PROJECT : "AARU"

TRIDHARA

Division : on site construction worker housing

PROJECT PARTNER – AGR INFRA DEVELOPERS

Final design report
April 2023

Solar Decathlon India

MANIPAL SCHOOL OF ARCHITECTURE AND PLANNING
MANIPAL
(A constituent unit of MAHE, Manipal)

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EXECUTIVE SUMMARY

The on–site construction worker's housing is the least considered building sector all over the world. The present living conditions of the worker's housing are extremely difficult where there is a lack of ventilation, no proper indoor thermal comfort, maintaining less hygiene, etc.… Considering all climate zones Which makes the construction worker's housing an extreme habitat to live in.

We here from the MANIPAL SCHOOL OF ARCHITECTURE AND PLANNING with 14 team members, faculty leads, and advisors from different fields including architecture, building science, and engineering (civil and structural) in collaboration with **AGR infra developers (project partner)** to come up with the solution for the different problems which is faced.
As the workers are packers and movers the modules must be able to adapt according to the different environmental conditions.

The project **''AARU''-''DESIGNED TO TRAVEL**'' aims to provide basic facilities and comfort for the workers and reduce the investment cost for the project partner. And, so aims to create adaptable modules according to the climate zones of INDIA. The modules can be folded, transported, and assembled again in the new environment and site. By introducing net zero energy, water, and waste.
The project depicts and addresses the 10 contexts of the competition. **Energy is generated** by ROOF TOP PV PANELS which is 120.21kwh/m^2 /year. Which helps in the reduction of gird power leading to net positive. The PV panels are grid-connected and extra generation of electricity can be sold to the municipal electricity board (selling of clean renewable energy).

The embodied carbon generated is reduced by sourcing the materials near the site (Hyderabad). The materials used for walls, roofs, and floors are green-rated. From this compared to the base case which is conventional housing the proposed case is 6 times more efficient for a span of 10 years.
10 years life span of the module also says that the reuse of the materials is done which reduces the overall investment cost compared to the conventional setup.

Use of light materials: use of UPVC frames for doors and windows, transparent plastic sheets, and lightweight furniture aluminum bunker beds which leads us to easy transportation.
Improved indoor thermal comfort by incorporating different passive strategies and envelopes which are super ECBC compliant.

This shows the improvement in living conditions which will have a drastic change in the way the construction industry treats the on-site construction workers. Proper segregation of space and improved living conditions may increase the phycological impact and workability of the workers.

The project proposed will give the contractor positive feedback from the construction community and will be able to attract investors, skilled laborers, and government projects. And saves money.

SECTION	REVIWER'S COMMENTS	OUR RESPONSE
Energy Performance	Good attempt! Additional PV calculation would be appreciated.	PV calculations is been added in the slide:18
Water Performance	Good details both in calculations, visuals, and narratives! Units missing in Table 12. Also, can provide water fixture details.	Units and water fixtures details has been added in slide no:21&22
Embodied Carbon	Great details! A short narrative on the construction materials and technology would be appreciated.	The comment has been addressed in slide no:23
Resilient Design	Good details on the emergency preparedness plan.	No response
Engineering and Operations	Good effort! Can provide individual electrical layout and fixture details	The comment has been addressed in slide no:42
Architectural Design	Assuming Engineering and operations sheets and architectural design sheets are combined. (Might be a mistake in sheet heading)	Engineering, operation and architectural design are merged
Affordability	Good effort in cost comparison.	No response
Innovation	Good description. Please check grammar and font as all the first letters in each word are capitalized under headings- Wall Panels- Wall type 2 and Paneling.	The corrections has been and updated in the slide no:31,32&33
Health and well-being	Good details. Figure 26, can include the time of the three intervals. Figure 28 seems to show a few areas in the middle of the room with very less air movement/ stale air	The comment has been addressed in the slide no: 35
Value Proposition	The value proposition requires more clarity in terms of messaging the project's potential in terms of planning, design, function, and material.	The updated content according the comments is in slide no:36

Table 1 Response to reviewer - 1

SECTION	REVIWER'S COMMENTS	OUR RESPONSE
Energy Performance	Good work but the brief and requirements have not been fully met. More details on the kind of passive and low energy strategies are missing.	The update content on the comments is in slide no:16,17,18.
Water Performance	Very good work. Could be articulated better	The comment is addressed in the slide no: 21&22.
Embodied Carbon	Very good job	No response
Resilient Design	Very good work. Although Resilience points are addressed well, there are other points that are more of "features" than "resilience". Differentiate between features of the project vs resilience	The design features of the module has been added and the comment is addressed in slide no:22,23,24.
Engineering and Operations	Nice job overall. Most of the engineering aspects are being addressed. Right sizing can be given more attention. The daylight and CFD analysis can come in other relevant sections as they are more relevant to design and comfort aspects. Space provisions are elaborated well.	The content has been improved and corrected in the slide no:26,27,28.
Architectural Design	Architectural design section missing	Engineering, operation and architectural design are merged
Affordability	This section has been mostly related to building envelope, done well. However, many other topics like equipment, MEP, site development , contingency etc. have not been discussed	The content has been improved and added in the slide no:29,30.
Innovation	Your innovation section is more of an architectural design evolution process. Is there any other innovation that you would like to show?	The comment has been addressed in the slide no:31,32,33.
Health and well-being	Good attempt on this. More details from annual simulations can make this more robust.	The comment has been addressed in slide no:34,35.
Value Proposition	You have made a good attempt. Some more clarity and depth on how both the users and the project partner mutually benefit from the project can be added. Articulation needs to be better.	The content has been improved and added in the slide no:36.

Table 2 Response to reviewer - 2

Team Name : **TRIDHARA**

Name of The Institution : Manipal school of architecture and planning

Division : **On site construction workers housing**

Ideology :

- Construct a modular flexible and mobile structure while maintaining a balance in the environment
- Tridhara just like the triple point theory aims to maintain equilibrium in the environment in all phases of construction

Faculty lead

Vaibhav Jain
Assistant Professor- Senior Scale
Manipal School Of Architecture And Planning
He has experience in green building performance-oriented design and operations, and he is also the Program coordinator of master of design in sustainable design (M.Des.SD) along with Coordinator of IGBC student chapter , MSAP .He is also a part of CSBE at MSAP

Faculty Advisors

Prakash Rao Gurpur
Assistant Professor- SI. Grade
Manipal School Of Architecture And Planning
Faculty Advisor

Dr. Nandineni Rama Devi
Director
Manipal School Of Architecture And Planning
Faculty Advisor

Amarnath
Assistant Professor- selection Grade
Manipal School Of Architecture And Planning
Faculty Advisor

Garima
Assistant Professor- Sr. Scale
Manipal School Of Architecture And Planning
Faculty Advisor

Team Members

Pre - Design

Mohammad Samar Iquebal
3rd Year, B.Arch.

Prem Chandran
3rd Year, B.Arch.

Chiranth
3rd Year, B.Arch.

Energy Analysis

Aysha Summan
2nd Year , M.Des

Reetwik Mukherji
3rd Year, B.Arch.

Pawar Karthik
Civil Engineering

Ankur
5th year , B.Arch.

Design Development

Naveen Kumar P
(Team Leader)
2nd Year, M.Des.

Devansh Aggarwal
3rd Year, B.Arch.

Nimisha Kumar
3rd Year, B.Arch.

Media & Presentation

Kavana
3rd year, B.Arch.

Deepthi
3rd year, B.Arch.

Vaishnavi
3rd year, B.Arch.

Madhusmitha
3rd year, B.Arch.

Background the lead institution

The Manipal School of Architecture & Planning (MSAP), is a constituent of Manipal Academy of Higher Education, (MAHE) started in 1978, In 2010, it became the 22nd institute of Manipal Academy of Higher Education, Manipal, India.

a)

MSAP offers courses

- **Architecture**
- **Urban Design**
- **Interior Design**
- **Fashion Design**
- **Management and Sustainable Design at undergraduate and post graduate level**

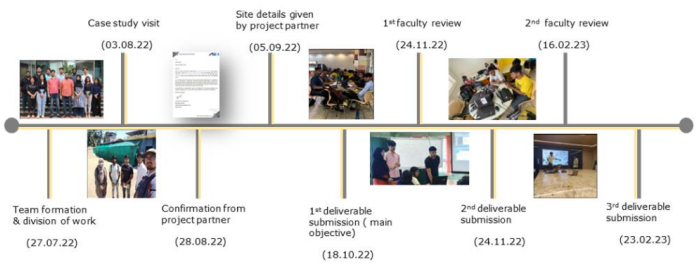
b)

Figure 1 a) Manipal School of Architecture and planning new building entrance b) Manipal school of architecture and planning

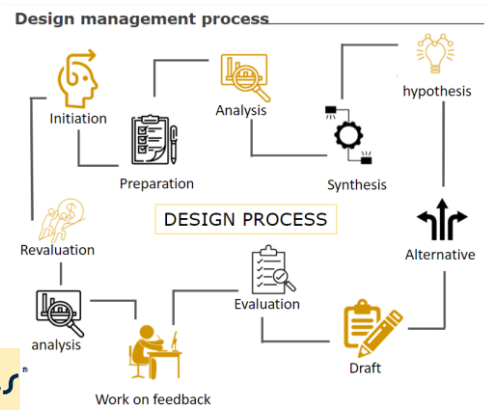
The Institute has the following **Major Emphasis Areas**, which are integrated in the curriculum and pedagogy:

1. Urban & Environment Management
2. Urban Sociology & Healthcare
3. Sustainable Built Environment
4. Heritage Conservation & Management
5. Behavior Psychology in Built-Environment & Participatory Design

Working Timeline



Design management process



Interactive platform and tools

Approach

The team members are segregated according to their strong-hands. The master's students who are well versed with simulation software are guiding and helping the energy and climate analysis team. Similarly, UG students are involved in design and researching about innovative strategies and providing reasoning for value proportion and estimation to propose the project in monetary terms.

Project Name : AARU (ఆరు)

Project Partner :

AGR infra developers
(Vinay Kumar vuppalancha : managing director)
Sy. No 59/2/1 , vv towers , main road , karkhana , secunderabad , Hyderabad – 500009

- AGR infra developers is a property development company in Hyderabad.
- It is committed to transforming the dreams of customers of buying property into reality where their main focus is on developing projects with uncompromising standards of quality
- The focus of the firm is to ensure that it meets the special demands of its discerning customers and provide them with the best option in today's real estate market.

Project Description

The housing conditions for CWS has been neglected by the contractors.

Present housing conditions has a negative impact on the health and workability of the workers

present houses are not adaptable to all the climatic aspects and leads to higher cost .

Need of housing that is modular affordable sustainable and climate responsive which turns out to be beneficial for the client, contractor and foremost the construction workers

One of the similar requirement was taken into consideration and was to be tackled by the AGR INFRA DEVELOPERS

a)

b)

Location : Mundunuri residency, Kompally, Telangana – 500014.

Latitude : **17^32'29.7" N**
Longitude : **78^29'08.1" E**

Worker housing unit area : **1230 sq.m**
Soil type : **red sandy soil**

seismic zone : **seismic zone - 1** which makes the land least exposed to earthquakes

Figure 2 a) & b) Site location photos (Hyderabad)

About On-going project

- Total Land area: 6278 sqm.
- Project: 17 floors (residential apartments)
- No of units: 170 (10 for each floor)
- Min unit size: 1995sft
- Max unit size:2730sft
- Project name: Aranya Kalanjal

- Beams and Columns Developers LLP is a construction company with a mission to build simple, solid, and sustainable residential homes focuses on creating housing that prioritizes functionality, durability, and eco-sensitivity.
- Their homes are designed with minimalist aesthetics, utilizing high-quality materials to ensure long-lasting structures.
- The company places an emphasis on incorporating sustainable features such as efficient energy systems, water management systems, and environmentally friendly building practices.
- Their goal is to provide families with comfortable, low-maintenance homes that reduce their carbon footprint and have a positive impact on the environment.

About the project

Total site area : **1232 Sq.M**

Estimated total built-up area : **714.57 Sq.M**

Energy Performance Index (EPI) Goal in kWh/m2 per year for your NetZero-energy design.

Base case : **47.5** in kWh/m2
Proposed case : **22.8** in kWh/m2

Preliminary estimate of on-site renewable energy generation potential, mentioning the amount from each renewable energy source (kWh/year)

From solar panels : 120.2 kWh/year

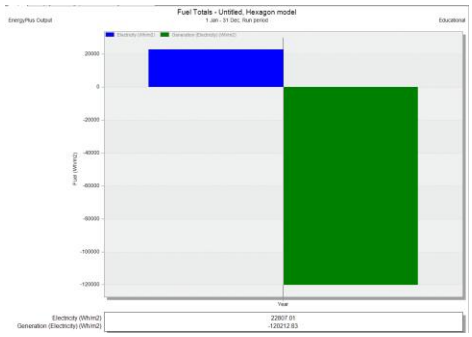


Figure 3 a) Solar panels (source: Google) b)Calculations of the amount of energy generated from solar panels

Preliminary construction budget (INR/m2) and timeline (if any) in the format provided in Appendix A (Revised from D2 as needed)

Special requirements of the Project Partner

Modular spaces which can be deployable

Natural ventilation

Better health of workers

Cost effective

Interactive to occupant surrounding

Scalable based on the location and size

Natural lighting

solid waste management - disposal, handling, and treatment of the waste.

Use of renewable sources of energy

Project Summary					
Project Information	**Project Information**				
	Team:	TRIDHARA			
	Division:	On-site Construction Workers		Land Cost:	**26 Million INR**
		Site Area (sqm)	**1,230**	City:	**Hyderabad**
		Built-up Area (BUA) (sqm)	**2,460**	State:	**Telangana**
		Ground Coverage (Plinth Area) (sqm)	**492**		

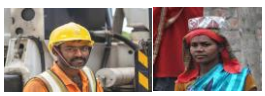
S.No.	Particulars	Definition	Baseline Estimate (Project Partner / SOR basis)			Proposed Design Estimate		
			Amount (Million INR)	**%**	**Amount** (INR per sqm)	**Amount** (Million INR)	**%**	**Amount** (INR per sqm)
1	Land	Cost of land purchased or leased by the Project Partner	26.00	98.5%	2,000	26.00	89.0%	2,000
2	Civil Works	Refer Item A, Civil works in Cost of construction worksheet	0.02	0.1%	8	0.02	0.1%	8
3	Internal Works	Refer Item B, Civil works in Cost of construction worksheet	0.02	0.1%	8	1.80	6.2%	732
4	MEP Services	Refer Item C, Civil works in Cost of construction worksheet	0.05	0.2%	20	0.05	0.2%	20
5	Equipment & Furnishing	Refer Item D, Civil works in Cost of construction worksheet	0.00	0.0%	-	1.10	3.8%	447
6	Landscape & Site Development	Refer Item E, Civil works in Cost of construction worksheet	0.00	0.0%	-	0.05	0.2%	20
7	Contingency	Amount added to the total estimate for incidental and miscellaneous expenses.	0.30	1.1%	122	0.20	0.7%	81
TOTAL HARD COST			**26.4**	**100%**	**10,728**	**29.2**	**100%**	**11,878**
8	Pre-Operative Expenses	Cost of Permits, Licenses, Market research, Advertising etc	-	0.0%	-	-	0.0%	-
9	Consultants	Consultant fees on a typical Project	-	0.0%	-	-	0.0%	-
10	Interest During Construction	Interest paid on loans related to the project during construction	-	0.0%	-	-	0.0%	-
TOTAL SOFT COST			**-**	**0%**	**-**	**-**	**0%**	**-**
TOTAL PROJECT COST			**26.4**	**100%**	**10,728**	**29.2**	**100%**	**11,878**

Context analysis

Population And User Analysis : *Table 3 Project summary*

Hyderabad District is a city district in the state of Telangana, It is the smallest in terms of area, among all the districts in the state, but has the highest human density.

The workers are ''PACKERS AND MOVERS'' From different parts of ''INDIA''. The users reside till the construction period which can be up to 2 – 2.5 years according to the building typology. The project currently undertakes workers from the states of BIHAR ,UTTAR PRADESH, and LOCALLY AVAILABLE WORKERS.

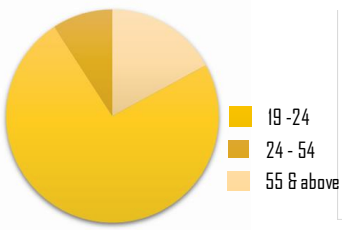


User comfort : According to the IMAC model we are trying to set the indoor environmental quality.

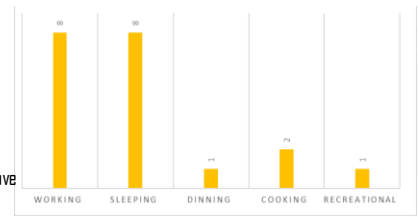
Users Occupancy

Moring shift 8: 30am – 1:00pm

Afternoon shift 2:00 – 6:00pm



Workers age groups



Workers daily activity

Present condition – CWH sector

Figure 5.1 Case study – Mangalore

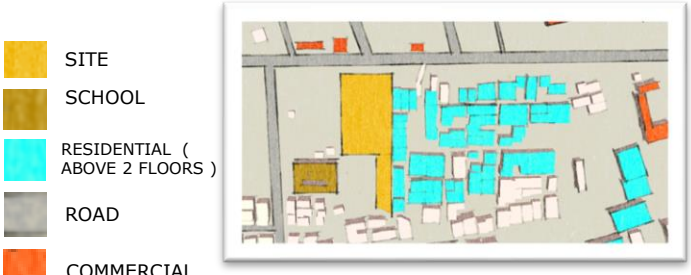


Figure 4 a) site plan model (Source: sketch up)

Regional Environment Issues :

Lakes are contaminated with industrial effluents and domestic sewage. Air is polluted by vehicular and industrial emissions. Soil is contaminated by leachates in municipal wastes and other toxic substances.

GOALS AND STRATEGIES

Design to travel

The **main** problem **with workers housing is,** they are **built** for temporary use, but **the** materials and **techniques used** are **mainly** used in permanent **construction. These buildings** are **generally** used for **1-2** years, later **given up as waste or largely destroyed . Designed to travel** provides the solution to reuse the module at different sites during different period with the ability to move them. This reduces the wastage of material as well as it provides clean site after being removed once work is done

Reduction in construction cost

With **rising material prices, there is a growing demand for** new **and** cheaper **materials** and **techniques.** Use of **conventional materials** for workers' housing; construction **costs usually increase as well with the** completion of **the project,** the investment in these are **lost.**
Our module **solves** this **problem** by **offering** the **possibility of** reuse without demolition or **new construction. This** saves the **contractor** money **on renovation** or **demolition work.**

Achieving thermal comfort

Our research shows that the use of **materials with** high thermal conductivity **such as** metal, tin, exposed masonry, in addition to exceeding the occupancy limit in **a** normal worker housing **system, reduces comfort while** the **absence/ minimal** opening **increases** discomfort. **The holes and low thermal conductivity materials used in our** modules **provide a livable environment** by **ensuring adequate** ventilation, lighting and **thermal** insulation **by** strictly limiting the **number of occupants** in each

Satisfy the quality of the indoor thermal comfort

Fewer openings and being inconsiderate of the alignment of these workers' housing increase the thermal discomfort in the living space. Ensuring sufficient openings in our module, e.g., B. Roller shutters, tilting windows controlled according to user comfort, reduces discomfort by ensuring adequate ventilation. The arrangement of our modular panels according to climate, wind and sun direction enables cooling by thermal conduction and creates corresponding overpressure and depression zones. The use of a material with low thermal conductivity guarantees more comfort in the rooms.

Reduction in cost and investment and solutions to benefit the project partner

Usually, the modules are constructed for 1 to 2 years and then demolished which costs around 8 to 9 lakh for (160 users). These modules after demolition can't be reused hence all money goes in loss. Our module which initially costs 20 to 25 lakhs (160 users) can be reused up to 10 years hence saving 95% investment of the project partners.

Net zero energy

Even with the advancement in technologies very few construction worker housing sites use any renewable source of energy like, solar. This leads to providing of less facilities like, fan, light, to the workers. Some places where these facilities are provided face the issue of consumption of more power eventually increasing the operating cost.

When we talk about net zero energy, our modules hold solar panels for each module the need of energy is being taken care by the provided solar panels, where we **are achieving 120kWh/sq. m annually**. It is 6 times more **the required energy that is 22kWh/sq. m annually.**

Net zero water

Even with the introduction of RWH system, it is used very rarely at C.W.H (construction worker housing system). With the high demand of water (130-140 lt/day/person) the budget also increases. Using RWH system we are saving and utilizing the saved water for different uses. For the present case which is 3.3k litre of water collection per day from rain (4 lakh/year) and using modern fixtures bring the water usage to 70 lt/day we are saving 29.4% of municipal water

Less carbon emission

The use of materials like cement, brick, metal and machines used in base case of C.W.H produces **739.8 kg of CO2 annually** while construction. This goes with most of the built C.W.H systems.

Use of precast material like AAC blocks, UPVC door, acrylic sheets, Plano roofing tiles reduces the carbon emission to **14.8 kg(148.4kg/10 year)**. Which makes our module eco-friendlier.

Safety and flexibility

In our base case we observed that there are **very less safety measures** given to the workers and the structure they live in. There is no provision used for safety from flood, earthquake, or any other natural calamity. The site are provided with an assembly area at the most and a medical room in name of safety measures.

We on our site don't only provide the basic requirements of assembly point and medical rooms but also the **structural elements used in our modules** like, high plinth level, telescopic plinth, earthquake resistant steels, flexible joints **can resist/survive these calamities** in much better way than the conventional structures being used.

Easy to handle and less material wastage

Usually the C.W.H takes a lot of time, energy, investment, material to come which sometimes become a headache for the contractor. And to save this time, money, material the contractors mostly provide inhabitable condition to the workers.

With the use of prefabricated material, we are reducing the material, money, time wastage. These materials give a habitable form of living spaces to the workers too

Starting with the observation through case studies and research papers, an idea of project and its requirement was achieved. The observation included the materials used, consumption of energy, zoning of different areas, areas provided, occupation detail, time-table of workers, safety provisions provided, everyday activity of workers and activities taking place on site.


a)


b)


c)


d)


e)

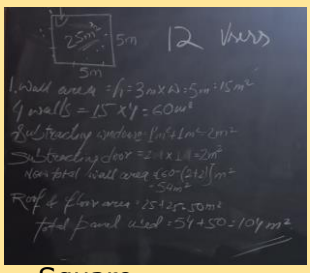

f)

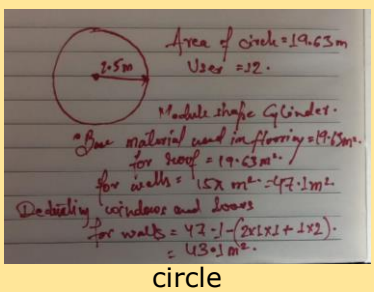
Figure5.2 a),b)c),d),e),f)Case study images Mangalore

By these observations we began with preparation of our requirements, and what more we can add to make our modules more habitable. These ideas and theories lead us to different form for our module.

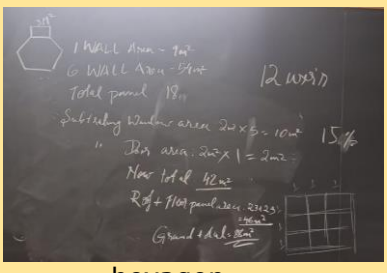
The first consideration for a building form in group housing is its ability to arrange on a plane / how well it can occupy space. Beginning with the square shape we analysed the carpet area being covered while providing occupant density, where the square was taking 25 sq. m space (5 x 5 x 3)m for 12 users. It was not only taking more area but also was using more material with limitation on the orientation. It also limited the group arrangement of the blocks. It was easy to construct the square module but the orientation, more use of material placed a halt on the concept. The total area for panel to be used was 104 sq.m

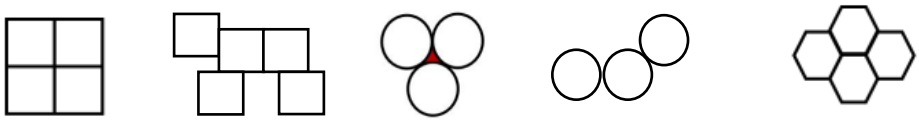
In a search for a shape which uses less panel area while providing more occupant area lead us to circle, which was providing floor area of 19.63 sq.m , reducing the floor area by 22% compared to square. The panel area used by the cylinder shape module was 82.36 sq. m. Hence, a circle encompasses the most area relative to the circumference. So, in a way a circle would be the most efficient shape. But **the inefficiency of the circle** starts when arranged in groups. Internal circulation and furniture arrangement was also an back point for circle shape


Square



circle


hexagon



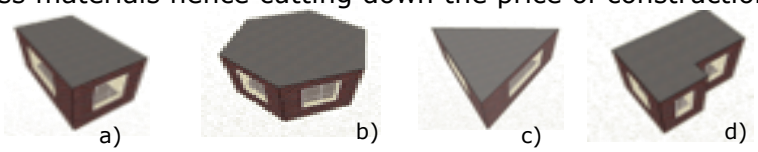
Process of analyzing different shapes for area and material usage

Further analysis and search for a proper shape led us to bees where we got inspiration from the bee-hive as they are considered one of the most complicated habitats but are ideal for space arrangement and accommodation of many users. Bee-hive are made from basic shape of hexagon which when fixed fits together perfectly. Not only that but **"The geometry of this shape uses the least amount of material to hold the most weight,".** After all, materials made with hexagon shapes can also handle a lot of force, even if they are made from a lighter materials.

Further analysis of hexagon showed that it can provide proper space while consuming less floor area as well as deducting material usage. It also gives an option of multiple orientation while using different panels in different directions.

According to calculation for 12 users the hexagon uses 23.38 sq. m area for flooring (7% less than square,16% more than circle), while total panel area including roof, floor, walls join up to 88 sq. m (16% less than square, 7% less than circle). This shows that the hexagon can accommodate same number of users while using less materials hence cutting down the price of construction.

Figure5.3 a),b)c),d) Form analysis

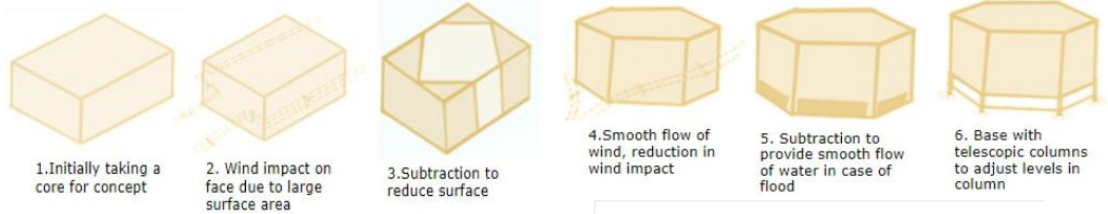


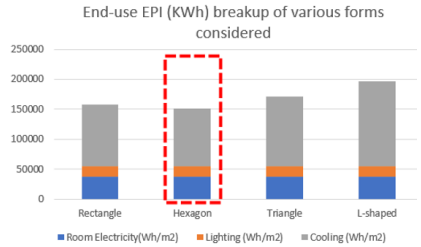
	Rectangle	Hexagon	Triangle	L-shaped
Indoor air temperature eg.C	26.7	26.77	26.99	27.14
Outside air-temperature, deg.C	26.94	26.94	26.94	26.94
Surface area, m2	45.36	40.59	49.7	34.02
Operative temperature (June)deg.C	28.32	28.26	28.59	28.65
Discomfort hours for June, (hrs)	348.5	349	343.75	339

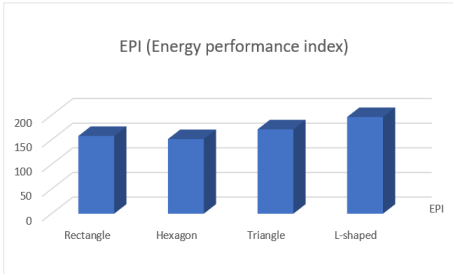
Table 4 Comparison criteria for different forms

Analysing more shapes like L-shape, triangle we observe that hexagon has one of the lowest indoor temperature of 26.77 deg. C without any use of cooling system, when the exterior temperature is 26.94 deg. C. The hexagon shape was achieved from a cube.

Form development







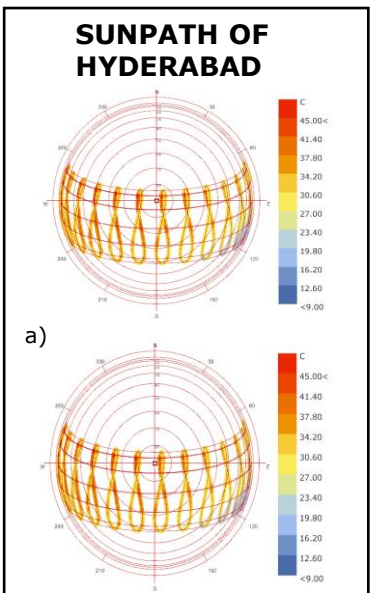
TEMPERATURE RANGE –HYDERABAD– SOURCE: CLIMATE CONSULTANT

- Comfortable range : 21 - 27℃
- Comfortable months : July – Feb
- Uncomfortable months : March - June

Parameters	Air temperature (℃)	Humidity (%)
Summer Average	31	75%
Winter Average	30	80%
Monsoon Average	27	85%

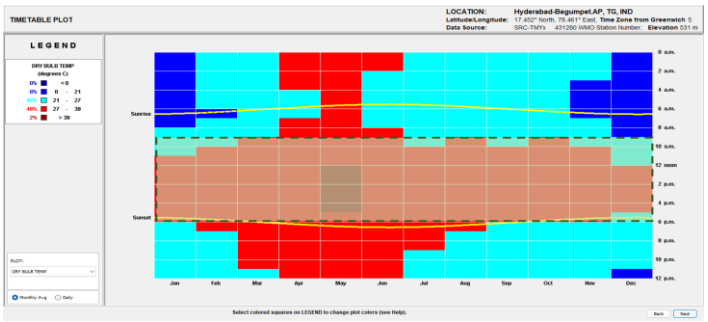
Table 5 Air temperature and humidity

Hyderabad experiences a composite climate where it is neither consistently hot & dry nor warm & humid. Their characteristics change from season to season, alternating between hot & dry period to shorter period of rainfall & high humidity.



a)

Figure6 a) Psychometric chart b) Sun path of Hyderabad



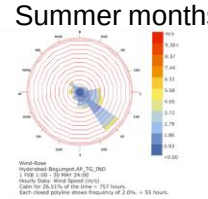
b)

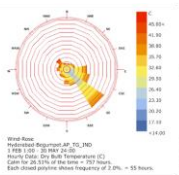
OBSERVATION:
Occupants experience uncomfortable temperatures from march to June, from the beginning to the end of working hours.

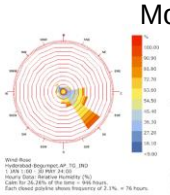
INFERENCE-
Use materials that can emit heat faster or allow the hot air to escape. Building materials that have a high SRI index/ high u-value for wall surfaces. Provide ventilation shafts to allow hot air to escape.

WINDROSE DIAGRAM

Summer months



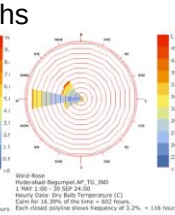




Winter months

Figure7 Wind rose diagram summer months

Monsoon Months



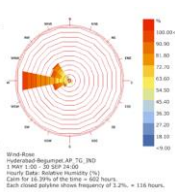
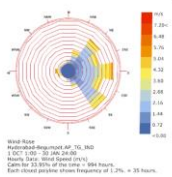
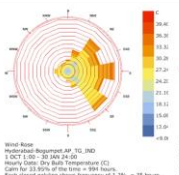


Figure8 Wind rose diagram monsoon months





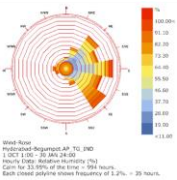


Figure9 Wind rose diagram winter months

OBSERVATION:
From the wind analysis across the seasons, we can infer that during the summer and winter seasons, the prevailing hot winds are from the southeast – the humidity and temperature of the winds experienced are also high.

INFERENCE:

- Reduce the WWR% on east.
- Since the prevailing winds for most of the months are high(more temperature & humidity)– the zoning of the blocks is done in a way to deflect the hot winds away from the low-pressure zones and hence convective cooling.

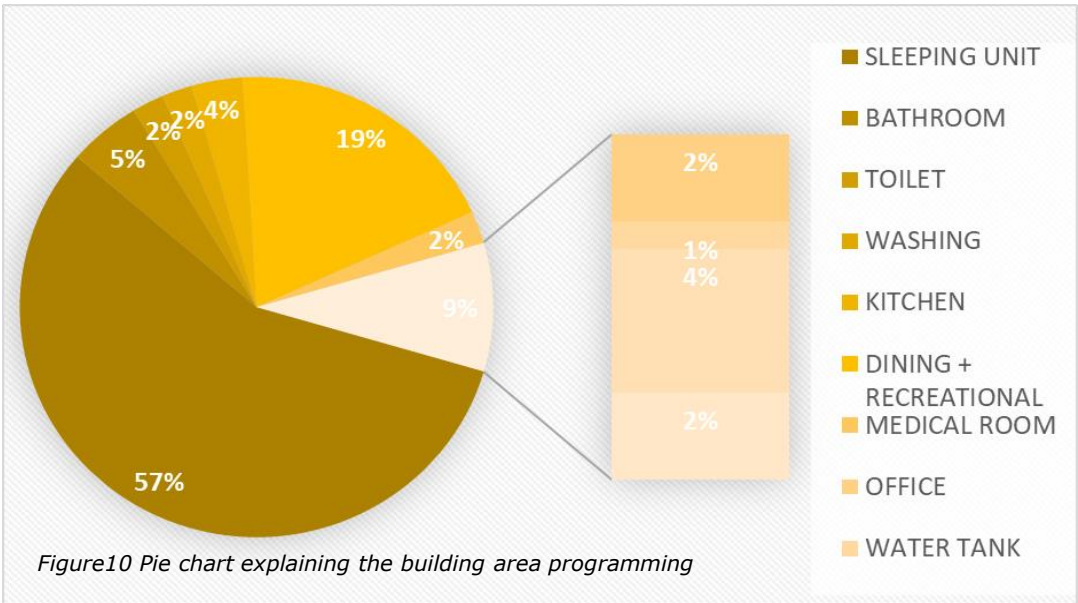


Figure10 Pie chart explaining the building area programming

S. No	Function	No Of Users (Per Unit)	Area In Sq.M (Per Unit)	No Of Units	Total Area (Sq.M)	Conditioning
	LIVING ZONE					
1	SLEEPING UNIT	8	16.24	25	406	NO
2	BATHROOM	14	2.5	14	35.7	NO
3	TOILET	20	1.56	10	15.6	NO
4	WASHING	1	4.9	3	14.8	NO
	COMMON ZONE					
5	KITCHEN	8	25	1	25	NO
6	DINING & RECREATIONAL AREA	-	48.06 + 47.04 + 41.76	-	136.86	NO
	WELL - BEING ZONE					
7	MEDICAL ROOM	3	16.24	2	32.48	NO
8	OFFICE	6	16.24	1	16.24	NO
	SERVICES					
9	WATER TANK	-	2.54	2	5.08	-
10	SEWAGE TANK	-	17.29 + 9.52	2	26.81	-
	TOTAL			**59**	**698.33**	

Table 6 Area programming

Base-case Output	
Room Electricity	41,380.5 Wh/m²
Lighting	5,949.51 Wh/m²
Discomfort hours	7896.67 hrs
Operative temperature (Summer months)	33.09℃
Total EPI	47.3 KWh/m²/yr

Table 7 EPI Output of Base Case

Proposed case Output	
Room Electricity	19,533.79 Wh/m²
Lighting	3272.22 Wh/m²
Discomfort hours	7452.51 hrs
Operative temperature (Summer months)	26.98℃
Total EPI	22.8 KWh/m²/yr

Table 8 EPI Output of Proposed Case

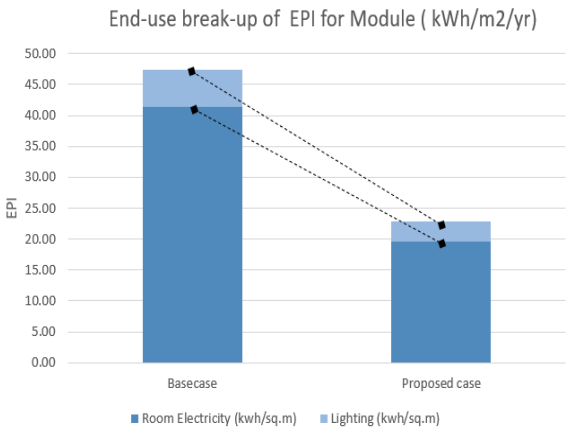


Figure11 End use break up of EPI module

- The base case was analyzed by looking into the typical CWH around India consisting of a masonry wall with concrete flooring and GI sheets for walls and roof. This design attained an EPI of 47.3kWh/m2 -yr.
- Thermal Comfort & energy analysis for the base case was then simulated and the corresponding ECMs were proposed for the Final design to achieve the target EPI.

INPUT PARAMETERS BASE CASE

Input Data File - Proposed Case		
Input Parameters	**Units**	**Proposed Design Values**
Site		
Location		Hyderabad, Kompally
Weather File		Hyderabad, Begumpet
General		
Building Type		On-site construction worker housing
Building area	m²	407.75
Conditioned Area	m²	0
Number of floor above grade	numbers	1
Floor to floor height	m	2.7
Electricity Rate	INR/ kWH	7.03
Length	m	2.5
Breadth	m	2.5
Individual Hexagon module Area	m²	16.31
Occupancy Schedule	_	6:30pm-8:30am ; 12:30pm-2:00pm
Average Occupant Density	m²/person	0.49
Internal Loads		
Lighting Power Density	W/m²	2.2
List of Lighting control	_	-
Minimum OA Ventilation (Building Average)	l/sec.m²	
Envelope / Construction Materials		
Wall - 4mm Fibreboard + 67mm AAC bloak + 4mm Fibreboard	W/m²K	u-value - 1.096 W/m²K
Roof - 8mm concrete tiles	W/m²K	u-value - 6.881 W/m²K
Floor - 19mm Ply	W/m²K	u-value - 2.1 W/m²K
Openings		
WWR (Window wall ratio)	%	20%
Glazing material - Glazing material - Dbl LoE (e2=.1) Clr 6mm/13mmAir	W/m²K	u-value – 1.786 W/m²K
Window SHGC	-	0.598
Window VLT	%	0.769
Infiltration Rate	ac/h	5
Window height	m	1.5
Domestic Hot Water		
Solar hot water		0.2 (l/m²-day)
EPD		
Equipment power density	W/m²	9.62

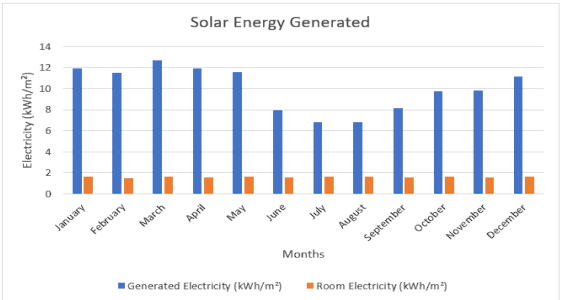
Table 9 Input parameters base case

OUTPUT PARAMETERS PROPOSED CASE

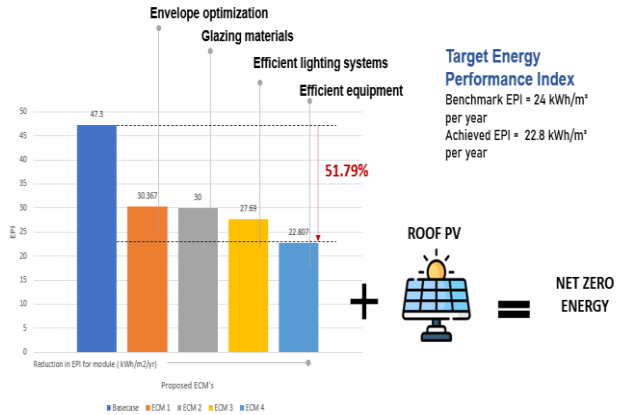
Output Parameters	Units	Proposed Design Values
Total EPI (On-site consumption)	KWh/m²/yr	22.6
Electricity	KWh/m²/yr	19.53
Fans	KWh/m²/yr	
Lighting	KWh/m²/yr	3.27
Total Envelope Heat Gain (Peak)	W/m²	
Annual Operating Energy Cost	INR/ m²	
Annual Unmet Hours		
Annual Hours of Comfort without Air Conditioning		
On-site generation	Type	Monocrystalline photovoltaic panels
Installed capacity	KWh/m²/yr	120.21

Monthly Energy Performance	Unit	Generation	Consumption
January	kWh	11.94	1.65
February	kWh	11.53	1.49
March	kWh	12.67	1.65
April	kWh	11.92	1.6
May	kWh	11.6	1.65
June	kWh	7.95	1.6
July	kWh	6.83	1.65
August	kWh	6.78	1.65
September	kWh	8.11	1.6
October	kWh	9.74	1.65
November	kWh	9.84	1.6
December	kWh	11.15	1.65

Table 10 Output parameters proposed case



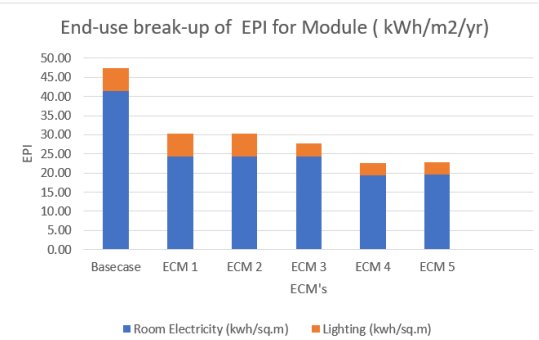
Proposed Case

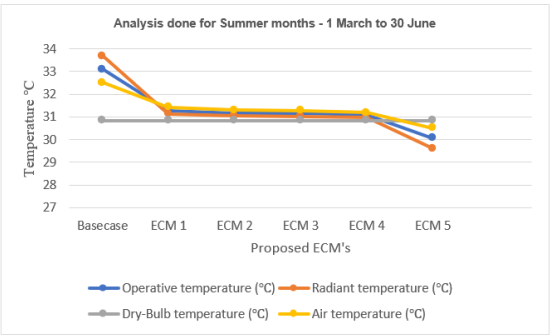


• For the proposed case inference from climate analysis and shoe-box modeling was taken to optimize the massing and orientation to control the heat gain through the envelope.

Most of the windows are arranged to face north & south to improve daylight.

•Some passive strategies that have been applied to achieve thermal comfort and energy efficiency are a material selection for walls and roofs, efficient glazing, efficient lighting systems, equipment, night flushing, etc.





Hybrid System

•Each module is provided with solar panels for electricity and has battery storage of 45kWh in times of low power.

•It is also linked to the utility grid, allowing excess amounts to be delivered the grid.

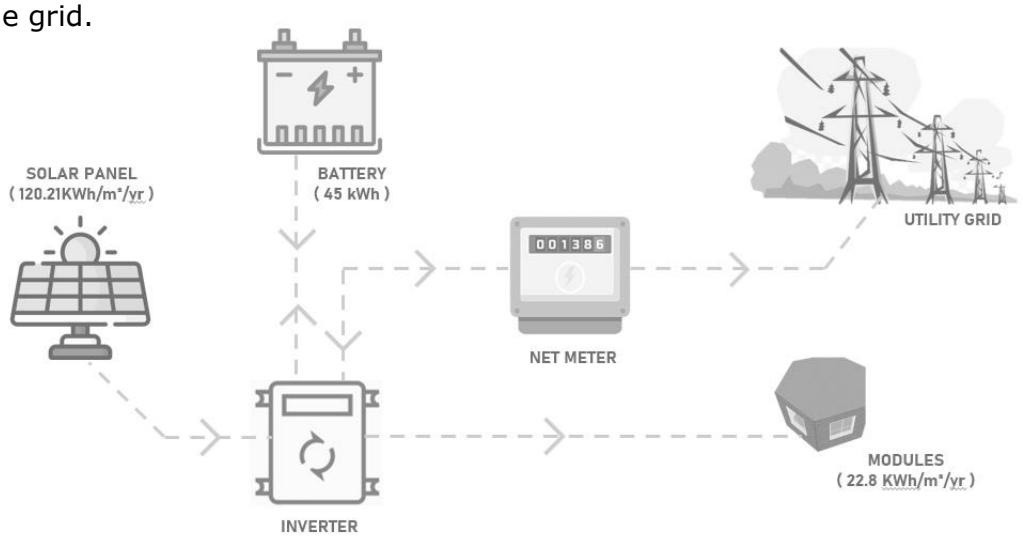


Figure 12 Power distribution

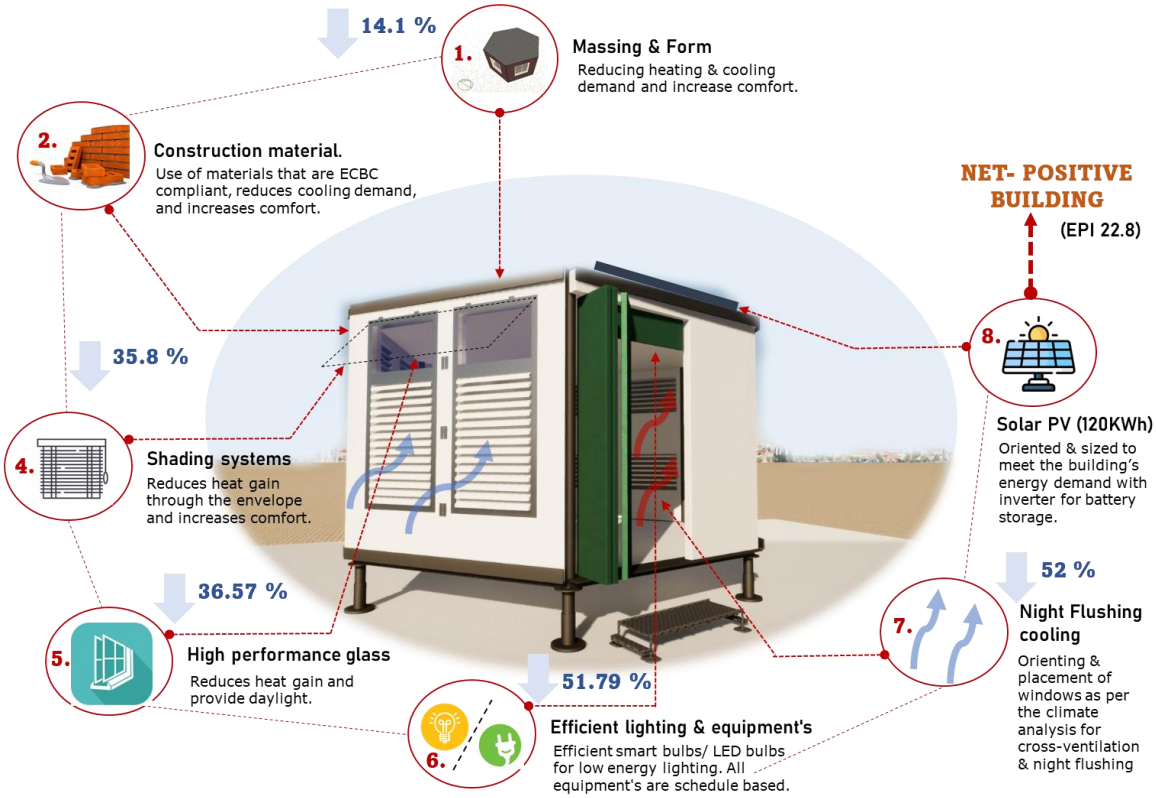


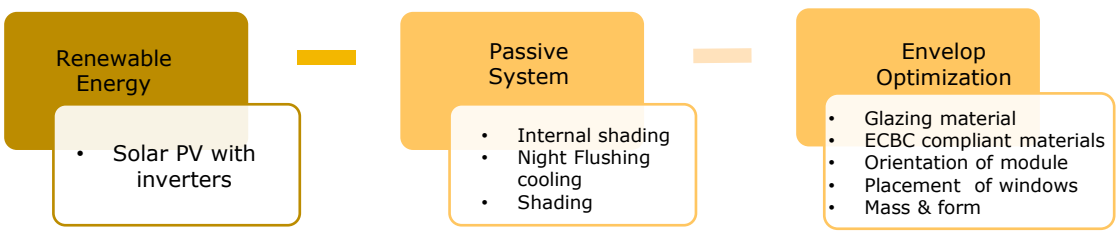
Figure 13 Passive strategies applied to each module

Solar PV calculations

Brand : Solar Universe
Panel type : Mono-crystalline (410W)
No of cell : 72
Annual energy consumption of load = 22.8KWh/year =0.062KWh/day

For Hyderabad
Average Daily Irradiance (annual) = Annual Irradiance / days or year
=1607 kWh/m².year / 365days/year = 4.402 Wh/m²
Solar energy available in roof top(kWh/day) = Irradiance(kWh/m².day) x Area (m²)
Rooftop Energy available per module = 4.402 x 16.31 = 71.79 kWh/day
Daily Energy Use = Monthly Energy Use / Days in Month
=1.9 (kWh/month) / 30 = 0.063 kWh/day
Power Output = Daily Energy Use * Daily Hours of Full Sun
=0.063 (kWh/day) x 4.402 (hours/day) = 0.278kW
Considering derate factor as roughly 80% (or 0.8).
PV System Size = Power Output / Derate Factor
= 0.278 / 0.8 = 0.223 kW

For 17 modules = 0.223 x 17 = 3.791 kW
Solar PV size = 2.01m x 1.02m



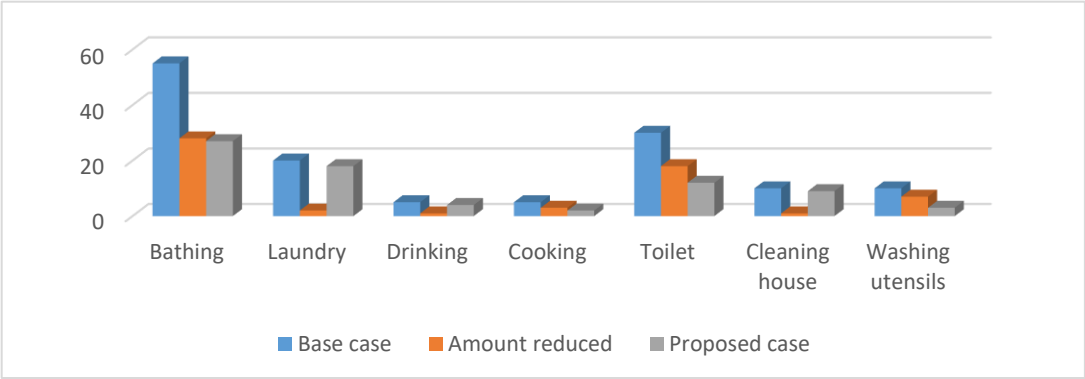
Per Capita daily consumption	Number of occupants	Total daily consumption	Grey water filter efficiency
50.9	160	8142.7	70%

Table 11 Water consumption

Our proposed case aims to reduce the water demand by 55% from the Base case. This is achieved implementing bucket bath, rainwater harvesting, greywater treatment systems and using aerators and E-toilets.

Occupant's Activity	Percent usage	Quantity
Bathing	50.0%	4071.35
Washing clothes	5.0%	407.135
Drinking	8%	635.1306
Cooking	4%	317.5653
Toilet	24.0%	1954.248
Cleaning house	3.1%	252.4237
Washing Utensils	6.0%	488.562
Others	0.20%	16.2854

Table 12 Water usage as per user activity per day



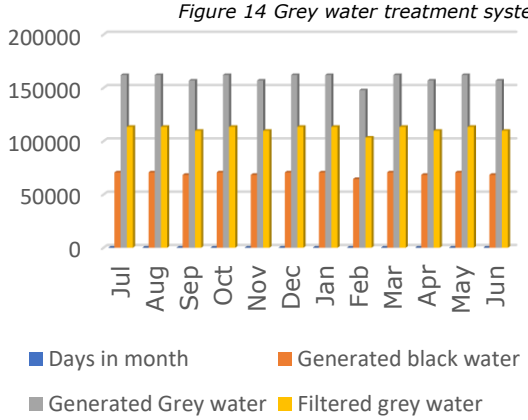
GREYWATER TREATMENT SYSTEM

The process involves the collection of greywater, which would normally be discharged outside, and repurposing it to flush toilets. All sewage from bathrooms and sinks is channeled into a recycling system. Once recycled, the treated greywater is returned for further use.

Figure 14 Grey water treatment system

PRODECT SPECIFICATION

Feed Flow Rate	50 m3/day
Brand	Swati Water Purification
Phase	Three Phase
Material	Mild Steel
Power Source	Electric
Frequency	50-60 Hz
Voltage	440 V
Country of Origin	Made in India



RAINWATER HARVESTING

Rainwater harvesting surfaces	Area m^2	Runoff coefficient	Effective catchment area m^2
Roof Surfaces	370.26	0.85	314.721
Hardscape areas	0	0.00	0
Softscape areas	861.74	0.22	189.5828
Total Effective catchment area			**504.3038**

- Total rainwater harvested through Roof= 249574ltrs
- Total rainwater harvested through soil surface= 249574ltrs

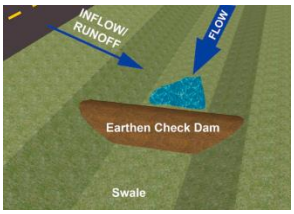
Table 13 Total effective catchment area

Months	Rainfall (mm)	Effective rain (mm)	Harvested rainwater (l)
July	180	175	88253
August	205	200	100861
September	135	130	65559
October	105	100	50430
November	25	20	10086
December	5	0	0
January	9	4	2017
February	9	4	2017
March	20	15	7565
April	20	15	7565
May	30	25	12608
June	110	105	52952

Table 14 Annual harvested rainwater

SOIL SURFACE RAINWATER HARVESTING

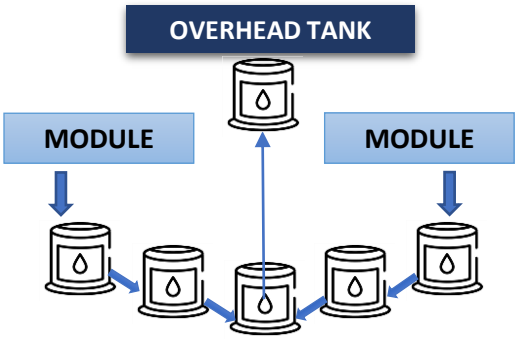
BIOSWALE SECTION



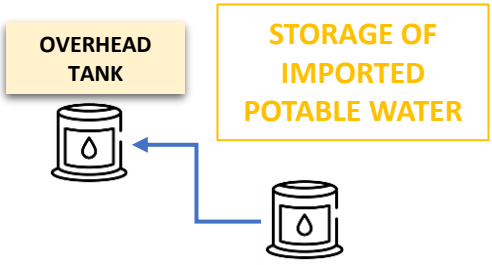
Softscape water is collected and filtered using bioswale. The collected water is sent to the tank through the drain tube.

ROOFTOP RAINWATER HARVESTING

Total number of tanks= 10
Each tank capacity= 10,000ltrs.



10,000 ltrs Tank



10,000 ltrs tank for Imported Potable water

SPECIFICATION OF FILTER USED:

❖ **Aqua2use GWDD UG**

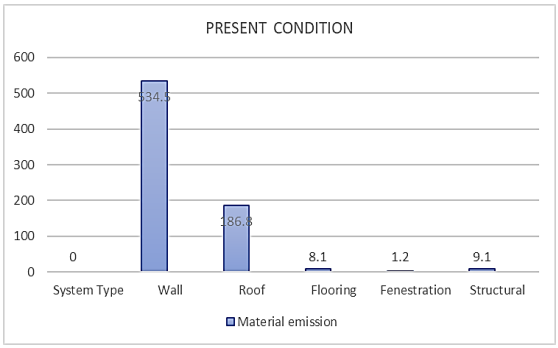
•50 gallons capacity
•31.5" Length x 23.6" Wide x 26" Height
•Greywater inlet connection of 2"up to 4"

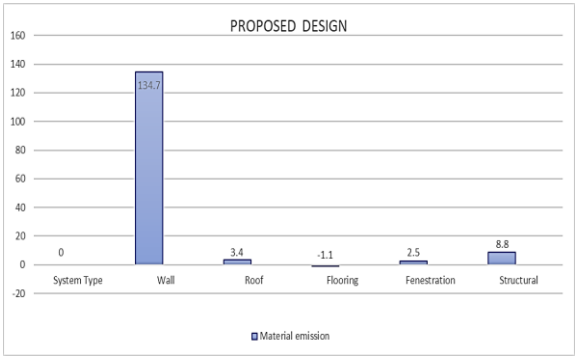
TANK Brand name	Unit cost (Rs. Per litre)
Storex, Ganga	2.75

SUBMERSIBLE WATER PUMP

Product Specification
Head: Up to 100 mtrs
Capacity: Up to 2000 cu Mt/Hr
Lubrication: Water
Power: 1.5 to 200 H.P
Speed: 2900/1450 rpm
Bearing: Bush Bearing

EMBODIED CARBON





Total carbon dioxide emitted for construction of base case is **739.8 kg** –CO2 e (for one year).

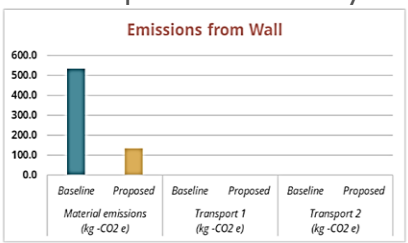
Total carbon dioxide emitted for construction of proposed case is **148.4 kg** –CO2 e (for ten years).

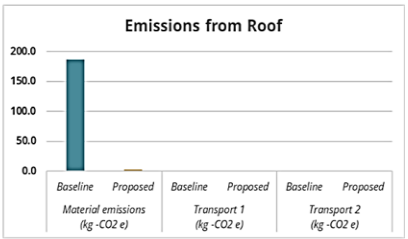
Use of precast building components with wall made of AAC block and fiber board, roof of concrete tiles, and floor made of plywood reduces the carbon emission for construction up to 14.84 kg/year. These components require less machinery at site hence cutting carbon emission further.

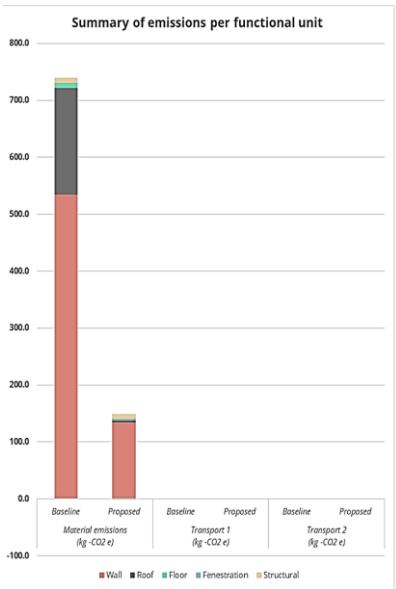
System Type	Baseline				Proposed			
	Material emissions ($kg\text{-}CO_2\ e$)	Transport 1 ($kg\text{-}CO_2\ e$)	Transport 2 ($kg\text{-}CO_2\ e$)	Total ($kg\text{-}CO_2\ e$)	Material emissions ($kg\text{-}CO_2\ e$)	Transport 1 ($kg\text{-}CO_2\ e$)	Transport 2 ($kg\text{-}CO_2\ e$)	Total ($kg\text{-}CO_2\ e$)
Wall	534.5	0.0	0.0	534.5	134.7	0.1	0.0	134.8
Roof	186.8	0.0	0.0	186.9	3.4	0.0	0.0	3.4
Floor	8.1	0.0	0.0	8.2	-1.1	0.0	0.0	-1.1
Fenestration	1.2	0.0	0.0	1.2	2.5	0.0	0.0	2.5
Structural	9.1	0.0	0.0	9.1	8.8	0.0	0.0	8.8
Grand Total emissions per functional unit ($kg\text{-}CO_2\ e$)				739.8	Grand Total emissions per functional unit ($kg\text{-}CO_2\ e$)			148.4

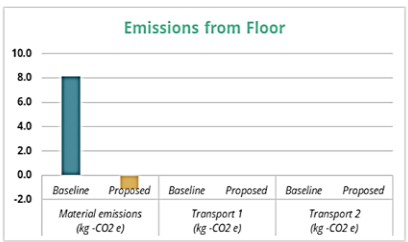
Table 15 Carbon emission of base case and proposed case

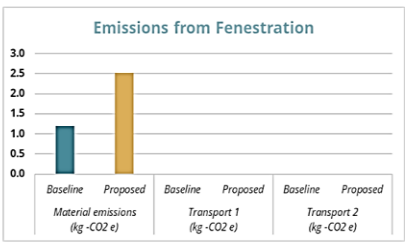
This is the split of different elements of the module and showing comparison of every element between Present situation and Proposed design.

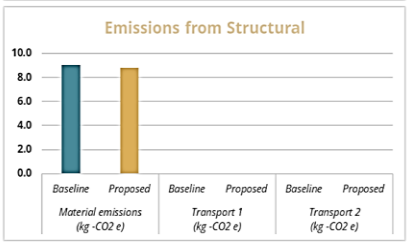












This is the split of different elements of the module and showing comparison of every element between Present situation and Proposed design.

DESIGNED TO TRAVEL

The Modules Are Designed To Travel And Adapt To Different Conditions.

IDENTIFYING THE PROBLEMS: Sanitization of space and maintaining hygiene

The current conditions of the on-site construction workers' housing are extremely difficult for living.

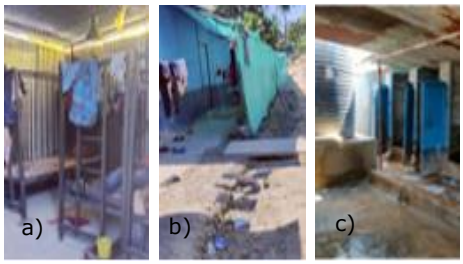


Fig.15 a), b) , c) Explaining the of worker housing in present (source: case study visit)

The health hazards that arise are mainly from uncleanliness, unplanned settlement pattern – organic structure, and improper waste segregation and disposal.
The modules are arranged in such a way as to segregate the gathering, cooking, washing, and disposal areas which will not create any interference with each other to maintain health and hygiene.

IDENTIFICATION OF POTENTIAL RISKS AND STRATEGIES TO OVERCOME

ADAPTABILITY AND MODULE FEATURES

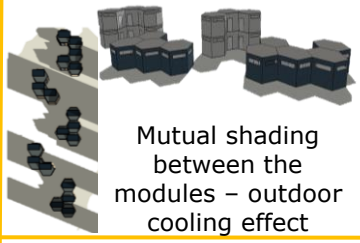
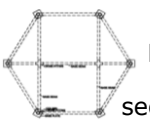
ADDRESSING THE PROBLEMS	MODULE FEATURES
OUTDOOR HEAT	 Mutual shading between the modules – outdoor cooling effect
INDOOR COMFORT	 Super ECBC compliant – resilient and maintains indoor thermal comfort in all climatic zones of INDIA  Double-glazing window panel reduces internal heat gain
PROTECTION	 Open and closable louvers – protection for dust and rain from entering the module.
STRUCTURAL STABILITY	 Cross joinery is provided on the overlap of the secondary beams to prevent movement and provides stability.

Table 16 Module features

Reuse of material: This reduces the cost and manufacturing new material.

FIRE AND DURABILITY

The site is provided with a secondary exit in order to provide an immediate escape in case of fire. And fire extinguishers is provided inside and outside the module.
Module life span: 10 years in all climatic zone of India.

The light roof structure

Continuous disposal and cleanliness ensure hygiene and well-being.

ZERO WASTE MANAGEMENT PROGRAM

Organic solid food waste is composted and stored in a compost tank on-site which will generate compost for the plants that are grown on-site. The organic waste matter takes 1 – 2 months to get generated into a composite which is a short period of time in the total stay of the workers.

STRATEGIES DURING VULNERABILITY PERIOD

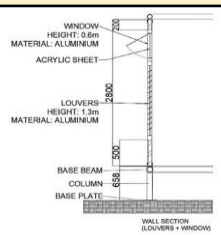
RISK TYPE	PREVENTIVE MEASURES	SUPPORTIVE IMAGE
FLOOD	All the modules are at a stilt level. Of +0.65m, this allows the water to easily flow through the site without any hindrance.	
EARTHQUAKE	The structural steel columns and the foundation is designed to resist earthquake by following earthquake-resistant design IS 1883 - which is applicable to disaster-prone regions. - Increases evacuation time. And IS CODE 800(Steel structure) for design.	
FIRE	The material of the module is fire-resistant, and green rated which increases the evacuation time to escape from the module.	 ROOF TILE  WALL PANEL – fibreboard sandwiched with ACC Blocks

Table 17 Strategies during vulnerable period

ANATOMY OF CRITICAL FUNCTIONS (BACKUP)

ENERGY BACKUP:

Installation of solar PV modules on the roof surface, we can generate 120kWh/m^2.yr peak summer months which be stored in batteries as backup/ grid connected – net metering. This can give the site the backup energy of 45kwh which is enough to handle the power use for more than 72h. The energy consumption per module is 22.8kWh/m^2.yr

Figure 16 Single module with solar panels

WATER BACKUP:

Collection of rainwater in the harvesting tank. When it is pumped for other activities on site the excess water overflow on heavy rainy days can be redirected and stored in the site construction tank, so there is a steady supply of water for non-portable use.

POTABLE WATER TANK
Water storage capacity = 20000l Total amount of water consumption per day = 6224.4l Total water autonomy days = 3.2days
GREY WATER TANK
The total amount of water consumption per day = 5400l Total water autonomy days = 3.3days

Table 18 Water autonomy

Waste generation calculation – 80g of waste generated per person per day.
Total users: 160. **total compost generated per month**: 348kg.

Organic compost Market selling price: Rs.20/Kg. It is an income generation source for the site.

Maintaining Of Thermal Comfort | Proper Segregation Of Space | Proper Disposal Of Waste | Durability Of The Module

INITIATION OF EVACUATION DURING RISK

ALARM SIGNALS

ASSEMBLING TO THE REFUGE AREA (ZONED END OF THE SITE)

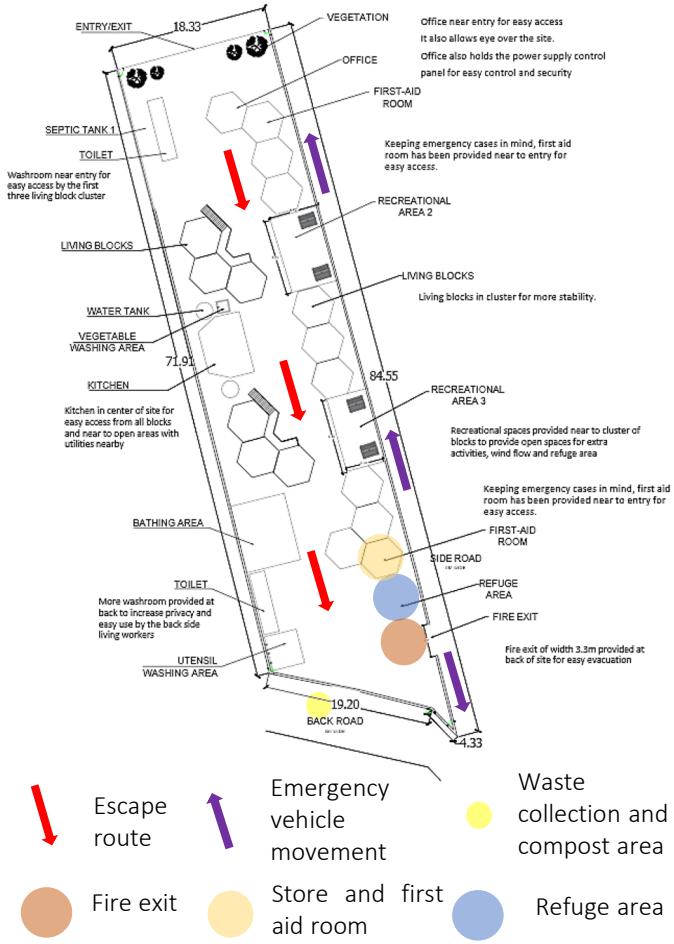
BASIC TREATMENT AND MEDICATION ARE PROVIDED IF NEEDED.

IMMEDIATE EVACUATION FROM THE EMERGENCY EXIT OF THE SITE.

END OF EVACUATION

Flow of people

Risk management and rescue plan



Emergency Exit plan and assembling point and segregation of spaces

SUSTAINING OPERATIONS AFTER THE EVENT

Verification of damage and analyzation

Easy replacement of materials if damaged.
Battery backup is provided for – 72 hours (Three days).

Sustaining operations

These main functions can continue the function of the module during the disaster period in case of minimum damage caused.

PROVIDING OF FIRE TYPES OF EQUIPMENT: SAND BOX - ON SITE, FIRE EXTINGUISHER – PROVIDED INSIDE THE EACH MODULE.

MINIMIZING THE STRESS AND DISRUPTION DURING THE EVENT

Educating the workers: To ease the escaping process

Assembling in the refuge point.
Creating awareness of the risk situation
Immediate evacuation from the site
Training to use fire extinguishers.
Informing the emergency services.

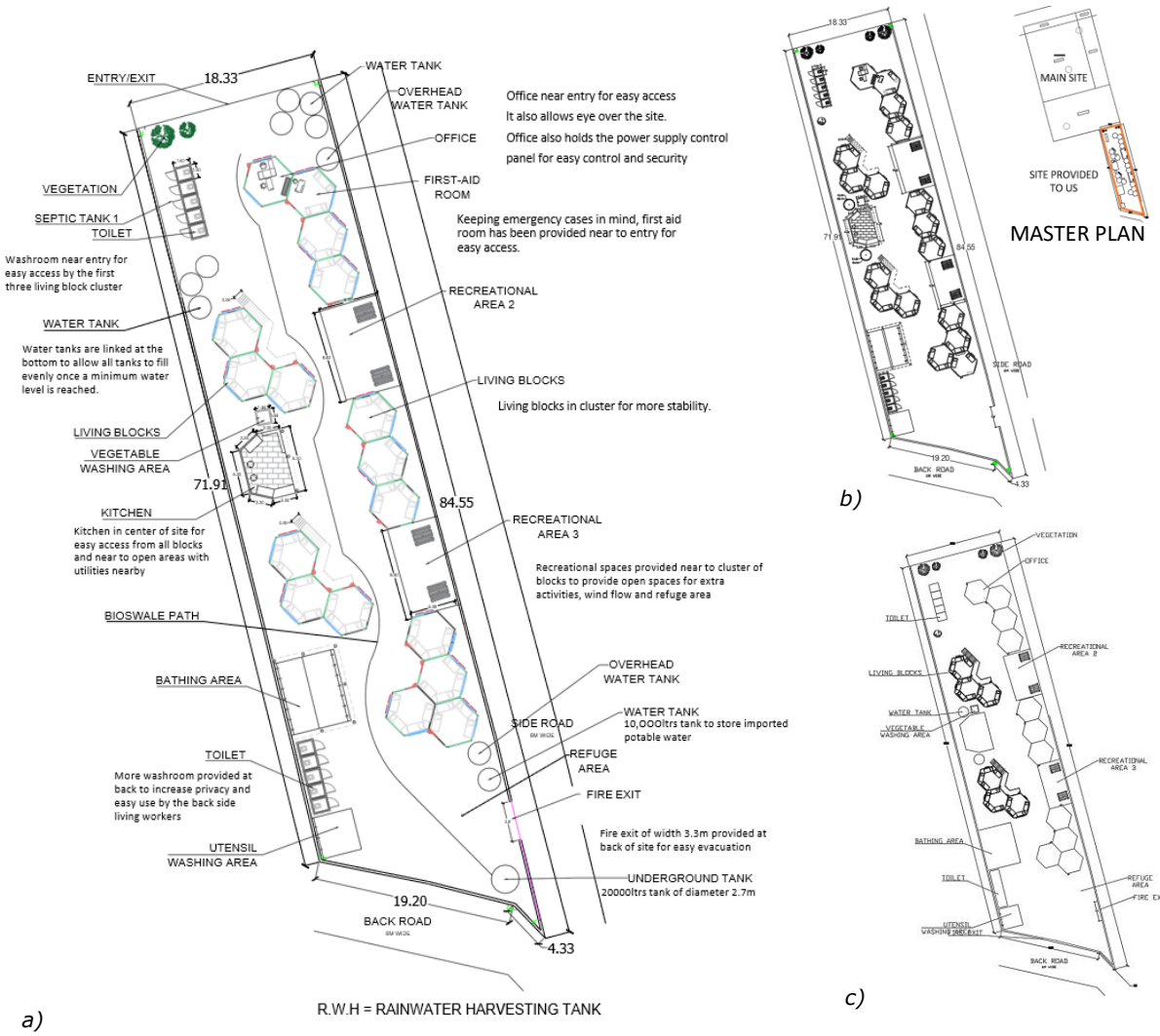
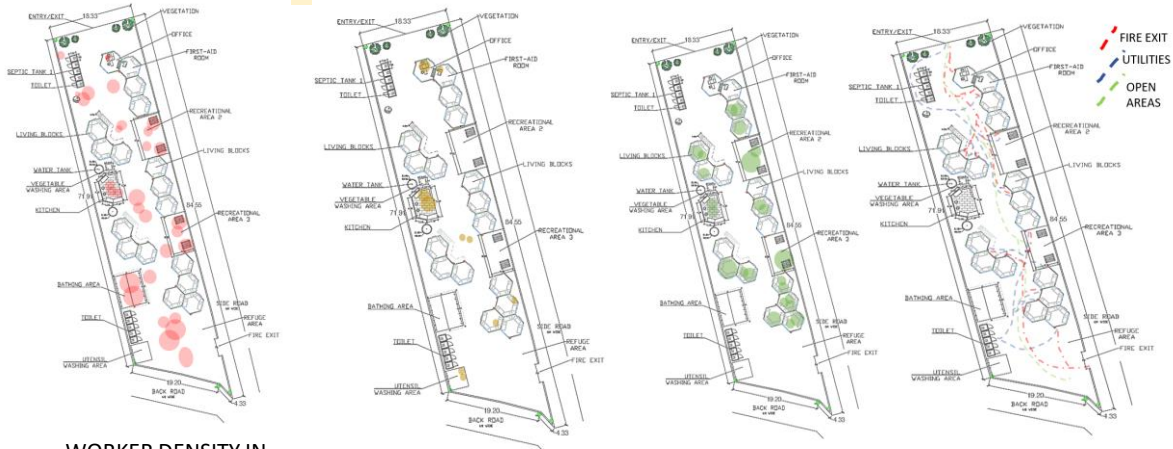


Figure17 a) Site plan, b) Ground floor plan, c) first floor plan

ROOF PLAN ALL IN M



WORKER DENSITY IN THE MORNING a)

WORKER DENSITY AT WORKING TIME b)

WORKER DENSITY AT LUNCH AND NIGHT c)

CIRCULATION AT SITE LEVEL d)

Figure18 a), b),c) population density – site level, d) circulation at site level

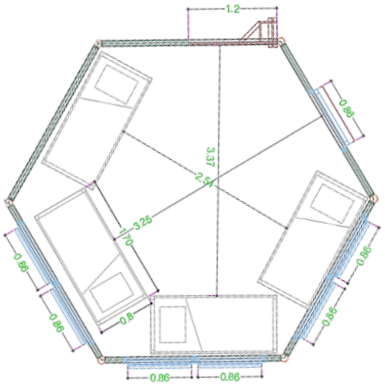


Figure19 Living blocks

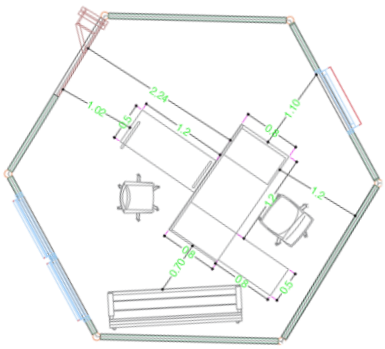


Figure20 Office blocks

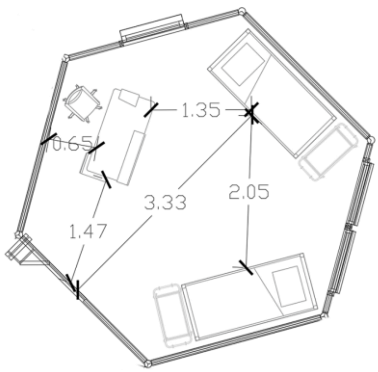


Figure21 First aid room plan

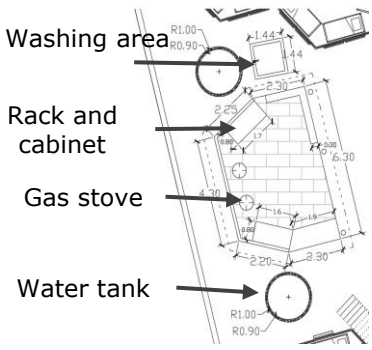


Figure22 Kitchen plan

Individual Block Detail All In M

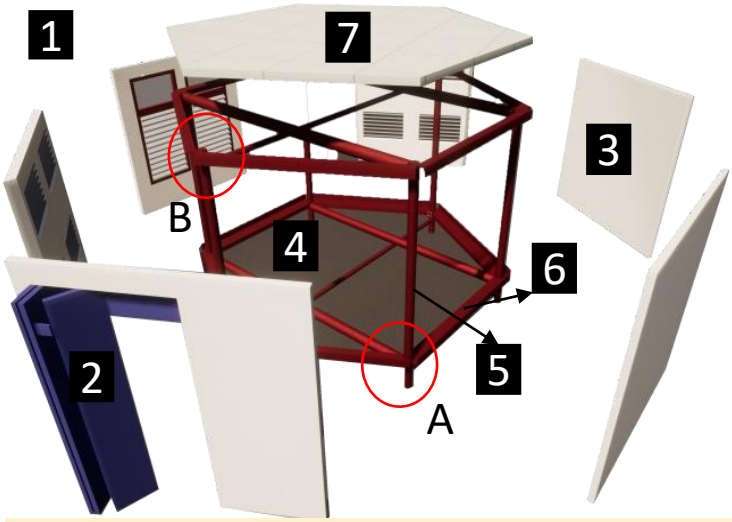


Figure23 Exploded view

1	Glazing material (acrylic sheet) - Dbl LoE (e2=.1) Clr 6mm/13mmAir
2	Folding UPVC door
3	Wall -4mm Fiberboard + 67mm AAC block + 4mm Fiberboard
4	Floor - 75mm Plywood
5	Circular MS columns - 100mm
6	Circular MS beams - 100mm
7	Roof - 75mm concrete tiles

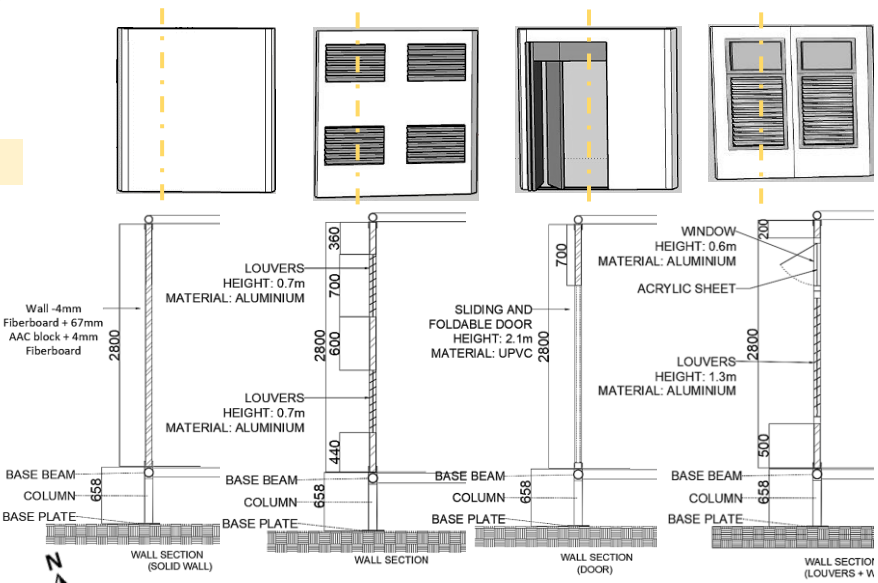
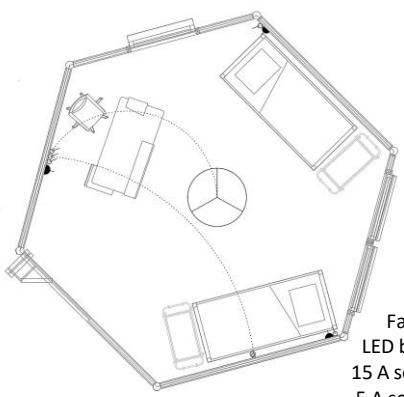
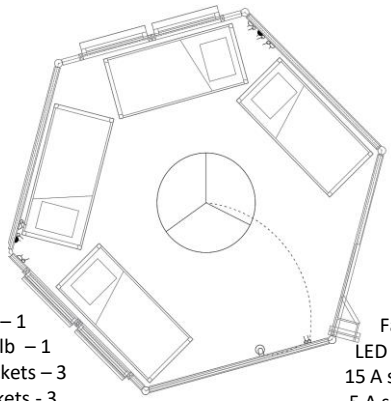


Figure24 Elevation and section of wall panels



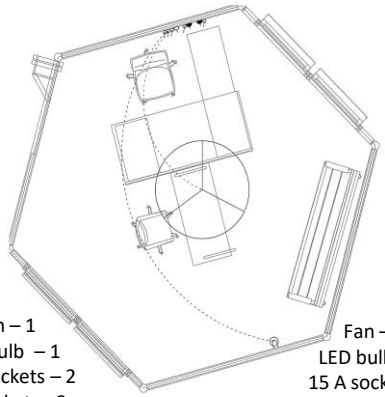
First-aid block

Fan – 1
LED bulb – 1
15 A sockets – 3
5 A sockets - 3



living block

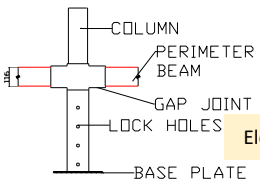
Fan – 1
LED bulb – 1
15 A sockets – 2
5 A sockets - 8



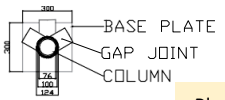
Office block

Fan – 1
LED bulb – 1
15 A sockets – 2
5 A sockets - 2

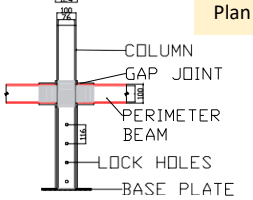
Figure25 electric layout of different blocks



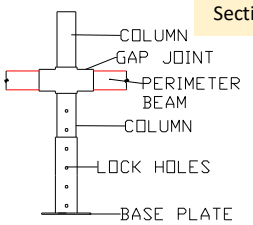
Elevation



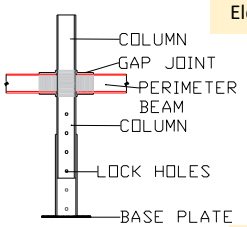
Plan



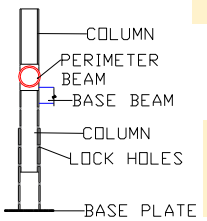
Section



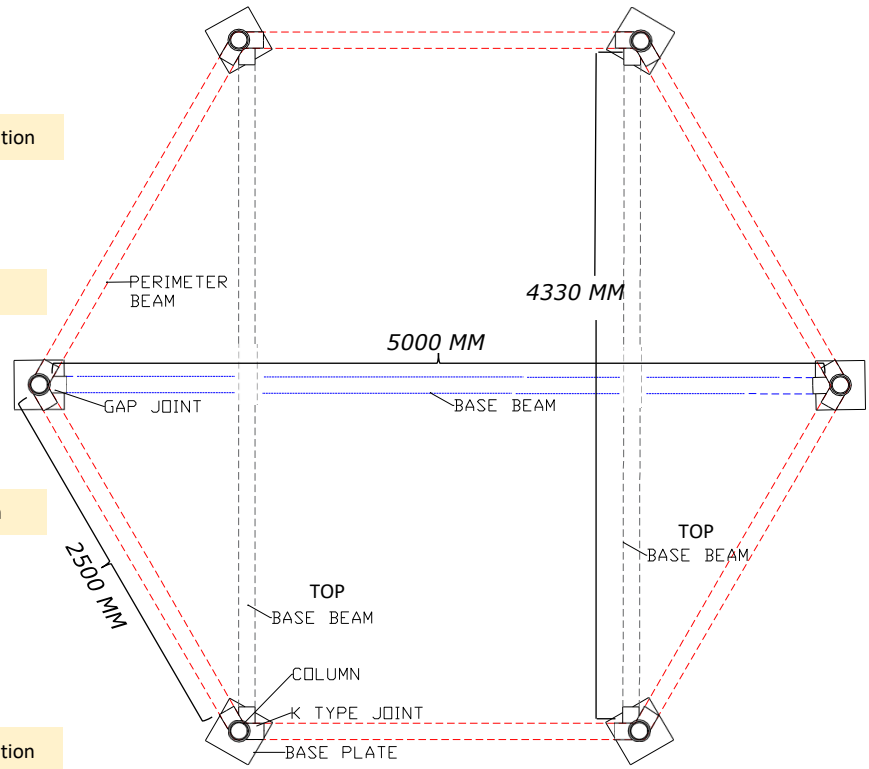
Elevation

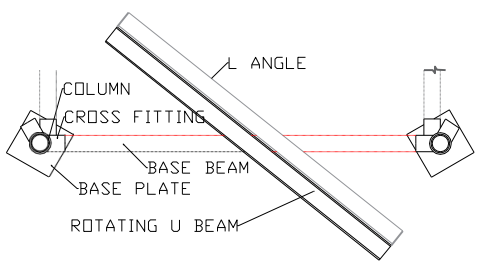


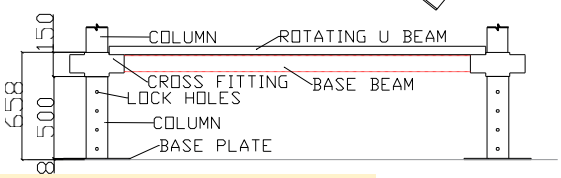
Section



Side Elevational section



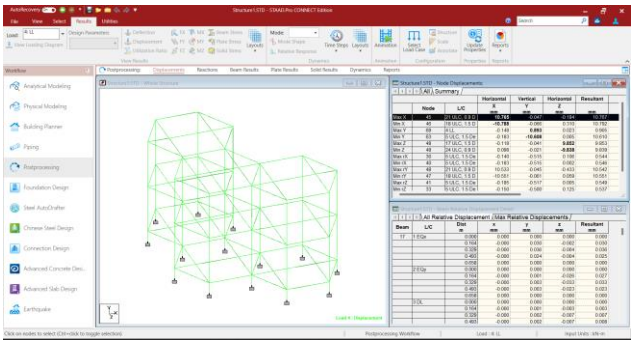




External diameter of beam 100mm with 12mm thickness

ALL IN MM
N.T.S

Figure26 joinery detail of structure



DEFLECTION OF STRUCTURAL MEMBERS LIMITS

HORIZONTAL DEFLECTION = H/250 = 6258/250 = 26.075mm

6258mm = TOTAL HEIGHT OF THE STRUCTURE

VERTICAL DEFLECTION = SPAN/150 = 4920/150 = 32.8mm

4920mm = SPAN OF THE BEAM

ANALYTICAL MODEL RESULTS

Here the analytical model results say that the total vertical deflection is -10.608mm

Horizontal deflection is -10.788mm

The deflection values fall under the maximum deflection limit for the structure considering the maximum possible combination and high earthquake values.

This gives us the conclusion that the modules can be transportable and can withstand the possible dead, live and seismic loads.

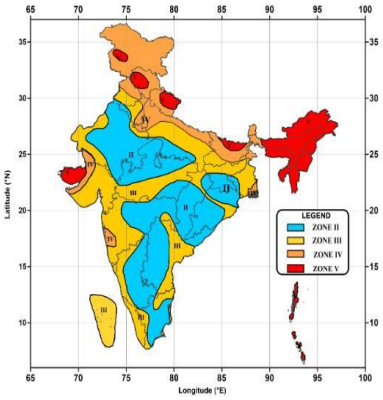


Figure 27 Seismic zones of INDIA

Base Case

a) 

b) 

Living Blocks

No proper openings and circulation space, affecting the activities and thermal comfort of block

c) 

d) 

Figure 28 a),b),c),d) Case study images – Mangalore

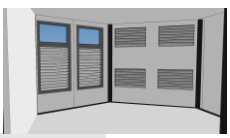
Bathing, cleaning and washroom area together affecting the hygiene and privacy

No proper openings and circulation space affecting thermal comfort and activities in kitchen

These Issues Have A Physiological Impact On Workers, Lowering Their Productivity And Eventually Leaving The Job

Proposed Case

a) 

b) 

Living Blocks

Living blocks having proper opening and space for better circulation and ventilation

c) 

d) 

Figure 29 a),b),c),d) Rendered images of living blocks, washroom, dining, and kitchen

Bathing, cleaning and washroom area with separation for more hygiene and privacy

Kitchen interior with proper spaces and circulation area while openings for thermal comfort

Good Living Condition Will Attract Skilled Workers .Better living conditions and provision of basic amenities will increase the chances hiring skilled laborers

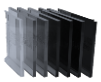
	BASELINE DESIGN	PROPOSED DESIGN
CONSTRUCTION COST ANALYSIS	**Materials used:**  Red clay bricks These materials are easily and locally available but does not possess durability and sustainability.  This has a lower initial construction cost but higher maintenance, service, and operation costs due to the low effectiveness of the materials, absence of a renewable source of energy and design strategies.	**Materials used:**  Fibre board  Acrylic sheets  AAC blocks  Aluminium louvres  UPVC doors  MOD Roof Plano roof tile and plywood tends to be durable These materials are sustainable and more long lasting than the baseline design  These materials are locally available and also acts as a part of the design strategies  Installation of solar panels , rainwater sting techniques increases the initial construction cost but tends to reduce the service and maintenance cost
FINANCIAL COST ANALYSIS	  • This module uses traditional construction technique due to the implementation of brick masonry and concrete support structure - increases the maintenance cost • As the module is not a modular system it increase the service and operation cost	• Modularity and de-modularity of the structure and the use of steel structural member helps in quicker construction of the module  • Faster construction technique lowers the service and operation cost 
LIFECYCLE COST ANALYSIS	• Lower initial construction cost but higher service , maintenance , operation and disposal cost makes it ineffective for the proposed design module • This module requires higher energy supply demand • Due to the use of mentioned materials absence of renewable energy and no modularity the life of this module reduce. • This module can only sustain max up to 2 years as the GI corrugated sheets can get easily damaged and bricks cannot be reused again 	• Initial cost of the design is efficient as local and easily available materials are being used for construction  • Low maintenance cost is achieved as the materials and the technique used are durable and sustainable • Lower service and operating cost than the baseline design due to the implementation of renewable source of energy (solar panels) , various design strategies and easy transportation of the structure (modularity feature) • Disposal cost is minimum as the structure can be used again for different projects due to its long life and its effectiveness • The life of the proposed design module tends to be about 10 years

Table 19 Monetary comparison of baseline case and proposed case

COST TABLE

Baseline Case		
S .no	Category	Cost (Rs)
1	Walls	2310
2	Roof	990
3	Floor	16087.5
4	structural	5000
5	Fixtures	5400
6	Miscellaneous	5000
Total cost per unit (INR)		34,787.5
Total cost per 25 units(INR)		8,69,687.5

Table 20 Cost table of baseline case

Proposed Case			
S .no	Category	Cost (Rs)	Cost per year (Rs)
1	Walls	39,780	3,978
2	Roof	7,175	717.50
3	Floor	3500	350
4	structural	19,554	1,955.40
5	Fixtures	5,000	500
6	Miscellaneous	24,400	2,440
Total / unit		99,409	9,940.90
Site Clerance – lump sum		7,200	-
Equipment cost		21,000	-
Total / 25 units		2,513,425	209,452.08

Table 21 Cost table of proposed case

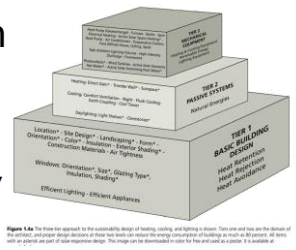
*Transportation cost is added up the total according to the distance covered (truck capacity: 2500kg): Rs 775 for 7kmmm

- Affordability :
- The proposed design module is more affordable than the baseline design module as the proposed design has lower operation , maintenance , service and disposal cost but higher construction cost due to the implementation of solar panels and rainwater harvesting .
- Due to the low cost of the module at different stages and is longevity the proposed module tends to be highly affordable than the baseline module

CHALLENGE: TO ACHIEVE THERMAL COMFORT AT A LOWER COST.

- ❑ Basic building design
- ❑ Passive systems
- ❑ Mechanical systems

Form
Orientation
Material
Openings placement, glazing, and size



FORM

The first consideration for a building form in group housing is its ability to arrange on a plane / how well it can occupy space.

Taking the above considerations, we arrive with

- Rectangles
- Squares
- Hexagons

A circle encompasses the most area relative to the circumference. So, in a way a circle would be the most efficient shape. Hexagon then is the closest regular polygon to a circle that can tessellate a plane. Meaning that there is no space between the cells.

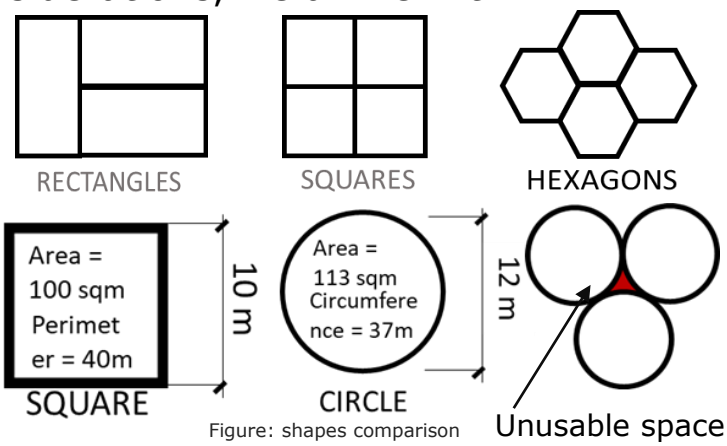


Figure: shapes comparison

Proving :

The angle at each corner for a regular n-sided polygon is **a=180-360/n**. When you tessellate a plane with these, you put the polygons around one corner so that they evenly divide the full circle or 360 degrees. So around one corner, you have m=360/a polygons meet.

m = 360/a
= 360/(180-360/n)
= 360/((n*180)/n-360/n)
= 360/((n*180-360)/n)
= n*360/(n*180-360)
= n*2/(n-2)

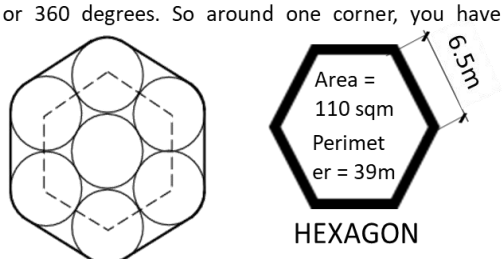


Figure: Hexagon development

Therefore n-sided polygons you have n*2/(n-2) polygons around one corner. Obviously, this needs to be a whole number for the tessellation to work. **y=x*2/(x-2)** is a hyperbola and y is a whole number only at x = 3, 4 or 6. It has the asymptotes of y=2 and x=2. **So you can tessellate a plane only with triangles, squares, and hexagons. Of this hexagon is the closest to a circle.**

Therefore, hexagon uses lesser panel material for a given area Hence reducing panel material cost for a building unit

Paneling

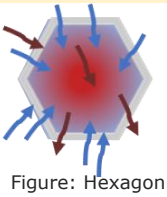


Figure: Hexagon with 6 openings

Hexagon Has 6 Sides, Providing An Opportunity To Have Openings In 6 Different Directions. But Opening In All Directions Is Not Helpful and Might Lead To Heat Gain. Hence Understanding And Segregating Types Of Panels Was A Measure Towards Achieving Thermal Comfort

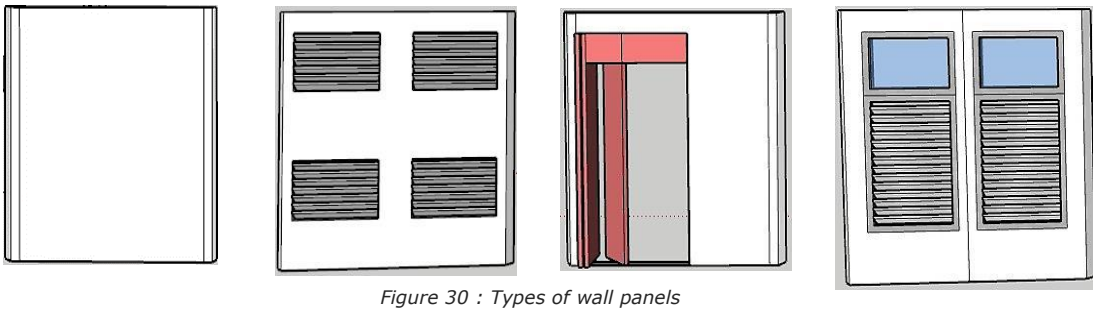


Figure 30 : Types of wall panels

SOLID WALL PANEL	VENTILATION PANEL	DOOR OPENING PANEL	LIGHT AND VENTILATION PANEL
It can also be provided in west and east if they are not the major wind direction to reduce the thermal gain inside the structure. They can also be provided in the direction where no opening is needed	This panel can be used in the direction of prevailing winds for maximum cross-ventilation inside the units without allowing the low-angle incident solar. It can also be placed in the direction where privacy is needed.	Holding a folding door reduces the amount of opening area needed. It can also function as a base-to-ceiling window in case more ventilation is required	Wall panels with louvers and glazing can be placed in the north to allow diffused sunlight to enter the space and for the wind to come inside.

Table 22 Comparison of different panels

Structural

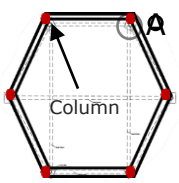


Figure: structure column placement

The module must be raised or lowered to the required height according to varying conditions..
To deal with this case we have proposed a telescopic channel that can be adjusted to a required height between +/-0 to +450 mm.
This type of structural element is placed at each column and footing interjection, The module must be raised or lowered to the required height according to varying conditions

uneven base

filling the whole land to flatten

our proposal telescopic plinth stand to adjust acc. base conditions

Figure 31 : Module placement on uneven ground

Low-cost Cooling

Internal

Mist-cloth cooling for indoor

Integrating pressure mist sprayers in the peripheral of the cabin fans already proposed within the modules

This idea is inspired by different vernacular strategies used like

- Vernacular cooler
- Cooling towers
- Surface wetting
- Outdoor mist fan

Figure: Misting system

Figure: Proposed system

Small water reservoir in form of a refillable garden sprayer bottle for each fan/ module according to requirement and pressure sprayer.

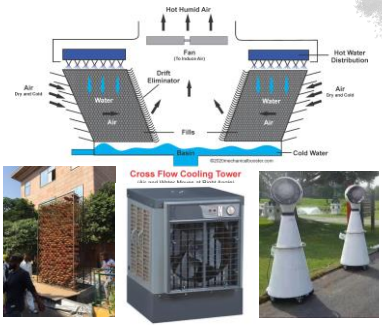


Figure32 Strategies inferred

To overcome wetness due to mist spray, a **cotton cloth** will be hung around the mist sprayer so that the mist hits the cloth and wets it, then the mist spray can be paused manually, and when the fan blows across the wet cloth, cool air spreads across the room.

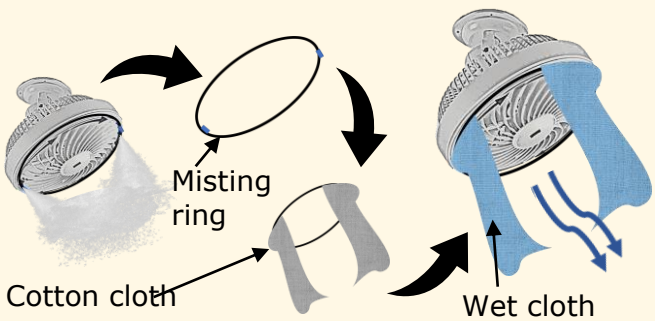


Figure: Proposed system with cotton cloth

Advantages :

- Affordable
- Low maintenance
- Easy installation
- Zero additional electricity requirement
- Low water requirement
- Instantaneous cooling

Disadvantages

- Mist can wet the furniture

External

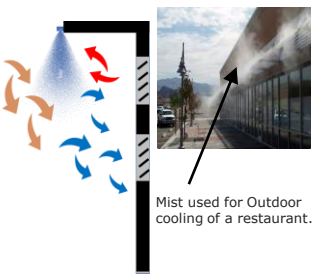


Figure: Outdoor misting illustration

Mist Sprayer In Shading Devices To Cool Outdoor.

Mist sprayers will be used in shading devices to cool the outdoor temperature around the module During required peak cooling hours.

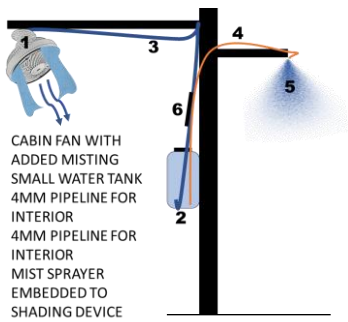


Figure33 Mist system schematic working

Provision of indoor thermal comfort

The chosen comfort model is IMAC. The only mode of operation of the building is Natural ventilation and no HVAC systems running on any given day. The louvres are always open, and the top-hung windows can be opened according to the user comfort. Also, the orientation of the panel will perpendicularly or obliquely face the wind direction to enable cooling by conduction and create positive and negative pressure zones respectively.

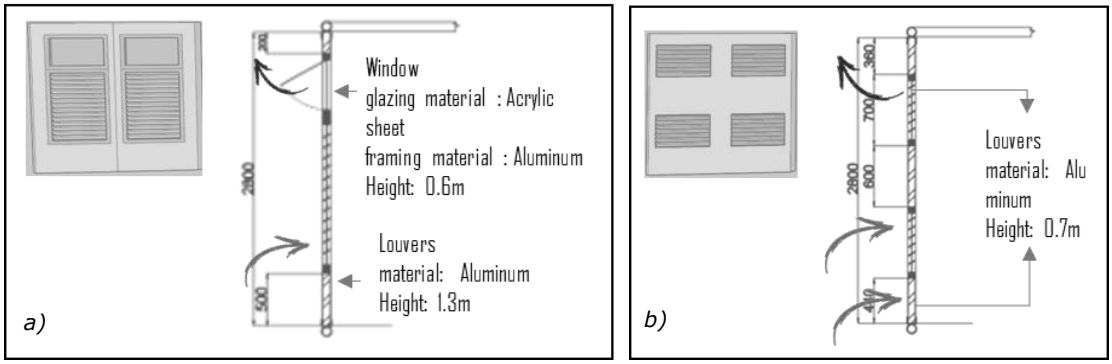
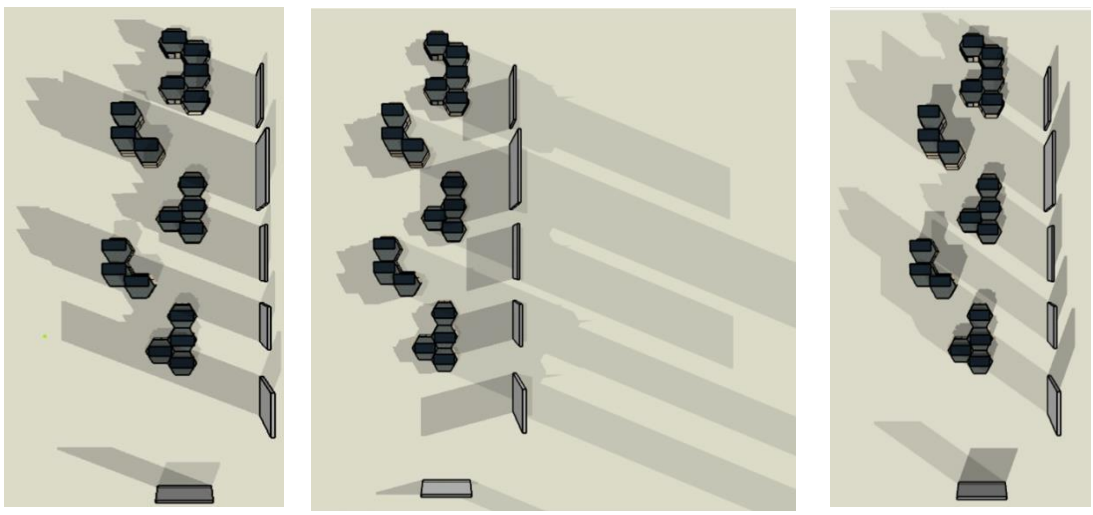


Figure34 a),b) Wall, window detailing and section

Strategies for reducing thermal stress in the outdoor environment

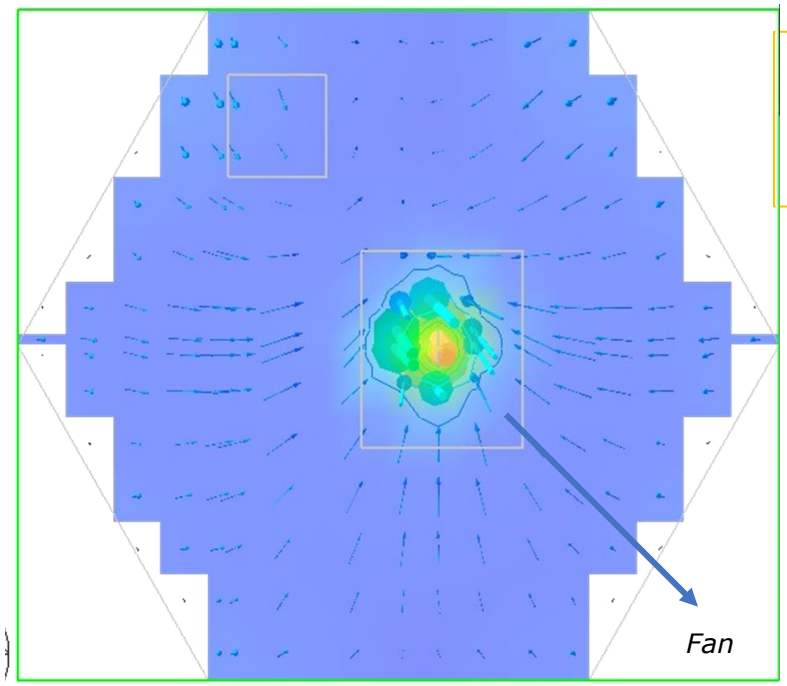
The module is placed in a way to minimize the direct solar radiation in the outdoor spaces- which will increase outdoor comfort during outdoor gathering time.

Annual shadow pattern for present site in Hyderabad has been shown in figure using 3 intervals of a day(08:00, 13:00, 16:00) in different months. It shows common gathering spaces are protected from direct sun- providing cool-shaded outdoor areas- this reduces outdoor thermal stress too.



a) **February** b) **June** c) **December**

Figure35 a),b),c) mutual shading



Annual avg. Operative temperature –27degC. Percentage of People dissatisfied - 33.6%

The CFD diagram generated through Energy Plus (design builder) shows internal circulation of air throughout the module with no stale air zones.

Figure36 CFD model

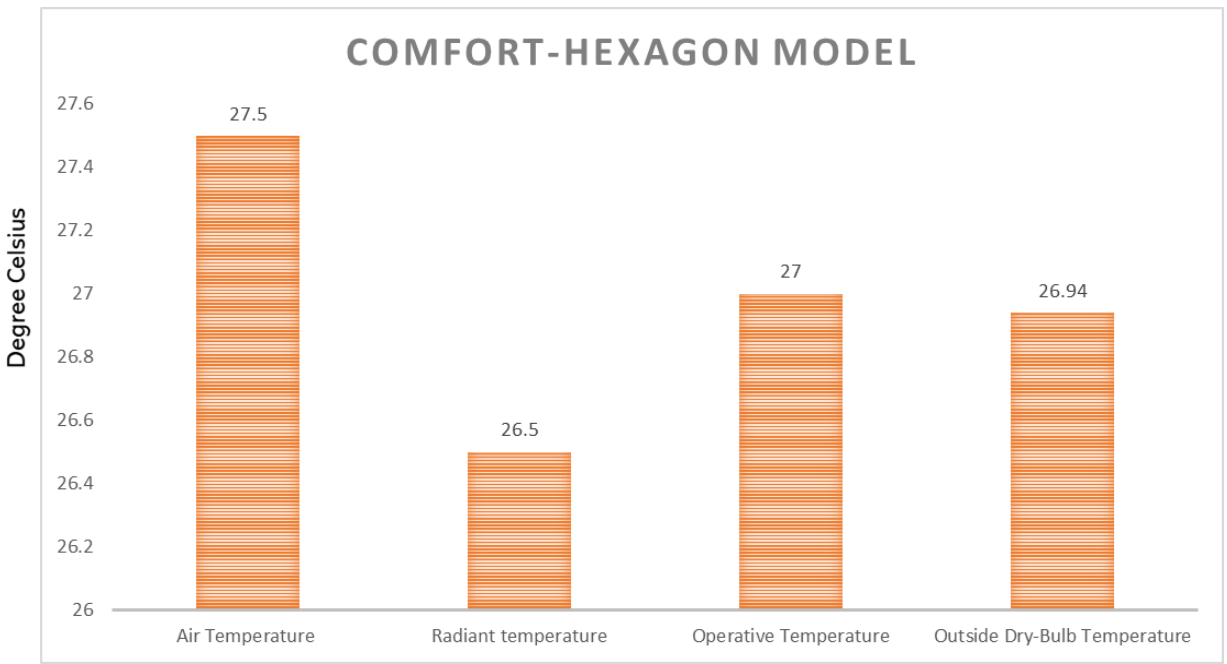


Figure37 Thermal comfort

Relative Humidity(%)= 65.61
Fanger PPD (%)= 33.59
Fanger PMV 0 = 0.15

The housing conditions for construction workers have been disregarded by the contractors.
Even more so is a net zero energy and water design.

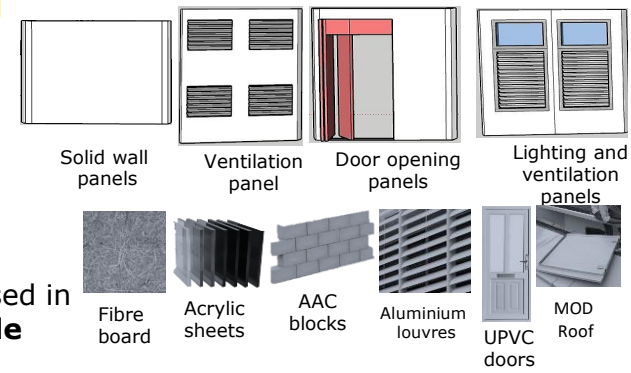
A diverse team of students of as from the fields of architecture, and structural engineering, along with assistance of our experienced faculty have developed sustainable and resilient housing modules which will be comfortable and resilient for all climatic zone of India using a data-driven, and integrated design approach.

Figure38.1 Rendered image of modules

Aaru ensures construction employees' hygiene and living conditions on the job site, which has a positive humanitarian impact and draws in foreign investors.
The flexibility of the hexagon's arrangement allows better area segregation, hygienic maintenance, mutual shading which promote outdoor cooling effect.

MODULE FEATURES

Four panel types can be assembled in different climatic conditions to obtain maximum comfort.
Reuse of material: This reduces the cost and manufacturing new material.
Locally available materials are used in construction which is **sustainable** and **long lasting** (10yrs)



Modules are provided with **stilt** at a level of +0.65m that allows the water to flow during flood in the site
Steel columns designed to **resist earthquake**
Fire resistant and **green rated** materials.

Zero waste management on site which coverts organic waste into compost for plants on site

Figure38.2 Outdoor rendered view of modules

Solar PV panel and **rainwater harvesting** system is provided on site which adds to initial cost but helps in reducing the maintenance cost
Rainwater harvesting is capable of meeting 14.% (equal to 399913 liters) of the project's yearly water demand
Bioswale provided on site to filter softscape water

The cost of construction for base case is Rs 2825475 for a span of 5 years whereas for proposed case the cost of construction is Rs 2978975 for a span of 10 years which results in savings of Rs 2671975 in total span of 10 years.

FINAL ESTIMATION

Area	Material Specificaton					
16.25	PANEL	MATERIAL	MATERIAL DETAILS	DIMENSIONS	COST	UNIT
175						
	SOLID WALL	WALL PANEL	fiberboard sandwich with AAC blocks	75	130	MSQ
		HINGES	Stainless Steel Double Ball Bearing	5" X 3" X 3mm	150	PER PIECE
	WALL WITH 4 LOUVERS	LOUVERS	ALUMINIUM LOUVERS	1.5 mm thickness	150	PER SQ FT
WALL						
	WALL WITH 2 LOUVERS AND 2 OPERATABLE WINDOWS	C channel	Steel - 3 to 6mm(thick)		60	per piece
		Acrylic Sheet	Thickness (20mm)	4" x 8"	50	per sq ft
	WALL WITH DOOR	DOOR	upvc door	6' x 9'	290	per sq ft
			glass thickness 9 to 14mm(thick)			
ROOF	Flat Tile Concreate Monier - Plano Roofing Tiles				41	PER SQ FT
	MOD ROOF			50 CM X 50 CM	190	PER SQ FT
FLOORING	Plywood			8'x4'x12mm	20	per sq ft
WATER TANK					5000	PER PIECE
STEEL STRUCTURE	U Shaped channel				250	per piece
	round column			15 x 15 x 2	39	per piece
	round beams			10X20, 10X25,12X25, 12X35, 12X55	220	per kg
	cross fitting				560	per piece
	t fitting		M8	16mm	75	per piece
	Steel Plate				220	per kilogram
	Steel Holders				250	perpiece
	Foundation Bolts				150	per piece
SOLAR PANEL				5.4' x 3.2'x 200mm	6000	per piece
CALCULATIONS						
WALLS	SOLID WALL				23200	
	WALL WITH 4 LOUVERS				4800	
	WALL WITH 2 LOUVERS AND 2 OPERATABLE WINDOWS				5110	
	WALL WITH DOOR				6670	
			total wall		39780	
ROOF	Plano roof tiles				7175	
flooring	plywood				3500	
solar panel					600000	
						50455
structure(substructure)	12 x u channel+6 round columns+12 round beams+6 plates+6 cross fiting+6 t fitting+12 nut bolts+18 locks(holders)+24 foundation bolts +				19554	
for 1 unit					70009	
for 25 units					1750225	
MISCELLENAOUS						
Solar Panel					600000	
Water Tanks					10000	
total					610000	
ELECTRICITY						
	NO. OF FIXTURES	WATTS	COST OF PRODUCT		TOTAL COST	TOTAL WATTS
CEILING LIGHTS	4	8	500		2000	32
CABIN FAN	1	5	2200		2200	5
					4200	
INCULDING WIRING					5000	37
FOR 25 UNITS	25				125000	925
TOTAL COST					2485225	

Project Summary

Projec Project Information

Team:	TRIDHARA			
Division:	Worker Housing		**Land Cost:**	100 Million INR
	Site Area (sqm)	1,232	**City:**	Hyderabad
	Built-up Area (BUA) (sqm)	408	**State:**	Telengana
	Ground Coverage (Plinth Area) (sqm)	276		

S.No.	Particulars	Definition	Baseline Estimate (Project Partner / SOR basis)			Proposed Design Estimate		
			Amount (Million INR)	%	Amount (INR per sqm)	Amount (Million INR)	%	Amount (INR per sqm)
1	Land	Cost of land purchased or leased by the Project Partner	100.00	75.3%	2,45,248	100.00	88.8%	2,45,248
2	Civil Works	Refer Item A, Civil works in Cost of construction worksheet	0.38	0.3%	930	0.33	0.3%	815
3	Internal Works	Refer Item B, Civil works in Cost of construction worksheet	0.00	0.0%	-	0.02	0.0%	43
4	MEP Services	Refer Item C, Civil works in Cost of construction worksheet	11.57	8.7%	28,376	0.00	0.0%	-
5	Equipment & Furnishing	Refer Item D, Civil works in Cost of construction worksheet	0.05	0.0%	114	0.05	0.0%	119
6	Landscape & Site Development	Refer Item E, Civil works in Cost of construction worksheet	0.00	0.0%	-	0.00	0.0%	-
7	Contingency	Amount added to the total estimate for incidental and miscellaneous expenses.	0.36	0.3%	883	0.24	0.2%	584
	TOTAL HARD COST		**112.4**	**85%**	**2,75,551**	**100.6**	**89%**	**2,46,809**
8	Pre Operative Expenses	Cost of Permits, Licenses, Market research, Advertising etc	0.10	0.1%	245	0.10	0.1%	245
9	Consultants	Consultant fees on a typical Project	0.10	0.1%	245	0.10	0.1%	245
10	Interest During Construction	Interest paid on loans related to the project during construction	20.25	15.3%	49,673	11.72	8.8%	28,748
	TOTAL SOFT COST		**20.5**	**15%**	**50,164**	**11.9**	**9%**	**29,239**
	TOTAL PROJECT COST		**132.8**	**100%**	**3,25,714**	**112.6**	**100%**	**2,76,047**

Table 23 Final estimation

The blue dash line indicates at which position the horizontal panels will be resting on beams.
While the red dash line running along the perimeter of structure shows the extended L angle for supporting the floor panels.
While in case of supporting the roof panels the L angle will sit directly on perimeter beam.

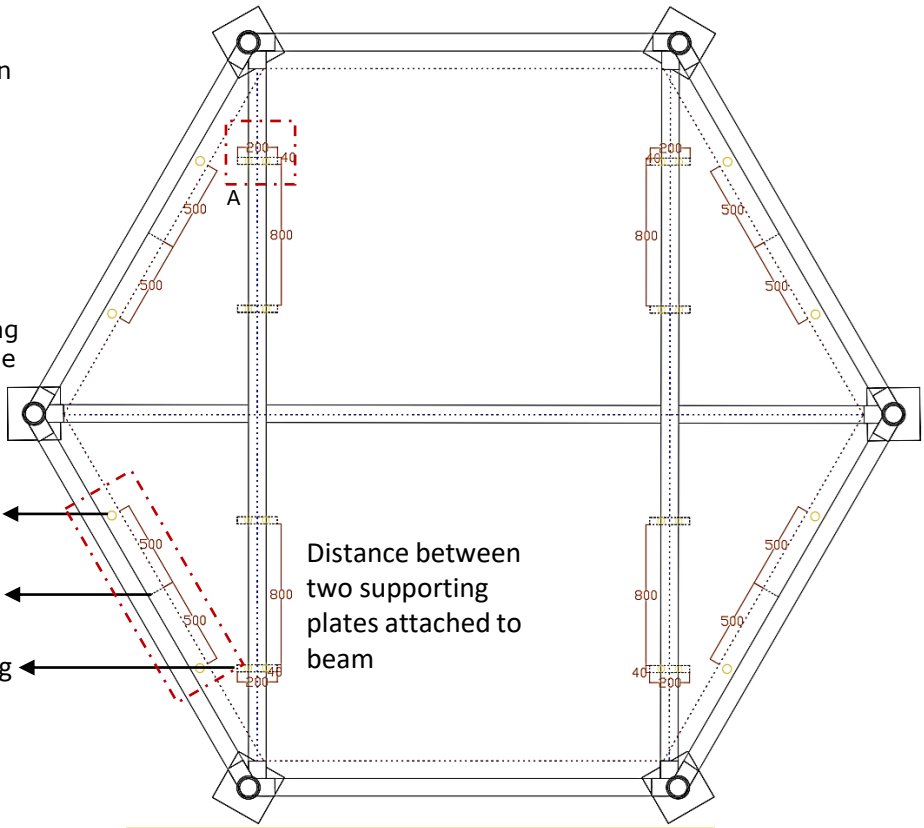
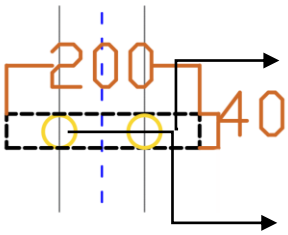


Figure39 Bolt, L angle, and supporting plate placement plan

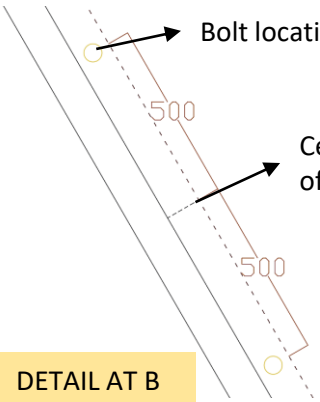
ALL IN MM
N.T.S



Supporting plate attached to beam

Bolt location in supporting plate attached to beam
Centre to centre distance is 100 mm

DETAIL AT A



Bolt location in L angle

Centre line of L angle

DETAIL AT B

ALL IN MM
N.T.S

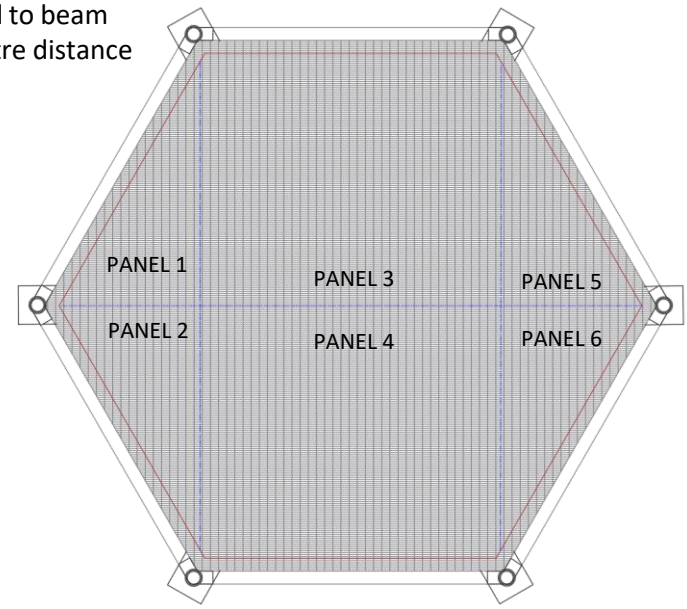


Figure40 Plan showing placement of horizontal panels and joining points (blue line)

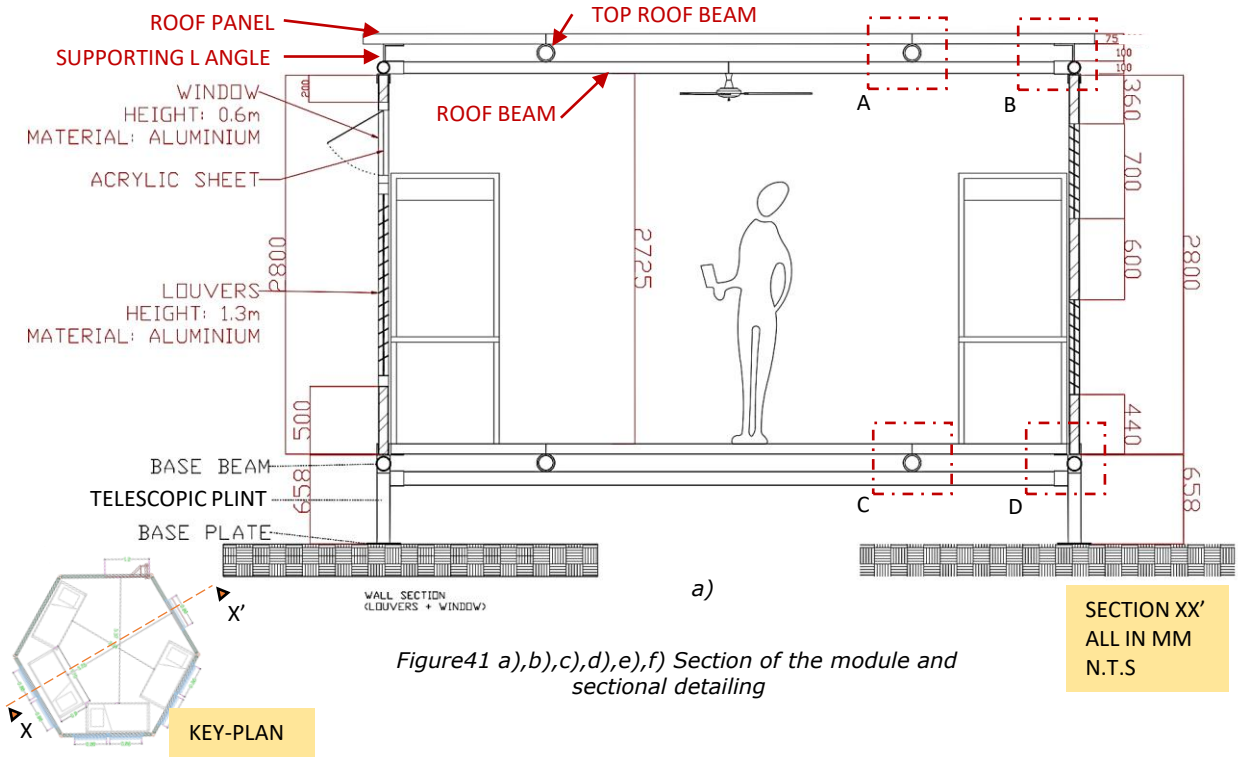
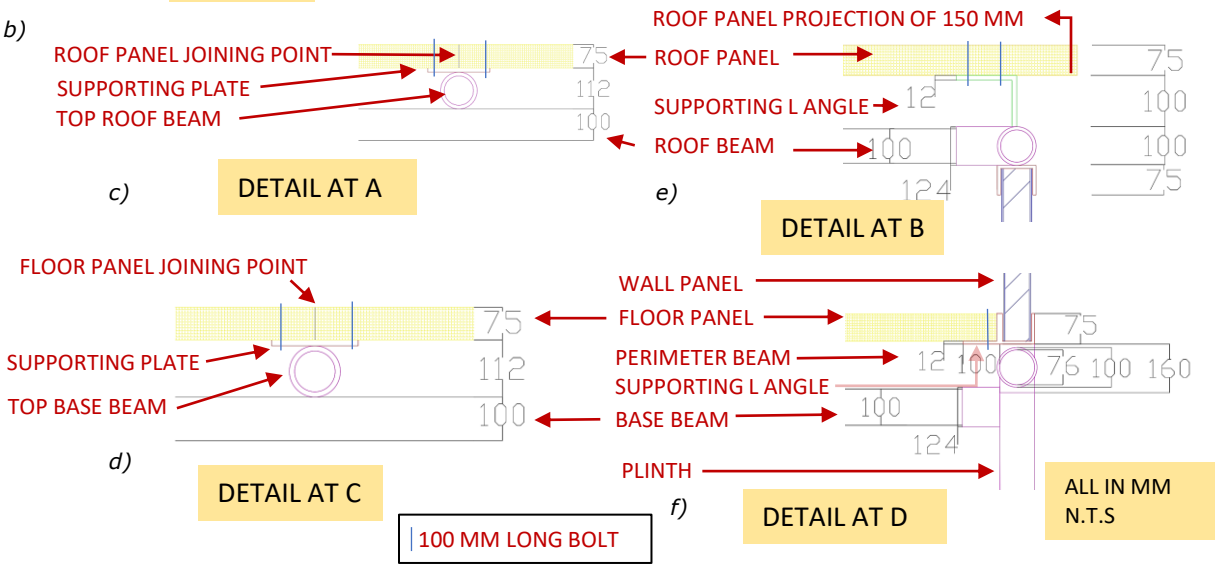
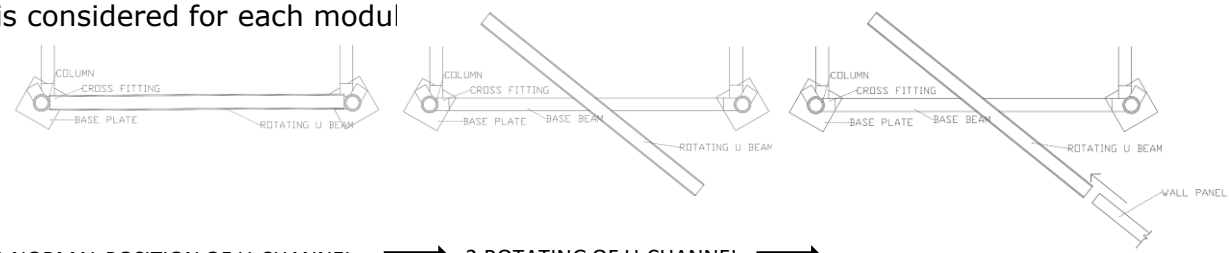


Figure41 a),b),c),d),e),f) Section of the module and sectional detailing



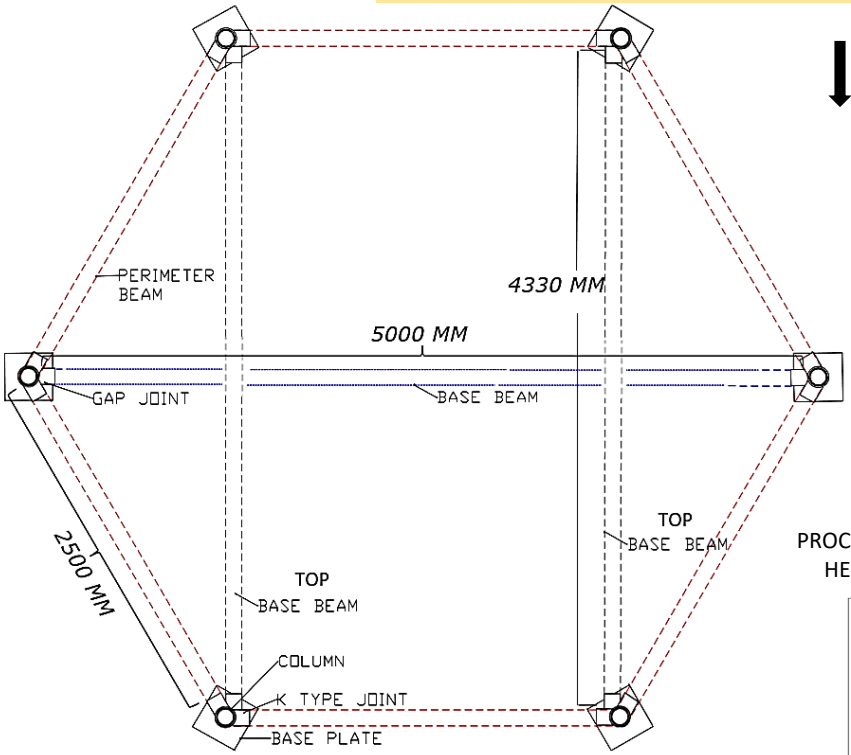
The above figure shows sectional detail of a typical module according to human and furniture scale.
Detailed view of all major joints has also been provided for better understanding.
According to the design when we use continuous beam at base (named as top base beam and base beam) and top (named as top roof beam and roof beam) the structure is stable but it also gives a challenge of level difference in the beams as shown in section. To over come this issue L angle for support has been provided which will hold floor and roof panels at their positions respectively. The roof and floor panels will be held at their position using bolts. This also makes them more stable at their position.
This system also lets us to divide the horizontal panels in 6 parts. More detail has been shown in next sheet

The modules are supported by steel frame structure which can be dismantled in order to transport from one place to another. This also reduces the use of heavy machinery. The module has a rotating U channel which is rotated to slide the wall panel inside it and then can be rotated back to its original position while locking the walls with column using lock as shown in fig.------. The goal of **DESIGN TO TRAVEL** is considered for each modul

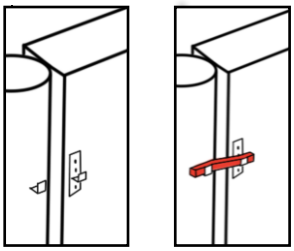


1.NORMAL POSITION OF U-CHANNEL → 2.ROTATING OF U-CHANNEL → 3.SLIDING WALL PANEL IN U-CHANNEL

Process of placing wall panels

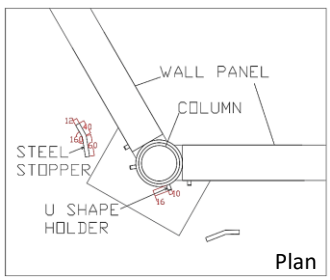


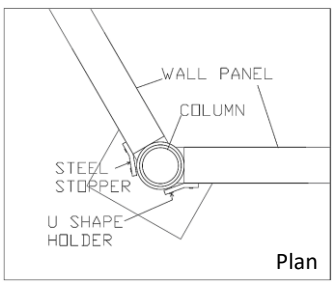
4. NORMAL POSITION OF U-CHANNEL AFTER SETTING WALL

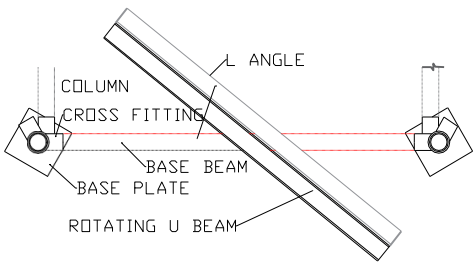


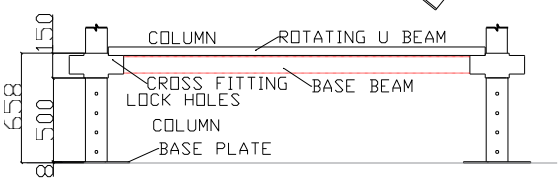
3-D view

PROCESS AFTER LOCKING OF WALL WITH HELP OF ROTATING STEEL STOPPER

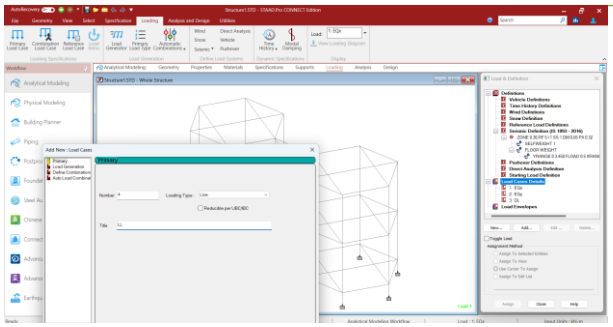




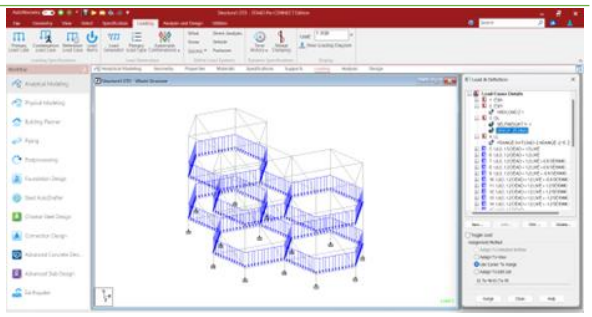




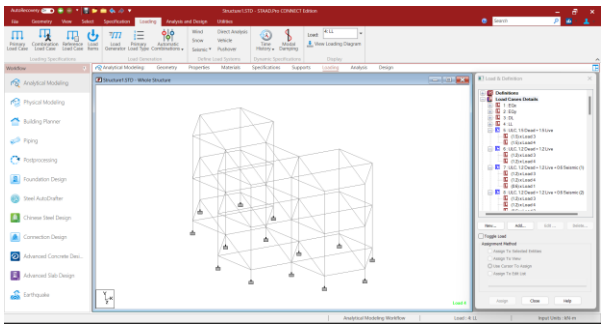
NOTE : U-CHANNEL HAS BEEN MENTIONED AS U-BEAM AT SOME PLACES



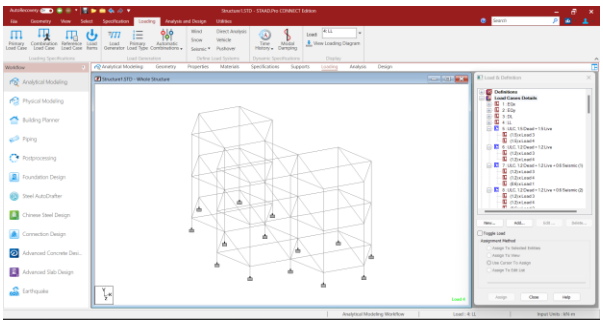
ADDING LOAD CASES – Dead load, Live load, and Seismic load



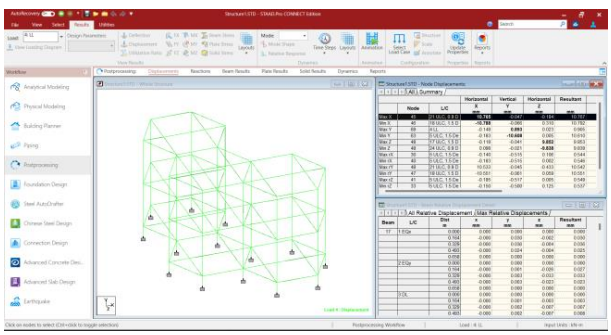
LOAD CASES DETAILINGS



STRUCTURAL ANALYTICAL MODEL



STRUCTURAL ANALYTICAL MODEL

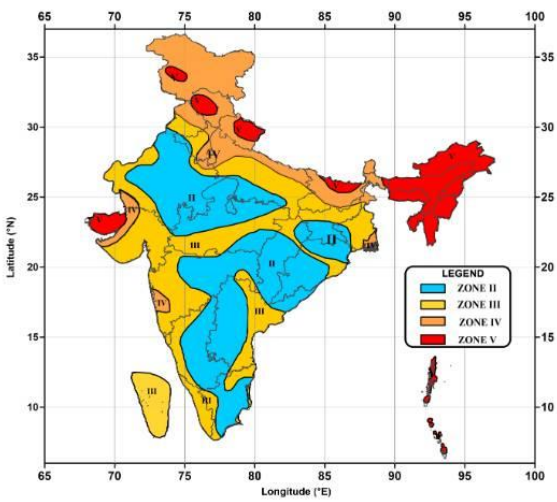


ANALYTICAL MODEL RESULTS

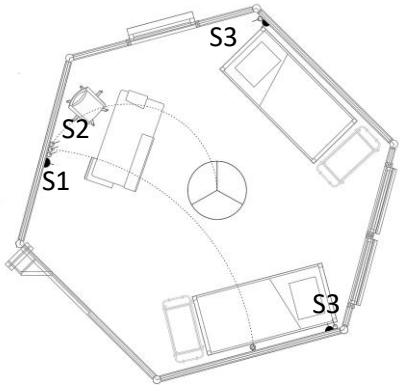
Here the analytical model results say that the total vertical deflection is -10.608mm
Horizontal deflection is -10.788mm
The deflection values fall under the maximum deflection limit for the structure considering the maximum possible combination and high earthquake values.
This gives us the conclusion that the modules can be transportable and can withstand the possible dead, live and seismic loads.

DEFLECTION OF STRUCTURAL MEMBERS LIMITS

HORIZONTAL DEFLECTION = H/250 = 6258/250 = 26.075mm
6258mm = TOTAL HEIGHT OF THE STRUCTURE
VERTICAL DEFLECTION = SPAN/150 = 4920/150 = 32.8mm
4920mm = SPAN OF THE BEAM



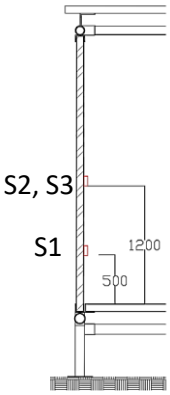
SEISMIC ZONES OF INDIA



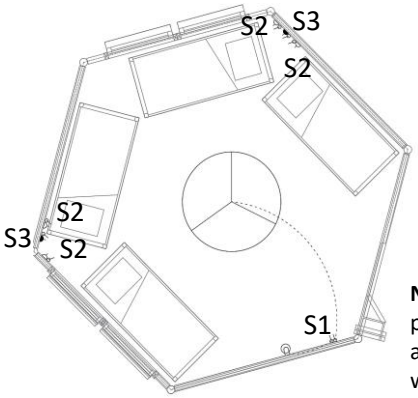
First-aid block

TOTAL ELECTRICAL EQUIPMENTS

Fan – 1
LED bulb – 1
15 A sockets – 3
5 A sockets – 3
Switches - 8



S1----------
SWITCHES – 2
15 A SOCKET -1
5 A SOCKET - 1
S2----------
SWITCHES – 4
5 A SOCKET – 1
15 A SOCKET -1
S3 X 2--------
SWITCHES – 2
15 A SOCKET – 1
5 A SOCKET - 1

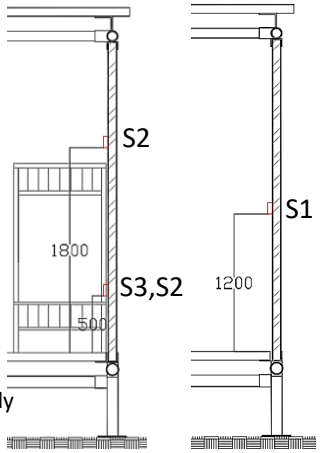


Living block

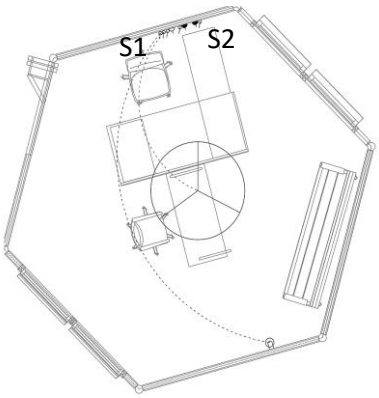
TOTAL ELECTRICAL EQUIPMENTS

Fan – 1
LED bulb – 1
15 A sockets – 2
5 A sockets – 8
Switches - 12

NOTE: S2 has been provided for below and above user both separately which makes it total 4 above + 4 below = 8



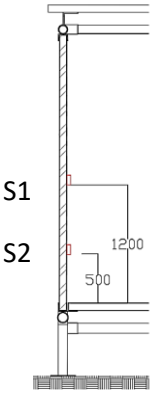
S1----------
SWITCHES – 2
S2 X 8-------
SWITCHES – 1
5 A SOCKET - 1
S3 X 2-------
SWITCHES – 1
15 A SOCKET - 1



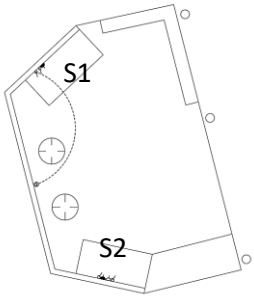
Office block

TOTAL ELECTRICAL EQUIPMENTS

Fan – 1
LED bulb – 1
15 A sockets – 2
5 A sockets – 2
Switches - 6



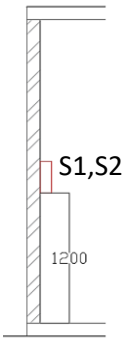
S1----------
SWITCHES – 4
5 A SOCKET - 2
S2----------
SWITCHES – 2
15 A SOCKET - 2



Kitchen

TOTAL ELECTRICAL EQUIPMENTS

LED bulb – 1
15 A sockets – 2
5 A sockets – 2
Switches - 5



S1----------
SWITCHES – 3
5 A SOCKET – 2
S2----------
SWITCHES – 2
15 A SOCKET - 2

ALL IN MM
N.T.S

Electrical equipment detail and layout

TRANSPORTATION : ----------

Transportation is very important
In our concept as it is DESIGN TO TRAVEL. Road transportation plays a major role. To understand vehicles which can be used for road transportation following data has been provided.
the figure on right shows mostly used trucks for transportation which gives us a vast option. Choosing one is a challenge.

Tata 407 Capacity: 2300 Kg
Details: With a dimension size of 9.5ft x 5.5ft x 5.5ft. This is an ideal vehicle light loading..

Truck LPT Capacity: 4500 Kg
Details: With a dimension size of 17ft x 6ft x 6ft. This is an ideal vehicle light loading..

Truck LP Capacity: 9000 Kg
Details: With a dimension size of 17.5ft x 7ft x 7ft. This is an ideal vehicle light loading..

Truck Toursh Capacity: 15000 Kg
Details: With a dimension size of 22ft x 7.5ft x 7.5ft. This is an ideal vehicle light loading..

Container Capacity: 7500 Kg
Details: With a dimension size of 32ft x 8ft x 8ft. This is an ideal vehicle light loading..

Container Capacity: 15000 Kg
Details: With a dimension size of 32ft x 8ft x 8ft. This is an ideal vehicle light loading..

CALCULATING WEIGHT OF 1 MODULE :

42.8 Kg/m2 - wall-panel
Total wall panel in one module- 6
Dimension of each panel = 2.8 x 2.5 (l x h) (in M)
Area of 1 wall panel = 7sq.m
Weight of total wall panel/module = 7 x 6 x 42.8 = **1797.6 kg**

Similarly,

Weight of beam = 12kg/m
Total length of beam used in one module = base beam + top base beam + top roof beam + roof beam + perimeter beam for roof + perimeter beam for floor= (4.33 x 2) + 5 + (4.33 x 2) + 5 + (2.5 x 6) + (2.5 x 6) = 57.32 m
Therefore, total weight of beams = 12 x 57.32 = **687.84 kg**

Weight of column = 12kg/m
Total length of column = 2.8 + 1 (1 m here shows the part of column going inside telescopic plinth) = 3.8m
Total columns = 6 therefore, total length to column = 3.8 x 6 = 22.8 m
Total weight of column/module = 22.8 x 12 = **273.6 kg**

43 Kg/m2 – roof panel and floor panel
Total panel in one module- 2 (including roof and floor panel)
Area of each panel = 16.24 sq.m
Area of both panel = 16.24 x 2 = 32.48 sq.m
Weight of both panel/module = 32.48 x 43 = **1396.64 kg**

TOTAL WEIGHT OF ONE MODULE = 4155.68 KG

For transportation if we use TATA truck of capacity 15,000 kg it can hold parts of 3 and half module.

Material List

Wall

Wall Panel – Fiberboard sandwiched between AAC blocks (100mm thick) - Rs 130/m2 – weight: 43kg/m2

Hinges – Stainless steel Double Ball Bearing (5” x 3” x 3”) – Rs 150/piece

Louvers – Aluminum Louvers (1.5mm thick) – Rs 150/sqft

Acrylic Sheet (20 mm thick) – Rs 50/sqft

Rotating steel stopper – Rs 200/piece

Door – Upvc Door – Rs 290/sqft

Total cost of wall – Rs 44980 (for 1 unit)

Total cost of wall – Rs 1124500(for 25 units)

Roof

Plano Roofing Tiles (50cm x 50cm) – 190/sqft

Total cost of roof panels – Rs 7175 (for 1 unit)

Total cost of roof panels – Rs 179375(for 25 units)

Floor

Plywood (8’ x 4’ x 75mm) – 20/sqft

Total cost of floor – Rs 3500 (for 1 unit)

Total cost of floor – Rs 87500(for 25 units)

Steel Structure

U shaped Channel – Rs250/piece

Round Channel – Rs39/piece

Round Beams – Rs220/piece

Gap Joint – Rs560/construction

K joint – Rs 75/piece

Steel Plate – Rs 220/piece

Steel Holders – Rs 250/piece

Foundation Bolts – Rs 150/piece

Total cost of structural fixtures – Rs 18954 (for 1 unit)

Total cost of structural fixtures – Rs 473850(for 25 units)

Electrical

Ceiling Light (13 W) x 1 – Rs 550

Ceiling Fan (32W) x 1 – Rs 2700

Sockets x 10 – Rs 350

Wiring – Rs 500

Total cost of electrical fixtures – Rs 7350 (for 1 unit)

Total cost of electrical fixtures – Rs 183750(for 25 units)

Renewable Energy Generator & Miscellaneous

Water Tank – Rs 2.75/litre – 10 overhead water tanks (10000litres) – 27500 – 1 underground water tank (20000 litres)

Solar Panels - 6000/piece

Total cost of water tanks – Rs 330000

Total cost of solar panels – Rs 600000

TOTAL COST OF PROJECT –

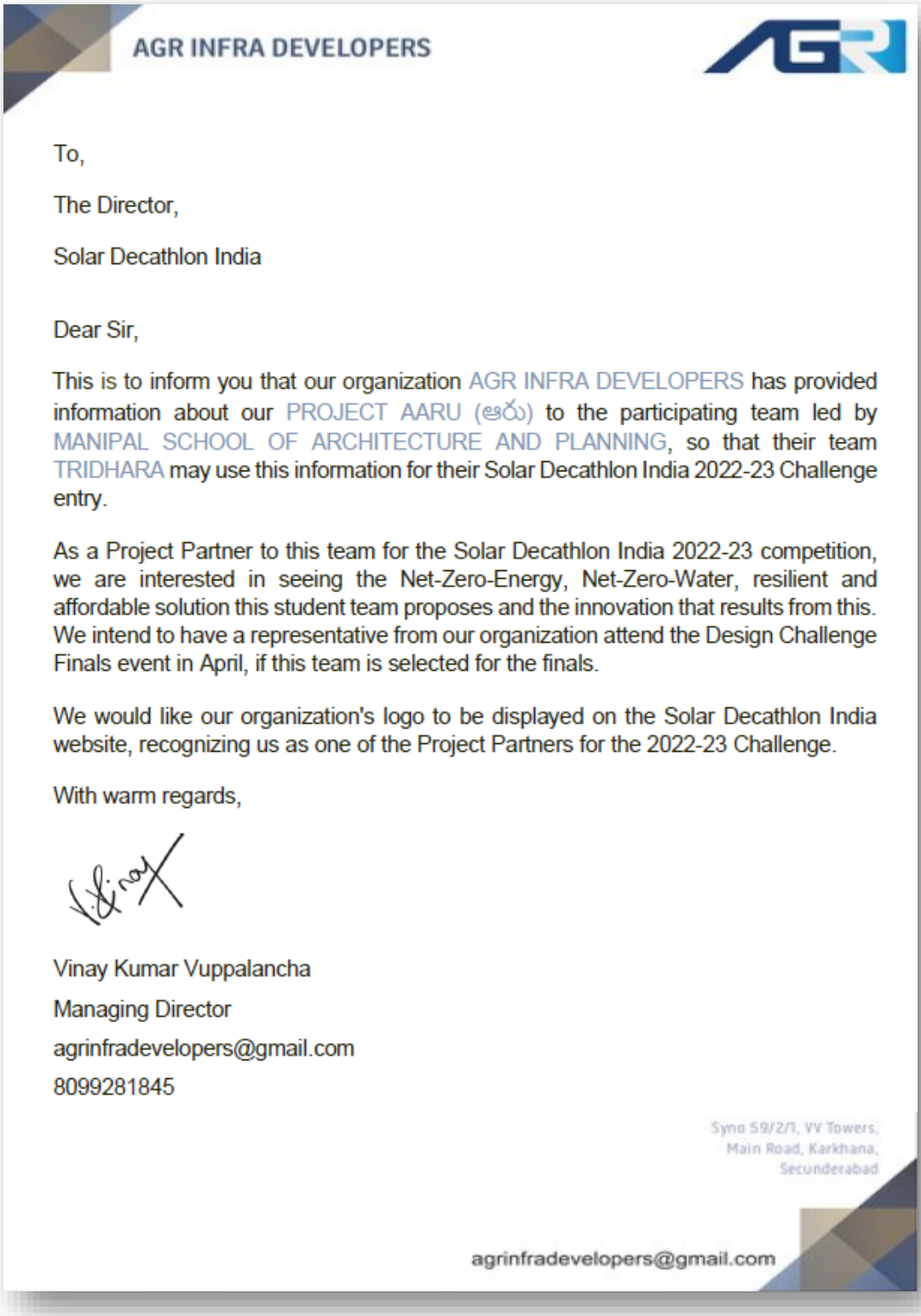
Rs 2978975

Conclusion:

Cost of construction for base case – Rs 2825475 (Material life span 5 years)

Cost of construction for the proposed case – Rs 2978975 (Material life span 10 years)

CONFIRMATION LETTER



AGR INFRA DEVELOPERS

To,

The Director,

Solar Decathlon India

Dear Sir,

This is to inform you that our organization AGR INFRA DEVELOPERS has provided information about our PROJECT AARU (ఆరు) to the participating team led by MANIPAL SCHOOL OF ARCHITECTURE AND PLANNING, so that their team TRIDHARA may use this information for their Solar Decathlon India 2022-23 Challenge entry.

As a Project Partner to this team for the Solar Decathlon India 2022-23 competition, we are interested in seeing the Net-Zero-Energy, Net-Zero-Water, resilient and affordable solution this student team proposes and the innovation that results from this. We intend to have a representative from our organization attend the Design Challenge Finals event in April, if this team is selected for the finals.

We would like our organization's logo to be displayed on the Solar Decathlon India website, recognizing us as one of the Project Partners for the 2022-23 Challenge.

With warm regards,

Vinay Kumar Vuppalancha

Managing Director

agrinfradevelopers@gmail.com

8099281845

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Main Road, Karkhana,
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