CEPT UNIVERSITY

Solar Decathlon India

Team 0:0:0

Multi Family Housing for Savvy Infrastructures Pvt Ltd

Final Design Report | April 2021

Contents

List of Tables

List of Figures

1.0 Executive Summary

A net zero energy, multi-family housing project is a relatively less explored area in the building industry. A net zero energy and water design are even more so. Team 0:0:0 from CEPT University upgraded the Savvy multifamily housing project located in Ahmedabad to triple zero design, that has net-zero energy and water, and has minimal waste thrown out from the system. The design process was developed with a data driven, integrated design approach by a multidisciplinary team from building science, architecture and engineering disciplines along with the technical support of industry partners.

The project was envisaged by the Savvy group of Ahmedabad to fill an important housing gap in the local residential market - compact, affordable 1-bedroom units for the middle-income group. The density of this project (2144pph) is much higher than other affordable housing projects like Aranya in Indore (300pph) and Tara Apartments in Delhi (375 pph). Achieving net-zero status for a high population density site within the scope of the affordable housing sector, shows the scope for net zero status for other residential scenarios.

Energy and water use in residential buildings is driven to a large degree by building occupants. Data was gathered regarding the prospective building occupants for this project from multiple sources (e.g., Google search volume trends, publicly available demographic data and a bespoke survey especially designed for this project). The survey (240 respondents) gave us insights into potential conflicts between occupant's expectations from their personal living environment and the goals of the project. For example, explicit provision has been made in our design proposal to give access to at least one open to sky terrace to all occupants which would have otherwise been used to install a larger PV array. This led to creating a user-oriented design where needs and interest of the occupants are given importance.

With careful considerations to principles of building science, affordability of users, market forces and user's desire to upgrade their lifestyle, a Renewable Energy Service Company (RESCO) model has been adopted for solar photovoltaic systems. The model has also been extended to making active cooling systems accessible to all occupants as a service, which, if purchased and operated individually, would be beyond the financial means of the occupants of the intended income group.

A total number of 530 dwelling units that have an EPI of 22.1kWh/m^2-yr are provided. The rooftop array helps attain net positive energy target by generating 23.1kWh/m^2-yr of energy. Net water is attained by reducing water usage by efficient fixtures, rainwater harvesting and wastewater treatment. The waste generation is limited by reusing the waste for energy production. The resulting design achieved full FSI with an incremental cost of almost Rs. 3.2 crores and an annual operational savings of Rs. 10,560 for every apartment in terms of their electricity bills.

2.0 Team Summary

2.1 Team Name — 0:0:0 *(Zero is to Zero is to Zero)*

2.2 Division — Multi-Family Housing

2.3 Team

Mili Jain	Amar Agrawal	Jayati Chopra	Dhruvi Gami	Urvi Shah	Ayushi Mishra	Archie Parakh	Uma P	Roota Trivedi

2.4 Institute - CEPT University

CEPT University is recognized internationally for high quality research and practical experience in energy efficiency and net-zero energy buildings. As part of the M.Tech program in Building Energy Performance, students learn to assess building energy performance using simulation tools. They tackle complex technical problems and participate in a multidisciplinary environment. Research work done at Center for Advanced Research in Building Science and Energy (CARBSE) at CEPT, **learning at a net-zero-energy building, and the array of testing and metering equipment,** allow students to be extremely hands-on.

(a) (b)

Fig. 1 a) CEPT University, b) Net-Zero Energy Building (NZEB) on campus

2.5 Faculty Lead - Prof. (Dr.) Minu Agarwal

Adjunct Assistant Professor, Faculty of Technology, CEPT University Prof. Agarwal is a researcher in the field of performance driven building design. She is an experienced LEED consultant who has worked through 3 generations of the LEED rating system with developers, architects and mechanical engineers. She was also a key contributor to first successful Living Building Challenge project.

2.6 Industry Partners

Water
Dipen Mehta
Aqua Utility Designs and Management Pvt Ltd

Water
Naimish Mehta
Technogas Systems Pvt Ltd

Photovoltaic
Karan Dangayach
Shashwat Cleantech

Prefab
Shabbir Lokhandwala
Slabs Engineering Pvt Ltd

Biogas
Ashish Vaishnav
Gangotree Energy Projects Pvt Ltd

Sustainability
Vardan Soi
CoLead LLP

3.0 Project Summary

3.1 Project Name - Savvy Studioz

3.2 Project Partner - Savvy Infrastructures Pvt. Ltd.

The Savvy group was established by Mr. Jaxay Shah, Mr. Sameer Sinha and Mr. Jigish Shah in 1996 as a professional construction group to satisfy the needs of the discerning customer interested in prime commercial or residential space. Savvy is well known for its integrated design & construction and they take extra efforts to ensure energy efficiency, water & waste management and user's comfort using latest innovative technologies across all their residential projects.

The 0:0:0 team is working closely with Mr. Sameer Sinha, MD of Savvy group and Chairman, CII-Indian Green Building Council (IGBC) and Ms. Ruchi Gandhi, Project Manager at Savvy group, who has led the 'Savvy Studioz' project right from the initial planning stages.

3.3 Project Description

Situated in the hot and dry climate of Ahmedabad, the project is meant to provide affordable, 1-BHK starter homes to the young working class. The project is currently under-construction and anticipates occupancy by August 2022. The project has a build-sell-operate model as per requirements of Gujarat RERA. The Savvy group will lead formulation of the RWA that will undertake maintenance of the common infrastructure after the first 5 years.

(a) (b)

Fig. 2 Site Location a) with respect to Sabarmati River, b) within Gota, Ahmedabad (Source: Google Maps)

3.4 Special Requirements of Project Partner

- The developer has purchased extra FSI to ensure profitability on the project. A minimum FSI of 2.7 is to be achieved for the site. This gives the project its high density.
- No substantial increase in costs can be currently incorporated.

3.5 Context and Market Analysis

Provision of housing is a basic human necessity. With the increasing population, high land values and higher rates of under and unemployment, affordable housing is means for people to have a roof over their heads and create a motivation to strive for better living. Net-zero energy, water and waste design will help communities and people to attain comfortable living with minimal stress on their finances. Additionally, Net zero building is generally expected to be an expensive investment which has not seen its application much on the housing sector. Hence provision of net zero building in the affordable housing sector will be a game changer to most of the population while being sensitive to the environment around us.

The population density on site is 81% more than the Pol areas (old city) of Ahmedabad and 89% more than the entire city of Ahmedabad. **Achieving net-zero status for a high population density site in the affordable housing sector shows scope for net-zero status for other residential scenarios.** The design when compared to many of the known cities in the country and the world aims to work towards housing sufficiency to the ever-increasing population while being considerate the environment.

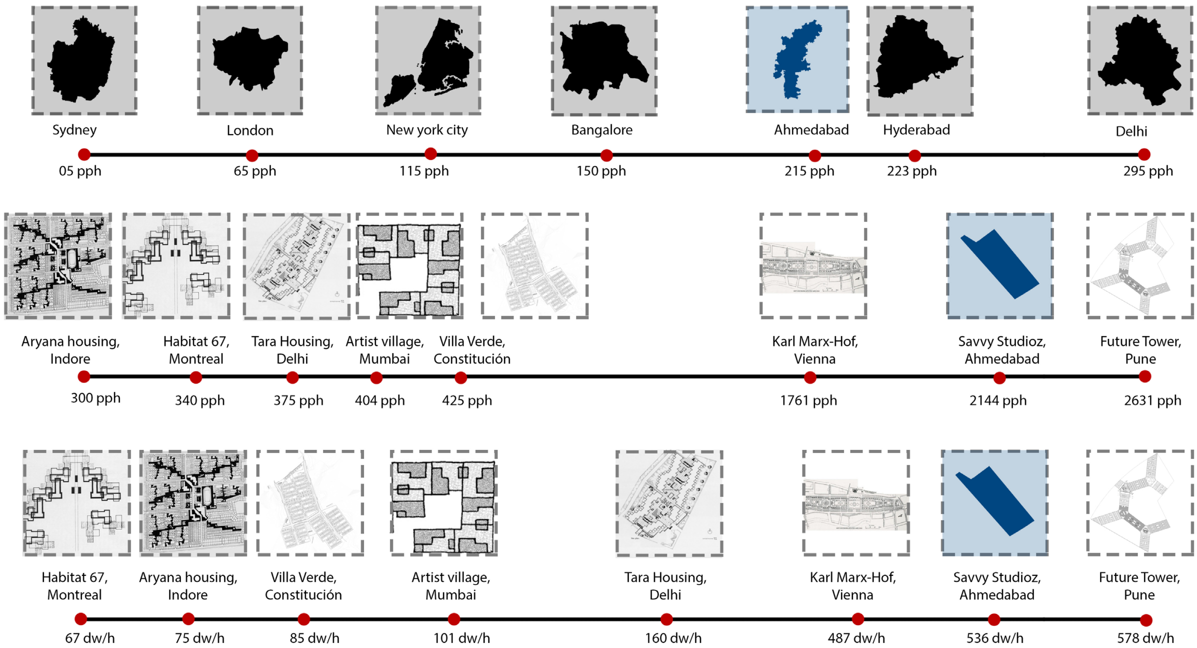


Fig. 3 Understanding the project through densities (Persons per hectare (pph)) (Dwellings per hectare (dw/h)[a]

3.6 Site & Building Program

The building area program has been defined by the Project Partner. Additional FSI purchased by them has increased the site FSI to 2.7. The project also has about 1,500 sqm of area that includes ancillary activities like Aanganwadi, Temple and Community Hall. While this area will be considered in the architectural design and site planning interventions, it is out of scope of all net-zero targets and related interventions.

Table 1 Developmental Norms

Information	Area(sqm)	Notes
Plot area	8,934	*As received from Project Partner*
Build-able Area (For FSI=1.8)	16,081	*As per General Development Control Regulations (GDCR), Gujarat*
Additional Build-able Area (Purchased FSI=0.9)	8,041	*Bought by the Project Partner*
Total Build-able Area	24,121	*FSI = 1.8+0.9*
Total Built Area	22,197	*As per Table 15*
Remaining Area	1,925	*Additional Area*

a Praja Foundation. Housing, FSI, Crowding and Densities - Handbook Vol I (S. B. Patel (ed.); Vol. 1). Praja Foundation.

4.0 Project Specifications

As per the climatic zone classification, Ahmedabad qualifies as Hot and Dry. The climate is characterized by high temperatures in summer and low temperatures in the winter. Low humidity levels are observed throughout the year.

Table 2 Performance specifications for the project

Parameter		Values
Envelope (U-Values)	Wall	0.8 W/m^2K
	Roof	0.8 W/m^2K
Glazing Specification	U-Value	2.7 W/m^2K
	SHGC	0.75
	VLT	0.8
HVAC System	System type	Shared VRF system (Cooling as a Service)
	Condenser	Air cooled
	Cooling Capacity	344.5 kW
	COP	3.3
	Annual Unmet Hours	234 hrs
	Conditioned Area[a]	4294 m^2
	Unconditioned Area	17905 m^2
Lighting	LPD	3.1 W/m^2
Equipment	EPD (Residential)[b]	35.7 W/m^2
	Installed Equipment (Common)	1240 W
On-Site Consumption	EPI	22.1 kWh/m^2-yr
On-Site Generation	Type	Photovoltaic panels
	Installed Capacity	297.4 kWp
	Efficiency	21%
	Total Energy Generation	478,235 kWh
	Water required for maintenance	3 liters/ panel / week
Water Systems	Total water demand (Liters per day)	172 kLPD
	Rainwater storage tank	600 m^3
	Recycled water	98 m^3
Waste system	Waste generation	965 kg per day
	Hot water produced	42k liters per day for winter using 530kg of organic waste

a (Mishra et al. (2021) (Under review)) showed that 35% of the households have 1 air conditioner and 72% of them are installed in the bedroom area hence the project considers one AC per unit leading to a conditioned area of 4294 m^2

b To establish consistency in the use of occupancy, lighting, and equipment schedules were developed using the high-resolution stochastic model for residential buildings called CREST developed by the Loughborough University, UK.

5.0 Goals

The team name "0:0:0" is representative of the three major goals for the project; **Net-Zero Energy**, **Net-Zero Water** and **Net-Zero Waste**.

Net Zero Energy - The amount of energy generated by on-site renewable energy sources will be equal to (or greater than) the amount of energy used by the building annually.

Net-Zero Water - As per United States Environmental Protection Agency (USEPA), achieving Net Zero Water means limiting the consumption of water resources and returning it to the same watershed so as not to deplete the resources of that region in quantity or quality over the course of the year.

Near-Zero Waste - Project aims to reduce, reuse, and recover waste streams by converting them into valuable resources along with ensuring proper measures for the safe disposal of hazardous/ toxic waste.

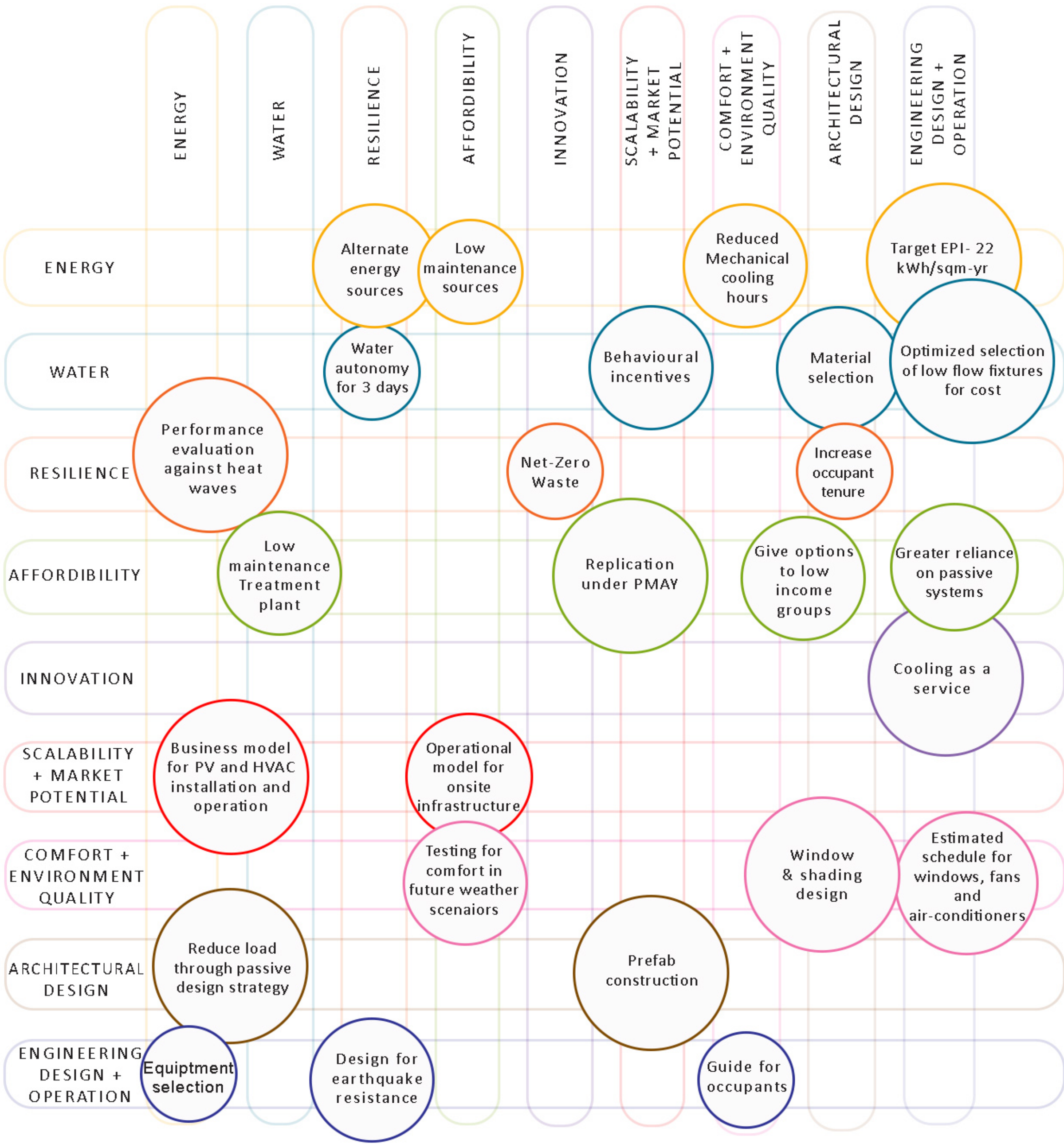


Fig. 4 Goals for the project based on competition guidelines

6.0 Documentation of Design Process

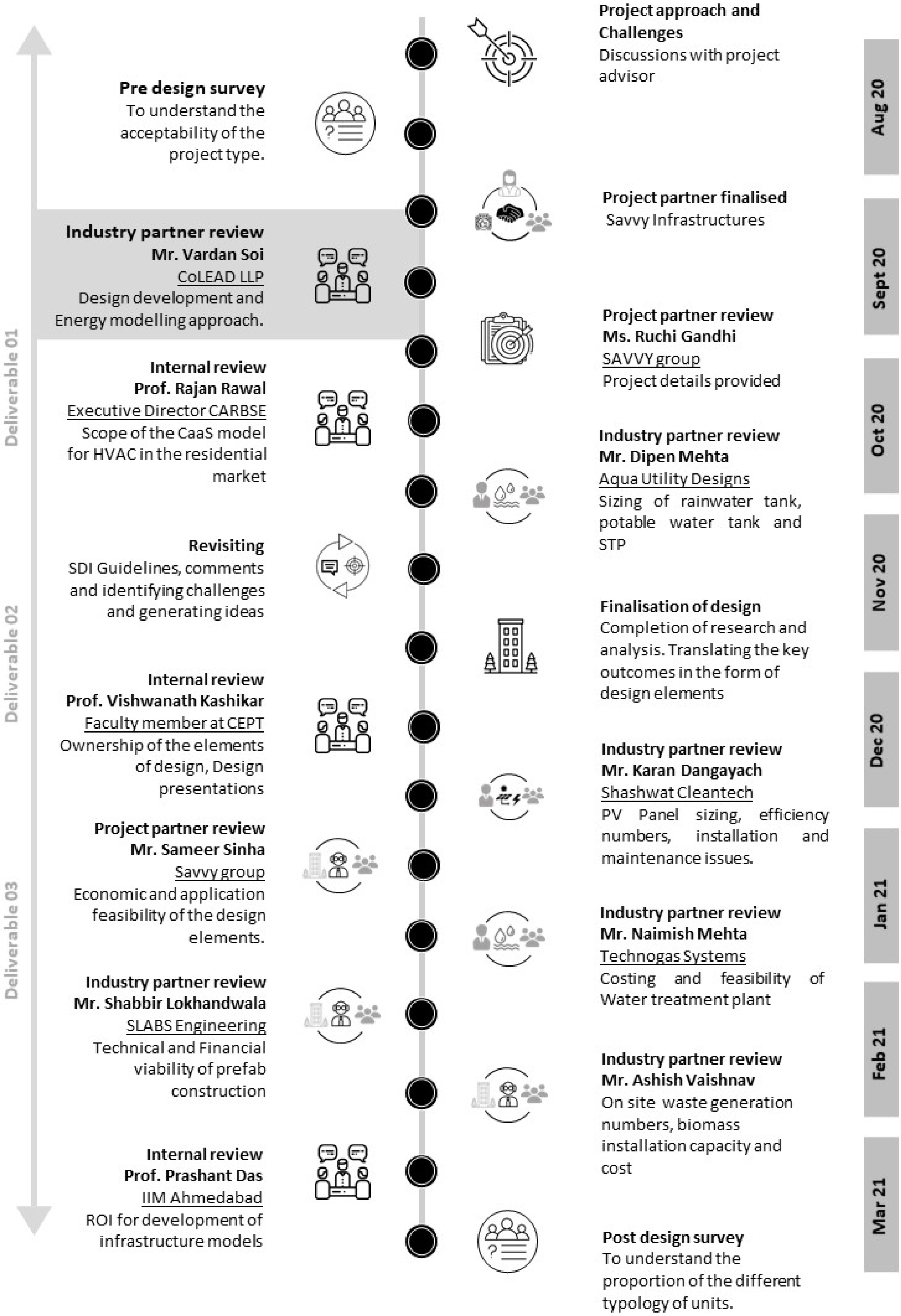


Fig. 5 Design process timeline with internal and external reviews

6.1 Case Studies

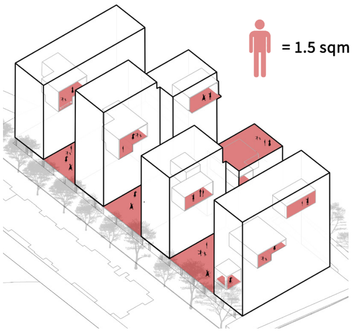
Based on a preliminary objectives, appropriate case studies were identified and explored. A macro and a micro level study has been conducted on the areas mentioned in Figure 4. At the macro level, study has been segregated into five broad categories which further branches out to specific technologies, materials and design approaches.

Table 3 Case Studies for Different Aspects of the Project

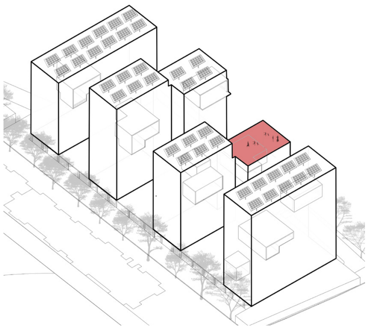
	Architectural Design		Passive strategies	Water Conservation	Resilience	Renewable energy systems			Innovative technologies and Materials
Name	**Unit level approach**	**Façade systems and balcony**	**Natural Ventilation (Stack and Buoyancy)**	**Rain water harvesting**	**Earthquake safe construction**	**BAPV & BIPV**	**Solar Hot water systems**	**Biomass**	**MIVAN Construction**
Aranya Housing, Indore	√	√							
Tara Housing, New Delhi	√	√							
LIC Housing, Ahmedabad	√	√							
Tel Aviv Arcades, Israel		√							
Solstice on the Park, Chicago		√							
Empresa de Desarrollo Urbano, Medellin			√						
CH2 Melbourne City Council House, Melbourne			√						
IFFCO Township, Kalol, Gujarat		√		√					
MLDL, Chennai					√				
ACC Greens Village								√	
Bursagaz, office building, Turkey						√			
The General, Mixed use residential, Melbourne						√			
DEWA, R&D Centre, Dubai						√			
Suvidha Housing Society, Bangalore							√		
Oricon Scorpio, Pune	√			√			√		
Sucheta community, Bangalore								√	
Aparna Sarovar Zenith, Hyderabad									√

6.2 Challenges and Responses

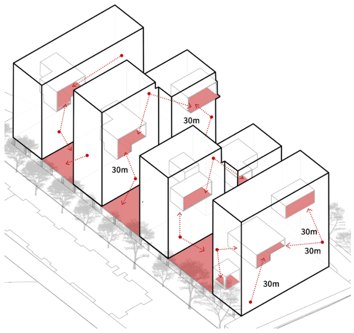
Challenge 1 - Insufficient open spaces for cultural activities like Makar Sakranti and Garba for the given FSI and on-site energy generation targets.



Provide open areas @ 1.5 sqm/person[b]

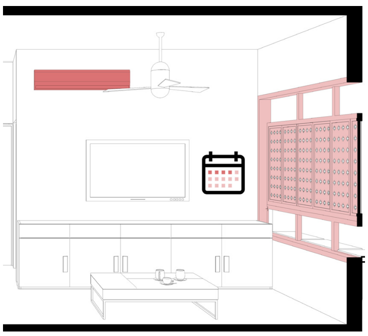


Usable Terrace Area (atleast 15% of Roof Space)

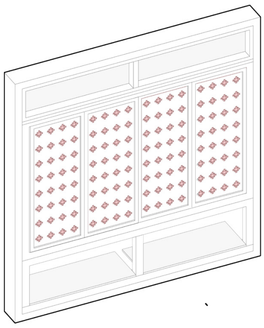


Provision of open area within 30m of every unit

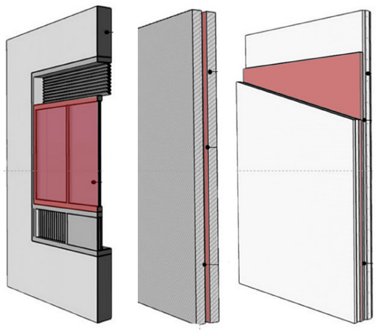
Challenge 2 - Reducing electrical consumption to be able to meet EPI goals without utilizing the entire terrace



Hours with need for refrigerant-based mechanical cooling < 1000 hours for every apartment

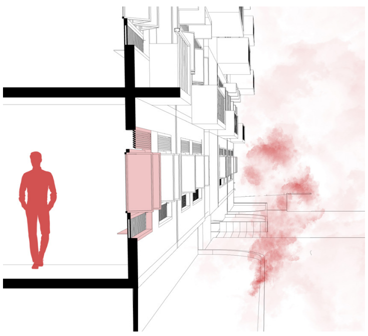


Possibility to reduce heat gains in summer with flexibility in effective WWR (12% to 30%)



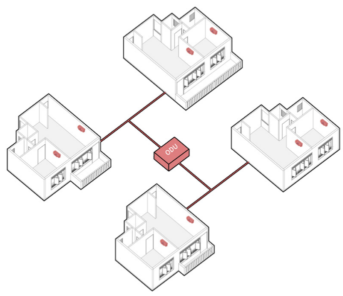
Wall and window insulation tested to perform during heatwaves

Challenge 3 - Ensuring implementation of proposed Strategies



Considering impact of poor AQI on natural ventilation as a strategy

Promote use of BEE 5-star rated equipment to reduce consumption due to equipment by 50%[c]



Affordability of air-conditioning system ensured through RESCO-based operational model

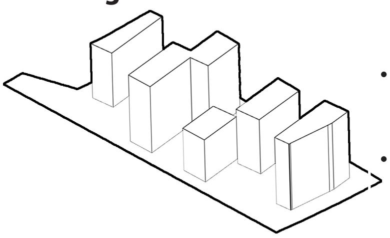
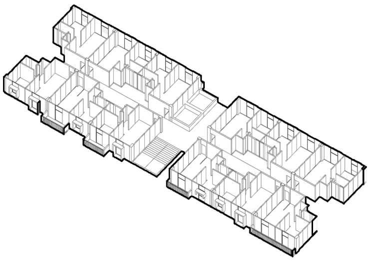
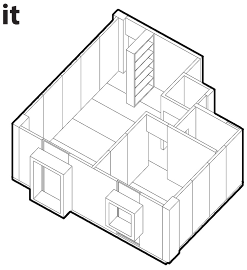
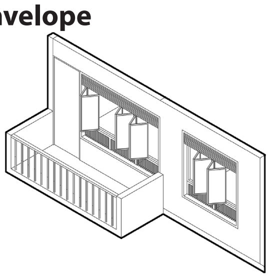
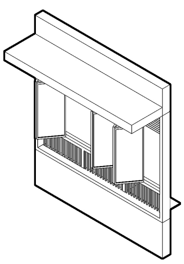
b Need for safe, accessible open areas is crucial, now more than ever (Considering the on-going pandemic). (https://www.downtoearth.org.in/blog/urbanisation/covid-19-and-green-open-spaces-what-is-going-to-be-our-new-normal--71501)

c A recent survey of affordable homes revealed that the energy usage of naturally ventilated affordable homes was much more closely related to the total wattage of the home appliances owned by a household than the design related factors such as orientation, window etc. (https://indianexpress.com/article/india/gujarat-study-to-focus-on-thermal-comfort-and-energy-use-in-affordable-houses-6118460/)

6.3 Design Process - 5 Step Optimization

Understanding the project brief and requirements led to explorations on five different scales of the project. The strategies used for the different scale were selected based on the targets set for the project. For instance, irradiation of walls was minimized to reduce heat gain at the massing level. The unit was iteratively fed into the massing script as it got more and more optimized for prefab construction. This helped in increasing robustness and reliability of the top options for each scale.

Table 4 Process, parameters and tools used to conduct five-step optimization

Optimization	Strategies / Process	Parameters	Tools
Massing 	• Minimized irradiation on walls • Maximized irradiation on roofs • Maximize Views (Horizontal Angle angle and Layers of Environment)[d]	Number of Towers Orientation Number of Floors	Grasshopper with Ladybug
Floor Plate 	• Placement of Open Areas within Mass • Low discomfort hours in free running model (50% window open) • Minimize cooling loads	Aspect Ratio (Tower Widths)	Grasshopper with Ladybug Design Builder
Unit 	• Maximize daylight (depth and time of penetration) • Optimization of module elements (size and weight) for prefab construction	Internal Layouts Module Sizes	Design Builder
Envelope 	• Shoe-box Modeling • Variation in provisions of balcony • Performance of envelope in 2050	WFR U-Values	Design Builder
Shading 	• Use of horizontal and vertical shading elements as per orientation and location in terms of height • Window design for vision, light and ventilation panels	Response to Winter Sun vs Summer Sun Material Quantities	Design Builder Sun Path - Andrew Marsh Tools[e]

d Views quantified as per recommendations of IES-LM-83 and EN 17037
e http://andrewmarsh.com/apps/staging/sunpath3d.html

7.0 Ten Contests

7.1 Energy

7.1.1 Climate Analysis and Passive Strategies

Implementation of passive design strategies is the first stepping stone on the path to design net zero energy building. Passive design strategies are features that guide to the form and design of a building that channelize available natural resources to ensure thermal comfort. These climate specific approaches based on sun, wind, light and micro-climatic considerations help in designing net zero energy buildings. The decisions about building form, orientation, shading, and ventilation, taken during the early design stage have the most significant impact on the energy use of the building. Proposed Passive design strategies aim at reducing cooling requirements during the summer and heating in the winter through appropriate orientation, external shading, appropriate amount of glazing, and natural ventilation.

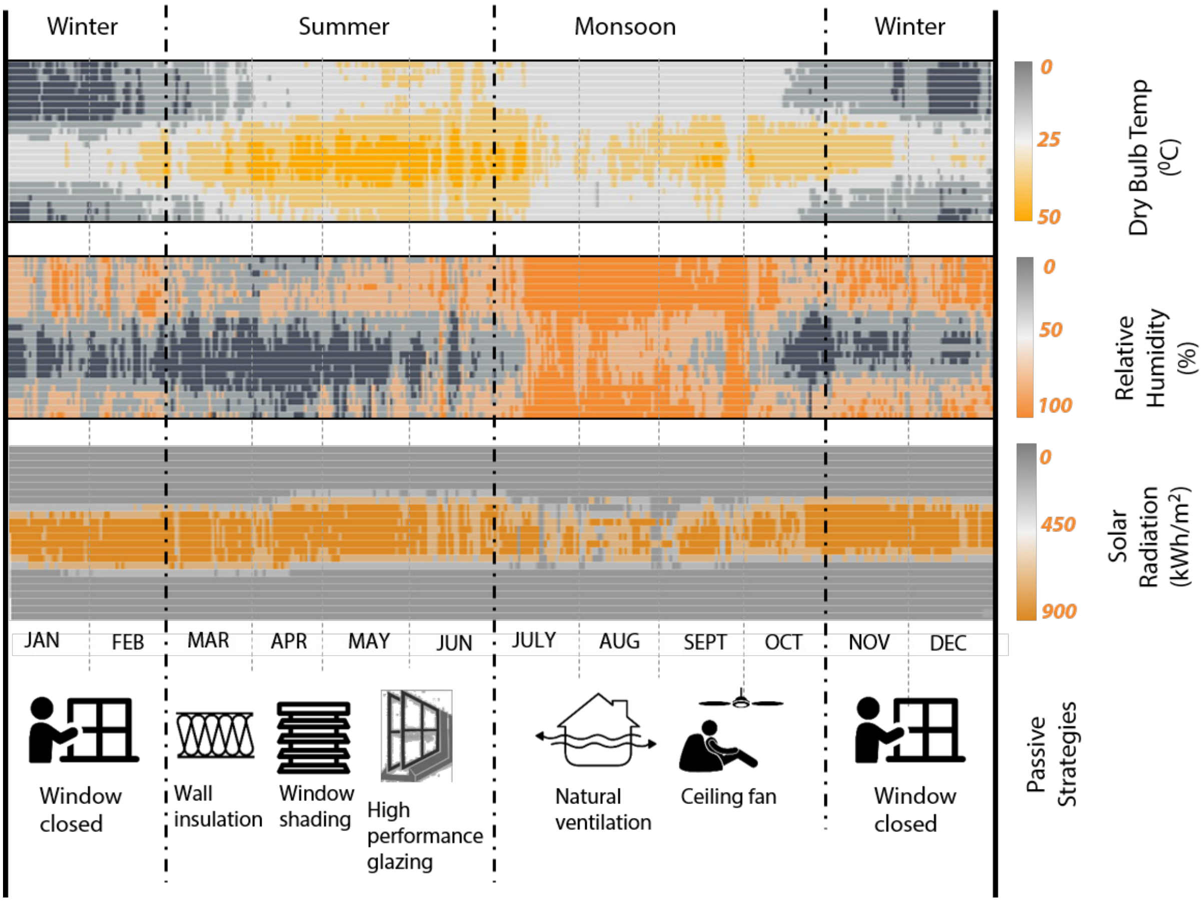


Fig. 6 Potential passive strategies determined through evaluation of climate of Ahmedabad

7.1.2 Massing Optimization

The building area program opens a range of possibilities for master planning on the site. The geometric possibilities of design on the site were tested with a fixed ground (30%) and maximum height (45m/14 floors). The parametric inputs selected for this exercise were number of towers, orientation, aspect ratio and number of floors. The outputs generated from this parametric exercise were more than 500 in number (as illustrated in Fig. 7).

Minimum irradiation on walls and maximum irradiation on the roof were used to shortlist the options to almost 80. Further on, fewer towers and wider floor plates were given preference to maximize area served by a circulation core. This lead to 4 massing options that were detailed for floor plate and unit configurations. The third filter considered was a quantitative analysis of views as detailed in the Section on Comfort and Environmental Quality.

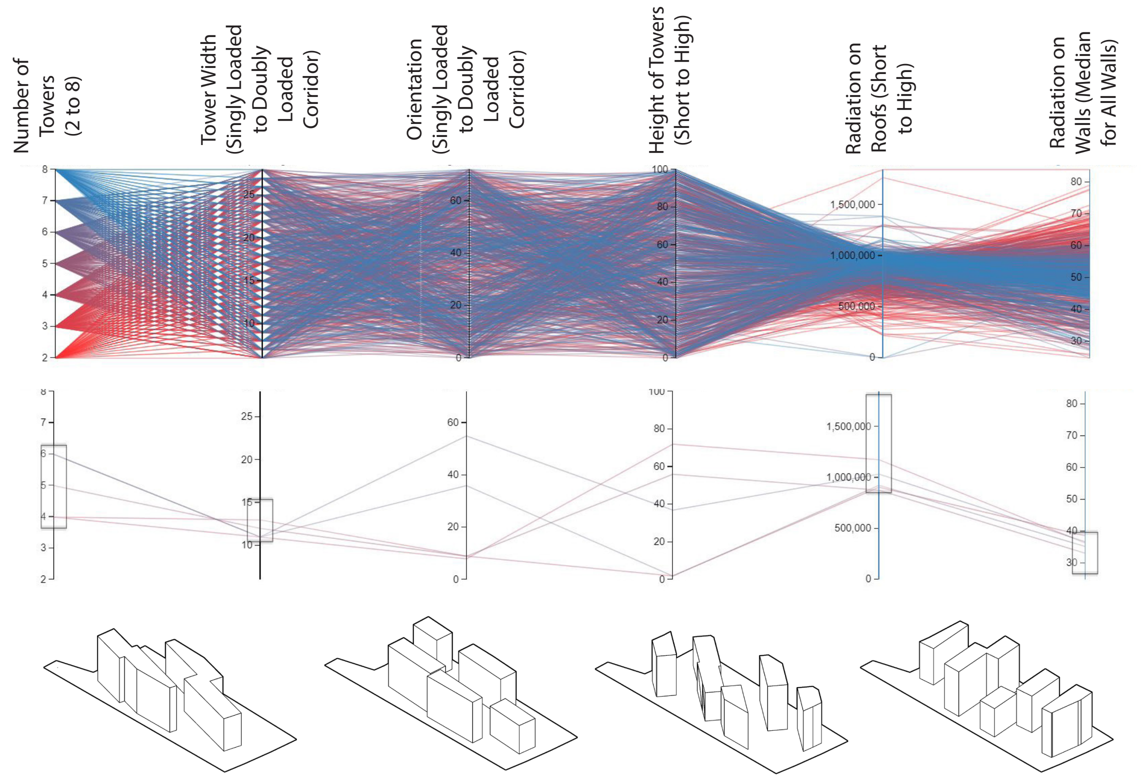


Fig. 7 Parametric study for massing optimization Top) all possible options, Middle) shortlist based on maximum irradiation on roof, minimum irradiation on walls, widest floor plate and least number of towers, Bottom) Top 4 massing options shortlisted

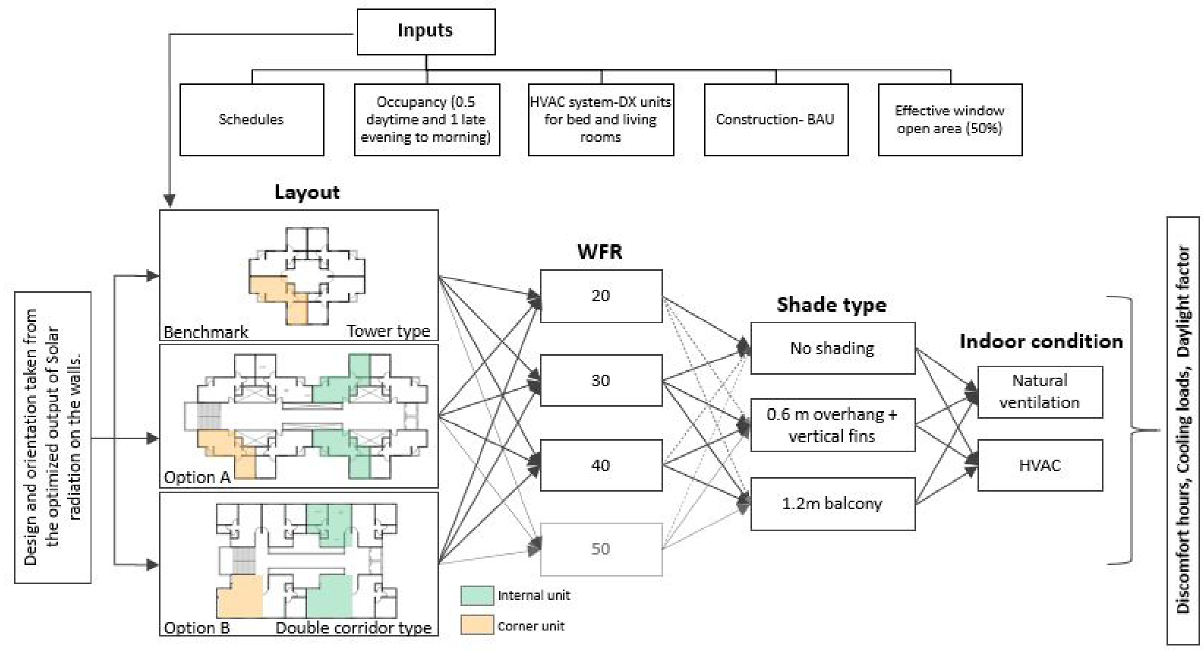


Fig. 8 Simulation considerations and iterations

Floor Plate Optimization

Using the derived floor plate depth and building height, a shoe-box model was simulated to decide the floor plate layout, WFR, and shading type. The parameters of the study and outputs analyzed have been illustrated in Fig. 8. The inputs and considerations of the shoe-box are elaborated in Appendix. Simulation results of the design shows that the Option B design with a WFR of 30 with 0.6m shading is the option that can be taken forward for the architectural design. The option has the least cooling load while providing a daylight factor greater than 2% in all the rooms (analyzed at 1m from the darkest wall). Daylight factor greater than 2% hints towards availability of daylight in a room under an overcast sky condition. The compact design of Option C has 17% less discomfort hours in the southwest unit living room compared to the living room in benchmark typology with the same WFR as the walls and fenestration have lesser exposed surfaces and hence lower heat gains.

7.1.3 Shading Optimization

The indoor temperature and relative humidity of the apartments simulated in the shoe-box model have been plotted in Fig. 9. Based on the comfort bands recommendations, a potential scheduled was developed for natural ventilation, ceiling fans and an active cooling (or air-conditioning) system. This developed schedule has been used in further energy simulations. The window design has also been developed in tandem to support thermal comfort in the varied conditions that may occur.

- Based on the Indian Adaptive thermal comfort model (IMAC) 90% acceptability limit and PM 2.5 and PM levels, the schedule of window operation is derived taking into account the occupant behaviour.
- The PM levels are referred from CPCB standards and the levels which fall below moderate levels are considered as good air quality
- The potential of ceiling fans to reduce the hours of active cooling (hours which fall above IMAC MM upper band) is offset by 1.8 C at 0.9m/s (as per LECaVIR report)
- The hours which fall above the ceiling fan band requires active cooling.

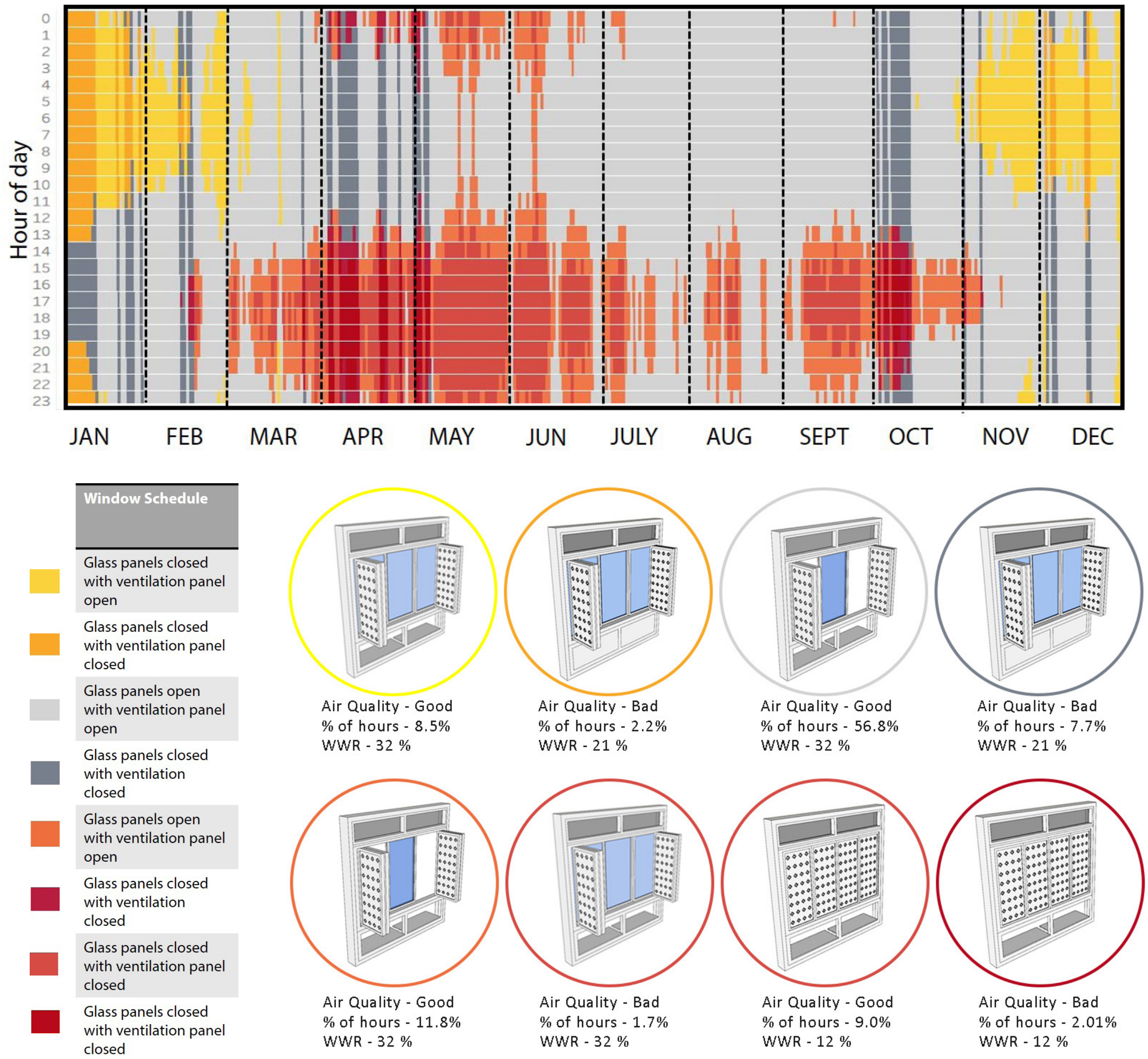


Fig. 9 Operational schedule for windows, ceiling fans and air-conditioning

7.1.4 Envelope Optimization

The envelope U value was decided through a parametric analysis of the possible combinations and its impact on the cooling loads and the total energy use. The best options were then analyzed over its cost implication. The transmittance of the wall is reduced with the use of Insulation. The roof and window transmittance is reduced by providing an air cavity. The details of the envelope selected are presented in the table below. Costs of the envelope have been determined as part of the costs of the prefabricated panels.

Table 5 Thermal properties of the envelope

	Base Case		Proposed Case	
	U Value(W/m²-K)	Assembly	U Value (W/m²-K)	Assembly
Wall	2.5	15mm plaster + 200mm brick+ 15mm plaster	0.8	75mm concrete +30mm XPS + 75mm concrete
Window	5.8	4mm clear glass	2.7	4mm clear glass + 13mm air gap + 3mm clear glass
Roof	4.3	15mm plaster + 130mm concrete+ 15mm plaster	0.84	60mm concrete + 30mm air gap + 60mm concrete

7.1.5 Energy Performance Index (EPI)

Energy performance index depicts the annual energy consumed per unit area of the built space. The access the energy consumed and its reduction on the implementation of the energy conservation measures, a base case is developed. To establish consistency in the use of occupancy, lighting, and equipment schedules were developed using the high-resolution stochastic model for residential buildings called CREST[1] developed by the Loughborough University, UK. The HVAC and window opening schedules used is as shown in section 2.2.2.

- The base case is the design created by the project partner. The base case has 5 towers forming a shape E in plan. Each of the towers has 12 floors accommodating 536 dwelling units. The envelope was considered to be a simple 230mm brick wall with plaster on either side with a single pane glass and concrete floor slab. The HVAC considered was a split unit air conditioning system. This design attained an EPI of 52.6 kWh/m²-yr.

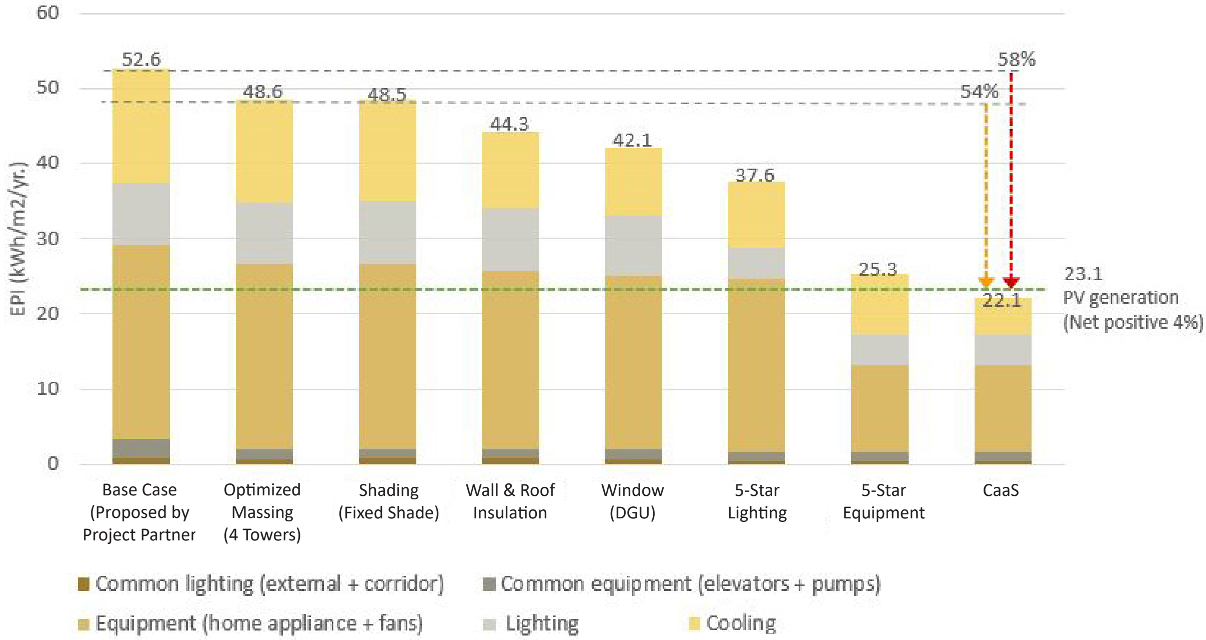


Fig. 10 Reduction in EPI with ECMs

1 Barton J., Thomson M., Sandwell P., Mellor A. (2020) A Domestic Demand Model for India. In: Singh S., Ramadesigan V. (eds) Advances in Energy Research, Vol. 1., pp 743-753 Springer Proceedings in Energy. Springer, Singapore, https://doi.org/10.1007/978-981-15-2666-4_70

- The massing was optimized to ensure minimal solar exposure on walls, maximum sun exposure on roof and optimal tower height, through a detailed solar radiation study. The shoe box allowed the selection of unit type, window size etc. This led to a reduced EPI of 48.6 kWh/m^2-yr.
- Next a detailed study of the sun movement and shading mask, led to the design of shading devices on the different facades of the building, reducing the EPI to 48.5 kWh/m^2-yr by reducing solar heat gains.
- The other element of the building construction that influences heat gains are the walls and roof. Using envelope of lower U value (Table 5), the EPI was reduced to 44.3 kWh/m^2-yr. With use of double-glazed windows (Table 5), the EPI was further reduced to 42.1 kWh/m^2-yr.
- The use of efficient lighting and equipment (as detailed in the appendix) further reduced the EPI to 25.3 kWh/m^2-yr.
- Finally, the HVAC system was changes from a split to a shared VRF system with separate indoor units, leading to a CAAS model. The helped achieve the target EPI of 22.1 kWh/m^2-yr.

7.1.6 On-Site Renewable - Photovoltaics (PV)

A PV plant is proposed to be set up on 85% the roof of the building. 15% of the roof area is kept free of PV and open to the residents. The PV power generation potential is estimated on the System Advisor Model (SAM) developed by NREL (Fig. 11). The tool considers inputs like the panel orientation, and inverters. It also takes into account losses due to cloud cover, module mismatch, wiring defects, soiling etc. The specifications for the Solar Panel considered were based on recommendations of the Industry Partner (as shown in the appendix).

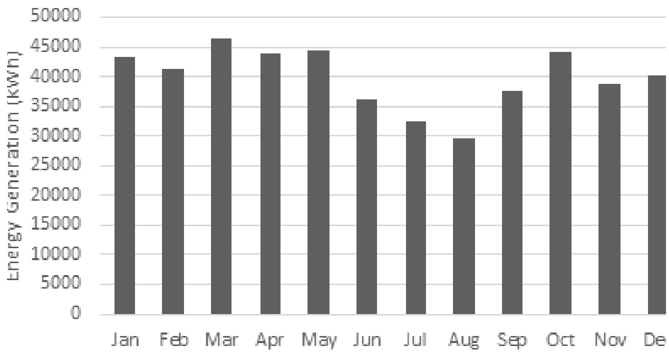


Fig. 11 Variation in on-site generation across the year (Simulated using System Adviser Model)[2]

Table 6 Cost and capacity of on-site photovoltaic plant

Parameter	Capacity
Annual Generation	478,235 kWh
EPI attained with Generation	23.1 kWh/m^2-yr
EPI of Project	22.1 kWh/m^2-yr
Balance (Positive balance attests to Net-Zero status)	1.0 kWh/m^2-yr
Water Required for PV Cleaning	3 liters/panel-week
Total Cost of PV Installation (As detailed in Appendix)	₹ 1,22,90,979
State Subsidy in Gujarat[3]	₹ 59,48,800
MNRE Subsidy (20%)[4]	₹ 24,58,342
Net Cost of PV Installation	₹ 38,83,983
Annual Maintenance Cost of PV (1% of Total Cost)	₹ 1,22,910
Roof Area Covered	2315 m^2

2 Blair, Nate, Nicholas DiOrio, Janine Freeman, Paul Gilman, Steven Janzou, Ty Neises, and Michael Wagner. 2018. System Advisor Model (SAM) General Description (Version 2017.9.5). Golden, CO: National Renewable Energy Laboratory. NREL/ TP-6A20-70414. https://www.nrel.gov/docs/fy18osti/70414.pdf.
3 MNRE. (2017, January 24). National Solar Mission - Grid Connected Solar Rooftop Program in India. Ministry of New and Renewable Energy-Government of India. https://solarrooftop.gov.in/notification/Notification-24012017.pdf
4 MNRE. (2017, August 27). Guidelines on implementation of Phase-II of Grid Connected Rooftop Solar Programme for achieving 40 GW capacity from Rooftop Solar by the year 2022. Ministry of New and Renewable Energy, Government of India . https://mnre.gov.in/img/documents/uploads/7ccd3b4b3bb94a51af516e2ee4fdede3.pdf

7.2 Architectural Design

7.2.1 Site Development

The proposed brief features a basement for parking and a stilt on the ground. Excavation for basement adds a significant cost to the project. The stilt, as a soft storey, is a hazard in earthquake-prone Ahmedabad. Therefore, instead of these, a podium is being developed to incorporate the parking at the ground level. The usable open area is then developed on the top of the podium, and is free of any vehicular movement.

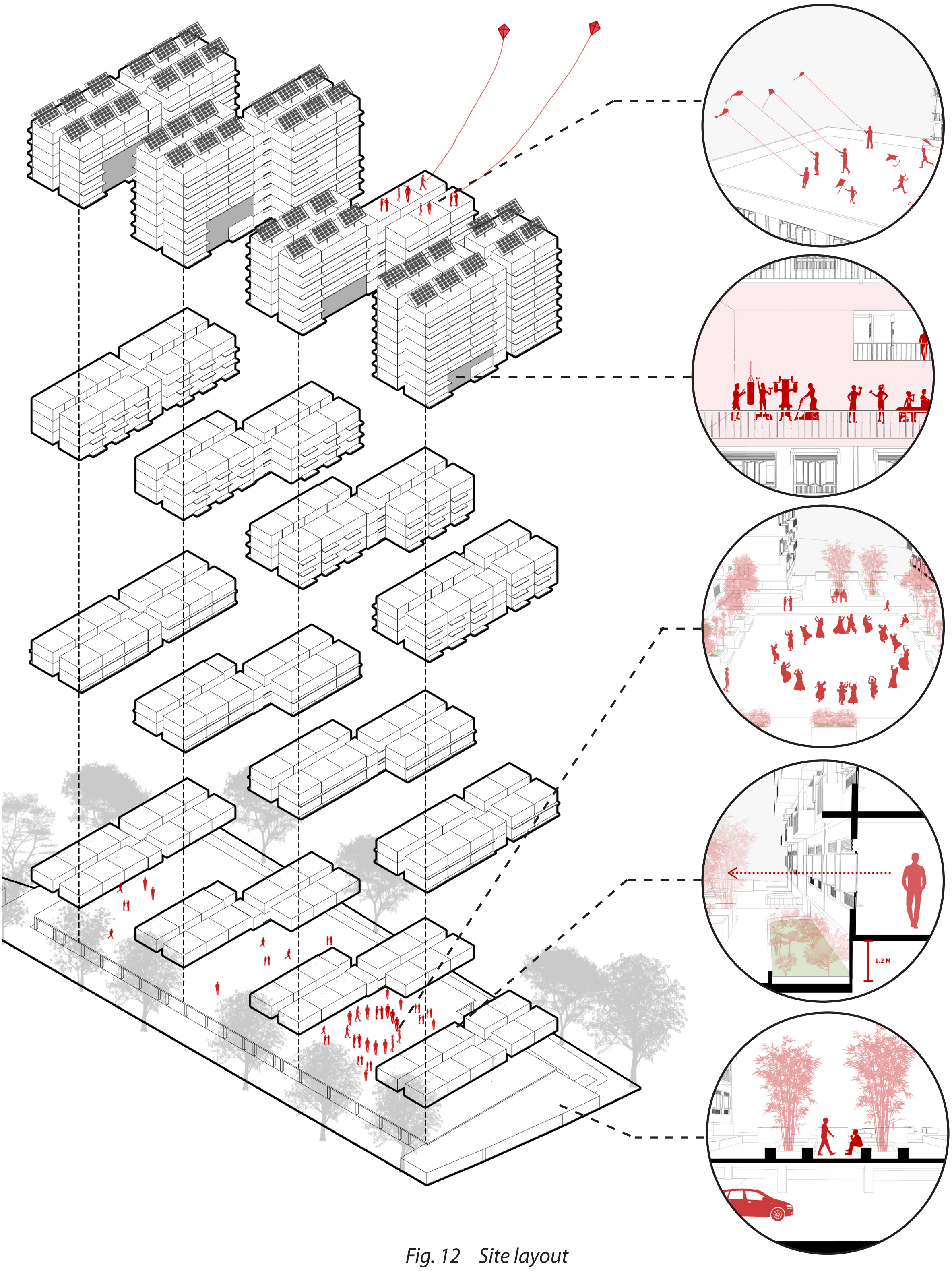


Fig. 12 Site layout

Fig. 13 Site plan

7.2.2 Facade Optimization

For shading design the building geometry was imported in Andrew Marsh software to understand areas that requires shading and areas that falls under mutually shaded space. Critical points for shading on the floors of towers A and D were identified and shading requirements were understood through a shading mask (Fig. 14). Shading masks for windows in Tower C and Tower B showed a benefit of mutual shading and a brief, seasonal requirement of vertical shading during evenings.

As the plot is oriented to North West and South East, we aimed at cutting down West sun and South sun predominantly. Vertical louvers were introduced on East and West side which can be used in both ways as panels as well as shading element as per the requirement. The lower horizontal louvre has been designed as in reference to Ahmedabad pol houses to cut down the solar radiation to the maximum extent.

The modular optimization extends to the window as well. While requirements are different for different orientations and floors, the flexibility in shading has been provided through operative elements rather than fixed design. This allows mass production, lowering manufacturing costs of for the units. The window pane has been divided into three parts to fulfill the different requirements. Further details are under development.

1. Daylight Panel - A glass, louvered panel in the top that can enable stack ventilation.
2. Vision Panel - A typical vision panel with an opaque shutter. When the shutter is open, it acts as a vertical louvre.
3. Ventilation Panel - A jaali panel has been proposed below the vision panel. This allows the possibility of ventilation while maintaining indoor privacy and reducing heat gain. The bottom hinged shutter, when open, can act as a usable ledge for the house.

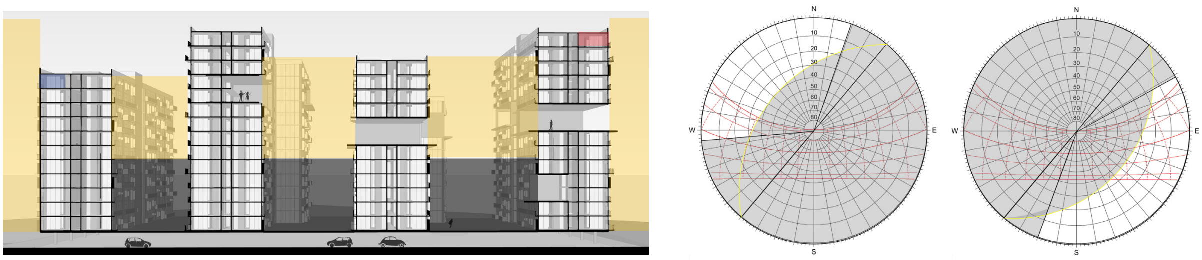
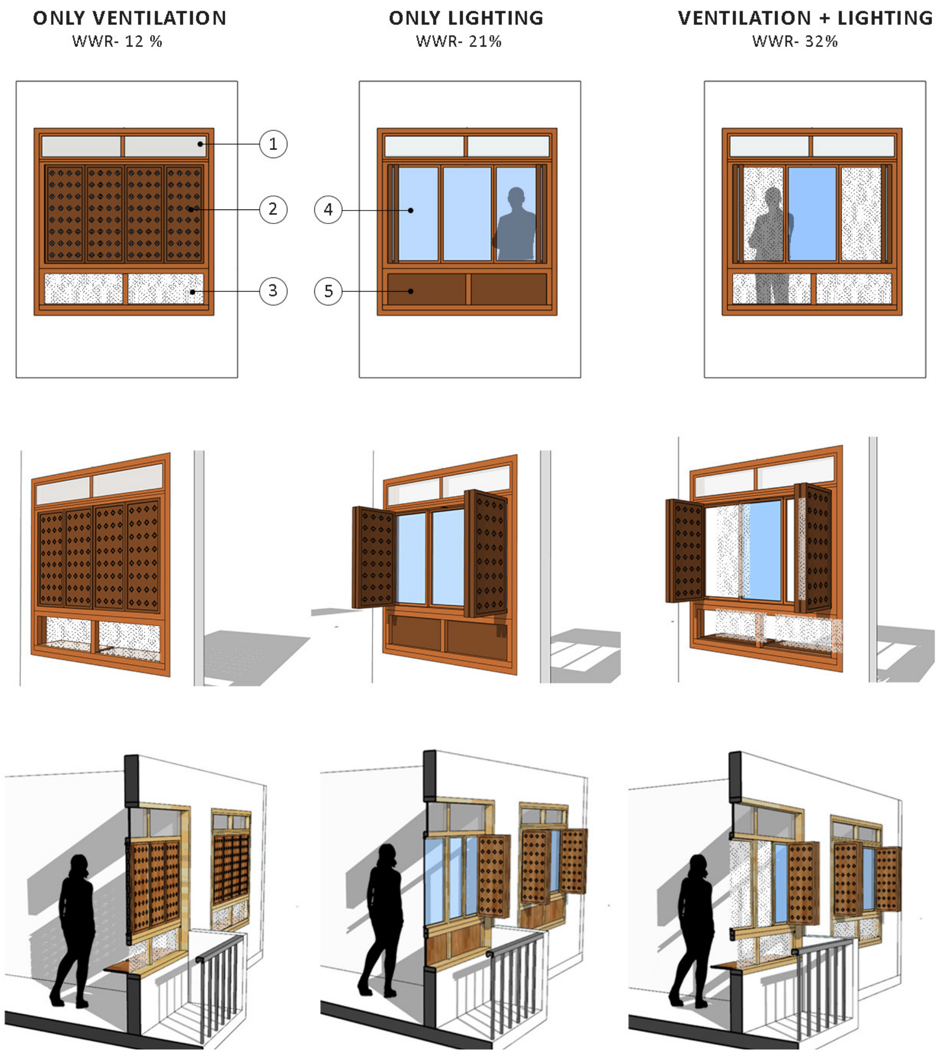


Fig. 14 Different apartments within the projects have different shading requirements. This has been verified through shading mask analysis for apartments on different floors on each facade. The extreme cases have been illustrated here.



LEGEND

1. 300mm high, transom window with frosted glass at 2100mm sill level
2. Opaque sliding folding shutters
3. 300mm high chicken mesh in ventilation panel at 600mm sill height
4. DGU sliding glass window with 13mm air gap
5. Bottom hinged opaque shutters

Fig. 15 Proposed shading system

7.2.3 Open Areas

The high density of the project has a risk of making spaces feel cramped. To avoid crowding on open spaces on the ground and terrace, open spaces have been spread throughout the built mass to encourage interaction. (Fig. 16 right) The placement of these open areas has been done strategically in places on the facade that are visible to most units in the periphery. This helps by ensuring that these open spaces are safe and also avoids any units that have no privacy due to proximity to other units. The identification of these spots (Fig. 16 left) was done through the development of cones of vision in grasshopper and creating a heat map on the facades with areas of maximum visibility.

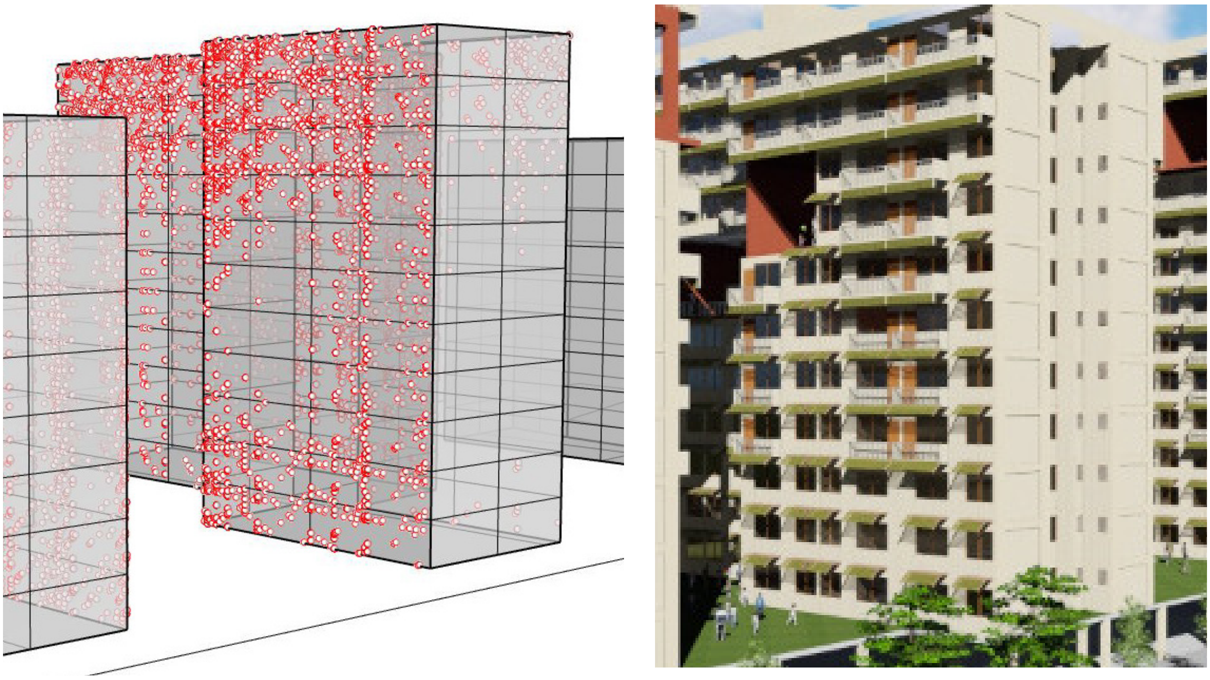


Fig. 16 Points of high visibility on facade translated into open spaces to ensure privacy of units and safety of open spaces

7.2.4 Livability

Choosing to live in a net-zero residence does not only mean choosing an energy-efficient space but also, choosing an energy-efficient lifestyle. When occupants make this choice, it is imperative that the project offers them flexibility in aspects like furniture layouts and partitioning systems. This allows them to alter their space as the familial structure changes. It also crucial to simplify occupant-driven strategies and devise incentives to maintain occupant interest in the net-zero incentive.

Fig. 17 Possible alterations to interior layouts with change in family structure to increase tenure time

7.3 Comfort and Environmental Quality

7.3.1 Thermal Comfort Model

The comfort band has been expanded based on recommendations of IMAC and LECaVIR. For hours that fall below IMAC MM lower band, the windows are expected to remain closed. For the hours that fall between IMAC MM upper band and IMAC lower band (90% acceptability range), the windows remain open for natural ventilation as the hours fall in the comfortable band. For the hours that fall between ceiling band (offset of 1.8°C at 0.9m/s as per LECaVIR) and IMAC MM upper band, the ceiling fans help in reducing the temperature by falling in the comfortable band. For the hours above ceiling band, active cooling is required to get the hours under comfortable band.

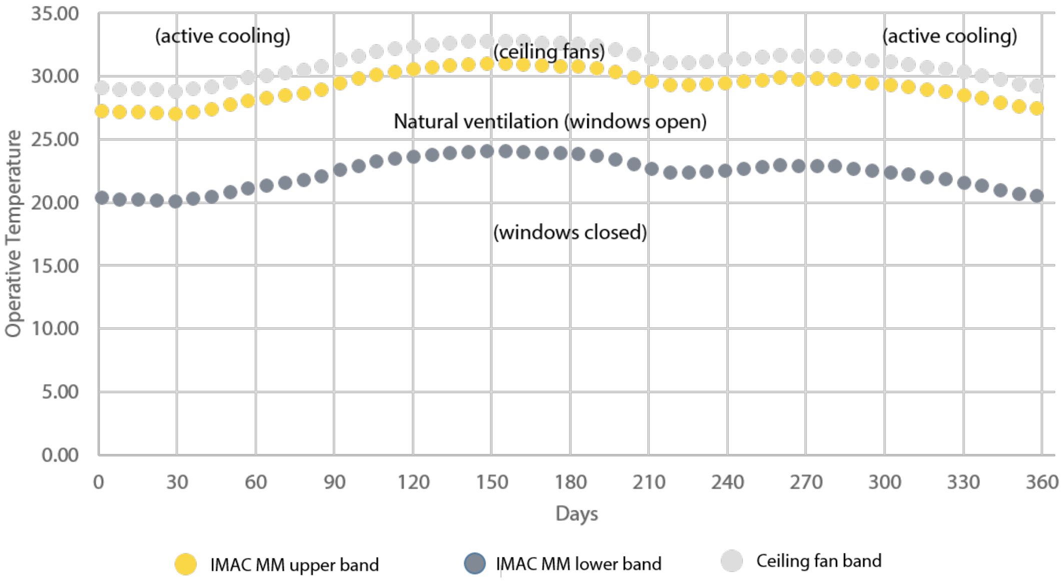
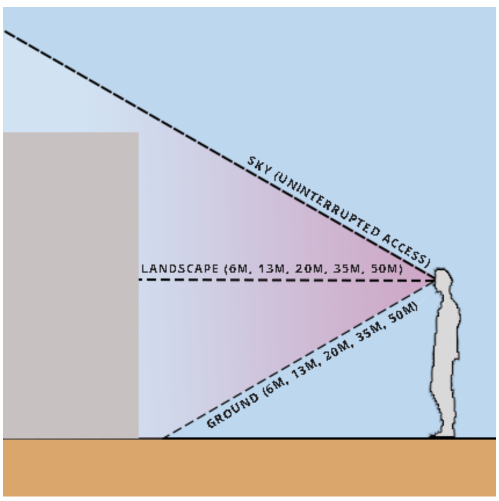


Fig. 18 Comfort band expanded based on recommendations from IMAC and LECaVIR

7.3.2 Indoor Environmental Quality - Views

In a typical affordable housing project, the targets lean towards maximizing sell-able area in the most space efficient way possible. In such a situation, ensuring quality of views ends up taking a backseat. For Savvy Studioz, this has been approached through quantification of views based on recommendations of IES-LM-83[5] and EN 17037.[6]



Layer of Environment	View Distance	Score
Ground	6m	0.8
	6m to 13m	0.6
	13m to 20m	0.4
	20m to 35m	0.2
	35m to 50m	-1
Landscape	6m	-1
	6m to 13m	0.2
	13m to 20m	0.4
	20m to 35m	0.6
	35m to 50m	0.8
Sky Score	Uninterrupted View	2

Fig. 19 Methodology developed for quantification of views based on cone of vision and distance to view

5 IES. (2012). IES LM-83-12. https://www.stdport.com/standards/ies-lm-83-12.html
6 Standards, B. (2019). Daylight in buildings. https://shop.bsigroup.com/ProductDetail?pid=000000000030342286

For the top 4 massing options, the analysis was done be creating a grid of points. At each point, 5 cones of vision (of varying sizes) were set up using Grasshopper (as illustrated in Fig. 19 (left)). These points of evaluation were set as per the following criteria

- Height – 1.5m on First Floor
- Distance – 1m from Facade
- Spacing - 5m between points
- Orientation - Facing outward, perpendicular to the window (Fig. 20)

Fig. 20 Visualization of points used for analysis of views

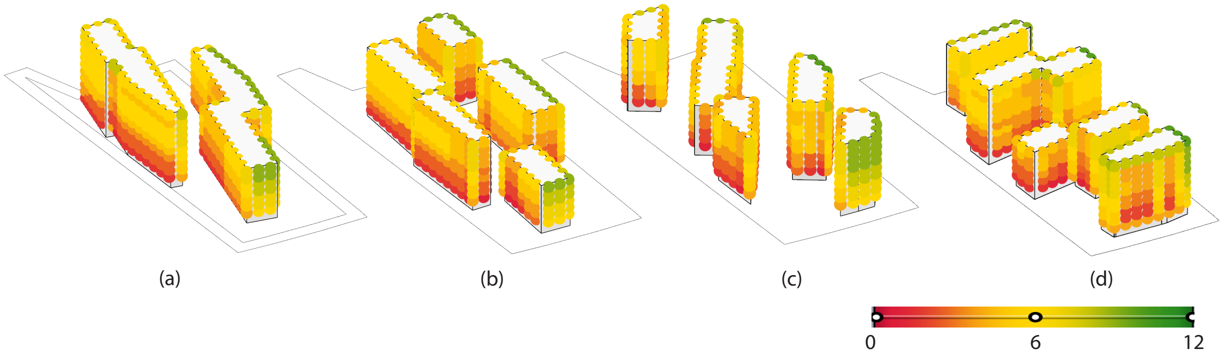


Fig. 21 Points of evaluation for all 4 massing schemes were scored as shown in Fig. 19. A higher score implies a better quality of view. For comparison between the four schemes, median values for all points were calculated and considered

Scoring of Views

The cones of vision have been intersected with the three layers of the environment - Ground, Landscape and Sky. The distance between these three for each point has been evaluated and scored as shown in the table in Fig. 19. For example, if the cone of vision hits the landscape within 6m, it scores a negative 1. If the cone of vision hits the ground between 13m to 20m, it scores a 0.4. Scores for all points in a massing scheme have been aggregated to get a total score as shown in Fig. 22.

Option D of the massing scheme scored the highest. Parallel site planning schemes developed for the 4 options show that Option D also needs the least number of elevators and has the maximum parking. Therefore, based on these three considerations, option D has been selected as the final massing.

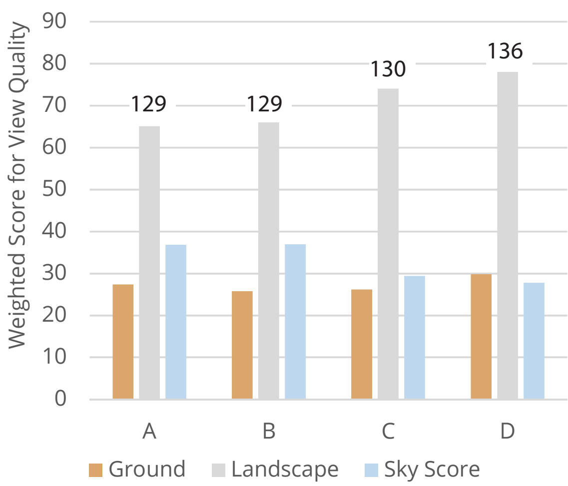


Fig. 22 Scores top 4 massing options for View Quality

7.3.3 Spatial Distribution of Indoor Operative Temperature

The window design includes operable shutters to cut off the solar radiation on extreme summer days, to make the space comfortable. To validate this window design, Thermal autonomy[7] (Ko WonHee, et al. 2017) simulation was carried out on proposed unit model facing North-West direction for 18th May 3:00 pm.

- Case 1 - With shutters closed - The indoor operative temperature recorded for Case 1 is 32.8C, which falls in the 90% acceptability MM comfort band as calculated from IMAC standard.
- Case 2 - With shutters open - The indoor operative temperature recorded for Case 2 is 33.5C, which falls out of the 90% acceptability MM comfort band as calculated from IMAC standard.

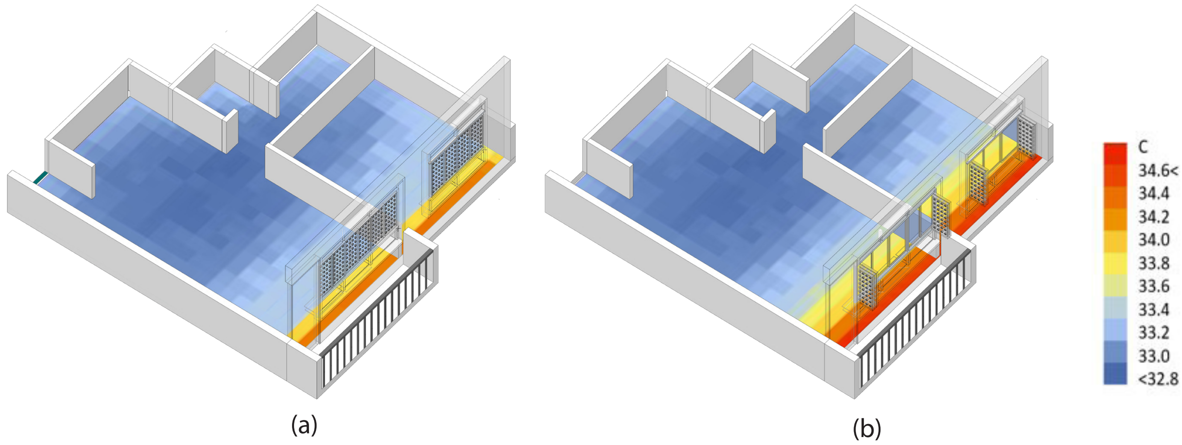


Fig. 23 The effectiveness of the window design has been tested through thermal autonomy simulations with a) shutters closed and b) shutters open

7.3.4 Daylight Distribution and Autonomy

The proposed unit was simulated for Daylight analysis. Since there are no daylight standards for India, requirements of the IES LM 83-12 and IGBC Green Homes were used as proxies.

Spatial Daylight Autonomy (sDA) is a measure of daylight illuminance sufficiency for a given area reporting a percentage of floor area that exceeds a specified illuminance level of 300 lux for 50% of the annual hours from 8AM-6PM (IES LM-83-12). sDA for the space is recorded to be 88.5% which as per IES LM-83-12 can be termed as "favorable" or "preferred".

IGBC Green Home Rating System recommends 75% of the regularly occupied spaces in the building achieve daylight illuminance levels for a minimum of 110 Lux (and a maximum of 2,200 Lux) in a clear sky condition on 21st September at 12 noon, at working plane. On simulation more than 75% of the occupied spaces records illuminance levels >110 Lux.

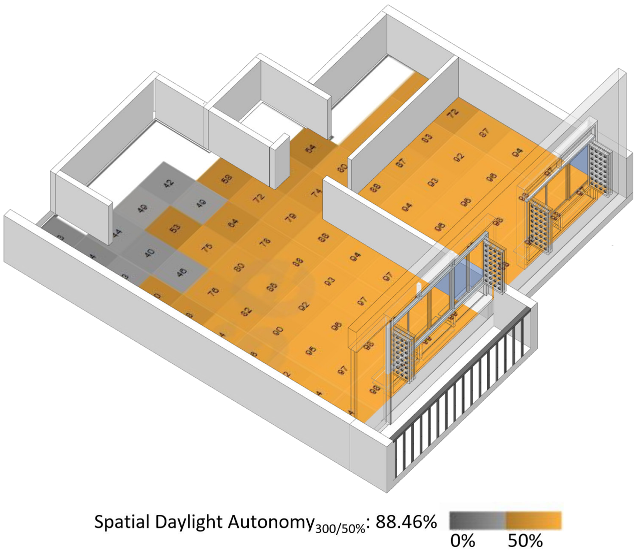


Fig. 24 Daylight levels evaluated to test window design

Table 7 Material reflectance used to evaluate daylight propagation

Surface	Material	Reflectance
Wall	Concrete	50%
Floor	Tile	40%
Ceiling	Plaster	70%
Glass	Frosted	VLT- 45%
Glass	DGU unit	VLT- 45%

7 Ko, Won Hee and Schiavon, Stefano (2017) 'Balancing Thermal and Luminous Autonomy in the Assessment of Building Performance', Proceedings of the 15th IBPSA Conference - San Francisco, CA, USA, Aug. 7-9, 2017, https://doi.org/10.26868/25222708.2017.527

7.4 Water

7.4.1 Proposed case strategies and target saving

As per National building code 2016, Standard case fresh water demand is 135 LPHD (As shown in the Appendix) for residential buildings. Proposed case aims to achieve a water demand reduction of 37% i.e., a fresh water demand of 84 LPHD by applying strategies such as using water efficient plumbing fixtures and behavioral measures. The achieved fresh water demand of 84 LPHD will be catered by the recycling of the generated black and grey water up to the water quality of 10 Biochemical oxygen demand (BOD) and 10 Total suspended solids (TSS) making the effective demand to be 27 LPHD. A system to cater to the remaining 27 LPHD will be proposed as a future intervention in order to recycle the grey water up to a level of 0 BOD and 0 TSS to fulfill the bathing, drinking and cooking water needs on site

Site has a rainwater harvesting potential of 1778 kL annually through roof and hardscape areas and will be used to meet the potable needs such as bathing, drinking and cooking.

Potable water requirement of 37487 kL will be catered by the municipal supply annually. In order to achieve a net zero water status, the campus will hold the capability to return the same amount of water back to the shed and hence an on-site black water treatment plant will be proposed to treat 37487 kL of the black water till 30 BOD 30 TSS quality.

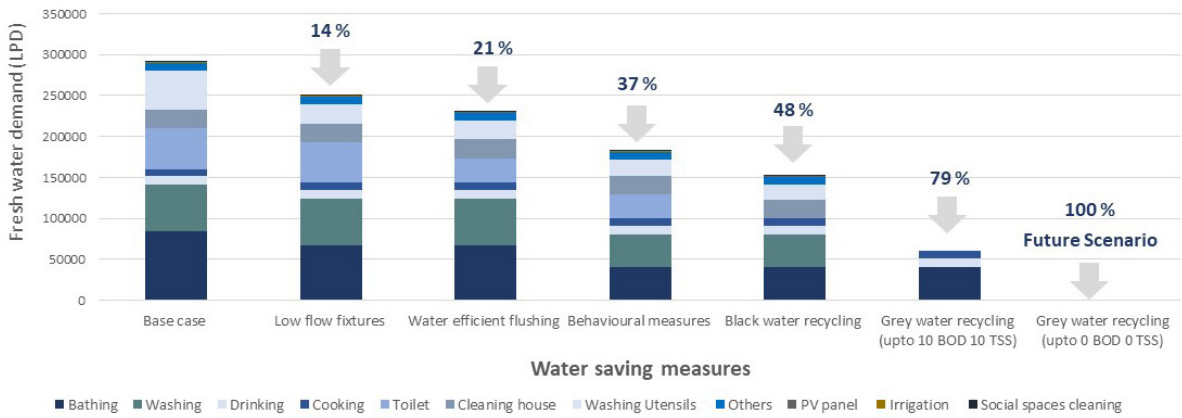


Fig. 25 Reduction in Fresh water demand

7.4.2 Engineering Measures

The U.S.EPA identifies water saving strategies in two categories i.e. engineering and behavioral. In this case Dual flow aerators are proposed to reduce the water consumption at the washbasin and kitchen sink by 35%. The fixtures were determined by conducting trial and error to meet target water demand and by fixing a cost limit to Rs 7000/ unit in fixtures (as shown in the appendix). The base case flushing system had a 3/6 L flushing system which is proposed to be replaced with a 2/4 L flushing system which will reduce the demand by 33%.

Table 8 Summary of Water Tanks

Parameters	Capacity
Total water demand	172 kLPD
Rainwater storage tank	600 m^3
Potable water tank	100 m^3
Non-Potable water tank	80 m^3
Grey water recycling plant	68 m^3
Sewage treatment plant size	30 m^3
Water autonomy (3days)	59 kL

7.4.3 Behavioral measures

Koop et al. (2019) showed that active feedback on water use leads to a reduction of 8% to 40% as compared to houses getting just a passive feedback at the month end. An incentive-based water monitoring program is proposed to monitor and send real time water use details through sub meters at the inlet level. Continuous monitoring systems will also identify water use patterns and make it easier to identify leakages which could be immediately treated by a plumber will leading to an overall reduction of 40%. Weekly water management reminders such as 'covering vehicles to lower need for daily washing' would be sent to the occupants.

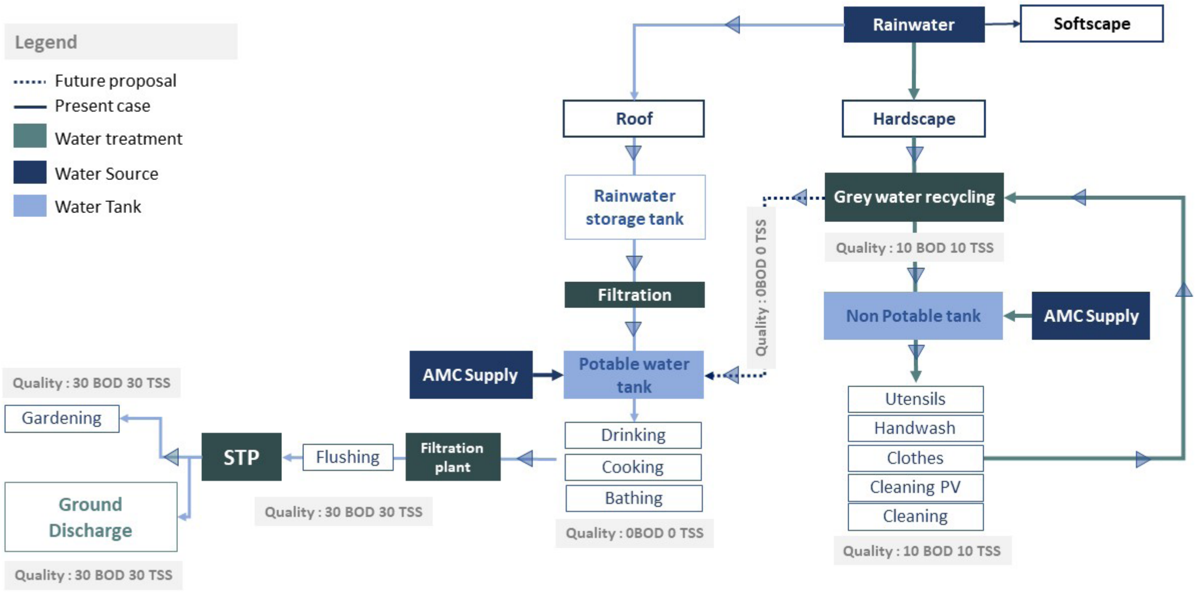


Fig. 26 Water cycle

7.4.4 Water Treatment - Efficiency and Costs

BioMicrobics FAST Nitrification and denitrification system is proposed for on-site black water treatment. Plant will have a capacity of 30 m³ with an efficiency of 85%. The treated Water is expected to have a quality of at least 30 BOD and 30 TSS so that it can be used for irrigation and ground recharge. The system will be integrated into a standard septic tank, leading to space savings. The system also offers higher levels of nitrogen removal (NSF/ ANSI 245) with an intermittent operation of the blower reducing electricity usage up to 45%. The system has a life span of 25 years with low maintenance. A grey water treatment system having 85% efficiency catering to 68 m³ of grey water is proposed on site (As per Table 8). Recycled water of 10 TSS and 10 BOD quality will be used to cater to demands such as PV panel cleaning, washing clothes and utensils. Component of capital costs of the proposed strategies have been detailed in Table 9.

Table 9 Capital cost components

Water saving Measures	Components
Low flow fixtures	Single flow aerator, Health Faucet, Shower head (01) and a hand-held spray
Water efficient flushing	2/4 L flushing system
Behavioral measures	Water submetering system
Grey and black water treatment	Septic tank, Nitrification and denitrification system, carbon filters

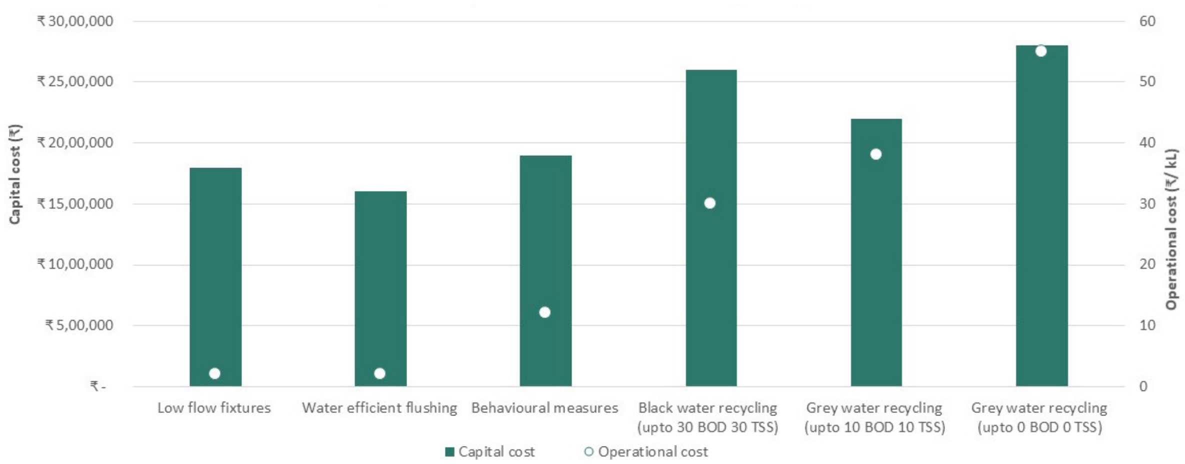


Fig. 27 Capital and operational costs of water saving strategies

7.5 Resilience

7.5.1 Risk of Heatwaves

In the past few decades, occurrence of heat waves in Ahmedabad has increased by 32%.[8] The government has identified three levels of alerts during heat waves.

- Yellow - Hot Day Advisory - 41.1 to 43 °C
- Orange - Heat Alert Day - 43.1 to 44.9 °C
- Red - Extreme Heat Alert Day - 45°C +

Measures Taken

In the coming years, this occurrence is likely to increase even further. This makes it important for the building envelope be able to handle any added heat stress. The building envelop needs to be robust, in terms of thermal performance and infiltration (tightness). The thermal performance of the proposed envelope has been tested under severe conditions.

As seen in Fig. 29, the proposed envelope shows a 36% reduction in heat gain through the windows as compared to the base case. The results presently show an analysis of the window areas since windows are typically the weakest points of a building. Therefore, windows were given first preference. Other than this, the pre-fabricated wall panels and with insulation and roof with the air gap are making the building robust for future climate change.

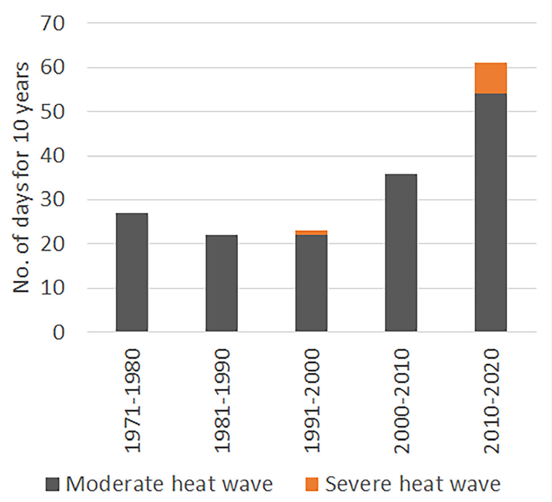


Fig. 28 Occurrence of heatwaves in Ahmedabad

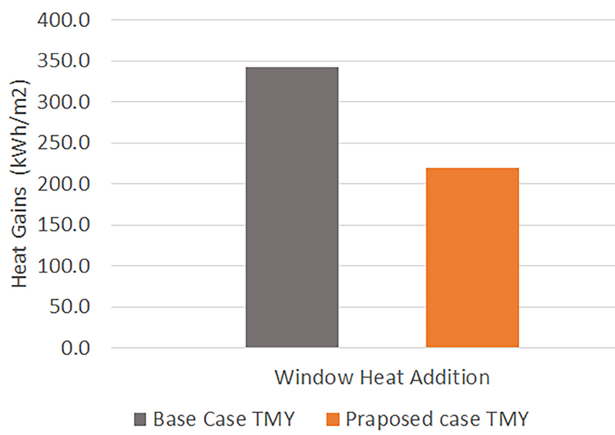


Fig. 29 Reduced heat gains for proposed case due to efficient insulation

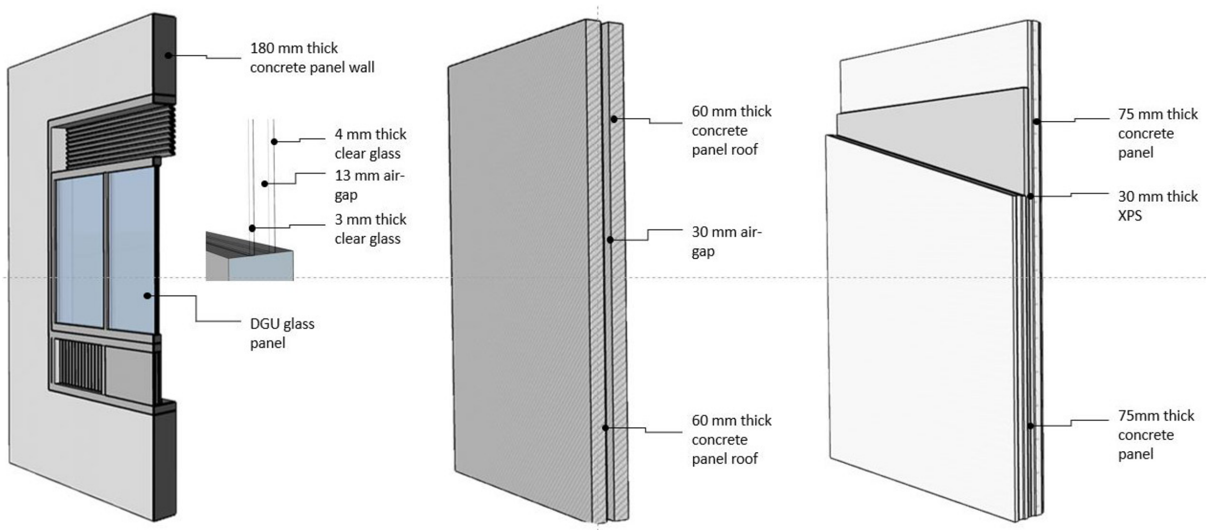


Fig. 30 Envelope specifications for window and external walls

8 Murari, K. K. et al. (2015) "Intensification of future severe heat waves in India and their effect on heat stress and mortality," Regional Environmental Change, 15(4), pp. 569–579

7.5.3 Future Weather Scenario

Typically, the TMY file used for building simulation is generated from the past years weather data. How the building performs in the future needs to be tested using a future weather file. For the TMY file of Ahmedabad, a future weather file of 2050 for A2 weather scenario, was generated using CCWeatherGen[9]. The A2 family of scenarios is characterized by a world of independently operating, self-reliant nations, increasing population, regional economic development & high emissions.

The base case and proposed models have been simulated for the year 2050. While the base case sees a 5% increase in EPI, change in the proposed case is almost negligible. Assuming a constant rate of generation due to the on-site photovoltaics, the building will continue to be Net Zero till 2050.

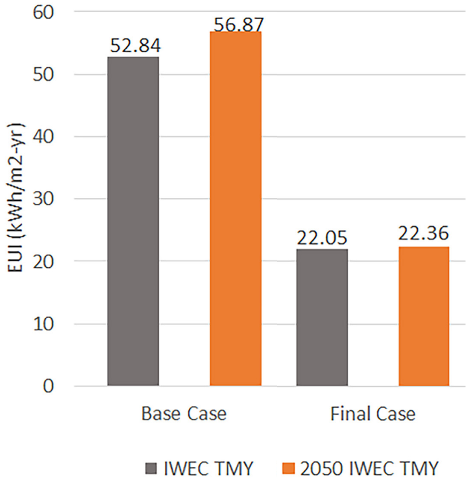


Fig. 31 Base case and proposed case simulated using a future weather file for 2050

7.5.4 Response to Earthquake

As per the vulnerability atlas, Ahmedabad falls under seismic zone III. This zone is classified as a Moderate Damage Risk Zone which is liable to MSK VII. Recommendations of IS 1893 for this zone have been closely followed for the project. These include

1. Reinforcement of soft storeys with shear walls
2. Avoidance of heavy shading systems by using wooden shutters for shading
3. Lack of vertical irregularities in the structural system. The open spaces on the upper floors of the building have been incorporated without breaking the structural grid or use of floating columns.
4. Offset in towers B and C detailed as an expansion to avoid structural pounding during earthquake

Fig. 32 Vertical shading incorporated as window shutter to avoid additional dead weights

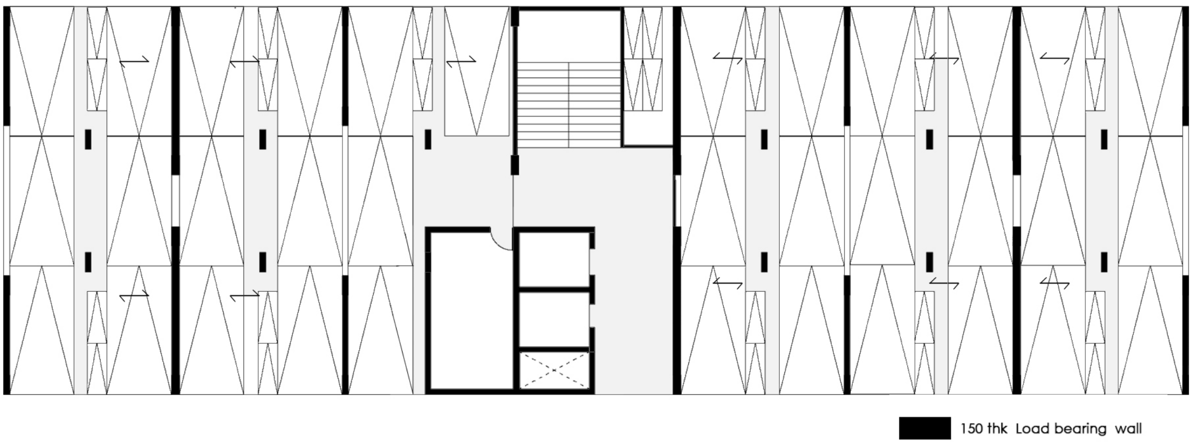


Fig. 33 Reinforcement of soft storeys with shear walls

9 Jentsch M.F., Bahaj A.S. and James P.A.B. (2008) Climate change future proofing of buildings – Generation and assessment of building simulation weather files. Energy and Buildings,Volume 40, Issue 12, December 2008, pp 2148-2168.

Water Autonomy

Water System resilience is critical for providing the water delivery post a disaster to support community resilience. The goal of the proposed water system is to have the ability to restore and continue the potable water supply as rapidly as possible in the case of any disaster. In order to do so, an excess storage of 34990L of potable water has been proposed to cater to at least 3 days of drinking and cooking water demand.

Table 10 Water tank requirements for 3 day water autonomy

Parameter	Capacity
Potable (Drinking + Cooking + Bathing) water demand (Daily)	61404 l
Water required for autonomy (Drinking + Cooking) (For 3 days)	34990 l
Total potable water to be stored (L)	96394 l
Underground Potable water Tank Size	100 m^3
Underground Potable water Tank	6m x 7m x 2.4 m

7.5.2 Net-Zero Waste

The project aims to minimize the waste going in the landfills over the course of the year by reducing, reusing, and recovering waste streams and converting them into valuable resources. The waste-pickers based collection model as proposed in Pune city, is a non-energy intensive and has a low carbon footprint, compared with formal and conventional technological approaches, such as mechanized, centralized waste collection schemes and incineration.[10]

The different types of waste generated on the site will be treated as follows:

- Dry waste, wet waste and hazardous waste will be segregated at the occupant level. This will be collected door-to-door by society housekeeping agency.
- The organic waste is converted into Pellets in Biomass Pellet Burner. These pellets are then fed into Biomass based water heater, which is connected to the overhead tank, as fuel to generate heat. Outlet tap of the water heater is connected to the bathroom taps of the dwelling units.
- Hazardous waste generated on site will be segregated and disposed safely with the help of a third-party agency.

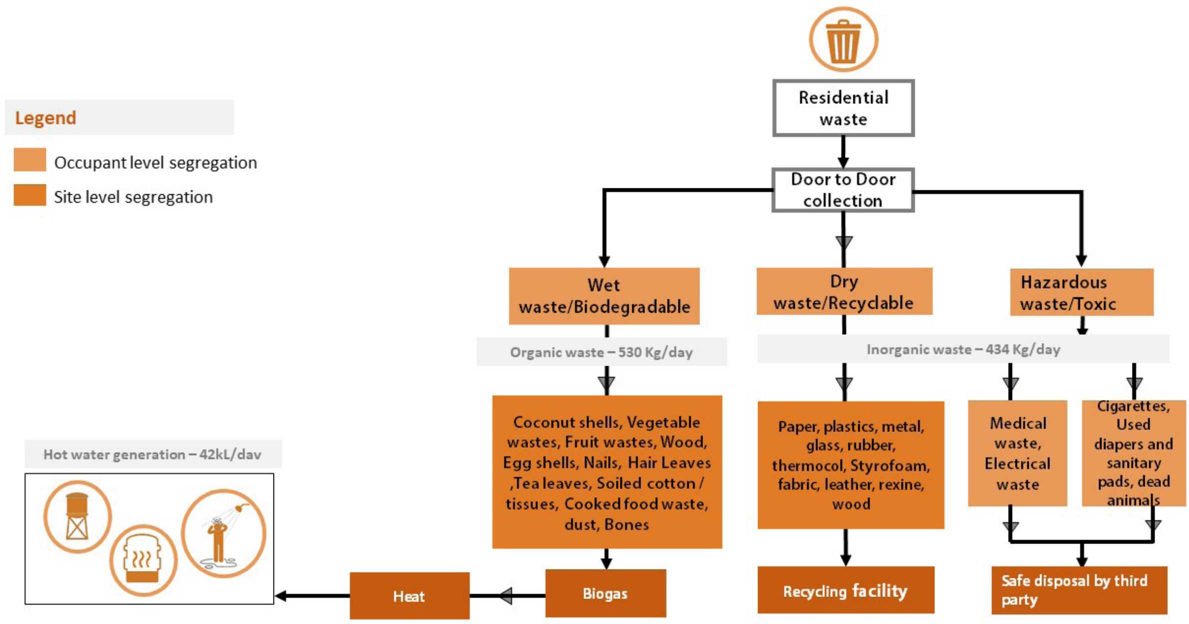


Fig. 34 Proposed mechanism for on-site waste segregation, handling and disposal

10 Moora, H. and Barde, H. (2018) 'Environmental impacts of informal plastic waste management', in Emmons, K. (ed.) 'Closing the Loop: Innovative partnerships with informal workers to recover plastic waste, in an inclusive circular economy approach – Pune, India case study', pp 18-19.

7.6 Innovation

7.6.1 Problem 1 - Achieving Comfort with Low-Energy Cooling Systems in Hot and Dry Climate

The HVAC schedule developed using computer-based simulations showed the need for active cooling for 25% hours in the summer time. This is the annual peak condition as well. Once the operational schedule is finalized, a low-cost, low-energy evaporative cooling system is selected based on the climate analysis that shows hot, dry summers. Modeling the cooler in Design Builder showed that the discomfort hours increases by 71% compared to a typical Split DX system. This is because of the evaporative cooler's inability to provide comfort in Monsoons. Though evaporative coolers come at low capital and monthly costs, they add almost 10lphd water demand on days that the cooler is filled. This adds water stress onto the project and is not technically feasible considering the net-zero water goals of the project.

The second option that was tried is an evaporative cooler with a convention Split DX system. This model is based on typical situations in Ahmedabad. While this system brings down comfort hours closer to the acceptable limits, capital costs for two systems and water losses are still higher. For this project, compromise on discomfort hours and water goals is not accepted. Therefore, a third option is needed that can cater to diversity in requirements across the year. One option for such a system is a Variable Refrigerant Flow (VRF) based cooling system. A summary of the analysis criteria is presented in Table 11.

Table 11 Analysis of evaporative cooling system in comparison with split-DX and shared VRFs

Proposal	Cooling EPI (kWh/m^2-yr)	Discomfort Hours (hrs)	Capital Costs (INR/Appt)	Monthly Cost (INR/Appt)	Annual Water Losses (LPD) (All Appts)
Base Case (Savvy's Proposal with Split DX Systems)	15.4	285	25,000	296	0
Proposed Case with Desert Cooler	2.5	1003	9,400	48	9000
Proposed Case with Desert Cooler and Split DX System	3.1	452	34,400	60	9000
Proposed Case with CaaS (Shared VRF)	3.6	234	60,000	69	0

7.6.2 Problem 2 - Inability of Users to Afford Individual VRF Systems

The post-design survey (Survey form in Appendix) conducted with people of the target income bracket showed only 11% of respondents owned an air-conditioner. This was in line with the study[11] conducted by Mishra et al. (2021) (Under review) wherein only 35% of the sampled occupants had an AC. Thermal comfort for them is clearly not affordable.

Therefore, a shared model is proposed where outdoor unit (ODU) is shared between 6 units as shown in Fig. 35. The ODU can be bought by the developer or a third-party. This reduces financial stress as every unit only needs to purchase an indoor unit, possibly making it cheaper for them than buying a conventional Split-DX system. In such a shared situation, metering of indoor units becomes necessary (of refrigerant or consumption) to be able to calculate accurate electricity bills. Individual purchase of indoor units also opens the possibility of some occupants choosing to have air-conditioning in the living room as well. The operational model for this system is under development and details can be seen in Section 6.9.4.

11 Mishra, A. and Agrawal, S., 2021. Evaluating the role of adaptive, non-adaptive, and contextual factors in determining the air conditioner usage behavior in Indian households. Under review. CEPT University.

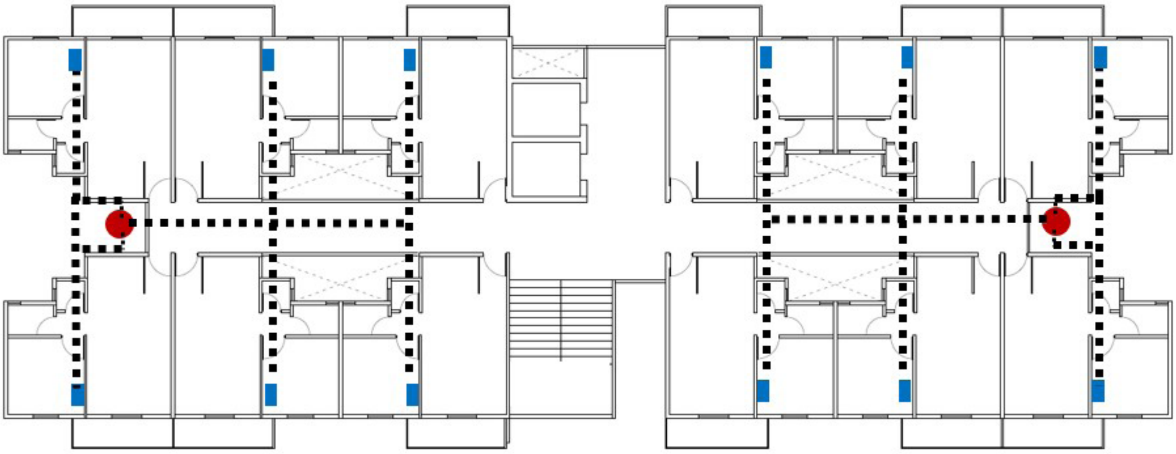


Fig. 35 Layout of VRF system with common outdoor units (ODUs)

7.6.3 Problem 3 - Financing of Shared HVAC Systems

The proposed CaaS model consists of two participants that is RESCO, the service provider and Residents. RESCO will be responsible for capital expenditure as well as annual operational and maintenance expenditure. This means RESCO will install as well as maintain solar PV array and cooling equipment.

To avail this service, the residents will have to pay ₹6.2 (prevailing market rate) per unit consumed that is supplied by RESCO. The parity in the per unit electricity rates that consumers will pay to electricity supplied by RESCO and to electricity supplied by GRID will make the proposed CaaS model attractive to the residents. Based on the forecasts of annual cash flows detailed in Table 12, the RESCO will achieve an ROI of 10.3%.

In base case, residents pay for purchase and maintenance of equipment and electricity which accounts for ₹16,680 annually. Whereas in the proposed CaaS model, RESCO pays for purchase and maintenance of equipment and residents pay for electricity which accounts for ₹5,540. The difference between the amounts that the residents pay under two scenarios is 66%. The high ROI for RESCO along with substantial savings for residents makes the business model compelling.

Table 12 Annual cash flows for RESCO

Cost of investment	**-1,61,71,983**
Year 1 Cashflow	23,12,217
Year 2 Cashflow	22,82,567
Year 3 Cashflow	22,53,213
Year 4 Cashflow	22,24,152
Year 5 Cashflow	21,95,382
Year 6 Cashflow	21,66,900
Year 7 Cashflow	21,38,702
Year 8 Cashflow	21,10,787
Year 9 Cashflow	20,83,151
Year 10 Cashflow	20,55,791
Year 11 Cashflow	20,28,705
Year 12 Cashflow	20,01,889
Year 13 Cashflow	19,75,342
Year 14 Cashflow	19,49,060
Year 15 Cashflow	19,23,041
Return on Investment	**10.3%**

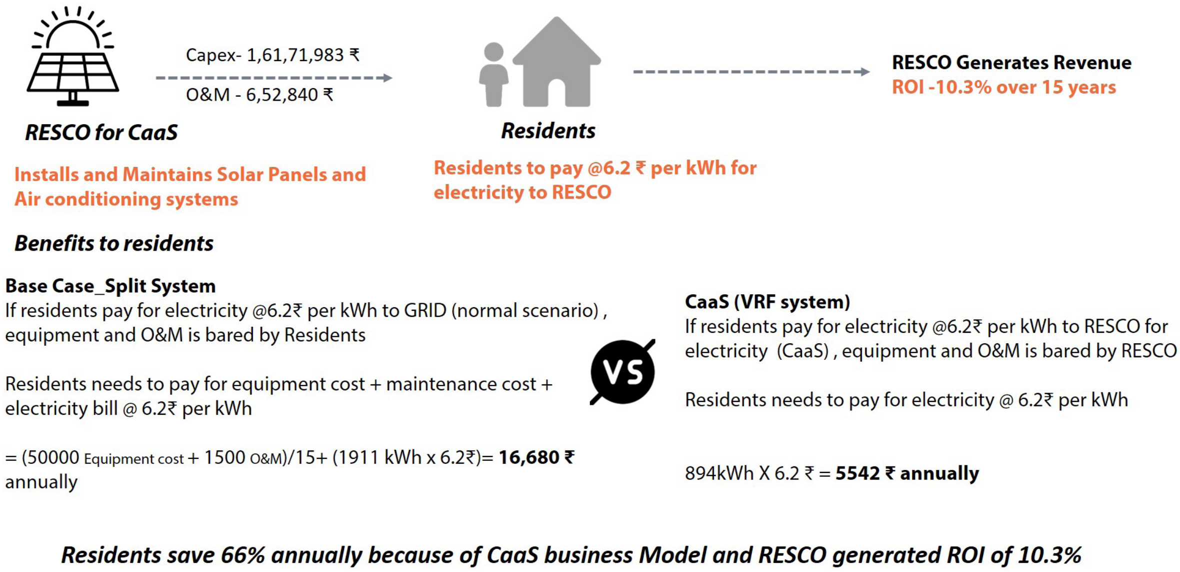


Fig. 36 Operational model proposed for CaaS and PV

7.6.4 Problem 4 - Occupant's Potential Willingness to adopt the System

A post-design survey was conducted to understand people's interest and willingness to adopt a shared HVAC system. The sample set was chosen in a purposive manner keeping the lower income group in focus. Through in-person interviews, people were asked for their preferred choice when presented with the following two options:

A. Individual system - Rs 30,000 (Capital cost) + Rs 400 (Operational cost)

B. Shared system - Rs 25,000 (Capital cost) + Rs250 (Operational cost)

While only 11% of the people surveyed have a AC at their place, 77% of the respondents were interested in having a shared system.

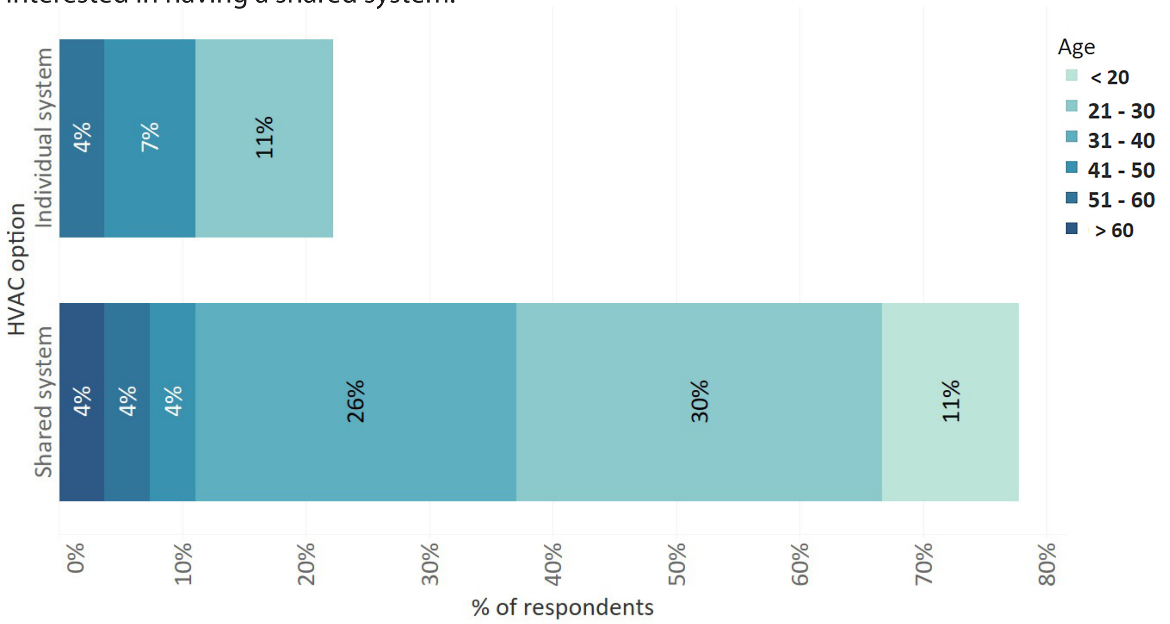


Fig. 37 Survey responses that show people's willingness to adopt the Cooling as a Service (CaaS) model

7.6.5 Summary

A preliminary business plan has been developed for a RESCO to invest in cooling as a service for the affordable housing market. The highest potential for implementation potential is in new projects. A more detailed market analysis can reveal the population group that would be the best fit for such a system to speed-up and ensure uptake.

7.7 Affordability

7.7.1 Capital Costs

The project costs as per the project partner are Rs 1697/sqft. With Team 0:0:0's interventions, this cost goes upto Rs 1936/sqft, which is only a 14% increase. The limited increase is owed to two major aspects. Firstly, there is a reduction in cost due to accommodation of parking on the ground and lack of a basement. Costs of building a basement are higher than costs of building a podium. There is also a lack of requirement of plastering and painting due to adoption of exposed concrete finish in precast panels.

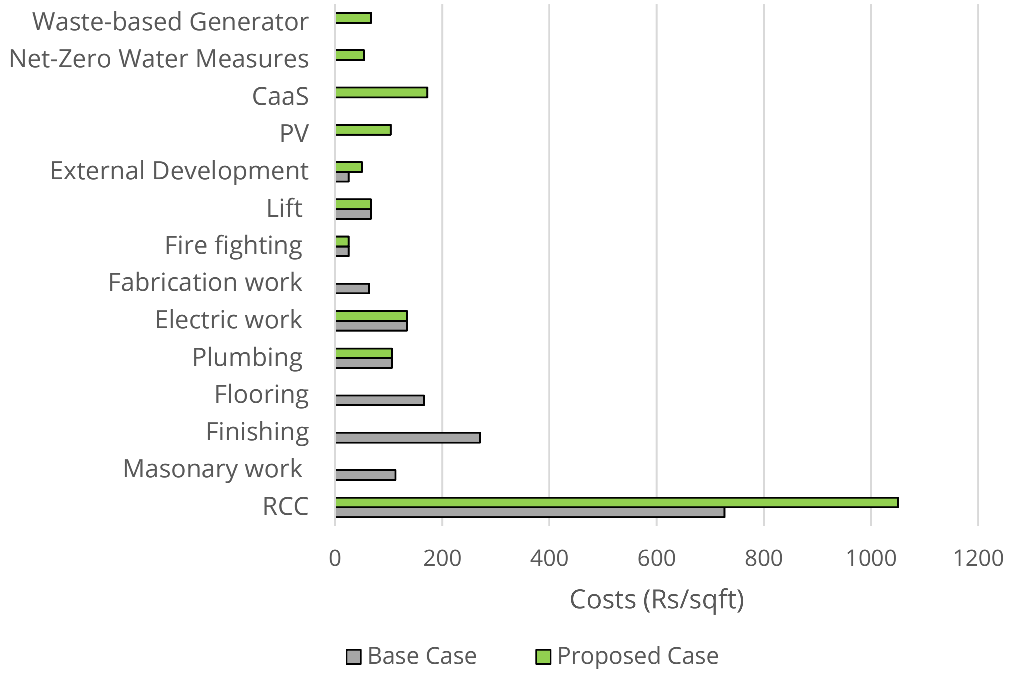


Fig. 38 Summary of proposed costs with respect to base case costs

7.7.2 Operational Costs

Infrastructure set up in the initial stages needs to be properly maintained to be able to ensure efficient performance. However, the affordable nature of the project requires operational costs to be budgeted as well. Therefore, as seen in Table 13, monthly expenses for each unit are calculated as a percentage of the capital costs. These annual cost is distributed equally to all 536 units that share the common infrastructure. For this calculation, earnings due to net-metering also split between all units equally. In practice, this can be split as a function of the monthly consumption of each unit. Consequently, the monthly expenses of every unit are reduced by 80%. This leads to annual savings of almost Rs 10,000 for every unit. This increases affordability of the project and widens its market prospects.

Table 13 Monthly expenses of each unit reduced by 54% in comparison to the base case

	Base Case	Proposed Case	Notes
Monthly Electricity Bill	1019	466	Expenses @Rs 6/kWh
Net-Zero Water Measures	0	19	10% of CapEx Annually
Waste-based Generator	0	47	20% of CapEx Annually
Net Monthly Expenditure	**1019**	**532**	Σ Expenses - Σ Earnings
Annual Savings	**0**	**5,844**	(1019-532) x 12

7.7.3 Participatory Process

A person looking to buy an affordable 1BHK in Ahmedabad is far from spoilt for choice. Also, the affordable sector is not made of one number that fits all. It holds a range of budgets as well. To accommodate this diversity and give users some choices, the design has been given flexibility in terms of types of balconies. The options provided have been explained in Table 14. There is also a possibility that the developer chooses to level the field by selling all types at the same cost. The share of each of these units have been discussed in the section on Design Delivery Model.

Table 14 Variation in units offered to increase options in terms of space and costs

Type	Area (in FSI) (Sqm)	Area (free from FSI) (Sqm)	Total Area (sqm)	Construction Cost (INR)	Relative Difference wrt L1 (%)
L1	38.0	0.0	38.0	748250	0
L2 (Standing Balcony)	38.0	2.1	40.1	788617	5
L3 (Half 1.2m-wide Balcony)	40.1	2.1	42.2	829967	11
L4 (Full 1.2m-wide Balcony)	41.9	3.9	45.7	899870	20

7.7.4 Post-Design Survey Results

A survey was conducted with the people of Ahmedabad to understand the preferences of typology of various proposed 1 BHK units. The results are based on 30 survey responses which were conducted in person keeping the COVID guidelines in mind. The sample set was chosen in a purposive manner keeping the lower income group in focus.

63% of people were interested in buying 1BHK, those who did not show interest were mainly the people living in a joint family of more than 3 members. 90% responders were below the age of 40 years with an average monthly salary less than 50,000 /-. None of the responders owned a 4-wheeler, however some of them had 2-wheelers for general commute.

When asked about the unit typology preference, 51% of the respondents wanted to opt for big balcony. The prime reason appeared to be the possible scope of using the balcony later for other domestic purposes or to experience open space. Respondents were willing to pay an of up to INR 5,00,000/- for a bigger balcony unit.

When asked about the floor preference and view from the balcony 58% of the respondents opted for a garden view and 46% preferred to stay on 1st to 3rd floor, prime reason for which were ease of access. A very small segment opted the units above 8th floor. In terms of view from the balcony, the most preferred view is of the garden followed by main road.

Fig. 39 Post-design survey conducted in person

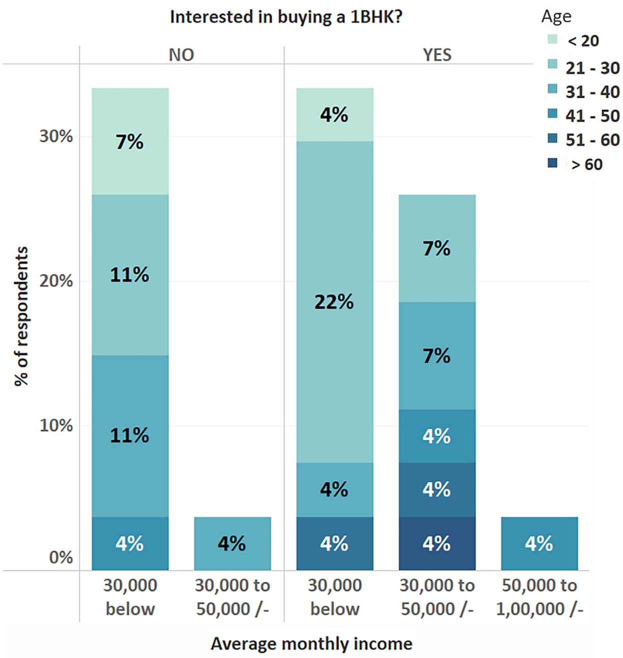


Fig. 40 Respondent profile for post-design survey

7.8 Scalability and Market Potential

7.8.1 Occupant Preferences and Concerns (Pre-Design Survey)

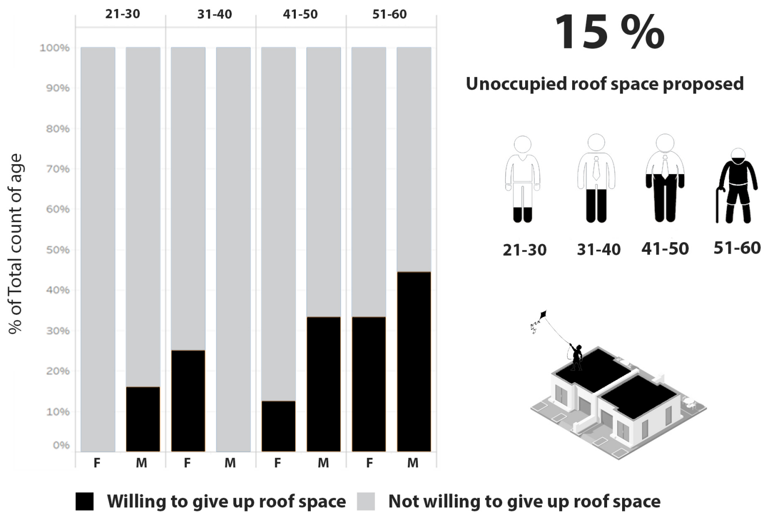


Fig. 41 Need to have access to roof understood through results of occupant survey

The team conducted an online survey to understand the perspective of prospective occupants towards energy-efficient buildings (Survey form can be seen in Appendix). Results received from almost 240 respondents point us towards challenges that could emerge due to energy conservation measures on a Net-Zero energy project. As illustrated in Fig. 41, the results showed that a only a small fraction of occupants could be willing to trade roof space for PV arrays. Thus, the incorporation of PV systems must be done in a way that allows the use of the terrace to be able to maximize the market potential of the project.

7.8.2 Market Potential

The applicable codes and policies in Ahmedabad enumerate guidelines on various aspects that indicate that the government and industry are pushing for Energy Efficient strategies. Thus, there is a market for Net-Zero buildings. An analysis of policy interventions in different cities shows similar trends across the country. This is a positive indicator of the potential of replicability for the project. An analysis of policy interventions in the various cities can be seen in Appendix.

When choosing between two equally priced projects, a project with a popular green rating is bound to hold greater interest. The proposed design has been tested against requirements of IGBC Green Homes and GRIHA for Affordable Housing. With the Project Partner's assurance that the best possible construction practices will be followed, the project rates IGBC 5 Star and GRIHA 5 Star. This easily increases buyer's interest in the project, and may even lead to reduction in promotional expenses of the developer. A detailed evaluation of the rating system is presented in Appendix.

7.8.3 Replication across India under PMAY (Unit Optimization for Prefab)

The unit has been optimized for prefab construction in a way that ensures both, technical and financial, viability. This has been done without compromising on the resultant quality of space. Feasibility of prefab constructions comes from two aspects. Firstly, repetitive fabrication of similar elements. The second aspect looks at the size and weight of the elements that can be fabricated in most prefab facilities in India.

The unit has been optimized for these constraints based on the calculation of weight of each element. As per discussions with the Industry Partner, these constraints are boundary dimensions of 12m x 4m and a weight of 8 Tons (Table 15). Therefore, the project can be replicated for similar costs across India in terms of the construction technology and unit size. An appropriate massing scheme for any city can be developed using the Grasshopper script used for this project that takes climate data (EPW weather file) and site boundary as a preliminary input.

While the project has been optimized for prefab, it needs verification of its structure. In seismic zone 3, like Ahmedabad, a fully precast structure may not be possible. Soil conditions on site may need a heavier footing design than typical conditions. Two alternate methods are being proposed.

First would be a typical on-site construction system. The second method would involve on-site construction of the structural elements (columns and slabs), while the wall panels (A to K) can be prefabricated. The placement of columns for this option would need to be worked out.

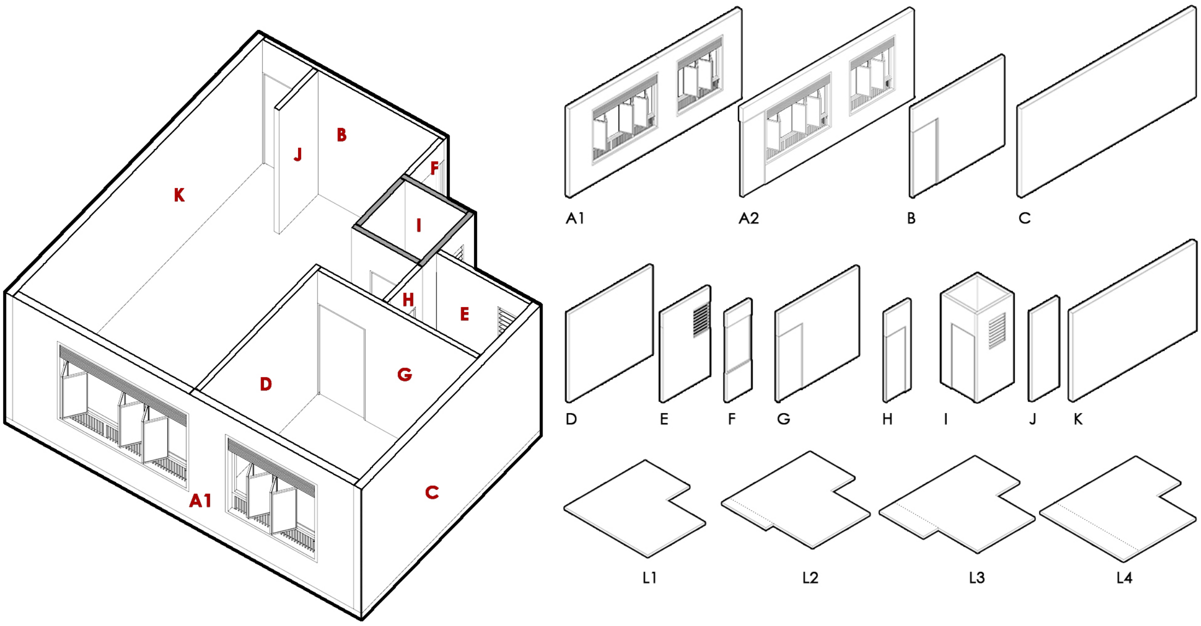


Fig. 42 Kit of parts for each unit (optimized for prefabrication)

Table 15 Technical feasibility of prefab panels evaluated through verification of length (max = 12m), height (max = 4m) and weight (max = 8 Tons). Financial feasibility verified if panel is manufactured at least 100 times.

Type	Number of Pieces in Unit	Length (m)	Thickness (mm)	Height (m)	Volume (m^3)	Weight of Each Unit (Tons)	Number of Pieces in Project
A1*	1	6.4	150	2.85	1.9	4.79	134
A2*		6.4	150	2.85	1.6	4.10	402
B	1	3.4	150	2.85	1.5	3.63	536
C	1	6.5	150	2.85	2.8	6.95	360
D	1	3.1	100	2.85	0.9	2.21	536
E	1	1.75	150	2.85	0.7	1.87	536
F	1	0.85	150	2.85	0.4	0.91	536
G	1	3	100	2.85	0.9	2.14	536
H	1	0.9	100	2.85	0.3	0.64	536
I	1	4.9	150	2.85	2.1	5.24	536
J	1	1.45	100	2.85	0.4	1.03	536
K	1	4.6	150	2.85	2.0	4.92	360
L1#	1	6.4	150	6.5	6.2	15.60	134
L2#		6.4	150	7.1	6.8	17.04	134
L3#		**6.4**	**150**	**7.7**	**7.4**	18.48	134
L4#		**7**	**150**	**7.7**	**8.1**	20.21	134

**Volume calculated after subtracting doors and windows. #Weight and Dimension limit is not applicable to slabs (L1 to L4).*

7.9 Engineering Design and Operations

7.9.1 Equipment Selection

Equipment selection was done based on the market survey conducted for knowing the wattage of various equipment used in a small residential unit. A detailed list is available in Appendix. As the project is supposed to be a net zero building, using energy saving equipment will be encouraged.

Table 16 Summary of Equipment and Lighting Power Densities for the Project

		Base Wattage	5-Star Wattage
Equipment for a Unit	Total wattage (W)	*4422*	*1355*
	EPD (W/m^2)	*116.4*	*35.7*
LPD of a Unit	Total wattage (W)	*189*	*117*
	LPD (W/m^2)	*5.0*	*3.1*
Common Equipment	Elevator	*1200*	*1200*
	Security Camera	*40*	*40*
	Total EPD of common spaces (W)	*1240*	*1240*

7.9.2 Structural Design

The prefabricated structure will be composed of load-bearing concrete walls and flat, hollow concrete slabs. The hollow concrete slabs help in reducing the dead weight. Joinery details and earthquake-resilience mechanism are under development.

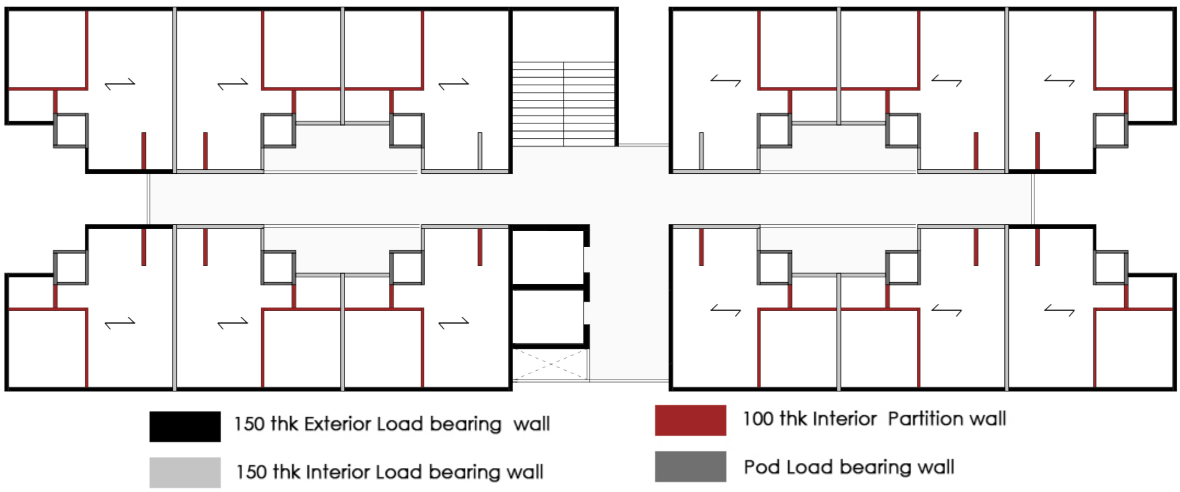


Fig. 43 Locations of load-bearing prefab panels on a typical floor plan

7.9.3 Design Delivery Model

The design delivery model refers to the process by which the 4 types of units (L1, L2, L3 and L4) will be selected, constructed and allocated to the buyer. Four possible options for this have been proposed.

1. Option 1 - Randomized selection by developer/Team 0.0.0. Buyers will be presented a brochure of options and units will be sold on a first-come-first-serve basis.
2. Option 2 - 1.2m wide balconies in Unit L4 have the maximum self-shading while lack of balconies in Unit L1 implies no shading. Based on this integrated shading, units with maximum shading are placed on the upper floors while units with least shading are placed on the lower floors. Intuitively, this option is likely to have least heat gains.
3. Option 3 - Floor-wise phasing of the project allows maximum flexibility in choice. In the first phase, the developer can choose a division based on their understanding of the market requirements. In subsequent phases, the division can be altered based on market interests and

types of units sold.

4. Option 4 - Tower-wise phasing of the project follows the system of Option 3. However, it has a distinct advantage that tower-wise municipal approvals under RERA are easier to obtain. Floor wise approvals are challenging.

The design delivery models was presented to the developer and discussions on the RERA approval process make it clear that Option 3 and 4 have major logistical challenges. Option 1 has high uncertainty in terms of market interest. Therefore, option 2 was selected to be developed further and has been used for energy modeling. However, the proportions of the 4 types of units is still not clear and could not be based on any existing market studies. Therefore, a post-design survey was conducted in March where people from the expected income bracket were presented the design and costs in the form of a brochure. Results of that survey have been used to decide the number of each type of unit as shown in Table 17. The distribution of the units results in a 20% increase in sellable area. This has further explained in the section on the Pitch to the Project Partner.

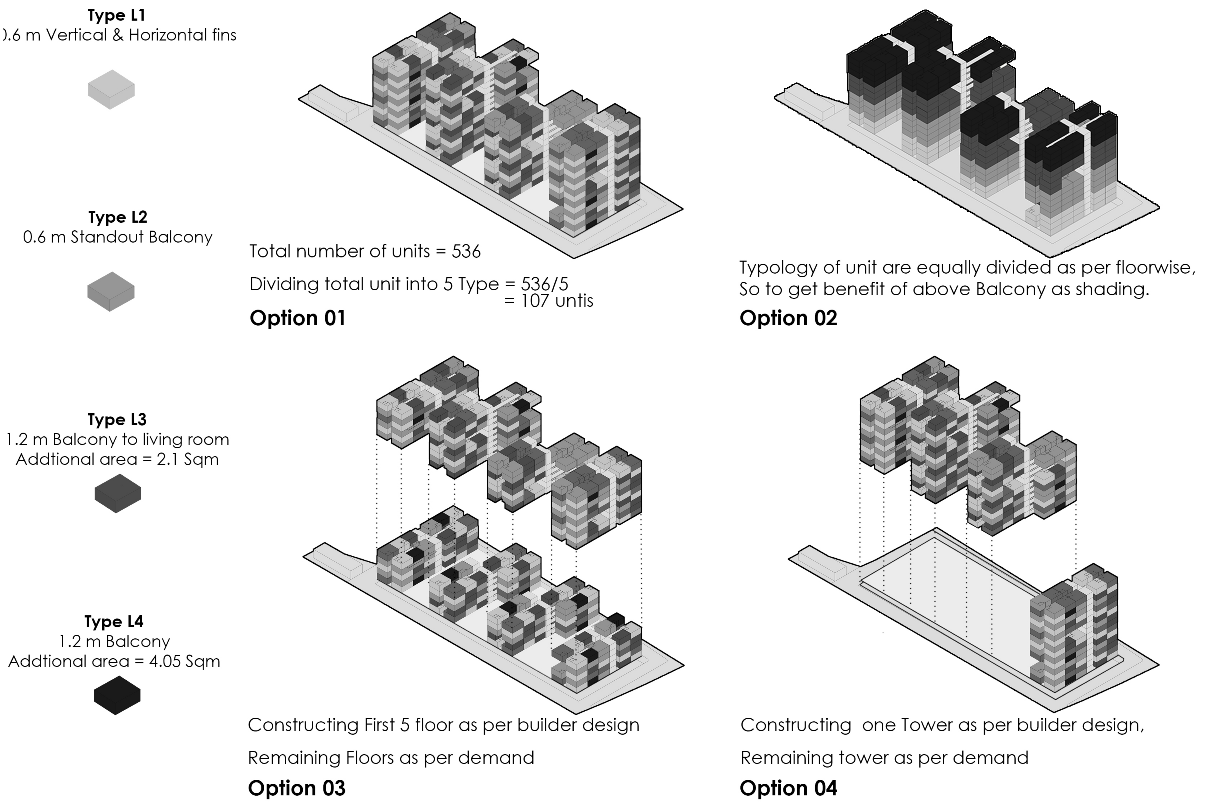


Fig. 44 Different delivery models proposed to encourage buyer participation and increase marketability; Option 2 selected for detailed development based on discussion with the Project Partner

Table 17 Distribution of different types of units in the project based on results of post-design survey

	Type	Area (in FSI) (Sqm)	Area (free from FSI) (Sqm)	Total Area (sqm)	Construction Cost / Unit (INR)	Relative Difference wrt L1 (%)	Number of Units	Total Area in FSI
Base Case	L1	38.0	0.0	38.0	748250	0	512	19,456
Proposed Case (As per post-design survey results)	L1	38.0	0.0	38.0	748250	0	37	1401
	L2	38.0	2.1	40.1	788617	5	73	2782
	L3	40.1	2.1	42.2	829967	11	110	4394
	L4	41.9	3.9	45.7	899870	20	292	12235
						Total Area of Project		23,428

7.9.4 Policy to Ensure Use of 5-Star Equipment

The use of inefficient equipment leads to higher rates of consumption. In a residential unit, the major energy consumers are the refrigerators, geysers, television, fans, washing machines and mixers. From the energy model we can observe that energy efficient appliances are critical for achieving net-zero energy use. Similar observations have been made in other studies as well.[12]

As new home buyers will be occupying the residential units a few clauses can be implemented to ensure the use of energy efficient appliances and lighting. The first option is to mandate the purchase of BEE- 5 star rated equipment as a clause in the housing loan purchase. The implementation of this clause will be during final approval of the loans where the home buyer needs to produce a bill of the purchased or ordered appliances.

Such clauses could be built into a green financing scheme that Savvy Studioz could be eligible for. Green financing schemes resulting in lower interest home loans have been facilitated from time to time by various climate funds. However, while these have been on the horizon in India since 2008, no significant growth has been seen in this regard (NHB, & Sunref India, 2020).

While green financing is a powerful policy measure, it appears unlikely that it will come to fruition in the next 5 years given its history in India. Thus, we propose that the developer could potentially pre-order a list of approved models for equipment and lighting, from which the owners can select and purchase them. This could be beneficial to both parties as the providing agency can buy or order the equipment / lighting in bulk; thereby reducing the cost price and the owners can select the equipment models they like at a discounted rate. For example EESL[13], an ESCO has been able to make several energy efficient appliances affordable and accessible to a wide set of people through deep discounts via mass purchace order. This will enable profits to both parties while reducing the overall consumption of energy.

7.9.5 Post Occupancy App

Data access in India is increasingly cheaper and affordable. A post occupancy guidance App has been proposed to guide the occupants towards a sustainable & healthy lifestyle. The App will be used to suggest operational changes like opening windows, peak load shaving strategies, guidelines for waste segregation, reports on water quality, and warnings about heat waves. It will also be used to increase occupant involvement and interest in the functioning of site-level infrastructure.

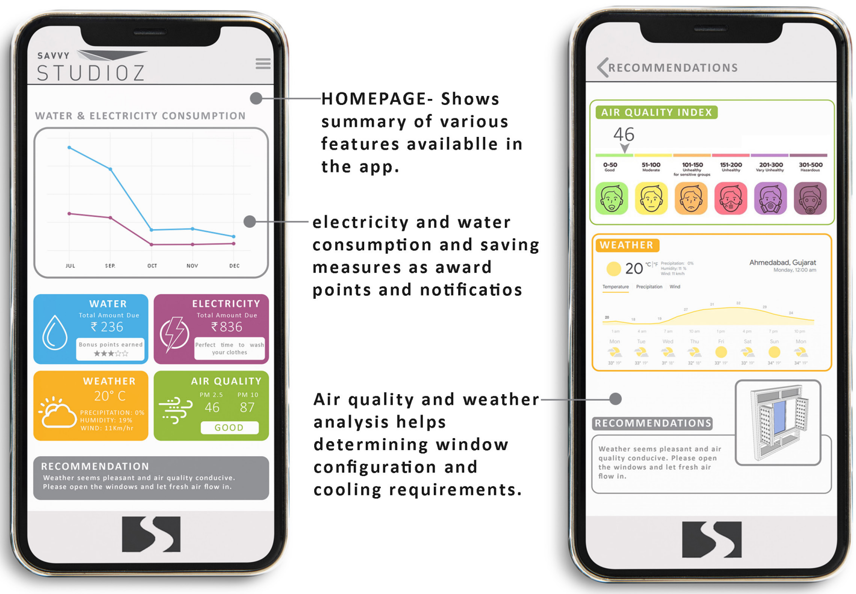


Fig. 45 Post-occupancy app interface

12 ENS. (2019, November 14). Gujarat: Study to focus on thermal comfort and energy use in affordable houses | India News,The Indian Express. The Indian Express. https://indianexpress.com/article/india/gujarat-study-to-focus-on-thermal-comfort-and-energy-use-in-affordable-houses-6118460/a

13 EESL. (2017). Energy Efficiency Services Limited. Retrieved April 14, 2021, from https://eeslindia.org/en/home/

8.0 Pitch to the Project Partner

A net zero energy, multi-family housing project is a relatively less explored area in the building industry. A net zero energy and water design are even more so. Team 0:0:0 from CEPT University upgraded the Savvy multifamily housing project located in Ahmedabad to triple zero design. The design process was developed with a data driven, integrated design approach by a multidisciplinary team from building science, architecture and engineering disciplines along with the technical support of industry partners. The team's intent can be broken down into the following:

- Net-Zero Energy: The project consumption has been decreased from 52.6 to 22.1 kWh/m^2-yr. This has been brought on by integrating passive design measures, providing an efficient HVAC system and proposing policies that promote use of energy-efficient equipment. The reduction in consumption translates to annual savings of almost Rs. 6,000 in every occupant's electricity bill. This is equivalent to savings of more than Rs 31 lakhs every year for the project.
- Net-Zero Water: Water consumption has been decreased from 135 LPHD to 80 LPHD through strategies such as Low flow fixtures, water harvesting, Water recycling, and occupant behavioral measures. An annual potable water requirement of 37487 Kl will be catered by the municipal supply in return for which the same amount of treated black water will be sent back to the municipality. The operational cost for the complete water system will be 6 paise/liter.
- Net-Zero Waste: While proper waste management does not translate into direct economic earnings, it shows commitment towards a low carbon footprint. It also adds an alternate heat source to the site that helps in managing the hot water requirement.
- 5-Star Rating: The three net-zero measures result in 5 star ratings from both, GRIHA and IGBC Green Homes. When choosing between two equally priced projects, a project with a popular green rating is bound to hold greater interest.
- User Interest: To accommodate diversity within the affordable sector and give users some choices, the design has been given flexibility in terms of types of balconies (Table 14). As shown in the table below, prospective buyers surveyed have shown a willingness to pay extra for a balcony.
- Operational Challenges: Any design and technical intervention can fail unless implemented as intended. This is particularly applicable to window operation and equipment usage. Therefore, a post-occupancy guidance app has been proposed to allow behavioral monitoring and recommendation.
- Capitalizing on Policy: The applicable codes and policies in Ahmedabad enumerate guidelines on various aspects that indicate that the government and industry are pushing for Energy Efficient strategies. This increases the viability of the project from the point of view of approvals and legal formalities.

Table 18 Prospective buyers surveyed showed a willingness to pay extra for the balcony

	Type of Unit	Total Area (sqm)	Construction Cost / Unit (INR)	Number of Units	Total Area	Total Cost of Construction	Buyer Willingness to Pay Extra	
							Worst Case	Best Case
Base Case	L1	38	7,48,250	536	20,368	40,10,62,214	0	0
Proposed Case	L1	38	7,48,250	39	1,466	2,88,76,479	0	0
	L2	40	7,88,617	77	3,070	6,04,45,881	0	1,00,000
	L3	42	8,29,967	115	4,835	9,52,00,560	0	3,00,000
	L4	46	8,99,870	306	13,987	27,54,10,478	2,00,000	5,00,000
				Total	**23,358**	**45,99,33,398**		

Costs

The interventions result in an incremental costs of almost 4 crores. It has been proposed that this cost be split between Savvy and a third party. The third party functions as a Renewable Energy Service Company (RESCO) to fund and maintain the PV array and CaaS-based HVAC model. The attractive ROI of 10.3% makes it a lucrative business proposal for any investor.

Table 19 Project costs split between Savvy and a RESCO (third-party investor)

	Base Case	Proposed Case	
	Savvy	**Savvy**	**RESCO - (SPV)**
Construction	1697	1662	0
PV	0	0	15
CaaS	0	0	51
Net-Zero Water Measures	0	54	0
Waste-based Generator	0	68	0
Cost / Sqft	1697	1727	66
Relative Difference		5%	4%
Total Construction Cost	₹ 40,52,50,250	₹ 42,60,69,172	₹ 1,61,71,983
Land Cost	₹ 45,59,21,753	₹ 45,59,21,753	₹ 0
Total Project Cost	**₹ 86,11,72,003**	**₹ 88,19,90,925**	**₹1,61,71,983**

Team 0:0:0's intents lead to two major benefits for Savvy:

1. Brand development of Savvy through positive marketing - The value-additions can lead to media coverage due to their climate-friendly approach. This not only helps in building up Savvy's brand value but also provides "free" marketing of its projects.
2. Positive marketing leading to positive sales - Savvy would be least at risk if units are sold before or during construction. The positive marketing will lead to early sales of the units. Early sales would reduce the time Savvy needs to pay-off the loans and help saving on interest.

9.0 References

Barton J., Thomson M., Sandwell P., Mellor A. (2020) A Domestic Demand Model for India. In: Singh S., Ramadesigan V. (eds) Advances in Energy Research, Vol. 1., pp 743-753 Springer Proceedings in Energy. Springer, Singapore, https://doi.org/10.1007/978-981-15-2666-4_70

Cook, M., & Rawal, R. (2018). Low energy cooling and ventilation in indian residences. In Science and Technology for the Built Environment (Vol. 24, Issue 8, p. 819). Taylor and Francis Inc. https://doi.org/10.1080/23744731.2018.1522144

EESL. (2017). Energy Efficiency Services Limited. Retrieved April 14, 2021, from https://eeslindia.org/en/home/

ENS. (2019, November 14). Gujarat: Study to focus on thermal comfort and energy use in affordable houses | India News,The Indian Express. The Indian Express. https://indianexpress.com/article/india/gujarat-study-to-focus-on-thermal-comfort-and-energy-use-in-affordable-houses-6118460/

Freeman, J. M., DiOrio, N. A., Blair, N. J., Neises, T. W., Wagner, M. J., Gilman, P., & Janzou, S. (2018). System Advisor Model (SAM) General Description (Version 2017.9.5). https://doi.org/10.2172/1440404

GDCR (2017) "Gujarat Comprehensive Development Control Regulations - 2017," 2017.

IES. (2012). IES LM-83-12. https://www.stdport.com/standards/ies-lm-83-12.html

Jentsch M.F., Bahaj A.S. and James P.A.B. (2008) Climate change future proofing of buildings – Generation and assessment of building simulation weather files. Energy and Buildings,Volume 40, Issue 12, December 2008, pp 2148-2168. Joustra, C. M., & Yeh, D. H. (2015). Framework for net-zero and net-positive building water cycle management. Building Research and Information, 43(1), 121–132

Khanna, P., Sinha, R., Sen, I., Goswami, G., Mutz, D., Arora, R., Prakash, R., & Sinha, P. (2020). Resource Flows in Indian Cities: City Profile of the Construction Sector in Ahmedabad. https://www.eu-rei.com/pdf/publication/GIZ_Ahmedabad City Report_17 Aug.pdf

Ko, H., Schiavon, S., & Ko, W. H. (2017). Balancing Thermal and Luminous Autonomy in the Assessment of Building Performance . https://escholarship.org/uc/item/7b4909sf

Koop, S. H. A., Van Dorssen, A. J., & Brouwer, S. (2019). Enhancing domestic water conservation behaviour: A review of empirical studies on influencing tactics. Journal of Environmental Management, 247(March), 867–876. https://doi.org/10.1016/j.jenvman.2019.06.126

Manu, S., Shukla, Y., Rawal, R., Thomas, L. E., & de Dear, R. (2016). Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC). Building and Environment, 98, 55–70. https://doi.org/10.1016/j.buildenv.2015.12.019

MNRE. (2017, January 24). National Solar Mission - Grid Connected Solar Rooftop Program in India. Ministry of New and Renewable Energy-Government of India. https://solarrooftop.gov.in/notification/Notification-24012017.pdf

Moora, H. and Barde, H. (2018) 'Environmental impacts of informal plastic waste management' , in Emmons, K. (ed.) 'Closing the Loop : Innovative partnerships with informal workers to recover plastic waste, in an inclusive circular economy approach – Pune, India case study', pp 18-19.

Murari, K. K. et al. (2015) "Intensification of future severe heat waves in India and their effect on heat stress and mortality," Regional Environmental Change, 15(4), pp. 569–579

NHB, & Sunref India. (2020). SUNREF-Affordable Green Housing India programme launched by Agence Française de Développement (AFD), France in partnership with National Housing Bank (NHB) and support of European Union (EU). https://nhb.org.in/refinance-assistance-from-nhb/

The Daylight Metrics Committee, (2012). 'IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)' , pp 1-3

USEPA 2017, Promoting Sustainability through Net Zero Strategies,<https://www.epa.gov/water-research/net-zero-concepts-and-definitions>.