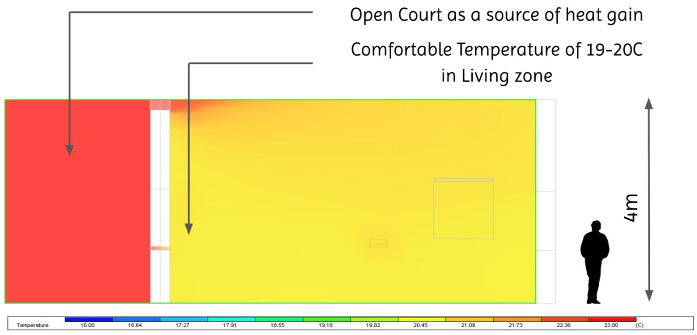


Figure 37 : CFD Analysis for winter design day

Time: 13:00 p.,m, 30th Dec.

Main Strategy Used :
Heat gain through Open Court and EATHE

INFERENCE: 100% Comfort Hours can be achieved in winters by utilizing the Heat gain through the Open Court and EATHE along with Internal Gains.

CFD Analysis was performed to understand the comfort during monsoon and to check the need of Dehumidifiers. (August 7 - Relative Humidity 71%)

MONSOON COMFORT ANALYSIS

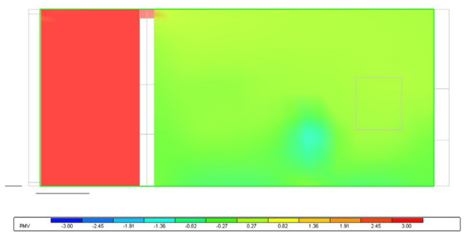


Figure 38 : CFD Analysis for humid day

INFERENCE:
Av. PMV is coming out to be 0.12 during the hottest time in the most humid day of the year. Hence, Dehumidifiers are not installed.
Clo. factor = 0.4 Clo,
Metabolic Rate = 1.10 Met

ANNUAL HOURS OF COMFORT WITHOUT AIR CONDITIONING

Figure 39 : Annual hours of comfort without air conditioning

7255 comfort Hrs can be achieved without any sort of air-conditioning. The comfort threshold for the remaining hrs is met with the help of VRV unit.

VENTILATION STRATEGY

EAHE system is used to meet the minimum required ventilation rate as given in NBC 2016. The required air flow rate was then calculated and decided upon the earth air tunnel specifications.

SPACE	AREA (m²)	AIR CHANGE PER HOUR REQD. AS PER NBC	ACH TAKEN	HEIGHT (m)	TOTAL VOLUME (m³)	AIR FLOW RATE REQD. (m³/h)	AIR FLOW RATE REQD. (m³/s)	TOTAL (m³/h)	NO. OF UNITS	TOTAL VOLUME AIR FLOW REQD (m³/h)
1 BHK										
BEDROOM	12.5	2 TO 4	3	4	50	150	0.04	518	10	5180
LIVING ROOM + DINING + KITCHEN	23	3-6 (LIVING ROOM) 6 (KITCHEN)	4	4	92	368	0.10			
2 BHK										
BEDROOM 1	12	2 TO 4	3	4	48	144	0.04	710	12	8520
BEDROOM 2	12.5	2 TO 4	3	4	50	150	0.04			
LIVING ROOM + DINING	27	3 TO 6	4	4	108	416	0.11			

Table 14 : Air flow calculation for Ventilation

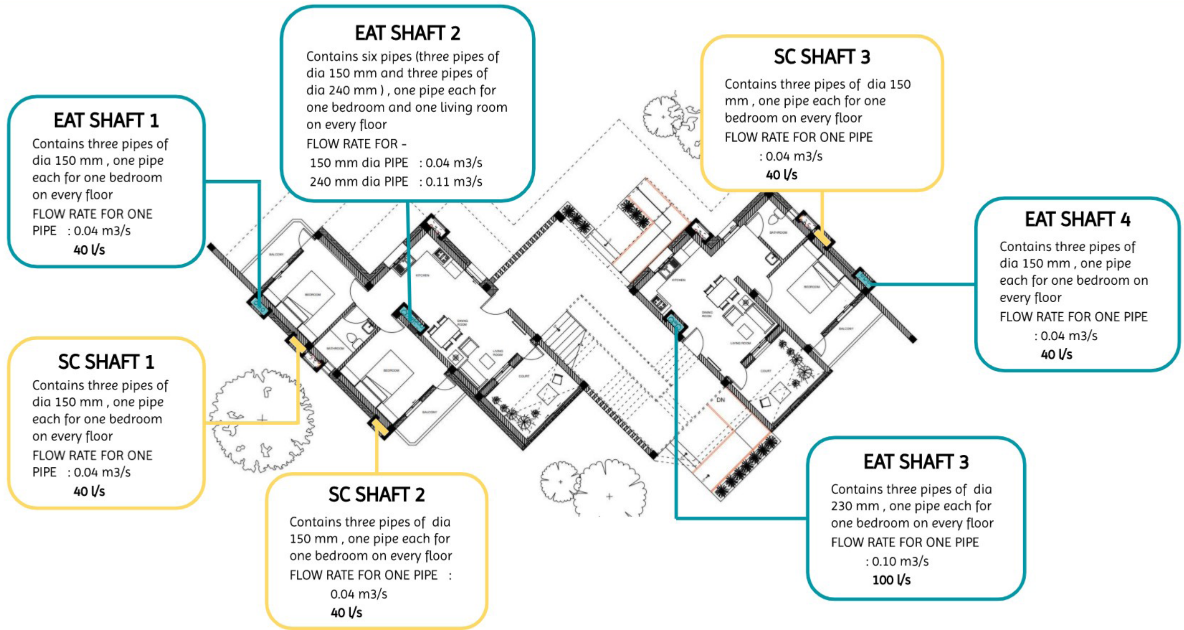


Figure 40 : EAHE specifications

CONSTANT FRESH AIR SUPPLY THROUGH EAHE

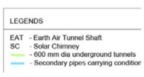


Figure 41 :HVAC Single-line drawing showing Duct/Shaft layout for a row (Semi-cluster)

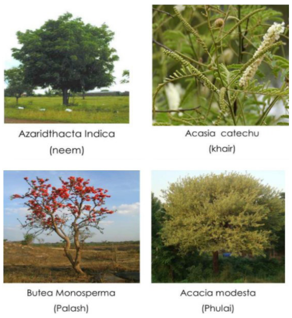
The Shaft/Duct configuration has been carefully designed to avoid interfering with the proposed design layout and has been incorporated with landscaping. The 600mm dia underground tunnels that deliver fresh air are represented by the green line. Before reaching individual units, the fresh air is cooled in the AHU space. Every space's ducts are separated in the vertical shaft.

SUSTAINABLE LANDSCAPE

Deriving from the soul of the development that Dhun has been envisioned as, the very foundation to the evolutionary design process. The very key features that are further developed to maximize biodiversity of the region and environmental confort.

Swales and native tree landscaping

> Edge Plantation (a natural barrier from uncontrolled development in the adjacent area and wind sheltering)
> Swales connecting main water bodies serves as the primary spine for pedestrian movement and circulation.
>Native trees used are:



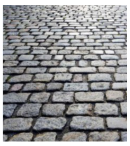
Grey water reeds

> Reed bed constructed wetland for water treatment. Plants like Common reeds like Aka Phragmite australis are used.

Xeriscaping

> Drought tolerant native species are used to reduce the water conception to 70% and less maintenance compared to regular lawn landscaping.

Pedestrian pathways and signages



> Less embodied energy, carbon footprint native materials like local stone are used for pathways, community area.
> Solar powered street lights, signage etc are as part of safety measures.
> Community areas are shared with tree canopy and building mass.

Sustainable transportation

> maximizing pedestrianized and fossil fuel-free zones.

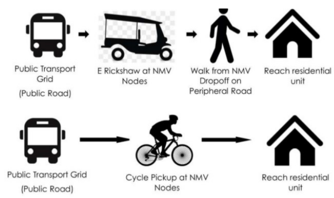


Figure 42 : Landscaping strategies

UNIVERSAL ACCESSIBILITY AND FIRE SAFETY

Universal Accessibility

Compliance with guidelines isn't all when it comes to accessibility. It's all about creating solutions that cater to the needs of all people, including those with and without disabilities. The idea of universal design, which is now commonly used in the private sector, is being healthily promoted in our design. The ground round floor units and the community areas of this housing are made completely disable friendly.

Dwelling Level

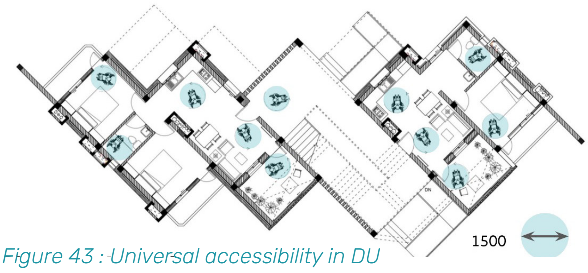
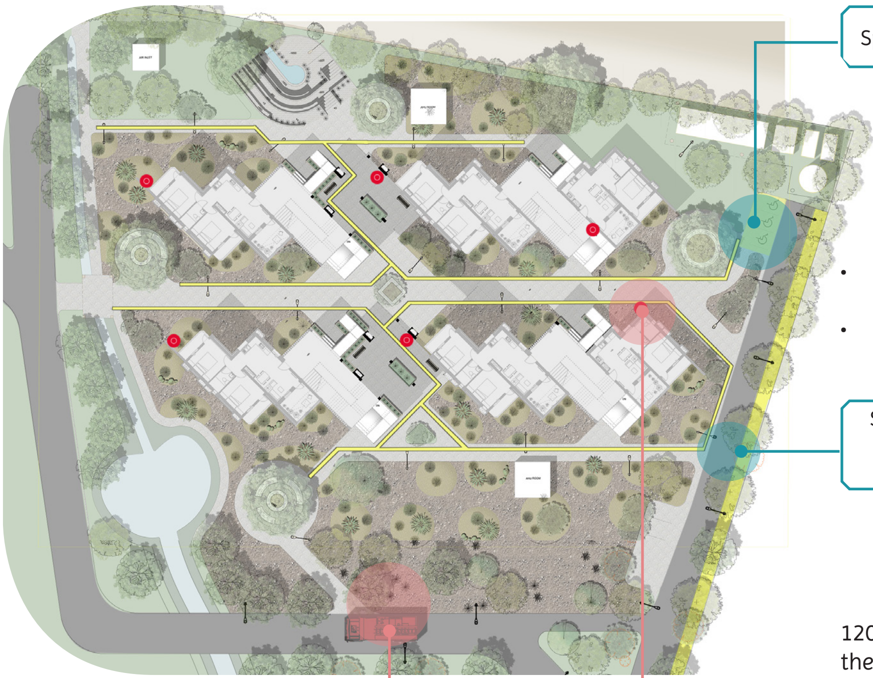


Figure 43 : Universal accessibility in DU

- 900mm wide door openings and disable friendly toilet as per the standards of NBC.
- Guiding blocks to guide outdoors.
- The slope of the climbing(min. ramp slope 1:12)

Cluster Level

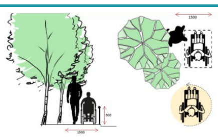
- Installation of information/signage board in braille.
- Installation of tactile payments and safe 1200mm wide foot paths along the vehicular roads sides.



Special Parking slots, Ramps

- Special parking slots are provided near the cluster.
- The slope of the climbing(min. ramp slope 1:12)

Safe Pedestrian pathways, tactile pavements and signages



1200mm wide paths along the vehicular road side and 3000mm wide pedestrian path along the street.

FIRE SAFETY LAYOUT

Pedestrian pathways and signages

- 4500mm wide emergency fire engine paths are provided, which is accessible to all part of the site.
- The master plan is laid in such a way that in case of fire, people can easily access the open

Street side fire hydrants

- Fire hydrants are provided along the street sides, which is connected to the central water tank.
- Sand bags and fire extinguishers are provided in each staircase landings for immediate response in case of fire

Figure 44 : Universal accessibility and fire safety at cluster level

WATER PERFORMANCE

Irresponsible usage of water and overexploitation of ground water sources have lead to water shortage in the country and elsewhere. Embodied water of typical urban constructions in India was found to be around 27 Kilolitres/sq m of total built-up area. In this project, various strategies are employed to meet the water demand and take care of wastewater consciously at all the stages.

STAGE 1: BEFORE CONSTRUCTION - SITE REVIVAL

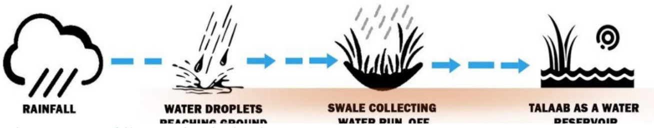


Figure 45 : Site revival strategy

As part of Dhun's site rejuvenation plan, various water harvesting techniques were introduced, like bunds, swales and water retentions ponds for the collection of water and planting of native trees for the seepage of water into ground. Thus raising the ground water level.

STAGE 2: DURING CONSTRUCTION

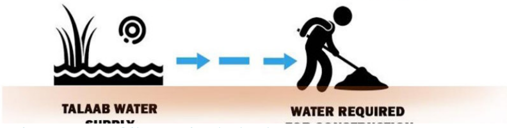


Figure 46 : Site revival strategy

The harvested water collected in the pond is also used to meet the water demand for the construction work (concrete curing and others)

STAGE 3: AFTER CONSTRUCTION

The water consumption was brought down to 75 lpcd from 135 lpcd through water saving fixtures, front load washing machine and efficient water supply system. Thus, the total occupant water demand of the cluster was calculated to be 6600 Lpd in a cluster of 22 units, consisting of maximum 88 people.

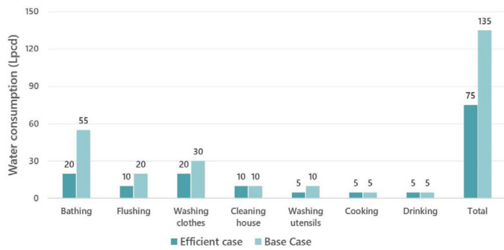


Table 15 : Water consumption breakdown per person

Type of DU	No.of DU's in a cluster	No.of individuals per DU's	Water consumption per head (L)	Total water consumption (L)
1 BHK	11	3	75	2475
2 BHK	11	5	75	4125
Total water requirement for a Cluster in a day (L)				**6600**
Total water requirement for a Cluster in a year (L)				**24,09,000**

Table 16 : Total water consumption table

Water efficient fixture	Conventional	High Efficiency/water saving
Water Closet	6 Lpf Full flush	4.5/3 Lpf Dual flush toilets
Shower Heads	10 Lpm	5.7 lpm 43% lpm savings
Taps/ Faucets	8 Lpm	aerators, flow fixtures with 5 Lpm
Washing machine	top loading	front loading uses 40% less water

Table 17 : Water fixtures specifications

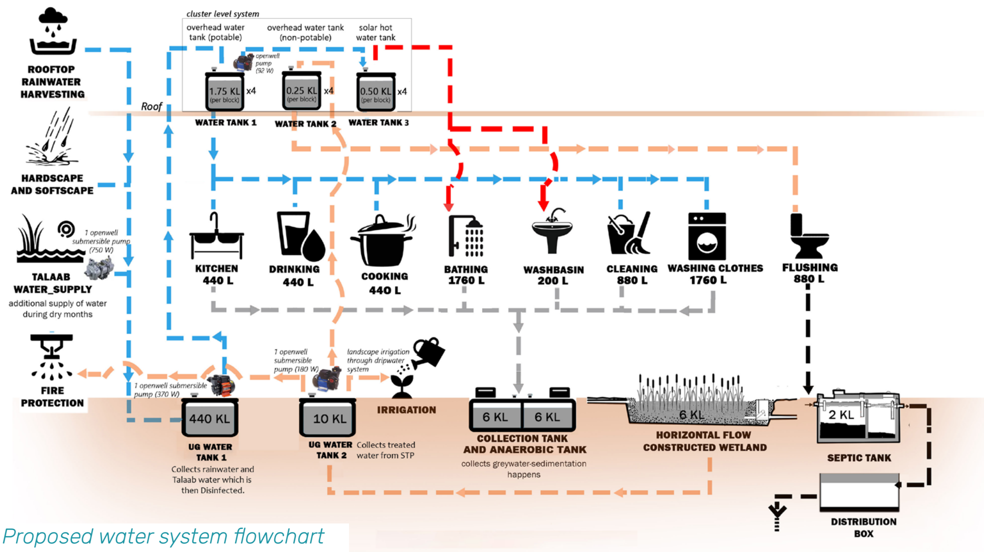


Figure 47 : Proposed water system flowchart

The grey water produced on site is treated and used for irrigation and flushing (880 litres per day). The filtered black water is used to raise the groundwater level.

Occupant's Activity	Percent usage	Quantity (L)	Grey water (L)	Black water (L)
Bathing	26.00%	1760	1760	0
Washing	26.00%	1760	1760	0
Drinking	6.50%	440	0	440
Cooking	6.50%	440	0	440
Toilet	13.00%	880	0	880
Cleaning house	13.00%	880	880	0
Washing Utensils	6.50%	440	440	0
Others	2.20%	150	150	0
Total		**6750**	**4990**	**1760**

Table 18 : Grey and black water generation

RAINWATER MANAGEMENT

Harvested rainwater from the site, pond, and treated greywater for flushing and irrigation are the water sources known for the water demand. Rainwater collected on site is filtered through a biosand filter before being deposited in a 440 KL underground water tank (UGT). Table 1 shows the average amount of rainfall received in different catchment areas over the course of a year.

The total amount of rainfall collected annually (945 KL) and filtered grey water needed for flushing annually (321 KL) combined do not meet the cluster's occupants' water consumption demand (2410 KL). As a result, pond water is used to meet the total occupant demand. The excess treated greywater is used for irrigation and groundwater recharge.

Rainwater harvesting surfaces	Area (m2)	Runoff coeffecient	Effective catchment area (m2)	annual rainfall of site (m)	Harvested rain annually (m3)	Harvested rain annually (liters)
Roof Surfaces	790	0.85	671.5	0.579	388.7985	388799
Hardscape areas	900	0.7	630	0.579	364.77	364770
Softscape areas	1100	0.3	330	0.579	191.07	191070

TOTAL EFFECTIVE CATCHMENT AREA IN A CLUSTER = 1631.5 m2
TOTAL RAINFALL HARVESTED IN A YEAR = 9,44,639 L

Table 19 : Rainwater harvesting calculation

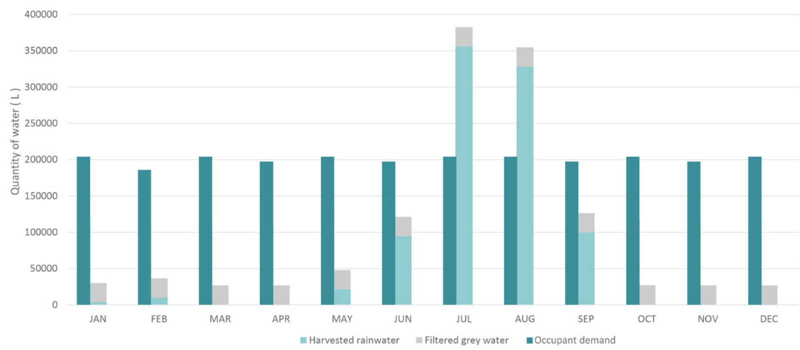


Figure 48 : Water usage v/s generation

During the dry months, additional water is pumped from pond to the potable water UGT (1143 KL annually). Floating covers and windbreakers are used according to Dhun's techniques to avoid evaporative loss of pond water.

Total domestic water required for a cluster annually(L)	Total rainwater harvested in a cluster annually(L)	Total recycled greywater used in a cluster annually(L)	Taalaab water required annually(L)
24,09,000	9,44,639	3,21,200	11,43,161

Total amount of water in Taalaab in a year(L) = 22,28,000 (after annual evaporative loss)

Table 20 : Annual water consumption and generation

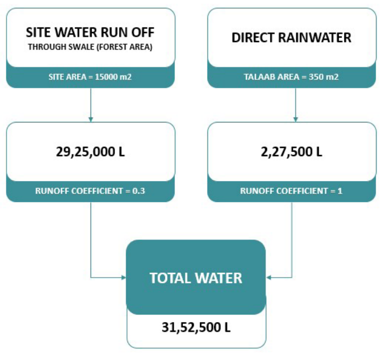


Figure 49 : Sources of taalaab water

Water is pumped to the overhead tanks (OHT) of each block by 5 star graded pumps from the UGTs (440 KL potable water and 10 KL non-potable water) at cluster level, catering to potable demands (1.75 KL per block) and non-potable demands (0.25 KL per block). To meet hot water needs, each block has a 0.5 KL flat plate solar water heater (600). The units are then fed by gravity.

WASTE WATER TREATMENT

The closed-loop design aims to achieve the target of zero water discharge by allowing water produced on the site to be returned to the site. Greywater is generated and filtered at a 75 percent efficiency treatment plant before being sent to the non-potable UGT (10 KL) to be reused for flushing. The produced black water is treated in a 2KL septic tank, and the residue is filtered before being discharged to the ground.

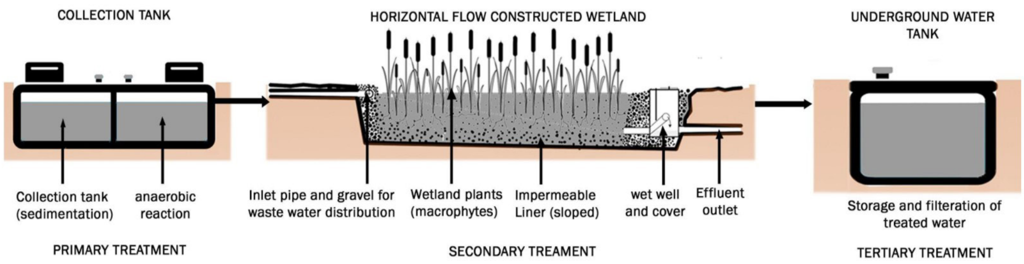


Figure 50 : Horizontal flow constructed wetland

Greywater is collected at the cluster level in a 6KL storage tank, where sedimentation occurs, and then undergoes anaerobic reaction in another 6KL tank before being filtered by the wetland system (6KL/day). The treated grey water is used for xeriscaping irrigation and flushing (1KL/day) (366 KL annually upto three years after which water used for landscape irrigation will be discharged for groundwater table replenishment).

SOLID WASTE MANAGEMENT

We encourage users to control resources and waste because of the negative effect waste has on the environment. Waste is separated into dry and wet waste at the source (Unit) and processed for use as fertiliser and animal fodder in the township. Septic waste is also processed, with sludge digested and converted into fertiliser for the Dhun township's farms and gardens, and black water is treated and distributed into the field for natural treatment. According to Dhun's sustainability policies, the site's dry waste is separated, recycled, and incinerated.

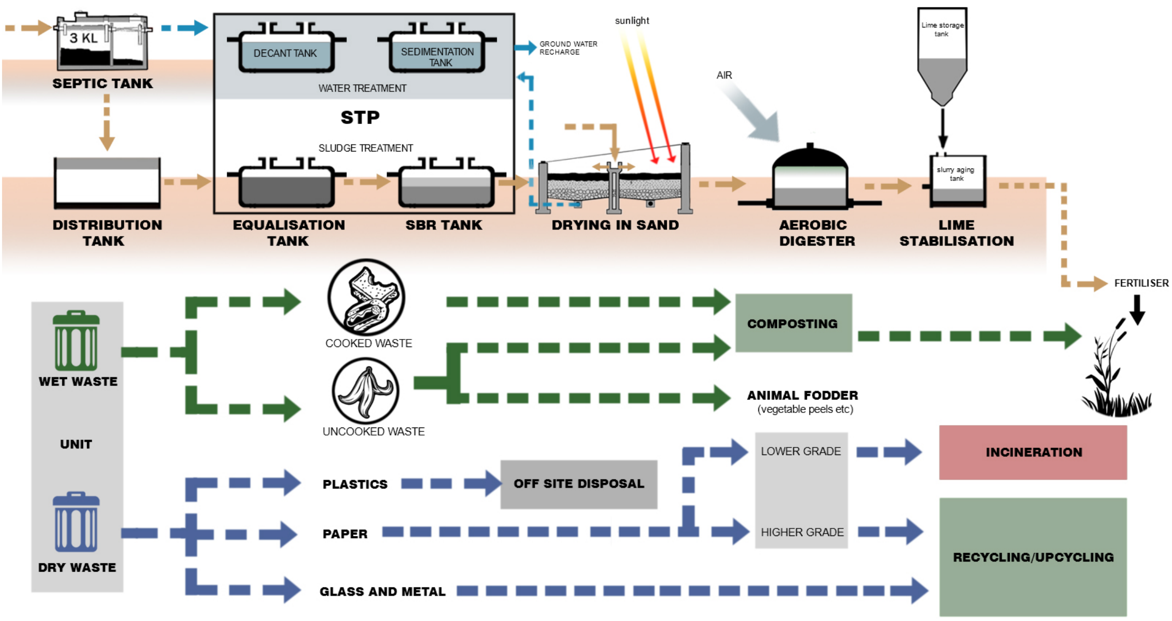


Figure 51 : Waste system flow chart

RESILIENCE

Being in a non-cyclonic - seismic zone, our main concern while addressing resilience in this project was to mitigate the effects of heat wave prevalence and water scarcity in this region. The following methods were adopted to prevent the same at various levels :

SITE LEVEL

- Site planning is done in such a way that there is easy access to first responders like the fire department, police, and medical response in case of a calamity.
- Public greens provided by the method of xeriscaping to reduce water consumption as well as reduce the urban heat island effect.
- Edge plantation around the site to protect against extreme hotwinds.
- Water self sufficiency achieved using various methods, hence no water supply problems arise.

CLUSTER LEVEL

- Community gathering spaces provided at various levels that encourage physical activity as well as promote social well being of the occupants.
- Grid interruptions prevented during calamity times through the usage of solar panel system installed on roof.
- Shaded, compact outdoor spaces provided for pedestrian movement
- Mutually shaded facades to protect against heat waves

DU LEVEL

- Spatial flexibility in the layout for evolving needs (combined kitchen, dining and living without any partition walls)
- Thermally resistant building envelope and incorporation of passive strategies like earth air tunnels, solar chimneys protect against heat waves prevalent in the region.

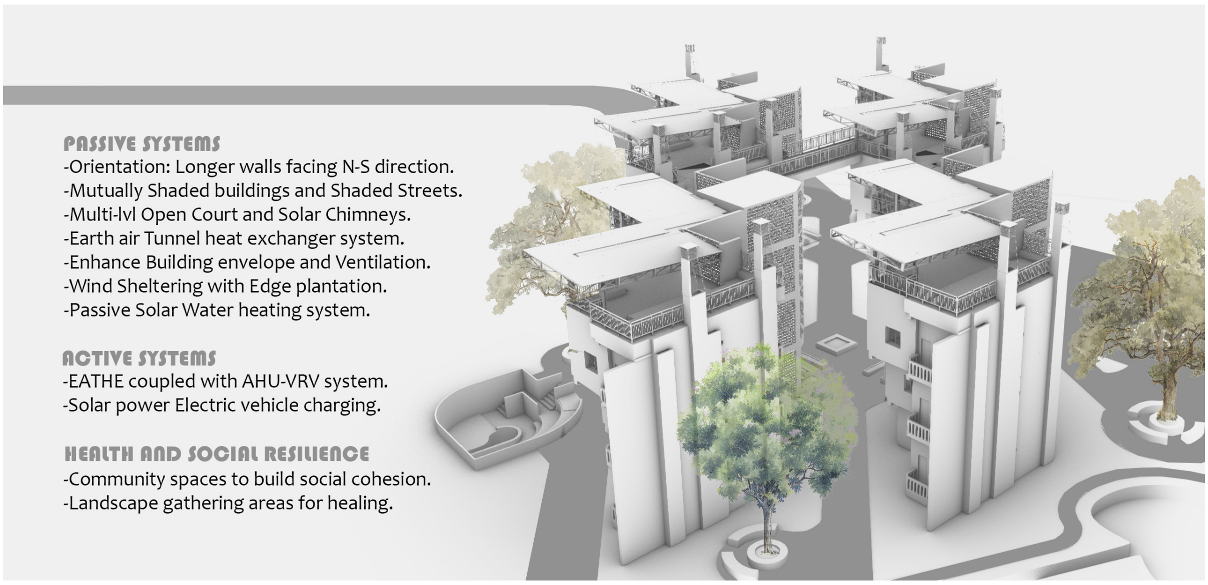


Figure 52 : Resilience at various levels

AFFORDABILITY

ENVELOPE SELECTION

To narrow down the selection process for the envelope design, a list of local materials was studied based on different criteria. One of the key governing factors for the decision was cost and local availability.

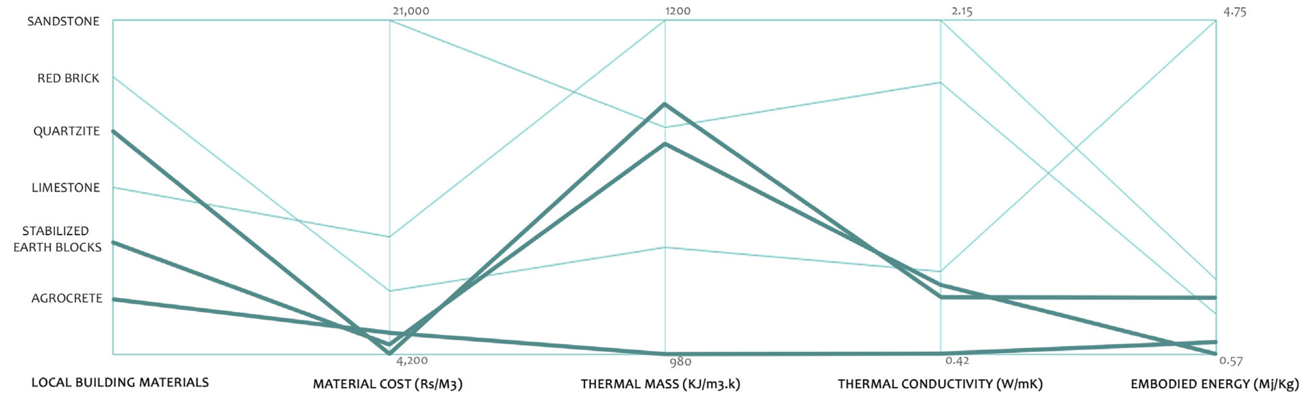


Figure 53 : Basic Material Study

A set of Low-E Double glazed units were analysed with the aid of Asahi Glass Pvt ltd. for the selection of glazing, and the best three were chosen for further parametric simulation.

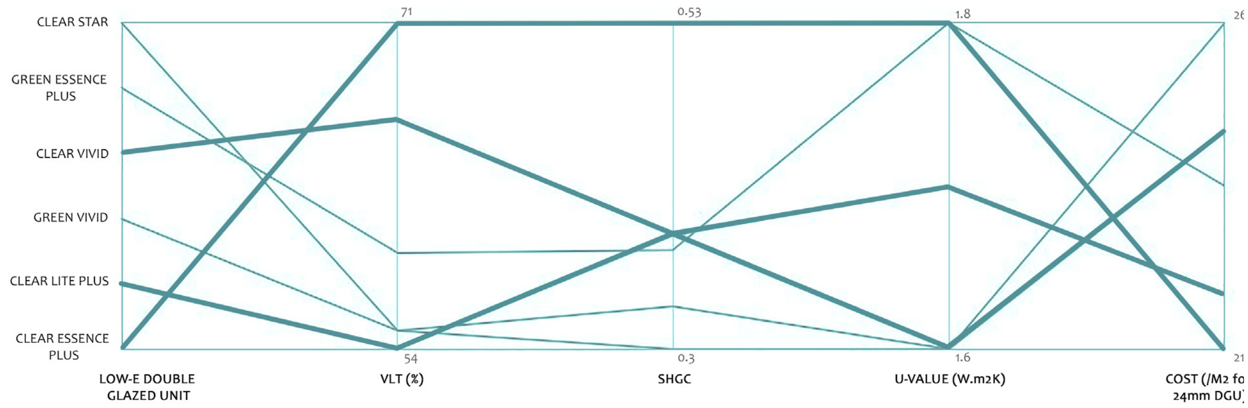
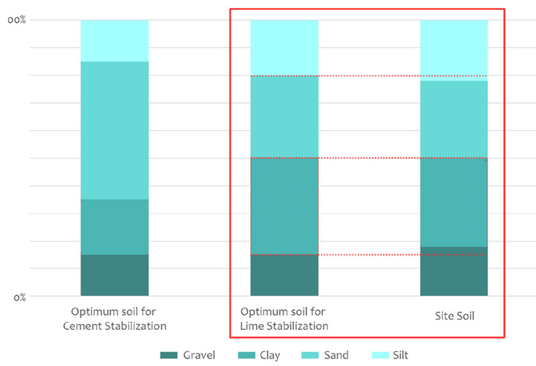


Figure 54 : Basic Window Study

The prime objective was to use the cheapest construction materials available in the area and build an envelope that could withstand the extreme heat. The capacity of site soil as an envelope block was investigated as part of the project.



Specific Details of the Site Soil

pH	Conductivity (dS/m)	OC (%)	Phosphate	Potash	Zinc (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Sulphur
8.2	0.15	0.1	28	199	1.01	3.9	0.32	2.64	15.2

Figure 55 : Study showing the resemblance of site soil with Optimum soil for Lime Stabilization

The properties of site soil for lime stabilisation are very similar to those of optimum soil. As a result, along with agrocrete, LSEB was selected as one of our primary building materials.

LIFE CYCLE COSTING

Cost estimation from the project partner is chosen as the BAU for comparison of life cycle cost. Life cycle cost is calculated for 40yrs of proposed life time for the housing building. It includes changing of solar panels after every 20yrs, HVAC (10 yrs), building painting and other OPEX, repair, maintenance and utility costs.

YEAR	COST COMPONENTS	BASE (INR in millions)	PROPOSED(INR in millions)
0	Capex - Cluster Construction	80.21	93.89
5	Opex + Repair and Maintenance + Utility Costs	8.3	5.1
10	Opex + Repair and Maintenance + Utility Costs	9.1	6.1
15	Opex + Repair and Maintenance + Utility Costs	8.2	5.8
20	Opex + Repair and Maintenance + Utility Costs	9.6	8.1
25	Opex + Repair and Maintenance + Utility Costs	8.4	5.9
30	Opex + Repair and Maintenance + Utility Costs	9.6	6
35	Opex + Repair and Maintenance + Utility Costs	8.7	5.9
40	Opex + Repair and Maintenance + Utility Costs	9.6	8.1
	Life Cycle Cost (LCC)	151.71	144.89

Table 21 : Lifecycle cost calculation

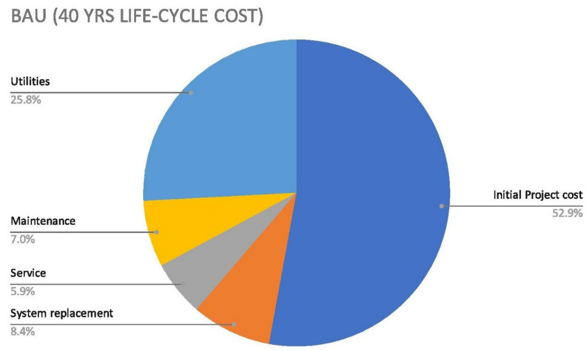


Figure 56 : BAU Life-cycle cost

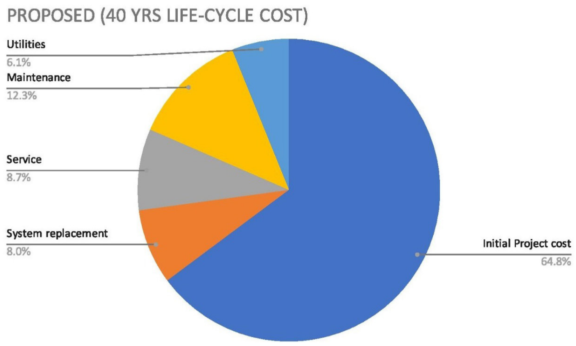
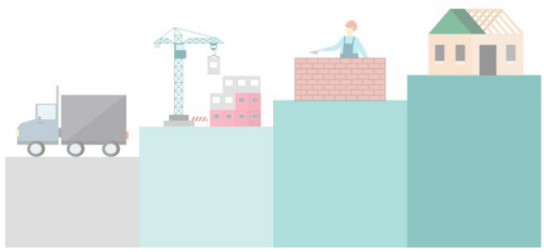


Figure 57 : Proposed Cluster Life-cycle cost

CONSTRUCTION TIMELINE

The primary benefit of integrating precast construction with cast-In-situ, is the reduction in time of construction.

Almost 50% of construction time is saved by Integrating hollow-core slab prefab modules into the project, thereby saving labour charges. They also tend to improve the quality standard, modularity, and uniformity of the structure.



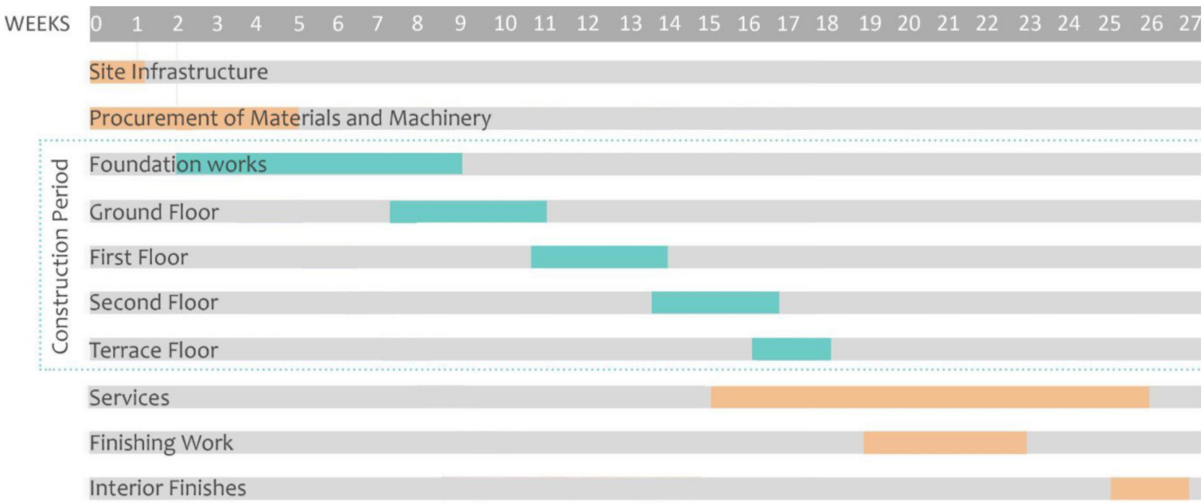


Figure 58 : Construction Timeline for the proposed

INNOVATION

ARCHITECTURAL DESIGN

An approach to creating sustainable net zero housing without sacrificing the occupants' architectural experience. Rajasthani traditional architecture and passive techniques are reimagined using innovative interpretation and cutting-edge technology.

1. A parallelogram building form is combined with street-facing balconies with shared shade, enhancing the space's quality and comfort.
2. A building envelope that emits less pollution.
3. Contact spaces that are multi-leveled, ranging from public to semi-public to private
4. Differential architectural knowledge from both the outside and the inside.

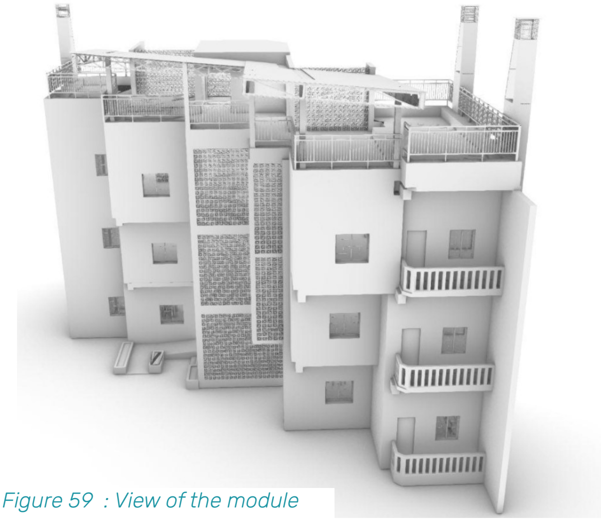


Figure 59 : View of the module

MULTI-LEVEL OPEN COURT

Multilevel courts are designed as an element of Architecture that serves two purposes:

1. Passive cooling and heating
2. Private social space for dwellers

These multi-level courts are designed and positioned in such a way so that it faces towards the south side of the dwelling units. This enhances their functionality of removing hot air in summer and acting as a solar gain in winter

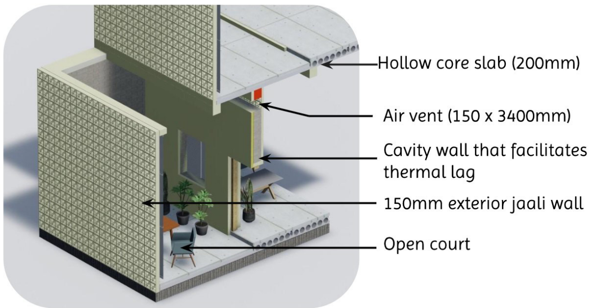


Figure 60 : Multi-Level court

Solar Court in Summer

In Summer, the Hot air rises through the top vent and escapes out through the open court thereby facilitating cool air movement in the living zone.

Solar Court in Winter

In winter, the doors and windows can be opened towards the court to let in warm air into the living space.

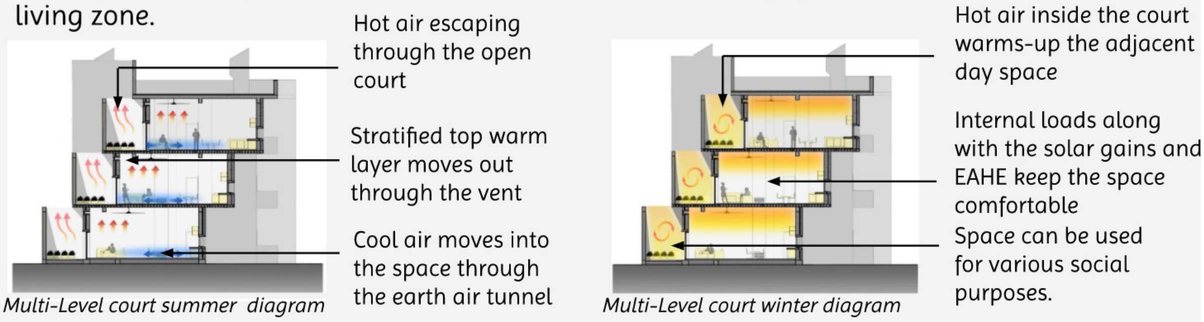


Figure 61 : Multi-Level court in summers and winters

DAYSPACE - NIGHTSPACE SEGREGATION

A survey was conducted to understand the support staff worker's work schedule. Almost 95% of the support staff were completely day workers and 5% shift workers. Shift workers tend to have have 2-4 days night shift in a week. Hence, comfort was majorly prioritized for the majority.
Two separate building envelopes were designed based on their use:

- Day Space (has a high thermal mass envelope with the desired U-value)
- Night Space (has a low thermal mass envelope with the desired U-value)

For day space, this ensures that the thermal mass is cooled down due to night purging preparing it for the day.
For night spaces, it ensures that the night purging strategy doesn't cool the mass rather it cools the space at night.

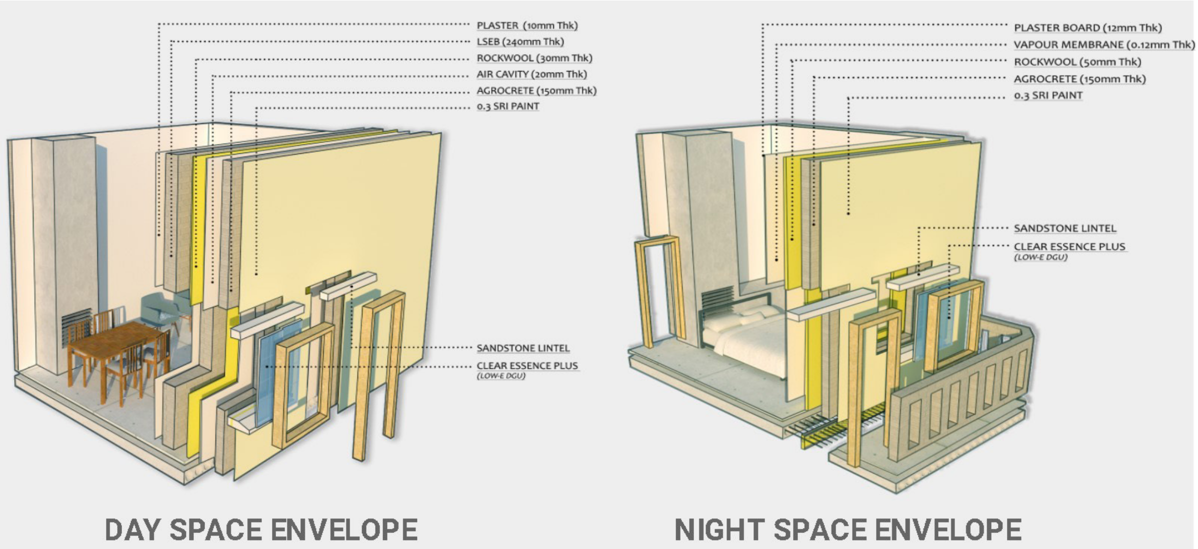


Figure 62 : Day space and night space envelope

INNOVATION IN EARTH AIR TUNNEL

The biggest hurdles of maintenance and water seepage are been resolved in this innovative implementation of this technology in our design. Various ways that issues could occur and preventive solutions are:

01. **Damages caused by rodents:**
Hume pipes system of 100MM thick concrete pipes are laid at a depth of 4 meters from the ground level. This depth automatically takes away the chances of any reptiles entering these pipes.

02. **Rusting and Disintegration of pipes:**
Cement pipes have no issues of rusting, better than flexible pipes, and independent on soil for strength. These are rugged enough to take the wear and tear and due to their high conductivity, they create a perfect medium for heat transfer between air and soil.

03. **Improved efficiency with AHU-VRV coupling and proper operation scheduling .**
An active system is coupled with EATHE to balance the temperature fluctuations. The EAT operation time is efficiently scheduled to provide a minimum of 6 hours shut down for the land to rejuvenate and maintain a cool air supply. This can improve the lifespan of this system.

SCALABILITY AND MARKET POTENTIAL

Scalability in similar geo-climatic context (Passive house that can be replicable to any similar context with less water, hot and dry climate).

MODUARITY

Flexibility in the arrangement of the module along with its innovative form makes it attractive in the contemporary market.

It can be linearly arranged, stacked, or clustered depending up the available amenities.

Figure 63 : Ground Floor Plan @ Lvl +1950

Figure 64 : First Floor Plan @ Lvl +6175

Figure 65 : Second Floor Plan @ Lvl +10400

Figure 66 : Terrace Floor Plan @ Lvl +14800

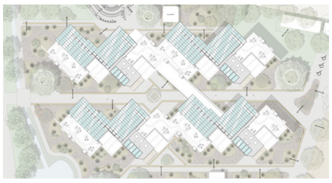


Figure 67 : Roof Plan

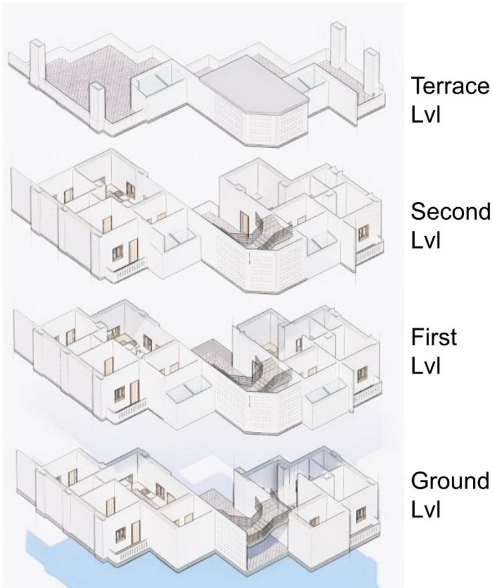


Figure 68 : Exploded view of the proposed Module

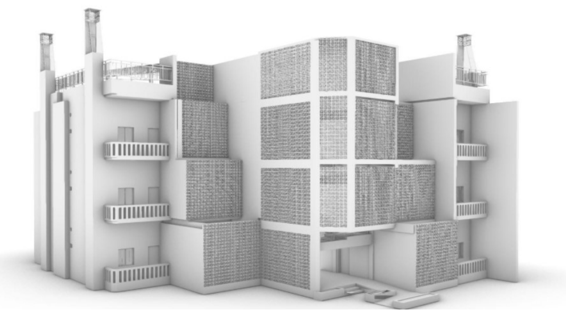


Figure 69 : Southern view of the module

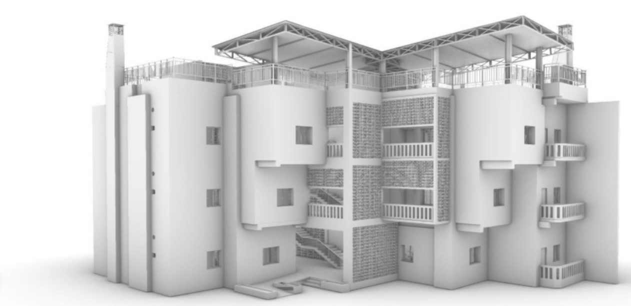
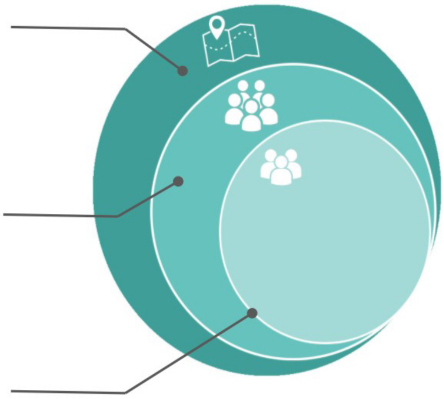


Figure 70 : Northern view of the module

Total addressable market
Referring to the entire population of the country living in hot and arid climate

Serviceable market
Aiming conclusively to the local market i.e. Rajasthan which is 8.3 crore people which serves to the aim of the project partner as well.

Target market
The main summarised target market is the people residing in parent township of Dhun.



SCALABILITY (MICRO LEVEL)

Scalability in a similar geo-climatic context - A passive house that can be replicated in any similar geo-climatic context with less water, a hot and dry atmosphere. The aim was to create a housing that would meet the needs of people of all ages and abilities. Flexible accommodation that can adapt to changing needs and occupant numbers.

Source: UNEP-WCMC

The module's flexibility in arrangement, as well as its innovative design, make it appealing in today's market. It can be stacked, clustered, or linearly arranged (up to G+2). Rajasthan, where our site is located, is one of India's hottest states. With an arid to semi-arid climate and annual rainfall of less than 650 mm, the climate is arid to semi-arid. It can be scaled up to similar geoclimatic locations in India, such as Maharashtra and Gujarat, as well as Pakistan, Egypt, the United Arab Emirates, Mexico, and Western Australia. This module tackles issues such as water shortages, dust storms, high solar fluxes (including lethal UV radiation, heat waves), high diurnal temperature fluctuations, and a higher evaporation rate to make it scalable in

An approach to designing a versatile space that adapts to changes in the house users' needs, as well as the physical and cultural climate, and is suitable for all categories from LIG to MIG. We wanted to be able to use a room in a number of ways without having to make any physical adjustments to the internal structure.

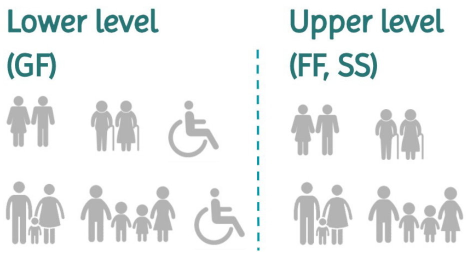


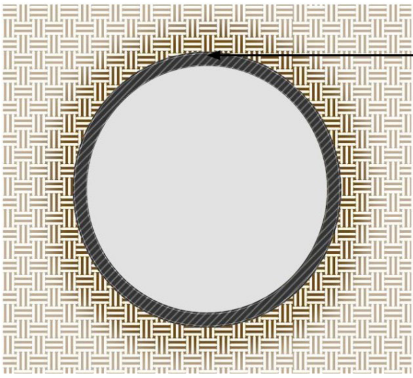
Figure 71 : Typical layout iteration

Figure 72 : Special layout iteration- people using floors for their activities(No furnitures)

STRATEGIES FOR MACRO LEVEL SCALABILITY

Scalability of cooling system in a water available context.

Sites with similar geo-climatic context and high water availability can use water for cooling. Installing misters inside the Earth-air tunnel to humidify the air during the intense dry summers is one way to use water in this proposed design.



EAT without water misters
RELATIVE HUMIDITY - 25 - 30%
PMV - 0.64

EAT with water misters
RELATIVE HUMIDITY - 50 - 55%
PMV - 0.06

(PMV calculated considering parameters of outlet air from EAT and human behaviour in peak

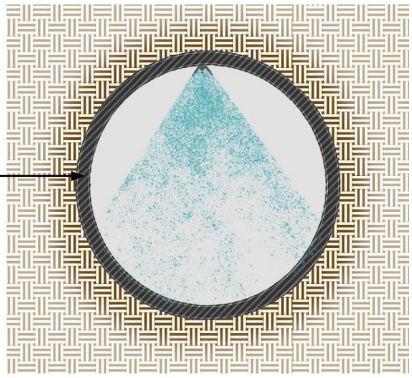


Figure 73 : EAT without water mister

Figure 74 : EAT with water mister(Evaporative Cooling)

Alternative envelope for an urban and sub-urban context.

Because of their local availability, LSEB and Agrocrete are the key components in the building envelope. These components will not be feasible in all geographical settings. As a result, an alternative envelope with similar properties is constructed using widely available building blocks across the country.

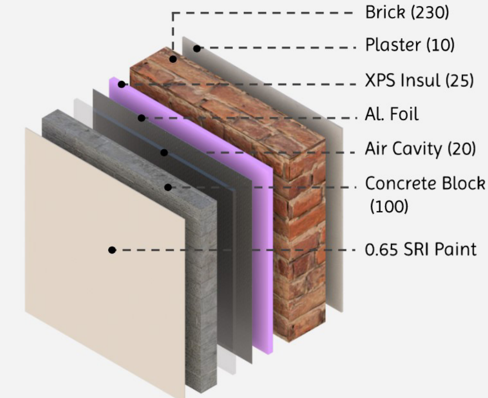


Figure 75 : Proposed Alternative Envelope

-**Clay Brick and Concrete blocks** are used as the basic building blocks due to its wide availability in the market.

-**XPS Insulation** is also used due to its Market availability.

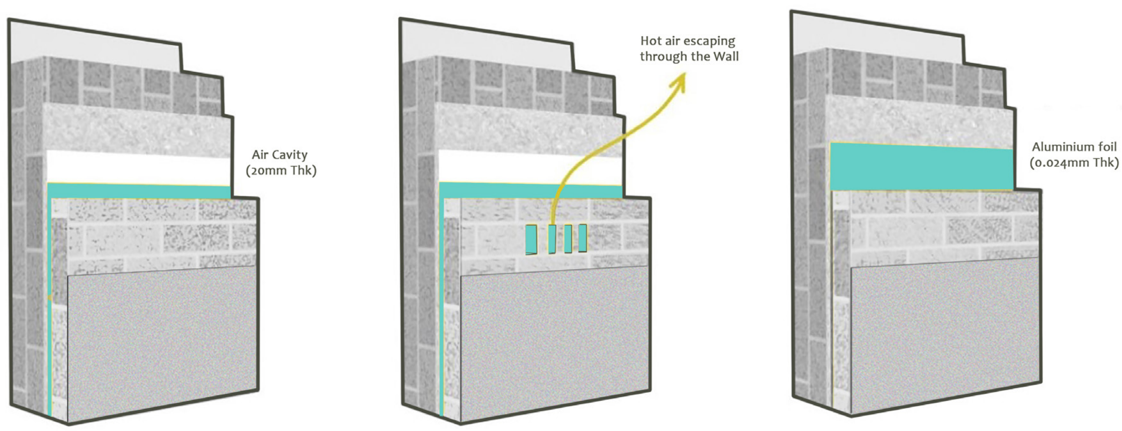
-Envelope with **Thermal mass leaf inside and insulation outside.**

-U Value = 0.59 W/m2
-SRI Value = 0.6 (Almond)

REDUCING CONDUCTIVE HEAT TRANSFER THROUGH ENVELOPE

REDUCING CONVECTIVE HEAT TRANSFER THROUGH ENVELOPE

REDUCING RADIATIVE HEAT TRANSFER THROUGH ENVELOPE



Cavity wall with less thermal bridge helps to reduce the conductive heat transfer.

Holes on outer leaf of the Cavity wall removes the hot air from inside and reduce the effect of convective heat transfer heat transfer.

The Aluminium foil reflects upto 96% of radiant heat, thereby reducing the radiative heat transfer in Summer. It also helps to contain heat in Winter

Figure 76 : Properties of Proposed Envelope

ARCHITECTURAL DESIGN

In one-third of the site, we designed a net-zero multifamily housing prototype that can be replicated further while keeping mother project Dhun's netzero ideologies in mind. Our net zero housing concept takes into account the economy, climate, and local regulations.

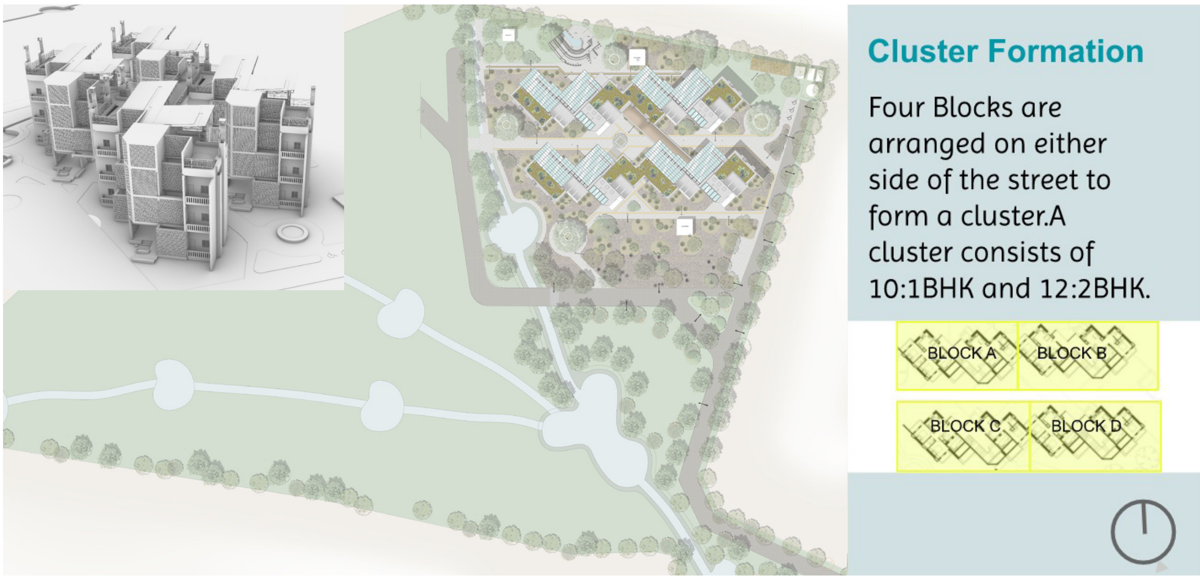


Figure 77 : Site plan at roof level

Figure 78 : Ground Floor Plan @ Lvl +1950

CLUSTER PLANS

Figure 79 : First Floor Plan @ Lvl +6175

Figure 80 : Second Floor Plan @ Lvl +10400

CLUSTER PLANS

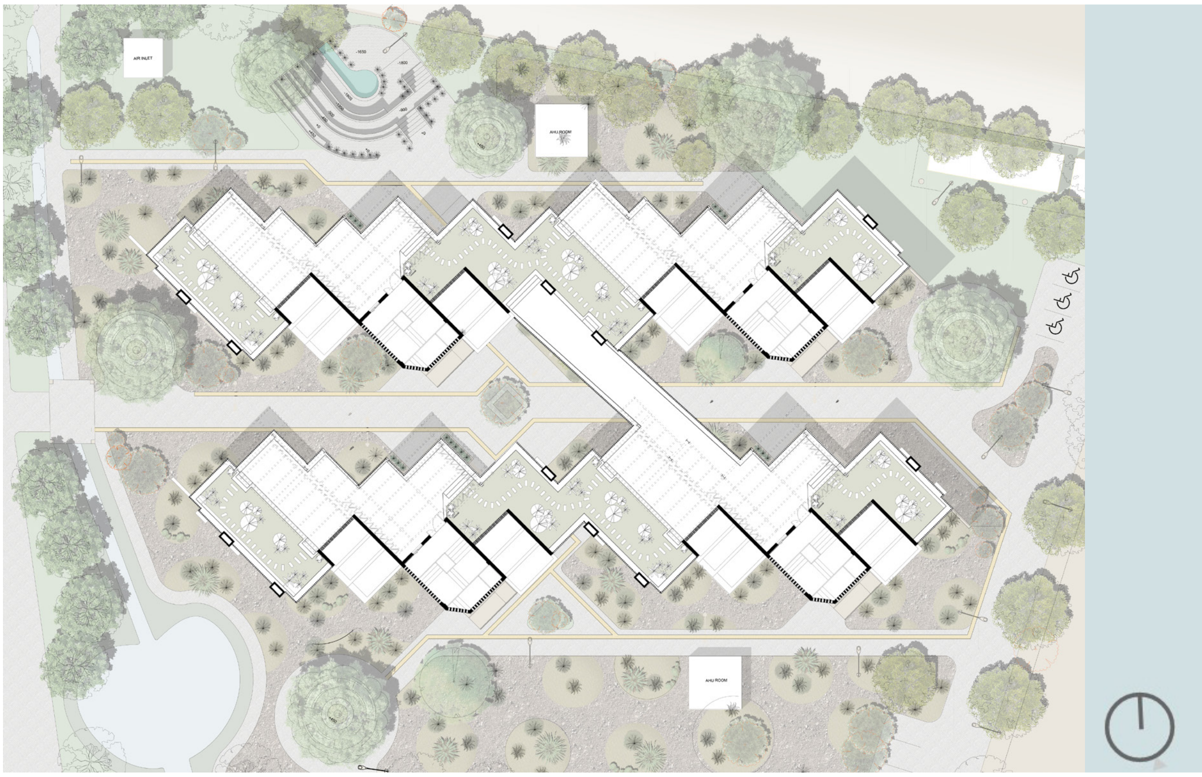


Figure 81 : Terrace Floor Plan @ Lvl +14800

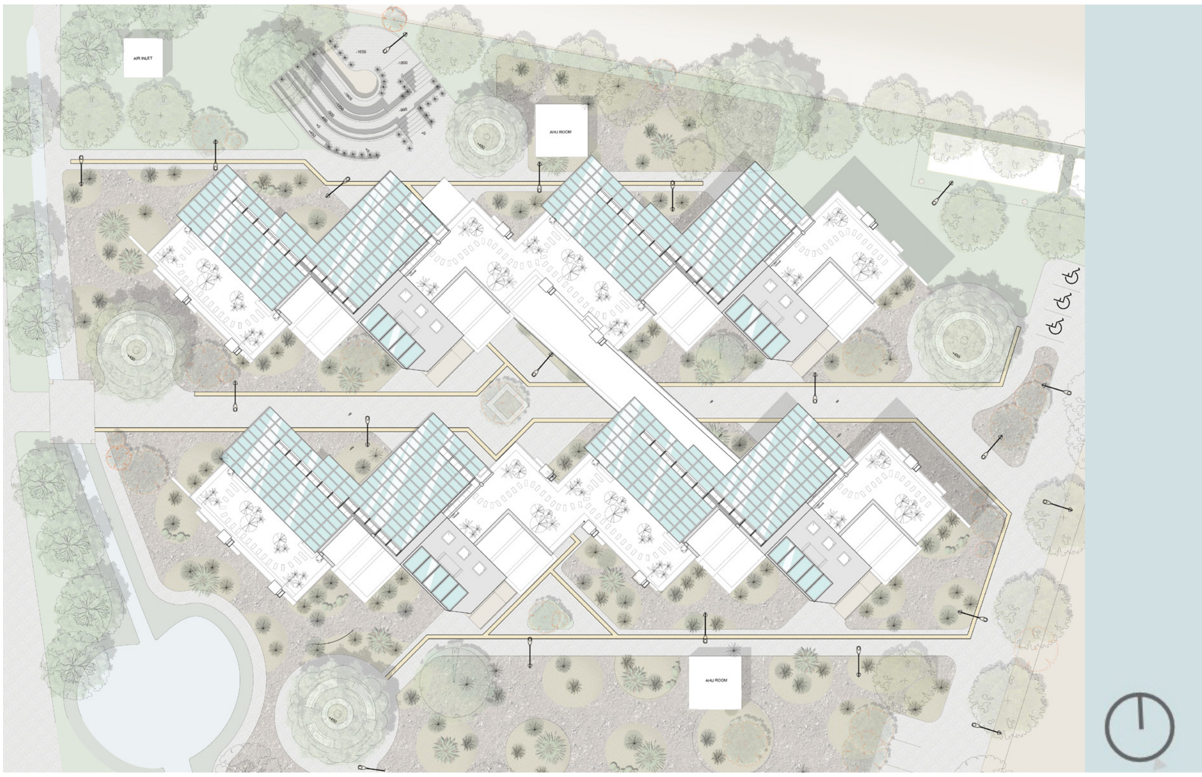


Figure 82 : Roof Plan

CLUSTER ELEVATIONS AND SECTIONS

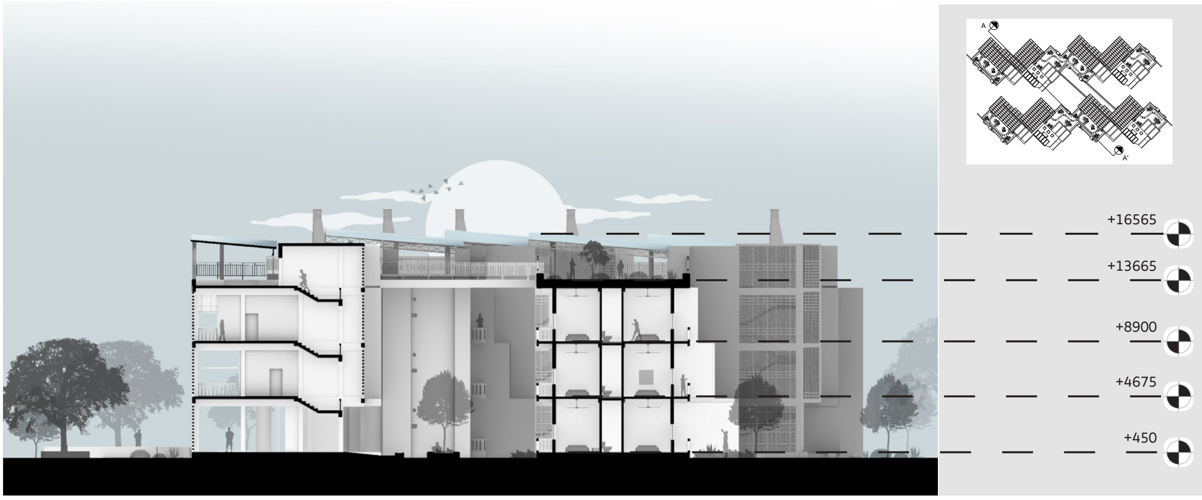


Figure 83 : Section AA'

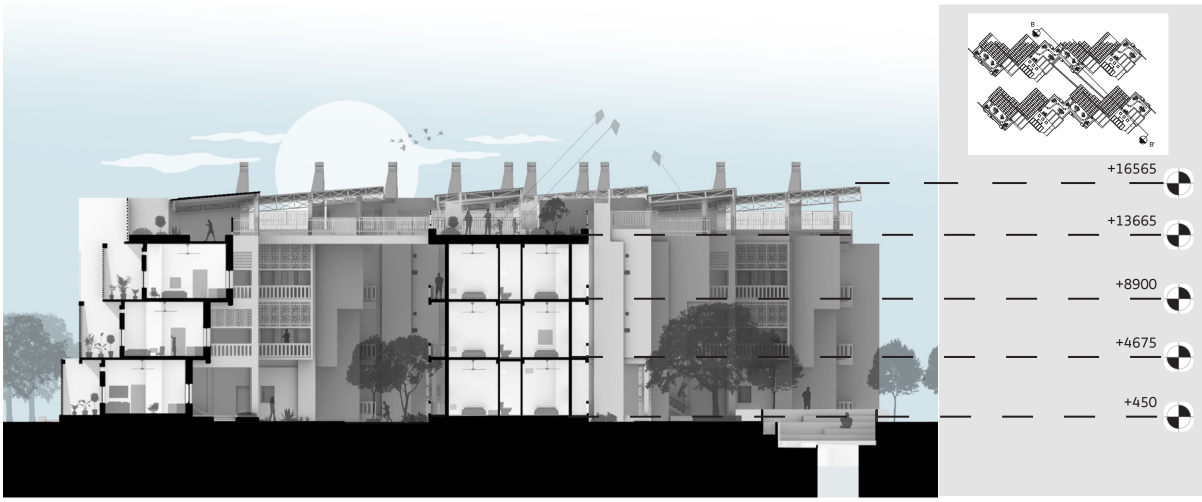


Figure 84 : Section AA'

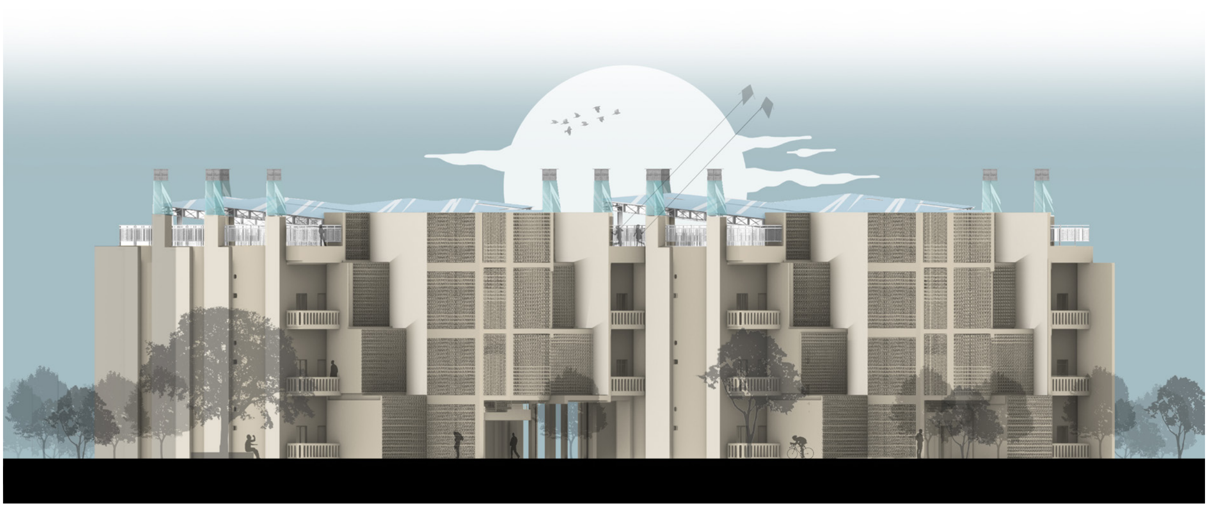


Figure 85 : South Elevation

ENGINEERING DESIGN AND OPERATION

STRUCTURAL DETAILS

We chose a composite structural design with an RCC skeletal structure where a portion of the cement can be replaced with fly ash. Since the soil has an SBC value of 8, it is strip footing with a depth of 2700. It has a 450-foot plinth with rammed earth, quartzite stone, prefabricated hollow slabs, prefabricated slabs, and polished concrete layers. Prefabricated hollow core slabs and prefabricated slabs makeup intermediate floor slabs and terrace slabs. A cavity wall (505 thk) and a lighter lightweight wall make up the envelope (215 thk).
The terrace is an active community area since it is paved with solar PV panels raised on trusses and has terrace gardening spaces.

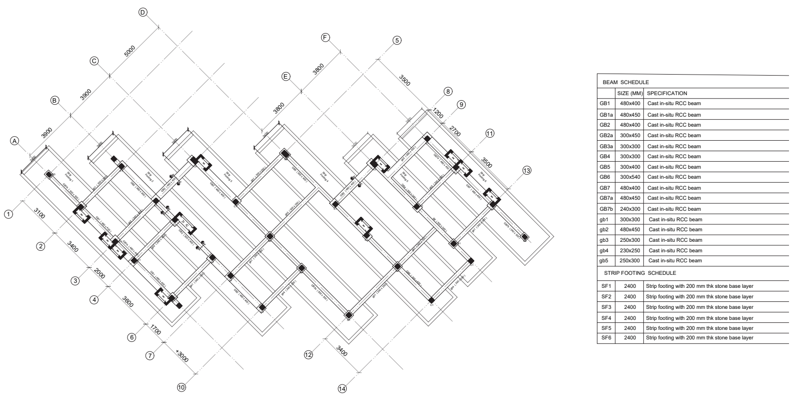


Figure 86 : Foundation Plan

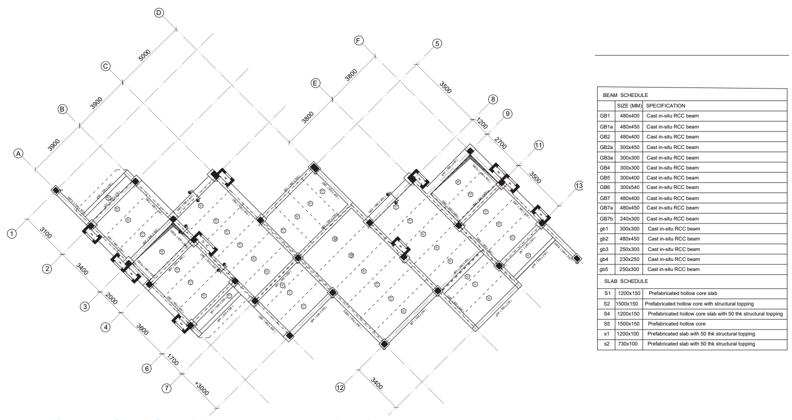


Figure 87 : Grade Beam Layout Plan

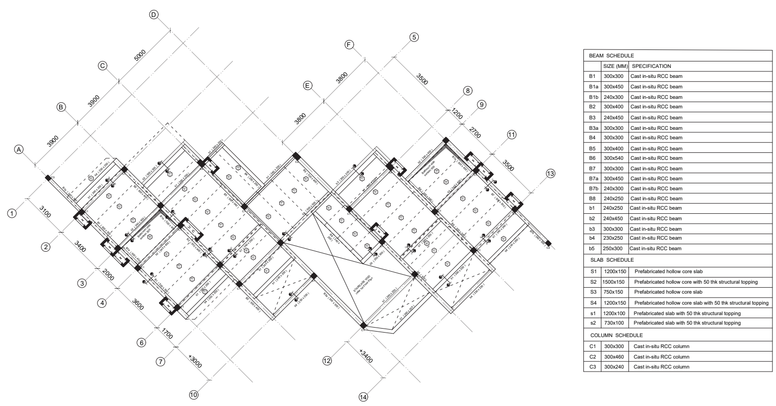


Figure 88 : Ground Floor Framing Plan

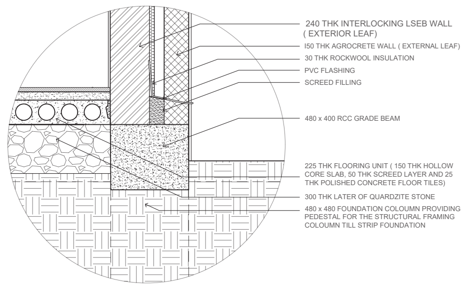


Figure 89 : Section AA' (Foundation grade beam detail)

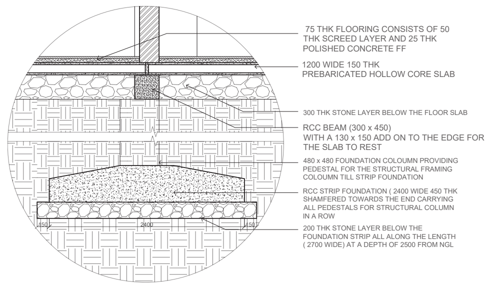


Figure 90 : Section BB' (Foundation Grade Beam detail)

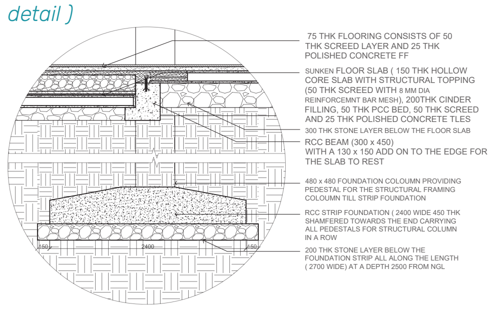


Figure 91 : Section CC' (Foundation Grade Beam detail)

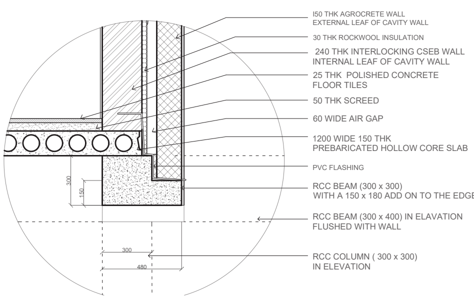


Figure 92 : Section AA' (Cantilever cavity wall detail)

STRUCTURAL DETAILS

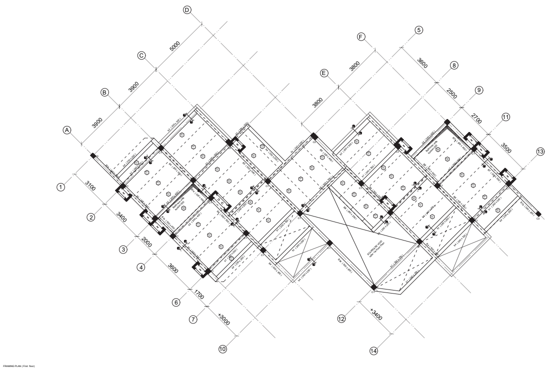


Figure 93 : First Floor Framing Plan

BEAM SCHEDULE		
	SIZE (MM)	SPECIFICATION
B1	300x300	Cast in-situ RCC beam
B1a	300x450	Cast in-situ RCC beam
B1b	240x300	Cast in-situ RCC beam
B2	300x400	Cast in-situ RCC beam
B3	240x450	Cast in-situ RCC beam
B3a	300x300	Cast in-situ RCC beam
B4	300x300	Cast in-situ RCC beam
B5	300x400	Cast in-situ RCC beam
B6	300x540	Cast in-situ RCC beam
B7	300x300	Cast in-situ RCC beam
B7a	300x450	Cast in-situ RCC beam
B7b	240x300	Cast in-situ RCC beam
B8	240x250	Cast in-situ RCC beam
b1	240x250	Cast in-situ RCC beam
b2	240x450	Cast in-situ RCC beam
b3	300x300	Cast in-situ RCC beam
b4	230x250	Cast in-situ RCC beam
b5	250x300	Cast in-situ RCC beam
SLAB SCHEDULE		
S1	1200x150	Prefabricated hollow core slab
S2	1500x150	Prefabricated hollow core with 50 thk structural topping
S3	750x150	Prefabricated hollow core slab
S4	1200x150	Prefabricated hollow core slab with 50 thk structural topping
s1	1200x100	Prefabricated slab with 50 thk structural topping
s2	730x100	Prefabricated slab with 50 thk structural topping
COLUMN SCHEDULE		
C1	300x300	Cast in-situ RCC column
C2	300x460	Cast in-situ RCC column
C3	300x240	Cast in-situ RCC column

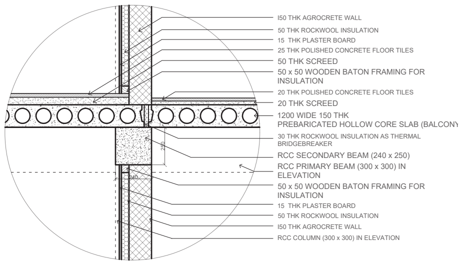


Figure 96 : Section BB' (Balcony section detail)

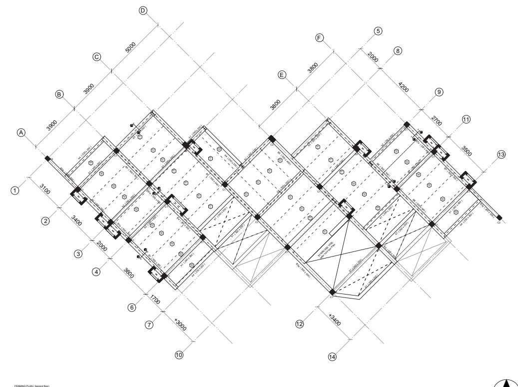


Figure 94 : Second Floor Framing Plan

BEAM SCHEDULE		
	SIZE (MM)	SPECIFICATION
B1	300x300	Cast in-situ RCC beam
B1a	300x450	Cast in-situ RCC beam
B1b	240x300	Cast in-situ RCC beam
B2	300x400	Cast in-situ RCC beam
B3	240x450	Cast in-situ RCC beam
B3a	300x300	Cast in-situ RCC beam
B4	300x300	Cast in-situ RCC beam
B5	300x400	Cast in-situ RCC beam
B6	300x540	Cast in-situ RCC beam
B7	300x300	Cast in-situ RCC beam
B7a	300x450	Cast in-situ RCC beam
B7b	240x300	Cast in-situ RCC beam
B8	240x250	Cast in-situ RCC beam
b1	240x250	Cast in-situ RCC beam
b2	240x450	Cast in-situ RCC beam
b3	300x300	Cast in-situ RCC beam
b4	230x250	Cast in-situ RCC beam
b5	250x300	Cast in-situ RCC beam
SLAB SCHEDULE		
S1	1200x150	Prefabricated hollow core slab
S3	750x150	Prefabricated hollow core slab
S4	1200x150	Prefabricated hollow core slab with 50 thk structural topping
COLUMN SCHEDULE		
C1	300x300	Cast in-situ RCC column
C2	300x460	Cast in-situ RCC column
C3	300x240	Cast in-situ RCC column

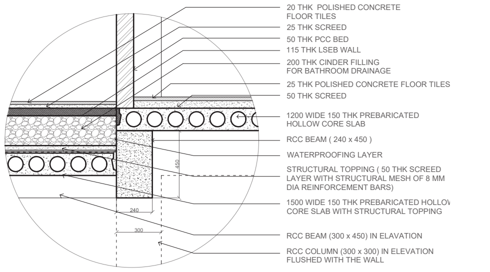


Figure 97 : Section CC' (Bathroom section detail(1))

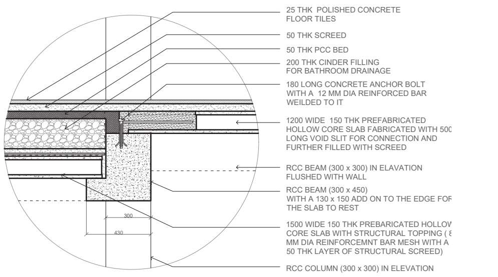


Figure 98 : Section DD' (Bathroom section detail(2))

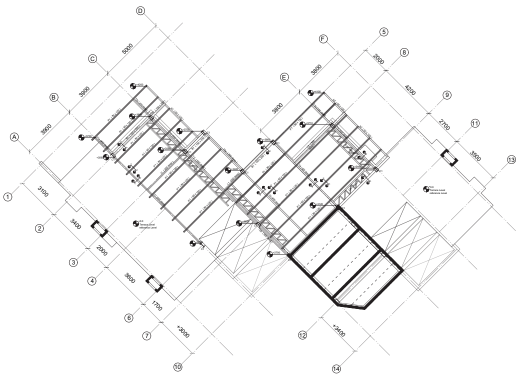
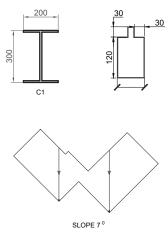


Figure 95 : Rooftop Truss Framing Plan

TRUSS SCHEDULE		
	SIZE (MM)	SPECIFICATION
P1	80X120	PREFABRICATED STEEL PURLIN (DOUBLE REBATED, REBATE OF 30 X 30)
T1	550 DEEP	PREFABRICATED PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 95)
T1a	450 DEEP	PREFABRICATED PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 95)
t1	300 DEEP	PREFABRICATED 300 WIDE PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 80)
T2	550 DEEP	PREFABRICATED PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 95)
T2a	450 DEEP	PREFABRICATED PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 95)
T3	400 DEEP	PREFABRICATED PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 95)
T4	400 DEEP	PREFABRICATED PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 95)
T5	300 DEEP	PREFABRICATED PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 95)
T5a	450 DEEP	PREFABRICATED PARALLEL CHORD ROUND PIPE STEEL TRUSS (PRIMARY CHORD DIA OF 95)
B1	150X250	CAST IN-SITU RCC BEAM
b1	50X120	CAST IN-SITU RCC BEAM
		CAT WALK - 550 WIDE PREFABRICATED PARALLEL CHORD STEEL TRUSS WEILDED TO THE PERPENDICALAR i SECTION AT A DEPTH OF 250



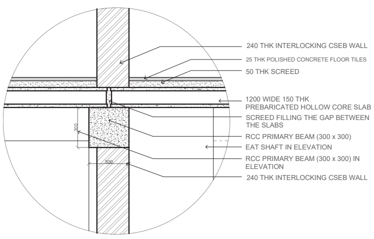


Figure 99 : Section EE' (Internal beam-slab connection)

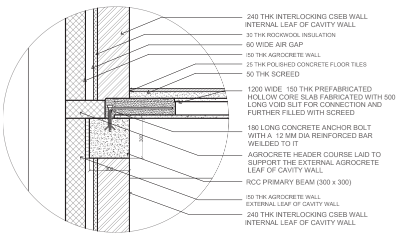


Figure 100 : Section FF' (Exterior Cavity Wall))

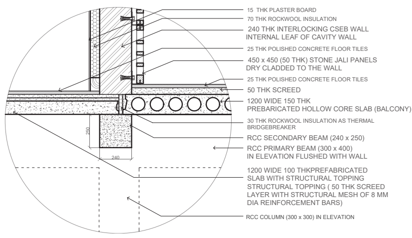


Figure 101 : Section GG' (Court and living junction detail)

STRUCTURAL DETAILS

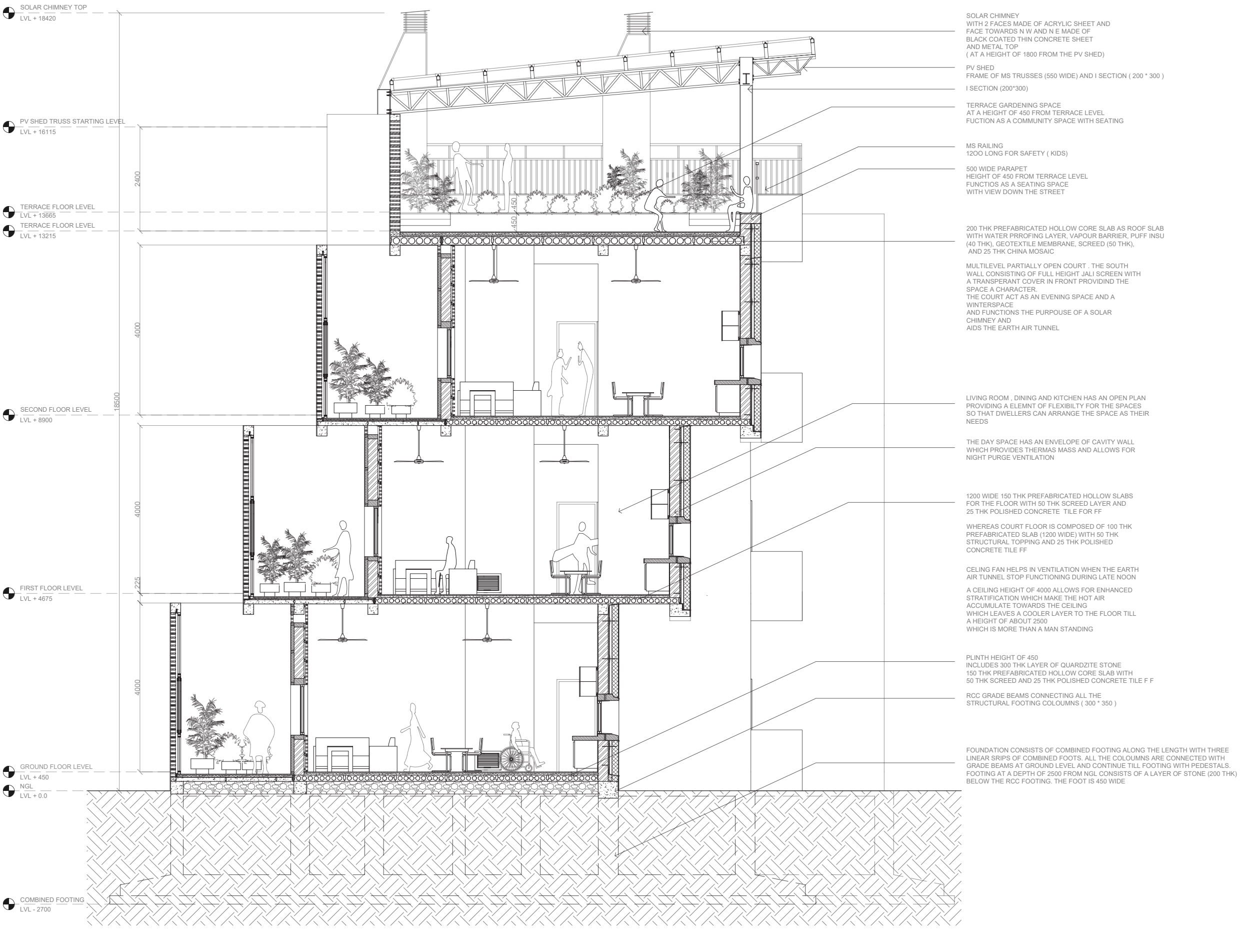


Figure 102 : Section through Multi-Level court

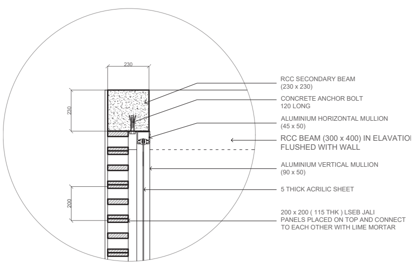


Figure 103 : Section HH' (Court exterior wall detail)

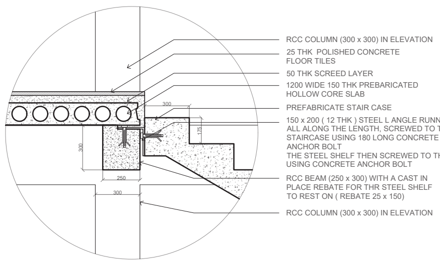


Figure 105 : Section I I' (Pre-fab staircase detail)

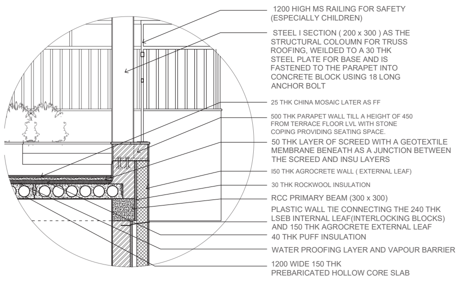


Figure 104 : Section KK' (Terrace parapet detail)

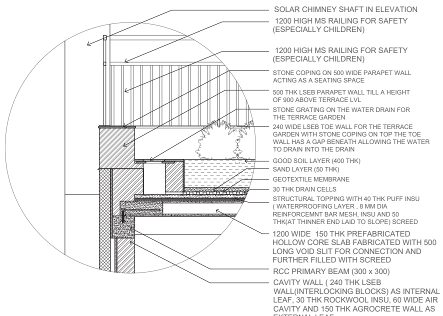


Figure 106 : Section LL' (Terrace garden drain detail)

OPERATIONS AND SPECIFICATIONS

EQUIPMENT SELECTION AND OPERATIONAL SCHEDULE

The main goal was to choose appliances that were energy efficient, low maintenance, and had a long lifespan.
The equipment was chosen using the Government of India's Bureau of Energy Efficiency's (BEE) Star Labeling software.

The equipment EPI was reduced from 14 kWh/m2/yr to 8.5 kWh/m2/yr by optimizing equipment range. (NOTE: Calculations and sizing for optimal HVAC systems are covered under Energy and Comfort.)

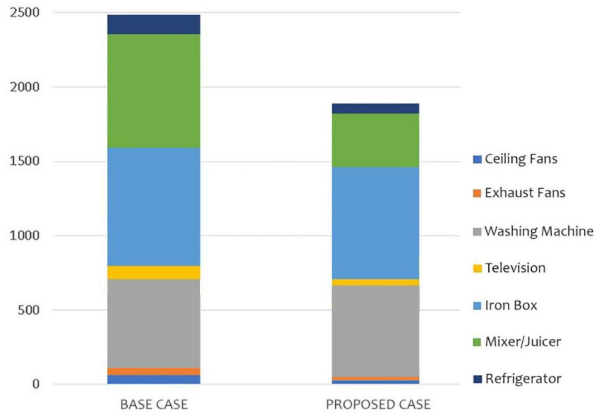


Figure 107 : Equipment power comparison before and after Optimization

Operational schedules are designed after a selective survey of 18 support staff houses to derive the pattern of space occupation.

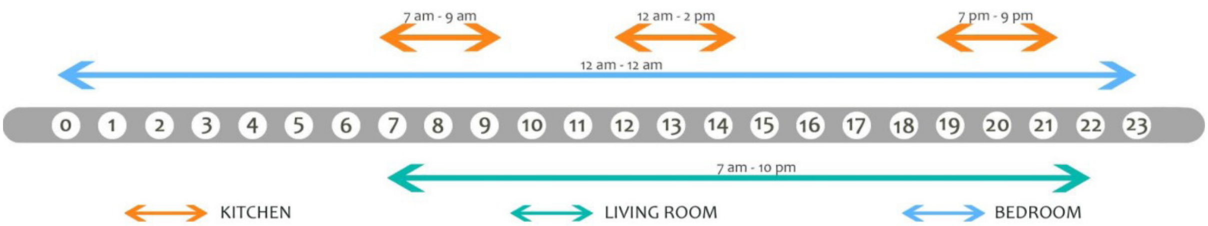


Figure 108 : Operational Schedule for Dwelling units

Kitchen and Living room are a part of Day space. However, bedroom although being a night space, functions for 24hrs considering comfort of the shift-workers.

EQUIPMENT SELECTED	DESCRIPTION	EQUIPMENT SELECTED	DESCRIPTION	EQUIPMENT SELECTED	DESCRIPTION
	Company - Havells Model - Efficiencia Neo 48" Power - 26 W Cost - Rs.2849		Company - LG Model - 32LM565BPTA LED smart TV Power - 45 W Cost - Rs.16999		Company - Kirloskar Model - TINY-180 Power - 180 W Cost - Rs.3440
	Company - Havells Model - Ventilair DX 150mm Power - 22 W Cost - Rs.1200		Company - Daikin VRV VI Model - VRV RXYTQ8U7YF Tonnage - 5.4 Power - 380 - 415V/50 Hz		Company - Kirloskar Model - SUPERSTAR Power - 370 W Cost - Rs.5020
	Company - LG Model - FHM1006ADW 5 star Power - 462 W Cost - Rs.23990		Company - Philips Model - Diva GC83 dry iron Power - 750 W Cost - Rs.450		Company - LG Model - GL-D241APZZ 5 star Power - 68 W Cost - Rs.17990
	Company - Havells Model - Aspro Power - 500 W Cost - Rs.2469		Company - Philips Model - Linea wall light Power - 8.5 W		Company - Philips Model - AP LED Plus Power - 7 W, 8.5 W, 12 W

Table 22 : Selected Appliances for Multi-Family Housing

ELECTRICAL LAYOUT

1 BHK ELECTRICAL LAYOUT

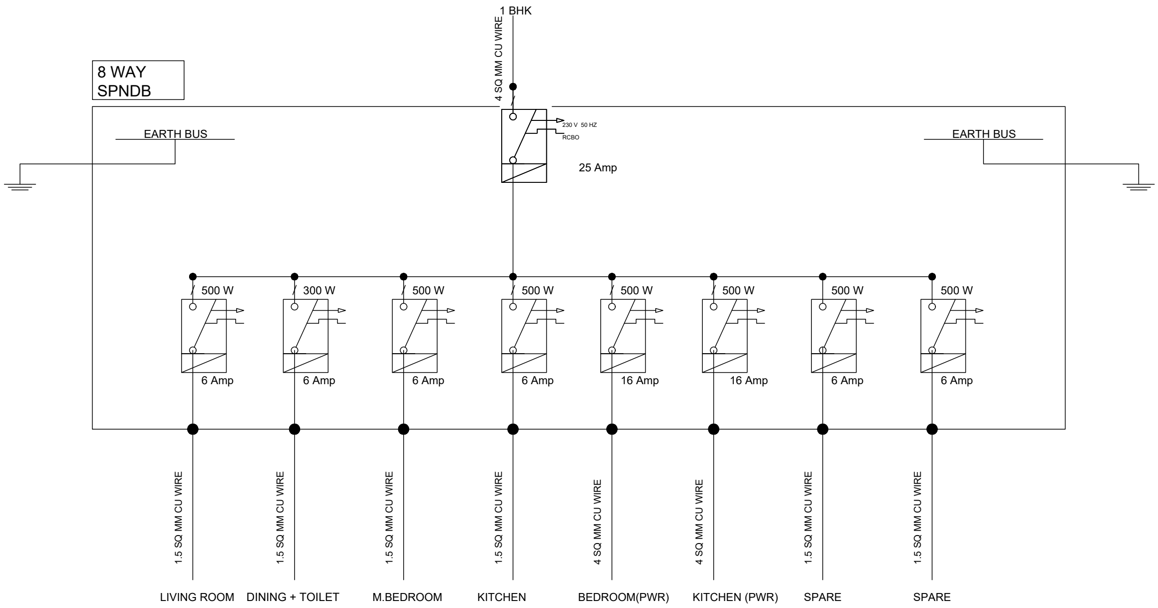


Figure 109 : Electrical layout for 1 BHK

2 BHK ELECTRICAL LAYOUT

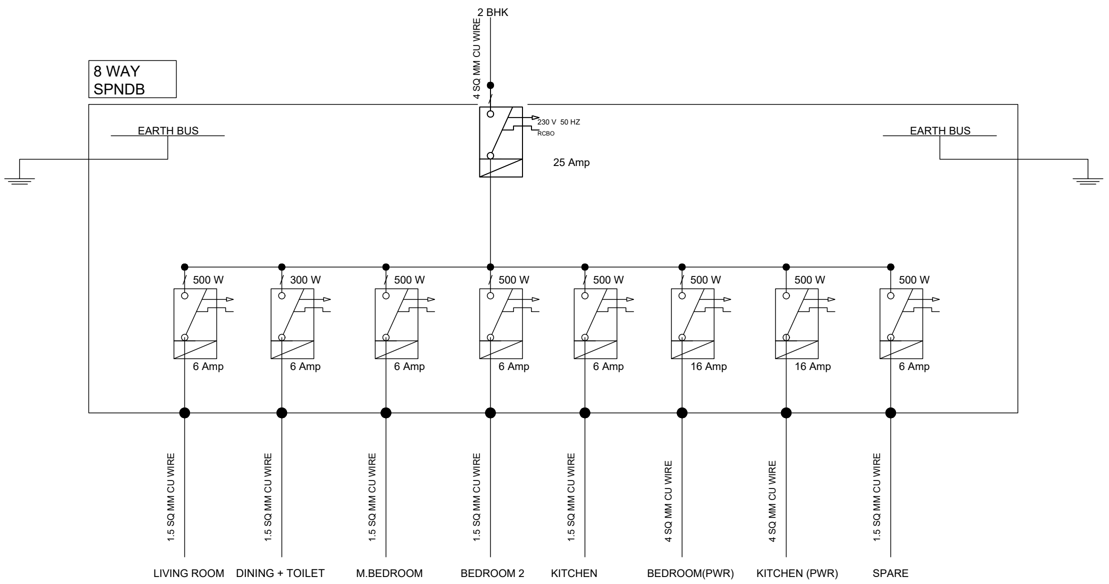


Figure 110 : Electrical layout for 2 BHK

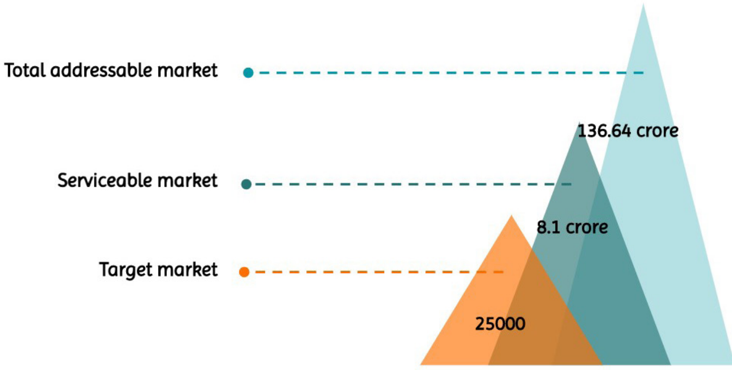
PITCH TO YOUR PROJECT PARTNER

Sustainable development touches all aspects of life, from growing populations, climate change, halting biodiversity loss, to migration and youth employment. With a vision of a sustainable future we are a small group of students who took upon a challenge to comply with your ideology and requirements to build a residential unit with net zero energy, water and waste. With having net-zero approach in mind the basic purpose of the design is to provide equity to all.

PROBLEM AND SOLUTION : Harsh climatic conditions; comfortable living environment in an affordable range and providing all with minimal energy consumption.
The ideas that were created as a result of this strategy were the result of a creative approach. Providing an earth air heat exchanger that works in parallel with an open court (at every level) to control air flow and maintain temperature within residential units. All of this is accomplished using locally available materials, resulting in lower embodied energy.

MARKET ANALYSIS :

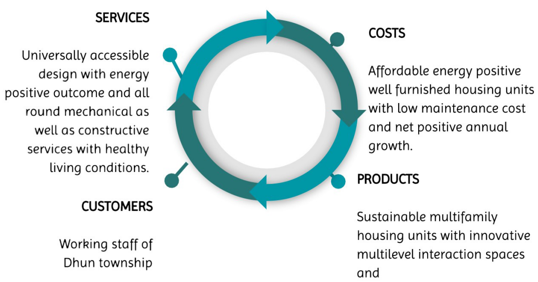
The total available market is India's population; however, to preserve regionality, the serviceable market is the citizens of Rajasthan. The citizens who will be a part of the Dhun township are the final target market.



SERVICE DESCRIPTION : Staff housing for 150 people employed in Dhun is being built as an eco-friendly sustainable housing prototype that rises two floors above ground level.

1. Contact spaces with several levels: Private court, Balconies(Unit Lvl), Staircase landings (block lvl) street and street with balconies(cluster lvl), The terrace, the community area around the well (inspired by typical community engagement spaces), and the community area between the blocks.
2. Eliminating social class barriers (such as MIG/HIG) and prioritising occupant privacy without jeopardising the egalitarian approach
3. It is less expensive to maintain, making it more accessible to the consumer.
4. Modifiable spaces that can be adapted to the user group's culture and use.
5. A long-term investment that aims to make a return right away by growing in a linear fashion.

BUSINESS MODEL



INVESTMENT AND GROWTH PLAN

The primary budget of the 4.6 acres project is 4 crores with a linear growth plan. The design is unique in its own way but is even adaptable when replicated in other regions with similar climatic conditions. Therefore, the scalability of the module is a key factor that influences its growth. The innovative feature of having multi-level open court provides an aura of social stability and authenticity of regional private open space.

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