Final Report

Green Building Initiatives for Affordable Housing

Prepared for

Human Settlement Management Institute (HSMI)

A Research and Training Wing of

Housing and Urban Development Corporation Ltd.(HUDCO)

teri

The Energy and Resources Institute

...towards global sustainable development

hudco

Suggested format for citation

T E R I. 20th October, 2014

Report on Green Building Initiatives for Affordable Housing

Bangalore: The Energy and Resources Institute. 290pp.

[Project Report No. 2014BG02]

For more information

The Energy and Resources Institute
4th Main
2nd Cross
Domlur 2nd Stage
Bangalore – 560 071
India

Tel. 25356590 **to** 25356594
E-mail minnim@teri.res.in
Fax 25356589
Web www.teriin.org
India +91 • Bangalore (0)80

Housing and Urban Development Corporation Ltd.
HUDCO Bhawan, Core-7-A
India Habitat Centre
Lodhi Road
New Delhi - 110 003
India

Tel(EPABX) :011-24649610-23,24627113-15,24627091,92,95
After Office Hours: 24648193-95
Fax:011-24625308
Email: mail(at)hudco(dot)org
Visit us at : www.hudco.org

Project Team

Principal Coordinator - Dr. SK Gupta, EDT HSMI

Technical Coordinators - Dr. Manika Negi, Fellow, CAH, HSMI and
Ms. Vijaya R.Vasu, DGM, HUDCO Bangalore Regional Office

TERI Team

Ms. Minni Sastry- Project in Charge

Mr. Sanket Puranik- Co - PI

Mr. Hara Kumar Varma Namburu

Mr. Kiriti Sahoo

Mr. Kiran Kumar DEVS

Ms. Malvika Saran

Ms. Meghana Manjunath

Project Advisor

Ms. Mili Majumdar

Secretarial Assistance

Ms. Padmini P H

Mr. Soy Joseph

Acknowledgements

TERI would like to acknowledge all the owners of case study buildings, Architects, Developers, Contractors, MEP consultants, Manufacturers and other agencies who supported our request for conducting field study in the identified projects. Their efforts in participating in the interview and to collate the required documents during field studies.

The support and detailed comments given by Dr. Manika Negi, Fellow, HSMI and Ms. Vijaya R Vasu, DGM (Projects), Bengaluru Regional Office, HUDCO have been very vital in pursuing the activities and completion of reports at various stages of the project.

We would like to express our sincere gratitude to Mr. N L Manjoka, Director- Corporate Planning, HUDCO, Dr. S. K . Gupta, Executive Director, HSMI and Ms. Mili Majumdar, Director, Sustainable Habitat Division, Professor Shaleen from TERI University for their continuous guidance and support for completing the study.

We also wish to acknowledge the comments received by the Expert Committee.

Table of contents

List of Tables

List of Figures

1 Introduction

Green building initiatives for affordable housing is a study carried out to document and evaluate, green building features integrated in existing affordable residential projects. Information gathered through the study is useful to assess the benefits of green building features for their adoption and replication in affordable housing projects. Appraisal parameters for financing green building features with respect to affordable housing and policy inputs to mainstream green features in affordable housing are being recommended.

A two pronged strategy was adopted to undertake the study. In the first phase, exhaustive desk research was undertaken. This involved study of relevant material on the rationale of green building concepts and its linkages with affordable housing concept covering studies done both within India and abroad. This was followed by the second phase of field studies mapping the initiatives in all 5 climate zones of India, covering Moderate, warm-humid, composite, hot-dry and cold. During field visits, quantitative monitoring was performed to test the environment performance inside the homes, as well as interviews were conducted with user group, architect, developer, contractor to evaluate the effectiveness of green initiatives. The study locations were Bangalore (Moderate), Chennai (Warm-humid), Ahmedabad (Hot-dry), Delhi (Composite) and Leh (Cold). The study enabled drawing lessons, effective evaluation of the benefits that have accrued from the implementation of green building initiatives. For all the green features documented, affordability and replicability analysis was carried out, which formed the basis of recommending policy guidelines and mandatory regulations.

2 Aim, Objective & Methodology

2.1 Need for the study

Human Settlement Management Institute (HSMI, which is the Research & Training Wing of HUDCO has the mission of making a significant contribution towards enhancing quality of life through action plan, research and capacity building. HSMI achieves this through policy research, evaluation studies, documentation and dissemination. The study on "Green Buildings Initiatives for Affordable Housing" has been funded by HSMI. The information gathered from case studies in the project, will serve as information base for HUDCO in its affordable housing projects. HSMI shall disseminate learning from the study to enhance the effectiveness of such initiatives.

2.2 Aim & Objective

The aim of assignment was to document the "Green Building Initiatives for Affordable Housing" with objective to arrive at

- Documentation of best green building practices in residential sector.
- Derive affordability for green features for their replication in affordable housing projects.
- Assess and appraise parameters for green building financing
- Frame policy guidelines and mandatory regulations for mainstreaming green building initiatives in affordable housing projects.

2.3 Scope of work

Scope of work entailed country wide study covering all climate zones for data collection from green building case studies and their analysis covering the following parameters during field visits:

- Siting of buildings
- Climate responsiveness
- Building materials and structural systems
- Waste management system
- Energy conservation
- Carbon Footprint
- Biodiversity
- Performance of the housing other innovative initiatives.

2.3.1 Limitation

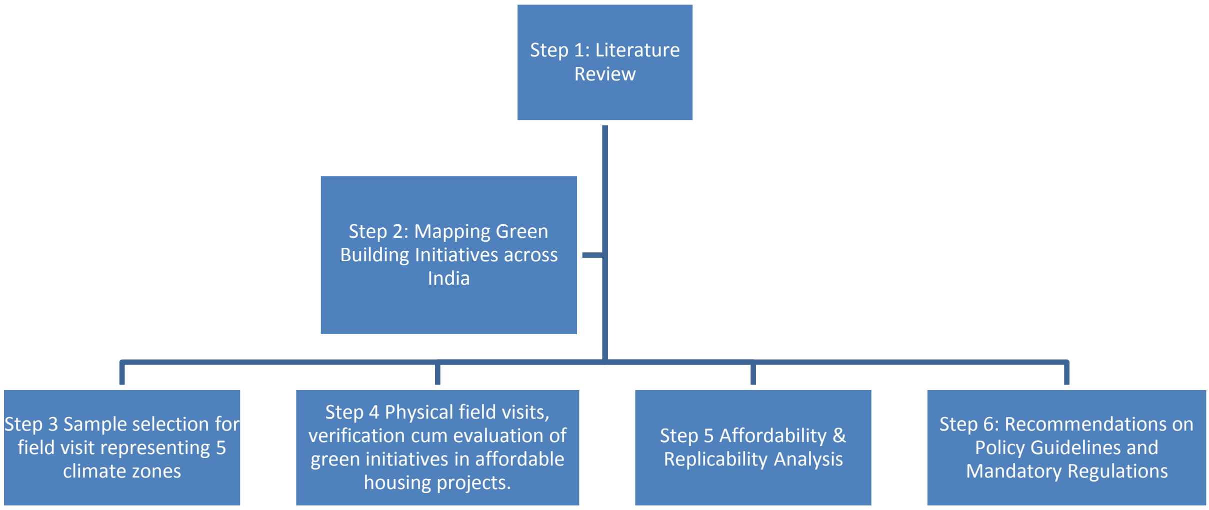
The short duration study is limited to documentation of only a few field studies in five climatic zones in India and performance monitoring of environment parameters for a day. Analysis of performance parameters to assess the impact of green feature on temperature, RH, and light levels etc is complete if the impact for all seasons is captured, which requires a study of longer duration.

2.4 Methodology

A two pronged strategy was adopted to undertake the study. In the first phase extensive literature review was carried out covering green building concepts, affordable housing concepts and case studies both within India and abroad.

The second phase comprised of field studies, mapping of green building initiatives in residential sector was undertaken covering all climate zones. This was followed by physical checks and verification including interactions with various stakeholders in selected affordable projects where green initiatives were integrated.

After the physical field studies, affordability cum replicability analysis was carried out which, formed the basis for framing policy guidelines and mandatory regulations. To summarise the above activities, flow chart is given below:



2.5 Methodology for field case study selection

2.5.1 Mapping of Green Building Initiatives in Housing and affordable housing

India is divided into 5 climate zones. As per the National Building Code 2005, these are: Composite, warm-humid, hot-dry, cold and temperate (or moderate). Green building initiatives in affordable housing in all the climate zones were mapped in India. The list of these projects is given in **Annexure 1**. From the housing projects, affordable housing projects were shortlisted for selecting case studies for detailed documentation and analysis from all climate zones. Map of India showing all five climate zones is given below.

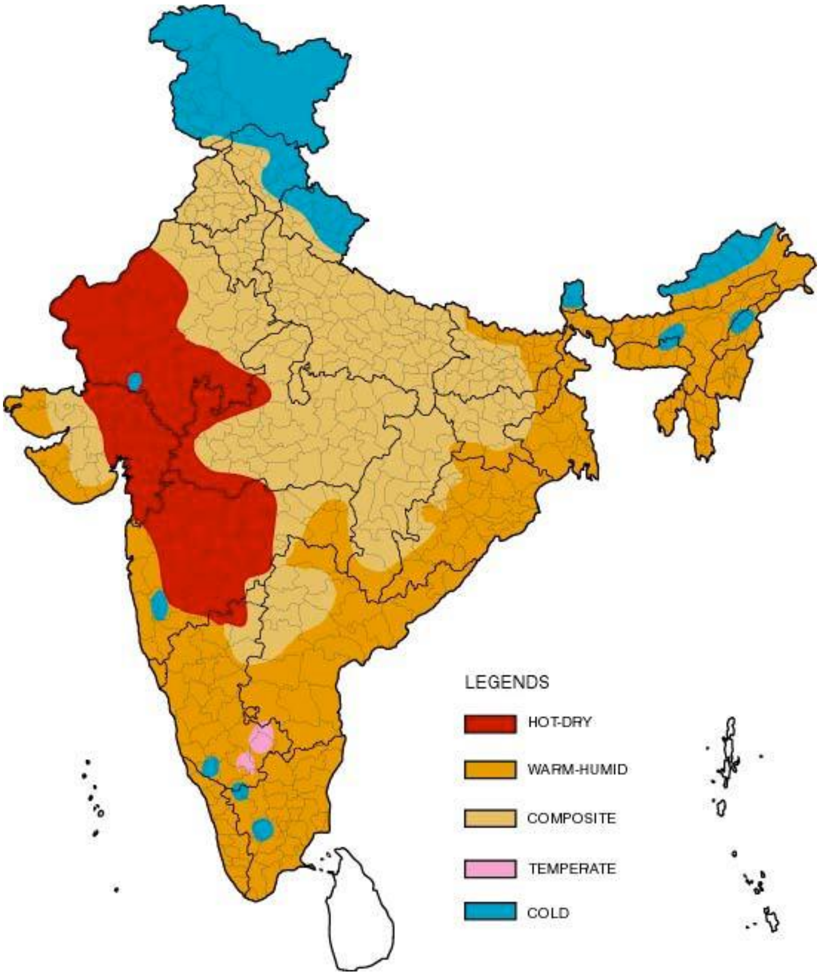


Figure2.1: Map of India showing different climatic zones. Source: National Building Code of India 2005.

2.5.2 Methodology of carrying out case studies

After the mapping process of affordable housing projects for green initiatives was completed, a few sample case studies were selected for physical studies.

During the physical studies, performance evaluation of green initiatives was evaluated for their replicability.

Performance was evaluated through interviews with user group (occupants), designers/consultants/contractors. During the physical field studies monitoring of thermal and visual comfort levels were also carried out. Documentation of projects was carried out through collection of drawings, pictures. Energy bills were collected wherever possible.

Thus there are both qualitative and quantitative research techniques that were used to evaluate the performance of case studies.

Qualitative tools included the following:

- Questionnaire for contractors, Architect
- Questionnaire for consultants
- Questionnaire for maintenance team

- Interview guide for user group
- Interview guide for developer/owner
- Interview guide for manufacturers

Quantitative tools included the following:

- Thermal comfort monitoring on site which will include monitoring of temperature and Relative Humidity.
- Visual comfort monitoring on site which will include lux level measurements inside the house.
- Energy bills will be collected and Energy Performance Index will be derived. This will help in calculation of carbon footprint.
- Water consumption if monitored, data will be collected to calculate water consumption pattern.

Besides the above tools, during the field studies green features integrated in the design of habitat projects will be collated through drawings and photos, covering the following parameters:

a. Sustainable site planning
b. Building materials and construction technologies
c. Energy
d. Water management
e. Waste management

2.5.3 Selection criteria of sample case studies with green features

The study samples had to be selected from each of the five climate zones. The study samples were required to cover both housing schemes and a housing unit with green building initiatives.

Green features based selection criteria was developed to finalize the sample field study case studies. The projects that were finally selected for field studies, has at least minimum of 50% of green building features mentioned below.

Table 2.1: Green building features for a residential project

Sl No	Green building features
1.	Siting and climate responsiveness
	Orientation
	Zoning
2.	Energy, renewable energy & building materials
	Building envelope to respond to outside climate
	Roof treatment, roof garden
	Shaded windows
	Walls to respond to outside climate
	Local materials to reduce embodied energy
	Pre-fab construction technologies to reduce time and volume of construction
	Natural ventilation

Sl No	Green building features
	Daylight integration
	Efficient outdoor and indoor lighting by use of T5/T8 flourescent lights with compatible energy efficient ballasts, CFL, LED etc. Ref : http://www.ecospecifier.com.au/knowledge-green/technical-guides/technical-guide-5-high-performance-fluorescent-lighting.aspx
	Efficient fans or other heating/cooling technologies
	Solar based outdoor lighting
	Solar based water heating
	Solar PV panels to generate electricity
3.	Efficient landscape design
	Pervious pavers
	Sedimentation control measures in the landscape design
	Use of native species
	Source of landscape water
	Irrigation equipment
4.	Water management
	Waste water treatment system
	Rain water harvesting
	Dual plumbing system
	Efficient plumbing fixtures
5.	Waste management
	Segregation of waste
	Resource recovery from organic waste
	Resource recovery from recyclable waste

2.5.4 Selection of case studies with green features

Moderate Climate zone

In the Moderate climate zone, there were 20 residential projects found which are green (Annexure 1), out of these 5 projects are at Habitat scale. These include:L ZED Earth, ZED Collective, ZED Wood, Good Earth Malahar, Suvidha Retirement Village and Faculty Housing in Bangalore. All of these comprise of more than 50% of the above green features indicated. Further according to the unit size, affordability, cost and year of construction a comparative analysis was carried out. Based on the available information on green features, location, built up area, construction cost, client support**, Good Earth Malhar Footprints** was selected for first case study. At individual house level, **Rohan's House** designed by Architect Chitra Vishwanath was selected for detail study.

Warm Humid Climate zone

In the Warm and Humid climate zone, there were 12 projects identified which are green and affordable (Annexure 1), out of these 7 projects were at Habitat scale. These include:TATA Subh Gruha in Mumbai, Govardhan Village in Thane, Auroville Earth Institute in Auroville, Rabirashmi in Kolkata and MARG Swarnabhoomi, Happinest, VBHC Vaibhava Oragadam in Chenani. All of these comprise of more than 50% of the above green and affordable features indicated. Further according to the unit size, affordability, cost and year of construction a comparative analysis was carried out. Based on the available information on green features, location, built up area, construction cost, client support, **VBHC, Chennai** was undertaken for detailed field study.

Cold Climate zone

Three projects were identified in cold climate in India and were documented in literature review. Of these the once carried out by Groupe Energies Renouvelables, Environment et Solidarités (GERES) is on housing/community level. The houses constructed are cheaper (INR 60,000 per house this cost corresponds to year 2008 – 2010 as compared to INR 10 lakhs for TATA eco hut). The GERES project has a holistic approach, i.e., it intends to solve environmental, social and economic challenges faced by people living in far off places of western Himalayan region. In this project emphasis has been given on replicability and dissemination of features along with being sustainable without external support of NGO's. These characteristics of the GERES project make it an interesting case study especially which can be replicated in inaccessible places solving both problems of housing and livelihood shortages for people. Thus, **Passive Solar Homes in Ursi village, Leh, by GERES** was selected for detailed field visit.

Hot-Dry Climate zone

There are 15 housing projects identified under literature review that are green in Hot-Dry climate zone of India. On contacting all the developers and Architects, it was found out that all the identified projects at Habitat scale were either still under construction or constructed but not operational. Only one project, the developer confirmed that the project was occupied and operational, was **SAVVY Solaris in Ahmedabad**, thus this was selected for detailed field study. For individual house, Architect **Surya Kakkani's house** was selected for detailed field study.

Integrated Housing and Slum Development Programme in Lonar is a Central Government sponsored slum rehabilitation project under JNNURM. Construction for this project though not completed, the case is documented through secondary sources, as it is a Government project, to highlight the green features adopted in such projects.

Composite Climate zone

There are many projects in Composite climate zone at habitat level, which are undergoing green certification; however, most of these projects are Luxurious housing projects. Based upon the interactions with Architects/consultants/RWAs for various projects, two projects were selected in Delhi for detail field study. These are:

- **Girls Hostel in TERI University**
- **Mahindra Life Spaces – Aura, Gurgaon.**

Both the above projects were selected after speaking with Architects, owners, TERI team realised that these projects have features that are green, affordable and replicable.

Table below shows the final projects selected for detail field study along with their green features with reference to Table 2.2

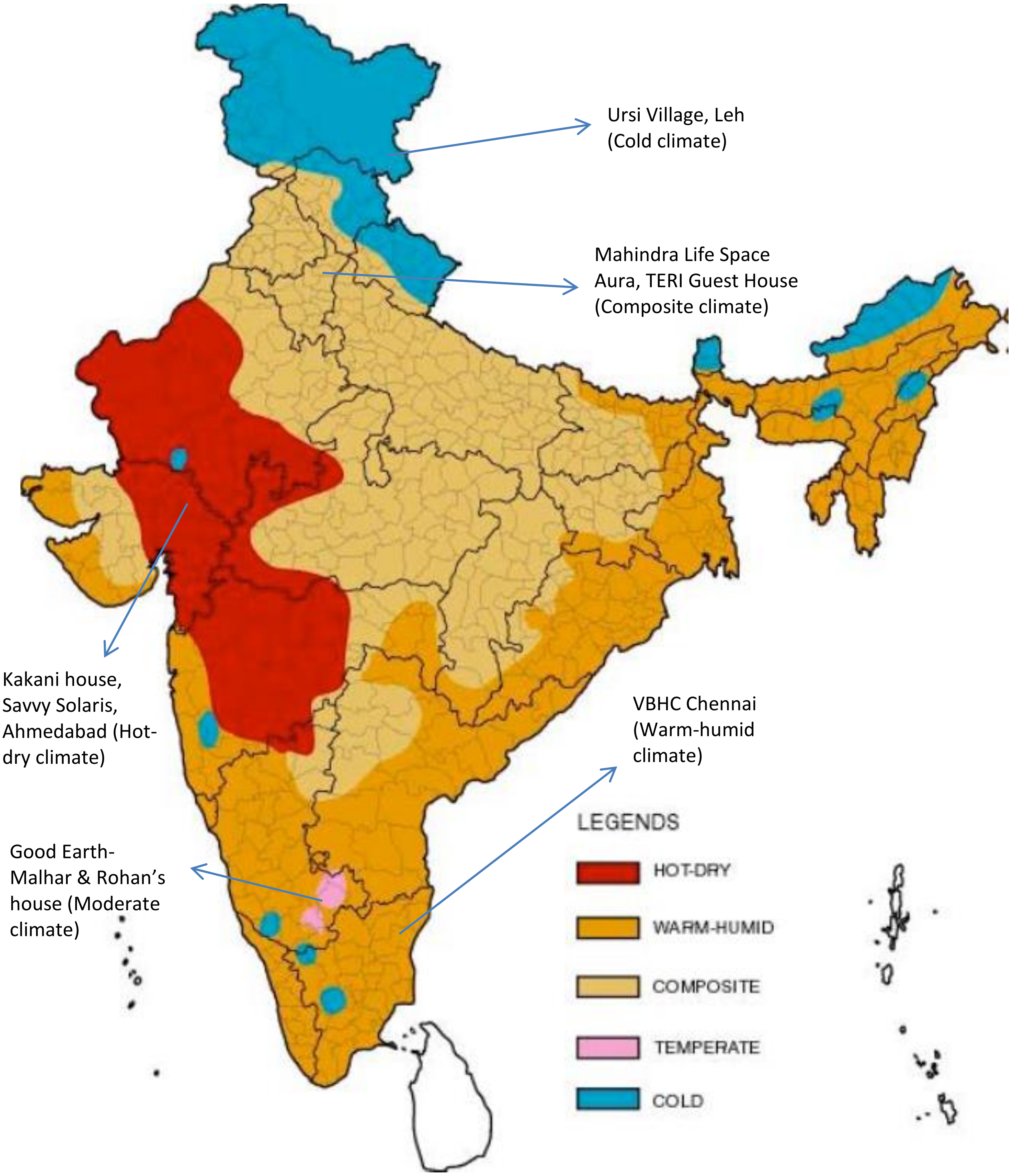


Figure2.2: Field studies undertaken under five climate zone

Table 2.2: Green building features identified in selected field studies of 5 climate zones of India

Sl No	Green building features summary	Good Earth Malhar footprints, Bangalore(G+1 group housing)	Rohan and Reshmi's House, Bangalore (G+1 Individual House)	VBHC Oragadam, Chennai (G+4, Group housing)	Solar Passive House- Ursi Village, Leh (individual house)	TERI university hostel block, Delhi (G+4, Hostel)	Mahindra Aura, Delhi (G+10, apartments)	Surya Kakkani's House, Ahmedabad (G+2, individual house)	Solaris Savvy, Ahmedabad (G+10, apartments)
	Climate	**Moderate**	**Moderate**	**Warm and Humid**	**Cold**	**Composite**	**Composite**	**Hot and dry**	**Hot and dry**
1.	**Siting and climate responsiveness**								
	Orientation	✓	✓	✓	✓	✓	-	✓	-
	Zoning	-	✓	✓	-	✓	-	✓	-
2.	**Energy, renewable energy & building materials**								
	Building envelope to respond to outside climate	✓	✓	✓	✓	✓	✓	✓	✓
	Roof treatment, roof garden	✓	✓	-	✓	✓	✓	✓	✓
	Shaded windows	✓	✓	✓	NA	✓	✓	✓	✓
	Walls to respond to outside climate	✓	✓	✓	✓	✓	✓	✓	✓
	Local materials to reduce embodied energy	✓	✓	-	✓	✓	✓	✓	✓
	Pre-fab construction technologies to reduce time and volume of construction	✓	✓	✓	NA	-	-	-	-

Sl No	Green building features summary	Good Earth Malhar footprints, Bangalore(G+1 group housing)	Rohan and Reshmi's House, Bangalore (G+1 Individual House)	VBHC Oragadam, Chennai (G+4, Group housing)	Solar Passive House- Ursi Village, Leh (individual house)	TERI university hostel block, Delhi (G+4, Hostel)	Mahindra Aura, Delhi (G+10, apartments)	Surya Kakkani's House, Ahmedabad (G+2, individual house)	Solaris Savvy, Ahmedabad (G+10, apartments)
	Climate	**Moderate**	**Moderate**	**Warm and Humid**	**Cold**	**Composite**	**Composite**	**Hot and dry**	**Hot and dry**
	Natural ventilation	✓	✓	✓	✓	✓	✓	✓	✓
	Daylight integration	✓	✓	✓	✓	✓	✓	✓	✓
	Efficient outdoor and indoor lighting by use of T5 lamps, CFL, LED etc	✓	✓	✓	NA	✓	✓	-	✓
	Efficient fans or other heating/cooling technologies	-	-	-	NA	-	-	-	-
	Solar based outdoor lighting	-	-	✓	-	-	-	-	-
	Solar based water heating	✓	✓	-	-	✓	✓	✓	-
	Solar PV panels to generate electricity	✓	✓	-	-	-	-	-	-
3.	**Efficient landscape design**								
	Pervious pavers	✓	-	✓	NA	✓	✓	✓	-
	Sedimentation control measures in the landscape design	✓	-	✓	NA	✓	✓	✓	-
	Use of native species	✓	-	✓	✓	✓	-	✓	-

Sl No	Green building features summary	Good Earth Malhar footprints, Bangalore(G+1 group housing)	Rohan and Reshmi's House, Bangalore (G+1 Individual House)	VBHC Oragadam, Chennai (G+4, Group housing)	Solar Passive House- Ursi Village, Leh (individual house)	TERI university hostel block, Delhi (G+4, Hostel)	Mahindra Aura, Delhi (G+10, apartments)	Surya Kakkani's House, Ahmedabad (G+2, individual house)	Solaris Savvy, Ahmedabad (G+10, apartments)
	Climate	**Moderate**	**Moderate**	**Warm and Humid**	**Cold**	**Composite**	**Composite**	**Hot and dry**	**Hot and dry**
	Source of landscape water from recycled water	✓	✓	✓	NA	✓	✓	-	✓
	Irrigation equipment	✓	-	-	NA	-	✓	-	✓
4.	**Water management**								
	Waste water treatment system	✓	✓	✓	-	✓	✓	✓	✓
	Rain water harvesting	✓	✓	✓	-	✓	✓	✓	✓
	Dual plumbing system	✓	✓	✓	NA	✓	✓	✓	✓
	Efficient plumbing fixtures	✓	✓	✓	NA	✓	✓	-	✓
5.	**Waste management**								
	Segregation of waste	✓	✓	✓	NA	✓	-	-	✓
	Resource recovery from organic waste	-	-	-	✓	✓	✓	-	✓
	Resource recovery from recyclable waste	-	-	-	✓	-	✓	-	✓

3 Literature Review

Green affordable housing as the name suggests has two key components, i.e. affordability and green features. Affordability for a household as discussed earlier is function of price, area income, income of household, and size of household. Affordable housing in some countries like Singapore means houses built and operated by public authorities like housing department. In country like U.S. most of the affordable housing is built buy for-profit developers and community based organization (The costs and benefits of green affordable housing, 2005). While in developing countries like India affordable houses are built through financial aid from government organizations or from international agencies.

3.1 Green Building Concept

Concept of Green building is again defined differently by various organisations throughout the world. Some definitions by prominent organizations are discussed below:

1. Ministry of New and Renewable Energy (MNRE), India: MNRE, in its "Green building movement" issue of Akshay Urja (Urja,2011), defined green building as one which can function using an optimum amount of energy, consume less water, conserve natural resources, generate less waste and create spaces for healthy and comfortable living, as compared to conventional buildings. In other words, a green building minimizes the demand on fossil fuel based energy and maximizes usage of renewable energy along with the reuse and recycle of resource.
2. GRIHA (Indian green rating system), India: GRIHA has a holistic approach to green buildings. Ideally green building should: ("The costs and benefits of green affordable housing."2005.)
    a. Optimize demand for electricity, water and other natural resources (in construction, operation and demolition),
    b. Generate all its electricity on site through renewable means,
    c. Cater to all its water demands through sustainable processes such as rain water harvesting, waste water treatment and reuse.
    d. Grow its own food on site and Recycle and,
    e. Reuse all its waste on site and burden the environment to the minimum.

GRIHA has a strong emphasis on local context as without it sustainability definition of sustainability is incomplete. Therefore in Indian Context GRIHA defines Green buildings as those:

a. Designed using an integrated approach (as mentioned in NBC, Part 0),
b. Providing its users with an "optimal" level of comfort catering to local needs(as per NBC-Part 8),
c. Using minimum resources, sourced locally (as per various IS codes and other local materials),
d. Consuming minimum energy and water (as per ECBC and NBC), and

e. Generating optimum waste, processed locally (as per CPCB, and MoEF norms) during its construction, operation and demolition (i.e., over its entire life cycle).

3. Indian Green Building Council (IGBC), India: According to IGBC -*"A green building is one which uses less water, optimizes energy efficiency, conserves natural resources, generates less waste and provides healthier spaces for occupants, as compared to a conventional building."*(IGBC, n.d.).

4. Green Business Centre (GBC), India: GBC provides a shallow definition of green building by simply saying that green buildings are similar to other building however, the difference lies in the approach, which revolves round a concern extending the life span of natural resources: provide human comfort, safety and productivity. This definition is ephemeral and does not go deeper.

5. Environmental protection agency (EPA) USA:EPA defines Green buildings *as the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building* (Green Building Definition, n.d.).

6. Green Building Index (GBI), Malaysia: The GBI states that Green building is one which focuses on increasing the efficiency of resource use – energy, water, and materials – while reducing building impact on human health and the environment during the building's lifecycle, through better siting, design, construction, operation, maintenance, and removal. Green Buildings should be designed and operated to reduce the overall impact of the built environment on its surroundings (Green building, n.d.)

7. Green Building Label (GBL), Taiwan: GBL has an interesting take on definition of green building. Apart from being ecological, healthy, energy efficient, and less waste producing, green building also has to adapt to local climate, and adjust to the seasons on its own rather than relying on energy-consuming modern machinery (Green building, n.d.). Taiwanese philosophy of green building also incorporates affordability, thus green buildings also has to be cheaper (lower developmental and operating costs) than conventional buildings.

Above definitions from different leading organization in the field vary generally on the vision. Some are focused mainly on resource efficiency (both during construction and in utilization phase), health issues, and impact on environment. Some have broader vision and include impact on community, culture, and blending with natural surroundings. Benefits from green buildings can be broadly divided into three categories, i.e. economic, environmental and social.

3.1.1 Economic benefits

Implementing green feature increases the upfront/developmental cost of a building. This increase in cost varies from place to place and also on number of features incorporated. In India the increment in developmental cost is around 10 %(Kalra, Ripin and Bonner, 2012). Report on cost and benefits of green and affordable housing in U.S. shows increase from 9%-

18% in upfront developmental cost, while the average increase in all the projects documented in study is about 2.4%. However it has been shown that with careful planning and making smart choices one can reduce this increase in development cost to almost negligible (Wilson, Alex, 1999),(Wells, Walker, 2007).

When green features are embedded into the building it performs efficiently as compared to conventional building, thus reducing operating cost. With green building comes another important concept of life cycle cost. This concept forms a counter argument for those claiming higher development cost of green buildings. Green building have high resource efficiency by which operating costs are reduced thus when overall life cycle cost of a building is considered, the savings in operating costs compensated for higher developmental costs. It is estimated that around 10%-40% of energy can be saved during operation4.

Along with these direct economic benefits in terms of savings in cost there are indirect economic benefits which results from increased productivity of occupants, increase in market demand for green product and services ("Why build green", n.d.).

3.1.2 Environmental benefits

The inception of green building was to reduce environmental impact of buildings. As buildings contribute on an average about 30% of greenhouse emissions in the world it is imperative to reduce carbon footprint of this sector for sustainable growth in future. The environmental benefits of green buildings have been analysed and abundant documents for the same are available today. In brief the environmental benefits are 1) conservation and restoration of natural resources, 2) reduced carbon emission during construction as well as operating phase, 3) reduced resource utilization throughout life cycle (savings of more than 30% in embodied energy is expected by using affordable green materials), 4) reduced waste emission, 5) enhancement and protection of biodiversity and ecosystem, 6) Increase air and water quality.

3.1.3 Social benefits

Social benefits includes improved health and comfort of people, increased aesthetic qualities, reduced strain on local infrastructure, and improved overall quality of life[5].

Following is literature review carried out on affordable housing

3.2 Affordable housing- The Indian context

Task Force on Affordable Housing (set up by the Ministry of Housing & Urban Poverty Alleviation (MHUPA) in 2008): Affordable housing for various segments is defined by size of the dwelling and housing affordability derived by the household income of the population. The households division is as in Table 3.1.

Table 3.1: Affordable housing definition according to MHUPA, Source: Task Force on Affordable Housing, MHUPA, 2008

	Size (Carpet area)	Cost	EMI/Rent
EWS*	300 - 500 Sqft	Not exceeding four times the gross household annual income	not exceeding 30% of gross monthly income of buyer
MIG**	not exceeding 1200sq Feet	Not exceeding five times the gross household annual income	not exceeding 40% of gross monthly income of buyer

- *EWS: Economically weaker section
- **MIG: Middle income group.

1. *JNNURM mission directorate (2011):* The definition is detailed out in followingTable 3.2.

Table 3.2: Definition of affordable housing: JNNURM directorate (2011)

	Size	EMI/Rent
EWS	minimum 300 sqft built up area & minimum 269 sqft (25 sq m) carpet area	not exceeding 30-40% of gross monthly income of buyer
LIG***	minimum 500 sqft built up area & maximum 517 sqft (48 sq m) carpet area	
MIG	600-1200 sqft built up area & maximum 861 sqft (80 sq m) carpet area	

***LIG: Lower income group

2. *Royal Institution of Chartered Surveyors (RICS):* According to RICS affordable urban housing means provision of 'adequate shelter' on a sustained basis, ensuring security of tenure within the means of the common urban household. RICS Practice Standard Guidance Notes (GN 59 2010) states that 'affordable housing is that provided to those whose needs are not met by the open market'.
3. *KPMG:KPMG Report on 'Affordable Housing –* A Key Growth Driver in the Real Estate Sector' (2010), defines affordable housing in terms of three main parameters, namely income level, size of dwelling unit and affordability. Whilst the first two parameters are independent of each other, the third is a dependent parameter that can be correlated to income and property prices. (See Table 3.3).
4. *'Affordable Housing –as per Reserve Bank of India (RBI)*

Recently the reserve bank of India (RBI) has taken decision to relax regulations on long term bonds by banks aimed at lending to infrastructure and affordable housing. According to the circular DBOD.BP.BC.No.25/08.12.014/2014-15 dated 15th July 2014, RBI has acknowledged that affordable housing is an important part of economy which needs long term financing. The current new guideline has increased the gamut of people which are eligible for affordable house loans. Previously only priority lending sector people were included in the scheme. Priority lending sector consists of economically weaker and low income group, i.e. those households whose annual family income is less than INR 1,20,000 per annum irrespective of location. The maximum cap for loan is 10 lakhs for priority lending sector. With the new guideline house loans are extended upto INR 50 lakhs for houses of values upto INR 65 lakhs located in the six metropolitan centres and INR 40 lakhs for houses of values upto INR 50 lakhs in other centres for purchase/construction of dwelling unit per family. This new guideline thus also includes the middle income groups living in various cities across India.

Table 3.3: Affordable housing definition according to KPMG report ('Affordable Housing – A Key Growth Driver in the Real Estate Sector' (2010)

	Income level	Size of dwelling	Affordability
EWS	less than INR 1.5 lakh per annum	upto 300 sqft	EMI to monthly income: 30% to 40% House price to annual income ratio: Less than 5:1 (Task Force headed by Deepak Parekh)
LIG	INR 1.5-3 lakhs per annum	300 - 600 sqft	
MIG	INR 3-10 lakhs per annum	600 - 1200 sqft	

3.3 Affordable housing - European and U.S. context

1. *U.S. Department of Human and Urban development (HUD):* As per US department of HUD a household which pays more than 30 percent of their income for housing are considered cost burdened and may have difficulty affording necessities such as food, clothing, transportation and medical care. Thus housing which costs less than 30% of household income is considered affordable.

2. *Eurostat (Directorate-General of the European Commission):*According to Eurostat's definition (EU-SILC, n.d.) when the total housing costs ('net' of housing allowances) represent more than 40 % of disposable income ('net' of housing allowances), the household is considered 'overburdened'. Housing costs include mortgage or housing loans interest payments for owners and rent payments for tenants. Utilities (water, electricity, gas and heating) and any costs related to regular maintenance and structural insurance are also included.

3.4 Affordable housing – Asia

1. *Singapore:* 82% of population in Singapore lives in public housing built by Housing and Development board. Such housing are economical than privately built houses and also maintain good quality. Singapore doesn't have problem related to acute poverty and being a country with high income level, affordable housing generally doesn't mean providing cheap housing. Apart from commonly accepted definition of affordable housing based upon percentage of income, Singapore Centre for Applied and Policy Economics at National University of Singapore has come up with two new indicators. According to research by Abesinghe and Gu (Abeysinghe, Tilak and Jiaying, Gu, 2011) affordability has two aspects: 1) accessibility and 2) long-run affordability. Accessibility is ratio of upfront payment to available savings and house having ratio less than or equal to one is considered accessible. While long-run affordability is ratio of total cost of

housing (including transaction cost) to long run income (including the current savings). The long run affordability ratio of a house less than or equal to 0.3 is considered affordable.

2. *China:* Currently affordable housing in China is mainly for lower income groups living in urban areas (You, Jia, Wu and Han, 2011). Whilst provision like low-rental housing and public rental housing are for poor residents with and without housing facility, new immigrants without house and residents belonging to moderate income group. Various incentives like subsidies in selling price, lower land prices, etc. are provided. Definition of affordable housing has changed over course of time and has been documented in paper by *You et al*.

3.5 Why green affordable housing?

It is separately shown what green building and affordable housing mean in earlier sections. Combining merits of both is definitely going to give superior housing experience to the people. In developed countries there is no gap between supply and demand of housing but in country like India there is a huge gap between supply and demand. According to Ministry of Housing and Urban Poverty alleviation (MHUPA) there was estimated shortfall of 18.8 million houses in urban India and 46.7 million units in rural India in 2012. This shortage affects 95% of EWS and LIG group of population which lack proper finances. Along with increasing urbanization it is projected that there will be requirement of 30 million houses by 2020 (RICS, 2010).

High urbanization and unplanned development of cities has resulted in widespread environmental degradation in India. The Yale environmental performance index ranks India 174 out of 178 countries considered for study making India's air one of the most unhygienic in world. According to world health organization report more people die due to asthma in India than anywhere else in world. With increasing demand in housing sector if right measures are not taken then irreconcilable harm to environment is inevitable. In India where 75% of buildings which would exist in 2030 are yet to be built (India Global Building performance Network, n.d.), with high housing demand resulting in growing construction business the pressure on environment is massive. From the experience of developed nation it is clear that building green buildings in first place is much better option than targeting green renovation after the houses are built. The green affordable housing projects can thus effectively help in reducing the growing carbon foot print of country.

Due to lack of finances and availability of housing it is estimated that around 13.9 million household and 65.5 million people live in slums (Census report, 2011) which lacks basic amenities, like access to water, energy, etc, for living. The living condition in slums is highly deplorable and unhygienic. Fulfilling the housing need is not enough in Indian scenario. Factors like hygiene; access to basic amenities like water, clean energy is also need of hour. Green affordable housing will not only fill the gap of housing shortage but will also provide healthy and sustainable built environment at affordable price. EWS and LIG people generally spend high percentage of their income on energy as compared to other groups. Green affordable housing will additionally reduce energy need in operational period thereby reducing burden of energy expenses and will also aim at replacing older and more polluting technology with newer less polluting one. The Green affordable housing thus has potential to solve multitude of problem the country faces today.

Most of the green building projects happening in India are expensive and thus unaffordable. Very few housing projects which are affordable exist but are no properly documented which create information gap and hinders dissemination of information which can make green affordable housing success in Indian market. It is important to understand needs of housing according to climate and come up with green features which are affordable and can be replicated. This report thus aims at filling these gaps by documenting various affordable green housing projects in India across different climatic zone. The report intends to highlight green features applied in such projects, how effective they are in actual conditions and whether they can be replicated affordably.

In the following sub section we will review some of the international and local cases on Green affordable housing. The case studies are divided upon location, i.e. US, EU, Asia and rest of world, as part of International case studies. The National case studies literature review is carried out climate zone wise.

3.6 Vernacular Practices and National Case studies

Literature review for five climate zones of India has been carried out to document green features adopted in housing across the country. Traditional passive design practices followed in these climate zones are also covered.

3.6.1 Vernacular Practices

Table 3.4:Vernacular practices in Moderate climate.

Sl. No.	Features	Details	Images
1	Agrahara Row Houses, Mysore (Satish, BK, Brennan, J & Pedreschi, R 2011)	▪ Prevalent during 1904 in the region of Mysore. ▪ These are row houses that are built either around a central park, wherein the central park serves as a common gathering space for the community or the houses are aligned linearly. ▪ The row houses have common walls, thus reducing the cost on an additional wall construction and also ensuring no space wastage.	 *Agrahara housing*
2	Entrance verandah (*Jagali*) (Satish, BK, Brennan, J & Pedreschi, R 2011)	▪ Jagali is a partially raised open space, located at the entrance of the Agrahara house, which is the transition space between the road and the inside of the house. ▪ These places are always in the shade. Serves as a climate modifier by cutting down excess of heat from entering into the interior of the building. ▪ Since this area remains shaded throughout, it is used for interaction and socialising, by	 *View of Jagali*

Sl. No.	Features	Details	Images
		the people.	
3	Openings (Satish, BK, Brennan, J & Pedreschi, R 2011)	▪ Small openings are seen in the Agrahara houses, thus preventing too much radiation from entering into the interiors and allowing a cool temperature inside the house. ▪ Due to the presence of such small openings, at night, cold air can be prevented from entering to the inside, keeping homes warmer than outside.	 *Minimal openings towards the shaded space*
4	Dormer window (Dormer window, n.d.)	▪ Dormer window is a type of window that projects out from the sloped roof surface of a building. ▪ It functions similar to a skylight. ▪ It is a source of light and ventilation for the above floors. ▪ It permits larger amount of headroom on the top floor and allows more usable space. ▪ Dormer windows are found in colonial buildings in Mysore.	 *Dormer windows in old colonial buildings in Mysore*
5	Central hall (Satish, BK, Brennan, J & Pedreschi, R 2011)	▪ A central hall (similar to a courtyard) is seen in a few traditional houses, which is a multifunctional space used for working, dining and sleeping during summer time. ▪ It captures maximum natural daylight and ventilation, thus preventing the use of mechanical ventilation and artificial lighting.	 *Central courtyard*
6	**MATERIALS**		
a	Cob walls (ICAEN; 2004)	▪ A cob mixture consists of soil with enough amount of clay, straw, rough sand or small stones, and water. ▪ Cob walls have good thermal properties that go well with passive solar designs. ▪ Stabilizes indoor air temperature. ▪ Fire proof and can be recycled. ▪ This vernacular building technique doesn't favour deforestation, pollution or mining, thus proving to be environment friendly.	 *Cob wall*
b	Terracotta tile (Carlye Jones, 2014)	▪ Terracotta tiles are fireproof, lasts long and requires low maintenance ▪ It is an eco-friendly material and can be recycled as well.	*Terracotta tiles used as roofing material* 

Sl. No.	Features	Details	Images
c	Red oxide flooring (Suvasini Sridharan, 2013)	▪ Red oxide flooring is long lasting and cost-effective. ▪ Has low maintenance and is eco-friendly. ▪ This flooring method is adopted in Bangalore and in other parts of Karnataka.	 *Red oxide flooring widely used in old houses in Bangalore*

3.7 Recent Green Housing Case Studies from Bangalore - under Moderate climate

3.7.1 ZED Earth Villa, Bangalore

ZED Earth Villa is a 25 acre development located on Yelahanka-Dodabellapur Road 30 km from Bangalore city centre. There are 3 Villa Clusters (Gabion, Meteo, and Icon Classic) and 1 Townhouse cluster in this campus (6 villas per acre). Each cluster is unique in character, yet in harmony with the larger campus of ZED Earth. The campus is design by architects of BCIL with first phase competed. Environmental sustainability has been integrated to suit the moderate climate of Bangalore and it has been certified 5 star as per SVAGRIHA Rating system (ZED Earth Villa, n.d.).

Key features: The envelope has been designed with Thermal & Acoustic insulation reducing internal temperature by 4 degree temperature. It is able to achieve 50% + reduction in electric bills by using adequate day lighting, energy efficient lighting, Grundfos Pumps, Solar Thermal with electrical back-up, and Grid Tie Solar Power systems. It maintains 100% water positive with no Municipal & Tanker water requirement, Rain Water Harvesting and waste water management and reuse through Tertiary Treatment Plants for homes with zero dependence on Sewerage Board. Solid waste management is efficient through mandatory segregation at source, Natural and vermin-composting systems for all wet waste and scientific landfill for all clinical, chemical and other leachate waste. It has 15 years of maintenance-free internal roads and 10 years maintenance by company. The green features of ZED earth has been highlighted below:

1. Daylight integration in all homes with insulated windows and skylights.
2. Thermally insulated wall to maintain thermal comfort.
3. Thermally Insulated & warm flooring to help arthritis and rheumatism.
4. Energy efficient lighting that saves 80% energy bill.
5. All wastes are recovered, reused and recycled.
6. 35000 liters of rainwater harvested every year.
7. 100 % recycling and reuse of waste water.
8. 50% reduction on air conditioning units.
9. Chemical free community in internal finishes.

10. Solar heating and geysers save 80% on water heating requirement.

3.7.2 Zed Woods, Bangalore

ZED Woods is a low-slung set of 60 apartment homes with a ground floor and 3 upper floors. There are 20 luxury apartments that are as good as independent homes, and have no common walls with the next door apartment. It's located on Yelahanka-Dodabellapur Road 30 km from Bangalore city centre. There are 3 typologies, namely, 1, 2 and 3 BHK apartment units. The apartment is designed by architects of BCIL. Environmental sustainability has been integrated to suit the moderate climate of Bangalore (ZED Earth Villa, n.d.).

Key features: The envelope has been designed with Thermal & Acoustic insulation reducing internal temperature by 4 degree temperature. It is able to achieve 50% + reduction in electric bills by using adequate day lighting, energy efficient lighting, Grundfos Pumps, Solar Thermal with electrical back-up, and Grid Tie Solar Power systems. It maintains 100% water positive with no Municipal & Tanker water requirement, Rain Water Harvesting and waste water management and reuse through Tertiary Treatment Plants for homes with zero dependence on Sewerage Board. Solid waste management is efficient through mandatory segregation at source, Natural and vermin-composting systems for all wet waste and scientific landfill for all clinical, chemical and other leachate waste. It has 15 years of maintenance-free internal loads and10 years' maintenance by company.

Source: http://www.99acres.com/zed-woods-yelahanka-bangalore-north-npxid-r1088?gclid=CNGOl5PYtcACFVYVjgodvhUANg.

Figure3.1: ZED woods houses as seen from the garden outside

3.7.3 T Zed Homes, Bangalore

T ZED Homes is a 5 acre development located on Old Airport-Whitefield Road, Bangalore 20km from Bangalore city centre. There are 76 Apartment homes and 15 single family homes in this campus. The campus is design by architects of BCIL and competed in 2007. Environmental sustainability has been integrated to suit the moderate climate of Bangalore with location coordinates as 12°57'35.6"N 77°44'37.5"E (ZED Trans Indus, n.d.), (Architecture and Development association de solidarité international, n.d.).

Key features: The total number of homes is based on the carrying capacity of the land. The streets are designed as per systematic segregations of pedestrian and vehicular paths. Building materials like stones, mud, filler slabs, incorporating fly ash blocks, laterite blocks , soil-stabilised blocks, green roof(using lightweight mulch and coir pith without soil), which helps in controlling the temperature for thermal comfort. Rubber wood, Palm wood, compressed coir door panels and bamboo composites have been used for interior that are low energy in nature. Rainwater harvesting with recharge through a system of drains, percolation pits, trenches and wells for water management. Solar water pumps are used for drawing water from bore well. Solar water heaters have been installed for daily hot water consumption. All wastewater (grey water) is treated, through filtration, aeration and ozonisation to be reused for flushing and gardens eventually percolates into the open wells for use and generation. Centralised district refrigeration system and air conditioning system using an ammonia-based chilling unit has been provided to the campus. Intelligent lighting systems blend motion sensors, ambient light sensors and timers for control and Compact fluorescent lamps and light emitting diodes (LED's) are used for common areas, cutting power consumption by up to 80 per cent while protecting lighting efficiency. Each home also has "conscience meters", monitoring electric watts and water consumption with meters installed on the kitchen and bathroom taps for monitoring. Kitchen wastes are segregated into organic /inorganic wastes. Organic waste goes to the vermin-composting pits for gardening. Black water from the toilets and bathroom are treated in Sewage Treatment Plant (anaerobic digester) where 70% of the biological matter is decomposed. Grey water proceeds to a decentralised water treatment system connected to root zone treatment system which is used for irrigation of herbs, plants and grass and percolates to shallow aquifer.

Source: http://www.zed.in/homes/completed-projects.

Figure3.2: T-zed homes as seen from front site along with the green pathway

3.7.4 PRANA, Bangalore International Exhibition Centre (BIEC)

'Prana', is **India's first energy efficient home office exhibit** at **BIEC** (Bangalore International Exhibition Centre). Spread over an area of 3000 sq. ft. ,it comprises of entrance deck, entrance lobby, Living and Dining room, Conference Room, Bed Room and Toilet (Bangalore open the doors to a Greener tomorrow with 'PRANA', 2012), (PRANA The Life force, 2013).

Key Features: The home has been installed with Earth Air Tunnel system which works in synergy with air monitoring sensors, thus running as per requirements to save energy. Radiant Cooling system with cooling pipes embedded in the roof slab and floor has also been integrated to maintain standard indoor temperatures. The chillers have a provision to produce simultaneous cooling and heating and the hot water produced in parallel is used for the toilets. The building management system of the building ensures an optimized performance of all the technologies used. Renewable energy is captured through Solar PVs that have been installed to provide lighting (LED lights are used) and heating for building and through a Rain water harvesting system which collects the rain water in an underground recharge tank. A STP has been installed where the sewage water is recycled and used for landscaping, flushing in toilets, etc. The Construction materials used are either locally manufactured (reducing the carbon footprint) or are recyclable -Local clay blocks, glass inset roof tiles, unpolished kota flooring, waste glass, refurbished doors, old windows and waste pine packaging. Toilets and kitchens have been fixed with low flow fixtures and the furniture is made out of bamboo and other renewable materials. Low VOC paints are used. The cost varies from Rs 200 to Rs 500 per sq. feet approximately for the construction of conventional buildings.

Figure3.3: Prana house as viewed from front (BIEC, n.d).

3.7.5 Karnataka State Police Housing Board – Houses for Police Personnel, Bangalore

Karnataka State Police Housing Corporation Ltd (KSPHC) in association with Pearls Mii Home, Australia constructed two model flats made of prefabricated expanded polystyrene panels (EPS) in November 2011. The flat is a set of a kitchen, two bedrooms, a toilet, bathroom and hall and measures 750 sq. ft. The flats were constructed in just 15 days once the basement was laid and have a life expectancy of 50 years. The construction cost was about 1500 INR per square feet including the foundation since the EPS panels were imported from Australia, but will come down to Rs.1000 once their manufacturing starts in India (Bangalore strong and sleek houses, 2011), (Smt Mamata Varma, n.d.).

Key Features: These flats are resistant to fire, flood, wind and earthquake. They were certified as the first platinum rated building in the government sector by IGBC. From an architectural perspective, these homes offer a high degree of flexibility in floor plan design and aesthetic treatment, having high reflectance roofing thus reducing heat island effect. The unit has two tanks installed for rain water harvesting with a capacity of 1000 liters each. The low flow fixtures in the house give a saving of 46%. The building envelope makes the unit energy efficient as well, saving up to 42% energy. The solar panel installed produce a power of 720 W per day and the solar water heaters produce 20 liters/person/day of hot water. All the electric appliances in the flats are either 4 or 5 star rated. Waste segregation is also practiced at homes. The unique fastening system used to build them reduces the usage of adhesives and sealants, reducing exposure to toxic and volatile organic compounds. The paints and sealants used are low VOC.

Figure3.4: Left Picture-Side View of the model unit of KSPHC housing. Right Picture – Top View of the same

3.7.6 Development of Solar Passive Building for Silkworm Rearing, SSTL Campus, Bangalore

This project was executed by TERI (The Energy and Resources Institute) in association with Silkworm Seed Technology Laboratory –SSTL, Bangalore. The main objective of this study was to develop and demonstrate solar passive building for silkworm rearing by utilizing solar passive energy for maintenance of optimum condition during silkworm rearing throughout the year for improving the quality of seed cocoon (TERI report, Manual for Solar Passive Building, n.d.).

Figure3.5: Solar Passive Building for Silkworm Rearing, SSTL Campus, Bangalore

Key Features: The long façade of the house was oriented in the North-South direction as suggested by the results of the solar-radiation analysis. External walls of the house have been insulated with 50mm thermocol and the roof through 75mm mineral wool. The house does not have any windows. Natural ventilators and solar chimneys were designed to facilitate natural ventilation. Techniques like evaporative cooling, radiant heating and cooling, and trombe walls have been integrated, each to be used for a particular season to maintain the required indoor temperatures. In summer, when the outside temperature is high and RH is low, evaporative cooling is used through wet *khas khas* pads. These pads are fitted in the ventilators on North and West facade, which are facing the leeward side. One fourth roof over the rearing room is flat where a roof pond has been integrated for thermal comfort. The South wall of the rearing room has a collapsible overhang, which provides shading during summer's months and is removed in winters. In the summer months, the water in plastic bags on the roof is exposed to the night sky, the sky acts as a sink and water dissipates the heat to the sky. During the day, the water in the plastic bags is covered using the movable insulation. In monsoons, the *khas khas* pads are removed and free air movement is allowed through the vents. In winters, the trombe walls on the south façade are used for air circulation. Trombe wall comprises of a glazing or clear polycarbonate sheet facing the sun and a brick wall which has been painted black on the outer side for increased absorption of radiation. A gap of 100 mm has been provided between the wall and clear polycarbonate sheets, which acts as an air passage. The solar radiation through the glass is absorbed by the wall, raising its external temperature as well as that of the air. The two openings that have been provided in the wall (one at the lower level, second at a higher level) are left open during the winter. Cool air enters through trombe wall from the lower opening, gets heated up and flows into the room from the upper opening. The roof pond in the winter months over *chawki* and rearing room is open to solar radiation during day time to keep the house warm and in the night the water bags are covered to retain the heat using the movable insulation.

3.7.7 ZED Collective, Bangalore

ZED Collective (72 apartments in 1.75 acres) is a residential project Off Yelahanka-Doddaballapur Road, Bangalore by Biodiversity Conservation India Limited (BCIL). The structure is G+3 and the apartments vary from 550 to 1481 sq. ft. The construction was completed in November 2011 and is known to have made a sharp reduction in carbon emission in the composite patterns of building materials employed. BCIL Zed Collective offers mere 48 designer homes per acre when the industry norm mentions 65 - 90 homes an acre (ZED Collective, n.d.), (ZED Trans Indus, n.d.).

Key Features: A Geo-thermal air-conditioning system is the major attractive feature of this project which helps maintain comfortable indoor temperatures. Other green features include terrace gardens for every apartment, ecoscaped mezzanine floor on the ground floor, low VOC interior paints, grit plastering for external surfaces. Features contributing to making the apartment's energy efficient are energy efficient lighting fixtures, elevators that consume less energy, solar water heater. Water efficiency is achieved through common water treatment plant, dual plumbing, efficient plumbing fixtures, drip irrigation and rain water harvesting.

Figure3.6: ZED Collective

3.7.8 Summary for Moderate Climate Zone

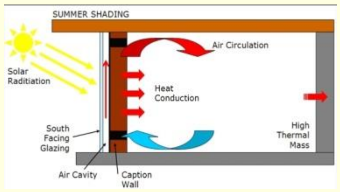
Vernacular home in a Moderate climate is defined through a semi-open space, like the courtyard, sloped roof with terracotta tiles, a raised entrance platform similar to a veranda etc. Courtyard is a characteristic feature seen in the Indian vernacular architecture, which provides sufficient light and air and acts as a good climate modifier. Veranda being a transition space, acts as a buffer between the exterior and interior. Minimal number of openings is incorporated, which prevents cold air from entering inside, at night. Characteristic building materials used in construction are cob walls, red oxide flooring and terracotta tiles for roofing, which are vernacular to this region. These elements and features depict the traditional architectural practices in the moderate climate zone.

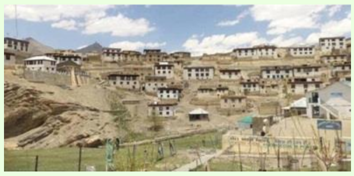
Affordability of green features in housing, for Moderate climate, have been analysed from various sources like case studies, literature studies and best practices in the local context. Literature study analyses were conducted for ZED Earth Villa, T- ZED Homes, ZED-Woods, PRANA, ZED-Collectives, Karnataka State Police Housing Board and Development of Solar Passive Building for Silkworm Rearing, SSTL Campus, which is all located in Bangalore. Green features like solar PVs, energy efficient lights, rain water management, solid waste management, solar water heaters, solar water pumps, sewage treatment plant, low VOC paints, daylight integration, and natural ventilation and terrace gardens have been incorporated in the above mentioned projects. Low cost construction techniques are adopted like the use of mud blocks and compressed stabilized earth blocks, made from locally available soil. Information was collected from various local professionals including Architects and contractors for the best regional practices that can be classified as green features in affordable housing.

3.8 Cold climate

3.8.1 Vernacular practices

Table 3.5: Vernacular practices in cold climate

Sl No.	Features	Details	Images
1	Dhajji wall (Chapter 2- Rural architecture of Kashmir,n.d.), (Jain and Singh, 2007).	▪ Dhajji walling system is commonly seen in old houses of Kashmir. ▪ It consists of a timber frame, placed in a diagonal manner, with infill of either baked brick in cement mortar or unbaked brick in mud mortar. ▪ This wall is lightweight and can withstand major earthquakes, causing minimal damage.	 *Dhajji wall with brick infill*
2	Taq wall (Chapter 2- Rural architecture of Kashmir,n.d.)	▪ The taq construction system comprises of thick brick masonry piers supporting wooden floor. ▪ The gap created between the piers consists of a window or brick masonry. ▪ This building technique is also resistant to earthquakes.	 *Taq house in Kashmir*
3	Trombe walls (ICAEN, 2004)	▪ Trombe wall is a wall made out of concrete, masonry or adobe, with vents or openings placed at the top and bottom, lying in winter sun side of the building. ▪ Also, consists of a glass panel fixed towards the outer surface of the wall, leaving an air gap in the middle. ▪ The exterior surface of the wall is painted black to absorb maximum solar heat. ▪ The air in the gap gets heated up and enters the living spaces through the vents by the principle of convection. ▪ At night, the heat stored during the day keeps the inside warm. ▪ This passive solar building technique is found in most parts of Ladakh.	 *Process by which air heats up through convection in a trombe wall*
4	Kath-kuni construction (Shah, n.d.), (Jain and Singh, 2007).	▪ This construction technique exists in Himachal Pradesh. ▪ It's a 2 to 3 storey house where the ground floor is for the cattle so that; this brings warmth to the above floors. The above floors consists the living, storage and kitchen spaces. ▪ The wall consists of an alternate course of dry stone masonry and wood	

Sl No.	Features	Details	Images
		without any cement mortar. Two wooden beams are placed with a fine gap in between, which is in filled with stones. This traps some amount of air which provides good insulation. ▪ The heavy wall keeps the house cool in summer and warm in winter. ▪ Semi-open cantilevered wooden balconies are constructed on the top floors, to capture as much as warmth from outside. ▪ This construction technique responds well with earthquakes, requires low maintenance and materials can be reused	 *Kath-kuni wall house and construction* 
5	Koti banal house (Rautela, Joshi, Singh, Lang, n.d.)	▪ Koti banal houses are found in Uttarakand and southern part of Himachal Pradesh. ▪ This house rests on a stone plinth in rectangular plan and can go up to 4 to 5 storeys. ▪ Wooden balconies are projected out from the top floors to capture warmth from outside. ▪ This type of building technique is resistant to earthquakes. ▪ Wooden logs, stones and slates are used. Small openings are provided to prevent cold air from entering inside.	 *Koti banal house*
6	Site planning (Kumar and Ashwani, 2014), (Jain and Singh, 2007), (Singh, Kumar, Mahapatra, and Atreya, 2011).	▪ Southern slopes are chosen for constructing houses, as this gives more solar exposure, keeps the inside warm and protects it from cold winds. This results in minimal consumption of energy. ▪ The buildings are spread out in open spaces to gain maximum solar radiation and prevent shadow formation.	 *Settlement layout in the Upper Himalayan region*
8	Planning (Kumar and Ashwani, 2014), (Jain and Singh, 2007), (Singh, Kumar, Mahapatra, and Atreya, 2011).	▪ Compact planning system is adopted in most buildings. ▪ Floor to ceiling height is comparatively lesser, maintained around 8 to 9ft, to keep the interiors warm. ▪ Small openings are provided which brings daylight, allows ventilation and responds well in seismic zone.	 *No openings are provided on the*

Sl No.	Features	Details	Images
		▪ Sloped roofs are mostly adopted in regions susceptible to rainfall and snow for proper drainage. ▪ The air between the roof and the attic space behaves as a good thermal insulator.	*ground floor so that the cold air doesn't enter*
9	**MATERIALS**		
a	Rammed earth (ICAEN, 2004)	▪ Earth mixture of sand, gravel and clay is compacted to create a solid wall known as rammed earth wall. ▪ Sustainable and natural building method. ▪ Resistant to earthquakes. ▪ It has good thermal properties and is resistant to fire. ▪ It is more suitable for extreme conditions as it can stabilize the indoor temperature. Hence, there is no need of conventional method of cooling or heating, thus saves energy.	 *Rammed earth construction seen in Leh*
b	Wood (Rautela, Joshi, Singh, Lang, n.d.), (Shah, n.d.), (Chapter 2-Rural architecture of Kashmir, n.d.), (Jain and Singh, 2007).	▪ Deodar wood is widely used in cold climate region as it is locally available there. ▪ Used in the construction of beams, roofs, truss posts, frame, doors and windows. ▪ Gives stability to the structure as it is strong and durable. ▪ Resistant to termites and insects. ▪ Wood is commonly used in cold climate, so that it keeps the building warm. ▪ It is resistant to moisture and is a poor conductor of heat.	 *Wooden house in Himachal region*
c	Stone (Shah. d.t.), (Chapter 2-Rural architecture of Kashmir), (ICAEN, 2004).	▪ Stone is used in the plinth and also seen in the Dhajji wall construction. ▪ Dry stone masonry responds well in seismic zone. ▪ Slate stones are laid over the wooden rafters on the roof. It protects the structure from strong winds.	 *Slate stone used for roofing*
d	Bamboo (Kati, d.t.), (Dowerah, n.d.), (Subhankar and Amol, n.d.), (Singh, Kumar, Mahapatra, and Atreya, 2011).	▪ Bamboo is a very common material used for construction in north-east region of India. ▪ This material is highly sustainable, strong and durable. It is flexible, lightweight and resistant to water. ▪ Bamboo is used for structural purpose, interiors and in making furniture.	 *Traditional Bamboo house in the*

Sl No.	Features	Details	Images
		▪ It is a cost-effective material and can be transported to the site easily. ▪ Responds well in seismic regions. ▪ Many different species of bamboo are grown in the north-eastern part of India. Hence, it is extensively used for construction purpose in this region. ▪ It's a versatile material and is used for scaffolding, furniture, fencing etc.	*north-eastern region of India.*
d1	Stilted Kutccha house (Kati, d.t.), (Subhankar and Amol, n.d.), (Singh, Kumar, Mahapatra, and Atreya, 2011).	▪ Materials used are wood, bamboo and thatch for roof. ▪ The entire house is elevated from the ground with a stilt height of 1.50 to 2.00m to keep away the effects of heavy rainfall or floods. ▪ The walls and floors are made up of 2 to 3 layers of woven bamboo strips laid with mud. ▪ The roof is constructed by fixing bamboo trusses over posts, which is covered by thatch later. ▪ Since bamboo is poor conductor of heat and is resistant to water as well, it ensures warmth within the house and keeps away the moisture from it. ▪ Planning is compact, with low ceiling height, to reduce the heat loss from the building.	 *Kutccha bamboo house elevated from the ground (to the left).* *Mud is laid over woven bamboo mat (to the right).*
d2	High pitched roof Kutccha house (Kati, d.t.), (Subhankar and Amol, n.d.), (Singh, Kumar, Mahapatra, and Atreya, 2011).	▪ This house has double pitched roof, which gradually reduces in height towards the back side of the house. ▪ The plinth is made of earth, covered with mud plaster, over which bamboo mats are laid. This plinth is raised, to act accordingly in case of floods or rains. ▪ Steep slopes ensure no water enters inside the house. ▪ Openings are kept minimal so that heat is not lost from the house. ▪ Reflects the local cultural, historical, environmental and regional climate.	 *Traditional bamboo house in Nagaland*
d3	Ikra Housing, Assam (Subhankar and Amol, n.d.), (Kakkad, Maulik D., and Capt CS	▪ The Ikra house or the Assam type of house is an example of a non-engineered bamboo structure which is highly resistant to earthquakes when compared to today's conventional building. ▪ Lightweight and made from locally	 *Assam style office building*

Sl No.	Features	Details	Images
	Sanghvi, 2001)	available bamboo, thatch, timber etc. ▪ Consists of a stone masonry up to 1m, just above the plinth, which is connected to the bamboo strips using steel angles and flats with bolts and nails. The bamboo strips are woven into a wooden framework and is then plastered with cement or mud. ▪ This type of housing didn't report any intense damages during the past earthquakes. ▪ Factors such as location, site planning, size, shape and form of the building, number and size of openings are integrated together, such that it the building responds well during earthquakes. ▪ The seismic force in a bamboo structure is less when compared to any masonry system. ▪ Ikra, which is a type of weed grown there locally, is used for wall infill along with cow-dung and mud mixture. Ikra is an insect resistant material.	*Assam style school building* *View of Ikra reed false ceiling*  
f	Surkhi mortar (Dowerah, n.d.), (Singh, Kumar, Mahapatra, and Atreya, 2011).	▪ Surkhi comprises of lime, brick powder, jaggery and sand. ▪ It is a type of a mortar used locally in the north east region of India. ▪ Generally, used to fix bricks and to plaster walls.	

3.8.2 GERES project, Leh

Context: Leh&Ladakh falling in western Himalayan ranges are highly inaccessible places where temperature drops to as low as $-30^{0}C$ during winters. Harsh winters with low rainfall leaves only 90 days for growing crops. Natural resources are also limited making livelihood of people dependent on livestock breeding and subsistence farming. Food and fuel can be air lifted to the region during winters but are unaffordable for the people. This scarcity of fuel makes children and women spend two months a year on gathering dung and bushes from pastureland. Thus life of people is such place is austere. The regions though receive ample sunshine and have about 300 clear days in a year. The focus of this study would be passive solar houses built by GERES during time period 2008-2009 in Ursi village (Energy efficiency and bioclimatic architecture in India, 2009), (Stauffer, Vincent, 2004), (Dissemination of Passive Solar Housing, n.d.).

Objective: improving quality of life through promotion of Low energy consumption house component (a building constructed according to special design criteria aimed at minimizing the buildings operating costs) or LEC and enhance socio-economic conditions of the local communities.

Key features: The project supported capacity building, enhanced institutional processes and helped in transmitting knowledge and technological innovation to the local communities through NGO's for creating sustainable dissemination mechanism of LEC technologies. Three simple bioclimatic architectures were used in the project, namely, 1) Attached greenhouse (AGH), 2) Solar wall (SW), and 3) Direct gain (DG). The project supported 126 AGHs, 247 SWs, 648 DGs installation in the region and was funded by EU, ADME, MNRE) the project cost was about 1.9 million Euros [around INR 153 million (€1 = ₹80.53, 2014)]. Average cost of promoting and constructing house was €750 (around ₹ 60,000)

Impact of project:

- 60% reduction in biomass burning as household level. €50 (₹ 4000) saving per year per household.
- Reduced indoor air pollution and respiratory disease by 50%.
- Reduced CO_2 emission (2.15MT/household/year).
- Increased room temperature from 6^{0}C to 12^{0}C.
- Reduction in time spent for biomass collection and dung by half.
- Increased winter income by 50% (among women).

Apart from tangible benefits in terms of money and health the project played vital role in shifting the thinking on potential role of women in development process in the existing traditional socio-cultural setting. The project was a success and all the features included are replicable in other household living in same climatic conditions.

Source: http://www.geres.eu/en/energy-efficiency-and-bioclimatic-architecture-in-india#project-description.

Figure3.7: Top picture shows greenhouse been erected next to the house. Bottom picture shows one of the affordable green home built in ladakh by GERES.

3.8.3 Carbon Neutral Eco-Hut, Lonavala

This is the first pilot model of Carbon Neutral Self Powered Eco-house in India which is developed by TATA power (Tata Power inaugurates first Carbon Neutral Eco-Hut, 2013).

Key features: The Eco-hut is built with investment of 10 lakhs as compared to 35 lakhs for a standard modern house and saving of 4.2 tonnes of CO2. The construction period was of 20 days. The lighting power is supplied through solar panels and windmills. Built-in solar water heater and cooker make the building independent of LPG consumption. The rooms are 5-6 degrees cooler in summers than in a standard constructed house. The Eco-hut is rainwater dependent thus supply from municipality or other private source is not required. The daily water need is 100 liters as compared to 400 liters for standard modern house of 600 sq. ft. The solid waste generated is degraded using vermin-composting, while the other wastes, i.e., metal & plastics, are recycled.

Figure3.8: A completed eco-hut by Tata power

3.8.4 The Doon School, Dehradun

The project consists of head masters residence at The Doon School. The house has 73% reduction in energy demand as compared to GRIHA benchmark. The EPI of building is 17 kWh/m2/year School (Griha Case studies, n.d.).

Key features: Sustainable site planning activities like top soil preservation, protection of existing trees, etc., were incorporated during construction period. 15% of cement in structural concrete was replaced by fly ash and 50% of roof tiles materials are recycled which reduced the carbon footprint of building materials. 100% of outdoor lightings have been installed with automatic controller and passive design technologies are used to reduce conventional energy needs. 58% reduction in water consumption is achieved.

Figure3.9: Collage of the completed green home in Doon school. Source: GRIHA case studies flyer

3.8.5 Summary for Cold Climate Zone

Traditional building techniques seen in the Cold climate are climate responsive and unique in concept, mainly built to respond well in the seismic zone. Each region has its own building style, like the dhajji wall and taq wall in Kashmir, trombe wall in Ladakh, kath-khuni house in Himachal Pradesh, Koti-banal house in Uttarakhand and bamboo houses in the north-eastern region. The common features in all these houses are that they are resistant to earthquakes, causing minimal damages and possess solar passive design elements which respond well with the microclimate. Planning system adopted is very compact, with sloped roofs to combat heavy rainfall and minimal openings to prevent cold air from entering inside. Locally available materials used for construction are mainly wood, stone, mud and bamboo, specifically in the north eastern region. The building techniques and materials adopted, signifies the architecture, vernacular to this region.

In the recent years, the contemporary green features adopted in the GERES project at Leh, Carbon Neutral Eco-Hut at Lonavala and The Doon School, Dehradun are- solar wall, solar panels, top soil preservation, protection of existing trees on site, passive design technologies, vermin-composting and attached green house, are the green elements incorporated in these projects. Using recycled materials and fly-ash instead of cement naturally reduced the carbon footprint of building materials. The objective of these buildings was to make it eco-friendly by consuming less energy and responding well with the microclimate naturally.

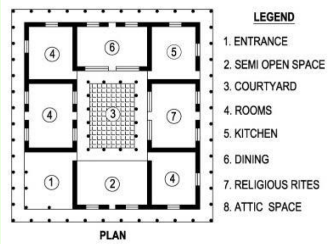
3.9 Warm and Humid Climate

3.9.1 Vernacular practices

Table 3.6: Vernacular practices in warm humid climate

Sl No.	Features	Details	Images
1	Courtyards (Tipnis; 2012), (Dili, A.S.,Naseer, and Varghese, 2009), (Dili, A.S.,Naseer, and Varghese, 2010).	▪ Courtyard is the most characteristic element in a Kerala vernacular home. ▪ The courtyard is either square-ish or rectangular in shape, surrounded by four blocks which is joined together. ▪ Courtyards allow air, light and rain to pour in. ▪ Acts as a good thermal regulator. ▪ Enables cross-ventilation in all rooms. ▪ Generally, the courtyards are sunken so that the cool air is retained and settles down. ▪ Creates a positive impact on the indoor comfort conditions. ▪ This concept is seen in most of the Kerala and Chettinad traditional houses.	 *Courtyard inside a traditional Kerala house*
2	Sloped roofs (Dili, A.S.,Naseer, and Varghese, 2009), (Dili, A.S.,Naseer, and Varghese, 2010).	▪ Sloped roofs are adopted, as this region receives heavy rainfall. ▪ The four blocks surrounding the courtyard is covered with sloped roofs, placed at angle of 45 degrees. ▪ This helps to drain off the rain water easily. ▪ Also, this pitched roof obstructs the penetration of rain water into the interior of the building.	 *Sloped roof to combat rain*
3	Openings (Dili, A.S.,Naseer, and Varghese, 2009), (Dili, A.S., Naseer, and Varghese, 2010).	▪ The houses lying in the warm-humid region usually have large openings, windows and ventilators. ▪ This provision enhances the comfort inside the house. ▪ Sometimes open gables (mughappu) are present in the roof and wooden jaali (azhi) is incorporated in the external walls. Warm air rises up and escapes through the open gable and cool air enters through jaali wall. This again, regulates the air movement. ▪ As the building houses open and semi-open spaces, this ensures good circulation of air constantly. ▪ Increases the ventilation rate which in turn	 *Many openings are provided for good flow of air*

Sl No.	Features	Details	Images
		removes the excess humidity from the air.	
4	Planning (Dili, A.S.,Naseer, and Varghese, 2009), (Dili, A.S.,Naseer, and Varghese, 2010).	▪ Planning system is more open and spread out. ▪ It's more of a scattered organization of spaces. ▪ This planning concept is utilized to enable good air circulation within the building.	
5	Verandas (Dili, A.S.,Naseer, and Varghese, 2009), (Dili, A.S.,Naseer, and Varghese, 2010).	▪ Along with courtyards, always comes the verandah. ▪ There are two verandas present, one towards the periphery of the courtyard and the second is found surrounding the rooms, towards the outside, similar to an exterior portico. ▪ Presence of two verandas enables people to shift their activities from one space to the other, according to the climate. ▪ These deep verandas protect the internal rooms from intense heat and rain.	 *Verandah along the periphery of the courtyard*
6	Overhang roof (Dili, A.S.,Naseer, and Varghese, 2009), (Dili, A.S.,Naseer, and Varghese, 2010).	▪ The sloped roof extends out till the verandah. ▪ This protects the internal rooms from direct heat and rain. ▪ Since this roof overhang shades the verandah, the verandah can form as an additional space for activities.	 *Overhang roof*
7	Water storage (Tipnis, 2012)	▪ Rainwater harvesting, collection and storage of water, and drainage systems have been a part of the traditional practices. ▪ Wells are seen in some old houses, which were used for drinking, agriculture, cleaning, bathing etc.	 *Well located outside the house*

Sl No.	Features	Details	Images
8	Internal spaces (Dili, A.S.,Naseer, and Varghese, 2010).	▪ The kitchen is located towards the north-east, as the wind blows from the south-west; hence this prevents spreading of hot air to the other spaces from the kitchen. ▪ The bedrooms and other spaces are arranged around the courtyard such that, it allows good air circulation.	 *Plan of a typical Kerala house*
9	Site planning (Tipnis; 2012), (Dili, A.S.,Naseer, and Varghese, 2010).	▪ The planning is done in such way, that it corresponds to the surrounding features– the backwaters, plantations, etc. creating harmony with it. ▪ Plan of the house is rectangular or square-ish, which responds back well, to the climate ▪ The entrance to the building is generally from south or east.	
10	**MATERIALS**		
a	Laterite stone (Shankar, n.d.)	▪ Laterite stone is used as the building material in Kerala, Karnataka, Goa and Andhra Pradesh. ▪ Low-cost construction material. ▪ It gains strength when exposed to air and sun. ▪ Normally, plastered with lime mortar.	 *Traditional home constructed out of laterite stone*
b	Mangalore tiles (Mangalore tiles, n.d.)	▪ Mangalore tiles are made out of laterite clay and widely used in Karnataka, Goa, and Kerala. ▪ Cheap, durable and eco-friendly. ▪ Used as a roofing material. Generally, used over kitchen and bathroom for the smoke to escape, as they are placed in a way such that small air gaps are left in between. ▪ These tiles are used over sloped surfaces; hence it helps to drain off the rain water easily. Appropriate material in the warm humid zone as it is prone to heavy rainfall.	 *Mangalore tiles used as a roofing material*
c	Coconut palms (Varanasi, 2011).	▪ Coconut palms are used in construction of vernacular buildings in Tamil Nadu and Kerala, as it is abundantly available in this region. ▪ The leaves are woven to form mats. This material is also used to make thatch. ▪ Locally available, cheap, can be replaced easily and is not labour intensive. ▪ It is sustainable and the appropriate choice of material for warm humid climate.	 *Coconut palm roofing*

3.9.2 GFRG Demonstration Building, IIT Madras, Chennai

This project consists of a single two storeyed building constructed by the civil engineering department of IIT Madras inside their campus. Researchers from IIT Madras have developed a method of design and construction to make use of Glass Fiber Reinforced Gypsum (GFRG) panels with the R&D support from Department of Science and Technology (DST), India and industrial support from Rapid wall building systems, Australia. The total built up area of the house is 1981sft holding two EWS flats (269 sft) and two LIG flats (497sft) Building (GFRG demonstration, n.d.).

Key Features: The construction is possible at a higher speed. The demo building with two storeys and four apartments was built in two month period. The GFRG panels reduce the use of RCC, water, cement, steel, and sand significantly thereby reducing energy and carbon footprint of the building. This savings in material also results in lower cost of construction. GFRG being a light weight material reduced building's weight contributes to in saving in foundation. 8-10 storey buildings can be built with load bearing system without any need of beams and columns. The demo building is targeting for EWS and LIG category households. The cost per square foot for this project was only INR 1250.

Figure3.10: Pictures showing the completed house at IIT chennai7

3.9.3 Govardhan Eco Village (GEV), Thane, Mumbai

The philosophy behind GEV is that nature provides for all the needs of and by syncing our lifestyle with nature, the adverse environmental impact can be completely removed. The concept behind housing is to create aesthetical and comfortable structures for the residents and guests, while not breaking the harmony with nature and our immediate surroundings (Govardhan Eco village activities, n.d.).

Key features: The residential places conform to GRIHA norms and have achieved 5 star GRIHA rating. To reduce carbon footprint 90% of all the building materials were sourced within radius of 100 Km of site. Natural mud was used as key material for construction. Compressed Stabilized Earth Blocks (CSEB) was used instead of conventional fired bricks to reduce embodied energy of building. CSEB has embodied energy of 0.275MJ/Kg as compared to 72.3 MJ/Kg of conventional fired bricks. The roof is sloped with double layer of Mangalore tiles with an air gap between the two layers as insulation ensuring that the temperature inside the room is moderate as compared to outside. To reduce dependency on conventional fuels three alternative energy sources were used: Bio-gas, solar, and animal driven prime motor. By using bio gas the community saves about 50 cylinders of LPG every month. This accounts to net savings of about INR 56000 every month. A unique technology of Soil Biotechnology (Symbiosis of human and agricultural waste) has been used in this project for waste management. Integrated development planning was used for the project.

Source: http://ecovillage.org.in/our-activities.

Figure3.11: Picture at top shows a completed house. Bottom left picture shows bio-gas plant installed in the village. Figure on bottom left shows worker constructing walls made of special bricks

3.9.4 VBHC,Vaibhava Oragadam, Chennai

VBHC Vaibhava Oragadam constructed by VBHC in Chennai is made affordable by implementing green features in the designs and sustainable construction technology during the construction. The project comprises of 2BHK apartments (148 no's) with floor area of 792sft spread over 2 acres of site (VHBC, n.d.), (VHBC, n.d.), (VHBC, n.d.).

Key features: Prefabricated aluminum form work is used to cast monolithic walls which saves time of construction, the wastage in the formwork, plaster material because of the smoother finish achieved for wall surfaces. These monolithic concrete structures are designed for seismic code compliance. The construction of this housing project is completed in 12-18 months of duration due to sustainable construction technology and management they have used. The cost of each apartment unit is 24.5 lakhs including land and infrastructure development. The project has been certified by IFCs Excellence in Design for Greater Efficiencies (EDGE) Program for its green building design.

The site plan is developed with almost 70% of the area is open with more green area and less paved area. Apartment units are designed in such a way that there is zero waste in the floor area. Enough space has been considered between the apartment blocks and 3 bay units are designed for providing natural daylight and free flow of air in the living spaces considering the climate of the city. The project has dual plumbing and dual flush systems to reduce fresh water usage. Energy efficiency and resource utilization is a key concern in the project. Solar water heating systems have been provided for the top two floors. Recharging pits are provided to recharge ground water using rain water collected from the project area. Solar based LED lighting has been provided for outdoor lighting. Recycled UPVC windows, granite kitchen platforms, composite doors are some of the features which have low embodied energy. Solid wastes are segregated and managed efficiently on site.

3.9.5 Happinest, Chennai

"Happinest" housing project developed by Mahindra life spaces is spread across 13 acres at Avadi in Chennai. The development consists of 1200 units including 1 BHK and 2BHK, the cost of which ranges from 10 to 20 Lakhs aiming the target income group of INR 20,000 to 40,000/- per month. The area of apartment units ranges from 396 sft to 677sft (Mahindra Life spaces affordable housing, 2014), (Mahindra Life spaces launches Happinest, n.d.), (Mahindra Life spaces affordable housing with Happinest, n.d.).

Innovative construction technology and hybrid foundation has been implemented for speedy execution and make it cost effective. Considering warm humid climate of the location, optimum window to wall ratio with louvers are provided for cross ventilation and cellular light weight block are provided for walls to reduce the heat gain into living spaces. The project also has sustainable features like rain water harvesting, top soil preservation, eco-friendly building materials etc. The project has been pre certified by the Indian Green building Council (IGBC) under their green township program.

3.9.6 Summary for Warm Humid Climate Zone

Warm humid climate is prevalent mainly towards the coastal belt, hence here; humidity becomes a dominant factor to be taken care of, while constructing houses. Courtyard is the characteristic element, which allows efficient light and air and behaves as a good thermal insulator, especially seen in Kerala Vernacular houses. Planning system is scattered and spread out, with lot of open spaces, to enable good circulation of air. Large window openings help in good air flow. Deep verandas on the interior and exterior periphery of the house and sloped roofs are incorporated to provide protection from rain and excess heat. Construction materials like laterite stone, Mangalore tiles and coconut palms are used, which are vernacular to the respective region.

Case studies and analyses were done for currently existing buildings and various information was gathered on the affordable green features. Literature study was done on GFRG Demonstration Building, IIT Madras, Chennai; Govardhan Eco Village, Thane, Mumbai and VBHC, Vaibhavaragadam, Chennai. Glass Fibre Reinforced Gypsum (GFRG) panels are used, which significantly reduced the energy and carbon footprint of the building. Compressed stabilized earth blocks are produced from locally available mud, to construct houses. Bio-gas, solar, and animal driven prime motor, soil biotechnology (Symbiosis of human and agricultural waste) for waste management, natural daylight, dual plumbing and dual flush systems, solar water heating systems, recharging pits, solar based LED lighting and recycled UPVC windows, are other green elements incorporated, thus reducing the cost and making it more environmentally friendly.

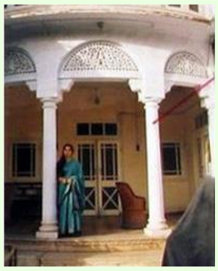
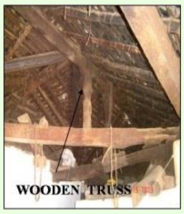
3.10 Composite climate

3.10.1 Vernacular practices

Table 3.7: Vernacular practices in composite climate

Sl No	Features	Details	Images
1	Aangan (Courtyard) (Ali, Asif, 2013), (Traditional Dwelling in Malkaganj, n.d.), (Traditional Dwelling in Delhi, n.d.)	▪ Courtyard known as *Aangan* in the local language is one of the characteristic features of the houses found in this region. ▪ It is located at the lowest level so that rainwater doesn't enter into the other parts of the house and can drain off easily. ▪ It is a source for ventilation and light and allows cool air to settle down which spreads towards the adjoining spaces. ▪ By the principle of convection, it regulates the flow of air constantly.	 *Courtyard house in U.P.*
2	Jaalis (Latticed screen) (Ali, Asif, 2013), (Traditional Dwelling in Malkaganj, n.d.).	▪ Jaali walls are extensively used in houses belonging to this climate zone. ▪ It controls the air flow. ▪ Allows diffused sunlight to penetrate inside. ▪ Cuts down excess radiation and filters the air while it enters into the interior spaces.	 *Jaali openings*
3	Openings (Ali, Asif, 2013), (Traditional Dwelling in Malkaganj, n.d.), (Study of Traditional Dwelling in Jaipur, n.d.)	▪ Large long window openings are seen on the façade having low sill level. Generally, found lying along the south west wall to capture enough heat during winter. Allows only fresh air to enter. ▪ Vents are located at a certain height, close the ceiling, to let out the hot air and maintain the air circulation within the building. ▪ Louvered doors and windows are adopted, which let cool air inside by still maintaining enough privacy. ▪ Openings like skylight, known as Roshandan is situated in the ceiling, which regulates the air flow by "stack effect". It is the process by which warm air inside the building rises up and escapes from the above openings and cool air enters from side openings at the lower level.	 *Ventilators are situated at the top, closer towards the ceiling, so that the hot air escapes out*

Sl No	Features	Details	Images
4	Chajja (Ali, Asif, 2013), (Traditional Dwelling in Delhi, n.d.), (Study of Traditional Dwelling in Jaipur, n.d.)	▪ Chajja is a shading element that is provided above windows or doors. ▪ It protects the interior space from rain water. ▪ As it covers most of the surface area, it obstructs direct radiation from hitting the wall by absorbing part of the heat and therefore, slows down the transmission of heat. ▪ Provides shade and creates a cool atmosphere below, for the people.	 *Chajja over the window, protects the wall and openings from excess heat*
5	Thick wall (Ali, Asif, 2013).	▪ Wall thickness adopted in this climate zone varies between 400-600 mm. ▪ Dressed stone masonry, brick and mud is used in the construction of wall. ▪ Thick walls have a good thermal impact on the indoor air condition. ▪ Ensures a cool environment inside the house.	 *Thick mud wall houses in Jharkhand*
6	Vegetation (Study of Traditional Dwelling in Jaipur, n.d.)	▪ Trees are planted to ensure a cool atmosphere around. ▪ It acts as a buffer by obstructing the heat from entering further to the inside. ▪ Improves the quality of air by evapo-transpiration by adding water vapour to the air and thus, reducing the temperature.	 *Tree acts as a buffer between the building and the sunlight*
7	Water body (Ali, Asif, 2013).	▪ Water body was frequently included in most of the Mughal structures, as one of their standard characteristic features. ▪ Improves the quality of air. ▪ Fountains sprinkle water droplets into the atmosphere by the principle of evaporation. ▪ Keeps the surroundings cool and ensures comfort in the outer spaces. ▪ Water channels are incorporated within the internal spaces of the building, which brings down the temperature through evaporative cooling.	 *Water body in Fatehpur sikhri*

Sl No	Features	Details	Images
8	Verandah (Ali, Asif, 2013), (Study of Traditional Dwelling in Jaipur, n.d.)	▪ Semi-open spaces are present at the entrance of most houses, which is called the verandah. ▪ It is the transition space between the outside and the interior. ▪ Acts as a buffer and prevents excess radiation from entering further inside. ▪ Keeps out the heat and rain by providing shade.	 *Entrance verandah in an old traditional Jaipur house*
9	High ceilings (Ali, Asif, 2013), (Traditional Dwelling in Uttar Pradesh, n.d.)	▪ High ceilings are incorporated in most buildings. ▪ This is to allow maximum comfort level. Due to high ceiling, there is enough space for air circulation. ▪ Arches, domes and vaults were commonly used earlier, as they absorb less heat compared to flat roofs. ▪ Vents are provided near the domes or towards the ceiling, for the warm air to escape out easily.	 *High ceiling increases the comfort level*
10	Other climate responsive features (Traditional Dwelling in Uttar Pradesh, n.d.)	▪ Houses are laced on raised platform, to prevent rain water from entering inside. ▪ Streets are narrow, with buildings on both sides, thus, creating shade and a cool environment for the pedestrians.	 *Buildings on both sides, provides shade to the narrow streets*
11	**MATERIALS**		
a	Teak wood (Sagwan, n.d.), (Traditional house in Jharkhand, n.d.).	▪ Sagwan or teak wood is widely used for construction in Delhi, Jharkhand, Chhattisgarh, Bihar, and U.P. ▪ It is a type of hardwood. Strong and durable. ▪ Resistant to termites. ▪ It can withstand most climatic conditions. Snowfall, heavy rains and extreme heat does not alter its strength.	 *Wood used for structural purpose*
b	Lime plaster ("Why use lime", n.d.)	▪ Lime allows the building to breathe by absorbing and releasing moisture, thus causing no damage to the walls. ▪ It stabilizes the indoor environment and makes it more comfortable. ▪ Long lasting and eco-friendly. ▪ Since its light coloured, it reflects the heat and keeps the house cool inside.	 *Buildings coated with lime plaster in Rajasthan*

Sl No	Features	Details	Images
c	Adobe blocks (Adobe brick technique, n.d.), (ICAEN; 2004)	▪ Adobe bricks are sun dried bricks comprising of earth, clay and straw. ▪ Natural material that is durable and resistant to fire. ▪ It water resistant. ▪ Enables a good impact on the thermal condition of the building.	 *Mud brick house in Punjab*
d	Sandstone ("What is sandstone used for", n.d.), (ICAEN; 2004)	▪ Sandstone is a very common building material used in the earlier days. ▪ Most of the monuments in Delhi and Rajasthan are constructed out of different coloured sandstones. ▪ Durable and long lasting. ▪ It can withstand extreme climatic conditions. ▪ Stone possesses thermal mass property, which is another element of solar passive design. Since stone is a dense material, it is able to conduct heat. Hence, during the day, it absorbs the heat, stores it and slowly radiates it during the night.	 *Pink sandstone is used in Hawa Mahal, Jaipur*

3.10.2 Aranya Homes, Indore

Aryan homes, located 6km from Indore centre, is community developed for mixed economic group (EWS, LIG, MIG, HIG) although the design is developed primarily in consideration to the EWS groups. Architect BV Doshi has won the Aga khan award in 1996 for this project. The development was initiated by Indore Development Authority for a cost of Rs 71.23/m2 in the year 1989 with an objective to upgrade the existing slum area and meet the housing needs of EWS groups. A detailed physical and socio-economic survey was conducted by the architect to draw inferences on habitat needs and thereby deduce design requirements like density, space etc. During the time of handover, the average monthly income was determined to be Rs 700/month of For EWS section down payment for plot allotment was provided at Rs 200 to Rs 400 range with a loan balance of Rs 2103 to Rs 7,748 and Rs 23.23 to Rs.85.23 as monthly installment (Aranya Community Housing, n.d.).

Key features: The project is developed with passive features that may not require any additional construction elements.

1. Minimum solar exposure with common walls, longer facades on north-south orientation
2. Natural light and ventilation from north and south openings.
3. Street and community areas shading through trees and buildings to reduce urban heat island effect.
4. Usage of local materials and labour
5. Storm water drainage

6. Common manholes for every 20 dwelling units to reduce cost
7. Sewer less sanitation
8. Underground cables are provided to reduce maintenance cost though initial cost was counted to be slightly higher than providing open cables through poles.
9. Construction as per natural slopes

Figure3.12: Typical street view of Aranya homes, Indore

3.10.3 Summary for Composite Climate Zone

Composite climate is characterized by extreme climatic conditions and appropriate traditional features have been designed for this. Courtyards are widely used to regulate the air flow by the principle of convection. Openings are present in the form of long windows, jaalis and ventilators (close to the ceiling), for constant air circulation and for the hot air to escape out. Chajjas are incorporated above openings, to provide protection from rain and intense heat. High ceiling is adopted within the interior space, to improve the thermal comfort. Sandstone is one of most prominently used materials. As it possesses thermal mass property, it's more suitable in this region. Apart from this, adobe blocks are seen in some of the vernacular homes. Some buildings are also coated with lime plaster, which helps in reflecting the heat.

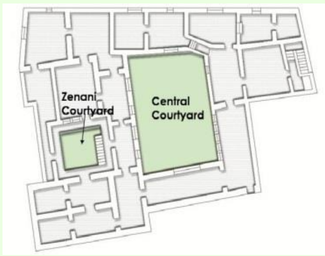
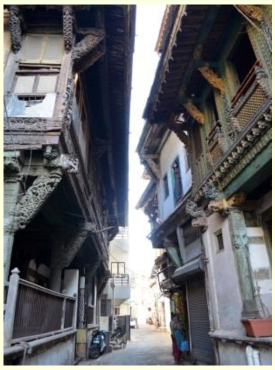
Aranya community is one of the best examples, in the Composite climate zone, for low cost housing. Passive design features have been incorporated here, like, common walls with minimum solar exposure, natural light and ventilation, storm water drainage, shading through trees and buildings to reduce urban heat island effect, use of local materials and labour, sewer less sanitation and underground cables to reduce maintenance cost. This is a simple basic design having appropriate passive features and meeting the needs of the low-income group.

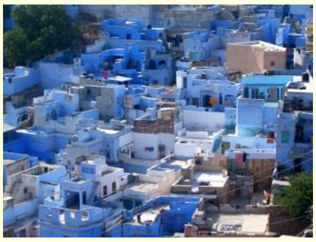
3.11 Hot & Dry climate

3.11.1 Vernacular practices

Table 3.8: Vernacular practices in hot dry climate

Sl No.	Features	Details	Images
1	Courtyards (Tipnis, 2012), (The vernacular architecture of Rajasthan, n.d.).	▪ Courtyards control the microclimate, as it is the main source of light and ventilation. ▪ According to the principle of convection, hot air rises from the courtyard, and cool air enters from the side through the openings. This process regulates the air circulation constantly. ▪ This open space is surrounded by verandas on all four sides. The rooms are arranged towards the outside, along the periphery of the verandah creating a linear pattern. These rooms receive light and air mainly from the central courtyard, as they have minimal openings to the outside. ▪ This concept can be adopted in any type of building, like commercial, institutional or industrial and not restricted only to residential. ▪ Courtyards favour air, light, security, privacy and tranquillity.	 *Courtyard within the house*
2	Johad (Johad, n.d.)	▪ Johad is a rainwater storage tank mainly found in Rajasthan, India. ▪ Its function is to collect and store water which can be used for drinking purpose. ▪ Made out of mud and rubble barriers built along a slope, to trap rainwater. ▪ Helps in percolation and groundwater recharge. ▪ Very common in the Thar Desert.	 *Rain water storage tank*
3	Jaali (Jali wall, n.d.)	▪ Jaali is generally a stone having openings carved through it, in a geometric or an ornamental pattern. ▪ Ensures natural ventilation and is an alternative to the use of expensive and non-eco-friendly air conditioning system. ▪ Jaali walls favour privacy and security. It is cost-effective as it can replace the use of windows in a building. ▪ Filters the air which is entering, from all the dust particles.	 *Jaali wall*

Sl No.	Features	Details	Images
		▪ Cuts down the excess radiation that is entering into the building, thus ensuring thermal comfort.	
4	Water bodies	▪ Water body brings down the temperature of the space through evaporative cooling. ▪ Acts as a modifier of microclimate and stabilizes the harsh ambient conditions in the hot arid zone.	 *Water body, which helps in cooling*
5	Verandas, Jharokas & Chajjas (Tipnis, 2012), (The vernacular architecture of Rajasthan, n.d.).	▪ By incorporating elements such as verandas and Jharokas (balconies) which provide shade during the hot dry period and also protection against rain in the monsoon signifies architecture suitable for the given region. ▪ Restricts excess of heat from entering into the interior spaces of the building. ▪ Jharoka and Chajja cast a complete shadow on the streets below, maintaining a cool atmosphere.	 *Narrow streets in Rajasthan*
6	The grid system planning (The vernacular architecture of Rajasthan, n.d.).	▪ The grid planning system is applicable to any type of site and topography. ▪ It is more sustainable in terms of economy and speed of construction. ▪ It is also easier to recycle materials if it was built on a grid.	 *Grid pattern seen in plan*
7	Pols & Narrow streets (Film on the heritage pols, n.d.)	▪ The city of Ahmedabad consists of POLS or in other words- dense neighbourhoods. Each pol has timber framed buildings built around courtyards and the streets are narrow, thus enhancing the thermal comfort within. ▪ The use of lime mortar and wood in the construction makes the building more durable and resistant to earthquakes. ▪ The building height is larger when compared to the width of the street so that the streets are shaded well enough, creating a cool environment for the pedestrians and for other activities on the road.	 *Pols in Ahmedabad city*

Sl No.	Features	Details	Images
8	Openings (Tipnis, 2012)	▪ The buildings are made up of thick walls, with very minimal openings, thus preventing dusty air from entering onto the inside. ▪ In regions where dust swirls in the settlement, the building façade is composed of almost blank walls with very less openings.	 *Minimal openings on the façade*
9	Step wells (Lautman, n.d.)	▪ Bawdis or Baolis are wells or ponds wherein the water can be accessed by descending a series of steps. ▪ Serves as storage and irrigation tanks, mainly developed in India. ▪ This water was used for irrigation, drinking, bathing and washing.	 *Step wells*
10	Planning (The vernacular architecture of Rajasthan, n.d.), ("Why do houses built in Rajasthan have thick walls and flat roofs?" n.d.).	▪ All the houses are situated very close to each other, leaving very minimal space between each other. ▪ This indicates compact planning which ensures enough amount of shade on the streets which in turn keeps the place cool.	 *Compact planning seen in jodhpur*
11	Flat roof ("Why do houses built in Rajasthan have thick walls and flat roofs?" n.d.).	▪ Houses in Rajasthan are mainly found having flat roofs as this region receives less rainfall so there is no need of having sloped roofs. ▪ Flat roofs help in retaining the rainwater and hence, keep the interior of the house cool.	 *Flat roofs used widely in Rajasthan*
12	Bhungha, Gujarat (Mehta and Gohil, n.d.)	▪ Bhungha is a traditional house found in the Kutch district of Gujarat. ▪ It consists of a cylindrical shaped room topped with a conical roof. ▪ It is durable and earthquake resistant. ▪ Bhungha consists of thick mud walls, which doesn't allow too much heat to penetrate through it into the interiors, and the roof is generally made of thatch. ▪ The overhang roof casts a shadow on the wall and protects the walls from direct sunlight.	 *Traditional Bhungha in Kutch region, Gujarat*

Sl No.	Features	Details	Images
		▪ The circular shape of the hut reflects back most of the direct heat received. ▪ Thatch used for the roof, is a poor conductor of heat, hence ensures thermal comfort.	
13	**MATERIALS**		
a	Stone (Tipnis, 2012), (ICAEN; 2004)	▪ Stone is used in making jaali walls and other ornamental elements like friezes, architraves and cornices which are seen on the façade of the building, to reduce the excess solar gain and ensure air circulation. ▪ In the desert areas, the most common stone used in vernacular architecture is the yellow sand stone. ▪ Stone possesses thermal mass property, which is another element of solar passive design. Since stone is a dense material, it is able to conduct heat. Hence, during the day, it absorbs the heat, stores it and slowly radiates it during the night. ▪ During summer, the sun is high. This prevents the walls from getting heated up, so the interior is kept cool. But during winter, as the winter sun is low, it allows the walls to absorb and store enough heat, which is gradually released to the interiors and ensures warmth within the space.	 *Yellow sandstone used in Jaisalmer*
b	Adobe walls (Tipnis, 2012), (ICAEN; 2004).	▪ Mud is extensively used in the hot arid zones of India. It can be mixed with cow dung, grass, straw, thatch, gravel etc. to give additional strength. ▪ Thick mud walls or adobe walls are frequently used in most houses in this region. ▪ They have the ability to absorb and store the heat in the day, and transmit it slowly, ensuring the interiors are cool during daytime. At night, the walls gradually transmit the heat to the interiors, making it comfortable and warm.	 *Adobe wall seen in a village*

Sl No.	Features	Details	Images
c	Wattle and daub (ICAEN; 2004).	▪ It's an old traditional sustainable building technique using mud. ▪ It is basically, mud mixed with ash, straw or cow dung that is plastered over a panel of woven reed wattle, which in turn is fixed and held between a bamboo or timber frame structure. ▪ Structure is lightweight and more suitable in seismic zones. ▪ It also has good insulation properties.	 *Construction of wattle and daub*
d	Whitewash ('What is whitewash?' n.d.)	▪ The whitewashing of lime plastered walls is a common practice in Rajasthan as it reflects back the harsh radiation. ▪ As the colour is light, it absorbs very less amount of heat and reflects back most of. ▪ It is cost-effective and environmentally friendly.	 *Whitewashed walls in Jodhpur*
e	Lime mortar ("Why lime?" n.d.)	▪ Lime allows the building to breathe by absorbing and releasing moisture, thus causing no damage to the walls. ▪ It stabilizes the indoor environment and makes it more comfortable. ▪ Long lasting and eco-friendly. ▪ Since its light coloured, it reflects the heat and keeps the house cool inside.	 *Blue lime plaster walls seen in Jodhpur*
f	Thatch (Johnson, n.d.)	• Thatched roof is ideal for hot arid region as it is a good insulator. • Since it is made up of a thick layer, it keeps the interior cool by not allowing any heat to penetrate through it. One of the materials used in making thatch (reed) does not absorb water; therefore, this roofing material is also proven to be water proof. • It is a versatile and sustainable material.	 *Thatch roof seen in a Bhungha house, Gujarat*

3.11.2 House of Surya and Jaai Kakani, Ahmedabad

The house of Surya and Jaai Kakani located in Ahmedabad follows principles of sustainable design to achieve comfortable living without air conditioning in the hot & dry climate of Ahmedabad. Sustainable design principles integrated in the house includes: verandahs terrace vegetable garden, thick walls which behave as insulation, use of lime plaster in place of cement, recycled wood instead of aluminum or steel. Thick walls and thick roof, lime plaster inside and outside along with a wind catcher installed on the roof to let fresh air inside keeps the house comfortable in all seasons. Rain water is harvested for drinking. Waste water from washing machine is used for flushing toilets and waste water from

Kitchen goes for gardening. The organic kitchen garden on terrace provides them with brinjal, tomatoes, carrot and other greens (Residential Energy Efficiency, 2013).

Figure3.13: Diagram showing various systems along with wind catcher in blue

3.11.3 Integrated Housing and Slum Development Programme (IHSDP) Lonar, Maharashtra

IHSDP is central government sponsored slum rehabilitation under JNNURM, to provide adequate housing, infrastructure and social amenities to slums dwellers. The plan involves a cluster of 14 blocks of residential units around a central green space, creating medium density neighborhoods. It is a project aiming 4-star GRIHA rating (HUDCO, 2012).

Key features: Filler slab, tumbler roofing and rat-trap were the most extensively used construction technologies. Fly-ash bricks and pre-cast members were used. Hard paving was optimized to increase ground water percolation. For waste water reuse bio filter technology was employed. To achieve optimum energy performance, radiance building simulation tool and day lighting analysis with reference to architectural design were incorporated. The premises lighting was achieved through solar powered street lights.

3.11.4 Residence at Vadodara, Gujarat

'Residence at Vadodara' was built by Harmony Architects and Planners. It received the HUDCO Design Awards 2012 (second prize) in the' Green Buildings' category. The project has a vernacular architecture, a climate responsive design and an indigenous lifestyle which makes it a sustainable/green design (HUDCO, 2012).

Key Features: The longer facade of the building has been facing in the North-South direction making it the ideal orientation. All the horizontal surfaces have been covered through gardens (terrace as well as on ground). Direct radiations on living spaces have been avoided through cavity walls on extreme east and west. Other spaces have been protected by respective buffer areas (toilets, verandahs etc.) thus minimizing heat gain during day time. A central courtyard vents whatever little heat gain takes place. In extreme summer the house is cooler by 13°C as compared to a house of similar orientation. Local materials have been used at various locations in the house. Earthen pans were used as fillers in RCC slab, mud blocks were used to construct walls and locally available stones were used for openings and arches. 95% of the materials obtained from the demolition of the old house were used again. Bricks from the old foundation were used for the new one, Wooden frames were reused as window frames, shelves, drawers etc., steel from the demolished slab was used in the new slab, mosaic tiles and bamboo were reused, old glass was resized and used again and so was the Kota stone flooring.

3.11.5 The ACC Greens Village, Bellary, Karnataka

The project is a sustainable residential campus spread over 50 acres being built for the staff of ACC at its' cement grinding plant at Kudithini, in Bellary, Karnataka. M/s Ashok B Lall Architects, ABLA, Delhi are the main Architects for this project. The project focused at creating a low ecological footprint built environment. A prototype unit was built first to identify all the hiccups and limit them to that one unit (The Sustainable Housing Complex for ACC, 2011).

Key Features: An afforestation programme was a major part of the project. Food sustainability was taken into account which saw the development of a sizable farm, cattle shed (for milk) and a fish pond. Rainwater management, harvesting and recharge were incorporated and biomass gasification infrastructure, supplement by woody biomass from the afforestation programme, and a bio-methanisation unit supplement by the dung from the cattle shed were installed for energy sustainability. Semi cast latticed RCC rafters and hollow pre-cast blocks were used as an alternative to RCC slabs. The hollow pre-cast blocks accommodated cooling tubes for thermal management of the house. This alternative technique saved 40% steel as compared to a conventional construction. GGBS blocks (blocks made using ground slag from steel plant) are being used instead of concrete blocks which are not only economical but also environmentally friendly as they use a by-product. The doors and windows for the entire project will see the use of reclaimed timber sourced from various reused timber merchants. The house flooring will be done entirely of pigmented cement avoiding stone flooring, lowering embodied energy footprint as well as the cost. Screens are provided in verandah to act as thermal barriers in summers. These screens use Bamboo Mat Board, BMB, instead of plywood (bamboo being a fast growing grass and not wood). A non-toxic approach is adopted for anti-termite treatment of the site by using a neem-based solution. Quarry dust instead of sand is used in plastering, mortar and concrete. A box trench foundation was designed, especially for the black cotton soil of this region. It is a lean concrete mix using large stone aggregate that is filled into this trench and allowed to cure. The technique is simple, quick and does not need any reinforcement.

Figure3.14: A completed and Occupied Unit of the Project

3.11.6 Summary for Hot Dry Climate Zone

Hot dry climate is prevalent in most parts of Rajasthan, Gujarat and partially in north Karnataka. Traditional elements are composed of courtyards, *jaali* openings in the walls, verandas, *chajjas* and flat roofs. Many unique and different features have originated from this region that is highly climate responsive. To deal with water issues, *johads* and step wells were constructed to collect and store water. Water bodies are present, to cool down the space through evaporative cooling method. Buildings are located on both sides of the narrow street, to provide shade and a cool atmosphere for the pedestrians. Sandstone, adobe walls, wattle and daub, lime mortar and whitewash are the different materials and building techniques used, that respond very well with the microclimate.

Literature case studies were done on House of Surya and Jaai Kakani, Ahmedabad; Integrated Housing and Slum Development Programme (IHSDP), Lonar, Maharashtra; Residence at Vadodara and The ACC Greens Village, Bellary, Karnataka. Terrace garden, rainwater harvesting, use of lime plaster and recycled wood, solar powered street lights, bio filter technology, fly-ash bricks and mud blocks for construction, biomass gasification infrastructure and bio-methanisation unit are the green features incorporated in the above mentioned projects.

3.12 International projects

3.12.1 Viva Verde, Bronx, New York, USA

The project was a result of juried competition for sustainable and affordable housing. The competition was conceived by the local New York chapter of the American Institute for Architects (AIA) and the City of New York Department of Housing Preservation and Development (HPD). The project, costing USD 70 million, has LEED Gold rating. The complex steps down from a 20-story tower to three- and four-story town houses (Green Features, n.d.).

Key features: More than 20% of material used in construction is recycled material. Over 20% of materials were locally procured reducing transportation energy and supporting local economy. 80% of construction and demolition waste was recycled. Rooftop garden provided to dissipate heat and to use rain water for growing fruits and vegetables. These gardens also reduced heat islanding effect and form place for social gathering. Motion sensors installed in corridors and stairways to reduce energy consumption. The complex has been equipped with 66kW rooftop solar system providing enough electricity for hallways, elevators, and public spaces. High level of insulation is used in building's construction with high efficiency windows. All the apartments are provided with energy efficient appliances along with provision for natural cross ventilation. The building is expected to perform 30% more efficiently than a normal building.

Figure3.15: Left picture shows rooftop vegetable farming and picture on right shows building integrated solar panel

3.12.2 Treelodge@Punggol, Singapore

Treelodge@Punggol is Housing & Development Board's (of Singapore) first eco-friendly project and Singapore's first Green Mark Platinum Award Public housing project. The project has implemented both passive design and green technology to be more resource efficient (Sustainable Development concepts, n.d.).

Key Features: Passive design includes all the façade windows facing dominant North-eastern winds to maximize natural lighting and ventilation. This also reduces solar radiation gain from east-west direction. The orientation and openness of the building creates wind tunnel through central spine of Eco-Deck. Solar panels are provided which generates sufficient electricity to meet demand of common area services like lightings, lifts, pumps etc. Building is provided with energy efficient LED's for lighting purpose in staircases and car parking area. For reducing water demand rainwater harvesting system is in place. The water collected is used for common area washing and irrigation purpose. All households are also installed with an Eco pedestal, which uses water from hand washing to flush the toilet. For the construction purpose pre-cast technology has been used. The pre-cast technology reduces construction time as well as construction waste. The Centralised Recyclable Refuse Chute are used which promotes recycling by providing convenience for residents to dispose their recyclables and also enhances the collection efficiency for waste collectors.

The project is located near to Punggol MRT (Mass Rapid Transit) and Damai LRT (Light rail transit) thereby giving more access to public transport. Bicycle parking facility is provided to promote their usage and decrease dependence on conventional vehicles.

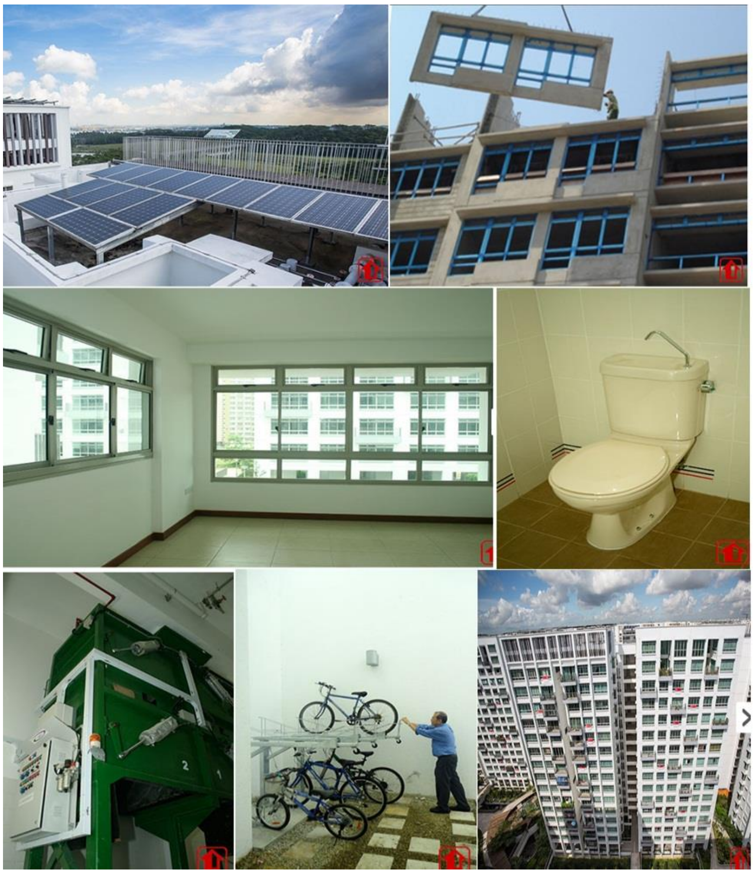


Figure3.16: Top left is picture showing solar panels being integrated on roof. Top right picture shows pre-cast technology. Middle left picture shows provision for natural lighting and ventilation. Picture on middle shows Eco-pedestal used to reuse water. Bottom left is the picture of centralised chute for waste collection. The cycle parking provision is shown in bottom middle picture. Bottom left is the building picture showing white outer self-cleansing paint

3.12.3 Coldharbour Lane, U.K.

This Project is residential development in Brixton, South London, consisting of 108 apartments constructed by Skanska. The project cost was USD 20 million developed for Notting Hill Housing and took about two years to complete. The project is energy efficient affordable housing development based on Skanska's ModernaHus concept. The housing meets level 4 standard of the code for Sustainable Homes in UK (level 6 being the highest code for zero carbon homes), (Skanska sustainability, n.d.).

Key features: Apartments are designed to consume 47% less energy than current UK building regulation. A 50kW central biomass boiler combusting wood pellets provides for

60% of development's winter heating requirement (running at 100% for 15 hours per day). In design stage study was done to calculate embodied carbon emission resulting from manufacturing and transport of key materials and their associated manufacturing processes. With such planning it was possible to reduce total embodied carbon by 25% by incorporating 20% pulverised fuel ash. All the major construction materials were sourced from within 200 km of the site. 94% of construction had been diverted from landfill. Around 85% of demolition material were either reused or recycle. With use of efficient water fixtures and fitting water efficiency of about 30% was achieved as compared to typical water use in UK.

Green roofing is provided on the top floor if buildings to provide further insulation and extends roof's lifespan by protecting it from withering an UV light. The site is designed to promote car-free environment by only providing eight disabled car parking spaces in the site and restricting residents from applying for street parking permit. 108 secure cycle storage spaces are also provided on site. The apartments are designed to be affordable. The government funds shared ownership scheme is implemented for the project. This scheme allows first time buyers to purchase a share of their home at below market value. Then the buyer can gradually buy further share of their home as and when they are able to afford to so.

Figure3.17: Coldharbour lane building picture

3.12.4 BoKlok project, Sweden

The concept of this affordable housing was initiated in 1996. Initially targeted for single parent or individual person now has become popular among families to. Green features have also been added to the concept to make houses sustainable. The housing includes both individual villa type houses as well as apartments (The Boklok project, n.d.).

Key features: The houses are compact and resource efficiently designed without leaving any unnecessary square meter of area. Designing is done in so as to receive maximum sunlight during the day (windows on south and west sides); this also increases passive heat gain and reduces heating needs. Materials for construction process are carefully chosen. Wood is mainly used for construction as it is renewable, cheap; production of it is less energy intensive and has low carbon emission as compared to other materials. Additionally wood is also readily available local material in Sweden. Family houses/villas are factory built modules whose architecture and plan is predefined and the customer has to choose from these pre-designs. Construction in factory makes it easier to produce in bulk thereby reducing the costs and making construction process more energy efficient. This also increases recycling capacity of materials, almost all the unused materials in factory are recycled which is hard task while constructing on-site. Such houses are 30% more energy efficient than Swedish norms of standard housing. Traditional Swedish building architecture is also kept in mid while designing houses.

Figure3.18: Three types of housing blocks available with BoKlok project

3.12.5 Green village – Lochiel Park, Australia

The project was instigated by government of South Australia in order to make South Australia a world leader in green approach to way of life. The vision behind this project was to make it country's Green Village incorporating Ecological sustainable technologies. This project is supposed to be an incubator of research, and development and education opportunities to assist in transforming the infrastructure industry into a greener future. The project has 106 dwellings constructed at a total cost of AUD 18 million (Lochiel Park, n.d.).

Key features: Photovoltaic cells are mandated on every roof (1kW per sq.m of habitable floor area). Community building is also provided with solar panels. Recycle water supply system provides for toilet flushing, cold tap washing machines, garden use and parkland irrigation. This water system captures storm water from a 190 hectare adjacent urban catchment which is cleaned through a wetland system and aquifer storage recovery scheme prior to reuse in houses. Low embodied and recycled energy materials are used in reserve and public realm infrastructure. Key materials used are fiber reinforced concrete, pavers and bricks which are manufactured on site using recycle waste materials and clay excavated from nearby wetlands. Lighting systems are efficient one are supplied from solar energy.10 hectare of forest biodiversity is created besides the project. With all these green features it is expected that the water consumption in household will reduce by 40% and energy bills will reduce by 66%.

Source:http://www.greenwayarchitects.com.au/lochiel-park-affordable-housing/

Figure3.19: Left figure shows houses in Lochiel Park and in right the picture shows ventilation system concept used in houses

3.12.6 Melrose Commons II: Sunflower Ways, Bronx, New york, USA

Melrose Commons II is a $12 million, 90-unit multi-family project featuring multi-level owner apartments and second- and third floor single-story rental flats. This complex of 30, three-story, three family homes totals 126,900 square feet of living area. The development is specifically for first-time homebuyers. The homes were designed and financed to be affordable for families making as little as $42,000 a year (or 80% of Area Median Income). The incremental cost to build green was $354,990 (The costs and benefits of green affordable housing, 2005).

Key features: Efforts to green Melrose focused on using precast concrete construction, improving energy efficiency through a variety of measures, and selecting environmentally preferable materials.

Low-flow shower controls, faucets and toilets were installed in bathrooms and kitchens of all of the units to reduce water use.

The project used faced R-11batts in frame walls and ½-inch rigid expanded polystyrene (EPS) insulation board between metal studs and exterior walls to prevent thermal bridging. In addition, 2-inch EPS was used in the basement up to two feet below grade, with 2-inch rigid fiberglass insulation on all exposed cellar walls. For roof insulation R-21 3.1-inch foam board was installed as were aluminized roof coatings to reflect summer sun. Large area double glazed low-e (Comfort E2) coated glass vinyl frame windows from a local manufacturer were installed in rooms and public spaces to improve envelope performance and increase natural lighting. The entire Melrose Commons II complex was constructed with structural precast panelized concrete and brick system (Oldcastle Precast) to create a tighter envelope. Each precast concrete-framed unit included poured concrete foundations, hollow core floor and roof planks, weight-bearing and non-weight-bearing wall panels, interior and exterior steps, U-shaped channels and cornices, and sills and lintels cast into the brick inlay exterior panels.

The project uses a single high efficiency (87+%) sealed combustion direct-vent (Burnham Revolution) gas boiler with a 65-gallon (Bradford White) automatic storage indirect water heater to provide heat and hot water for each building, rather than separate ones for each of the three units per building. In addition, the project used digital programmable thermostats and an outdoor reset control to modulate water temperatures in the radiators depending upon outdoor temperature. Energy Star compact fluorescent lighting fixtures are used throughout the complex.

To reduce use of virgin materials and conserve natural resources, the project used 100% recycled content PET carpeting made from recycled plastic bottles and containers laid over recycled rubber padding. In addition, recycled content vinyl composition tile (VCT) flooring was used in kitchens. To minimize impacts on indoor air quality low-VOC paints were used throughout the project as were low-VOC latex acrylic sealants throughout the interiors. In addition, solid wood and plywood were used instead of particle board in kitchen cabinets and countertop substrates with low-VOC lacquer finishes on the cabinets.

Figure3.20: Melrose Commons 2 houses

3.12.7 River walk Point I, Spokane, Washington, USA

Riverwalk Point-I is located in Spokane, Washington and is owned by Spokane Neighborhood Action Partners (SNAP). This low income housing project has been in service since 2003 and now has a total of 50 low income units in five buildings. The project has received Washington State's first certification for Energy Star multi-family housing. It exceeds the Green Communities standards by 28% and reduces annual CO2 emissions by 49 tons per year. The average cost per unit was $118,167 and the incremental cost to green was $317,285 which is 5.16% of total development costs (The costs and benefits of green affordable housing, 2005).

Key features: Low-flow fixtures have been used throughout the project. Exterior landscaping is made up of native and drought-resistant plantings that minimize irrigation and maintenance needs. Rainwater is used to irrigate landscaping. The landscaping plan also minimizes impervious surfaces, using grass in fill pavers for secondary parking areas at a $2,700 additional cost. Water efficiency upgrades added 0.3% to total design and construction costs.

All buildings feature high-efficiency heating and ventilation systems, good insulation. Buildings are oriented in such a way to provide maximum day light and passive solar gain without additional cooling loads in the summer. Four buildings have gas-fired, sealed-combustion forced air heating while the fifth building features a geothermal heat pump. This building also features air-to-air heat recovery ventilators for each unit. The upper floors of another building are constructed with Structural Insulated Panel (SIP) exterior walls. Prefabricated SIPs are load-bearing material made of rigid foam and fiber board which can be used with or without conventional framing and have exceptional R values.

Interior lighting fixtures are efficient compact fluorescent and T-8 fluorescents that use approximately 30% less electricity than conventional fluorescent lighting. All other units are equipped with Energy Star appliances.

By focusing on Site work and grading the materials, the transportation cost was lowered by approximately $1,000. An unfenced, native vegetation wildlife corridor was created which preserved many of the original trees and much of the original vegetation. Also a job site recycling plan, encouraged reuse and recycling of construction materials such as wood, drywall, cardboard and metals. All concrete used for the project contains 15-25% fly ash. This saved $1,500 over conventional concrete.

Advanced framing techniques were specified to enable better insulation of the building envelope which also reduced the amount of lumber required to frame a building, leading to a $12,294 savings on the project. Oriented Strand Board (OSB) was used instead of conventional plywood for roof and wall sheathing, resulting in a $12,300 savings in materials cost to the project. The project also utilized locally produced silica asphalt and durable pathway pavers saved approximately $1,000.

Several indoor air quality-enhancing features were included for little or no additional cost to the project. Low volatile organic compound (less than 20 grams of VOCs per liter) products were used for interior and exterior paints and finishes.

Figure3.21: Riverwalk Point I houses as seen from street outside

3.12.8 Glumslöv housing project, Sweden

This is a passive house project consisting of 35 houses ranging from one bedroom to four bedrooms. The goal of the project was to keep the rental cost for the apartment at a maximum of 100 €/m2 along with being well-functioning and sustainable passive houses. The housing project is created by Skanska with Landskronahem, the project owner, a municipal housing company, provides just such accommodation (Janson, Ulla, 2008), (Passive Homes in Glumslöv, Sweden, n.d.).

Key features: The houses in the project are self or passive heating ones which require no heating. The house gain warmth from the body heat of occupants, from solar gains as well as het gains from internal appliances. The buildings are designed to be tightly sealed with 45 cm thick insulation layer. The healthy indoor environment is further enhanced by well-designed ventilation system which has heat recovery capacity of 85%. With lack of heating cost incurred and no need special skill for operating and maintenance, the housing can be offered at lower rents. Landskronahem has estimated that the life cycle cost of the buildings in Glumslöv are 25 per cent lower than normal which was achieved without any additional costs in the construction phase.

Figure3.22: Shows front on the ground floor at Gumslöv and second picture shows a house during construction period

3.12.9 Casa Aqua, Sao Paulo, Brazil

AQUA is the Brazilian High Environmental Quality Rating System. In February 2010, the first version of the AQUA process for residential buildings was launched, and in April a prototype AQUA house for low-income families was exhibited in São Paulo. With an area of 40 square meters, the prototype has various green features integrated into it (GREEN CITIES, 2011).

Key Features: A rainwater harvesting system, consisting of a cistern and permeable soil; a solar water heater; fiber-cellulose shingles; and soil-cement bricks which are dimensioned and prefabricated to allow for faster assembly and do not use mortar. Such soil-cement bricks have lower cost than standard bricks. To increase natural lighting and ventilation inside the house, a sloped roof was designed with skylights.

Environmentally friendly products were used in the interior of the house such as cement board made from mineralized wood, which does not require finishing, and recycled Tetra Pak packaging on some walls. Installation of dual-flush systems in toilet reduces water usage. Fluorescent light bulbs were given for internal lighting. According to the developers, the use of eco-efficient solutions in the construction of the house had an additional cost of only BRL 5,000. The total construction cost for the unit was BRL 45,000.

Source: http://www.casaaqua.com.br via http://www.tuverde.com/2010/04/brasil-casa-aqua-una-edificacion-sustentable-y-popular/fdt-500-x-454/

Figure3.23: Model of the Casa Aqua project

3.12.10Bio Solar house, Thailand

A research team from Chulalongkorn University in Bangkok has built the Thailand's first "bio-solar" house. The house is self-reliant which produces its own electricity, water and cooking gas. The electrical needs of the house are completely fulfilled by solar panels. Nothing in this eco houses goes to waste (Krikke, 2003).

Key features: Cooking gas is produced by biogas plant installed in the garden; the biogas plant uses waste from kitchen as its feed. This biogas plant technology is newly developed by Kasetsart University and the Department of Alternative Energy Development and Efficiency in Thailand's Ministry of Energy. The house can harvest 80 to 100 liters of water every day. There are three sources for water harvesting, i.e. rain, dew, and condensation from air conditioning (AC) unit. AC unit produces about 30 liters of water every day, the water from rain and dew being seasonal is filtered and collected in a storage tank of capacity 3600 liters. Wastewater from the kitchen, showers, carport, and washing machine is filtered and reused for irrigation. On the roof of 180 square meter 22kW solar PV system in installed which is capable of storing electricity for three day use. The AC unit at peak consumes 7 kW thus the solar system generates 15 kW of additional capacity which can be used by other appliances. The AC unit is controlled by a central unit which can adjust both temperature and humidity in all rooms.

Between the roof and the one-foot- (30-centimeter-) thick insulation an air duct is provided which allows the wind to ventilate the heat absorbed by the roof. The garden along the house has several artificial mounts designed to direct the wind toward the house. The house is designed in such a way that sun rays never enter directly at any time of the day and all the windows are provided with triple paned glass. With all these features the bio solar house is 14 times more efficient than a standard house. The cost of house is calculated to be about USD 75000 not including cost of solar panels. The solar panels are imported and due to heavy duties by government are very expensive. Without the swimming pool the cost of house will come in the range of standard house in Thailand. It has been calculated that additional investment cost incurred in Bio Solar houses have payback time of seven years.

Source: www.architectureweek.com.

Figure3.24: Left- Bio solar house as seen from front, Right- Detail of PV solar system installed in house.

3.12.11Broad Sustainable building (BSB) Co. LTD, China

BSB is a Construction Company based in China which specializes in building factory made sky scrapers. The company has built about 30 buildings in China which are sustainable and affordable. Although this is not a housing project but the features incorporated by this company in its project is green and they are affordable (“Why Sky City?” n.d.).

Key features: All the buildings by BSB are capable of bearing earthquakes of magnitude 9 on Richter scale, sections of sky scrapers are prefabricated in a factory before assembling them on site. This prefabrication is done by e ‘professional labourers’ as compared to ‘day labourers’ in construction of conventional buildings. Thus quality of construction is superior. The design of sections is standardized. Due to prefabrication and high worker efficiency time period of construction is drastically cut down along with reduction in the cost associated with it. This also helps in reducing waste specially happening during construction period. Usually these buildings are 90% factory made with only 10% of time spent at actual construction site.

Features like thick insulation (70% heat loss reduction from wall), four paned windows (60% energy reduction from windows), external solar shading (30% energy savings in winter), and fresh air heat recovery (80% energy savings in HVAC) make these buildings highly energy efficient. BSB built buildings are generally five times more energy efficient than conventional buildings. 100% fresh air provided through three stage filtration process makes inside air nine times purer than outside air. The construction cost is estimated to be around USD 1000/sqm which is quite low (about 50% lower than conventional buildings).

3.12.12 BedZED (Beddington Zero (fossil) Emissions Development), United Kingdom

Architect Bill Dunster, Zed Factory, is known for his habitat development designs with Cost effective sustainable features. To name; BowZED, MMC Housing system (£1,275/m2 to £1,550/m2), St Matthews Key Worker Flats Estate Regeneration (12 flat apartment, Total cost: £1.5 Millions, 2005), Hockney Green Housing development (5 Terrace houses, 12 flats, Total cost: £2Millions, 2007). BedZED (Total cost: £14.5 Millions, 2002) is one of his famous and outstanding projects developed in Sutton, England.

Key features: The BedZED project contains 99 mixed use dwelling units and claims to be a highly energy efficient with sustainable materials and construction technologies and cost effective solutions. Materials were sourced from a radius of 35 mile, from natural, recycled or reclaimed content. The annual energy and water consumptions are nearly 60% and 58% less respectively than a local conventional habitat. The project also boosts with 60% higher household waste recycling practices and 65% reduced car ownership. BedZED residents use only 5.2 kWh of electricity per person per day which is 34% lower than the average resident in Sutton, 3.4KWh of heat per person per day which is 77% less. The design is developed with passive features like orientation along with active technologies like solar PV panels, ventilation cowls, water and power efficient appliances all contributing to meet a nearly zero energy design.

Figure3.25: BedZED, United Kingdom

3.12.13 Earth Sheltered Housing, Hockerton, Newark, United Kingdom

A small housing community was developed in Nottingham with earth berming and is considered to be the UK's first of its type. The project has remarkable features like zero carbon emission, low or no heating requirement.

Key features: The design is composed with local materials, pre-cast concrete beam and block roof. Passive solar design features like earth-bermed walls on north, east and west for thermal mass and sunrooms on south sides to reduce heating requirements are integrated with renewable technologies like wind turbines and PV panels to meet the energy requirements. Other features like low water flow fixtures, drinking water captured from conservatory roofs in copper pipes, Reed bed sewage systems to treat grey are provided.

Figure3.26: Earth Sheltered Housing, Hockerton

3.12.14Summary for International Case Studies

Thirteen international green residential buildings from various parts of the world are studied, to comprehend the different designs and methods adopted, in defining a green and sustainable home. Some of the buildings are given different green rating systems, depending on the features they exhibit. For example, Viva Verde, New York, USA, is a high rise building that has obtained the LEED gold rating, wherein, its constructed out of recycled and locally available materials, consists of a rooftop vegetable garden and solar panels, which is used to generate electricity. Treelodge, Punggol, Singapore is designed is such a way that it captures maximum natural light and ventilation, possesses solar panels to generate electricity, LEDs for energy efficient lighting and has incorporated rainwater harvesting system.

Coldharbour lane, U.K; BoKlok project, Sweden; Green village – Lochiel Park, Australia; Melrose Commons II: Sunflower Ways, New York, USA; Riverwalk Point, Spokane, Washington, USA; Glumslöv housing project, Sweden; Casa Aqua, Sao Paulo, Brazil; Bio Solar house, Thailand; BedZED (Beddington Zero (fossil) Emissions Development, U.K. and Earth Sheltered Housing, Hockerton, Newark, U.K. are the other projects studied as they all possess green features like solar PV panels to meet energy needs, low VOC paints, rainwater harvesting, green roofing, low carbon emission materials, efficient lighting systems, biogas for cooking, reuse of wastewater, provision for daylight and ventilation, low flow fixtures and highly energy efficient sustainable materials and construction technology.

4 Field Case studies under Moderate Climate Zone

4.1 Good Earth Malhar Footprints

4.1.1 Site location

Good Earth Malhar Footprints is a 7.5 acres Residential community development as part of the 50 acres Eco village located 1.5km off Mysore road, near Kengeri town. The coordinate of the place is 12.88 N, 77.46 E with an altitude of 931m above sea level. It is located 27km from Bangalore and experiences moderate climate as per NBC 2005 definitions.

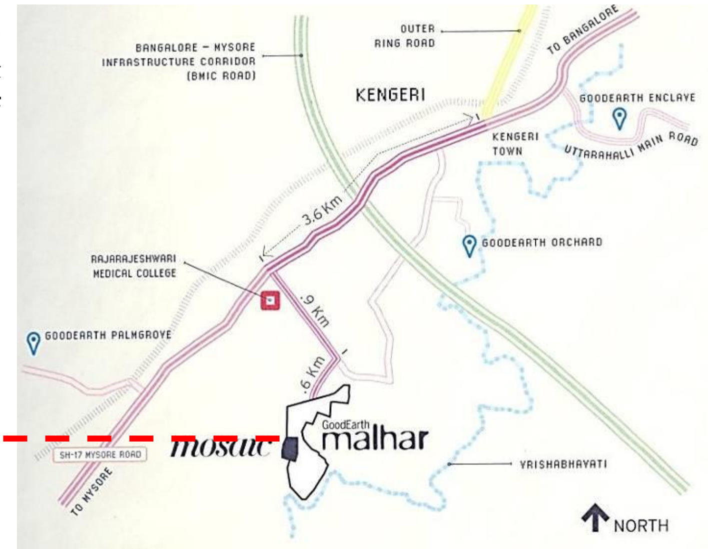


Figure4.1: Location of Malhar Footprints by Good Earth

4.1.2 Project Profile

A brief profile of the project has been depicted below:

- Project name : Good Earth Malhar Footprints
- Year of construction : Sep 2011 – Sep 2014
- Location & Address : Kengeri, Bangalore
- Climate (as per NBC) : Moderate
- Site area : 7.5 acres
- Architect : Good Earth
- Contractor : Good Earth
- Developer : Good Earth
- MEP Consultant : Good Earth
- Energy consultant : Good Earth
- Any energy performance certifications : No
- Total Cost of Construction : Rs. 2000/sq.ft (2014)
- Construction Cost of units : Between 25.6 to 51.3 lakhs (Excludes land cost and profit of developer
- Total Built up Area (Sq. mts) : 17966.17 sq.m (193316 sq.ft)
- Total site area (sq. mts.) : 30351 sq.m (7.5 acres)
- No of dwelling units : 96 units
- Typology of development : Cluster homes- G+1 homes
- Dwelling density : 12.9 units/acre
- Green technologies/features incorporated : Rain water harvesting, Ground water recharge, Waste Water Treatment and reuse, Solid waste management, Green Construction practices, integrating craft into the design, Use of local materials, Biodiversity and use of indigenous species in landscape, preserving top soil and ecology.

4.1.3 Details of green features in the project:

Good Earth Malhar Footprints integrates many green features as highlighted in the project profile table. Following paragraph discusses the details of the green features, its cost, affordability and potential to be replicable in affordable housing schemes.

Site planning & landscape

Footprints are the first phase of development at Malhar Eco village covering 7.5 acres. The 96 homes at Footprints are divided into 8 groups of 9-16 plots, each arranged around a cluster park. 3 central parking courts are tucked away beneath neighborhood parks and service 2-3 such cluster groups each. At the entrance of each group of clusters is a drop-off point with some surface parking for visitors or residents with special needs, beyond which a ramp continues down into the central parking area. Since the layout follows the natural slope of the land, with clusters being at various levels, these parking courts do not resemble typical basements. They are well lit and ventilated, and connected to the clusters through landscaped courts, sometimes even at the same level. The site planning data have been tabulated below.

Site Area (Sq.m)	7.5 acres, 30351 sq.m
Built up Area (Sqm)	17966.17
Floor Area Ratio (FAR)	0.75

The project was started in Sep 2011 with an initial planned construction budget of Rs. 1600/sq.ft which increased up to Rs. 2000/ sq.ft in 2014. The land cost was additional with Rs.1800/sq.ft.

Tree protection

At site level all existing matured trees have been protected, before and during construction, by careful layout of the units in the cluster. Following photographs shows the protected trees beside the units.

Figure4.2: Tree protected on site during excavation and around the housing units

Preservation of matured trees helps to control soil erosion during construction which further helps in maintaining comfortable microclimate without additional water demand. Protection of existing trees is a cost effective sustainable technique with no cost requirement. However in conventional practices, at site where trees are not protected, there will be additional cost for permission and cutting of matured trees. Hence, protection of matured trees during and post construction is affordable and has the potential to be replicated in affordable housing.

Top Soil preservation: Top soil for the site has been preserved before construction of the site, which helps to acclimatize new sapling for plantation on site as against conventional cases where top soil usually are not preserved. Preservation of top soil involves collection , storage and maintenance cost of Rs. 17/cu.m as against site where top soil are not preserved with cost for purchase of top soil cost, supply, staking and mixing of sludge, manure, sieving is up to Rs.228/cu.m. Hence, protection of top soil during construction is affordable and has the potential to be replicated in affordable housing.

Preserving site Levels& topography:The original levels of the site have been preserved by minor cut and fill. Below mentioned drawings depicts the part site section with level difference.

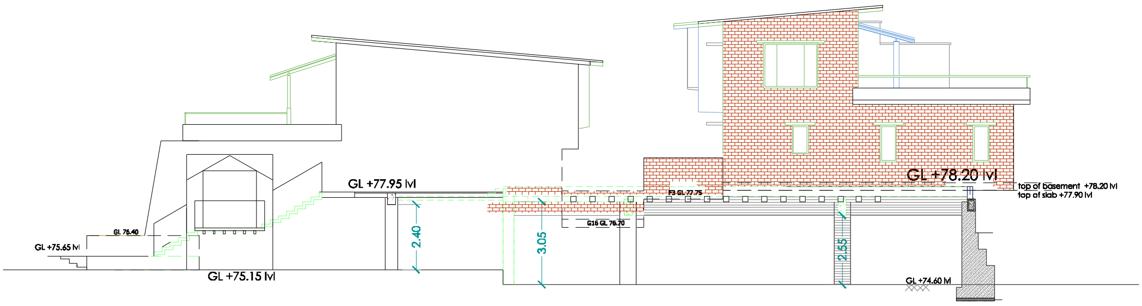


Figure4.3: Partial site section showing the level difference on site

The natural drainage pattern of the site was preserved which was embedded with gravels/aggregates/stones as a feature to enhance percolation of rainwater and helps in storm water management. It's a cost effective feature as the infrastructure for storm water management required will be lesser in size and capacity as against a site in conventional practice. The cost for trenching, excavation and cut & fill is Rs.110/m which is more in conventional practice than in Malhar's case. Hence, protection site levels and topography during construction is affordable and has the potential to be replicated in affordable housing.

Service corridor planning

Figure4.4: Service corridor trench on site and plumbing service line in each housing unit

Building services like water supply, electricity etc. is placed in aggregate utility corridors. It is a sustainable feature which helps in protection of pavements and from unnecessary trenching. In conventional cases, services are not planned systematically and multiple trenches damages roads and pavements. Rs. 180/running meter is the cost for trenching to create corridors and in conventional case it costs more than aggregate corridor as multiple trenching needs additional cost. The depicted image shows water supply plumbing lines underground in the form of an aggregate corridor for utility. Hence, aggregate service corridor planning is affordable and has the potential to be replicated in affordable housing.

Landscape paving materials:

Soft paving

Landscape soft paving includes mud concrete road and pervious pavement for pedestrian movement to maximize percolation of rainwater in the ground and reduce heat island effect. Materials like *chappadi*, hollow clay block, Cuddapah, Brick, Grass, mulching using wooden scraps as a waste from the sawing process, are used in the landscape pavement and softscaping. The cost of paving is Rs.295/sq.m. In conventional cases, although similar materials are used, perviousness of site is reduced due to increase areas of impervious paving without ground exposure. The cost is approximately Rs.350/sq.m. Hence, pervious paving laying is affordable and has the potential to be replicated in affordable housing.

Figure4.5:Paving with mud concrete, brick and Cuddapah and sadaralli stones

Figure4.6: Mulching over the soil to avoid soil erosion and Stone paving with grassing around a seating space

Hard paving:

In pavement areas for circulation, pedestrian and automobiles, impervious paving in the form of mud concrete (sand replaced by mud in PCC) and vacuum dewatered flooring (VDF) has been respectively used. Mud concrete is sustainable as it avoids sand and uses soil from site in comparison to conventional PCC. VFD pavement, although uses sand, still it is sustainable because it has high SRI (solar reflective index) which reduces heat island effect on site and avoids flooring like tiles/paver tiles as against plain cement concrete pavement. Mud concrete costs as much as regular concrete, Rs 6000-7000 per cu.m , with only the added labour cost of 10% due to mixing of soil and surkhi. In case of VDF pavement, only additional labour cost is for the base concrete with cost of 5000-6000 per cu.m. The overall cost of mud concrete and VDF will be cheaper than plain cement concrete (which costs 4500 per cu.m.), as additional cost of flooring is avoided as against PCC pavement. Hence, mud concrete and VDF is affordable and has the potential to be replicated in affordable housing.

***Brief details on Landscape areas and materials at Malhar Footprints**:*

Soft scape

- Soft scape Area : 19651 sq.m (including Lawn, bushes, shrubs

and trees (Sqm))

- Names of Native species : Terminalia, Arjuna, Ficus Religiosa
- Total site area : 30351 sq.m
- Total ground coverage : 8000 Sq.m
- % pervious pavement : 87.9 %
- % impervious pavement : 12.1 %

Hard Scape

- Pervious Paved Area : 500 sq.m
- Construction/ Material : Cuddapah, Chappadi, sadaralli
- Impervious Area (sq.m) : 2700 sq.m
- Construction/ Material : Mud concrete, VDF
- Details of any local materials used : Stone, mud blocks

Building Envelope and civil works:

Building plan is rectangular in form with surface to volume ratio as 0.43 for corner plots, 0.26 for the rest. The Window to Wall ratio is 18% for corner plots and additional 25% for others. The materials specification in the project has materials with potential green features which have been described below.

Roof

Roof is constructed of RCC roof slab with treatment in the form of shading has been provided using composite sheet made of GI and Onduline sheet fixed over the steel rafters. It helps to ventilate and shade the RCC roof, lower heat transmission from sun, supports solar hot water system and has gutter for roof top rain water harvesting. The cost of constructing the roof treatment is Rs. 1400/sq.m where costing for individual components are 538/sq.m for Onduline sheet, 538/sq.m for purlins and 323/sq.m for GI sheet. Double layered roof shading (GI + Onduline) over RCC roof has been depicted below. In conventional cases, roof treatment using brick bat coba for insulation is given which helps in lowering heat transmission and costs Rs.540/sq.m. Hence, we can conclude that, composite sheet made of GI and Onduline is not affordable and can't be replicated in affordable housing.

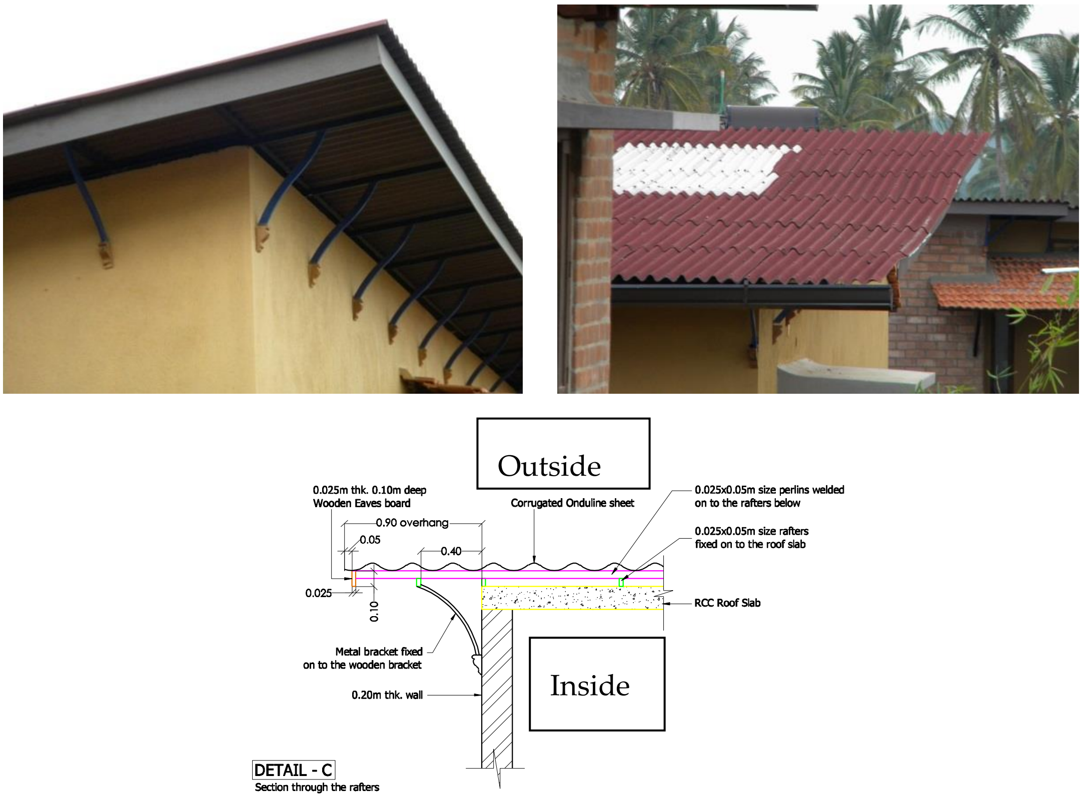


Figure4.7:Cross sectional details with photographs depicting wall bracket supporting the roof and color of the exterior surface

Walls

Exterior wall is made of CSEB (compressed stabilized earth block) and random rubble masonry which helps in lower heat transmission and maintains lower temperature in the interior space than outside. The wall photographs and cross sectional details have been depicted below.

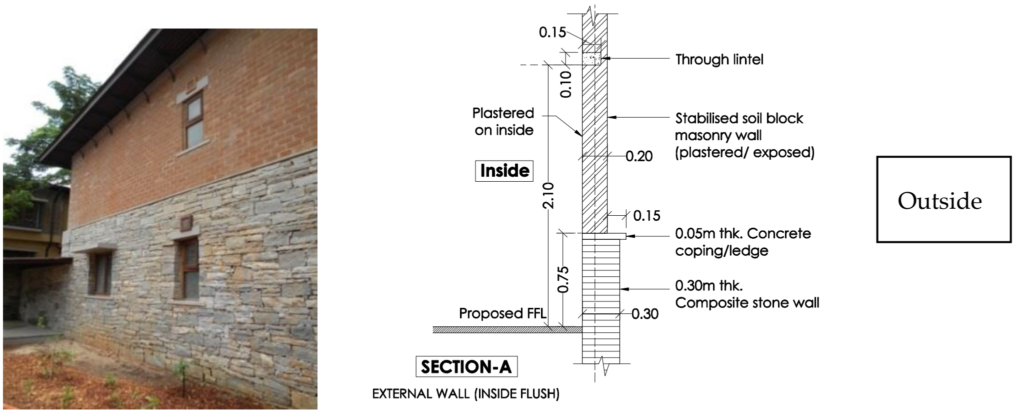


Figure4.8: Compressed Stabilized Earth Block & Random Rubble Masonry Wall

CSEB is more environmentally sustainable in comparison to conventionally used concrete block as it has less embodied energy with 631 MJ/cu.m (source: Auroville Earth Institute) as against 1880 MJ/cu.m for concrete block. (Source: GRIHA Volume 4, Criterion 16- Reduce embodied energy of construction by adopting efficient technologies and/low energy materials)The process of manufacturing for CSEB involves usage of soil from site whereas CMU (Concrete Masonry Unit) comprises of sand & aggregate which make these units higher in embodied energy. The cost of CSEB block is INR16/block (size – 400 mm x 200 mm x 100 mm) whereas concrete block costs around INR 35/block, (400 mm x 200 mm x 100 mm). The comparative table has been depicted below.

Table 4.1: **Comparative analysis for CSEB and CMU**

Parameters- civil	**CSEB**	**CMU**
U value (W/m².K)	2.02	3.062
Specific heat capacity (kJ/Kg.K)	0.85	0.70
Embodied Energy	631 MJ / m³	1880 MJ/m³
density	2000 kg/m³	2349 kg/m³
Recycled content	Yes - site soil - 90%	No recycled content usually but in some cases fly ask is used
cost	Rs. 16/block Rs.3789/cu.m	Rs. 35 /block Rs.4375/cu.m
thermal comfort /reduction of indoor temp as against ambient	Maximum reduction of indoor temp as against ambient is 7 deg C	(Limitation, as monitoring restricted to only green case studies. This could be taken up in Phase 2.)
Green Aspect	Low embodied energy as soil is sources from site and mixed with cement for stabilisation. Thus, Lower carbon footprint	High in embodied energy due to materials like sand, aggregate and cement involved. Higher carbon footprint.
Structural Strength	3 N/mm² at 28 days.	4 N/mm² at 28 days.
Constructability	Requires high skilled labour for manufacturing	Doesn't requires high skilled labour for manufacturing
Availability	preferred types are Sandy soil and clayey soil	Easily available

Hence, we can conclude that, compressed stabilized earth block is affordable and can be replicated in affordable housing.

Shade

Windows are shaded with RCC and Mangalore tile roof overhangs. Verandahs are also shaded with Mangalore tile roof overhangs. Both the features help in reducing solar radiation inside the house.

Window **Verandah**

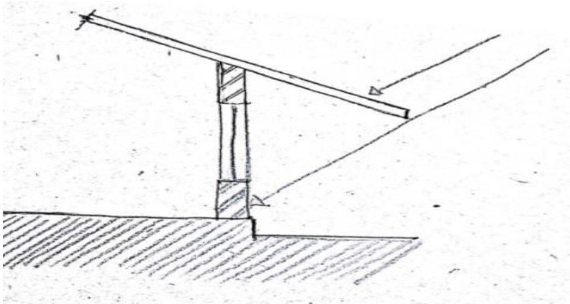


Figure4.9:Cross sectional drawing of window shade & schematic sketch of veranda

Passive/ low energy technologies integrated with building envelope:

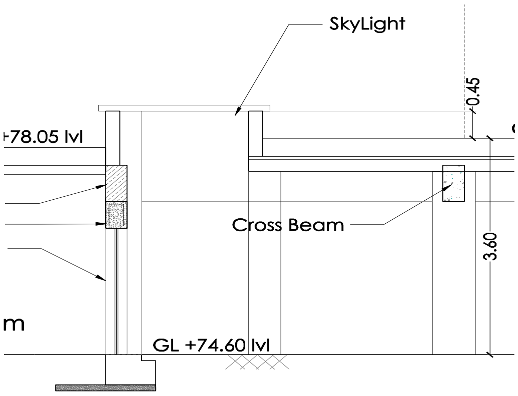
Day lighting

Daylight has been integrated through windows, courtyards and skylights in stairwell. It helps to harvests natural daylight to the interiors and avoids artificial light usage. In conventional practice, day lighting is provided with limitation, thus interiors are more dependent on artificial lighting and consume energy during day time. In terms of affordable analysis, single glazed units have been used in both the cases, costing in the range of Rs.592/sq.m. The glazing areas will be lesser in conventional case, thus cost on materials is lower than case study scenario. However, energy consumption will be higher in conventional case than the case study scenario. Hence we can conclude that, integration of day lighting is affordable and replicable in affordable housing. Photographs and drawings highlighting day lighting have been depicted below.

Roof skylight

window

Daylight through roof in parking



Cross section of roof for underground parking

Figure4.10: Cross sectional drawings of parking area and photographs showing daylight integration in housing units

Natural Ventilation:

Natural ventilation has been integrated through window, courtyards and high wall ventilators. No provision for air conditioning has been provided by the developer. This strategy helps in achieving thermal comfort and reduces dependency on air conditioning and fan. In conventional cases, natural ventilation is integrated in limitation with usage of air conditioning. The operating cost in case study scenario will be significantly lower than the conventional practice, thus proving to be affordable and replicable in affordable housing. Drawings highlighting natural ventilation have been depicted below.

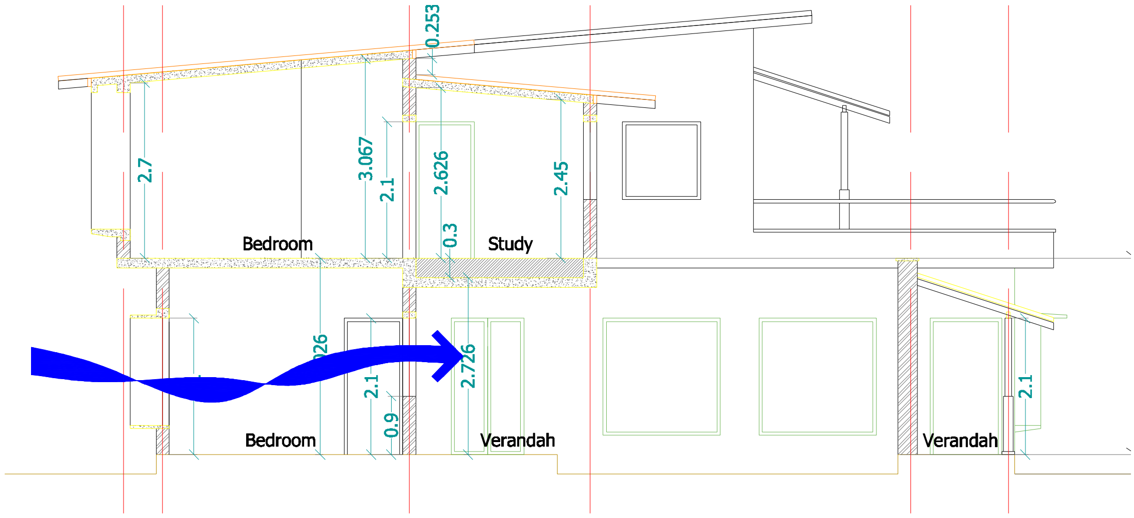


Figure4.11:Cross sectional elevation depicting cross ventilation in one of the units

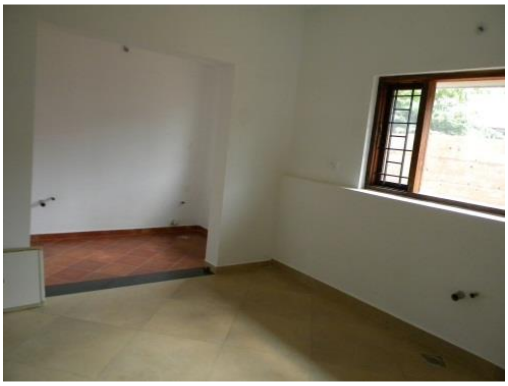
Interior flooring Materials

Floor finishes have been executed using green materials such as clay tiles, *athangudi* tiles, vitrified and ceramic tiles, etc. In conventional practices, terrazzo tiles have been used.

Clay Tiles

Red and Green *Athangudi* tiles

Ceramic Tiles



Vitrified tiles

Figure4.12: Interior photographs showing usage of various flooring materials

Athangudi tiles are handmade whereas vitrified, clay and ceramic tiles uses industrial processes. The embodied energy and prices of the tiles have been compared below in a table.

Table 4.2: Embodied energy and prices of the tiles

Tiles	Athangudi tiles	Clay tiles	Ceramic Tiles	Vitrified tiles	Terrazzo flooring
Price (Rs./sq.m)	538	237	323	592	388
Embodied energy (MJ/kg)	-	6.5	12	12	1.4
Recycled content	Yes	Yes	Yes	Yes	Yes

Embodied energy of *Athangudi* tiles have not been documented but can be comparable to terrazzo tiles as the processes are similar. All the tiles have recycled content. In terms of pricing, clay tiles and ceramic tiles are lesser whereas, *Athangudi* and vitrified tiles are costlier than terrazzo tiles. Therefore, we can conclude that, clay tiles, ceramic tiles and terrazzo flooring can be replicated in affordable housing.

Construction technologies

Vaulted roof with CSEB has been used for underground parking. In this technology, being sustainable, no centring is needed thereby reducing cost and time used in RCC roofing for conventional cases. The cost for CSEB roof works out at Rs.3789/cu.m as against a RCC roof which cost Rs. 5300 – 6000/cu.m. In both the cases RCC beams and columns are used for support. Therefore, it can be concluded that, vaulted roof with CSEB, is affordable and replicable in affordable housing.

A summary of green building materials used in Malhar Footprints have been highlighted below.

Table 4.3: Summary list of green building materials used in the project

Material	Application
Stabilized Earth Blocks	Walls (Exterior & interior)
Rammed earth	Compound Wall (Upper level)
Ashlar Masonry	Lower wall (ext.) for most residents. Some residents have all ground level.
Stabilized Mud Blocks (twice the size of normal bricks)	On all upper level of homes (above sill)(Some above GF)(Exposed bricks)
Finished walls (with stabilized mud blocks, plastered)	Purpose of aesthetics – mud plaster and distemper
Hollow clay blocks	Landscaping, hedging around plant &landscapes.
Cuddapah stone	Landscaping for hard surface integrated with soil
Wood	Recycled teak – sill for windows (interior) - column at balcony - balcony/shading structure - window frames - indoor staircase
Terracotta floor tiles	Indoor outdoor flooring (some houses)
Bangalore stone (Sadaralli)	Landscaping, hard surface, compound wall
Mud Concrete	Paving (soil + cement + aggregate)
Athangudi tiles, Clay tiles, Ceramic tiles	Interior flooring materials
Mud concrete, chappadi, hollow clay block, Cuddapah, Brick, Grass, Mulching	Landscape paving

Building services

Building services has been integrated in the complex to enhance the sustainable quotient. Plumbing and electrical systems have been detailed out as under.

Water demand and source:

Total project water demand of the community is 31.75MLYwith total building water demand @ 27 MLY (excluding drinking water). The required water is procured from ground water @12.7 MLY, Filtered Rainwater @ 5.3 MLY and recycled Water @ 21 MLY (million liters per year) of availability from the respective sources.

Water efficient fixtures

Water efficient low flow rate plumbing and sanitary fixtures has been used such as shower dual flush Water Closet with 3/6 - litres/flush as against 9 litres/flush used in conventional cases. The low flow water closet consumes 75% water less than conventional system. The cost of low flow fixture is approximately 23% costlier than a conventional water closet. However, on studying the water consumption pattern for one year, in a house of 4 members, annual water consumption using efficient fixtures will be 19710 litres as against 78840 litres for conventional water closet. In a scenario, say, water tankers of 6000 litres capacity each, are used to meet flushing water demand. Then 3 tankers would have been supplied for using efficient water closet and 13 tankers for using conventional water closet thus saving 75% on cost for water tankers.

Figure4.13: Water efficient features depicting water closet and faucet

Comparative analysis for cost affordability

Table 4.4: Comparative analysis

Parameters - water management	**Water Closet with 3/6 litre/flush dual flush**	**Conventional Water Closet of 14 litre/flush**
Cost/unit (Rs.)	6500	5000
Cost comparison (%)	23% more	-
Annual Water consumption for 4 member family (litres)	19710	78840
Water demand (%)	75 % less	-
Water saving through tankers supply		
Water tanker capacity for each supply (litres)	6000 litres	
Cost of each tanker (Rs.)	Rs. 750/-	
Total tanker required to meet the water demand	3 no.	13 no.
Total cost of supplying water through tanker (Rs.)	2250/-	9750/-
Cost paid for tanker	75 % less	-
Water required through tanker	75 % less	-

Therefore we can conclude that, even though water efficient fixtures cost 23%higher but it can save 75% on water demand and cost with it and payback can be realised in less than 1 year. Thus, dual flush 3/6 water closet can be affordable and replicable in affordable housing.

Irrigation:

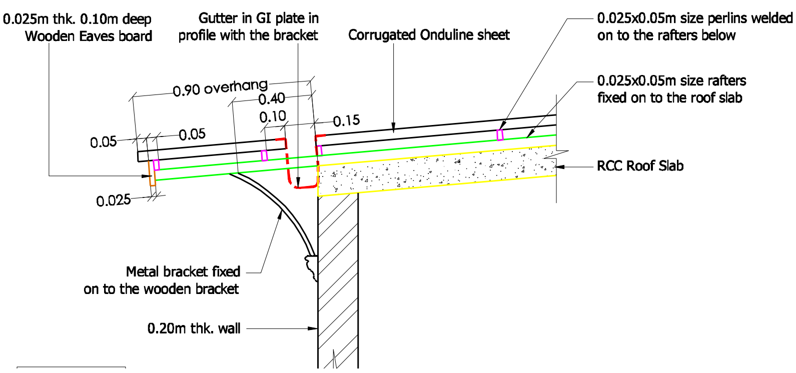
Irrigation system such as micro sprinkler & drip irrigation has been used in the landscape as depicted below in the photograph. In conventional cases, flooding method is used for irrigation. Micro irrigation and drip irrigation are highly efficient (0.85) with 41% less water demand and cost compared to less efficient (0.5) flooding system, preserving water resource. Initial cost of drip irrigation is around Rs.70000/acres where as its negligible for flooding system.

Figure4.14: Drip irrigation and micro spray irrigation in the landscape

However, after computing the water consumption for both the scenarios, initial investment, the payback for drip irrigation can be realised in less than one year. Hence, drip irrigation, is affordable and can be replicable in affordable housing.

Rain water harvesting system

The total roof area of 8000 sq.m harvests 5.9 Million liters of water annually from rainwater out of which 5.3 MLY is useful. Each house has the potential to harvest rainwater and re use. The size of rain water harvesting tank is 175000 liters for the community. Percolation pits along with soft drainage channels (gravel embedded) has been integrated in the ground for efficient recharge of rainwater. Rain water from landscape surfaces is used for recharging through percolation pits. Rain water from roof tops is used for drinking & cooking by storing in the rain water harvesting tank.



Roof water harvesting **Cross sectional drawings of roof**

Figure4.15:Rainwater harvesting integration in the housing units

Figure4.16:Surface rainwater capture & Soft drains with recharge pits on site

Components of rainwater harvesting system and its cost:

Type of rainwater harvesting system: Roof top harvesting with storage tank, site features for percolation to recharge ground water. The rainwater harvesting system comprises of following components:

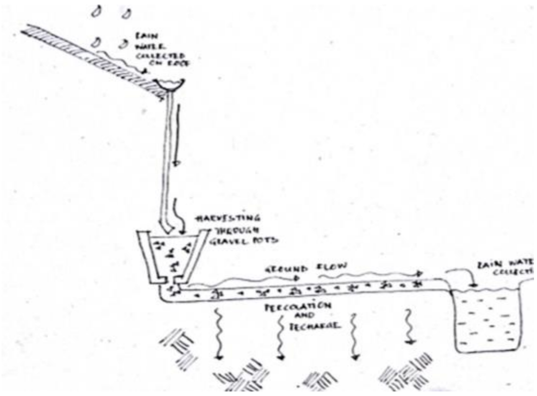


Figure4.17: Schematic sketch of rainwater harvesting network on site

- Catchment surface: the collection surface from which rainfall runs off
- Gutters and down pipes channel water from the roof to the tank
- Screens, first-flush system and filter components which remove debris and dust from the captured rainwater before it goes to the tank
- Storage tanks
- Delivery system: gravity-fed or pumped to the end use
- Treatment/purification: filters and other methods

In Malhar footprints, following components with respective cost are available:

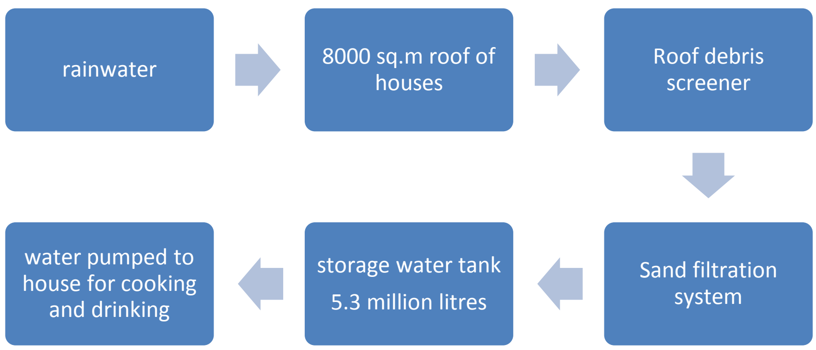
Table 4.5: Components and its costs

Component	Cost
Storage tank for rainwater	Rs.20, 00,000
Roof gutter system	Rs. 9, 00,000
Plumbing system	Rs. 12,00,000
Sand & gravel filtration system for each housing unit	Rs. 5000/- is included in the above cost
Total Cost	Rs.41,00,000/-
Unit level initial investment cost	Rs.42000
Annual maintenance cost	Rs.1000

Roof water, from rain, is channelled through pipes, passed through a series of filters (sand & gravel) and collected in the water tank. This process has been explained above. The maintenance of rain water harvesting system is very minimal where only twice a year, cleaning is required for the sand filter which costs Rs. 500 each time i.e. Rs. 1000/annum.

Following is the flow diagram of rainwater captured in Malhar Footprints:

Roof top rain water harvesting



Ground water percolation

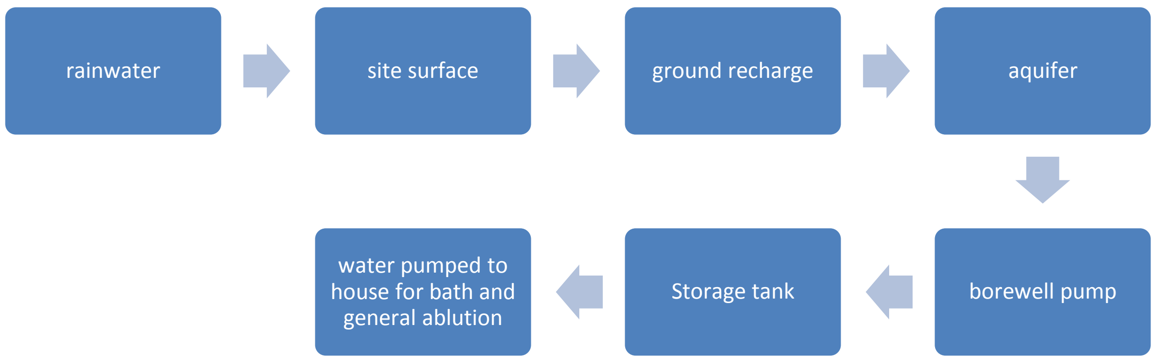


Figure4.18: Flow diagram of rainwater captured in Malhar Footprints

Sewage Treatment plant:

DEWATS (Decentralized Waste Water Treatment System) sewage treatment plant with dual plumbing for recycled water has been designed for the community. It has the capacity to treat waste water of 10,000 liters/day. The treated water is used for flushing and irrigation. The cross sectional details for the DEWATS have been depicted below.

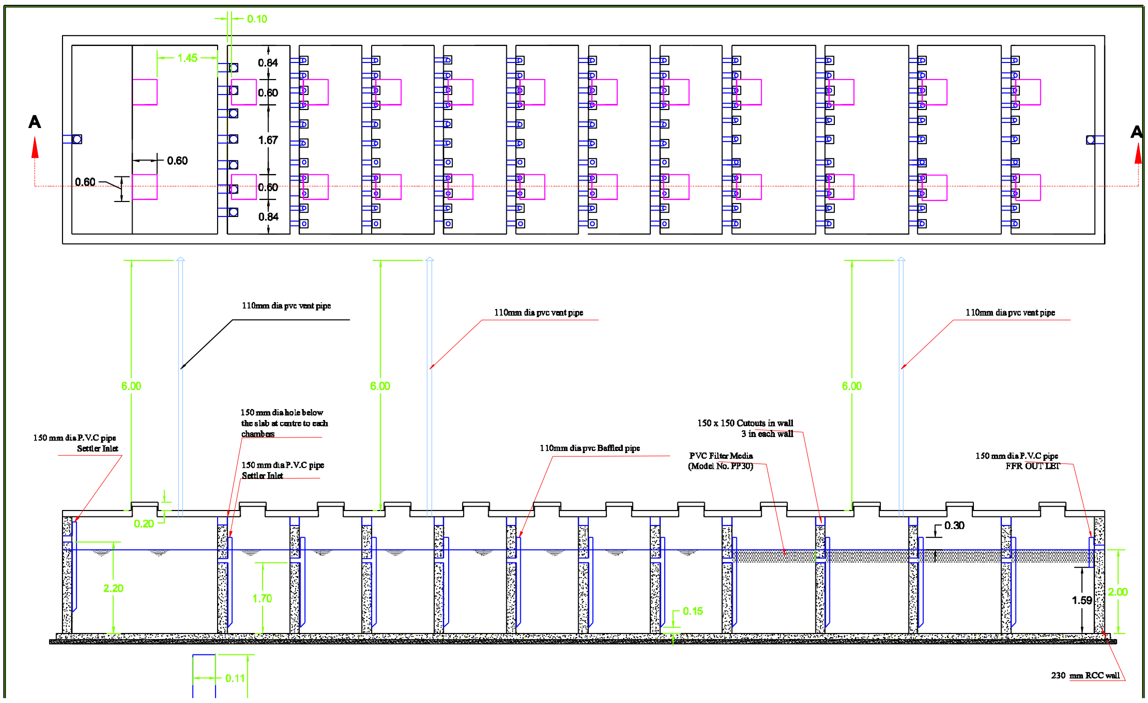


Figure4.19:Cross sectional drawings of Waste water treatment plant – DEWATS

The cost of DEWATS system is Rs.29, 00,000. On unit level, the total cost on a shared basis, will be Rs.30200/unit. The treatment process of DEWATS system has been depicted below:

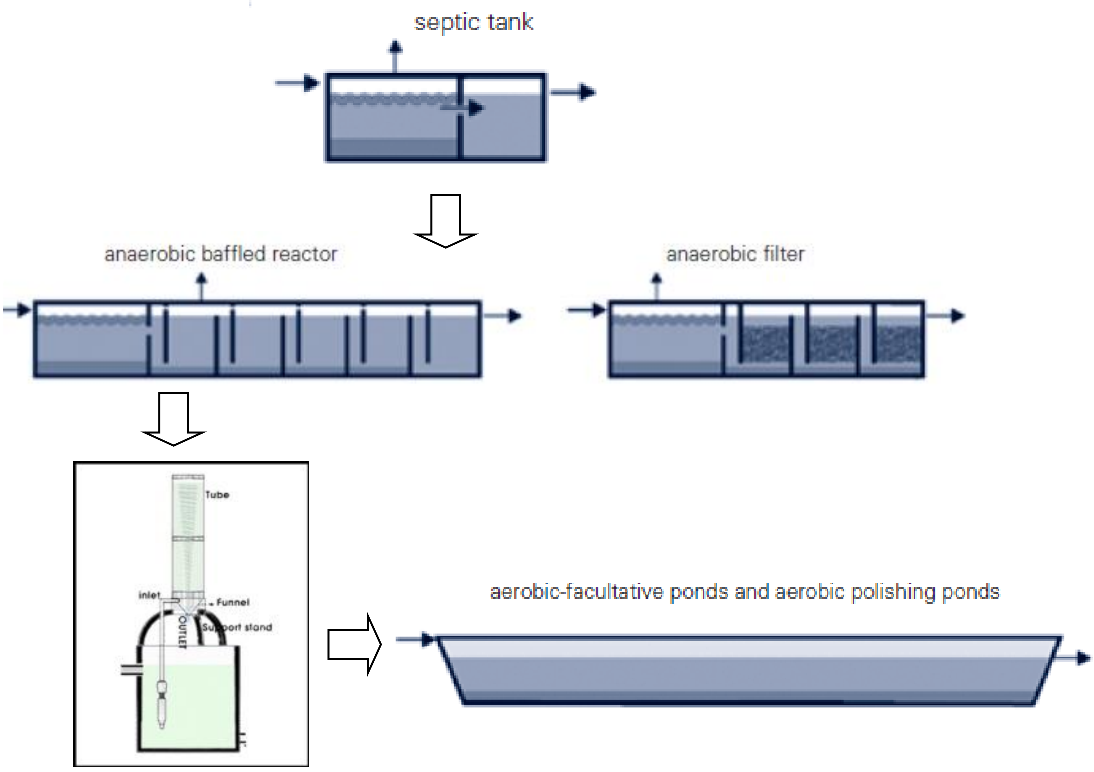


Figure4.20: treatment process of DEWATS system Malhar Footprints

Water balance chart

Water balance for the project has been depicted below.

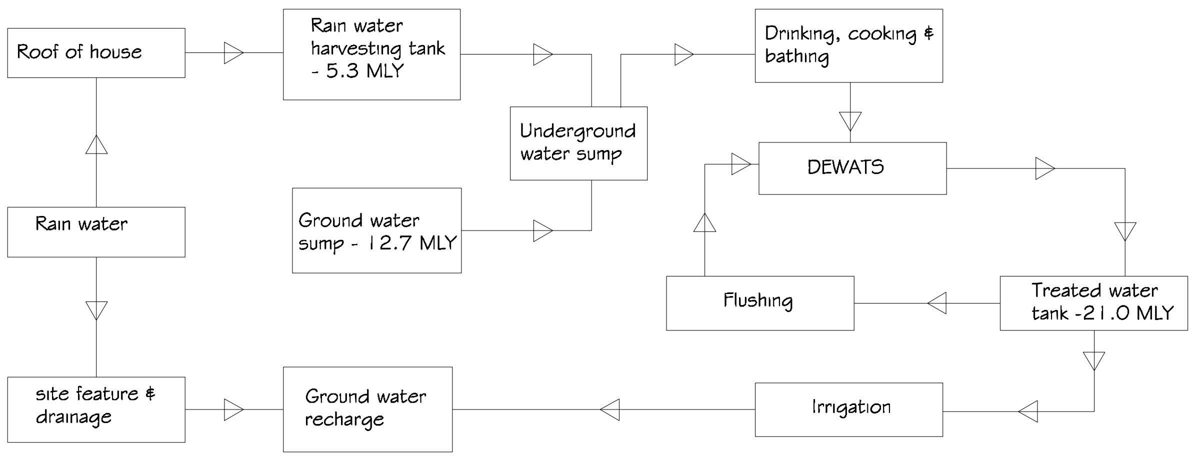


Figure4.21: Water balance chart for Malhar

Sustainable and Affordability Analysis for Water Management at Malhar Footprints:

An analysis was conducted for the sustainability and affordability for the water management system at Malhar Footprints. This has been explained in a tabular format below. A calculation was conducted for water demand and supply from various sources. This calculation takes into account the annual water demand from residents and irrigation, and supply of water from rain, recycled water and ground water.

Table 4.6: Calculation for water demand and supply from various resources

total water demand (litres)	87000	daily	
total water demand (litres)	31755000	yearly	
water from rain (litres)	5300000	yearly	
water from recycled water(litres)	21000000	yearly	
water from ground water (litres)	12700000	yearly	
each water tanker supply (litres)	6000	each tank	
Cost of each tanker (Rupees) in bulk supply	500	Rs/tanker	
Initial investment cost of each component for water supply such as rainwater harvesting, DEWATS system, ground water installation was taken into account.			
Cost of each component			**cost (Rupees)**
Installation cost of Rain water harvesting			**4100000**
Installation cost of DEWATS			**2900000**
Installation cost of ground water installation with break up below			**180000**
bore well drilling cost with casing			40000
Pump and electrical cable			120000
electrical panel and wiring			20000
total cost initial investment- (A) (Rupees)			**7180000**
Maintenance cost of each of the above components, for ten years, were taken into consideration as depicted below:			
maintenance cost for 10 years	**cost (Rupees)**	**Period**	**Cost for Ten Years Rupees)**
cost of Rain water harvesting	1200	per annum	12000
cost of DEWATS	66000	Per annum	6,60,000
electrical Consumption/day of	22000	per month	2640000

ground water installation			
maintenance cost per year	10000	per annum	100000
total maintenance cost (B)			2752000
Grand total A + B			**Rs. 10592000**

Therefore, the total cost of water supply, including initial investment and maintenance cost, will be equal to **Rs. 10592000/- .**

In order to verify, whether the above water management system will be affordable or not, a hypothetical scenario was compared where the project is fully dependent on water supplied through tankers and doesn't used rain water or treated waste water for routine usage. This scenario has been explained below in the table.

Table 4.7: Cost of water supply

Each water tanker capacity	**6000**	**each tank**
Cost of each tanker	500	Rs/tanker
No. of tankers required	5293	per year
Total cost (Rupees)	2646250	per year
Total Cost for 10 years (Rupees)	**Rs. 26462500**	

Therefore, the total cost of water supply, from water tanker for a period of 10 years, will be equal to **Rs. 26462500/- .**

The above analysis demonstrated that, the water management system employed at Malhar Footprints is cheaper than water supplied through water-tankers. The water management system with rainwater harvesting, DEWATS system, ground water installation saves up to 60% as against water supplied through tanker for a period of 10 years.

Renewable Energy Technologies

Renewable energy, as a source, is available at Malhar, in the form of solar hot water. As a sustainable feature, hot water from solar hot water system is available without electricity, thereby saving energy and conserve fossil fuels. The cost of solar hot water system is usually, Rs. 35000 for 200 litres capacity. In conventional cases, electric geysers are used which cost up to Rs. 10,000/-for 25 litres capacity and completely dependent on grid power.

Figure4.22:Solar Hot Water & Solar Photovoltaic panels integrated on roof top

An affordable analysis was conducted, taking into account 200 liters solar hot water system comparing with 3 units of 25L capacity electric geyser for a single residence at Malhar. After analysis it was observed that, payback for solar hot water is possible in less than 1 year.

Hence, it's concluded that, solar hot water system is affordable and replicable in affordable housing.

Electrical

The 7.5 acres campus has a Total Connected Load (kW) of 739 kVA with source of power from grid only. Energy efficient lamps such as 15W CFL, 15W FTL, 6W LED in internal and 150W Metal halide for external lighting have been used. No artificial cooling or air conditioning has been used or provision been made. 8 numbers of 24 HP motors have been used for all utilities. Passive technologies like day lighting (day lighting) and natural ventilation have been integrated to reduce utility/operating cost. A DG of 125 kVA capacities has been installed in the campus. Tariff rate per unit of electricity from grid supply is Rs. 4-6/unit. Details of energy consumption, energy generation from DG are not available as the community is occupied recently with metering being done recently.

Internal lighting:

In Malhar, energy efficient lighting has been designed with lamp types like 15W CFL, 15W FTL, 6W LED for internal lighting has been used. The mentioned lamps are efficient in nature which have longer life, better lumen output and consumes less energy than a normal 60W incandescent bulb. Contents of mercury in CFL and FTL should be taken care while disposal, which is not present in incandescent bulb. A comparison between 15W CFL, 40W FTL, 60 W incandescent bulb and 7W LED has been highlighted below. It's observed that, in an operational span of 5 years, the total investment will be highest and same for both CFL and incandescent lamp with FTL being the least followed by LED. Hence we can conclude that, in terms of environment sustainability and cost factor, LED has the potential to be replicated in affordable housing. The Details are given below in the table.

Table 4.8: Comparative analysis for Compact fluorescent lamp, Tube light and incandescent lamps

Parameters - systems	**lighting - CFL - 15W**	**Tube light - 40W (T8)**	**incandescent bulb 60 W**	**LED 7 W**
total watt	**18**	**48**	**60**	**7**
luminous efficacy	25	30	7	70-90
Operational energy in a year (kWh)	78840	210240	219000	30660
Post usage waste management	contains mercury that is hazardous to environment	contains mercury that is hazardous to environment	not toxic to environment	Not toxic to environment
Green Aspect	lowest in energy consumption		highest in energy consumption	Recyclable, no mercury, reduces night sky illumination ; less maintenance
life of fixture (hours)	10,000	7,000	750	24000
total days of life	833	583	63	2000
Cost(Rs/unit)	200	40	15	350
total investments	438	125	438	320

Parameters - systems	lighting - CFL - 15W	Tube light - 40W (T8)	incandescent bulb 60 W	LED 7 W
in 5 years(Rs.)				
Availability	yes	Yes	Yes	YES

Table 4.9: Comparison of metal halide & mercury vapour lamp sodium vapour and led lamp for external lighting

	Metal Halide	Mercury Vapour	Sodium Vapour	LED
Lamp Wattage (watt)	150	250	150	90
Ballast Wattage (watt)	18	45	22	3
Total Fixture Wattage (watt)	168	295	172	93
Lamp Cost (rupees)	550	275	250	15000
Ballast Cost (rupees)	600	750	600	0
(Lamp + Ballast) Housing Cost (rupees)	1900	1500	1750	0
Lamp Hours	8000	2000	5000	24000
Total Fixture Cost (rupees)	3050	2525	2600	15000
Considering equal lamp life -Total Final Cost (rupees)	3050	10100	4160	15000
Average operation per hour	10	10	10	10
Luminous Efficacy (Lm /watt)	80-110	40-60	80-100	90-120
Annual Operational hour	3650	3650	3650	3650
Annual Units Consumption (kWh)	613.2	1076.75	627.8	339.45
Energy Cost (rupees)	8	8	8	8
Total Annual Energy Cost (rupees)	4906	8614	5022	2716

Summary for outdoor efficient lighting

From the above analysis we can conclude that,

1. Since the capital cost and energy cost of metal halide is much less than Mercury vapours, it is both affordable, energy efficient and replicable in affordable housing project. In simple payback terms, it will be zero years.
2. Since the capital cost and energy cost of metal halide is marginally less than sodium vapour lamp it is both affordable, energy efficient and replicable in affordable housing project. In simple payback terms, it will be 9.5 years.
3. In comparison to Metal Halide, capital expenditure of LED is higher but consumes lesser energy. Uniformity and better vision is the advantage of LED in comparison with metal halide In terms of simple payback; LED will have 2.67 years in comparison to Metal halide.

Solid Waste Management

Solid waste management at Malhar has been systematically achieved through segregation of dry and wet waste. Dry waste is sent to the dump yard for systematic recycling by BBMP (Bangalore Municipality). Wet waste is managed at unit level by using potable composter that converts waste into manure/compost for garden use. The above process reduces environmental pollution arising from waste. The portable composter used, is a product from

Daily Dump, called *Kambha 3 Tiered Small*, costing approximately Rs.990/unit and ideal for a family of two. The additional cost of buying manure and its transportation is also avoided, making it affordable to replicate.

Performance monitoring

The qualitative analysis has been performed by studying instantaneous thermal and visual performance of the project along with occupant's experience. Since the habitat design do not have typical or repetitive layout designs of dwelling units, 3 of the 96 units which are close to most of the remaining layout's design were selected for instantaneous measurements i.e. B2, E12 and C4 units. Whilst, the chosen units have their exposed surfaces to the worst orientations which means, the readings taken can be considered as from typical worst cases. Occupant's experiences have been collected from units H13 and A6 as part of the qualitative analysis.

Measurements were taken between 15:00 to 16:30 Hrs on 22nd of August 2014. Sky condition was partially cloudy with illuminance range varying between 10000 to 18000 lux. DF (Daylight Factor) is calculated based on the outdoor simultaneous illuminance levels. Since there was no wind movement observed during the visit no air velocity was measured. However day lighting and thermal conditions are registered.

Methodology:

Instantaneous indoor day lighting measurements were taken at a height of 700mm with 'Lux meter' at a grid level of approx. 2000 mm X 2000 mm. Instantaneous thermal conditions were measured with 'Anemometer' at various points indoor and immediate outdoor. For Unit B2, a 24 hours reading was taken with 'Thermo hydro meter'. In addition surface temperatures of the main building fabric i.e. roof, walls, floor, were measured with 'Thermal gun'. Following are the images of the instruments used for field studies.

Lux meter 	**Anemometer** 
Thermo hygrometer 	**Thermal gun** 

Figure4.23: Different instruments used in study.

Unit B2

Unit B2 is one of the typical layouts with 2290 Sq.ft built-up area. The duplex type is exposed to its west and east while south and north are shared with common walls of the neighboring units. Therefore openings are on both east and west with a skylight in living space staircase. All the windows are provided with clear glass and shaded with horizontal projections. Skylight material is a polycarbonate sheet, allowing diffused natural light. West orientation is exposed to more open space against to east which is towards the cluster's court space. Flooring is provided with Athangudi tiles in bedrooms and Jaisalmer marble in living and kitchen spaces. Reflective factor of surfaces are considered as: Roof: 0.7, Wall: 0.6, Floor: 0.3.

<u>Instantaneous measurements information:</u>

Floor Plans of B2 Unit:

Figure4.24:Floor plans and photographs of Unit B2

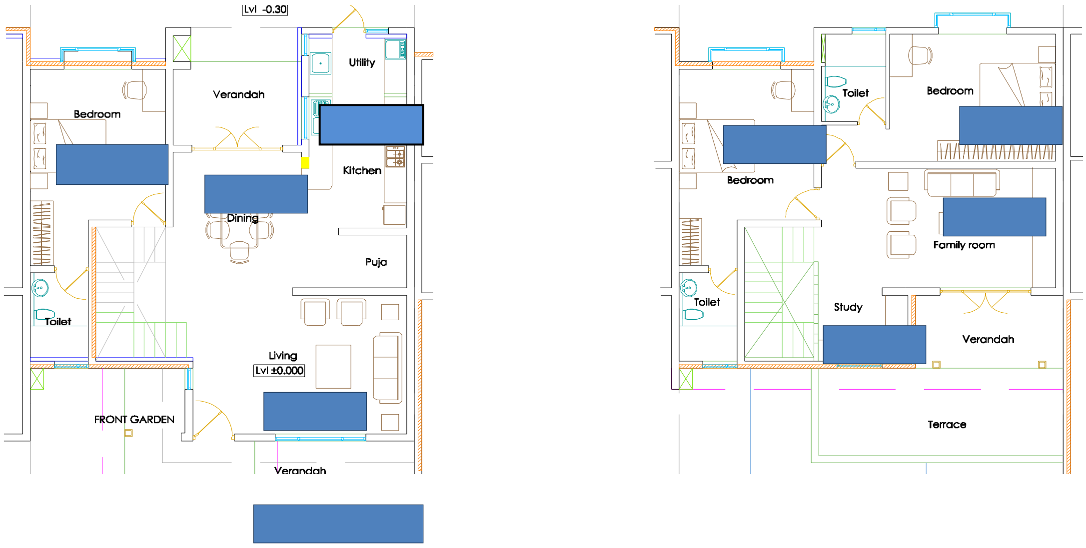


Figure4.25: Monitoring positions for the day light.

Monitoring positions for daylight have been depicted below in the house.

Day lighting

Space type	Average Lux level measured	Daylight Factor (DF) %	Recommended DF by NBC 2005	Compliance remarks for NBC 2005
Living/Dining (GF)	171	1.71	0.625	Yes
Bedroom (GF)	265	2.65	0.625	Yes
Bedroom (FF)	335	3.35	0.625	Yes
Bedroom 2 (FF)	345	3.45	0.625	Yes
Living 2 (FF)	603	6.03	0.625	Yes
Kitchen	200	2	2.5	No

Observation

The daylight quality of the house is acceptable in all living spaces exceeding the average daylight factor recommended by NBC 2005 except kitchen. Quality of the daylight is due to large windows with clear glass and high lintel height. Average window areas are 3.2sq.m varying from 1.1 to 5.2 sq.m. The window sizes vary with largest windows of 2.4m x 2.15m to 1.2m x 0. 9m and window heights vary from 1.2 and 2.15m which contributes to high daylight in the internal spaces. Window to wall ratio for houses are approximately 25%.

Monitoring positions for surface and dry bulb temperature have been depicted below in the house

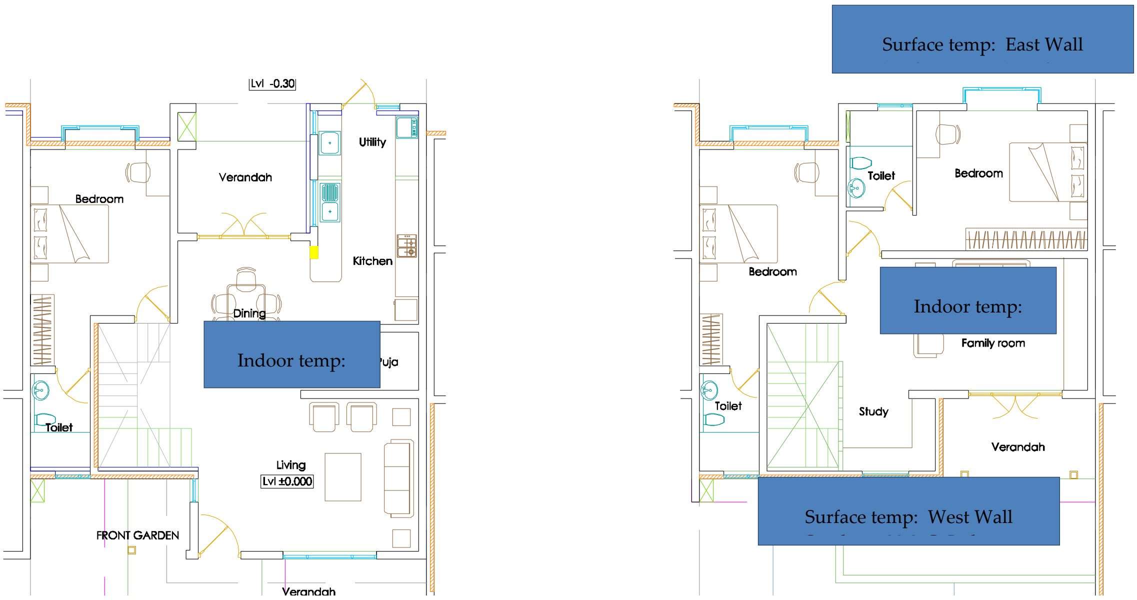


Figure4.26: Monitoring positions for the temperature and relative humidity.

Thermal

Surface temperature

Surface Type	Inner Surface temperature (C)	Outer Surface temperature (C)
Roof	28.6	-
East wall	28.4	30.8
West wall	28.4	30.8
North wall	28.4	Common wall
South wall	28.4	Common wall

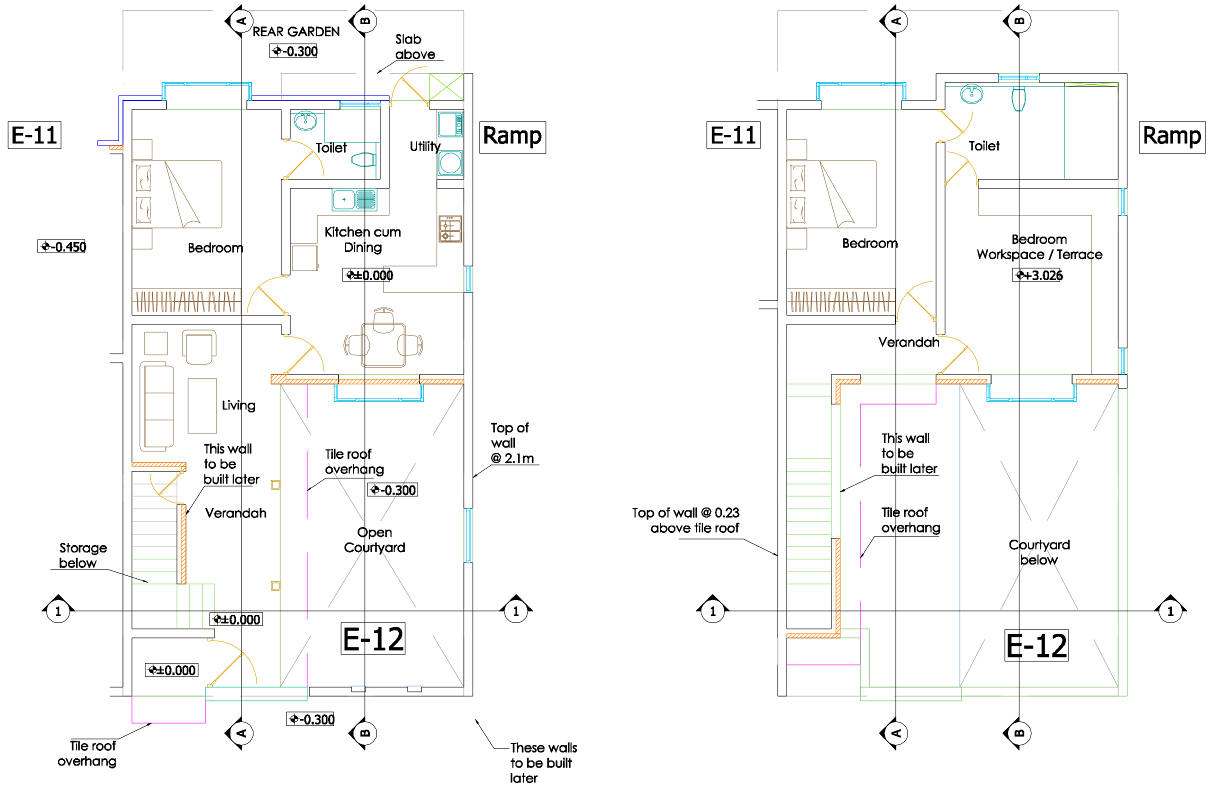
Summary

As per the analysis, the visual comfort inside the house is satisfactory with illuminance levels above the NBC recommended. Kitchen though is slightly less than required; most of the area is filled with enough day lighting that the user may not need to put on any artificial lighting. The thermal comfort is also in the range of NBC (National Building Code). As per NBC the achieved thermal values are still within the comfortable range. However, not much variation was found between indoor and outdoor conditions.

Unit E12

Unit E12 is a 2 bedroom studio type with of 1250 Sq.ft built-up area. The layout consist an open courtyard and open surfaces towards north, south and west while east side shares common wall with neighbouring unit. All the passages and living space are connected to courtyard directly which are semi closed. All the windows are provided with clear glass and shaded with horizontal projections. Flooring is provided with Jaisalmer marble in Living, dining and kitchen areas and Athangudi tiles bedrooms. Reflective factor of surfaces are considered as: Roof: 0.7, Wall: 0.6, Floor: 0.3.

Instantaneous measurements information:



Floor Plans of E12 unit:

Figure4.27: Floor plans and photographs of Unit E12

Day lighting

Space type	Average Lux level measured	Daylight Factor (DF) %	NBC Recommended DF
Dining/kitchen (GF)	493	2.7	2.5
Bedroom (GF)	304	1.7	0.625
Bedroom (FF)	330	1.8	0.625
Bedroom 2 (FF)	274	1.5	0.625

Surface temperature

Surface Type		Inner Surface temperature (C)	Outer Surface temperature (C)
Roof		27.8	
East wall		27.1	Common wall
West wall		27.1	30.8
North wall	27.8	30.8	
South wall	27.8	32	

Both visual and thermal comforts in the residential unit are acceptable as per NBC. Day lighting is available in plenty.

Unit C4

Unit C4 is another typical layout, close to most other layout types. The layout consists of an open courtyard with a total built-up area of 2000 Sq.ft. All the windows are provided with clear glass and shaded with horizontal projections. Flooring is provided with Jaisalmer marble in Living, dining and kitchen areas and vitrified tiles in bedrooms. Reflective factor of surfaces are considered as: Roof: 0.7, Wall: 0.6, Floor: 0.3.

Figure4.28:Floor plans and photographs of Unit C4

Monitoring positions for daylight have been depicted below in the house.

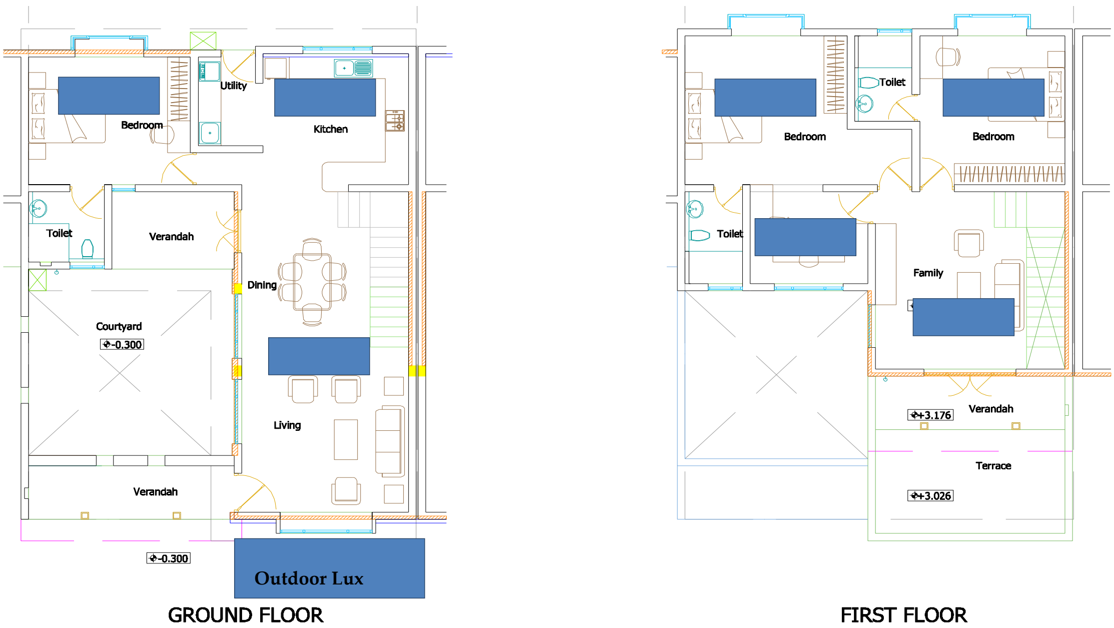


Figure4.29: **Monitoring positions for the day light.**

Observation

The daylight quality of the house is acceptable in all living spaces exceeding the average daylight factor recommended by NBC 2005 except kitchen. Quality of the daylight is due to large windows with clear glass and high lintel height. Average window areas are 2.3 sq.m varying from 0.6 to 4.2 sq.m. The window sizes vary with largest windows of 2.0m x 2.1m to 1.0m x 0. 6m and window heights vary from 1.0 and 2.1 m which contributes to high daylight in the internal spaces. Window to wall ratio for houses are approximately 25%.

Day lighting

Space type	Average Lux level measured	Daylight Factor (DF) %	NBC Recommended DF
Living (GF)	192	2.7	0.625
Kitchen (GF)	148	2.1	2.5
Bedroom (GF)	330	4.7	0.625
Family room	209	2.9	0.625
Study	368	5.2	1.9
Bedroom 1	329	4.7	0.625
Bedroom 2	330	4.7	0.625

Monitoring positions for surface and dry bulb temperature have been depicted below in the house.

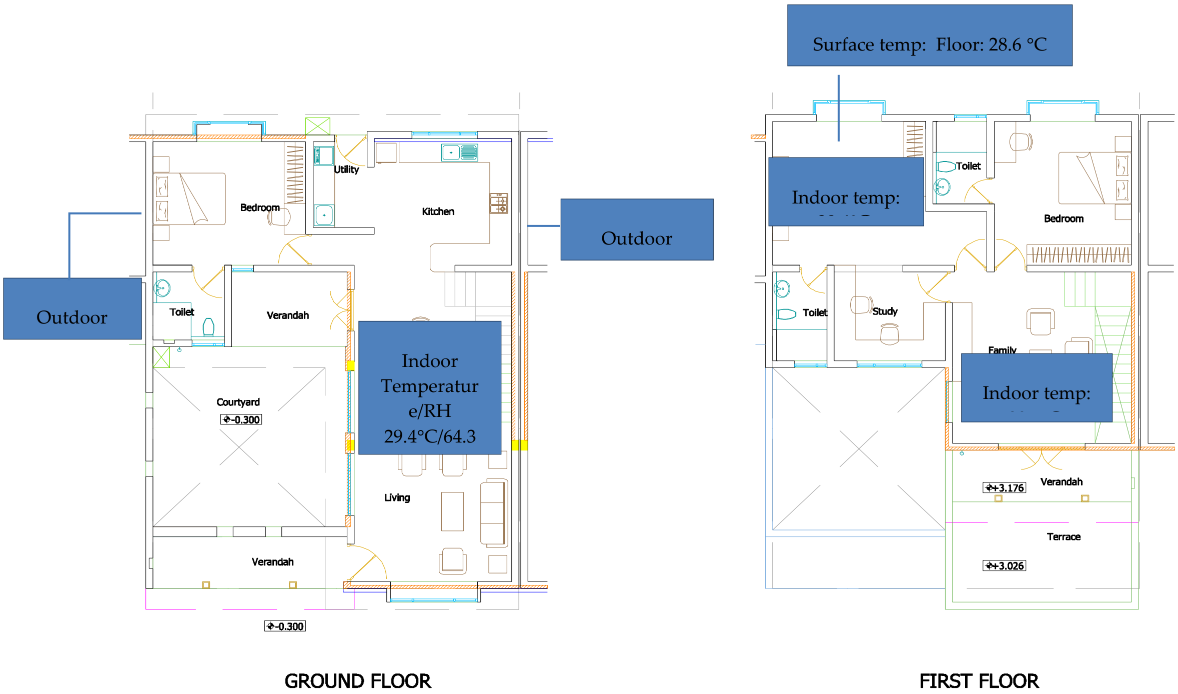


Figure4.30: Monitoring positions for the temperature and relative humidity.

Surface temperature

Surface Type	Inner Surface temperature (C)	Outer Surface temperature (C)
Roof	28.6	
East wall	33	30
West wall	38	42
North wall	27.8	30.8
South wall	27.8	32

Summary

The thermal performance measurements were taken in the **worst exposed room, i.e. bedroom in southwest**. During the measurement it is observed that for certain period of time the west wall is being exposed to sun at low incident angle hence considered to have resulted in higher internal temperatures. Whilst the large openings on west and east sides with clear glass added up heat gains. As per the architect these residence designs are intended to get shaded through landscape features in few months. Day lighting available is observed to be plenty during daytimes.

A data logging was conducted for one of the houses to analyses the internal temperature with respect to the ambient temperature. It was observed that, the room temperature was varying between 27 to 29 deg C as against ambient air temperature of 23 to 36 deg C. The relative humidity varied between 73 – 74% making it thermally comfortable for the occupant.

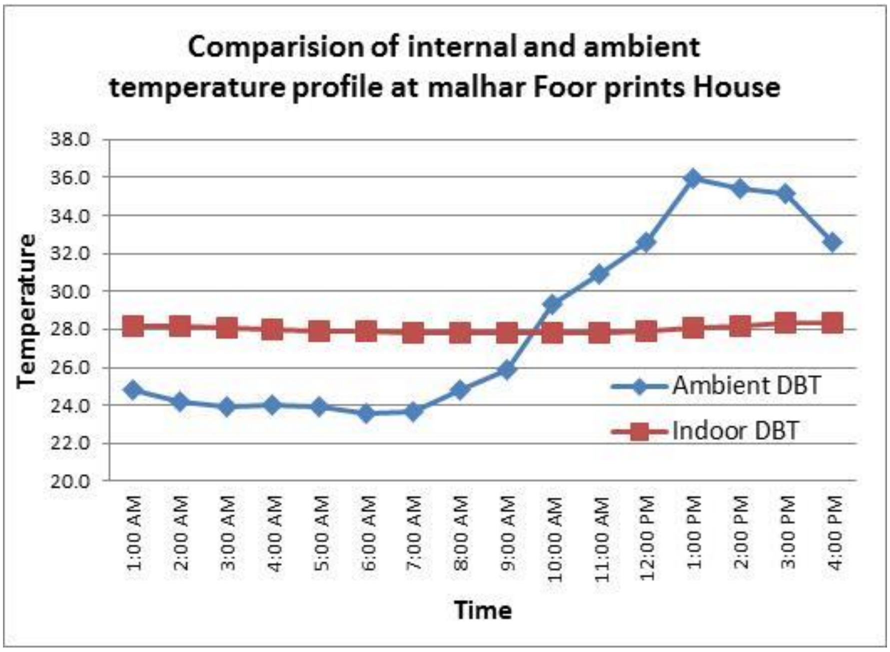


Figure4.31: Comparison of internal and ambient temperature profile at Malhar Footprints

4.1.4 Summary of on-field interviews

Developer: Malhar Footprints has been developed by Good-earth Eco – Developments (P) Ltd. at Kengeri. The developer has been working in the field of sustainable design and building for the past 25 years and envisioned to create sustainable housing solutions which can compete in the mainstream. Footprints, designed as a G+1 cluster homes, is developed with a total cost of Rs.1600/sq.ft (2011) to Rs.2000/sq.ft (2014) without seeking financial support from anybody. In order to develop as an affordable green housing, land cost, location from city, material availability; green features and its cost were taken into consideration. The unit cost of sale price was adjusted in the range of 55-90 lakhs. Operation and maintenance is beneficial in maintaining the characters by overcoming challenges of building services and providing one stop solution for home owners.

Architects: The architect provided all the data pertaining to area statements, construction details for site planning, landscaping, and civil works required for analysis. Architects had the challenge of integrating the green features along with the vernacular character of the cluster housing. Green features like pervious paving, rainwater harvesting, sun shade, and roofing have been aesthetically integrated by overcoming labour and pricing issues.

Contractor: Malhar Footprints was executed through labour contract method where multiple groups were working with 5-10 members in each team. It was a challenge to find skilled labour for executing green features on site.

User group: Two families, both house owners, were interviewed who are working with private organisations. The cost of the house was in the range of 72 to 94 Lakhs, which was affordable, spatially well arranged, thermally and visually comfortable, easy to maintain and socially acceptable. Waste recycling is done at municipality level and wet waste composted at unit level. The cost and affordability for green features with the pricing are acceptable for the users.

4.1.5 Summary from the case study

Table 4.10: Summary of the Green Features along with cost and affordability analysis for Good Earth Malhar Project

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	**Cost**	**Green Rationale**	**Whether Affordable Yes/No (Y/N)**	**Details**	**Cost**	
	Sustainable site planning						
1	Tree protection	None	Controls microclimate and soil erosion if protected	Y	Trees are usually cut.	additional cost for tree cutting and permissions (not available)	Y
2	Soil preservation	Helps in saving cost of bringing top soil from a nursery post construction. Collection , storage and maintenance cost of top soil is Rs. 17/cu.m	Preserves the natural top soil and natural biome.	Y	No soil preservation. Cost of new soil to be bought.	Purchase of top soil cost. Cost for supply, staking and mixing of sludge, manure, sieving is Rs.228/cu.m	Y
3	Preserving Contours & topography	No additional cost helps in saving on additional infrastructure for storm water management. Rs. 110/cu.m. Sizing of storm water management is less as it follows contour and gets less water from run off.	Preserves natural topography site features like drainage pattern and helps in storm water management.	Y	No Protection of Levels. Cut and fill process by contractor needs additional cost	Rs. 110/cu.m for trenching and additional cut and fills excavation. Sizing of storm water management is more as cut and fill cost and gets more water from run off to handle.	Y
4	Service corridor planning	Rs. 180/running meter for trenching. Combining of services reduces the cost on services lines. And its	Protection of pavements and from unnecessary trenching	Y	Service corridor planning from multiple direction & service corridors.	Rs. 180/running meter for trenching. Cost is more than Malhar case as multiple trenching needs	Y

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable Yes/No (Y/N)	Details	Cost	
		maintenance. Hence more economical than conventional.				additional cost	
Landscape paving materials							
5	Mud concrete Roads for pedestrian	Cost of sand is avoided in making roads and site soil is used as a replacement	Avoids sand and uses soil from site. Since this road finish is lighter in color, hence helps in reducing heat island.	Y	Pedestrian paths of PCC	Rs.4480/cu.m for supply and laying PCC.	Y
6	Pervious paving using local stones and grass	Rs. 295/sq.mts.	Controls Heat Island effect and enhances percolation of Storm water & run off control, recharges ground water.	Y	impervious paving	cost is higher than pervious paving due to high quantity of materials. Rs. 350/sq.mts.	Y
7	Mulching	Wood scrap waste generated from carpentry work used for mulching.	Protects soil from erosion and reduces evaporation of water from soil	Y	Grassing of soil is done.	no additional cost	Y
Passive Solar Features							

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable Yes/No (Y/N)	Details	Cost	
17	Compressed Stabilised Earth block masonry Wall	Rs 16/unit	Low embodied energy as soil is sources from site and mixed with cement for stabilisation	y	CMU	Rs 30/block,	Y
19	Plastering of wall -	30/sft (323/sq.m)	None, due to exposed CSEB		Plastering of wall -	30/sft (323/sq.m)	Y
20	Painting	15/sft (162/sq.m)	None, due to exposed CSEB		Painting	15/sft (162/sq.m)	Y
21	Double layered roof (GI +Onduline) over RCC roof	Rs. 50/sq.ft for Onduline sheet (538/sq.m) Rs. 50/sq.ft (538/sq.m) for purlins Rs. 30/sq.ft (323/sq.m) for GI sheet Rs. 5300 – 6000/cu.m for RCC	Ventilates and shade the RCC roof, low heat transmission from sun, supports solar hot water system and has gutter for roof top rain water harvesting	N	RCC Roof slab + Brick bat coba	RCC- Rs. 5300 – 6000/cu.m + 540/sq.m	N
22	Shaded windows &veranda	RCC- Rs. 5300 – 6000/cu.m for laying of shades	Cut down solar radiation to the interior space and minimizes heating	Y	Shading of windows	RCC- Rs. 5300 – 6000/cu.m	Y

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable Yes/No (Y/N)	Details	Cost	
23	Day lighting through windows , veranda , stairwell roof skylights in parking	Rs. 55/sq.ft of glazing(592/sq.m) used in the windows	Harvests natural daylight to the interiors and avoid artificial light usage	Y	Day lighting is provided with limitation	Rs. 55/sq.ft of glazing (592/sq.m) used in the windows. Cost of glazing may be lower as the window areas will comparatively lesser	Y
24	Natural Ventilation through windows and ventilator	No cost involved	Reduces dependence on AC and fan and keeps indoor air quality at healthy levels	Y	Natural ventilation is provided with limitation and equivalent cases have may have AC installed.	No cost involved	Y
Green materials in interior finish							
26	Athangudi tiles	Rs.50/sq.ft (538/sq.m)	Low embodied energy	N	terrazzo flooring	Rs. 388 /sq.m	N
28	Clay tiles	22/sq.ft (237/sq.m)	Low embodied energy	Y	terrazzo flooring	Rs. 388 /sq.m	Y
29	Vitrified tiles	55 /sq.ft (592/sq.m)	Recycled content	N	terrazzo flooring	Rs. 388 /sq.m	N
30	Ceramic tiles	30/sq.ft (323/sq.m)	Low embodied energy and recycling	Y	terrazzo flooring	Rs. 388 /sq.m	Y

Sl no.	Green Feature in Case study			Whether Affordable Yes/No (Y/N)	Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale		Details	Cost	
Water Management							
31	Rainwater harvesting with Roof harvesting and Site features	Tank – Rs.20,00,000 for 175000 litres tank capacity, for 96 families	Water recycling and usage of rainwater in domestic demand and landscape irrigation. Reduces dependency on municipal water for non-potable use.	Y	Rainwater harvesting with Roof harvesting and Site features. This feature is mandatory in Bangalore. Hence also used in conventional cases	Tank – Rs.20,00,000 for 175000 litres tank capacity	Y
		Roof gutter- Rs. 9,00,000, for 96 families				Roof gutter- Rs. 9,00,000	Y
		Plumbing- Rs. 12,00,000, for 96 families				Plumbing- Rs. 12,00,000	Y
32	Waste water treatment plant - **DEWATS**	Rs. 29,00,000.00 for 10,000 litres capacity for 96 families	Waste water recycling and reuse	Y	Directly connected to the municipal drainage		Y
33	Water efficient fixtures	Cost of the fixture is Rs.3500 for low flow faucets and Rs.6500 for dual flush 3/6 lp/flush water closets	High water saving in building water demand due to low flow efficient fixtures, thus conserving the water resource	Y	conventional fixtures	cost of the fixture is Rs.1750 for conventional faucets and Rs.5000 for Single flush 9lp/flush water closets	Y. Payback is less than 1 year for efficient fixtures
34	Irrigation with sprinkler and drip	cost of a sprinkler system depends on no. of sprinkler heads/pendants which costs around Rs.460 each	Low flow irrigation equipment with high efficiency helps in water saving in landscaping, , thus	Y	Pipes are used		Y

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable Yes/No (Y/N)	Details	Cost	
			conserving the water resource				
Renewable Energy Technologies							
38	Solar Hot Water	Rs. 20000/100 litres (Venus solar hot water)	Hot water without electricity is available thereby saving energy	Y	Solar Hot Water systems are available in conventional homes	Rs. 20000/100 litres (Venus solar hot water)	Y
Construction technologies							
40	CSEB Block vault for parking	Rs 16/unit (size to be specifies)+additional cost of RCC beams	No centring is needed thereby reducing cost and time	Y	RCC roof	RCC- Rs. 5300 – 6000/cu.m + 540/sq.m	Y
Energy							
43	15W CFL	200 - 250	Reduces energy consumption	Y	CFL	200 - 250	Y
44	15W FTL	200 - 250		Y	CFL	200 - 250	Y
45	6W LED	400	Reduces energy consumption	Y	CFL	200 - 250	Y
46	150W MH	1900			Mercury Vapour	1500	n

4.2 Field Study of Rohan and Reshmy's House, Bangalore

4.2.1 Introduction

The House of Rohan & Reshmy is located in Mariyanapallya, Bangalore. The residence is a two storey (G+1) load bearing construction. The front view and floor plans of the house are presented in Figure4.32&Figure4.33. Green and affordability concepts implemented in the house are described in detail in the following sections. Table 4.11presents an overview of the project details.

Figure4.32. Front view of Rohan & Reshmy's house

Table 4.11: Overview of the Rohan &Reshmy's house

Details about the project	
Climate (as per NBC)	Moderate
Location	Mariyanapallya ,Bangalore (13°03′ N, 77°36′E)
Site Area	158Sqm
Built-up Area	125 Sqm
F S I	0.8
Type of Project	Individual (3BHK)
No. of Units	1
Density	26 families/Acre if developed as individual plots
Distance from City	~15 KM
Year of Occupancy	2013
Construction Period	10 Months
Architect	Chitra Vishwanath
Contractor	Ranganath
Level of Mechanisation	Low
Skill level of Labour	High

Details about the project	
Total Cost of Construction	Rs. 2300/Sft
Total Life Cycle Cost (50 years)	Rs. 4100/Sft
Total Carbon Foot Print	~22Kgs of CO2 Equivalent/Sqm/Year
Green features/ alternative construction technologies incorporated	Rain water harvesting, Reed system for water treatment, Compressed earth blocks (CEB), masonry, Jack arch roofs, Local materials, Solar water heater, Solar photovoltaic cells, Energy efficient lighting fixtures and water efficient plumbing fixtures

4.2.2 Details of green and affordable features

Alternate Construction Techniques & Materials

The materials and techniques used for construction of the house are majorly alternative and locally sourced thus lowering the overall cost and embodied energy of the house. Details of the house construction are discussed in the following sections.

Wall

The Compressed Earth Stabilized Blocks (CESB) used for the house is manufactured using soil from the same site. The CESB is beneficial due to its uniform building component sizes, usage of local materials and reduction in transportation. Because of uniform surface texture and skilled work, the masonry of the CESB does not require any plastering or painting, thus resulting in material and cost savings.

Figure4.33: Floor plans of the house

Roof

The roofing of the entire house is of **pre-cast jack arched type**. Though the construction of the roof is labour intensive, this technique is highly cost-effective. The adoption of this technique helps the users save out on a lot of construction material (concrete and steel) and in turn money. The profile of the jack arch roof gives lateral or transverse strength to the panels for distributing the load through compressive forces. The strength of a jack arch roof is comparable to the conventional RCC roof due to its structure. Jack arch roof has low embodied energy as compared to the RCC roof because its quantity of cement/ cement per unit volume of the roof. It consists 40% less steel-however; the overall energy content is determined by the embodied energy of the brick tiles used in the roof construction. The roof has better thermal performance because of reduced thermal gains possible with the brick tiles used in it. Details of jack arch roof and an image of ceiling inside the house are provided inFigure4.34.

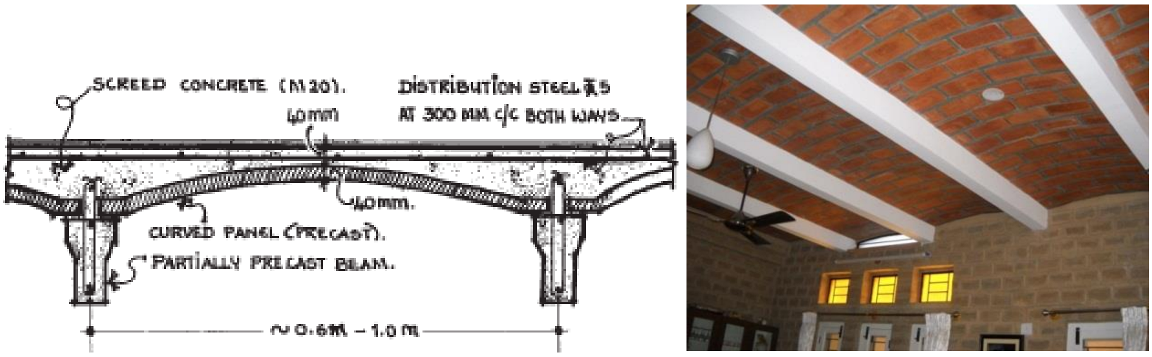


Figure4.34: Details of Jack arch roof construction

Lintel

An interesting technique used in the project is **U-shaped mud blocks to make the lintels**. Instead of providing a continuous lintel, the architects of the house came up with this cost-effective technique which not only saves material but also helps to impart a uniform look to the walls. Hollow mud-blocks were placed where the windows were to be made and were filled with steel and concrete. The technique saves a significant amount of concrete and steel and results in cost effective and less energy intensive. Figure4.35provide images of U-shaped mud blocks and view of a lintel inside the house.

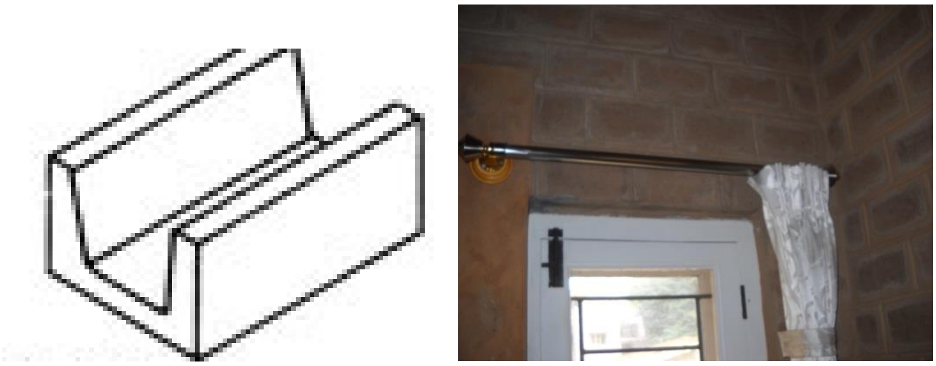


Figure4.35: Hollow Mud-Block used for Lintel construction

Doors & Windows

Doors used in the construction except the main door are flush doors. These doors are less expensive but durable. **Terracotta Jalis** were used near the first floor utility area instead of a steel grill. This results in reduction of the overall costs and embodied energy of the building.

Flooring & Other Materials

In bedrooms of the house, **clay tiles were used for flooring**, which contributes to the overall low embodied energy and costs of the building. Kota stone has been used for kitchen platforms & granite for cupboards. These local materials result in lower embodied energy.

Component wise embodied energy and costs of major items are compared with the conventional construction and the details are tabulated in Table 4.12 & Table 4.13. Figure4.36&Figure4.37illustrates the comparison of cost per unit and the embodied energy per unit of different components of envelope discussed above.

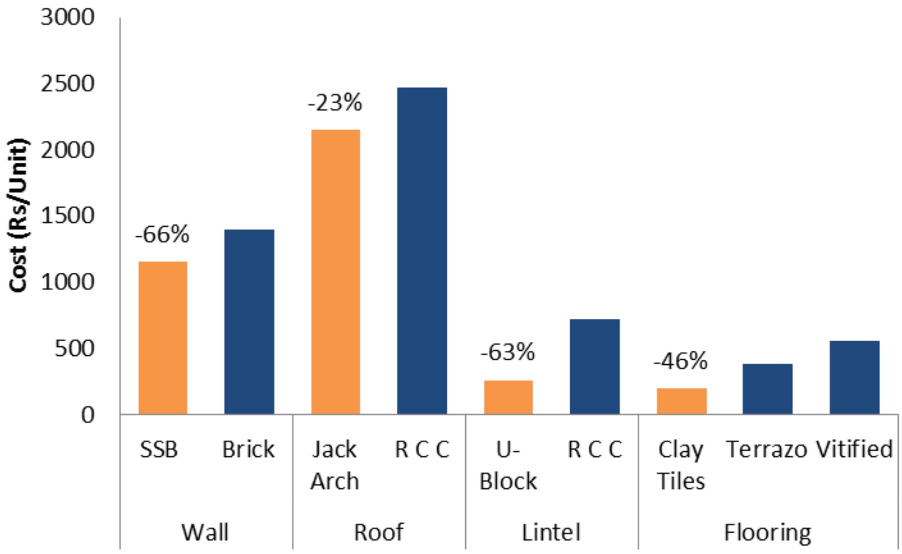


Figure4.36: Cost comparison of alternative low-cost materials with conventional materials

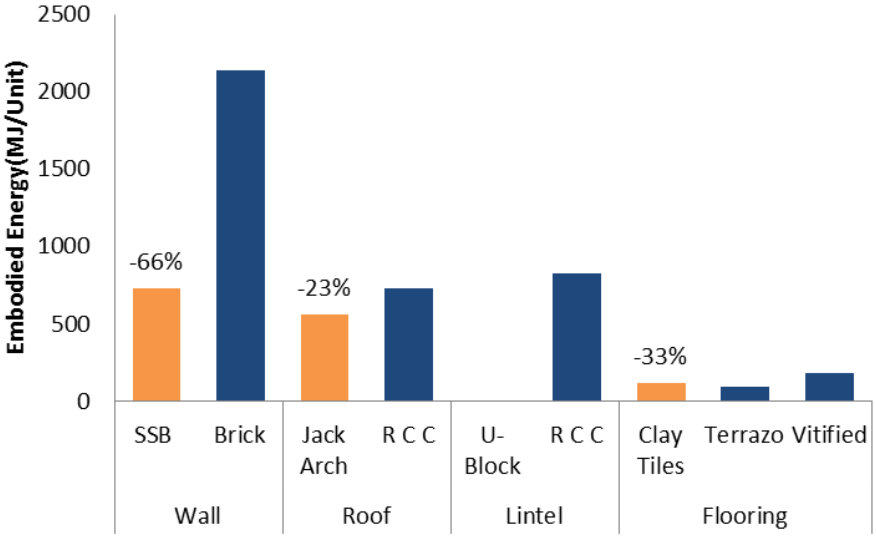


Figure4.37: Energy comparison of alternative low-energy materials with conventional materials

4.2.3 Component wise embodied energy of the building and the possible savings

Table 4.12:Component wise embodied energy of the building and the possible savings when compared to conventional construction

S. No	Building Component	Description of the material	Total Quantity	Unit	Embodied energy (MJ per unit)	Total EE of component (MJ)	Description of the material	Total Quantity	Unit	Embodied energy (MJ per unit)	Total EE of component (MJ)	Reduction in EE (%)
		Rohan & Reshmy's House					**Conventional House**					
1	Foundation	Stone Masonry	53.1	cum	1376	73060	Stone Masonry	53.1	cum	1376	73060	0
2	Plinth	R C C	18.8	sqm	830	15628	R C C	18.8	sqm	830	15628	0
3	Beams	R C C	17.3	sqm	830	14382	R C C	17.3	sqm	830	14382	0
4	Walls	Soil-Cement Block Masonry (7%cement)	64.1	cum	728	46678	Burnt Clay Brick Masonry	64.1	cum	2141	137238	66
5	Roof	RCC flat roof	41.1	sqm	730	30001	R C C Flat Roof	193.6	sqm	730	141318	18
		Jack Arched Roof	152.5	sqm	560	85394						
6	Flooring	Clay Tiles	42.0	sqm	121	5070	Terrazo Flooring	81.8	sqm	92.7	7582	-61
		Vitrified Tiles	39.8	sqm	180	7158						
7	Lintel	R C C filled in U-Blocks	5.7	sqm	830	4698	R C C	18.8	sqm	830	15628	70
8	Window shades-chajja	R C C	14.5	sqm	730	10552	R C C	14.5	sqm	730	10552	0
9	Doors	Teak door	0.1	cum	2250	194	Flush Doors	17.6	sqm	482	8483	9
		Flush Doors	15.6	sqm	482	7519						
10	RCC Staircase		5.6	sqm	830	4641	RCC Staircase	5.6	sqm	830	4641	0
		Total Embodied Energy (MJ)				**304975**	**Total Embodied Energy (MJ)**				**428513**	**29**
		Total Embodied Energy (GJ/ 100Sqm)				**244**	**Total Embodied Energy (GJ/ 100Sqm)**				**342**	

4.2.4 Component wise costs of the building and the possible savings

Table 4.13: Component wise costs of the building and the possible savings when compared to conventional construction

S. No	Building Component	Description	Total Quantity	Unit	Total Cost (in Rs)	Description	Total Quantity	Unit	Total Cost (in Rs)	Estimated savings (%)
		Rohan & Reshmy's House				**Conventional House**				
1	Site Works	Excavation, termite & water proofing and filling	-	-	33,111	Excavation, termite & water proofing and filling	-	-	33,111	0
2	Foundation	Stone Masonry	53.1	cum	1,96,998	Stone Masonry	53.1	cum	1,96,998	0
3	Plinth	R C C	3.8	cum	52,452	R C C	3.8	cum	52,452	0
4	Beams	R C C	4.0	cum	35,614	R C C	4.0	cum	35,614	0
5	Lintel	U-block lintel	80.9	rm	29,275	R C C	80.9	rm	52,452	44
6	Walls	Stabilised mud blocks- 9"thick and 4"thick	320.6	sqm	3,73,768	Burnt Clay Brick- 8" thick and 4" thick	320.6	sqm	4,48,522	17
7	Plastering	Cement, Mud plastering	760.3	sqm	1,62,898	Cement Plastering	760.3	sqm	2,45,588	34
8	Roof	RCC flat Roof	4.1	cum	36,304	RCC	29.0	cum	4,13,075	12
		Jack Arch Roof	152.5	sqm	3,27,627					
9	Flooring	Vitrified & clay tiles	98.5	sqm	99,812	Terrazo Flooring	98.5	sqm	38,226	-161
10	Windows	Glazing & Shutters with grill	18.2	sqm	1,88,084	Glazing & Shutters with grill	18.2	sqm	1,88,084	0
11	Window shade	Chajja & Loft	14.5	sqm	14,004	Chajja & Loft	14.5	sqm	14,004	0
12	Doors	Flush doors	26.3	sqm	1,42,916	Flush Doors	26.3	sqm	1,42,916	0
13	Staircase	Folded Plate RCC Staircase	0.6	cum	7,411	Folded Plate RCC Staircase	0.6	cum	7,411	0
14	Hand rail	Teak Wood	9.2	rm	11,762	Teak Wood	9.2	rm	11,762	0
15	Cupboards	Granite slabs (Part of civil structure)	32.6	sqm	2,69,560	Granite slabs (Part of civil structure)	32.6	sqm	2,69,560	0

S. No	Building Component	Description	Total Quantity	Unit	Total Cost (in Rs)	Description	Total Quantity	Unit	Total Cost (in Rs)	Estimated savings (%)
16	Painting	Only internal	546.2	Sqm	97,106	Both External & Internal	1100.0	sqm	1,94,213	50
17	Additional features	Skylight (civil works)	4.1	sqm	23,487	Nil	-	-	0	0
18	Services (electrical)	Excluding energy efficient fixtures	-	-	3,01,084	Excluding energy efficient fixtures	-	-	3,01,084	0
19	Services (plumbing)	Excluding rainwater components	-	-	1,89,408	Excluding rainwater components	-	-	1,89,408	0
20	Water Efficient Fixtures	Domestic & sanitary	-	-	1,03,630	Conventional	-	-	64,769	-60
21	Rain water harvesting system	RW filter, Sump tank construction (10K L capacity),water level controller, pipes	-	-	94,600	RW filter, Sump tank construction (10K L capacity),water level controller, pipes	-	-	94,600	0
22	Waste water treatment system	Reed Bed System	-	-	81,433	Nil	-	-	0	-
23	Energy efficient lighting fixtures	LEDs & CFLs	-	-	24,610	Conventional (Incandescent & FTL)	-	-	6,153	-300
24	Solar Hot water system	Solar Thermal System (125 Lts)	-	-	38,000	Nil	-	-	0	-
25	Photovoltaic Panels	1.25 kWp Capacity (including inverter, batteries, cabling etc..,)	-	-	2,18,500	Nil	-	-	0	-
		Total Cost (Rs)			**31,53,455**	**Total Cost (Rs)**			**30,00,000**	**-5**
		Total Cost (Rs/Sft)			**2,345**	**Total Cost (Rs/Sft)**			**2,230**	

Energy Management

Passive Design

The architecture of the house construction incorporates a few passive elements. A **skylight** above the stairs lights up the staircase and the common room on the first floor. A good number of **ventilators** in every room keep the spaces well-circulated. Windows and ventilators integrated with the roof ensure naturally lit and thermally comfortable spaces, thus reducing the load on artificial lighting and ventilation. The mud bricks keep the interiors very cool and the ventilators ensure fresh air, thus lowering the need of switching on fans also. Figure4.38provides the images of skylight and roof level ventilators provided inside the house.

Figure4.38: Skylight atrium and the ventilators below the roof

Energy efficiency

Energy check is kept on the house not just through the various energy efficient lighting fixtures used in the house. Majority of the energy is sourced from the alternative sources like **solar PV and solar thermal systems. Only CFLs and LED lights have been used** in the entire house. Although the initial cost of these fixtures is quite high the operational energy consumption is comparable. The house's dependency on the external grid power is only 7kWh/Sqm/annum out of the total consumption of the house 28 kWh/Sqm/annum, whereas the total energy consumption of a conventional house in Bangalore could be 85kWh/Sqm/annum.

Solar Photovoltaic Cells

Solar PV system of capacity 1.25 kWp integrated with power conditioning unit (PCU) has been placed on the roof which meet the energy requirements of the house. The PV cells produce energy and store them in batteries for use. The house meets its requirement from this renewable source till the battery level is above 20%. When it drops below 20%, the house draws electricity from the grid. When and if the grid fails, the house uses 20% reserve of the solar batteries. Currently, 44% of the house's annual energy demand is met by the Solar PV and 28% is met by the grid power.

Solar Water Heater

A **solar water heater with a capacity of 200 litres** is installed on the roof suffices the hot water requirement of the house. Although there is a geyser of 2kW capacity (25 Lts), it is used very seldom in the house.

Figure4.39: Solar PV cells and Solar water heater

Solar hot water feature reduces the load on one of the most energy consuming devices in the house. About 28% of annual energy used for hot water is saved due to this renewable energy feature installed in the house. Thus, a minimal grid power along with the solar power generated from Solar PV and the energy used for hot water through solar thermal systems make the house energy efficient. Figure4.40provides the details of energy balance in the house.

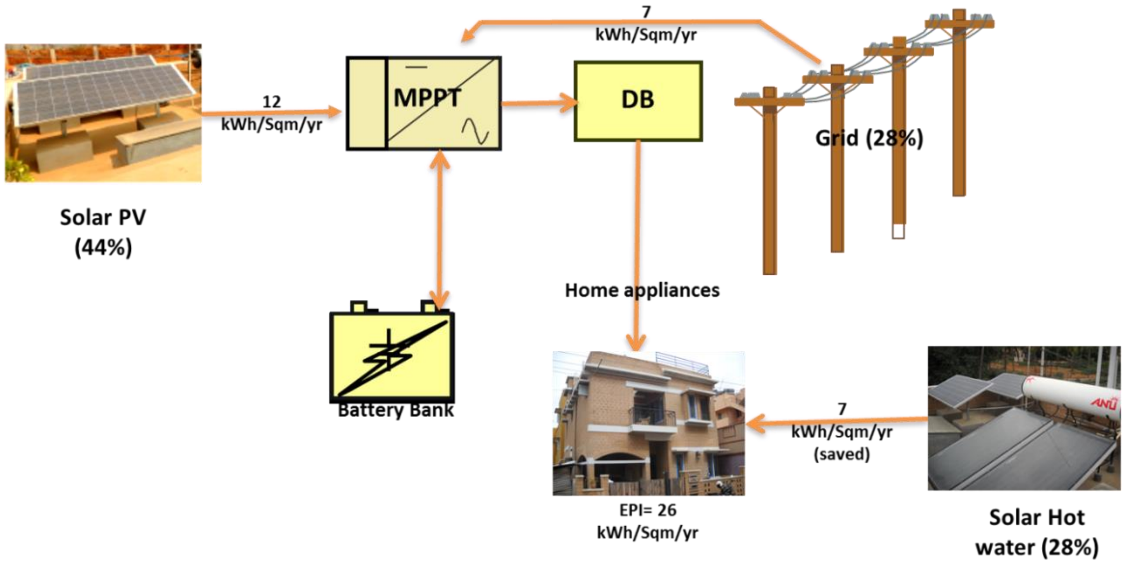


Figure4.40: Energy balance in the Rohan &Reshmy's house

Water Management

Rainwater Harvesting System

Rain water is the primary source of water for the residents of this house. An **8000 litre underground sump tank receives the rain water** that is directed from the roof to it through a charcoal bed for filtration (Figure4.41). **Another 2000 litre tank catches all the run off** from the paved surface around the house which is used for car washing and landscaping. The un-built area of the site was made paved with the sole purpose of catching the rain water.

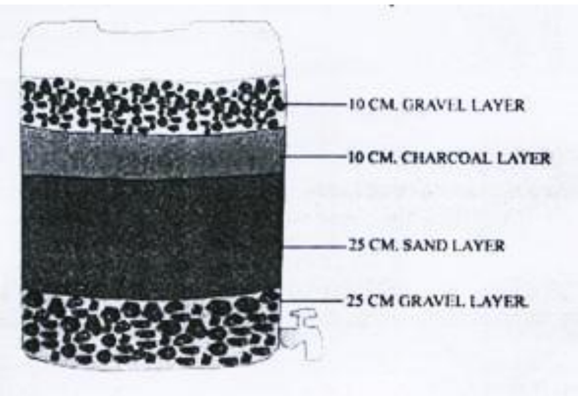


Figure4.41: Details of Rain water filtration system

Water Treatment and Re-use

The house employs a simple and effective water treatment system. The **water from the bath, washing machine and basins go to a reed bed system planted on the terrace**. The system is a 5 chambered set of reed beds which ensure a high degree treatment. The treated water is then used for flushing. Detail of the system is illustrated inFigure4.42.

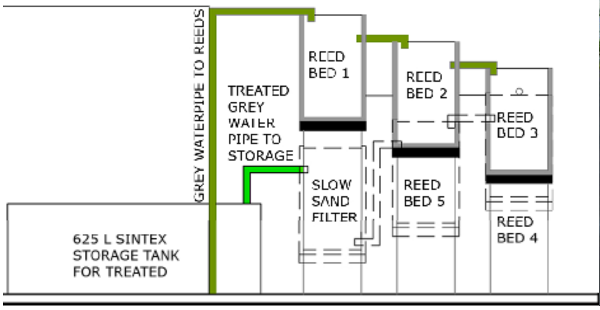


Figure4.42: Details of Rain water filtration system

Efficient Plumbing

The plumbing fixtures installed in the house are **low flow fixtures**. The water demand of house especially for plumbing and sanitary fixtures is almost 40% lower than the conventional. Though the initial investment for these fixtures, rain water harvesting system and the reed bed system is little high, it benefits in terms of operational cost savings with less dependency on the fresh water.

More than 70% of the water used in the house is the filtered rain water which reduces its dependency on the fresh/municipal water. Another sustainable practice is that there is no ground water used in the house to minimise the pressure on natural resources. Details of the water balance in the house are illustrated inFigure4.43.

Total Rain water collected (from roof tops & Paved areas)	:	250 LPD (70%)
Total Fresh water bought from outside	:	100 LPD (30%)
Total Waste Water Treated	:	170 LPD (50%)
Total Consumption of the Building	:	350 LPD

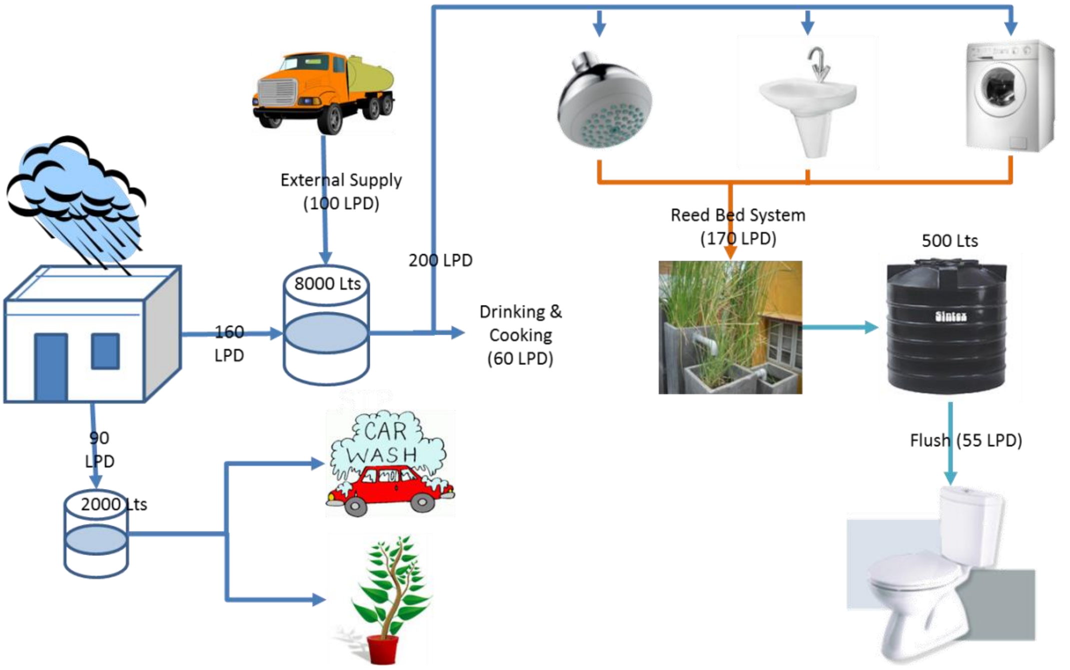


Figure4.43: Water balance in the Rohan &Reshmy's house

Performance Monitoring

Indoor environmental parameters that indicate occupant comfort conditions (both thermal and visual) inside house were monitored during the month of September. Thermo hydro data loggers, Infrared laser gun and a lux meter were used to monitor these parameters for a 24-hr occupied period.

Thermal Comfort

It is apparent that the materials used for construction of the house result in lower heat gains inside the space. Table 4.14&Figure4.44 presents thermal comfort parameters observed inside the house. One of the major parameters that were resulted due to massive wall is lower Mean radiant temperature (MRT). Lower air temperatures and MRT were observed on the ground floor due to shading by the surrounding buildings and the orientation. This parameter is expected to reduce further during winter and might cause much cooler environment inside the spaces.

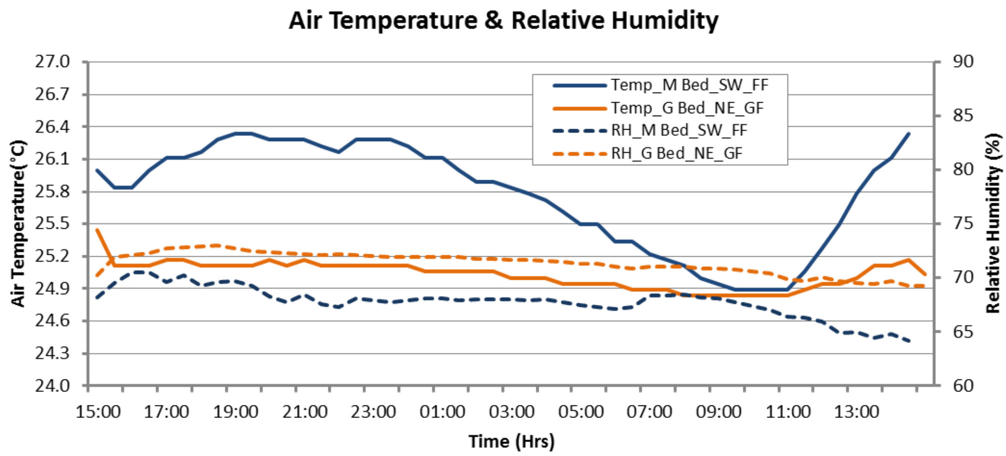


Figure4.44: Indoor thermal comfort conditions observed in Rohan &Reshmy's house

Table 4.14:Indoor thermal comfort parameters observed during the study period

Floor	Space	Avg. Air Temperature(°C)	Ag. Relative Humidity (%)	Mean Radiant Temperature
First Floor	Master Bed	25.8	67.8	25.3
	Family Room	25.4	67.7	-
Ground Floor	Guest Bed	25	71.3	24.6
	Children Bed	25.6	66.3	-

Visual Comfort

Daylight levels (with no artificial lights on) were observed around 3 PM during the study period. The sky condition was partly cloudy. It was interesting to notice that lower daylight levels were present on the ground floor compared to first floor. Higher daylight levels near the stair case and the family room were due to the skylight designed above the staircase. This feature results in minimal usage of artificial lighting during the daytime.

Table 4.15: Average daylight levels observed during the study period

Floor	Space	Avg. Daylight Level (Lux)
Ground Floor	Drawing Room	50
	Dining Room	30
	Kitchen	25
	Stair Case	300
	Guest Bed Room	45
First Floor	Family Room	600
	Master Bed Room	165
	Children's Bed Room	100

Life Cycle Analysis

It was observed in the earlier sections that the initial investment for Rohan & Reshmy's house was about 5% higher to make it energy efficient. The total embodied energy of the Rohan and Reshmy's house was assessed as 244 GJ/100Sqm built up area where as the conventional load bearing construction would be 342 GJ/100 Sqm built up area. The initial cost of construction of Rohan & Reshmy's house was estimated as Rs. 2345/ sft built up area where as the conventional house would be Rs. 2230/ sft built up area.

Greenness and affordability of the case was analysed by calculating Carbon footprint and Operational and Maintenance (O&M) Costs during the building life time. These figures were compared with the conventional building using the data compiledTable 4.16&Figure4.45. The buildings life time was assumed as 50 years.

Carbon Foot Print

To calculate total energy footprint and resultant carbon footprint of the building both initial energy of the structure (embodied energy) and the operational energy (electricity used) during its life time were considered. The operational energy taken from the grid of Rohan and Reshmy's house was significantly low as observed in section 4.2.4.1; this is because of the energy efficient and renewable energy features implemented in the house. Embodied energies of solar PV and solar thermal system for hot water systems used in the house were derived from the earlier studies. Energy that was spent on transporting materials to site, handling the construction equipment and preparation of materials was neglected in the analysis. Operational energy was considered from the actual data available in the electricity bills. Assuming all these energies in terms of electricity (kWh), carbon footprint (Table 4.16) was calculated for Indian conditions. The carbon footprint of Rohan & Reshmy's house was estimated as 22kgs of CO_2 Equivalent /Sqm built up area/year and the conventional house used for comparison would be 98kgs of CO_2 Equivalent /Sqm built up area/year.

Table 4.16:Energy and Carbon footprint of Rohan's house & conventional house

		Rohan & Reshmy's House	**Conventional House**
Total Embodied Energy (kWh)	Civil structure	84715	119031
	Solar PV (1.25 kWp)	10500	0
	Solar Water Heater (200Lts)	4854	0
Total Operational Energy taken from grid in 50 years Life time (kWh))		43750	531250
Total Energy footprint in 50 years life time (kWh)		143819	650281
Total Carbon footprint in 50 years life time (Tons of CO2 Equivalent)		136	614

Cost Analysis

Similar to energy calculations, both the initial construction cost and operational costs in terms of repairs and electricity & water consumed by the building during the entire life cycle of 50 years assumed. The initial costs of both the Rohan & Reshmy's house and Conventional house were comparable where the costs of previous one was slightly higher due to additional energy efficient and water efficient features implemented in the house. The operational energy and water costs were taken from the actual data taken from the electricity and water bills. Energy and water consumption of Rohan & Reshmy's house and its dependency on the grid and external supply was significantly low as discussed in sections 4.2.4.1 and 4.2.4.2 The Operational & Maintenance costs for repairs were estimated based on the construction costs using factors available in the literature. Cost of electricity was assumed as Rs 5.3/kWh and for water as Rs. 100 per 1000lts. The escalation rate for all the three costs (O&M, Energy & Water) was assumed to be 2% (fixed) every year. This analysis doesn't include the appreciation / depreciation costs and taxes on the built up property. Table 4.17presents the costs of studied case and the conventional case based on these assumptions. The analysis also presents that the payback for Rohan & Reshmy's house and it can be noticed that the higher initial cost spent on the building pays back in 2.5 years.

From both the cost and energy foot print analyses it was observed that the studied case (Rohan & Reshmy's house) has about 78% lower carbon foot print and about 50% affordable compared to conventional case. The carbon footprint of Rohan &Reshmy's house was observed as 1.1 Tons of CO_2/ Sqm built up area where as for the conventional house it was 4.9 Tons of CO_2/ Sqm built up area. The initial and O&M costs of Rohan & Reshmy's house in its entire life cycle was observed as 4102 Rs/Sft of built up area where as for a conventional house it was 8300 Rs/sft. Figure4.45presents the incremental energy and costs plotted for 50 years of life time.

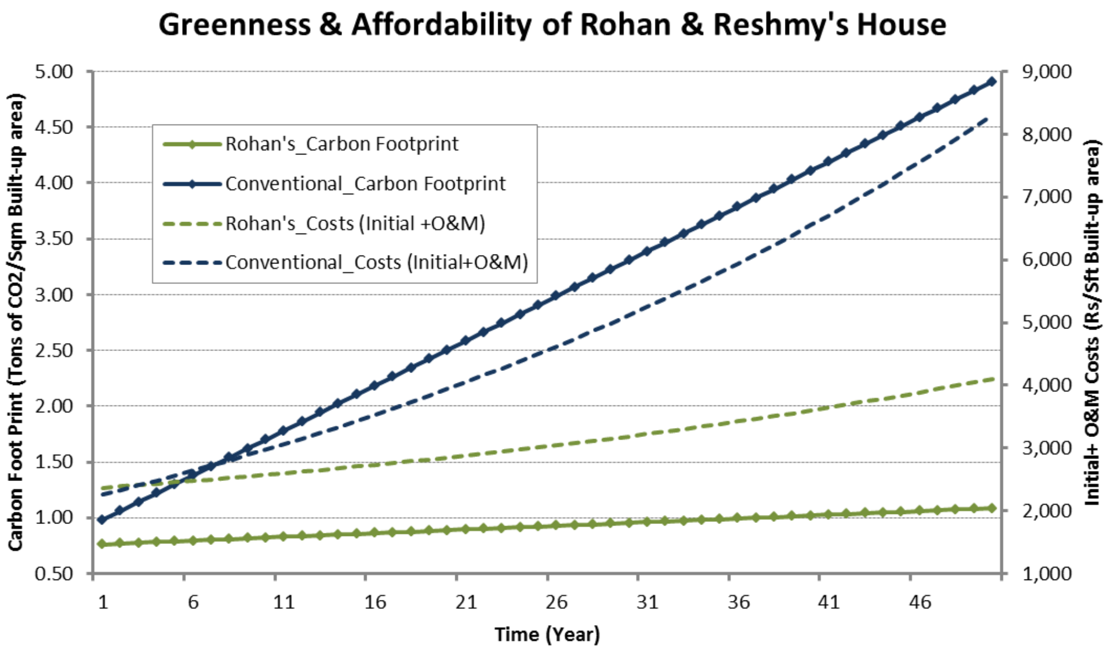


Figure4.45: Greenness and Affordability of Rohan & Reshmy's house in comparison with conventional case

Table 4.17: Initial & O&M costs of Rohan's house & conventional house

		Rohan & Reshmy's House	**Conventional House**
Total Initial Costs (Rs)	Building	25,92,682	28,34,479
	Energy Efficient Features (like SPV, Eff. Lighting & SWH)	2,79,663	6,153
	Water Efficient Features (Like STP, eff. Fixtures)	2,81,110	94,600
Total Operational & Maintenance Costs Including purchase of Electricity & Water for 50 years (Rs)		23,63,539	82,27,977

	Rohan & Reshmy's House	Conventional House
Total Life cycle Costs for 50 years (Rs)	55,16,994	1,11,63,208
Total cycle Costs for 50 years (Rs/Sft)	4,102	8,300

Table 4.18 presents the summary of major building components that may be replicable along with their costs. Table 4.19 presents various green features summarised from literature, case studies and best practices in the warm- humid climatic region.

Summary of Field Interviews

Feedback from the occupants, contractors and architects was collected and documented, along with a few observations that were made on site during the field visit.

It was observed that the owners of the house have gone for this kind of construction due to their concern for environment. The house is well connected to all the basic amenities. It was noted that because of the light coloured surfaces which were purposely made in the kitchen more daylight is present. There were a few stains and odour in the WCs until the weeds are fully grown in the reed bed system.

Thermally it becomes very cool in summers but little uncomfortable in winters because of the massive CSEB masonry, during when they occupy the bedrooms on the upper floor where more solar access is available. Ceiling fans are used majorly in summers. Ventilation of the house is good because of the ventilators provided at the appropriate locations inside the house. Overall the occupants are highly satisfied with all the green features that are part of the project.

The contractor of the project is a skilled and trained particularly to handle this type of projects. Due to high quality of construction there was no maintenance or repair during first year of the occupancy except a minor service works. **About 30-35% of the cost of construction was spent for labour due to their high skill level**. The fees of architect for developing such designs are in general high, however overall cost of construction including labour and consultancy fees is comparable to the conventional construction. In this case, the user was charged about 7% to the cost of construction where in a conventional case it would be 2-5%.

4.2.5 Summary from the case study

Table 4.18: Summary of replicable green & affordable features from the case study

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	**Cost**	**Green Rationale**	**Whether Affordable Yes/No**	**Details**	**Cost**	
1	9" thick Cement Soil Stabilised Brick Masonry	Rs. 1160/- per Sqm Wall Area	Low embodied energy as soil is sources from site and mixed with cement for stabilisation	Y	Burnt clay brick masonry	Rs 1400/- per Sqm Wall area,	Y
2	Jack Arched Roof	Rs. 2150/- per Sqm Roof Area	Low Embodied Energy due to less amount of steel and concrete used	Y	R. C C Roof	Rs. 2470/- per Sqm Roof area	Y
3	Vitrified Flooring	Rs. 560/- per Sqm Floor area	High Embodied Energy, no recycled content	N	Terrazo Flooring	Rs. 388/- per Sqm Floor Area	N
4	Clay Tiles	Rs. 898/- per Sqm Floor area	Higher Embodied Energy, no recycled content	N	Terrazo Flooring	Rs. 388/- per Sqm Floor Area	N
5	U- Block Lintels	Rs. 363/-per running meter	Low Embodied Energy due to less amount of steel and concrete used	Y	R C C Lintel	Rs. 720/- per running meter	Y
6	Rain Water Harvesting System	Rs. 94,600/-	Results in less dependency on the conventional water sources	Y	-	-	Y
7	Reed Bed system	Rs. 81,430/-	Results in less dependency on the conventional water sources	Y	-		Y

Sl no.	Green Feature in Case study			Whether Affordable Yes/No	Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale		Details	Cost	
8	Water Efficient Fixtures	Cost of the fixture is Rs.3500/- for low flow faucets and Rs.6500 for dual flush 3/6 lp/flush water closets	Results in less dependency on the conventional water sources	Y	Cost of the fixture is Rs.1750 for conventional faucets and Rs.5000 for Single flush 9 lp/flush water closets		Y
9	LEDs	Rs. 400/- per Fixture	Results in less dependency on the conventional energy sources	N	CFLs Rs. 200-250/- per fixture		Y
10	Solar thermal hot water system	Rs. 38,000/-	Results in less dependency on the conventional energy sources	Y	-		Y
11	Solar PV	Rs. 2,80,000/-	Results in less dependency on the conventional energy sources	N	-		Y

Conclusion and summary for Moderate Climate Zone

Affordability of green features in housing, for Moderate climate, have been analysed from various sources like case studies, literature studies and best practices in the local context. Study and analysis were conducted for Rohan and Reshmy's house at individual house level and Malhar Footprints at Habitat level, both located in Bangalore. Literature study analyses were conducted for ZED Earth Villa, T- ZED Homes, ZED-Woods, PRANA, ZED-Collectives which were all located in Bangalore. Information was collected from various local professionals including Architects and contractors for the best regional practices that can be classified as green features in affordable housing. Following table summarizes the green features which are affordable in moderate climate to be replicated at housing level.

4.3 Field study of waste management practiced at T ZED homes, Whitefield, Bangalore

T ZED Homes is being occupied since 2007. Solid waste management started from 2008.

Solid Waste management system at T ZED home is managed by the Residential Association, which constitutes of both tenants and owners, occupying 85 homes in the campus. It has a green building committee which takes care of the overall green life style of the campus. Every resident is briefed about the waste management system when they newly occupy and routinely for maximising the success of the plan. The waste generated on site are being collected by waste management team and handed over to third party organisations, depending upon the category of waste. The various organisations working with the resident association are Eco Maridi, Samarthanam Parisara, BBMP and software firms.

Type of waste generated at the T ZED campus is as follows:

a) Garden Waste, b) Kitchen waste, c) Paper and card boards, d) Plastic, metal & tetrapak, e) Unbroken glass bottles, f) Newspaper, g) Hygiene waste, h) Construction waste, i) E- waste, General wastes

These wastes are collected in different collection bins as shown in the Figure 4.46

Figure 4.46: Various Collection Bags/ containers used for handling different wastes

Following paragraph elaborates the process of waste management of the type of waste highlighted above

4.3.1 Garden Waste

The garden waste is collected every day, which constitutes green, dry leaves, coconut scraps etc..,. The green and dry leaves are shredded & ground and used for making compost in the back yard. In the composting process, cow-dung is mixed monthly once and microbes (from daily dump) are mixed every 15 days with the ground leaves. Composting (Figure 2) is completed in 1.5 months and used as manure in the kitchen gardens (Figure 3). Excess manure is sold to outsiders at Rs.10/kg. Vegetables from the kitchen garden are sold to residents at a nominal cost. The money collected through selling of manure and vegetables is used for maintenance. Coconut scrap is reused in the garden as mulch and substrate layer in private gardens.

(a)


(b)

Figure 4.47: (a) Stage wise process for composting ; (b). Bins Provided for Leaf composter


(a)


(b)

Figure 4.48: (a) Organic Kitchen Gardens maintained in the project ; (b). Coconut waste used as mulching and substrate

4.3.2 Kitchen waste

Kitchen waste is collected daily from the residents. It is collected in a stainless steel container with a lid, without any plastic or paper lining. The kitchen waste is fed to bio digesters (Figure 4.49) designed by Malhem Co. The bio digester releases bio gas for small cooking by facility management. The compost is used for gardening.

Figure 4.49: Bio digester plant

4.3.3 Paper, card boards, plastic , metal, tetrapak, newspaper, Unbroken Glass bottles

Paper, card boards, plastic, metal, tetrapak (Figure 4.50) are collected every Tuesday and Saturday whereas newspaper is collected every Tuesday and unbroken glass bottles on Mondays. Paper and cardboard is collected in white gunny bag whereas plastic, metal and tetrapak are collected in light blue gunny bag and newspaper in brown gunny bags. The collected paper, card boards, plastic, metal, tetrapak, newspaper is handed over to an NGO named Samarthanam Parisara. The NGO recycles the collected waste by selling to different organisation such as paper, card board and newspaper is given to ITC, tetrapak is sent to Mumbai and plastic carry/packing bags are given to KK Plastics for road building. Unbroken glass bottles are also collected by the same NGO. Every week 250 kg of waste, constituting card boards, plastic, metals and tetrapaks are generated from 85 homes.

Figure 4.50: Paper & Plastic collected from a household

4.3.4 Hygiene waste

Hygiene waste consists of bio medical wastes arising out of daily usage and they are collected on Monday, Wednesday and Friday. They are collected in three different ways – yellow bags for dressing and similar typology, blue bags for used plastic materials and puncture proof cans for needles and sharp objects. The above mentioned bio medical wastes are collected by Eco Maridi, a waste management firm for hygiene wastes.

4.3.5 Construction waste

Construction wastes are like PVC pipes are generated from daily maintenance works. The papers are collected to be handed over to Samarthanam and plastic pipes are reused for fencing

4.3.6 E wastes

E waste consisting of batteries, laptops, UPS and similar electrical and electronic items are collected and taken by the residents to their respective offices where recycling of E waste are done. This system is on temporary basis and an onsite system is under formulation to be implemented soon.

4.3.7 General waste

There are categories of waste, which can't be categories above, like coconut shells, large or hard bones, high cellulose items, etc are being collected by BBMP on 3 days a week.

4.4 Limitation and challenges

There are limitation and challenges being faced by the resident associate in the waste management process which is highlighted below

1. There are some categories of waste which are categorised as general waste which cannot be recycled. Therefore, it is handed over to BBMP for landfill. A work plan is being formulated to reduce the general waste.
2. Newspapers are not handed over to Samarthanam all the time. Sometimes the maid servants usually collect them to sell it in the local markets for monetary benefits.
3. There are scenarios when bio digester stops working. In such cases, the kitchen waste is mixed with the dry & wet leaves for composting.

4.5 Summary sheet for Waste management system:

Type of waste	Garden waste & construction waste	Kitchen Waste	Paper, Card board, Plastic Metal	News paper	Hygiene waste	Unbroken glass bottle	General waste
Primary collector	T ZED	T ZED	Samarthanam	Samarthanam	ECO Maridi	Samarthanam	BBMP
Recycler	T ZED	T ZED	ITC & KK Plastics	ITC	Eco Maridi	-	-
Collection days	All days	All days	Twice in a week	Once in a week	Thrice a week	Once in a week	Thrice a week

4.6 Summary of Green Features for Moderate Climate Zone

Table 4.19:Summary of Green Features for Moderate Climate Zone

Green features	Literature studies & traditional practices	Case studies	Best regional practices
Siting and climate responsiveness			
Orientation	Longer walls orienting towards North and south side		
Zoning	Shading Verandas and living spaces on critical orientations, courtyards		
Energy, renewable energy & building materials			
Roof treatment, roof garden	Green roof using organic materials, filler slab, terracotta tiles	Shaded roof, double roofs.	Hollow clay blocks, Insulated roofs, RCC with reflective tiles.
Shaded windows	Shaded windows		
Walls to respond to outside climate	Stone, fly ash block, Thermal insulation in walls and flooring	Compressed stabilised earth block (CSEB)	AAC blocks, Hollow concrete blocks, Hollow clay blocks, Stone masonry
Local materials to reduce embodied energy	Laterite blocks, Rubber wood, Palm wood, compressed coir door panels and bamboo composites, Cob walls, red oxide flooring	Flooring materials like terrazzo, ceramic tiles, Attangudi, clay tiles	Cuddapah Stones, Slates, IPS(oxide flooring)
Construction technologies to reduce time and volume of construction	common walls for reduction in materials	CSEB vaulted roof, Jack Arch roof	Precast sandwiched walls, Beams, columns, Shading devices, slabs, RCC door window frames
Natural ventilation	Through windows and high wall ventilators, small windows		
Daylight integration	Through windows and skylight, dormer windows	Through windows and light wells in staircase	Clerestory lighting, floor level opening, full height windows,
Efficient outdoor and indoor lighting by use of T5 lamps, CFL, LED etc		CFL and LED lights in interior, Metal halide lamps in the landscape	Fluorescent tube lights (T8 & T5), 5W CFLs, 2W LEDs
Efficient fans or other heating/cooling technologies	35W Ceiling Fans, Evaporative coolers for summer		
Solar based outdoor lighting	Outdoor light connected to Grid tied solar power system	-	Stand-alone LED street lights powered on Solar PV

Green features	Literature studies & traditional practices	Case studies	Best regional practices
Solar based water heating	Solar hot water system for individual house		
Solar PV panels to generate electricity	Solar heating and geysers, Solar water pumps, heating through solar PV energy generation		
Efficient landscape design			
Pervious pavers	Pervious paving using grass and stones like Sadaralli, Cuddapah, chappadi, bricks haven used alteration with grass and		
Sedimentation control measures in the landscape design	Soft drainage using aggregates filters, wood scrap and grass mulching		
Use of native species	Terminalia, Arjuna, Ficus, Religiosa		
Source of landscape water from recycled water	Treated water from STP		
Irrigation equipment		Sprinkler and drip irrigation	Drip irrigation using earthen pots
Water management			
Waste water treatment system	Tertiary Treatment Plants for 100% recycling of waste water, (grey water) is treated through root zone treatment	DEWATS system	
Rain water harvesting	Rain water harvesting and recharging through drains, percolation pits, trenches and wells	Roof harvesting for domestic use, rainwater storage tank and site feature design for ground water recharging	
Dual plumbing system	Multiple plumbing line for fresh water, treated water and rain water		
Efficient plumbing fixtures	Low flow plumbing fixtures, faucets with aerator, water level controllers, pressure regulating devices	Low flow dual flush cisterns for water closet	Energy efficient motors, dry toilets,
Waste management			
Segregation of waste	mandatory waste segregation, dry and wet waste segregation of kitchen	Waste segregation of dry and organic waste	
Resource recovery from organic waste	Natural and vermicomposting systems for wet waste	Potable composting of organic waste	
Resource recovery from recyclable waste	All waste recycled and reused		

5 Field Case study under Warm and Humid Climate zone - VBHC Vaibhava, Chennai

5.1 Introduction

VBHC Vaibhava Housing project developed by Value Budgeted Housing Corporation (VBHC) at Oragadam in Chennai was constructed in an affordable green manner, by implementing green design and construction technologies. The project (Figure5.1) comprises of 2BHK apartments (148 nos) with floor area of 792sft each, spread over 2 acres of site. (Figure5.2) The project has been certified by IFCs Excellence in Design for Greater Efficiencies (EDGE) Program for its green building design. Table 5.1presents overview of the project.

Figure5.1: A view from courtyard of the VBHC Housing

Table 5.1: Overview of the VBHC's Vaibhava

Details about the project	
Climate (as per NBC)	Warm& Humid
Location	Oragadam, Chennai (12°45'N, 80° E)
Site Area	8417 Sqm
Built-up Area	10952 Sqm (Each apartment unit 74 Sqm)
F S I	1.3
Type of Project	2BHK Apartment (Stilt + 4 floors)
No. of Units	148
Total saleable cost	~Rs. 26 Lakhs per unit

Details about the project	
Density	73 families/Acre
Distance from City	~50 KM
Year of Occupancy	2013
Construction Period	18 Months
Architect	Inform Architects
Contractor	V B H C
Level of Mechanisation	High
Skill level of Labour	Medium
Total Cost of Construction	~Rs. 1400/Sft
Total Life Cycle Cost (50 years)	~Rs. 4550/Sft
Total Carbon Foot Print	~115Kgs of CO2 Equivalent/Sqm/Year
Green features/ alternative construction technologies incorporated	Rain water harvesting, DEWATS with syphon for water treatment, reinforced concrete walls, Solar water heater, SPV- LED street Lighting, Energy efficient fixtures and water efficient plumbing fixtures

5.2 Details of Green and Affordable Features

5.2.1 Construction Technology & Management

Mechanization of construction, in terms of on-site assembly, replicable and consistent production of building components have contributed for control on time lines and overall costs of the project. Prefabricated aluminium form work was used to cast reinforced concrete walls and reduce the wastage and reworks and thus result in a better quality of construction. The construction of this housing project was completed in 18 months of duration due to various alternative construction technologies implemented on site. These monolithic concrete shear walls constructed in this project also meet the seismic code compliance requirements for Chennai.

Based on the preliminary data received from the developer, an analysis was carried out to see the affordability of this technology while replicating multiple numbers of apartment units. Although the initial investment on aluminium formwork is high, its reusability (number of times it can be used) is significantly high compared to a conventional wooden formwork. The labour cost is also almost half of the cost it takes for a conventional construction. The most important parameter is the time of construction using this technology that makes the construction 10 times faster than a conventional construction. Table 5.2presents the comparison of various aspects of construction between Reinforced Concrete (RC) wall and a conventional concrete masonry frames structure.

Figure5.2: Site Plan and typical unit plans of VBHC Housing in Chennai

Table 5.2: Comparison of R C Wall and Conventional construction

Parameters for Single unit	R C Wall	Concrete Block Wall
Quantity of Concrete (Sqm)	80	10
Rate (Rs/ Unit)	7,425 (150mm thick)	12,375 (200mm thick)
Quantity of Bricks (Sqm)	0	70
Rate (Rs/Unit)	0	2520
Total Material Cost (Rs)	5,94,000	3,00,150
Formwork Cost (Rs)	70,00,000	20,00,000
Reuse of Formwork	350	6
Labour Cost (Rs/Sqm Wall)	60	140
Total Wall Area (Sqm)	80	80
Total Labour Cost (Rs)	4,800	11,200
Time of Construction (Days)	6	60

The formwork was sufficient for constructing each apartment unit at a time. It was observed in this analysis that the cost of total construction becomes equal at 115th repetition and affordable thereafter. Figure5.3presents the comparison of cost of construction between RC wall and conventional construction as the number of reuse of formwork increases. Figure5.4presents the pictures taken during the construction of R C Wall.

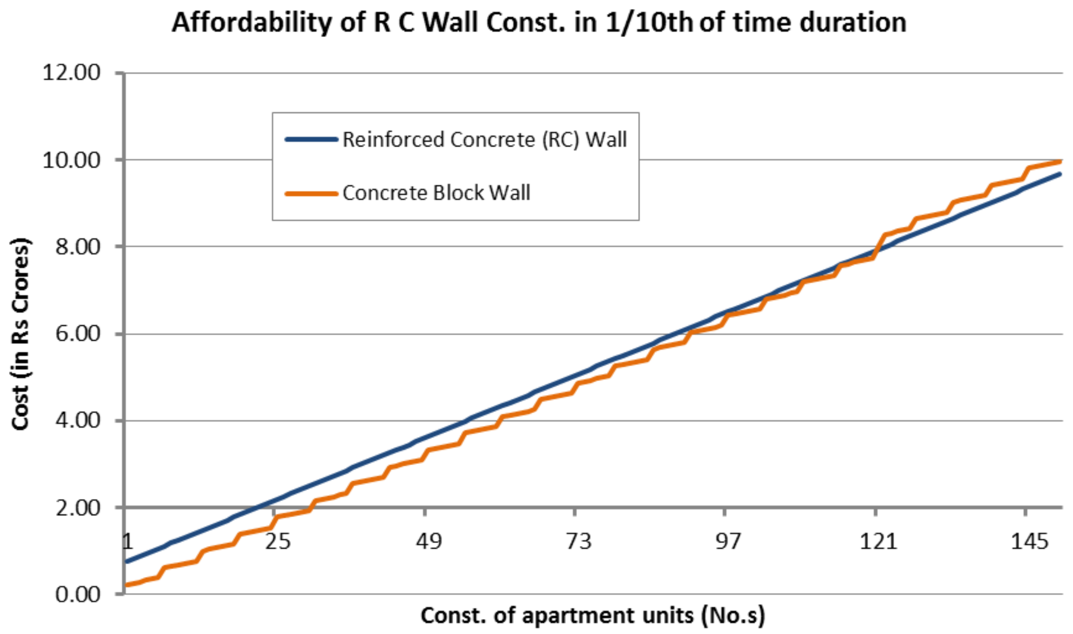


Figure5.3: Cost Comparison between R C Wall and Conventional wall

Figure5.4: Construction of Reinforced Concrete (R C) wall

5.2.2 Building Design

Site Planning

The site plan is developed with almost 70% of the area as pervious with more green area and less paved area. Enough space has been considered between the apartment blocks which enables mutual shading and free air movement thus reducing the heat gains. Precast concrete slabs used for compound wall (Figure5.5) save time during the construction and so the labour cost. Intermediate columns holding these slabs require less foundation compared to a conventional brick wall.

Figure5.5: Precast concrete slabs used for compound wall

Space Utilisation & Passive Design

Spaces inside the house were designed to comply with the minimum bye law requirement (bed room size, 3m X2.8m) of the city for an effective use of floor space. Simple three bay units were designed for natural daylight and free flow of air in the living spaces, considering the climate of the city. Full height windows (floor to lintel) in the living and bedrooms also enhance the ventilation requirement given in the bye law (20% of the Floor area). Similarly, the corridor widths were also kept to the minimum of bye-law requirement valuing the real estate cost and make the project affordable. These windows, having a clear glazing and optimised shading spread a natural and glare free lighting inside the living spacesFigure5.6. presents the images taken inside the house without any artificial light. Ventilators provided above the main door in the living room aids cross ventilation for improved thermal comfort.

Figure5.6: View of Kitchen and Kids Bedroom

5.2.3 Alternate Construction Materials and Technologies

Walls & Roofs

The reinforced concrete walls (150 mm thick) casted on site gives a smoother finish and results in saving of plaster material due to smoother finish achieved for wall surfaces. M20 grade ready mix concrete (RMC) and Fe 500 TMT steel reinforcement were used for constructing the R C wall. These straight walls are simple with less overlaps. Window shading has been integrated with the wall design and the remaining part on the wall is used as wardrobe from the interior.

Doors & Windows

Simple and minimum grill design has been used for windows (Figure5.7) to reduce the project cost. Recycled UPVC door/ window framed clear glazing have been used which may contribute to reduce the overall energy footprint of the building. Composite doors have been used to reduce the overall energy footprint and cost of the project.

Other Materials

There are other key features like granite kitchen platforms and its fixing using simple L-brackets and a groove in the peripheral wall make the building cost effective. Granite being a local material results in lower embodied energy. Kota stone has been used for stair cases

Figure5.7: Typical Window Grill design and Kitchen platform detail

Component wise embodied energy and costs of major items are compared with the conventional construction and the details are tabulated inTable 5.3 & Table 5.4.

Table 5.3: Component wise embodied energy of the building and the possible savings when compared to conventional construction

S. No	Building Component	Description	Quantity	Unit	Embodied Energy (MJ/ Unit)	Total Embodied Energy (MJ)	Description	Quantity	Unit	Embodied Energy (MJ/ Unit)	Total Embodied Energy (MJ)	Reduction in EE (%)
		V B H C Vaibhava					Conventional					
1	Scaffolding/ formworks	Aluminium	184	cum	515700	4,74,44,400	Wood	2300	cum	20	46,000	-103040
2	Foundation& plinth	R C C	2486218	kgs	1.1	41,74,839	R C C	2486218	kgs	1.1	41,74,839	0
3	Columns & beams	R C C	1042008	kgs	1.1	31,46,209	R C C	1042008	kgs	1.1	31,46,209	0
4	Walls	R C C	11840	Sqm	2150	2,54,56,000	Solid concrete blocks	10656	Sqm	1360	1,44,92,160	-76
5	Plastering	No Plaster	23680	Sqm	-	0	Cement	23680	Sqm	30	7,10,400	100
6	Roof	R C C	1896240	kgs	1.1	27,65,864	R C C	1896240	kgs	1.1	27,65,864	0
7	Flooring	Ceramic	27100	Sqm	180	48,78,000	Terrazo	27100	Sqm	92.7	25,12,170	-94
8	Windows	UPVC	917	nos	2980	27,32,720	Aluminium	917.02	nos	6000	55,02,120	50
9	Doors	Flush	1776	sqm	482	8,56,032	Flush	1776	sqm	482	8,56,032	0
10	Staircase	R C C	672552	kgs	1.1	12,59,807	R C C	672552	kgs	1.1	12,59,807	0
		Total Embodied Energy (MJ)				9,27,13,871	Total Embodied Energy (MJ)				3,54,65,601	-158
	Total Embodied Energy (GJ/100Sqm built up area)					843	Total Embodied Energy (GJ/100Sqm built up area)				323	

Table 5.4: Component wise Costs of the building and the possible savings when compared to conventional construction

S. No	Building Component	Description of the material	Total Quantity	Unit	Total Cost (in Rs)	Description of the material	Total Cost (in Rs)	Estimated Savings (%)
		V B H C Vaibhava				Conventional		
1	Site works	Cut & fill, Termite proofing, Trenching for foundation			2,54,383	Cut & fill, Termite proofing, Trenching for foundation	2,54,383	0
2	Scaffolding/ formworks	Aluminium Formworks (used for constructing every 350 units)	46,051	Sqm	40,90,887	Wooden Formworks (used for constructing every 6 units)	2,86,36,208	86
3	Foundation& plinth	R C C	1,036	cum	57,99,296	R C C	57,99,296	0
4	Columns & beams	R C C	434	cum	39,48,392	R C C	39,48,392	0
5	Walls	Reinforced Concrete (RC) Wall	11,840	Sqm	4,70,95,300	Cement concrete block Masonry	2,35,47,650	-100
6	Painting	Painting works	63,100	Sqm	62,21,597	Painting works	62,21,597	0
7	Roof	R C C	790	cum	45,15,220	R C C	45,15,220	0
8	Flooring	Ceramic & Vitrified Tile	27,100	Sqm	1,15,72,002	Terrazo	1,05,14,800	-10
9	Windows	uPVC framed	917	nos	69,95,938	Aluminium framed	34,97,969	-100
10	Doors	Flush doors	888	nos	55,55,394	Flush doors	55,55,394	0
11	Staircase	R C C	280	cum	17,76,413	R C C	17,76,413	0
12	Railing	Steel	957	rm	7,79,940	Steel	7,79,940	0
13	Waterproofing	Waterproofing works	5,096	Sqm	17,85,270	Waterproofing works	17,85,270	0
14	Building services - electrical	Excluding efficient fixtures			1,00,12,936	Excluding efficient fixtures	1,00,12,936	0
15	Building services- Plumbing	Excluding efficient fixtures			95,75,006	Excluding efficient fixtures	95,75,006	0
16	Water Efficient Fixtures	Low flow faucets, showers & WCs			24,24,788	Conventional	15,15,492	-60
17	Rain water harvesting system	Gutters, pipes, storage tank work, purification			20,79,722	Nil	0	-

S. No	Building Component	Description of the material (V B H C Vaibhava)	Total Quantity (V B H C Vaibhava)	Unit (V B H C Vaibhava)	Total Cost (in Rs) (V B H C Vaibhava)	Description of the material (Conventional)	Total Cost (in Rs) (Conventional)	Estimated Savings (%)
		system						
18	Waste water treatment system	DEWATS System (9000 LPD)			12,00,000	Nil	0	-
19	Energy efficient lighting features	CFLs			7,32,000	Incandescent	1,83,000	-300
20	Energy efficient fans	Energy efficient fans			14,80,000	Conventional	8,88,000	-67
21	Solar Hot water system	Solar Flat plate collector (7500LPD)			13,32,000	Nil	0	-
22	Solar PV- LED Street Lighting	14 W LED luminaires (20 Nos)			2,00,000	150 W Sodium Vapour (20 No.s)	82,000	-144
23	Labour Cost	At Rs 60/Sqm			7,10,400	At Rs 140/Sqm	16,57,600	57
24	Miscellaneous	Lump sum amount			10,00,000	Lump sum amount	10,00,000	0
		Total Cost (in Rs)			13,11,36,882	Total Cost (in Rs)	12,17,46,566	-8%

5.2.4 Energy Management

Energy efficiency and resource utilisation is a key concern in the project. Each apartment is connected to fixed load of 3kW, which prevents from the wastage of electricity in the entire housing. Electrical sockets are inbuilt in the R C wall based on the requirement and doesn't allow any additional plug points to capture the more loads.

Efficient Efficiency

Artificial lighting design has been done very optimally, for a uniform lighting distribution. Provision is given for fixing CFLs and energy efficient ceiling fans.

Renewable Energy Integration

Solar water heating systems have been provided for the top two floors. Stand-alone solar based LED lighting (Figure5.8) has been provided for outdoor lighting which makes the site lighting efficient and reduces the overall dependency on the grid electricity. The Initial Investment of the solar based LED Street light is almost double to the cost of conventional sodium vapour street light. However, since the PV generated the sufficient power to light up the LED luminaire, it pays back the cost within 3 years duration.

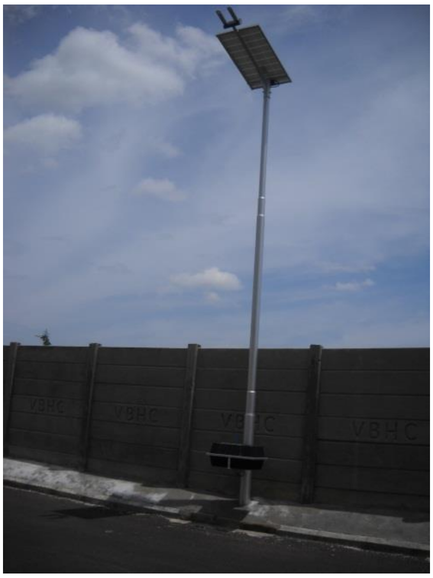


Figure5.8: Stand-alone solar based LED street lighting

All these features are resulting in total energy consumption of 84 kWh/Sqm/annum which is about 16% lower than the conventional house in Chennai's climate.

Solar Hot water System

Solar hot water system that is sufficient to supply for the top two floors was proposed to install on site. This system reduces almost half of the energy that goes for hot water in this project. Overall about 10kWh/Sqm/year estimated savings would be possible with this system. This makes the project energy efficient upto 74kWh/Sqm/year, whereas the energy consumption of a conventional house in Chennai would be 100kWh/Sqm/year.

5.2.5 Water Management

Rain water harvesting

Since the water table is very high and no external supply connected to the site, an innovative water management system has been implemented in this project. Rain water collected from the roof tops and the paved areas within the site have been collected in well through the peripheral swales (Figure5.9). The rain water gets filtered before entering to the well and adds up to the natural ground water that is already available due to high water table. 22% of the total building water requirement is met by the rain water and reduces its dependency on the natural resources.

Figure5.9: Peripheral swales and the open well-constructed on site to collect the rain water.

Waste Water Treatment

The project has dual plumbing and dual flush sanitary systems to reduce fresh water usage. Waste water generated from bathrooms and washing machines are connected an efficient water treatment system, which apparently consumes less energy. This system has a vertically positioned tube with a funnel shaped bottom element, inside the tube a natural self-purification effect from the effluent takes place during the continuous swirling moment without affecting the quality of water. Figure5.10presents the water balance taken place on site; the entire system results in saving about 15% of fresh water requirement by treating and reusing it.

Figure5.10: Dual plumbing and dual flush toilets installed in the project

Total Rain water collected (from roof tops & Paved areas)	:	13,000 LPD (22%)
Total Fresh water taken from well	:	57,000 LPD (78%)
Total Waste Water Treated	:	9,000 LPD (15%)
Total Consumption of the Building	:	60,000 LPD

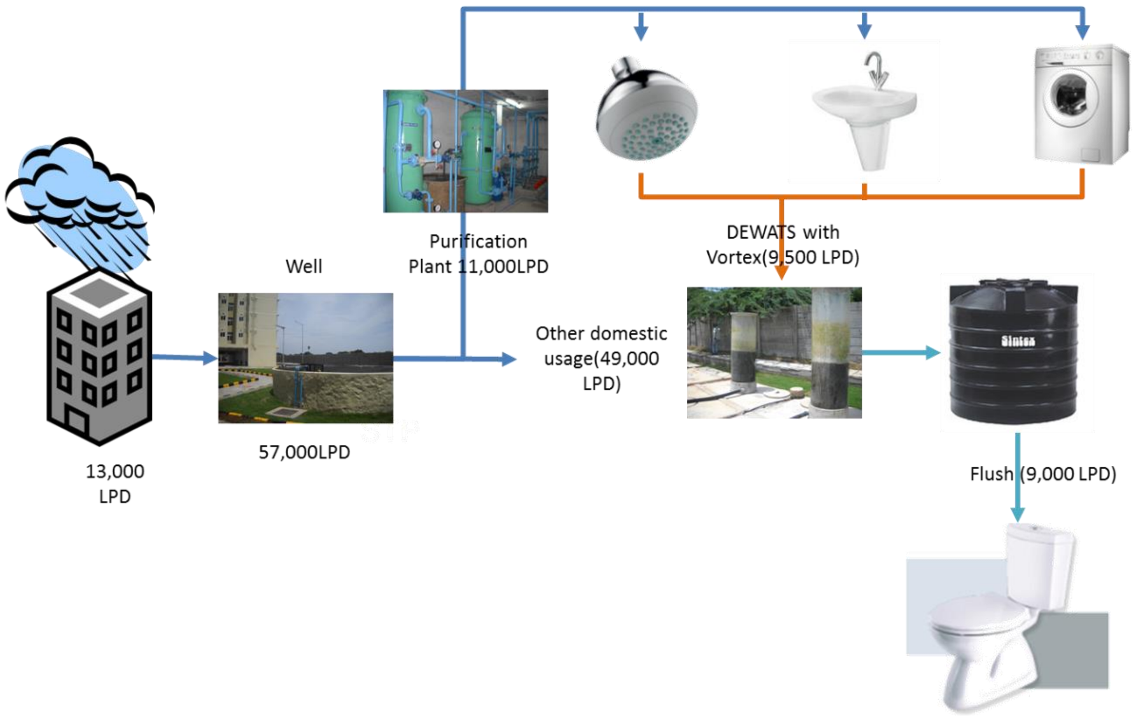


Figure5.11: Water Balance for VBHC Housing

5.2.6 Performance Monitoring

Indoor environmental parameters that indicate occupant comfort conditions (thermal and comfort) inside house were monitored during the month of September. Thermo hygro data loggers and surface temperature probes were used to measure these parameters instantaneously.

Thermal Comfort

It would be interesting to measure the indoor environmental conditions as a result of complete concrete envelope in hot and humid conditions of Chennai. One of the major parameters that would result due to higher heat capacity of the concrete wall is lower Mean radiant temperature (MRT). Measurements were carried in a bedroom of a typical apartment unit when the windows were closed. Lower MRT (29.15°C) was observed while the corresponding indoor air temperature and relative humidity were 29.6°C and 58% respectively. The ambient conditions during the measured period were 33.5°C and 59%. Thus there was a reduction of about 4°C in air temperature present with R C wall in the envelope.

5.2.7 Life Cycle Analysis

It was observed in the earlier sections that the initial investment for VBHC Vaibhava was about 8% higher. The total embodied energy of the VBHC Vaibhava was assessed as 847

GJ/100Sqm built up area where as the conventional framed construction with cement concrete block masonry would be 326 GJ/100 Sqm built up area.

Greenness and affordability of the case was analysed by calculating Carbon footprint and Operational and Maintenance (O&M) Costs during the building life time. These figures were compared with the conventional building using the data compiled in Table 5.5. The buildings life time was assumed as 50 years.

Carbon Foot Print

To calculate total energy footprint and resultant carbon footprint of the building both initial energy of the structure (embodied energy) and the operational energy (electricity used) during its life time were considered. The operational energy taken from the grid of VBHC Vaibhava was low as observed in section 5.2.4; this is because of the energy efficient and renewable energy features implemented in the project. Embodied energy of solar thermal system for hot water systems used in the project was derived from the earlier studies. Energy that was spent on transporting materials to site, handling the construction equipment and preparation of materials was neglected in the analysis. Also the recyclability aspect of aluminium formwork in case of VBHC was not into taken account. Since the energy saved by Solar PV based LED street light is very minimal, it was not accounted in the calculations. Operational energy was considered from the actual data available in the electricity bills. Assuming all these energies in terms of electricity (kWh), carbon footprint (Table 5.5) was calculated for Indian conditions. The carbon footprint of VBHC Vaibhava was estimated as 115kgs of CO_2 Equivalent /Sqm built up area/year and the conventional house used for comparison would be 112kgs of CO_2 Equivalent /Sqm built up area/year.

Table 5.5:Energy and Carbon footprint of VBHC Vaibhava & conventional house

		VBHC Vaibhava	Conventional House
Total Embodied Energy (kWh)	Civil structure	2,57,53,853	98,51,555
	Solar Water Heater (7500Lts)	1,82,041	0
Total Operational Energy taken from grid in 50 years Life time (kWh))		4,05,22,400	5,47,60,000
Total Energy footprint in 50 years (kWh)		6,64,58,294	6,46,11,555
Total Carbon footprint in 50 years (Tons of CO2 Equivalent)		62,737	90,993

Cost Analysis

Similar to energy calculations, both the initial construction cost and operational costs in terms of repairs and electricity & water consumed by the building during the entire life cycle of 50 years assumed. The initial costs of both the VBHC Vaibhava and Conventional house were comparable where the costs of earlier was slightly higher due to additional energy efficient and water efficient features implemented in the house. The operational energy and water costs were taken from the actual data taken from the electricity and water bills. Energy and water consumption of VBHC Vaibhava and its dependency on the grid and external supply was low as discussed in sections 5.2.4& 5.2.5. The Operational

&Maintenance costs for repairs were estimated based on the construction costs using factors available in the literature. Cost of electricity was assumed as Rs 5.3/kWh and for water as Rs. 100 per 1000lts. The escalation rate for all the three costs (O&M, Energy & Water) was assumed to be 2% (fixed) every year. This analysis doesn't include the appreciation / depreciation costs and taxes on the built up property. Table 5.6 presents the costs of studied case and the conventional case based on these assumptions. The analysis also presents that the payback for VBHC Vaibhava and it can be noticed that the higher initial cost spent on the building pays back in 2 years.

From both the cost and energy foot print analyses it was observed that there was not much difference in carbon foot print of studied case (VBHC Vaibhava) and the conventional case. About 33% affordable compared to conventional case. The total carbon footprint was observed as 6 Tons of CO_2/ Sqm built up area for both VBHC Vaibhava and the conventional case. The initial and O&M costs of VBHC Vaibhava in its entire life cycle was observed as 4950 Rs/Sft of built up area where as for a conventional house it was 7450 Rs/sft. Figure5.12presents the incremental energy and costs plotted for 50 years of life time.

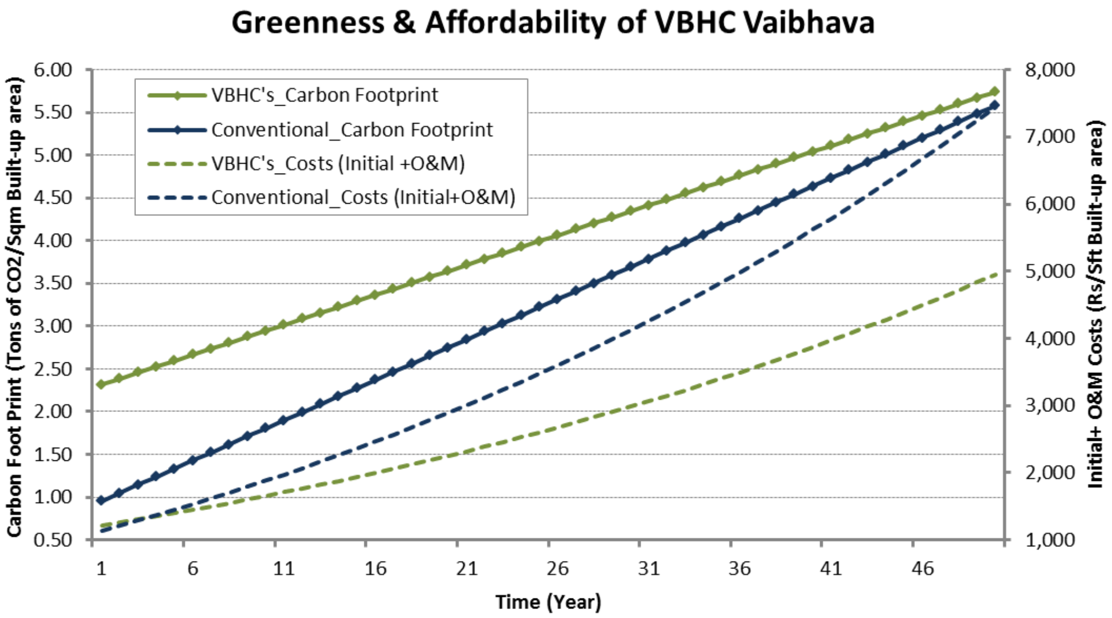


Figure5.12: Greenness and Affordability of VBHC Vaibhava in comparison with conventional case

Table 5.6: Initial & O&M costs of VBHC Vaibhava & conventional house

		VBHC Vaibhava	Conventional House
Total Initial Costs (Rs)	Building	13,11,36,882	12,17,46,566
	Energy Efficient Features (like Eff. Lighting & SWH)	3,74,400	11,53,000
	Water Efficient Features (Like STP, Eff. Fixtures)	57,04,510	15,15,492
Total Operational & Maintenance Costs Including purchase of Electricity & Water for 50 years (Rs)		44,67,95,003	75,34,04,487
Total Life Cycle Costs for 50 years (Rs)		58,40,10,796	87,78,19,545
Total Life Cycle Costs for 50 years Rs/Sft)		4,954	7,446

Table 5.6 presents the summary of major building components that may be replicable along with their costs. Table 5.7 presents various green features summarised from literature, case studies and best practices in the warm- humid climatic region.

5.2.8 Summary of Field Interviews

Feedback from the occupants, contractors and architects was collected and documented, along with a few observations that were made on site during the field visit.

It was observed that many the occupants belong to income group of 6-7 Lakh per annum and the cost they bought from the developer was affordable (Rs. 2,200 per Sft). However, most of the users have taken loan for a period of 15-20 years to buy these apartments. It was also noted from the users that the quality of construction is very good and they are satisfied for the money they have spent. Adequate daylight and natural ventilation is present because of the well-designed apartment units. Minimal air conditioning is required except for a few months, especially in upper floors of the apartment. The users are also impressed with the green features like waste water treatment and solid waste management. This also encourages occupants to become more alert in educating others.

The developer of the project has a skilled project management team, who used some advanced project monitoring tools to finish the project in a shorter time compared to a conventional construction. Although the direct cost (materials & procurement) is high in this project, the indirect costs (labour) are very less. The cost that is required for maintenance and repairs is very minimal because of the high quality of construction. In general it is a conception of general public that the indoor conditions become hotter in complete concrete construction. However, during the field visit it was observed that there was a temperature reduction inside the house that makes the occupant thermally comfortable.

5.2.9 Summary of the case study

Table 5.7: Summary of replicable green & affordable features from the case study

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable Yes/No	Details	Cost	
1	6" Reinforced concrete wall	~Rs 3980/- per Sqm wall area	High embodied energy	Y	Cement concrete block masonry	~Rs 1980/- per Sqm wall area	Y
2	Vitrified Flooring	Rs. 430/- per Sqm Floor Area	High Embodied Energy, no recycled content	N	Terrazo Flooring	Rs. 388/- per Sqm Floor Area	N
3	Window Frames & Simple Grill Design	~ Rs 7600/- per window	Recycled content, low embodied energy		Aluminium Frame	~ Rs 3800/- per window	Y
4	Rain Water Harvesting System	Rs. 20,80,000/-	Results in less dependency on the conventional water sources	Y	-	-	Y
5	DEWATS with Syphon	Rs. 12,00, 000/-	Results in less dependency on the conventional water sources	Y	-		Y
6	Water Efficient Fixtures	Rs.3500/- for low flow faucets Rs.6500 for dual flush (3/6)	Results in less dependency on the conventional water sources	Y	Cost of the fixture is Rs.1750 for conventional faucets and Rs.5000 for Single flush 9 lp/flush water closets		Y
7	LEDs	Rs. 400/- per Fixture	Results in less dependency on the conventional energy sources	N	CFLs Rs. 200-250/- per fixture		Y
8	Solar thermal hot water system	Rs. 15,00,000/-	Results in less dependency on the conventional energy sources	Y	-		Y
9	Solar Based LED Street Lights	Rs. 2,00,000/-	Results in less dependency on the conventional energy sources	Y	-		Y

5.3 Summary of warm and humid climatic zone

Table 5.8: Summary of Green features identified in warm and humid climatic zone

Green features	Literature studies	Case studies	Best regional practices
Siting and climate responsiveness			
Orientation	Longer walls orienting towards North and south side		
Zoning	Single bay units, Courtyards, Shaded Verandas and living spaces on critical orientations		
Energy, renewable energy & building materials			
Roof treatment, roof garden	Hollow terracotta blocks, Ferro cement slabs Filler Slabs, Madras Terrace with clay tiles,	Roof shading,	Insulated roofs, RCC with reflective tiles, Roof trellis
Shaded windows	Shaded windows		
Walls to respond to outside climate	Terracotta jalis, self-shaded walls,		AAC blocks, Hollow concrete blocks, Hollow clay blocks
Local materials to reduce embodied energy	Laterite blocks, Compressed coir door panels and bamboo composites, FalG Blocks	Flooring materials like terrazzo, ceramic tiles, red mud clay tiles	Granite, IPS(oxide flooring)
Construction technologies to reduce time and volume of construction	Funicular shells, adobe vaults, Jack Arch roof	R C Wall Const.	Precast RCC door window frames
Natural ventilation	Through full height windows, ventilators above doors/ windows, below roofs		
Daylight integration	Through windows and skylights	Through windows and light wells	Clerestory lighting, floor level opening, full height windows,
Efficient outdoor and indoor lighting by use of T5 lamps, CFL, LED etc		CFL	Fluorescent tube lights (T8 & T5), 5W CFLs, 2W LEDs
Efficient fans or other heating/cooling technologies	35W Ceiling Fans		
Solar based outdoor lighting		Stand-alone LED solar street lights	
Solar based water heating	Solar hot water system		
Solar PV panels to generate electricity			
Source of landscape water from recycled water	Treated water from STP		

6 Field Case study under Cold Climate zone - Passive solar houses, Ursi Village (Ladakh)

6.1 Project Profile

A brief profile of the project has been depicted below:

- Project name : Passive Solar Houses, Ursi Village
- Year of construction : 2008 – 2010
- Location : Ursi village, Ladakh, J&K
- Coordinates : 34.216^0 N, 76.894^0 E
- Climate (as per NBC) : Cold
- Architect :Groupe Energies Renouvelables, Environment et Solidarités (GERES)
- Contractor : Many local contractors
- Developer : GERES, ECOSPHERE, LEDeG, LEHO, LNP & SECMOL
- MEP : Not applicable
- Energy consultant : Not applicable
- Any energy performance certifications : No
- Total Cost of Construction : Rs. 833/sq.ft
- Total Built up Area for one house(Sq. mts) : 15.6
- Total site area (sq. mts.) : Whole of the village
- No of dwelling units : 15 units (Single ground floor homes)
- Cost of each house : INR 1.4 lakhs (2008-2010)
- Green technologies/features incorporated : Ground water recharge, Green Construction practices, solar passive architectural design, and Integrating craft into the design, use of local materials, Biodiversity and use of indigenous species in landscape, preserving and ecology.

6.2 Background

Ladakh lies between altitudes of 2800 to 4600 meters above the sea level. The climatic conditions are pretty severe with temperatures dropping below -20^{0}C during the winter season. The winter seasons are long and cold climate persists for six months in a year. Villages are cut-off from the cities during winter for about four to eight months and with highly dispersed population and difficult terrain many villages are not connected to central electricity grid. Ursi village approximately 150 Km from Leh is also cut-off from central electricity grid and has been recently connected via road. With almost negligible employment opportunities villagers rely on livestock breeding and subsistence farming. Army activities and tourism offers them temporary job opportunity. In Ursi village a household earns approximately INR 40,000 -50,000 (based upon interviews with villagers) in a year.

Traditional houses are poorly insulated and room temperature falls below -10 (GERES, 2011) in winters. The living conditions become harsh with such adverse conditions. The heating is dependent on traditional heaters, *bukhari,* which burns locally available biomass. Such heaters generate lots of noxious gases which are trapped inside house. The Passive solar houses (PSH) which are energy efficient and maintain high inside room temperature are highly desired in such locations. With PSH people can live in comfortable and healthy conditions even without access to modern technology.

Figure6.1: Ursi village.

6.3 Passive solar house design

There are three main design of PSH(Clottes, 2012), i.e. Direct gain (DG), Solar wall (SW), and Attached green house (AGH). **All the PSH are southward oriented** with or without any tilt depending upon the usage of building. Constructing windows on east and west walls is not recommended as it would increase solar gain during summer and thus increasing temperatures inside when actually not needed. Figure 6.2 below shows different PSH designs.

Figure6.2: a) A direct gain house, b) House with Solar wall, c) Attached green house to the house, d) Inside of a green house.

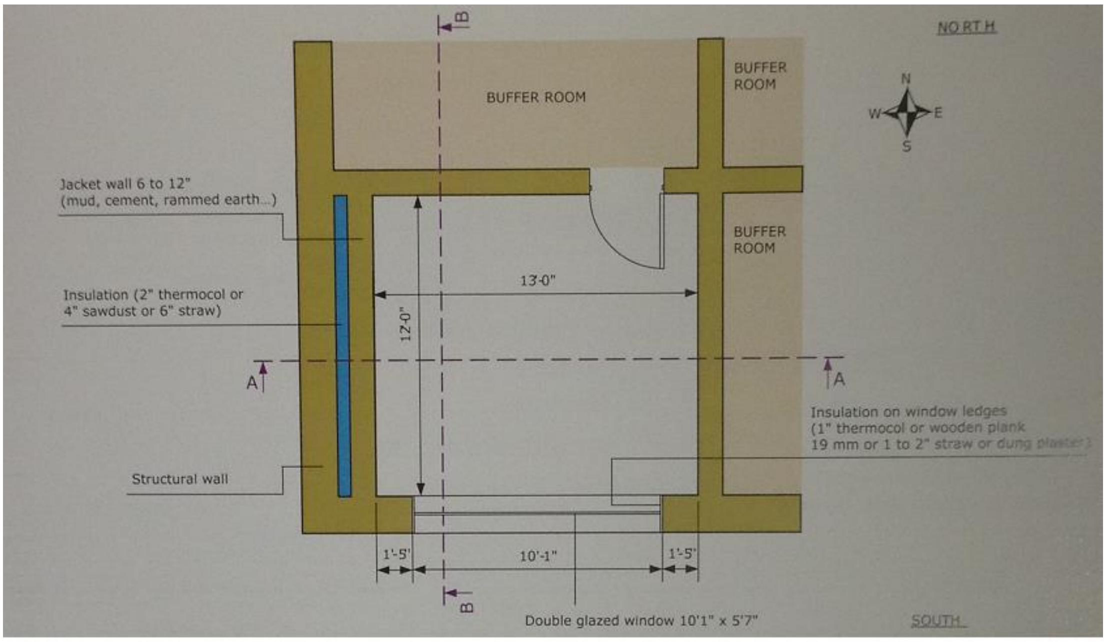
In all the three designs the modification are made to southern wall. Rest walls and roof construction is same in all the three designs. Standard sizes[65] of various components are:

- Standard room size: 3.66m x 4.27m x 2.44m (width x length x height) (12ft x 14ft x8 ft)
- Standard window size (for DG): 1.83m x 3.05m (6ft x 10ft)
- Standard window size (for AGH): 1.52m x 2.44m (5ft x 8ft)
- Standard window size (for SW): 4.27m x 2.44m (14ft x 8ft)

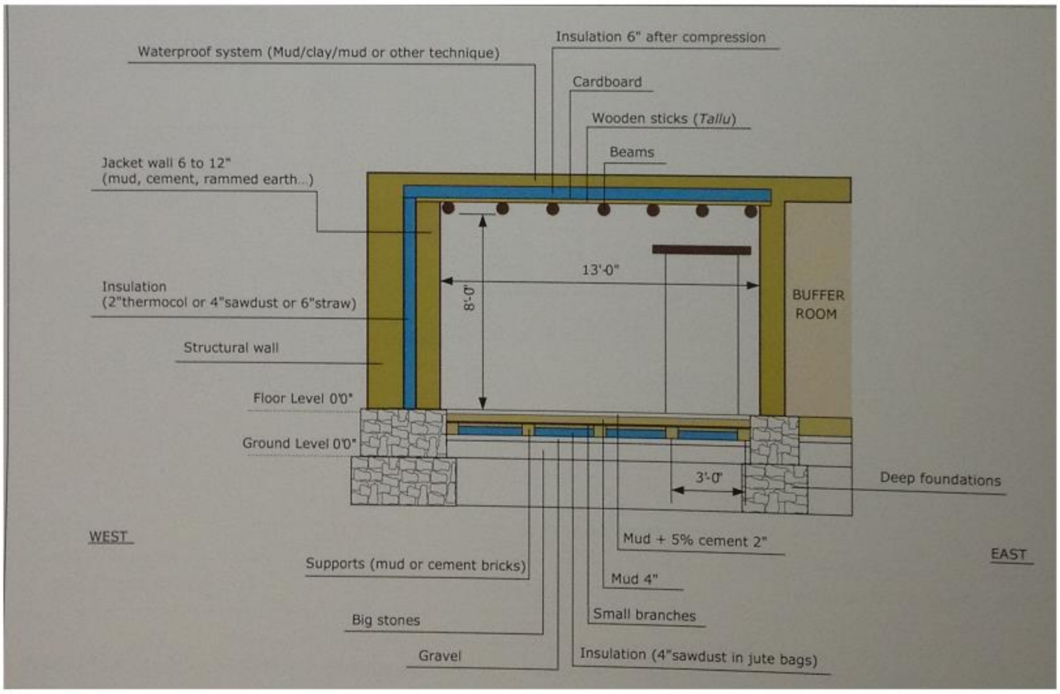
Note that window size changes with the room size to allow appropriate heat gain. General plan of a typical PSH is shown in figure 6.2. Figure 6.2a also shows typical wall, roof and foundation construction.

The **three sides of house are constructed with double walls separated by insulation**. The outside wall is for structural purpose and inside wall is for storing heat. Outside wall are generally made of mud bricks, rammed earth or cement brick depending upon availability and owners buying capacity. Inside wall is generally made from mud or cement bricks.

Commonly used **insulation materials for roof and walls are Yakzes, a locally available wild shrub, saw dust and hay**. EPS is also recommended but due to its high cost it is generally avoided. Table 6.1 gives details of the insulation materials which are recommended and are mostly locally resourced.



a



b

Figure6.3: Typical plan and elevation of PSH. Picture scanned from GERES booklet.

A typical roof section consists of wooden beams arranged perpendicular the wooden stick followed by layer of cardboard. After the layer of cardboard, insulation is placed and its thickness depends upon the type of insulation used. The final outer layer consists of mud. The roof is water proofed by various techniques like having layer of plastic before the layer of mud or mixing *markalak* clay with mud. Layer of wooden beam and sticks which is the inside layer of wall is shown inFigure6.3.

Figure6.4: Typical roof construction from inside the house.

Table 6.1: Recommended insulation materials for PSH

Section	Insulation material	Comments
Roof	EPS, 3-4 inches	Expensive
	Glass wool, 3-4 inches	Expensive and not available locally
	peat bill, 6 inches	Not recommended for wet rooms like kitchen and bathroom
	Saw dust, 6 inches	Not recommended for wet rooms like kitchen and bathroom. Low embodied energy material and usually a waste product.
	Yakzes, 6 inches	It is locally available wild shrub. Recommended for all rooms. As naturally grows, embodied energy is zero.
Wall	EPS (thermocol), 2 inches	
	Glass wool, 2 inches	
	foam mattress, 2 inches	
	Saw dust, 4-6 inches	
	peat bill, 4-6 inches	
	Hay, 4-6 inches	Natural product with no energy required for production, thus zero embodied energy.
	Straw, 4-6 inches	

Section	Insulation material	Comments
Floor	1 foot of Saw dust +layer of stone and fine gravel (4 inch in total)+mud bricks (4 inch thick)+sawdust bags and wooden stick layer + 4 inches of mud	
Window	EPS, 1 inch+ 6mm plywood	
	19mm wooden plank+6mm plywood	
	1-2 inches thick dung or straw plaster	When no wood is available

Figure6.5: Sun dried bricks being made on site.

Figure6.6: A cut through section of wall showing saw dust used as insulation material.

6.3.1 Direct Gain (DG) houses

The DG houses are **double walled insulated buildings** with south wall having double glazed window to trap solar energy during day time (see Figure6.7).

Figure6.7: DG house surveyed in the study.

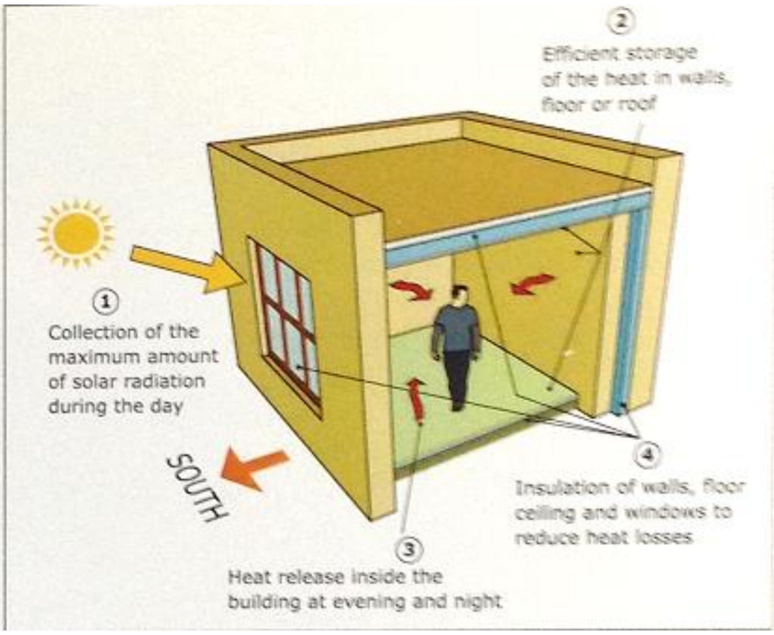


Figure6.8: Concept of DG house. Picture scanned from GERES booklet

Table 6.2: Advantages and disadvantages of DG type houses

Advantage	Disadvantage
• Cheap • Exterior aesthetics in alignment with local traditional architecture. • Applicable from south-20ºE to south-20ºW.	• Not efficient on cloudy weather.

6.3.2 Solar Wall (SW)

The concept of **SW is to store energy during day time** in the building walls with materials which have properties to store it. Such **walls are thick and facing south**. Good construction material for such walls in cement brick, burn or mud brick, rammed earth or hollow cement brick filled with cement or mud. Wall made from concrete block is most effective as it has high heat storing capacity. The walls are plastered and painted black from outside to increase solar heat absorption. Finally outside surface is covered with double glazed glass and vents are provided on the wall. The sun heat is trapped in between glazed surface and wall. Part of heat is stored in air which forms natural convection loop, warm air naturally goes inside the room and cold air comes out through lower vent as depicted in Figure6.9. Rest of the heat is stored in the wall itself which then releases it inside the house during night time. The air between glazing and wall also behaves as insulation during night period. The recommended thickness of SW is 8 inches to 1 foot.

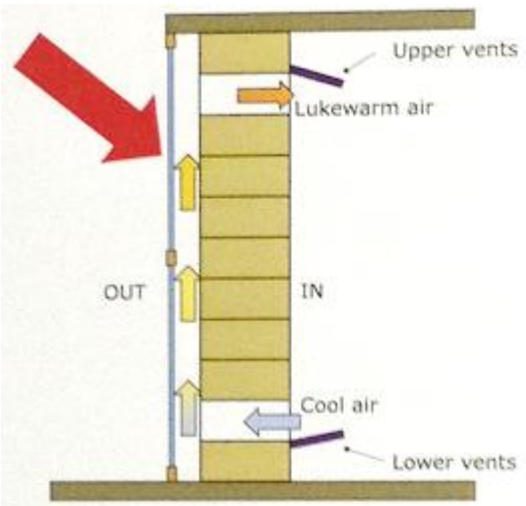


Figure6.9: Principle working of solar wall. Picture scanned from GERES booklet

a b

Figure6.10: a) House with SW, b) Inside of the SW house.

Table 6.3: Advantages and disadvantages of SW

Advantages	Disadvantages
• 24 hours warmed, • Efficient even after one or two cloudy day, • Applicable from south-20⁰E to south-20⁰W.	• Expensive, • Strange aesthetic looks, • Room may be considered dark, • Less efficient if thickness of wall exceeds one foot (30 cm).

6.3.3 Attached Green House (AGH):

AGH is **single glazed room attached to southern wall of the house** (see Figure6.11) and acts as a solar energy collector during winter day time to warm-up adjacent rooms during day and night. During day time heat is transferred through radiation via double glazed window of southern room and via convection by opening the shutters of double glazed windows and doors. At night time the heat stored, in the floor of AGH and partition wall of AGH and room, during day time is released inside the room. The AGH room thus acts similarly in principle to SW. Though glass is best suited material for constructing AGH but due to low income levels it is unaffordable for Ursi people. The cheaper and affordable alternative is UV resistant polythene sheet

Table 6.4: Advantages and disadvantages of AGH.

Advantages	Disadvantages
• Suitable for renovation, • Additional space, • Applicable from south-30⁰E to south-30⁰W.	• Investment and maintenance cost, • Space required.

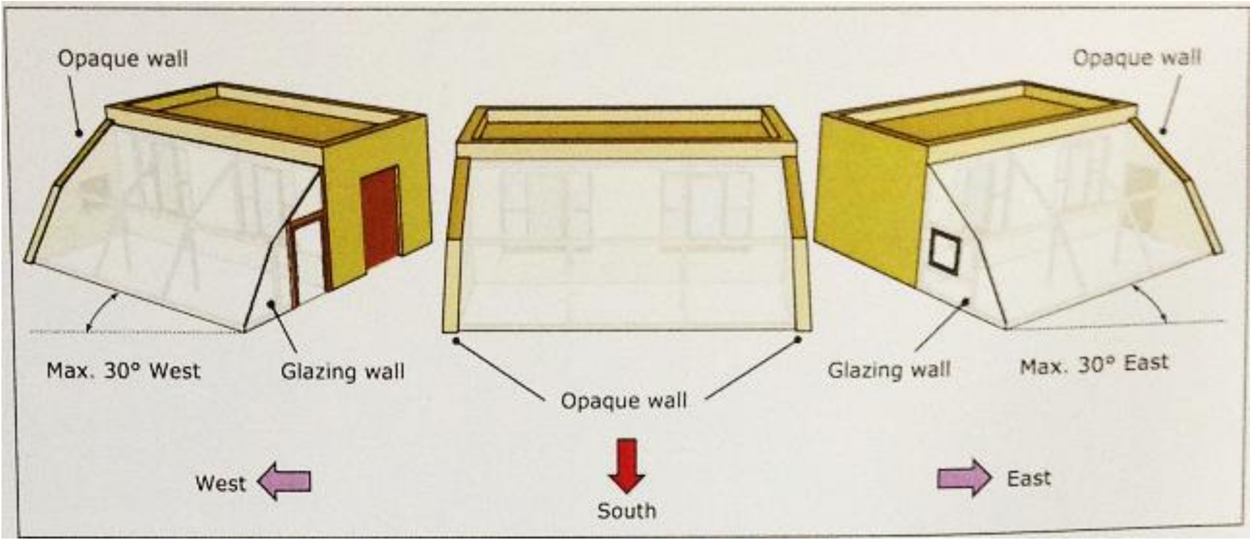


Figure6.11: Shape of AGH with minimum and maximum advised orientation angle

6.4 Water and waste management

People in Ursi village don't have water or waste water service lines. All their water demands are met by melted glaciers flowing downstream through their village. **Toilets are usually two storeyed where the lower storey is storage**. Every time the toilet is used the waste is collected in the storey below it and mud is pored over. After a year (or less depending upon size of family) the compost generated is emptied from the waste collection room and used as manure on the fields.

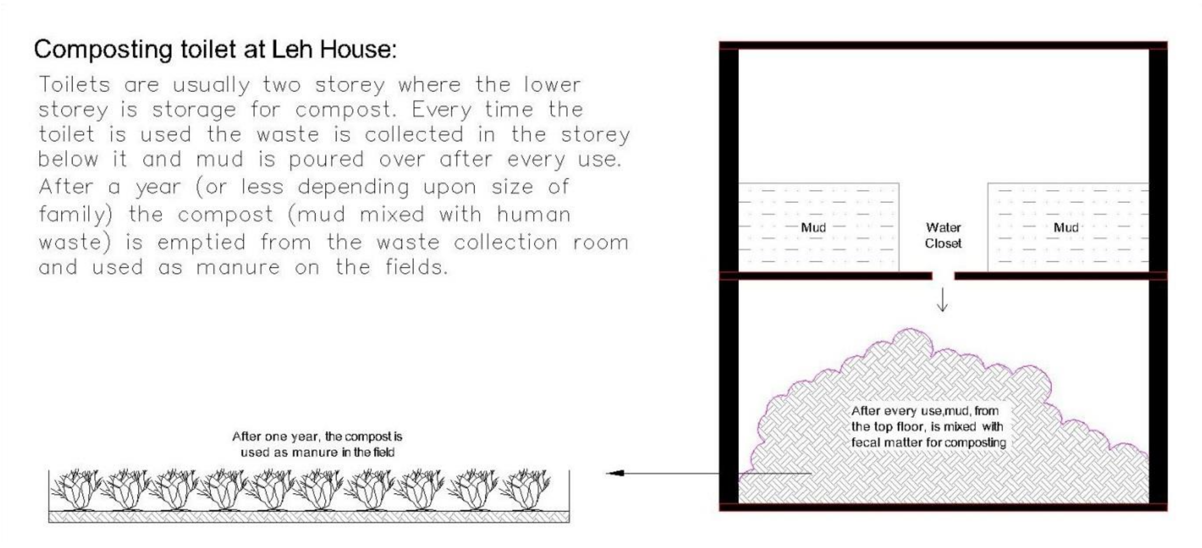


Figure6.12: Schematic showing how the waste is recycled in the house.

Figure6.13: Plan for PSH and toilet.

6.5 On-site monitoring for Indoor Environmental conditions

On site monitoring was done on 18^{th} September at 1 pm. During monitoring inside and outside air temperature, inside relative humidity, and inside lux level were measured. The monitored data is shown in

Table 6.5: instantaneous monitoring results

Parameters	DG	SW	AGH
Inside temperature (^{0}C)	23.4	19.9	21.1
Inside lux (Middle of room)	350	210	160
Outside temperature(^{0}C)	17.9	17.9	17.9
Relative Humidity inside (%)	26	20	20

6.6 Energy performance of PSH

Three PSH houses (DG, SW, & AGH) in Spiti were monitored[1] from 1 January 2009 to 11 April 2009. During monitoring temperature were measured inside and outside the houses. The results are shown in Table 6.6. The SW house is the warmest one among the three designs with minimum average inside temperature of 7^{0}C when outside minimum temperature is -14.4^{0}C. SW is about 21.4^{0}C warmer and on average PSH are 20.8^{0}C warmer. Analysis of all the data shows that minimum average temperature in a PSH never goes below 4.8^{0}C-5^{0}C.

Table 6.6: **Average temperature measured for three types of PSH design during winter period of 2008/2009 in Spiti.**

	DG room(^{0}C)	SW room(^{0}C)	AGH room(^{0}C)	Outside(^{0}C)
Average temperature for the full period	7.2	9.6	7.12	-8.13
Maximum temperature for the full period	11.57	12.97	11.2	0.87
Average of the minimum temperature	3.7	7	3.83	-14.4

Source: Monitoring data provided by LEDeG.

[1] Monitoring done by GERES and dataset were obtained via LEDeG.

Thus SW is the most efficient design of all. Recently another monitoring was done on SW houses. In this monitoring, temperatures at different depth of SW were measured during a winter day. The building has typical construction as shown in Figure6.7 with a difference in insulation. Roof insulation used in this building is 5 inches of sawdust. The wall was constructed with single layer of mud blocks with 2 inches of EPS as insulation. The results are shown in. It is seen that heat is stored in SW during day time and is dissipated slowly inside the room during night period. The time lag observed to be eight hours. The same house was modelled on a thermal performance measurement tool and simulation was performed for a year. 70% of energy saving was observed in SW house as compared to conventional local house. The results of these simulations are shown in Table 6.8.

Table 6.7: Annual fuel savings in PSH as compared to conventional house

	Consumption (Kg/house/winter)			Total biomass
	Wood	*Dung*	*Bush*	
Conventional house	613.06	673.82	336.81	1623.69
PSH	351.9	176.86	13	541.76
Fuel saved (Kg)	261.16	496.96	323.81	1081.93
Fuel saved (%)	42.60%	73.75%	96.14%	**66.63%**

Source: Monitoring data provided by LEDeG.

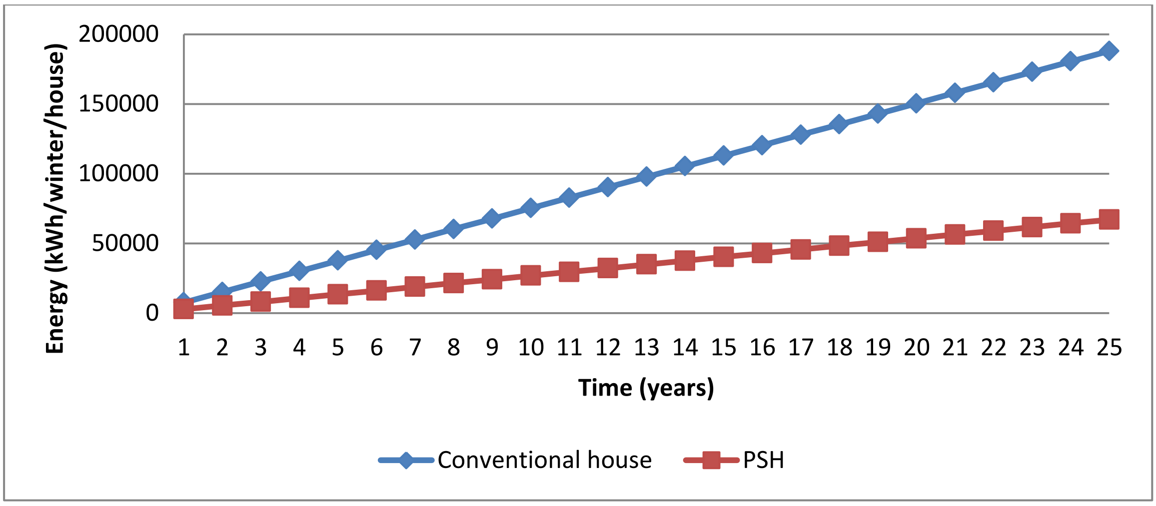


Figure6.14: Lifetime energy consumption in conventional house vs PSH

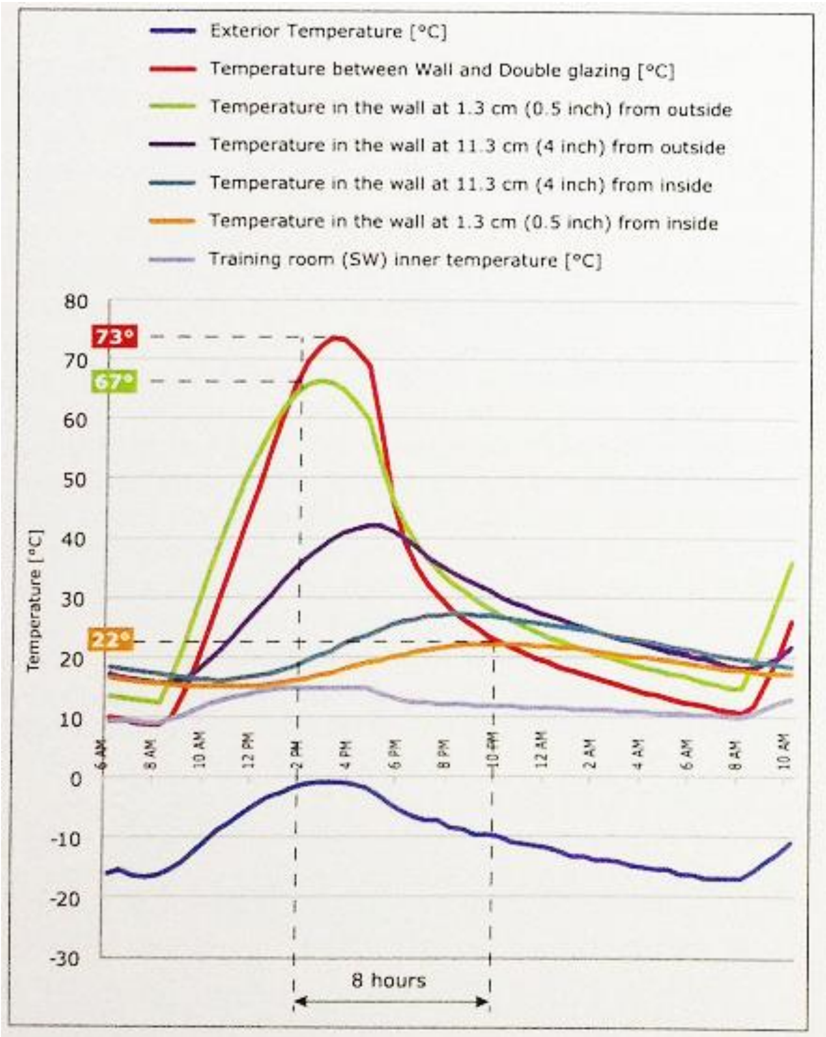


Figure6.15: Thermal performance evaluation of SW done on 12/01/2011. Source: Clottes Franck (December 2012). L.E.C. Integration Design Manual. GERES

Table 6.8: Energy simulation results for PSH and conventional house.

	Energy consumption, Tin=15^{0}C (kWh/year/m2)
Standard building	341
PSH (SW technology)	101
Energy Savings	*70.4%*

Source: Clottes Franck (December 2012). L.E.C. Integration Design Manual. GERES

6.7 Costing of PSH

The Table 6.9 shows costs of various components used in PSH's. The total cost of building a PSH 12 ft wide and 14 ft long comes around 1.4 lakhs, including labour cost. Per square feet cost comes around INR 830. Usually even this rate is expensive for people without proper livelihood. The GERES together with their local partners have come up with a model where they supply main PSH elements, like DG or SW wall material, windows, and insulation for walls. This reduces the cost to about half, i.e. INR 70,000 (in 2008). The prices are further reduced if the construction materials are locally available. Further in every village GERES and LEDeG along with other local partners have trained some of the locals from the village in construction technology of PSH. The community along with this, trained people help each other in constructing PSH in villages. This also brings down the labour cost.

Table 6.9: Costing of different components of a PSH. Price includes labour cost and material costs.

p	Cost	Comments
Passive solar windows (DG)	Rs 2154/Sq.m	Supplied by NGO, not available locally
Passive solar wall (SW)	Rs 1922/Sq.m	"
An 8 foot-width AGH (including timber frame and renovating inner south wall)	25,000	"
An 8 foot-width AGH (with local twigs and without renovating inner south wall)	15,000 to 20,000	"
Insulating one wall (double wall technique)	Rs 220/Sq.m	Done usually by Yakzes or sawdust
Insulating three walls (double wall technique: 4 inch sawdust + 1ft brick)	Rs 640/Sq.m	"
Roof insulation (6inch yakzes after compression)	Rs 160/Sq.m	Yakzes is locally available shrub, thus usually free of cost. As it grows naturally the embodied energy is zero
Floor insulation (2 options: poly bags with sawdust or trekking mats)	Rs 160/Sq.m	Locally available, free of cost.
Sun-dried mud block	0	Made onsite using local mud and without use of any machinery
Waste management (toilet waste)	0	The toilet waste is mixed with mud and used as manure on fields.

The cost saved from fuel savings is about INR 4000 per household per year, which is about 10% of the household income. Traditionally the houses are built using mud bricks and locally available wood and stone.

6.8 Payback time

To calculate payback time PSH with SW technique is chosen. Reason being 1) it is the most costly technique; 2) High quantity of manufactured material is required as compared to other two techniques.

For calculating energy payback time, the energy savings data from Table 6.10 is used. The difference between a traditional house and a house with SW is the use of double wall construction with Yakzes or sawdust as insulation. The SW is made from concrete blocks and covered fully with double glazed units. The double wall is made with mud blocks from locally available mud and no machines are used for making them. Thus they are considered energy neutral. Yakzes is locally grown shrub and sawdust is a waste by product and thus the insulation materials are energy neutral as well. Embodied energy is mostly in the concrete wall and double glazed glasses. The embodied energy of SW house calculated is 10.4 GJ (see Annexure 7). This is then compared with energy savings from the fuel used for space heating to get energy payback time.

For the cost payback time the cost of building SW is taken as rest of the building is constructed from locally available free material, i.e. mud from the area where the house is constructed, wood again from the land of owner, stone form same area. Cost of insulating walls and roof are included in the analysis. The cost of material and construction as mentioned in Table 6.9 is used for the analysis. The cost saving is from lower fuel consumption for heating in winters (see Annexure 7).

Table 6.10: **Cost and Energy payback time for PSH (with SW technique)**

Payback	Period (Year)
Cost payback time	10.5
Energy payback time	0.55

6.9 Summary of field interviews

Investment in PSH is initially higher than a regular house. People were earlier sceptical about the performance of the PSH and also their look was not like traditional houses. Therefore the NGOs set up couple of experimental houses in different village so that people could experience the benefits of the PSHs. This strategy was success and people who were happy with performance agreed to build PSG with the help of NGOs. Now people from various villages are requesting LEDeG (one of the key NGO which is still active in building PSH) to build more PSH for them. **But unfortunately due to limited funds the PSH cannot be built simultaneously in all the villages**. Priority of for LEDeG is far off remote villages.

With PSH people almost stopped using *bukhari* (traditional space heating technology) during the day time. At night time also due to better insulation the use of fuel for heating has reduced. This has resulted in big saving in terms of cost of fuel and time saved which otherwise went in collection of fuel. The PSH are very comfortable even at night and at sub-zero temperatures. People have in terms of better health in winters. Living in regular houses illness like cold, cough, and joint pain were common in winters but in PSH these have disappeared. The smoke produced inside the house by burning fuel has also reduced drastically. Children can study properly in winters and money saved from fuel can be invested in paying school fees of children as well as buying more rations. In winters it is impossible to get involve in income generating activities but in comfortable environment provided by PSH it is now possible, thus the income level of the household has increased as well.

The energy payback time is about half a year for PSH. The cost payback calculated using direct money savings from fuel is 10.5 years. If increase income parameter is also added then the cost payback reduces to about 5 years. Other benefit like improved health together with monetary benefits certainly outweighs initial investments. All the materials accept glass used for construction are green.

6.10 Affordability and green rationale analysis of PSH

Table 6.11: Affordability and green rationale analysis of PSH

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable Yes/No (Y/N)	Details	Cost	
	Sustainable site planning						
1	Tree protection	-	-		-	-	-
2	Soil preservation	-	-		-	-	-
Passive Solar Features							
3	DG wall	Rs 2154/m2	Traps heat during the day time.	Y	Concrete blocks/Mud blocks.	Rs 30/block, mud blocks usually free if procured from same site or locally.	Y
4	Solar wall	Rs 1922/m2	Stores heat during day time and dissipates in night	Y	Concrete blocks/Mud blocks.	Rs 30/block, mud blocks usually free if procured from same site or locally.	Y
5	AGH	RS 25000 for 8'-width	Traps heat during day and dissipates to adjacent room during night.	Y	Concrete blocks/Mud blocks.	Rs 30/block, mud blocks usually free if procured from same site or locally.	Y
6	Insulation in walls and roof	Rs 100/m2	Reduces heat loss	Y	No insulation	-	Y

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	**Cost**	**Green Rationale**	**Whether Affordable Yes/No (Y/N)**	**Details**	**Cost**	
Local sustainable materials							
7	Yakzes	Rs 100/m2	Locally available shrub which has good insulating properties.				
8	Double layered mud wall	Generally made by the owner himself using local mud, thus is free	Made on-site from sun dried mud brick with mud from the site itself. It has good heat storing capacity	Y	Sun dried mud brick	Made on-site from sun dried mud brick with mud from the site itself. It has good heat storing capacity	Y
9	Markalak clay	Cost free and available locally. Has water proofing property and also act as binder in mud brick.	Locally available shrub which has good insulating properties.	Y	-	-	Y
Waste Management							
10	Traditional toilets	-	The human waste is mixed with mud and then used as manure	Y	Traditional toilets	-	Y (Some improvising required)

6.11 Summary of cold climate

Table 6.12: Cold climate zone summary

Green features	Literature studies	Case studies	Other regional practices
Siting and climate responsiveness			
Orientation	Longer walls orienting towards North and south side		
Zoning	-		
Energy, renewable energy & building materials			
Roof treatment, roof garden	Wooden roof with thick insulation and water proofing.		Concrete blocks, Insulated roofs.
Shaded windows	Minimal shading for preventing rain & gable roof		
Walls to respond to outside climate	Trombe wall, dhajji wall, Taq wall	Sun dried mud block with Yakzes of saw dust insulation, Trombe wall, Direct gain, Attached green house.	Bamboo construction, rammed earth construction
Local materials to reduce embodied energy	Timber wood, deodar wood, bamboo, saw dust, mud, stone	Yakzes, Markalak clay, mud, saw dust, stone, rammed earth	Recycled tiles for roof.
Construction technologies to reduce time and volume of construction	-		
Natural ventilation	Through windows.		
Daylight integration	Through windows		
Efficient outdoor and indoor lighting by use of T5 lamps, CFL, LED etc	CFL lights in interior		
Efficient fans or other heating/cooling technologies	-		
Solar based outdoor lighting	-		
Solar based water heating	Solar hot water system for individual house	-	Solar hot water system for individual house
Solar PV panels to generate electricity	Solar heating and geysers, Solar water pumps, heating through solar PV energy generation	-	Solar heating and geysers, Solar water pumps, heating through solar PV energy generation

Green features	Literature studies	Case studies	Other regional practices
Efficient landscape design			
Pervious pavers	-		
Sedimentation control measures in the landscape design	-		
Use of native species	Yakzes		
Source of landscape water from recycled water	-		
Irrigation equipment	-		
Water management			
Waste water treatment system	Tertiary Treatment Plants for 100% recycling of waste water, (grey water) is treated through root zone treatment	Waste water mixed with mud and human waste to generate manure.	
Rain water harvesting	Rain water harvesting and recharging through drains, percolation pits, trenches and wells		
Dual plumbing system	-		
Efficient plumbing fixtures	Low flow plumbing fixtures, faucets with aerator, water level controllers, pressure regulating devices	-	Energy efficient motors, dry toilets,
Waste management			
Segregation of waste	-	Waste segregation of dry and organic waste	-

7 Field Case studies under Hot and Dry Climate zone

7.1 Mr Surya Kakani's House, Ahmedabad

7.1.1 Site location

Mr Kakani's house, located in Ahmedabad, Gujarat, is a renovated house of 1950s. The duplex was furbished in 2010 to triplex house for 2-4 people. The architect and owner of the house are same.

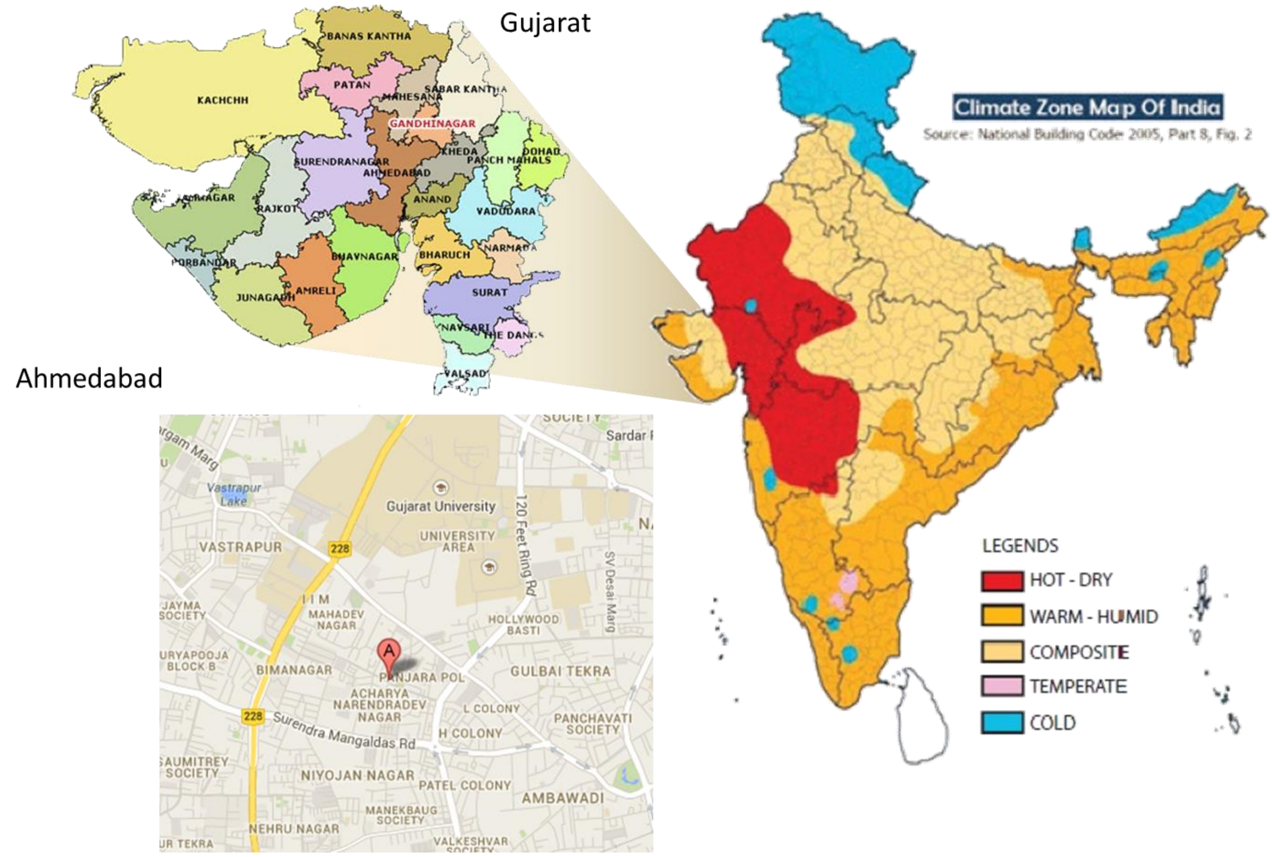


Figure7.1: Location of Mr Surya Kakani's house

7.1.2 Project Profile

A brief profile of the project has been depicted below:

- Project name : Surya Kakani's House
- Construction : 1950s
- Renovated : 2010
- Climate (as per NBC) : Hot & Dry
- Location : Ahmedabad
- Coordinates : 23.0, 72.5 (Aprox)

- Site area : 210 Sq.mt (2260 sq.ft)
- Total Built up Area (Sq. mts) : 264 Sq.mt (2841 sq.ft)
- Architect : Mr Surya Kakani
- Total Cost for Renovation : Rs. 10,56,000
- Skilled level of labour : High
- No of Units : 1 (Triplex house)
- Green technologies/features incorporated : Façade treatment – with respect to orientation, Rain water harvesting, Ground water recharge, Waste Water Treatment and reuse, Green Construction practices, Use of local materials, Biodiversity and use of indigenous species in landscape, preserving existing ecology, Naturally daylight and ventilated, wind catcher system

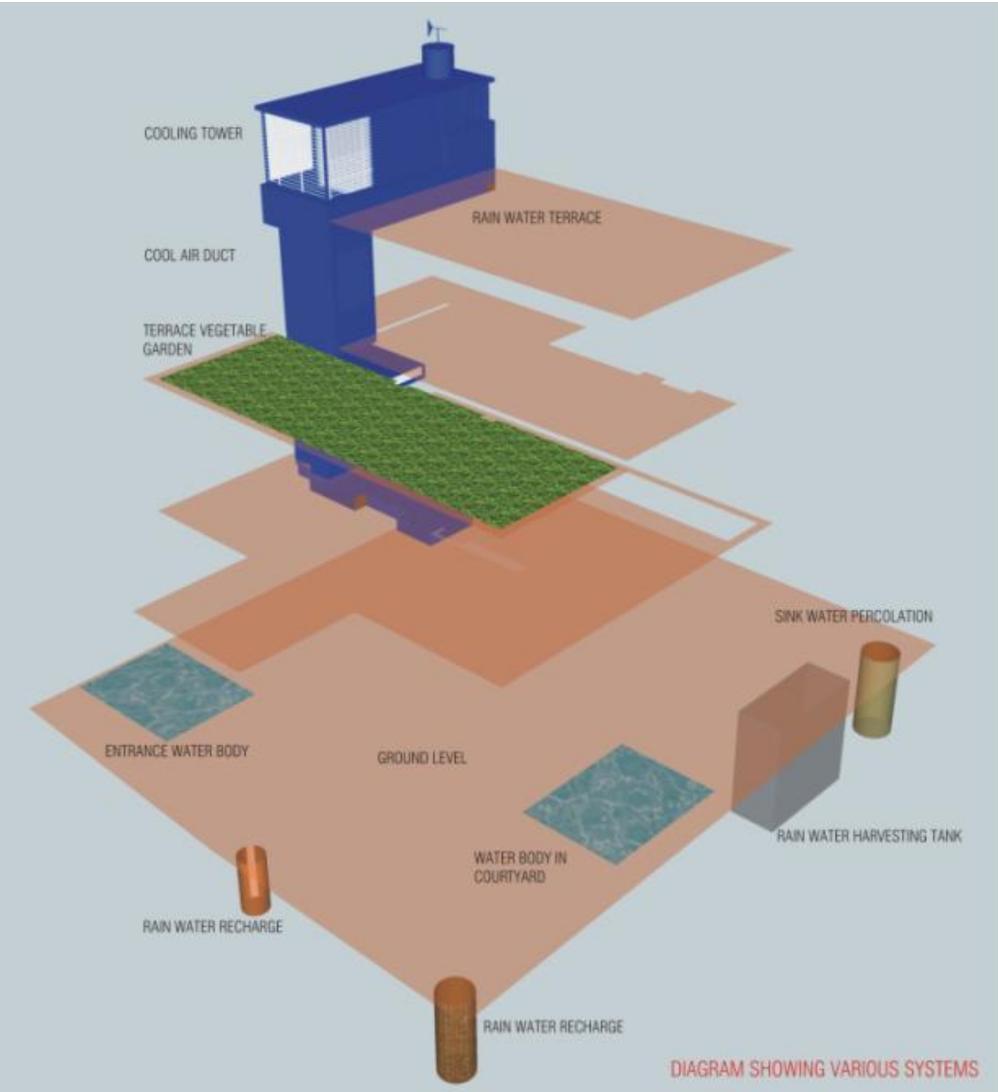


Figure7.2: Green features layout

7.1.3 Project Brief

The house was chosen for case study based on its passive features and reduced energy consumption. The occupants live in comfortable indoor environmental conditions without any air-conditioning.

Old walls retained   Demolished walls   Newly added walls

Figure7.3: Floor Plans (Left: Ground Floor, Right: First Floor)

The house is a semidetached duplex building sharing the south wall with neighbours. North and East sides are exposed to open areas and are shaded with trees while west side is semi open with neighbourhood at close by distance. The building was initially duplex which was converted to triplex by adding a library room above the first floor.

Figure7.4: Outdoor and indoor view of Mr Kakani's house

The below case study description entails only about the renovated/reconstructed/newly incorporated features. No old construction's features like the thick walls are analysed under cost or green rationales.

7.1.4 Details of green features in the project:

Renovation and Re-construction

Mr and Mrs Kakani owned an existing home in 2000 which they renovated in the year 2010. The house was initially built in 1950s which is still under good condition. Initially the architect's idea was to raze the structure and re-built a new one. However, realizing the potential features of the existing building's profile like the thermal walls (thick walls) etc and huge construction waste that will come out by tearing the building down, it was later decided to renovate instead. The first green step of the house has begun here by reducing and saving carbon emissions and cost respectively.

Figure7.5: Before, during and after renovation of the house respectively

Tree protection, landscape and bio-diversity

Existing trees were retained after owning the property. Further, native species plantation and vegetable garden on terrace are other ecological considerations under landscape. As per the occupant they experience good bio-diversity in the vicinity.

Various plantation species of the landscape that includes native species are:

Champa, Bougenvila, Paras, Juee, Chameli, Malti, Madhumalti, Kailashpati, Sitashok, Mogra, Brahmi, Nagarvel (paan), Madhunashini, Morpankh, Kaurav-pandav(krishnakamal), Water lilies, Kadipatta, Lemongrass, Tulsi, Damro, Amba haldi, Borsali, Parijat, Charoli, Madhukamini, Thor, Sontak, Desi gulab, Seasonal vegetables

Figure7.6: Top left: old house, Top right: During renovation, Below Left: After renovation, below right: Vegetable garden on terrace

The existing plantation before construction is retained while additional vegetation like terrace garden is built. The below images explain the bio diversity found within the vicinity of the house.

Figure7.7: Bio-diversity found in the vicinity (Images provided by Mr Kakani)

Pervious paving

The soft scape of the site is 64.Sq.m which includes trees, bushes, shrubs, terrace garden and lily ponds, while the hardscape consist pervious paved area built with Nimaj stone (kota cousin, leftover waste stone) and terracotta lime brick (from waste brick) pavers used in 2 mm gap for water percolation. Cost of local stone is Rs 300/sq.m and brick paver is Rs80/sq.m. The material has very low embodied energy which contains construction waste and is acquired locally. There is no bonding material used between bricks/stones.

Figure7.8: Nimaj stone and waste brick paved pervious surfaces

Alternative Energy efficient materials

All the building materials used in the project are transported locally, i.e. within Gujarat or Rajasthan. Most of the materials acquired are either traditional or recycled, thereby reducing the embodied energy to maximum.

Walls

Most of the existing walls were retained to avoid construction waste and further requirement of new materials. All the existing and new walls were built with bricks and finished with lime plaster. **The external wall finish is made of 'Lapti+lime jikki' and internal wall with 'lime jikki'.**

The building is a load bearing structure with wall thickness of 350mm. This thickness performs as a thermal mass. In Ahmedabad the climate is constantly hot for longer period of a year and has large temperature swings between day and night. Thermal mass effect can actually be detrimental in such conditions. The huge mass of the existing house helps in thermal lag and thereby reduces the need for additional thermal insulation.

The wall finishes are treated with lime plaster containing marble waste which has good thermal resistance and washable gloss finish. The material is locally available and also has very low embodied energy. The cost of lime plastering is very economical against conventional cement plastering. As per the occupant's experience and architect's explanation, lime plaster is found to be helpful in controlling the surface temperatures and is very easy to maintain.

Table 7.1: Cost comparison of surface finishing material

Project Case			Conventional Case		
Material	**Cost**	**Embodied energy**	**Material**	**Cost**	**Embodied energy**
Surkhi Lime plaster	Rs 350/sq.m	91 MJ/sq.m	Cement mortar + paints	485/sq.m	32 MJ/Sq.m
Jikki Lime plaster	Rs162/sq.m				

Figure7.9: Images showing internal wall thickness and wall finishes with lime plaster

Surkhi Lime plastering process

Wall plastering with lime mixed with Surkhi is done by mixing molasses, lime, fenugreek and commiphora as a mix. The ingredient of the plaster (one mixer load) has been tabulated below:

Table 7.2: Lime plaster ingredients

Ingredients	Proportions	Preparation of individual components
Lime	Lime: River sand: Surkhi = 6 : 8: 7 proportion	
River sand		
Surkhi		
Jute fibre	5 gms/mixer load	
Molasses	1 litre/mixer load	15 litres Molasses + 200 litres water
Fenugreek – Commiphora mix	1 litre/mixer load	Summer : 200 litres water+200 gms fenugreek+100 grams commiphora Winter : 200 litres water+200 gms fenugreek+200 grams commiphora

The plaster is applied in similar manner to conventional cement mortar application: The mix is thrown to wet wall with the help of trowel. A wooden planer is used to spread the plaster for coarse finish of 6mm thickness. After plastering, 24hours is given for setting, following which curing should begin (water to be sprayed thrice a day in summer, twice in winter over a jute cover on plaster (not directly). The curing should be carried out for a minimum period of 3 days. The application of the second coat should not be earlier than 4 days after the first coat is applied. Second plaster coat- same mix as in first coat (patra finish) jute not to be used. Line and level to be checked and finalized in this coat. Roughen surface lightly to prepare the base for the final cost.

Roof

The existing RCC roof of the house has been retained which was further treated with roof garden above it. The image below shows various sectional details of the green roof. Green roofs are known for heat resistance, therefore stabilises the indoor temperature underneath and improves thermal comfort.

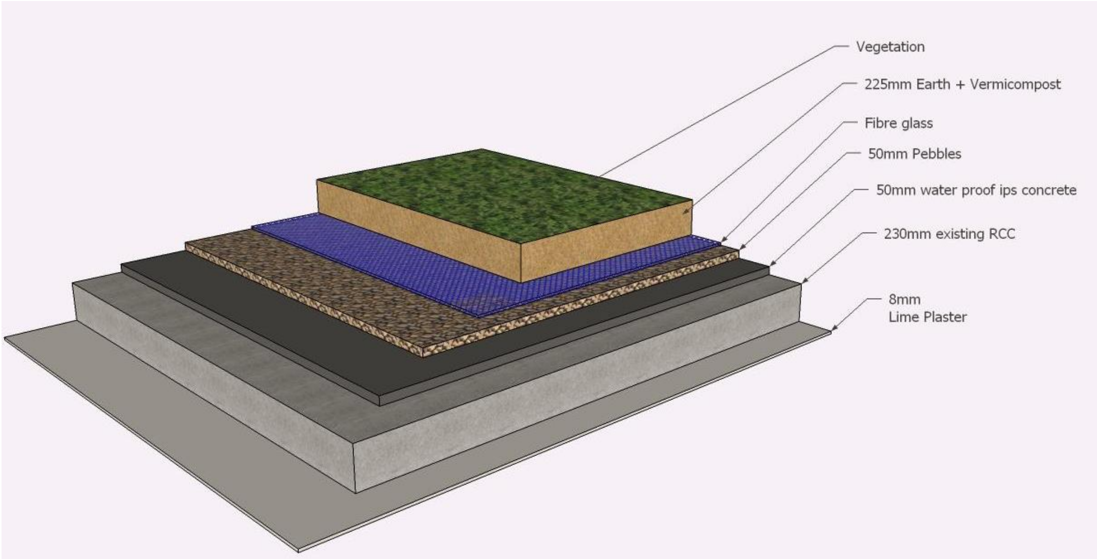


Figure7.10: Roof section for terrace garden

Library room was built above the first floor which has a roof area of 37 Sq.mt. this area is being used as rainwater catchment. The roof is built of RCC and an additional layer of brick waste (from demolished walls debris), sand and waste thermocol for insulation has been added. The exterior roof finish is treated with a white reflective coating to reduce the heat gains through radiation.

Figure7.11: Left: Terrace garden roof image Right: Insulated roof during construction (Image provided by Mr Kakani)

In conventional practise RCC roof is provided usually without any additional layer of thermal insulation. However currently many practises use brick bat coba or puff as insulation in addition to RCC slab. Cost analysis of the current project case is hence compared with these two materials. In the case study, cost for the insulated roof (waste brick, lime, sand, waste thermocol) is calculated to be economical by Rs.500/sq.m, in comparison to a roof with brick bat combat and china mosaic which costs around Rs 540/Sq.m or puff insulation of Rs 2250/Sq.mt

Figure7.12: left: demolished wall's construction waste used for roofing, right: thermocol waste for insulation (Images provided by Mr Kakani)

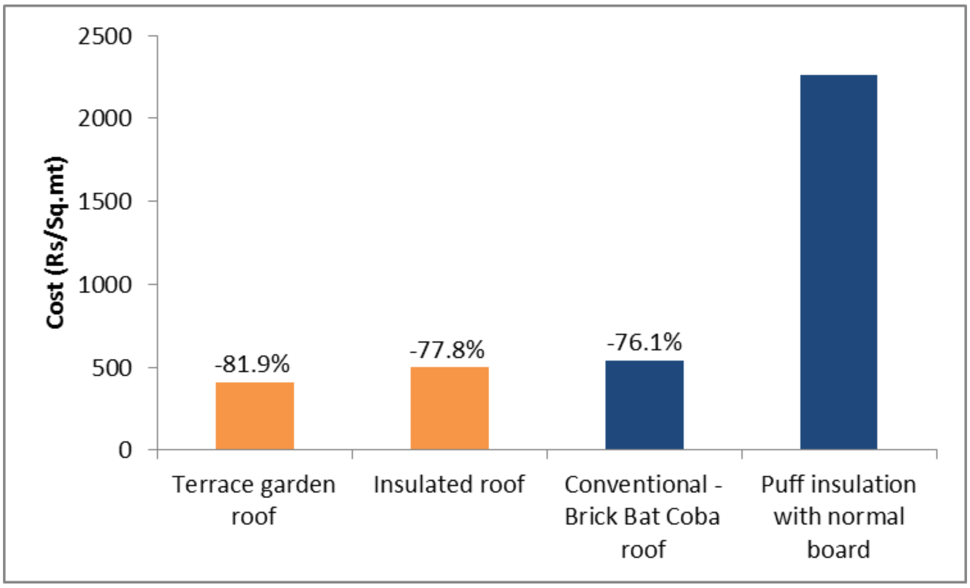


Figure7.13: Cost comparison of conventional practice against the roof types in the case study

Roof insulation is required for hot and dry regions to control the solar heat gains. The analysis explains that terrace garden roof is a very economical solution for climatic performance in comparison to the brick bat coba or puff. Based on the observation made by TERI team during the field visit, the insulated roof (brick waste + thermocol waste) is not performing as predicted because of poor performance of the reflective coating. This can be rectified by adding an additional layer with reflective tiles.

Flooring

Initially the existing building had a terrazzo flooring which was renovated with 40mm thick *Nimaj* stone. The material is a natural stone with low embodied energy and is available locally.

Figure7.14: Stone flooring

The material is however not cost effective at Rs 645/Sq.m against a low cost conventional material like terrazzo flooring at Rs 388/Sq.mt. Vitrified tiles usage is the most conventional practise in the region which costs Rs 560/Sq.mt.

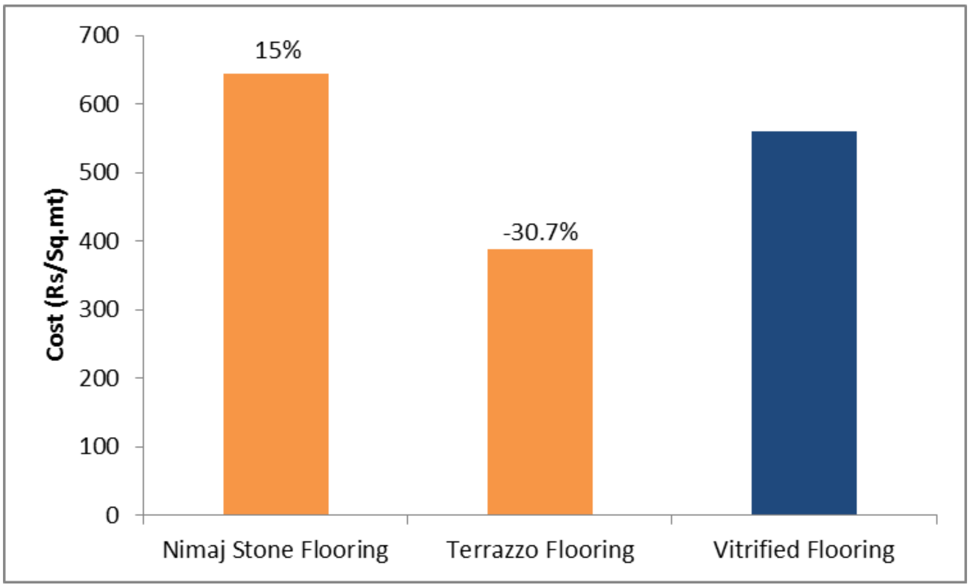


Figure7.15: Cost comparison of conventional practice against the flooring material in the case study

Door &Windows:

Doors and Windows along with the frames are made up of recycled old teakwood which is available locally. Glass is provided only for the north windows while the remaining windows are fitted with louvers system for diffused day lighting and reduce solar heat gains. Although the material is expensive, it has recycled content and is locally available. The material application is therefore a green practise however is not economical.

Passive Design Features

The renovated design house has been optimized with improved natural ventilation and day lighting strategies. North light is used for library space while east and west windows are provided with louvers to control the direct light and control glare while allowing natural ventilation.

Figure7.16: Images showing the day lighting quality on a typical equinox season (during field visit).

Design of cross ventilation in the house is observed to be an outstanding feature in all living spaces. The cooling tower is a supporting element to enhance the ventilation performance during discomfort hours.

Figure7.17: Clockwise: Wind catcher outlet, external louvers to provide privacy and direct ventilation, internal ventilation openings between kitchen and staircase, window louvers system to open natural ventilation while controlling direct sunlight

The building envelope with thermal mass of 350mm thick walls and insulated roofs helps in controlling the indoor thermal conditions. Water bodies (lily ponds) provided on east and north sides help in evaporative cooling during dry summer period. As per the occupant's interview, no artificial lights are required during daytime all year round. No air conditioning is installed. Ceiling fans are used for 8 months in a year during discomfort hours.

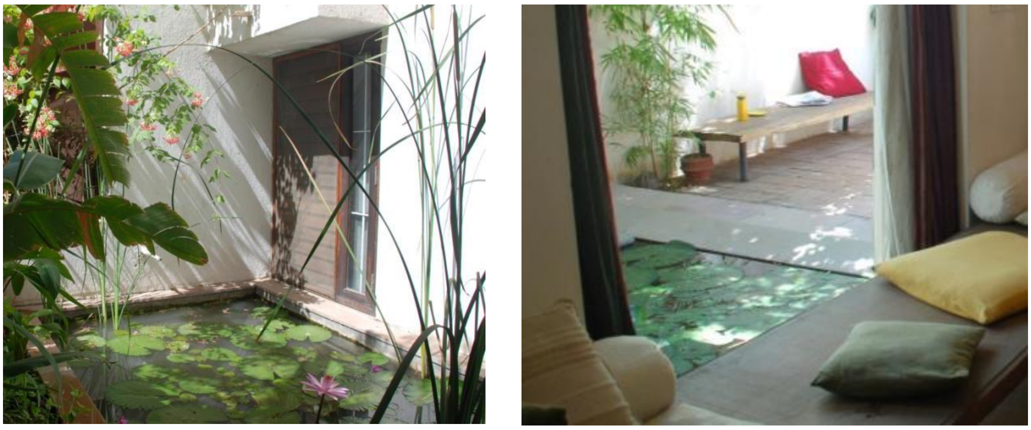


Figure7.18: Water bodies/lily ponds for evaporative cooling in summers

Wind catcher/Cooling tower

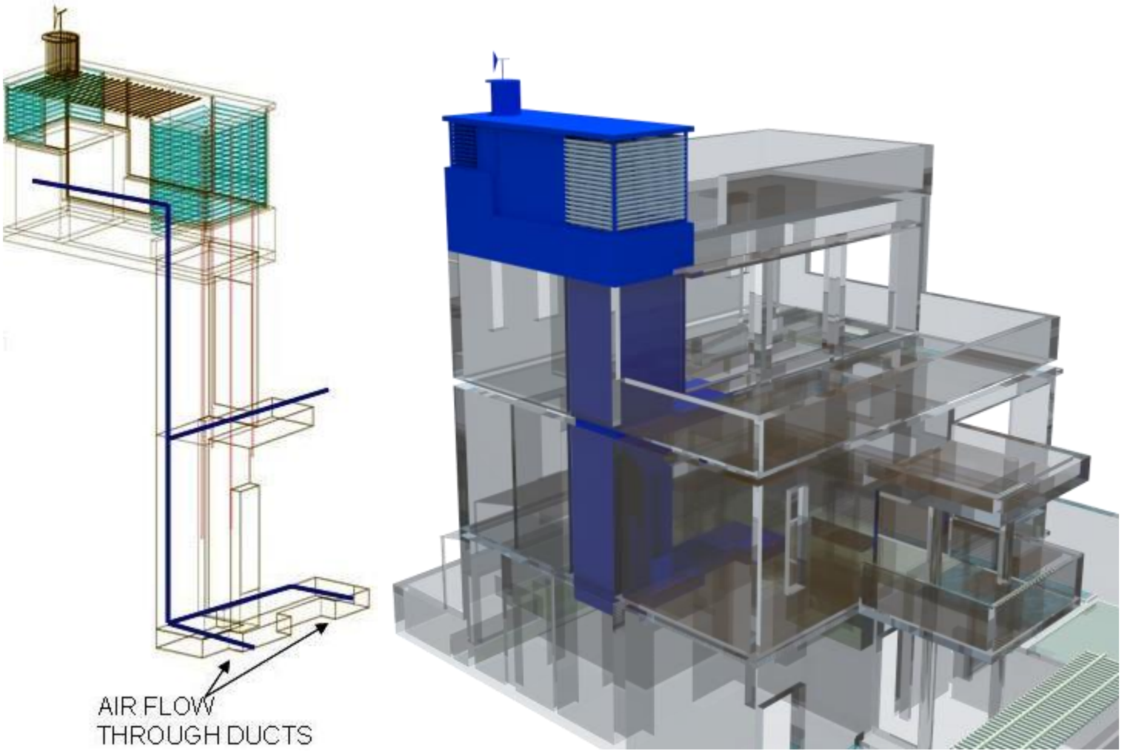


Figure7.19: Wind catchers and duct connecting all living spaces

One of the notable features in the residence is the cooling tower which was designed to reach all the living spaces at ceiling level. The system provides the additional cooling required in the house when the ambient conditions are extremely hot. The tower acts as a wind catcher receiving fresh and cold air to living spaces during summer nights and works in reverse direction with stack effect by removing hot air from living spaces during summer day times. In winter the tower is mostly closed from usage.

Figure7.20: Left: Cooling tower inlet, middle & right: Tower outlets

Usually the cooling towers are applied with downdraft system for evaporation. Since in the recent years Ahmedabad is experiencing higher humidity range in monsoon season, the occupants explain that they do not intend to use any downdraft system which would increase humidity range. Despite to the usage of evaporative system, the cooling tower is however able to enhance the air changes in the house.

Energy Consumption

Wind Catcher

The entire house benefits from natural day lighting and ventilation. No artificial lighting is observed to be in usage during day time for an entire year. As per the climate zone, high amount of energy for cooling and heating would be required to meet comfort standards. Wind catcher is highly effective in this aspect by adding ventilation rate with less or no additional energy. However peak temperatures and stuffiness is not met completely by wind catcher and hence mechanical ceiling fans are being used to overcome the stuffiness during extreme ambient conditions.

The house is therefore able to save a **high amount of energy annually by having wind catcher as an alternative system for cooling.** Cost effectiveness of the cooling towers is understood by comparing with a conventional cooling system. Dessert coolers are more appropriate for hot and dry regions which are economical than air conditioners to conventionally cool a living space. Therefore the comparative analysis is performed for wind catcher against dessert coolers.

Various assumptions were made for analysis: As per the occupant's usage, cooling requirement is assumed to be for 7 months in a year (Hottest period), 14 hours/day for 6 days and 24 hours for one day in a week (Total of 3488 hours in a year). Cost variation of equipment, maintenance, energy bills in 50 years are not considered in the analysis. In green case, ceiling fans are considered for energy consumption. Therefore the equipment and energy costs of ceiling fans have also been considered in this case. As per HVAC consultant the house requires 8000 cfm cooling. With this consideration, the size of the wind catcher has been designed for a capacity of 450 Cu.m.

Table 7.3: Cost comparison of wind capture and desert cooler

	Wind catcher (Green Case)	**Dessert cooler (Conventional Case)**
Initial cost	(*Construction cost for 450 cfm capacity tower + 4 ceiling fans*) 30,000 + 8,000	(*4 coolers of 0.24kw to meet cooling load*) 57,663
(approximate) annual energy consumption (kwh)	1,004	3,448
(approximate) energy consumption in 50 years (kwh)	2,91,317	9,99,903
Total (approximate) cost in 50 years INR	(*Including ceiling fans usage*) 3,21,317	12,88,220

The analysis clearly shows that the initial cost of the conventional case is costlier by 47% than the green case. Nearly 70% of operational energy can be saved annually with wind catcher and ceiling fans against conventional dessert coolers. Hence the system is identified to be economical and simultaneously sustainable.

Solar Water Heater

Hot water system is required in Ahmedabad during winter and monsoon seasons i.e. 5 months in a year. Water heating in Mr. Kakani's house is supported by solar energy with 200 litres capacity.

Figure7.21: Solar water heater on terrace

In a conventional practise water heating geysers are typically used. The energy consumption and cost saving by having Solar Water Heating system against conventional geysers has been performed.

It is assumed that two geysers units would be required for two bathrooms to meet the hot water demand in the green case. Each of with 20 litre capacity would cost Rs 10,000 approximately.

Table 7.4: Cost comparison for solar water heater and electric geyser

	Solar Water Heater (Green case)	Electric Geyser (2no.s) (Conventional Case)
Initial cost (INR)	35,000	20,000
Unit cost in 50 years with 4 replacements (INR)	1,40,000	1,60,000
Energy Consumption per year (Kwh)	0	2,470
Energy Consumption in 50 years (Kwh)	0	1,23,540
Total Investment in 50 years (INR)	1,75,000	3,06,010

Although the initial investment of renewable energy system is 75% higher than conventional system, in lifetime the latter is expensive by 12%. In additional, electricity of 426 units would be required annually by the geysers which would cost Rs 2470/year.

Water Management

Water balance

Total water demand for the house is 600 lt/day in which 20 lt/day is consumed by drinking and cooking. This water is acquired from rain water collected in a tank of 15000 litres capacity. Excess rainwater is percolated for ground water recharge. The building also uses municipal water supply in bathrooms, washing machine and terrace gardening. **Water from washing machine is collected to a tank beneath it and then diverted to a 300 litre tank on terrace which is then used for flushing purpose**. Waste water from bathroom and kitchen sinks is used for irrigation and percolation.

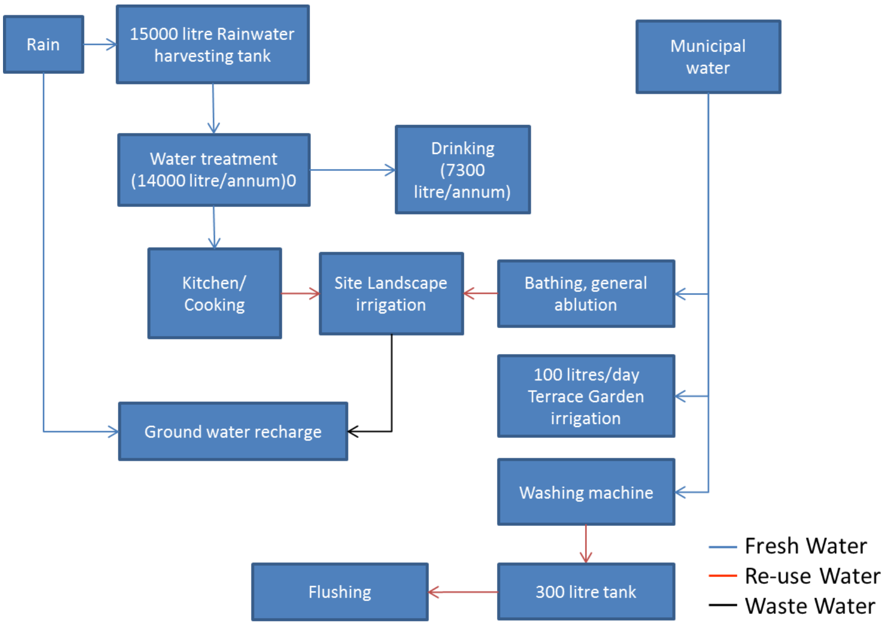


Figure7.22: Water balance Diagram

Rain Water Management

Rainwater is harvested for drinking and cooking which is collected in a tank of 15000 litre capacity. Excess quantity is diverted to ground water recharge pits through soft scape in courtyard and site corridor. The first two showers are left to wash away dust and unwanted particles from catchment area. The catchment area is cleaned before the water is collected into the tank. The total cost of the storage tanks is Rs. 90,000 (approx.) and plumbing of Rs.9,000 for 15000 litres storage tank.

Figure7.23: Left: Rain water system plumbing lines, Right: Soft scape for rainwater recharge

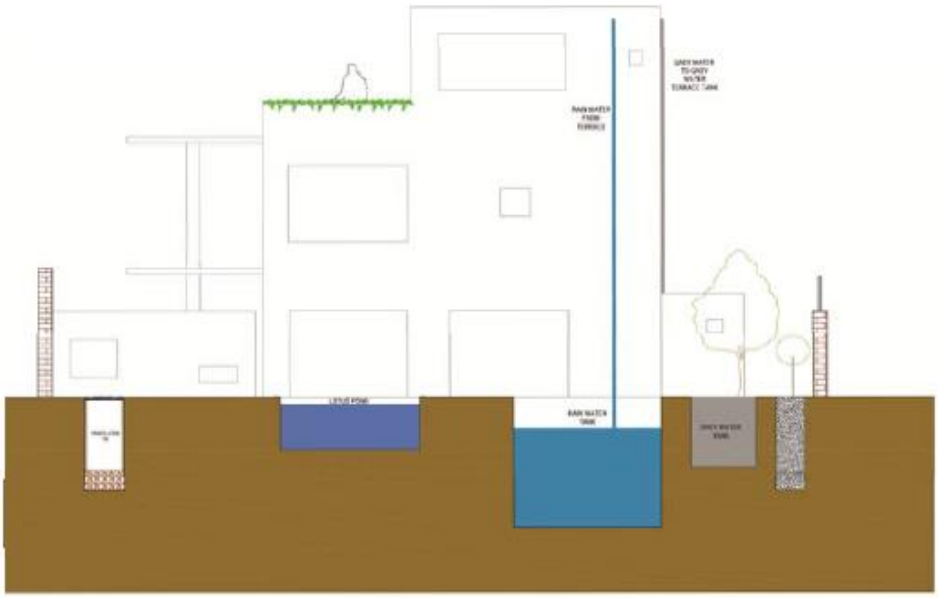


Figure7.24: Sectional image showing rainwater management

7.1.5 Instantaneous Performance Measurements

Instantaneous measurements were taken for few main living spaces during the field. Thermal and day lighting measurements were taken with the help of globe meter and lux meter respectively.

Ambient conditions at the time of measurement:

Time: 11:45, **Date**: 20/09/2014

Sky Condition: Clear & sunny

Surface Reflectivity: Roof: 0.7, Walls: 0.5, Floor: 0.3

Table 7.5: Day lighting performance Measured

Room	Avg Lux	DF Measured	NBC Recommended DF
Living Room	350	4.0%	0.625
Kitchen	200	3.1%	2.5
Bedroom 1	250	4.0%	0.625
Bedroom 2	345	4.1%	0.625

Table 7.6: Thermal performance Measured

	MRT (^{0}C)	DBT (^{0}C)	RH (%)
Outdoor		33	58
Ground Floor	29	29	66
First Floor	29	30	62
Second Floor	30	30	63

7.1.6 Summary of data collection and interview during field visit

As per the interviews, observation during field visit, the architect who himself is an occupant of the house has experimented various technologies for cost effective approach towards a sustainable performance of the house. The cost spent for renovation was considered as very economical and the design that helps them stay comfortably without the need of conventional cooling has reduced their maintenance costs further. The occupants who are currently using the rainwater for domestic consumption, intends to extend the usage for landscaping in future.

The house has majorly benefitted from reducing wastage by using the existing or debris of old elements demolished. Maintenance of finishes is also convenient and easy due to the long life and washable feature of the lime plaster. Nimaj stone is used with textured/rough finish to reduce the stress on knees while walking or standing. The practise can be replicated in most new constructions as well where the waste materials can be acquired from nearby sources. The materials are majorly supplied from local or nearby regions. **The construction technologies would require highly skilled masons and labour which is very scarcely available now**. These skills existed in past when most vernacular buildings were built which are highly energy efficient and environmental friendly. However, modernization is overpowering these skills and the architect urges to harness this strength before its existence fades out completely.

7.1.7 Case study summary

Table 7.7: Case study summary

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	**Cost**	**Green Rationale**	**Whether Affordable Yes/No (Y/N)**	**Details**	**Cost**	
1	Protecting existing vegetation and bio diversity	No cost	Preserves bio diversity and ecological values	Y			Y
2	Pervious paving with Nimaj Stone, pavers With waste brick	Rs 194/sq.m	Controls Heat Island effect and enhances percolation of Storm water & run off control, recharges ground water.	Y	Concrete pavers, impervious paving	Rs 500/Sq.mt	Y
3	Wall finishes using basecoat surkhi or jikki lime plaster	Rs 350/sq.m (surkhi lime plaster) Rs162/sq.m (jikki lime plaster)	Low embodied energy, Recycled material, Long life, Low thermal conductivity, Local material, Low maintenance	Y	Internal cement plastering with Plastic/matt paint finish	Rs. 485/- per Sqm	Y
4	Terrace garden roof	Rs. 409 Sq.mt + RCC cost	Thermal control, vegetation growth,	Y	Brick Bat Coba	Rs. 540 Sq.mt + RCC cost	Y
5	Insulated roof with waste thermocol and brick	Rs. 500 Sq.mt + RCC cost	Thermal control, reuse material	Y	Brick Bat Coba	Rs. 540 Sq.mt + RCC cost	Y
6	Nimaj stone flooring	Rs.645/sq.m	Natural stone Low embodied energy Locally Available	Y	Terrazzo Flooring Vitrified Flooring	Rs 388/Sq.mt Rs 560/Sq.mt	Y

Sl no.	Green Feature in Case study			Whether Affordable Yes/No (Y/N)	Conventional Features		Replicability in Affordable housing
	Details	**Cost**	**Green Rationale**		**Details**	**Cost**	
7	Solar hot water system	Rs. 35,000	Energy saved and carbon emissions reduced. Saving in longterm. 6 years payback time	Y	Electric Geysers (25 litres capacity per bathroom)	Rs 20,000	Y
8	Recycled teak wood for interiors and door window schedules	Rs 8608 /Sq.mt	Low embodied energy and recycled content	N	Normal wood	Rs 6456/Sq.mt	N
9	Rain Water Harvesting	Rs 2,00,000 (approx.)	Ground water recharge and re use	N	No system	-	N

7.2 Field study of Savvy Solaris

7.2.1 Site location

Solaris project located at Motera neighbourhood of Ahmadabad is a residential community development in **11235 sq.m**. It is a green building applied for IGBC rating. The coordinate of the place is 23.1N, 72.5E with an altitude of 30m above sea. level. It is located close to the railway station, 3km from airport and 8km from city Centre. Ahmedabad experiences hot and dry climate as per NBC 2005.

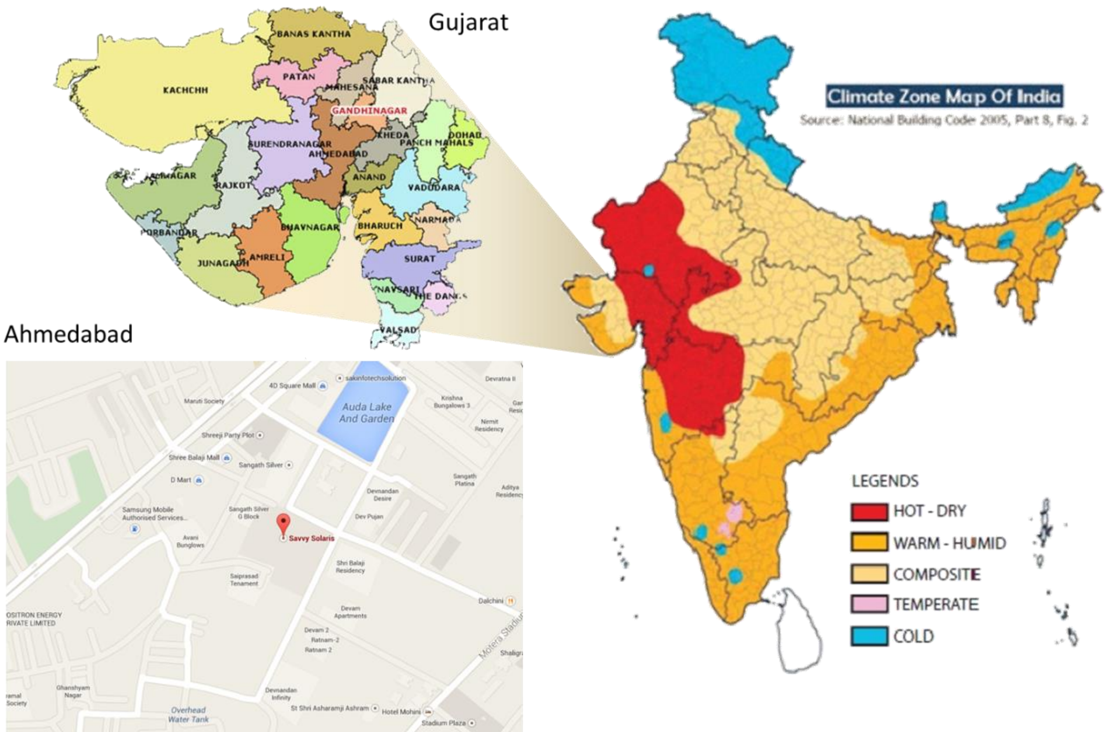


Figure 7.25: Location map of the project

Figure 7.26: Solaris residential apartments

Figure 7.27: Site plan of the project

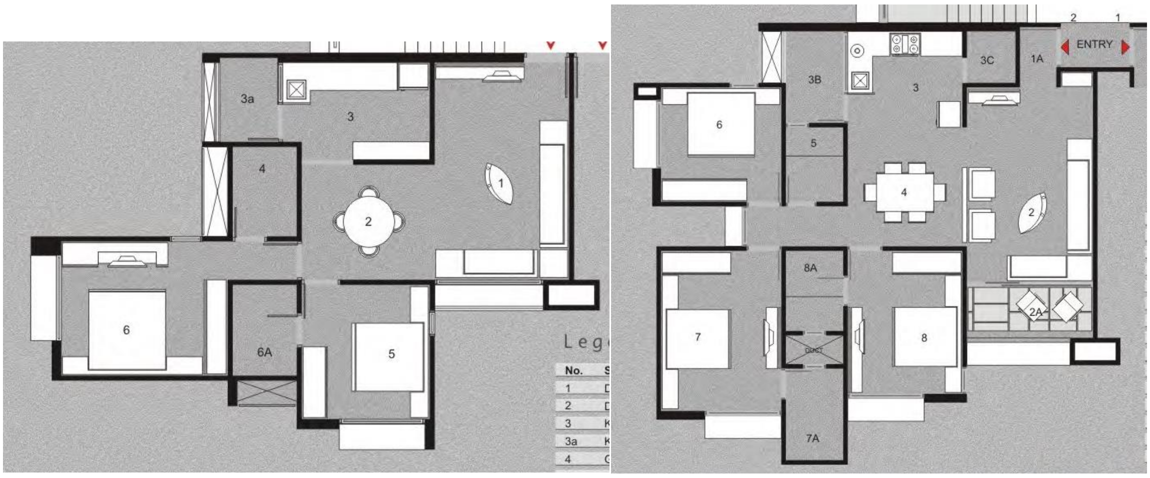


Figure 7.28: Typical Floor plans. Left: 2BHK, Right: 3BHK

7.2.2 Project Profile:

A brief profile of the project has been depicted below:

- Project name : Savvy Solaris
- Year of construction : 2013
- Location & Address : Motera, Ahmedabad

- Coordinates : N23.1, E72.5
- Climate (as per NBC) : Hot & Dry
- Site area **: 11235 sq.m**
- Architect : Mr Apoorva Amin
- Developer : Savvy
- MEP : Spectral & Trans Energy
- Any energy performance certifications : Constructed in compliance to IGBC,

however not applied for final certification

- Total Cost of Construction : Aprox *Rs 40 lakhs*

(purchase cost of a 2BHK)

- Typology of building : High rise apartments
- Floors : 10 & 11
- Total Built up Area (Sq. mts) : 2943 sq.m
- No of dwelling units : 348 Units
- Floor Area Ratio (FAR) : 0.26
- Type of Units (with quantity) : 2bhk: 170, 3BHK:178
- Built-up area of each unit type : 2BHK: , 3BHK:
- Dwelling density : 125.63 /acre
- Green technologies/features incorporated : Rain water harvesting, Ground water recharge, Waste Water Treatment and reuse, Solid waste management, Green Construction practices, integrating craft into the design, Use of local materials, Biodiversity and use of indigenous species in landscape, preserving top soil and ecology.

7.2.3 Details of green features in the project:

Site planning & landscape

Top Soil preservation: **Top soil for the site has been preserved prior to construction** of the Solaris project, which helps in growth of new sapling for plantation on site as against conventional sites where top soil is not preserved. Preserving top soil involves collection, storage and maintenance cost of Rs. 17/cu.m. In conventional sites, the cost for purchase of top soil involves supply, staking and mixing of sludge, manure, sieving accounting to Rs.228/cu.m. Hence, protection of top soil during construction is affordable and has the potential to be replicated in affordable housing.

Landscape paving materials:

Soft paving

Landscape **soft paving is executed using grass, or mulching, to maximise ground water percolation.** The cost of paving is Rs.4/sq.m. In conventional cases, perviousness of site is reduced due to increase areas of impervious paving without ground exposure. The cost is approximately Rs.350/sq.m. Hence, pervious paving laying is affordable and has the potential to be replicated in affordable housing.

Figure 7.29:Soft paving, with grass

Hard paving:

In pavement areas for circulation, pedestrian and automobiles; impervious paving in the form of concrete pavers and PCC flooring with high SRI finish are provided. Concrete pavers help in water percolation through joint and control storm water management and ground water recharge. In both the type of flooring system, high SRI finish reduces heat island around the building. In conventional scenarios, hard paved area has less percolation capacity and low SRI finish. Hence, heat island effect would be high and storm water control will be minimal. In both the scenarios, case study & conventional case, cost will be similar in the range of Rs. 300-350/sq.m. Therefore it will be beneficial, environmentally, to replicate concrete pavers and PCC in affordable housing.

Figure 7.30: High SRI PCC pavement and interlocking concrete pavers

Building Envelope and civil works:

Building plan is rectangular in form. The Window to Wall ratio is less 20%. The green materials used in Solaris have been described below.

Walls

All external and internal walls are made of **AAC block masonry** which helps in lower heat transmission and maintains lower temperature in the interior space than outside. The wall photographs have been depicted below.


Figure 7.31: Autoclaved aerated concrete masonry wall for external wall

AAC is more environmentally sustainable in comparison to conventionally used concrete block as it has less embodied energy with 197 MJ/sq.m (source: auroville earth institute) as against 235 MJ/sq.m for concrete block. (Source: GRIHA Volume 4, Criterion 16- Reduce embodied energy of construction by adopting efficient technologies and/low energy materials)

Table 7.8: Comparative analysis for AAC and CMU

Parameters- civil	AAC	CMU
U value (W/m².K)	0.576	3.062
Specific heat capacity (kJ/Kg.K)	0.22	0.70
Embodied Energy for wall with plaster	197 MJ / m³	235 MJ/m³
density	600 kg/m³	2349 kg/m³
Recycled content	Yes - site soil - 90%	No recycled content usually but in some cases fly ask is used
cost	Rs 3000/cu.m	Rs.4375/cu.m
thermal comfort /reduction of indoor temp as against ambient	Maximum reduction of indoor temp as against ambient is .... deg C	(Limitation, as monitoring restricted to only green case studies. This could be taken up in Phase 2.)
Green Aspect	Low embodied energy, insulated materials to reduce indoor temperature, 60% fly ash content	High in embodied energy due to materials like sand, aggregate and cement involved. Higher carbon footprint.
Structural Strength	5.6 N/mm²	4 N/mm²
Constructability	Easy	Easy
Availability	Easily available	Easily available

Hence, we can conclude that, autoclaved aerated concrete block is affordable and can be replicated in affordable housing.

Roof

The roof of the project is provided with **high reflective china mosaic finish** which is helping to reflect back the radiation het gains.

Figure 7.32: Roof finish in Solaris project

The cost information is unavailable. However as per the occupant's interview on ground floor the roof is performing better in terms of heat control. Since the material is available as a recycled item it has very low embodied energy. The material is also effective with low maintenance and longer life against conventional practice of reflective paint finish or concrete tiles.

Passive/ low energy technologies integrated with building envelope

Day lighting

Daylight has been integrated through windows and light wells. It helps to harvest daylight to the interiors and avoids artificial light usage. In conventional practice, day lighting is provided with limitation, thus interiors are more dependent on artificial lighting and consume energy during day time. In terms of affordable analysis, single glazed units have been used in both the cases, costing in the range of Rs.600/sq.m. The glazing areas will be lesser in conventional case, thus cost on materials is lower than the current project. However, energy consumption will be higher in conventional case than the current project. Hence we can conclude than, integration of day lighting is affordable and replicable in affordable housing. Photographs highlighting day lighting have been depicted below.

Figure 7.33: Photographs showing daylight integration in a flat

Figure 7.34: Photograph showing day lighting in basement parking area.

Natural Ventilation

Natural ventilation has been integrated through window and light well. No provision for air conditioning has been provided by the developer. This strategy helps in achieving thermal comfort and reduces dependency on air conditioning and fan. In conventional cases, natural ventilation is integrated in limitation with usage of air conditioning. The operating cost in case study scenario will be significantly lower than the conventional practice, thus proving to be affordable and replicable in affordable housing.

Interior flooring Materials

Floor finishes have been executed using green materials such as vitrified and ceramic tiles, etc. In conventional practices, vitrified tiles are majorly used. Vitrified and ceramic tiles use industrial processes with recycled content. The embodied energy and prices of the tiles have been compared in the table below.

Table 7.9: Comparison of energy and prices of the tiles

Tiles	Ceramic Tiles	Vitrified tiles	Terrazzo flooring
Price (Rs./sq.m)	323	560	388
Embodied energy (MJ/kg)	12	12	1.4
Recycled content	Yes	Yes	Yes

Ceramic tiles are cost effective than vitrified tiles. Therefore, ceramic tiles can be replicated in affordable housing. However **terrazzo flooring could be further economical and simultaneously highly environmental friendly**.

Building services

Building services has been integrated in the complex to enhance the sustainable quotient. Plumbing and electrical systems have been detailed out as under.

Water source

The water for Solaris project is supplied from ground water and municipality. Water is reused from rainwater and treated waste water. The reuse of water ensures, minimum dependency on ground water or municipal supply or water tankers, preserving water resource.

Water efficient fixtures

Water efficient **low flow rate plumbing and sanitary fixtures** has been used such as dual flush Water Closet with 3/6 - litres/flush and kitchen faucet as against 9 litres/flush used in conventional cases. The low flow water closet consumes 75% water less than conventional system. The cost of low flow fixture is approximately 23% costlier than a conventional water closet

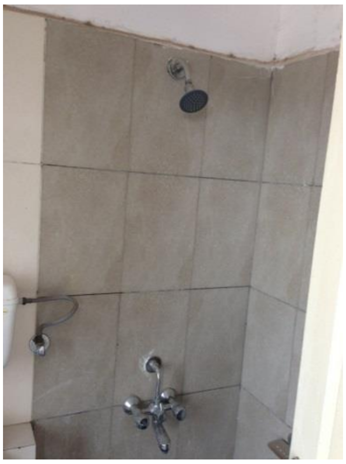



Figure 7.35: Water efficient features depicting water closet and faucet

7.2.4 Comparative analysis for cost affordability

Parameters - water management	Solaris		Conventional	
	Water Closet with 3/6 litre/flush dual flush	Faucet	Water Closet with 9 litre/flush	Faucet
Cost/unit (Rs.)	6500	3500	5000	1750
Water demand (%)	75 % less			

Therefore we can conclude that, even though water efficient fixtures cost 23%higher but it can save 75% on water demand and cost with it and payback can be realised in less than 1 year. Thus, dual flush 3/6 water closet and water efficiency faucets can be affordable and replicable in affordable housing.

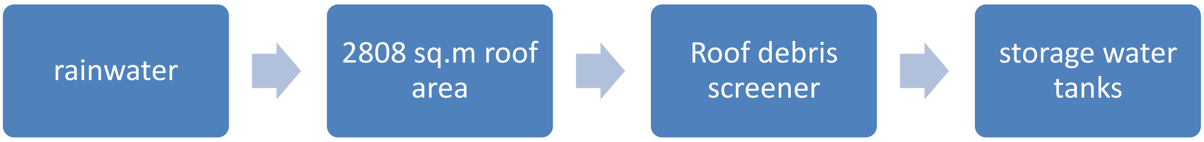
Rain water harvesting system

The total roof area of 2800 sq.m and impervious paved areas across the site acts as catchment areas and harvests rainwater annually for reuse in building. Rain water from landscape surfaces is used for recharging through percolation pits.

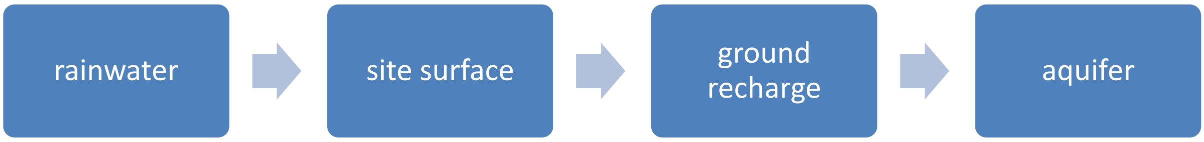
Figure 7.36: Storm water drains

Following is the flow diagram of rainwater harvesting:

Roof top rain water harvesting



Ground water percolation



Sewage Treatment plant:

Waste water treatment has been installed at Solaris. The typology of this STP is Moving Bed Bio Reactor – MBBR which has a treatment capacity of 210 KLD with a total investment of Rs 35,00,000 and efficiency of 92-98% which will be used for toilet flushing and landscape irrigation.

Figure 7.37:Photograph of Waste water treatment plant at Solaris

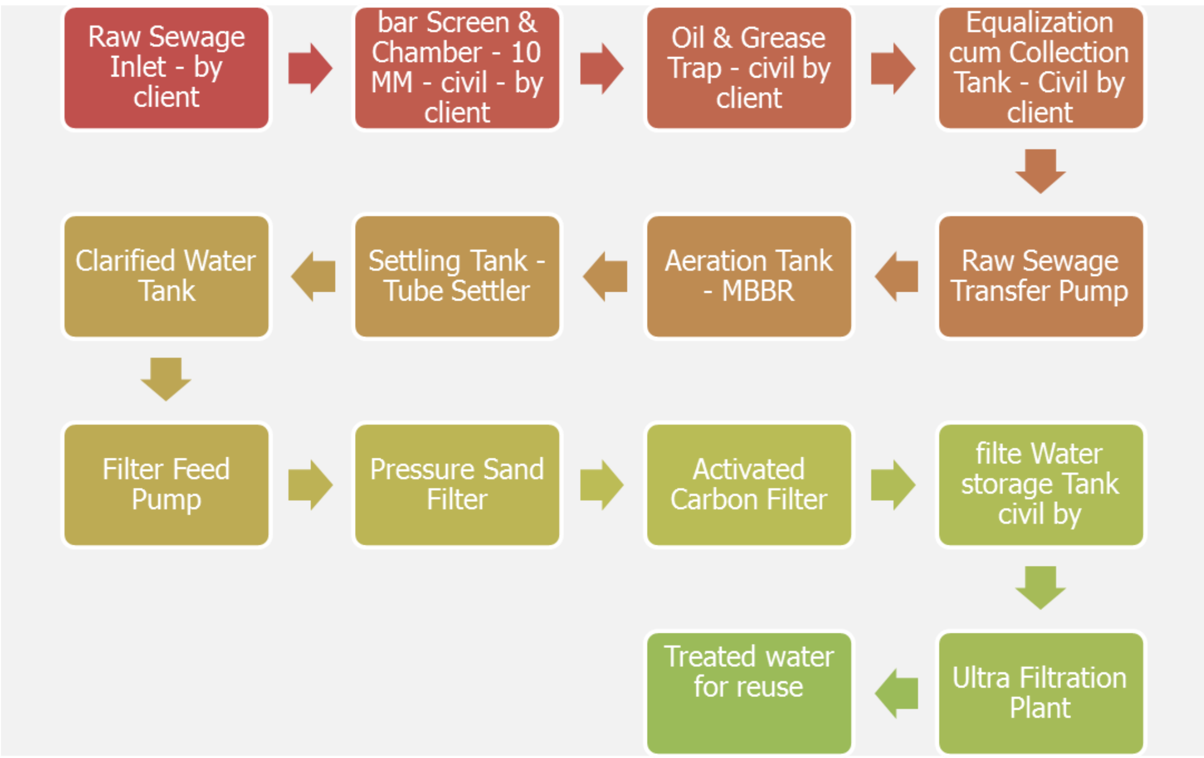


Figure 7.38:Treatment process of sewage treatment plant in Solaris project

The system is easy to install and operate. In the case study the system is fixed in basement floors and thereby saving area on ground level for other activities. However in case of conventional STP it has to be arranged on ground level usually which needs excavation and masonry construction.

Artificial Lighting

The street lighting provided with LED while the common corridors are provided with CFL and parking with T5 lamps.

7.2.5 Performance Monitoring

Instantaneous measurements were taken in the living spaces during the field. Thermal and day lighting measurements were taken with the help of globe meter and lux meter respectively.

Ambient conditions at the time of measurement:

Time: 17:00, **Date**: 16/09/2014, **Sky Condition**: Clear without sun

Floor: 5th,

Other: Shaded by adjacent tower during measurement

Floor: 11th (Top most floor)

Surface Reflectivity: Roof: 0.7, Walls: 0.5, Floor: 0.3

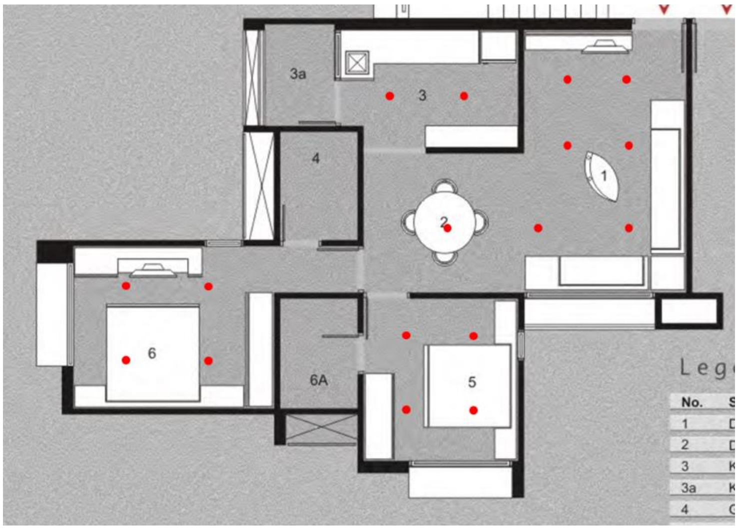


Figure 7.39: Lux level measurement grid

Table 7.10:Day lighting performance Measured

Room	Avg Lux	DF Measured	NBC Recommended DF
Living Room	3500.0	10.0	0.625
Kitchen	300	0.9	2.5
Bedroom 1	2000.0	5.7	0.625
Bedroom 2	1700	4.9	0.625

Table 7.11: Thermal performance Measured

	MRT (⁰C)	DBT (⁰C)	RH (%)
Outdoor	31.2	32.5	64
Living Room	30.9	30.8	61

The building envelop is helpful to reduce the indoor temperatures however the MRT is very low due to huge amount of lighting penetration. Since the field measurements were taken in an unoccupied flat, it is assumed that MRT gains would become low by having blinds and curtains. However the lighting levels may not be affected except the kitchen space.

7.2.6 Summary of Field Interviews

As per the interview of Savvy developers, the project attempted for IGBC green certification with all clauses considered. However final certification was not applied since the properties were sold by then. The developer attempts for green designs in all of their projects. Orientation, zoning, shading, thermal envelope are some of the basic features that would be followed in all of their projects including Solaris.

The maintenance of the property is handled by the developer and so far has not experienced any issues with the green features they have integrated.

As per an occupant the project is at affordable price for their income, whose monthly gross income is 1 lakh. The occupants need to use air conditioning in extreme seasons for 2-3 months. Remaining seasons is found to be comfortable with natural ventilation along with conventional ceiling fans. Day lighting is plenty and comfortable. The occupants do not experience any issue with the waste water treatments or reuse of the treated water. Due to the recommendations for low energy electric fixtures, the energy savings is effective.

7.2.7 Case study summary

Table 7.12: Case study summary

Sl no.	Green Feature in Case study						Conventional Features		Whether maintenance cost of green features are high?	Replicability in Affordable housing
	Details	**Cost**	**Green Rationale**	**Whether Affordable (Y/N)**	**Remarks**	**Information Source of cost**	**Details**	**Cost**		
	Sustainable site planning									
1	Top soil preservation	Helps in saving cost of bringing top soil from a nursery post construction. Collection , storage and maintenance cost of top soil is Rs. 17/cu.m	Preserves the natural top soil and natural biome.	Y	Cost is lesser than conventional		No soil preservation. Cost of new soil to be bought.	Purchase of top soil cost. Cost for supply, staking and mixing of sludge, manure, sieving is Rs.228/cu.m	N	Y
Landscape paving materials										
	Impervious paving									
2	High SRI concrete pavement	1200/sq.m	reduces heat island	N	cost is higher than conventional		concrete inter-locking blocks	Rs.350/sq.m	N	N
3	Concrete Pavers	1200/sq.m	reduces heat island	N	cost is higher than conventional				N	N

Sl no.	Green Feature in Case study						Conventional Features		Whether maintenance cost of green features are high?	Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable (Y/N)	Remarks	Information Source of cost	Details	Cost		
	pervious paving									
4	Grass lawns	3.85/sq.m	reduces heat island and reduces evaporation, helps in percolation	Y	Cost is lesser than conventional		concrete inter-locking blocks	Rs.350/sq.m	N	Y
Passive Solar Features										
5	AAC block	3000/Cu.m	insulated block and helps in thermal comfort	Y	Cost is lesser than conventional		Concrete blocks	Rs.4375/Cu.m	N	Y
6	High SRI roof tiles	Rs. 880 per sqm	Heat reflective and recycled content	Y	same cost		Concrete tiles	Rs.880 per sqm	N	Y
Green materials in interior finish										
7	ceramic tiles	Rs 323/ sqm	recycled content and low embodied energy	Y			ceramic tiles	Rs 323/ sqm	N	Y
8	vitrified tiles	Rs 560/ Sqm	recycled content	Y			vitrified tiles	Rs 560/ Sqm	N	Y
Water Management										

Sl no.	Green Feature in Case study						Conventional Features		Whether maintenance cost of green features are high?	Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable (Y/N)	Remarks	Information Source of cost	Details	Cost		
9	RWH		Helps in ground water recharge	Y	cost is equivalent		RWH Pit	Rs. 30000/pit	N	Y
10	STP	Rs.35,00,000 for 210KLD litres/day treatment capacity	Reuses in irrigation and flushing	Y	cost is equivalent		STP	Rs 40,00,000 for 650 KLD (Mahindra Aura)	N	Y

7.3 Integrated Housing and Slum Development Programme, Lonar

7.3.1 Introduction

Lonar is located in the Buldhana district of Maharashtra. With the Lonar crater (created about 50,000 years ago), the place has great archaeological, ecological, scientific and mythological value. The crater hosts a 400 acre huge lake and various ancient temples. To conserve the Lonar crater and develop the town, Municipal Council, Lonar proposed to relocate the slums developed around the Lonar salt lake to Durga Tekdi (1.5km from the crater). Hence, IHSDP, Lonar was planned. An area of 20 hectares has been allotted to this project. IHSDP Phase-II is central-government sponsored slum rehabilitation under JNNURM. The project is being implemented with the aim of providing an eco-sensitive rehabilitation solution and thus will be seeking a 4-star GRIHA Rating.

7.3.2 Site location

The IHSDP Lonar Phase – II is targeting two slums situated in a 100 m periphery of Daityasudhan Mandir and Nimbi Barav which are Archaeological monuments and need to be preserved. Buldana is located at 19.98°N 76.51°E. It has an average elevation of 639 m (2,096 ft).

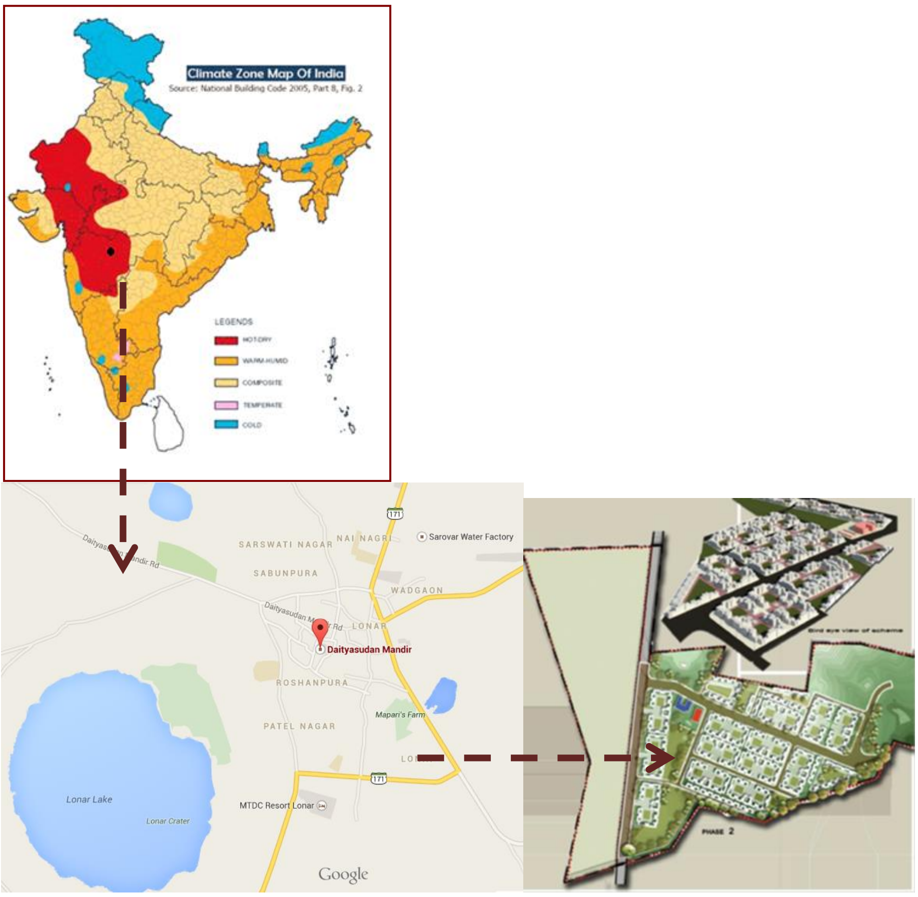


Figure 7.40: Site Location

7.3.3 Project profile

A brief profile of the project has been depicted below:

- Project name : IHSDP, Lonar
- Year of construction : On going
- Location & Address : Buldhana District, Lonar, Maharashtra
- Climate (as per NBC) : Hot and Dry
- Consultant : Shunya Consultants
- Site area : ~ 24.24 acres
- Energy consultant : TERI
- Any energy performance certifications : Undergoing GRIHA 4 Star Rating
- Total Cost of Construction : 1634.5 lakhs
- No. of dwelling units : 606
- Cost of construction per unit : RS. 1,32,800/-
- Type of Units (with quantity) : G+1 unit with two flats on the ground floor and one on the first floor
- Built-up area of each unit type : 25 m²
- Density : 25 units per acre
- Green technologies/features incorporated : Ground water recharge, Waste Water Treatment and reuse, Green Construction practices, Use of local materials, Biodiversity and use of indigenous species in landscape, preservation top soil.

7.3.4 Layout plan, dwelling unit plan and section for Phase – II

Figure7.41: Layout Plan for Phase II

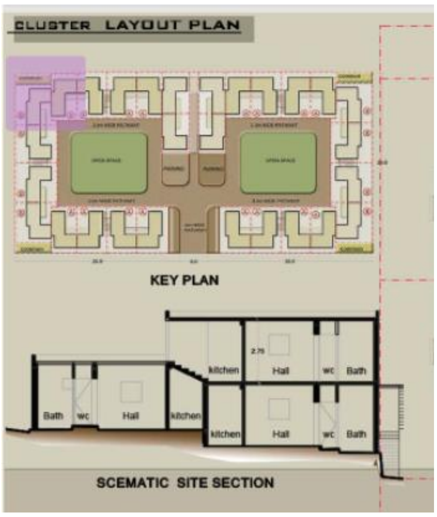


Figure7.42: Cluster Layout Plan

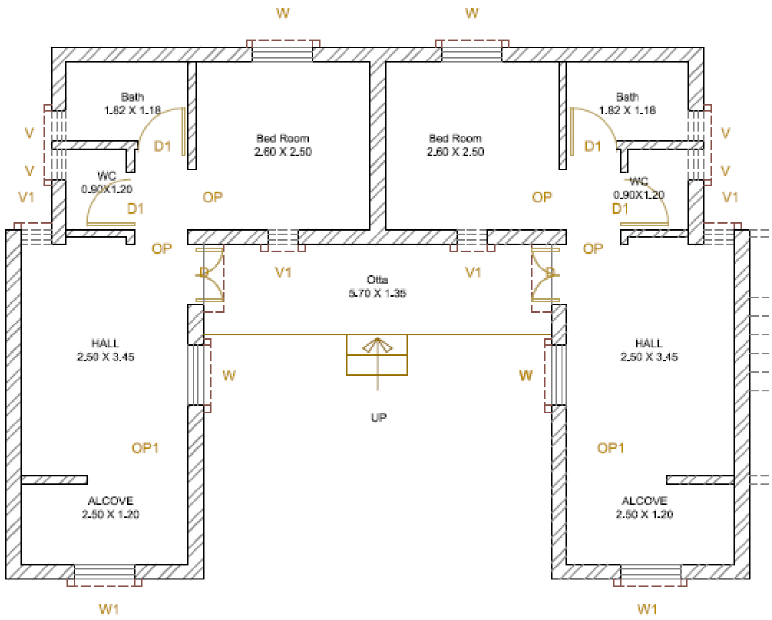


Figure7.43: Plan of a Dwelling Unit

7.3.5 Details of green features in the project:

Sustainable Site Planning.

The plan involves building houses in clusters in a symmetrical pattern. A cluster of 14 blocks of residential units will be built around a central green space that could be utilized for utilities and services, creating medium density neighbourhoods. The housing blocks (G+1) will be built along the natural site contours, minimizing the cutting and trenching cost.

Plantation

Majority of the plants are indigenous species requiring low maintenance and water once planted. A list of the plantations on the site has been given below:

Table 7.13: Plantations on Site

Plants	Value and Character	No. in each court
Mussanda Pink	Bold flowers all year through	1
Tabernaem Ontana (Tagar)	White swastika flowers used in puja, flowers throughout the year	2
Hibiscus Snowflakes	Provides for the typical and common red single jaswand used in puja	2
Plumeria Alba and Rubra (deci)	Deciduous in Nature with strong branching character when leaves are shed, provides for white flowers or red ones for puja.	2
Krishna tulus	Black tulas with high medicinal and purificational values used as bed planting	4
Gavti chaha	Profusely spreading herb with medicinal values. Can grow well on waste water from homes.	
Vekhanda Grass	Long grass like herb which forms neat clumps and acts as a strong mosquito repellent and also adds to the freshness of surrounding air.	6

Plants	Value and Character	No. in each court
Large tree for parking area	Varies with each cluster to give an identity to cluster entrance, mostly evergreen trees used for shade. All being native species	List of trees: 1. Bakul mimusops elengii (bankul) 2. Alianthus excels (maharukh, mahaneem) 3. Putranjiva roxiburghii (putranjive) 4. Alstonia Scholaris (saptaparni) 5. Ficus infectoria (pilkhan) 6. Manilkara hexendra (khirni) 7. Acacia auriculiformis (earpod wattle) 8. Kigelia Pinnata (sausage tree) 9. Azadiracta Indica (neem) 10. Senna siamea (kassod)

Top Soil Conservation

The excavated top soil is stored to be used later. The following drawing shows top soil collection and storage points on the site.

Figure7.44: AutoCAD drawing showing top soil collection and storage points

Paving

Pervious paving surfaces have been optimised to ensure water percolation into the ground so as to facilitate ground water recharge.

Passive Architectural Features

Since orientation was not in control at master plan level, each facade has been treated for its orientation.

Natural ventilation through windows will be used to achieve comfortable temperatures inside the house.

Building Envelope

Wall

Rat trap bond using fly ash bricks has been used for walls of the units. This not only reduces material consumption but also gives improved U-value, lower embodied energy and higher thermal insulation. Walls of the house have the following configuration:

230 mm brick wall with 15 mm plaster on both the faces

The overall U value of the wall assembly: 0.35 Btu/h/ft2/0F[2]

Figure7.45: Rat Trap Bond (Left) and Use of Fly ash Bricks (Right)

Roof

Tumbler roofing is being given to the units. **Burnt clayed conical tumblers are placed in arch on the roof.** All the groves and gaps are finished by sticking broken glazed tiles over the surface. Tumbler roof serves as a great insulator keeping the heat and cold out resulting in a temperature difference of about 7-8 degrees* between the external and internal environment. They are very light in weight (135 kg/sq.m) and have a very low construction time (3 days*). It needs no under-structure and has a load bearing capacity of up to 1 tone/sq. m.

Figure7.46: Tumbler Roof - View from Inside

---

[2] TERI Report

The test results of thermo physical properties of roof clay pots are not available so a different methodology was used to establish the heat transfer coefficient (U-value) of roof. Onsite measurements for roof's external and internal surface temperatures were taken using appropriate instruments. A computer model of the building was developed and the same was validated with the measured data for different U-values of roof. Thus, the overall U value of the roof assembly was calculated to be 1.0 W/m²/deg K*.

Glass

Single glass is used in the units. The specifications being:

U Value: 6.0 Btu/h/ft2/F*

Effective shading coefficient: 0.61*

Doors and windows

Precast frame (light weight) will be used for interior doors and windows. The door panels are to be made of any durable composite wood product.

Plaster/masonry

PPC with at least 30% fly ash has been recommended for use.

Flooring

Flooring is to be done with Shahabad stone in rough finish.

Partitions/built-in cup board

Locally available natural stone or composite wood product is to be used.

Figure7.47: Section displaying construction techniques used

Day lighting

Radiance Simulation tool was used to carry out the daylight analysis of the proposed building. The simulation model was prepared as per the architectural drawings received. For the calculation of the daylight area, only living areas were considered, i.e., Bedroom, Alcove and hall only.

The result obtained from the analysis was:

Total living area of the building = **54.37m²**

Total daylight area = **54.37m²**i.e. (**100% of living spaces daylit**)

Shading

Based on TERI's analysis, it was recommended to provide for horizontal shades of at least 30 cm to cut glare and direct heat gain.

Figure7.48: Perspective View

Energy Efficient Lighting

The lighting in the units will be energy efficient.

Table 7.14: Energy efficient Fixtures and Lighting Levels

Floor Level	Room/ Area	Room Dimension (L*W)	Luminaire used	Remarks
Sample Floor	Bed room	2.6mX2.5m	18W CFL	Lighting Power Density (LPD) meets ECBC requirements
	Hall	2.5mx3.45 m	18W CFL	Lighting Power Density (LPD) meets ECBC requirements

Services

Water Management

Water Efficient Fixtures

Water efficient fixtures will be installed in the units. A brief summary of the water fixtures used in the project has been given below:

Table 7.15: Water efficient Fixtures

S. No.	Fixture/Faucet	Design case flow rate
1	Water closet (solid) in lpf	2(residences);
2	Water closet (liquid) in lpf	1.5(residences);
3	Lavatory Faucets in lpm	7.5
4	Kitchen tap in lpm	7.5

The installation of these fixtures will result in a reduction of 62% (as calculated) in water demand.

Waste Water Treatment

Geo green Bio filter is used for treatment of black water (sewage). It is appropriately positioned to draw the waste water from the dwelling units using gravity only. The treated wastewater is proposed to be used for irrigation of adjacent agricultural fields and for cattle washing of the slum dwellers.

Figure7.49: Geo Green Bio Filter

Rain Water Harvesting

The project being low cost, rain water harvesting has been found to be not feasible. Additionally, the site being a hilly area, storing of the rain water would require high maintenance increasing maintenance cost.

Energy

Solar Energy

Installation and usage of solar water heaters and photovoltaic cells was also found to be not feasible economically for the project and hence will not be used.

Predicted Energy Performance Index

For calculating EPI, the energy consumed due to lighting and cooling is used along with the area:

Area of the each residential unit : 25 Sqm.

Annual lighting energy consumption : 295.6 kWh/yr

Area Annual cooling energy consumption: 584 kWh/yr

Total energy consumption : 879.6 kWh/yr

Energy Performance Index (EPI) of a single slum house : 35 kWh/yr/sqm

Energy Performance Index (EPI) of slum housing complex: 35 kWh/yr/sqm *(It is to be noted that EPI of slum housing complex will remain same as that of single slum house due to the fact the area of all the 607 slum houses is same along with the lighting and cooling load (kW).*

The GRIHA benchmark for a residential project in hot and dry climate zone is 100 kWh/sqm/year. Thus, the EPI of the dwelling unit meets the GRIHA Criterion.

Outdoor Lighting

The following recommendations have been made for outdoor lighting:

- Programmable timer to control all outdoor lighting circuits.
- Pole height >5m: use high pressure sodium vapor lamp with efficacy of 90 lm/watt

- Pole height 3-5m: use T-5 with efficacy of 75 lm/watt
- Pole height 1-3 m: Use CFL with electronic chokes having overall efficacy more than 50 lm/watt

Solid Waste Management

No waste management system has been planned. The waste will be collected individually and handed over to the municipality.

7.3.6 Summary Table

Table 7.16: Summary Table

1.	**Site**	• Cluster layout with central green space • Construction along natural site contour – reduced cutting and trenching cost • Plantation – indigenous species • Top soil preservation • Optimized pervious paving • Programmable timers to control outdoor lighting • Energy efficient outdoor lighting fixtures
2.	**Building Level**	• Walls: rat trap bond with fly ash bricks • Roof: Tumbler roof • Doors & Windows: Precast frame • Plaster/masonry: at least 30% fly ash • Built in cupboard/partition: locally available natural stone or composite wood product • Daylight: 100% daylit • Water efficient fixtures: 62% water demand reduction (calculated) • Waste water treatment: Geo Green Bio filters - treated water for irrigation, cattle washing • EPI: 35 kWh/yr/sqm

7.4 Summary of hot & Dry Climate zone

Table 7.17: Summary of hot & Dry Climate

Green features	Literature studies& traditional Practices	Case studies	Best regional practices
Siting and climate responsiveness			
Orientation	Longer walls orienting towards North and south side		
Zoning	Shading Verandas and living spaces on critical orientations, courtyards		
Street Design	Shaded streets, narrow width,		
Energy, renewable energy & building materials			
Roof treatment, roof garden	Tumbler roofing, filler slab, terrace gardens, flat roof, white wash	Reflective tiles, Vegetated roofs/terrace gardens, Insulation	Reflective tiles, flat roof, Vegetated roofs/terrace gardens, insulation
Shaded windows	Shaded windows, jallis		
Walls to respond to outside climate	Rat trap wall, cavity walls on east & west wall, bhungha circular wall,	High thermal mass, AAC blocks,	Cavity walls, Earth structures, thermal mass, hollow blocks, AAC blocks
Local materials to reduce embodied energy	Fly ash bricks, Semi cast latticed RCC rafters and hollow pre-cast blocks, GGBS blocks, reclaimed timber, oxide flooring, Bamboo Mat Board, quarry dust, stone, adobe, Wattle and daub Lime, thatch	Lime, Jikki, AAC blocks, Nimaj stone	Lime, adobe, thatch, mud blocks
Construction technologies to reduce time and volume of construction	Pre cast members, mud blocks, local stones, demolition wastes, kota stones	Recycled materials - brick waste, thermocol waste	Precast members
Natural ventilation	Through north and south windows, high ceiling for air circulation, water bodies for moisture		
Daylight integration	Through windows and skylight	Through windows and light louvers	Clerestory lighting, floor level opening, indirect lighting
Efficient outdoor and indoor lighting by use of T5 lamps, CFL, LED etc		CFL, T5 for indoor lighting, LED for outdoor lighting	Fluorescent tube lights (T8 & T5), 5W CFLs, 2W LEDs

Green features	Literature studies& traditional Practices	Case studies	Best regional practices
Efficient fans or other heating/cooling technologies	35W Ceiling Fans, Evaporative coolers for summer	Wind catchers, Ceiling fans	Evaporative coolers
Solar based outdoor lighting	solar power street light	-	Stand-alone LED street lights powered on Solar PV
Solar based water heating	Solar hot water system for individual house		
Renewable Energy	Biomass gasification, bio methanation,		
Efficient landscape design			
Pervious pavers	Lower hard paving		
Sedimentation control measures in the landscape design	Soft drainage using aggregates filters, mulching		
Use of native species	Tree plantation around habitat		
Source of landscape water from recycled water	Waste water from bathrooms and kitchen		
Irrigation equipment			Drip irrigation, sprinklers
Water body	Water bodies to improve humidity levels in dry season		
Water management			
Waste water treatment system		MBBR system	DEWATS
Rain water harvesting	Rainwater harvesting, stepped wells,	Ground recharge, Collection pits for reuse	
Dual plumbing system	Multiple plumbing line for fresh water, treated water and rain water		
Efficient plumbing fixtures	Low flow plumbing fixtures, faucets with aerator, water level controllers, pressure regulating devices		Energy efficient motors, dry toilets,
Waste management			
Segregation of waste	mandatory waste segregation, dry and wet waste segregation of kitchen		
Resource recovery from organic waste			
Resource recovery from recyclable waste	All waste recycled and reused		

8 Field Case studies under Composite Climate zone

8.1 Case Study Report for Mahindra Life Spaces - Aura

8.1.1 Site location

Aura is a new project which is attempting for IGBC gold certificate built in 17.6 acres of land. At the time of case study the project is at ready to occupy stage. The project is located in Gurgaon, Haryana. The site is located near Dwaraka Express and is only 6km away from main town. Gurgaon experiences Composite climate as per NBC.

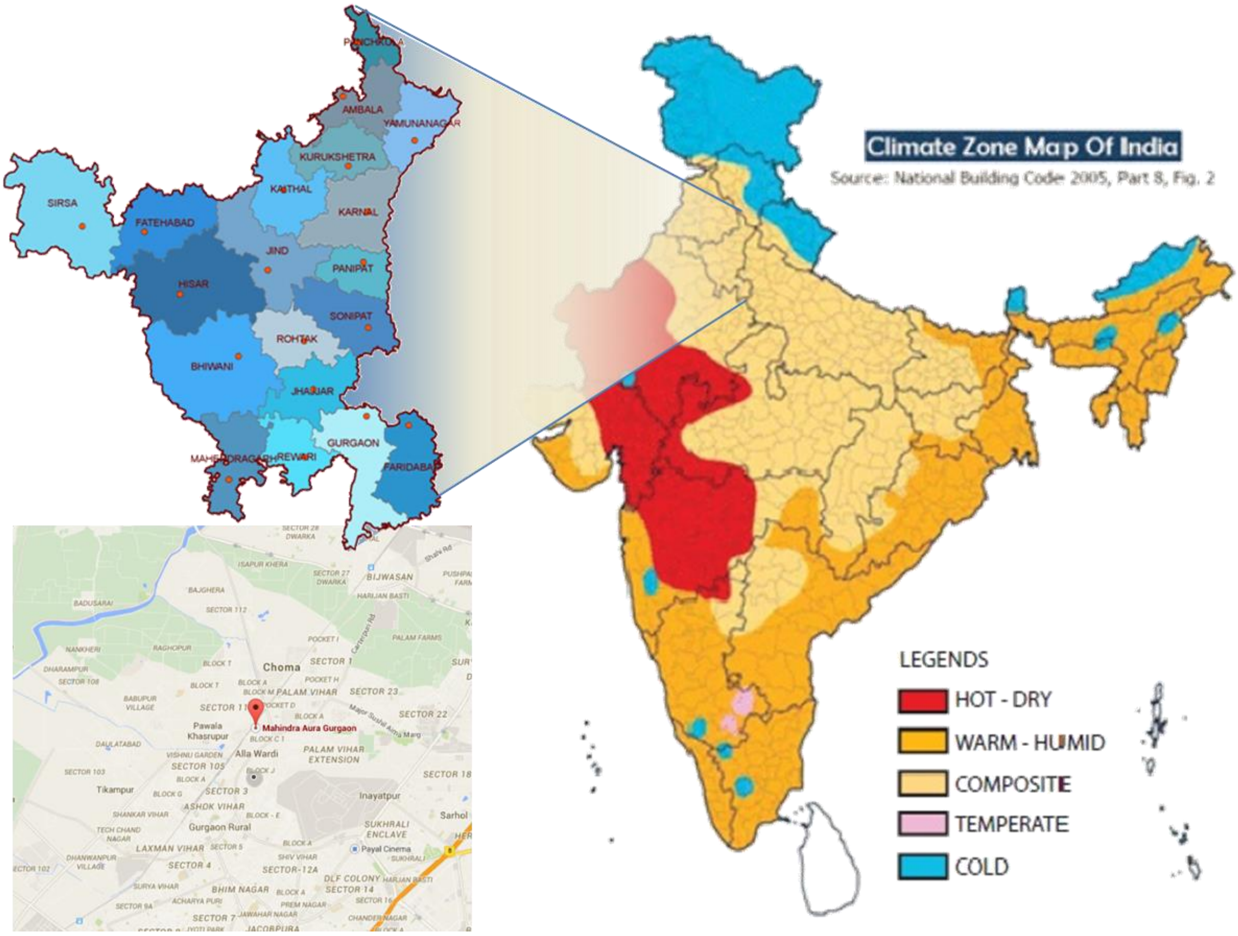


Figure8.1: Location of Mahindra Life Spaces - Aura

8.1.2 Project Profile:

A brief profile of the project has been depicted below:

- Project name : Mahindra Life Spaces - Aura
- Construction : 2014
- Location : Gurgaon, Haryana

- Climate (as per NBC) : Composite
- Coordinates : 28.5, 77.0
- Architect : RK Associates
- Contractor :GS Developers & RSB Infrastructure Ltd
- Developer :Mahindra Life space Developers Ltd
- MEP :Kumar Endicon & Kanwar Kishan Pvt Ltd
- Site area : 17.6 acres (71,000 Sq.mt)
- Total Built up Area (Sq. mts) : 26,200 Sq.m (2,82,014.4 Sq.ft)
- Total Cost of Construction : Rs. 290 Crores
- No of dwelling units : 895 units
- Typology of development : High rise apartments
- Floors : 14
- Dwelling Density : 50 Residential units/Acre
- Type of Units (with area) : 2BHK (950 Sq.ft)
  2BHK+Study (1150, 1275 Sq.ft)
  3BHK (1350, 1550 Sq.ft)
  3BHK+Servant (1875, 1900, 1960, 1985 Sq.ft)
  4BHK+Servant (2300 & 2330 Sq.ft)

Green Features at Site Level:

Rainwater Harvesting for Ground water recharge, Water Treatment & Reuse, Waste Segregation, Preservation of existing resources– Exiting Trees, Contours, Top Soil Landscaping – Draught Tolerant Species, Native Species, Soft scapes, Low Embodied Energy & Local Materials Usage, Efficient Plumbing System, Storm Water Runoff control, LED and T5 lamps for outdoors and common spaces respectively.

Green Features at Building Level:

Passive Designing – Natural Lighting, Sun responsive – Self shadowing layout, Shading of lower floor clusters by high rise structures, Solar Water Heating, Efficient Water Fixtures

Figure8.2: Site plan

Figure8.3 Typical Cluster layouts

Figure8.4 Left: 3BHK (1050 Sq.Ft), Right: 2BHK (950 Sq.ft)

There are totally 11 towers each of around 14 floors height. The apartments are planned in such a way that each flat would openings on at least 3 sides to maximize natural ventilation and day lighting. There are 5 different types of unit types to meet the financial and spatial needs of people. The project has saved 80% of site area for open spaces by going high-rise. Open spaces are considered for landscaping, parking and other communal facilities. Amenities are nearby along the city centre.

8.1.3 Site planning and Landscape

Top soil of the site has been preserved during construction which is later used for landscaping. 35 trees were protected during construction and native species are preferred for landscaping on post construction phase. Preserving top soil involves collection, storage and maintenance cost of Rs. 17/cu.m. In conventional sites, the cost for purchase of top soil involves supply, staking and mixing of sludge, manure, sieving accounting to Rs.228/cu.m. Hence, protection of top soil during construction is affordable and has the potential to be replicated in affordable housing.

Figure8.5 during construction after construction images

8.1.4 Alternative Materials

Pervious Paving - Grass Pavers

Pervious pavements are provided for a large area in site for water percolation towards ground water recharge and reduce Urban Heat Island. The paving is provided with vehicular load bearing capacity. With this the parking is provided across the site and no extra space or construction is afforded. Interlocking blocks are also provided for pedestrian pavements areas, allowing water percolation. Both the materials not only reduce Urban Heat Island effect but also reduce water flooding and wastage. Although conventionally, interlocking blocks have same properties grass pavers are more effective. Pervious paving is highly important for environmental protection.

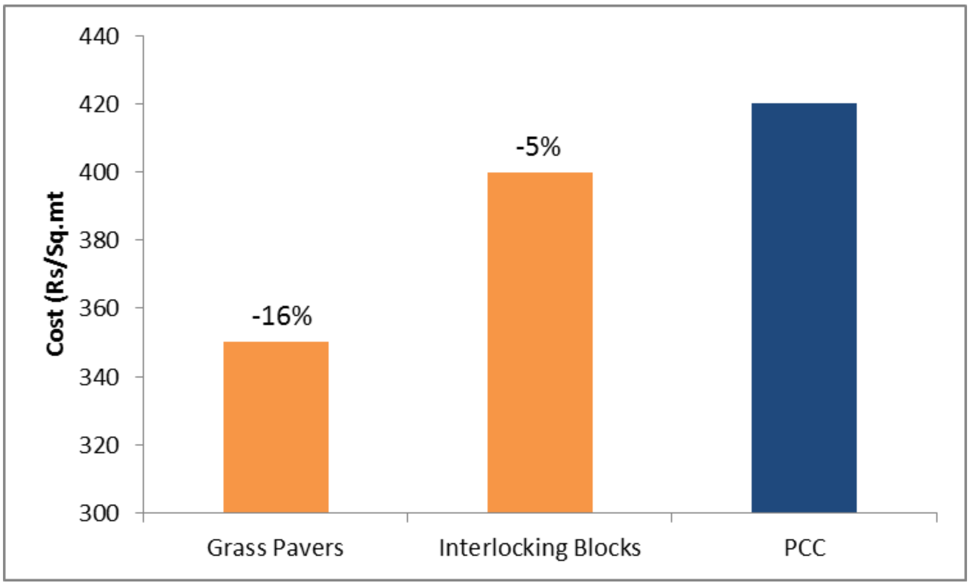


Figure8.6: Cost comparison of pervious paving materials

Figure8.7 Pervious paving materials 1. Parking on grass pavers 2. Grass pavers 3. Interlocking blocks

Storm water channel

High SRI concrete drain channels are used across the site to divert storm water towards rain water harvesting pits. The feature reduces the storm water flooding on impervious areas like asphalt road for vehicular movement. The shape of the material shall be helpful in managing excess water flooding during monsoon seasons. Delhi and Gurgaon usually experiences heavy rainfalls during monsoon season.

Figure8.8 Sedimentation tank and storm water drain

Building Fabric – AAC Blocks for walls

All the external walls of the project are provided with **AAC block as prime material**. The total cost of wall is Rs 5295/Cu.mt and U value 0.56. AAC block is the prime material for thermal performance in the project. The material is certified by ISI, GRIHA and IGBC for its effectiveness as a green material. The material is light weighted and thereby reducing transportation efforts and structural load, does not require special labour skills and hence easy for construction, fire resistant and thermally good insulator and hence preferred for composite climates. Also, the material has recycled content and has lower embodied energy of 197MJ/Sq.m against 235 MJ/sq.m for concrete block which is conventionally used.

Table 8.1: Layers of external wall

Layers	Material	Thickness	U Value
Outer Layer	External air film		5.9
Layer 1	External water Repellent Paint	0.03-0.07	
Layer 2	External cement mortar	1	0.5
Layer 3	Low density Fly ash Block	9	0.1
Layer 4	Internal cement mortar	0.6	8.3
Layer 5	Internal gypsum plaster	0.5	8.2
Inner Layer	Plastic Paint	0.03-0.07	0.0

Cost of AAC blocks is usually economical as compared to its equivalent conventional materials like Brick or concrete blocks. Nearly 15-20% of construction cost can be reduced with this material.

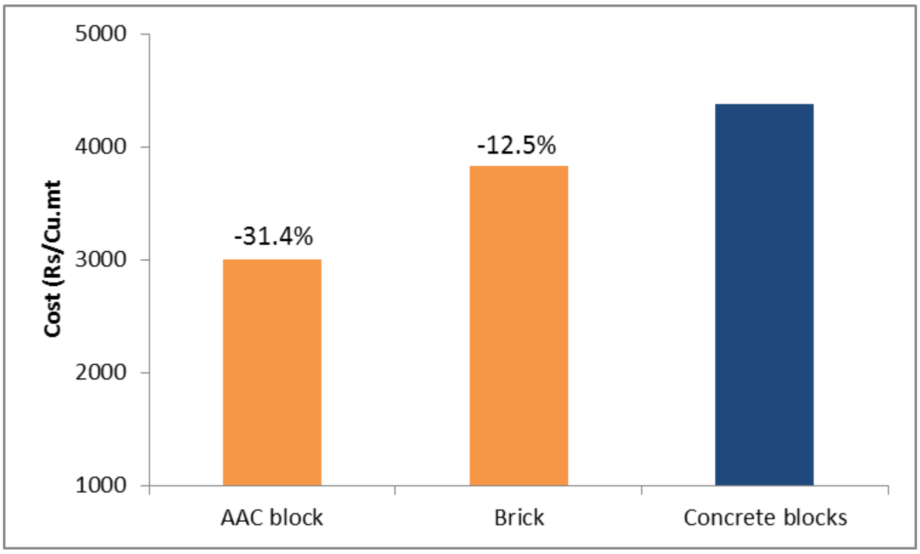


Figure8.9: Cost comparison between wall materials

Figure8.10: During and after construction images of AAC block walls

8.1.5 Water and Waste Management

Water balance

The project gets its main water sourced from local municipality which is used for domestic and bathrooms. The used water is transported to a conventional Sewage Treatment Plant of 650 KLD capacity, located within the site. The treated water is then used for flushing, car washing, cleaning roads, pavements and landscaping. Excess generated water is diverted to municipal sewer. Rainwater is used only for ground water recharge. Since the land here is having ground water scarcity issue, the developer does not prefer to use ground water. Below charts demonstrates the water balance chart for the project.

Table 8.2: Water balance chart

Total Water Demand	6,00,000 KLD
Fresh Water - Municipality	4,26,900 KLD
Waste Water generated to STP	5,13,630 KLD
Treated Water	4,34,000 KLD
Reused Water after treatment	1,73,080 KLD

Figure8.11: Flushing tank, 2. Domestic tank, 3. Multiple plumbing systems

Low flow water fixtures

Multiline plumbing system has been used in the project for fresh and recycled water usage and fire system. **Low flow fixtures** are used in all the bathrooms and kitchens to reduce the consumption. With this nearly 35% of water is being saved against a conventional practise of having normal water flow fixtures.

Figure8.12: Images of various low flow water fixtures as seen during field visit

Low flow fixtures used	Manufacturer	Flow rate (LPM)	Approximate Cost (individual)	Quantity (no)	Consumption Saving against conventional type (%)
Showers	Jaquar	8	4900	2046	33.33
WC	Jaquar	6&3	6500	4802	0
Wash basin	Jaquar	8	2800	2180	33.33
Kitchen Faucet	Jaquar	2.5	3300	895	62.5
Toilet taps	Jaquar	8	2800	2908	33.3
Other	Jaquar	2.5	NA	2180	33.33

Although the fixtures are expensive than normal water fixtures, saving of water is an important criteria especially in urban scenario. Since the buildings are not occupied and no water bill information is available, it is difficult to analyse the water savings through these low flow fixtures against conventional practise. However it is hypothetically assumed that water savings and subsequent water/energy bills savings would be higher than conventional systems in long term. The cost of conventional STP installed in the project is 70 lakh rupees for 650 KLD capacity.

Solar Water Heating system

Hot water system is supplied for all the kitchens through Solar Water Heater system provided in the terraces of all towers. The system has 60,000lt capacity, installed for a cost of 1 Crore aprox.

In conventional case electric water heaters are generally used. Considering one electric heater of 10 Litre capacity for each house (895 houses) with 2kw capacity, used during winter months (120 days) only for one hour a day, would consume 214800 kWh of energy annually. Although the initial cost of the system would cost only 58 lakhs, adding the energy bills for each year the payback period would be within 4 years. After the 4th year it is huge saving each year. In 15years (assuming as life time) nearly 69% of cost would be saved by having renewable energy against a conventional system.

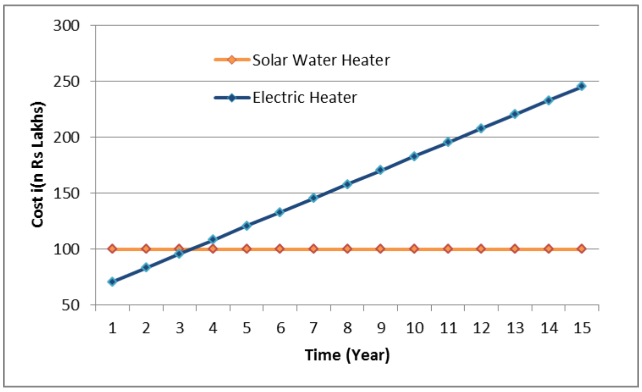


Figure8.13: Life cycle cost for Renewable energy system against conventional system

8.1.6 Performance Monitoring

Instantaneous measurements were taken for few main living spaces during the field. Thermal and day lighting measurements were taken with the help of globe meter and lux meter respectively.

Ambient conditions at the time of measurement:
Time: 17:00, **Date**: 16/09/2014, **Sky Condition**: Clear without sun
Floor: 5th, **other:** Shaded by adjacent tower during measurement
Surface Reflectivity: Roof: 0.7, Walls: 0.5, Floor: 0.3

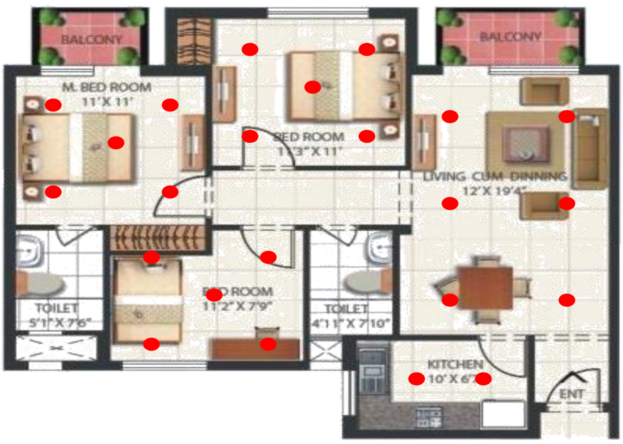


Figure8.14: Lux level measurement grid

Table 8.3:Day lighting performance Measured

Room	Avg Lux	DF Measured	NBC Recommended DF
Living Room	350.0	8.0	0.625
Kitchen	180	4.1	2.5
Bedroom 1	220.0	5.0	0.625
Bedroom 2	180	4.1	0.625
Bedroom 3	200	4.5	0.625

Table 8.4: Thermal performance Measured

	MRT (⁰C)	DBT (⁰C)	RH (%)
Outdoor		32	58.5
Living Room	31.4	31.4	59
Bedroom	31.4	31.3	62.5

8.1.7 Summary of Field Interviews

Since the project is not yet occupied already, most perceptions are considered based on observations made during field visit and interviews by the developer. During the field visit it was observed that some phase of the construction as already completed and is at ready to occupy stage, some phase of the project is under construction. This was taken as an advantage to observe the 'during' and 'after' construction aspects of the project.

As per the developer, the design has been developed with an intention to have maximum open areas, vegetation and communal features for good social sustainability. The building is attempting for IGBC gold certification. The location is well connected to all basic needs and transportation. Due to the closely arranged high rise structures, self-shading is an advantage during summer months. The AAC block is preferred for external walls due to its thermal performance. Since 3 sides of each dwelling unit are open and windows are provided with ample sizes on all the sides, cross ventilation is very effective during summer and monsoon seasons. Day lighting is observed to be ample and predicted to meet the minimum standards in all seasons.

The construction and technology used in the project are mostly simple which may not require any skilled labour. Due to effective planning the construction time span for construction was short and easier as per the developer's opinion.

8.1.8 Case study summary

Table 8.5: Case study summary

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	**Cost**	**Green Rationale**	**Whether Affordable Yes/No (Y/N)**	**Details**	**Cost**	
1	Top soil & contour preservation	No additional cost involved for contour preservation, Storage and maintenance of top soil preservation = Rs17/Cu.mt	Preserves natural topography site features like drainage pattern and helps in storm water management	Y	No Protection of Levels. Cut and fill process to be done	Cutting and trenching– Rs 110/Cu.mt Purchase of top soil – Rs 228/Cu.mt	Y
2	AAC wall	Rs 3000/Cu.m	Faster construction, Less embodied energy, Thermal insulation	Y	Concrete blocks Bricks	Rs 4375/Cu.m Rs 3828/Cu.m	Y
3	Ceramic	Rs 880/Sq.mt	Recycled content	N	Vitrified Flooring	Rs. 560/ Sq.mt	Y
4	Rain Water Harvesting System (pits + plumbing)	Rs. 40,00,000/-	Ground water recharge	Y	-	-	Y
5	STP	Rs. 70,00,000/-	Results in less dependency on the conventional water sources	Y	-		Y
6	Water Efficient Fixtures	Cost of the fixture is Rs.3500/- for low flow faucets and Rs.6500 for dual flush 3/6 lp/flush water closets	Results in less dependency on the conventional water sources	Y	Cost of the fixture is Rs.1750 for conventional faucets and Rs.5000 for Single flush 9 lp/flush water closets		Y

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	Cost	Green Rationale	Whether Affordable Yes/No (Y/N)	Details	Cost	
7	LEDs	Rs. 400/- per Fixture	Results in less dependency on the conventional energy sources	N	CFLs Rs. 200-250/- per fixture		Y
8	Solar hot water system (60,000 lt capacity in total	Rs. 1,00,00,000	Results in less dependency on the conventional energy sources	Y	Electric Geysers (25 litres capacity per bathroom)	Rs 2,04,60,000	Y
9	grass pavers with concrete	Rs 350/Sq.mt	Reduces heat island and helps in water percolation	Y	Heat Island Effect is less controlled	Rs 400/Sq.mt	Y

8.2 Field Case Study - TERI University Hostel

8.2.1 Project Profile

A brief profile of the project has been depicted below:

- Project name : TERI university hostel
- Year of construction : Sep 2007 – Sep 2008
- Location & Address : New Delhi
- Climate (as per NBC) :Composite
- Architect : Sanjay Mohe
- Contractor : Confoss Constructor
- Developer : Confoss
- MEP : Confoss
- Energy consultant : Airtron consultant
- Any energy performance certifications : No
- Total Cost of Construction : Rs. 1690/sq.ft (2008)
- Total Built up Area (Sq. mts) : 1220 sq.m (13131.97 sq.ft)
- Total site area (sq. mts.) : 8153.6 sq.m
- No of dwelling units : 35 (G+4 storey)
- Type of Units (with quantity) : Hostel dorms
- Green technologies/features incorporated : Orientation, Reflective finish roof, STP, RWH, Material reuse from site, local materials, Passive design features, Earth Air Tunnel

8.2.2 Details of green features in the project:

Site planning & landscape

The hostel in the campus is designed for girls studying in TERI University. The hostel consists of 30 rooms out of which 18 rooms are of double occupancy and remaining with single occupancy. The hostel is G+ 4 storey with a total height of 20m approximately. The orientation is appropriate with the longer façade directed towards N-S axis. The building is linear in design with a double loaded corridor in the central E-W axis. All rooms are well lit and ventilated. The details of site planning have been depicted in the following paragraph:

- Total Site Area (Sq.m) : 8153.60 Sq.m
- Total Built up Area (Sq.m) : 8390 Sq.m
- Built up Area of hostel (Sq.m) : 1220 Sq.m
- Floor Area Ratio (FAR) : 1.00

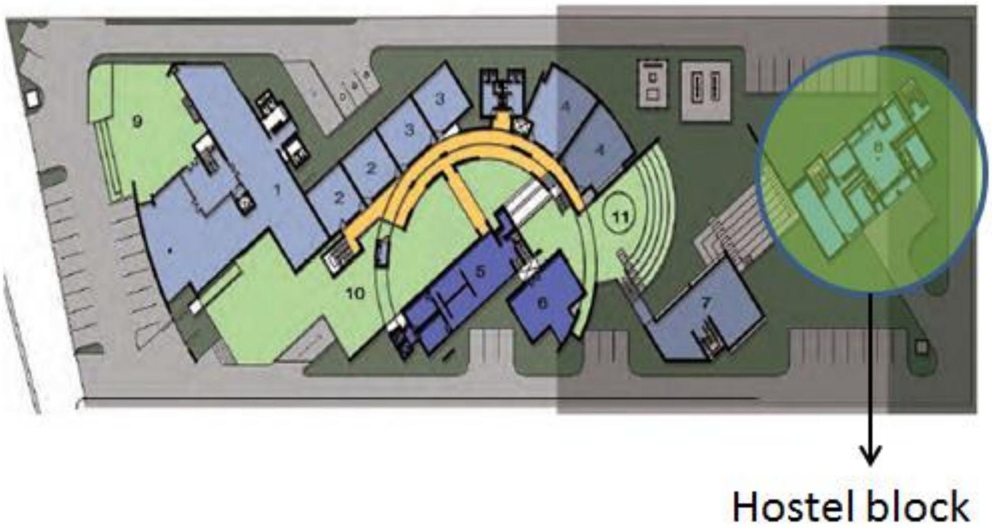


Figure8.15: Site plan if university campus highlighting hostel block.

Brief details on Landscape areas

- Building site area (not including office) : 1965 sq.m
- Building footprint area :265 sq.m
- Net building site area :1700 sq.m
- Hard paved area :697 sq.m
- Soft paved area : 1003 sq.m
- % of soft paved area : 59%
- % of hard paved area : 41%

Building Envelope and civil works

Building plan is rectangular in form with north and south facades having maximum exposure. The materials specification in the project has materials with potential green features which have been described below.

Envelope

Roof

Roof is **RCC with brick bat coba with outside layer of white tiles**. The details of construction is shown in table below. The green features are highlighted in green. The white tiles have high reflective index thereby reduces amount of heat absorbed by the roof. The following figure shows the tiles installed on the roof. The cost of construction of roof is INR 2356.5/sq.m.

Table 8.6: Table showing cost of construction of roof

Roof	Material Description	Thickness (mm)	Price	Net U value
Layer 1 (Outside layer)	*White tiles*	*18*	323 INR/sqm	2.27

Roof	Material Description	Thickness (mm)	Price	Net U value
Layer 2	*Mortar*	*20*	*323* INR/sqm	
Layer 3	*Brick bat coba*	*125*	*540* INR/sqm	
Layer 4	*RCC*	*150*	*5300-6000 INR/cu.m*	
Layer 5	*Plaster*	*6*	*323* INR/sqm	

In office building of the university **vermiculite insulation** is used which is a green material available locally. This insulation is used in **west facing wall** only. Cost of 75 mm thick vermiculite is INR 85/sq. ft. Vermiculite is a naturally occurring mineral used as insulation, as it increases the resistance value of construction and also makes the structure more fire proof than with fabric insulations. It can also be added to plaster mixers to make them more light weight, fire proof and insulating.

(Source: SURYA Min Chem, sister concern of Surya Plant)

a b

Figure8.16: Tiles installed on the roof

Wall

The detailed construction of wall is presented in table below:

Table 8.7: Wall construction

Wall	Material Description	Thickness (mm)	Price	Net U value (W/m2.K)
Layer 1 (Outside layer)	*Outside Sandstone Dry cladding*	*10*	-	0.525
Layer 2	*Brickwork*	*230*	*4300 INR/Cu.m*	
Layer 3	*PUF board*	*50*	*2300 INR/sq.m*	
Layer 4	*Brickwork*	*115*	*4300 INR/Cu.m*	
Layer 5	*mortar*	*8*	323 INR/sqm	
Layer 6	*Plasters inside with white*	-	323 INR/sqm	

	emulsion paint

The outside sandstone dry cladding is the green features as it is procured locally. *Aero screen louvres* are provided on western wall to reduce solar gain inside the building.

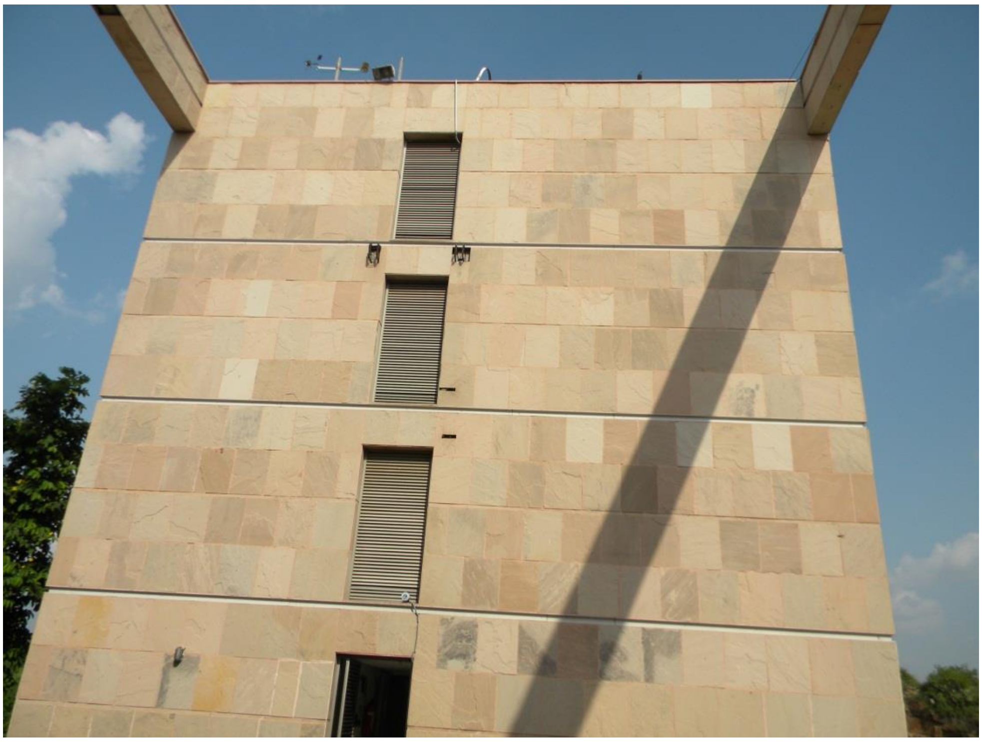


Figure8.17: Aero screen louvre on the west facing wall

Green building services features:

Rain water harvesting

This system exists for whole of the campus including the hostel. The rain water harvested is used for ground water recharge and excess surface water is used for future use.

Solar water heater

Solar water heater (SWH) is installed at the rooftop and provides for the daily hot water needs of hostel. The system can generate 2500 litres of hot water every day. However according to number of occupants the actual hot water needed is lower than this. The actual energy needed to heat water is calculated according to the occupants. The initial investment cost required for installing conventional geysers in calculated assuming capacity required to be equal to that of installed SWH.

Energy efficient lighting

Energy efficient CFL are used along with day light integration which has reduced the lighting power density (LPD) to 1W/Sq.ft from required 1.3 W/sq.ft.

Sewage treatment plant

Sewage treatment plant (STP) is installed at the basement of the building. The sewage generated by the hostel is treated using biological process using combination of micro-organisms and bio media filters. Such technique is efficient and requires less area. The STP system is provided by Enzotech and investment cost is 25 lakhs. The plant has capacity to treat 25000 litres of waste water every day. The raw water tank is of capacity 20,000 litre. 10,000 litres of treated water can be stored. It is estimated that hostel at full occupancy generates 8000 litres of waste water. The operation cost is INR 1,80,000 per annum and maintenance cost is INR 20,000 per annum.

Figure8.18: a) sewage treats plant

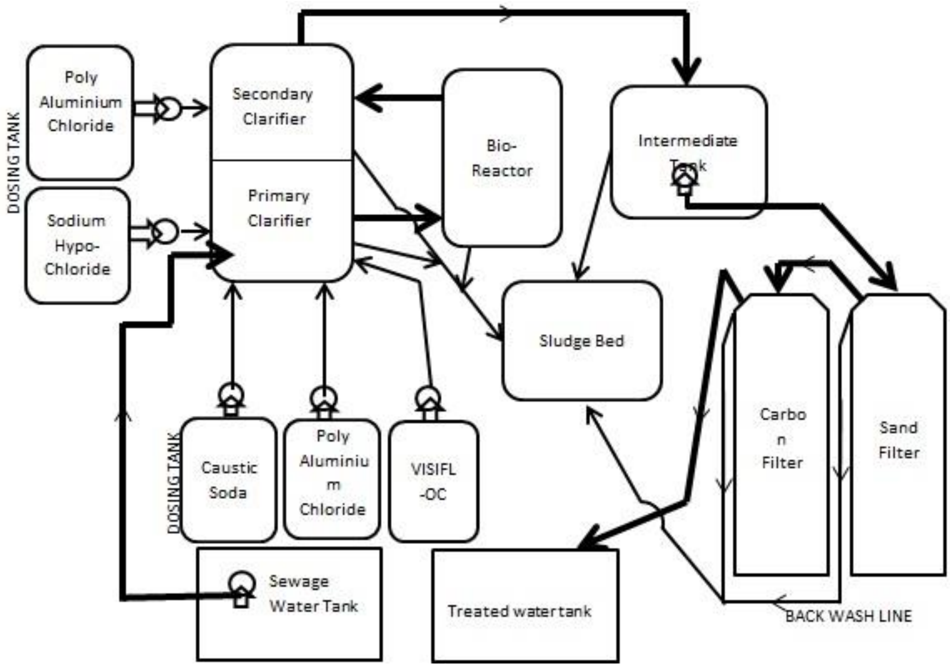


Figure8.19: Water flow diagram of sewage treatment plant.

Water management

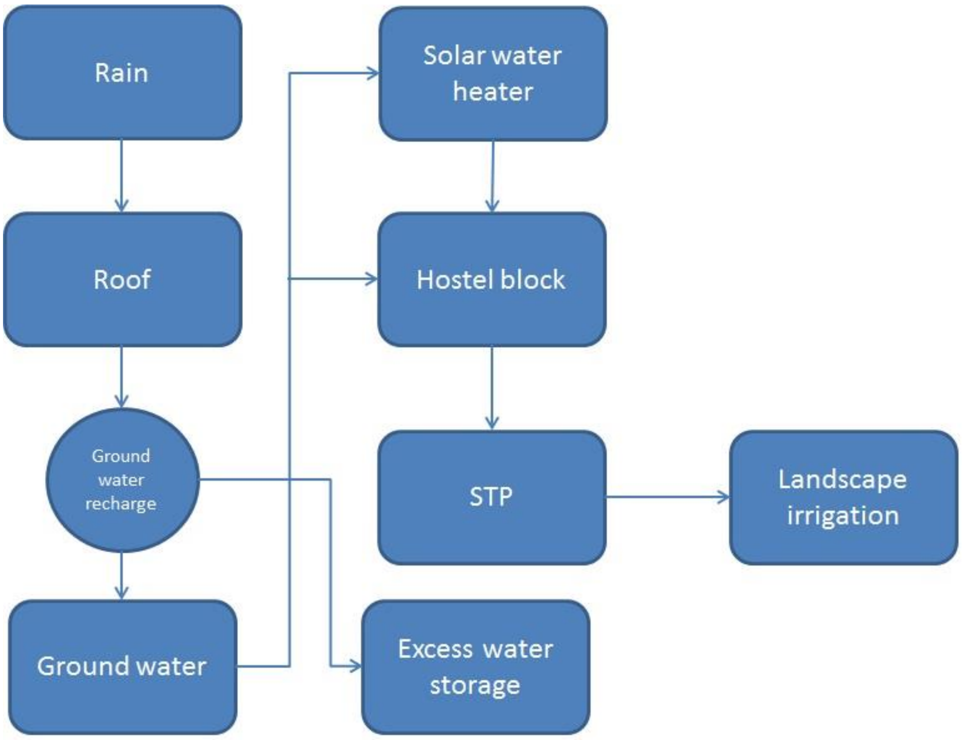


Figure8.20: water management in TU hostel.

Low flow water fixtures are used which saves 25% of water consumption resulting in annual savings of about INR 65000.

Earth Air tunnel

The ambient air temperature varies throughout the day and the year, while the soil temperature at depth of 4 m remains constant. The steady temperature maintained at this depth is equal to average annual temperature of the place. For Delhi this is about 25^{0}C. The system has been sized for an air flow rate of 4500 lps. Two sets of tunnels are provided with common AHU system & supply and distribution system. The two tunnels systems are independent and have capacity of 2250 lps each.

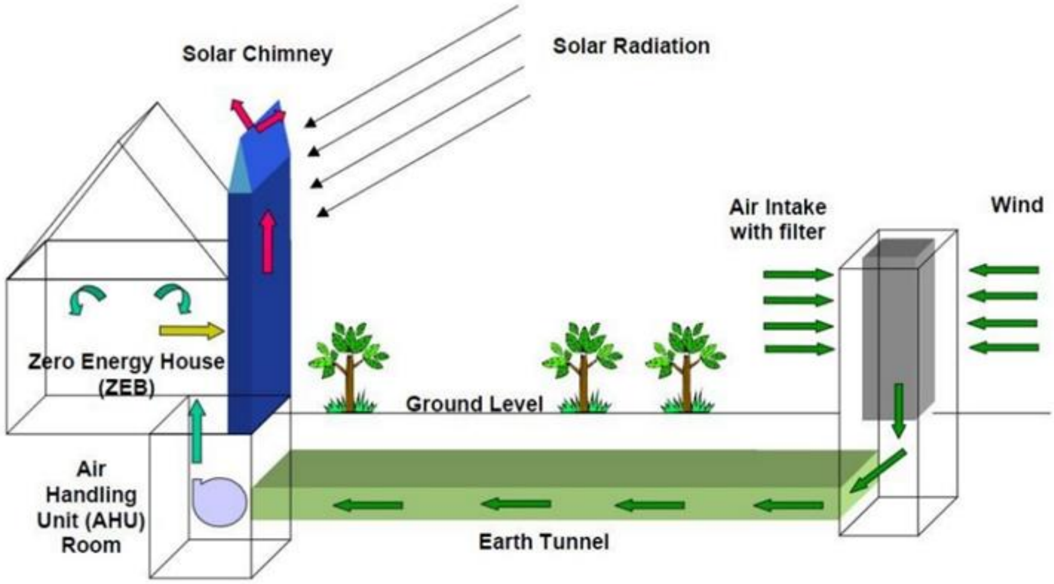


Figure8.21: Graphical representation of EAT system

Air is drawn through the intake which is above the ground and enters buried pipes through a plenum. Each tunnel has three tunnels made up of concrete and with diameter of 450mm. The air passes through AHU unit to hostel block via suitable ducting.

During summer, hot air (at around 39-41^{0}C) is taken in and cooled in the tunnel to about 28-30^{0}C. While in winters when outside temperature is around 7^{0}C, the tunnels warm up the air to temperatures of 21^{0}C. During monsoon cooling coil is used to dehumidify the humid air.

The initial simulations done with EAT system has shown energy reduction for cooling by 50% as compared to conventional cooling system. This technology is still in nascent stage and needs further advancement to be more economic and effective. The maintenance cost mainly comes for AHU which is around INR 60,000/year.

Figure8.22: a) Inlet to AHU from tunnel. b) Earth air tunnel intake chamber.

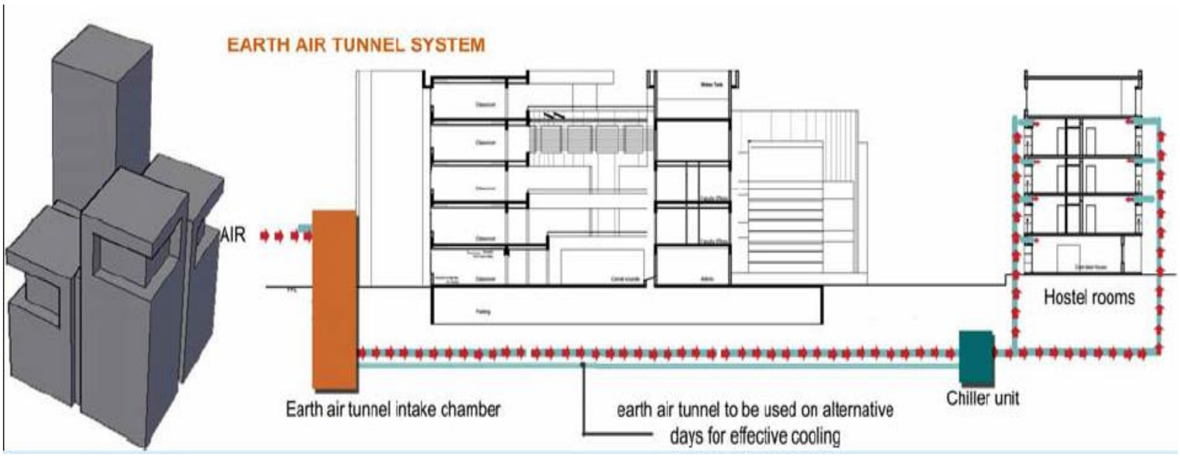


Figure8.23: Schematic of installed EAT at the TU.

8.2.3 Onsite monitoring

Onsite monitoring was done in a hostel room facing south and on the top floor of the building. The monitoring was done at 3 pm and the weather condition was cloudy.

Parameters	room
Inside temperature (^{0}C)	29.2
Inside lux (Middle of room)	200
Outside temperature(^{0}C)	34
Relative Humidity (%) inside	59.6

8.2.4 Summary

The passive design implemented in the building keeps it cooler and saves energy. Use of local material also helps in reducing the cost. Being a college hostel the occupants are single students and no family lives in the hostel.

As per occupant interview the room maintains comfortable temperatures throughout the year and in summers fans are needed all the time. EAT system is effective but condensation problems exists which needs to be solved. Although a green feature the EAT is not affordable. The STP system produces treated water which is used for gardening but the treated water produced is not enough for irrigating all the green landscape (as per interview with maintenance people)

8.2.5 Case study summary

Table 8.8: Case study summary

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	**Cost (INR)**	**Green Rationale**	**Whether Affordable Yes/No (Y/N)**	**Details**	**Cost**	
	Sustainable site planning						
1	Tree protection	None	Controls microclimate and soil erosion if protected	Y	Trees are usually cut.	additional cost for tree cutting and permissions (not available)	Y
2	Soil preservation	Helps in saving cost of bringing top soil from a nursery post construction. Collection , storage and maintenance cost of top soil is Rs. 17/cu.m	Preserves the natural top soil and natural biome.	Y	No soil preservation. Cost of new soil to be bought.	purchase of top soil cost. Cost for supply, staking and mixing of sludge, manure, sieving is Rs.228/cu.m	Y
3	Preserving Contours & topography	No additional cost helps in saving on additional infrastructure for storm water management. Rs. 110/cu.m. Sizing of storm water management is less as it follows contour and gets less water from run off.	Preserves natural topography site features like drainage pattern and helps in storm water management.	Y	No Protection of Levels. Cut and fill process by contractor needs additional cost	Rs. 110/cu.m for trenching and additional cut and fills excavation. Sizing of storm water management is more as cut and fill cost and gets more water from run off to handle.	Y
Landscape paving materials							
4	Pervious paving using local stones and grass	250-300/sq.m	Controls Heat Island effect and enhances percolation of Storm water & run off control, recharges	Y	impervious paving	Cost is higher than pervious paving due to high quantity of materials. Rs. 300-350/sq.mts.	Y

Sl no.	Green Feature in Case study			Whether Affordable Yes/No (Y/N)	Conventional Features		Replicability in Affordable housing
	Details	Cost (INR)	Green Rationale		Details	Cost	
			ground water.				
Passive Solar Features							
5	Shaded windows	Rs. 60/sq.ft of glazing(600/sq.m) used in the windows	Cut down solar radiation to the interior space and minimizes heating	Y	Shading of windows	RCC- Rs. 5500 – 6200/cu.m or Rs. 60/sq.ft of glazing(600/sq.m) used in the windows	Y
6	Day lighting through windows , stairwell roof	N/A	Harvests daylight to the interiors and avoid artificial light usage	Y	Day lighting is provided with limitation	N/A	Y
7	Natural Ventilation through windows and ventilator	No cost involved	Reduces dependence on AC and fan and keeps indoor air quality at healthy levels	Y	Natural ventilation is provided with limitation and equivalent cases may have AC installed.	No cost involved	Y
Green materials							
8	Sandstone		Natural material with low embodied energy and locally available		Plastered wall	Rs 30/sq.ft	Y
Water Management							
9	Rainwater harvesting	Rs.84300 part cost for the pond (120000L capacity)	Water recycling and usage of rainwater in	neutral	Rain water may not installed	similar	Y

Sl no.	Green Feature in Case study				Conventional Features		Replicability in Affordable housing
	Details	Cost (INR)	Green Rationale	Whether Affordable Yes/No (Y/N)	Details	Cost	
	with Roof harvesting and Site features		landscape irrigation. Reduces dependency on municipal water for non-potable use.				
9	Waste water treatment plant - **STP**	2500000 (for 25000 L capacity)	Waste water recycling and reuse	Y			Y
10	Water efficient fixtures	Cost of the fixture is Rs.3500 for low flow faucets and Rs.6500 for dual flush 3/6 lp/flush water closets	High water saving in building water demand due to low flow efficient fixtures, thus conserving the water resource	Y	conventional fixtures	Cost of the fixture is Rs.1750 for conventional faucets and Rs.5000 for Single flush 9 lp/flush water closets	Y. Payback is less than 1 year for efficient fixtures
Renewable Energy Technologies							
11	Solar Hot Water	Cost not available	Hot water without electricity is available thereby saving energy	-	Solar Hot Water systems are available in conventional homes	Rs. 20000/100 litres (Venus solar hot water)	Y
Energy							
12	15W CFL	200 - 250	Reduces energy consumption	Y	FTL	40	Y
13	Earth air tunnel	1 crore	Reduced energy consumption	N	Conventional Air conditioning	N/A	Y

8.3 Summary of Composite Climate zone

Table 8.9: Summary of Composite Climate

Green features	Literature studies& traditional Practices	Case studies	Best regional practices
Siting and climate responsiveness			
Orientation	Longer walls orienting towards North and south side		
Zoning	Shading Verandas and living spaces on critical orientations, courtyards		
Street Design	Shaded streets		
Energy, renewable energy & building materials			
Roof treatment, roof garden		Reflective tiles, Roof garden, Thermal insulation	Hollow clay blocks, Insulated roofs, RCC with reflective tiles.
Shaded windows in summer	Shaded windows, jallis	Shaded in summer, Sun penetration in winters	
Walls to respond to outside climate	Thick walls,	Insulation, Reflective finishes – Stone cladding, AAC blocks etc.	AAC blocks, Hollow concrete blocks, Hollow clay blocks, Stone masonry
Local materials to reduce embodied energy	Local materials, teak wood, lime plaster, adobe blocks, sand stones	AAC blocks	Lime, adobe, AAC blocks, Stone
Construction technologies to reduce time and volume of construction		AAC blocks, Grass pavers blocks for outdoor parking	Precast sandwiched walls, Beams, columns, Shading devices, slabs
Natural ventilation	Through north and south windows, high ceiling for air circulation		
Daylight integration	Through windows and skylight		Clerestory lighting, floor level opening, full height windows,
Efficient outdoor and indoor lighting by use of T5 lamps, CFL, LED etc		LED lamps outdoors, T5 lamps in common corridors	Fluorescent tube lights (T8 & T5), 5W CFLs, 2W LEDs
Efficient fans or other heating/cooling technologies	35W Ceiling Fans, Evaporative coolers for summer	Earth Air Tunnel	Cooling Towers, Solar chimneys
Solar based outdoor lighting	Outdoor light connected to Grid tied solar power system	LED Street lights	Stand-alone LED street lights powered on Solar PV
Solar based water heating	Solar hot water system for individual house		

Green features	Literature studies& traditional Practices	Case studies	Best regional practices
Solar PV panels to generate electricity	Solar PV Panels generated electricity used in common areas lighting.		Solar PV Panels generated electricity used in common areas lighting.
Efficient landscape design			
Pervious pavers		Grass pavers concrete and interlocking blocks	
Sedimentation control measures in the landscape design	Soft drainage using aggregates filters, mulching		
Use of native species	Tree plantation around habitat		
Source of landscape water	Treated water from STP		
Irrigation equipment			Drip irrigation, efficient sprinklers
Water body	Water body		
Water management			
Waste water treatment system		Conventional STP with 650KLD capacity	
Rain water harvesting	Storm water drainage	Groundwater recharge and re-use	
Dual plumbing system	Multiple plumbing line for fresh water, treated water and rain water		
Efficient plumbing fixtures	Low flow plumbing fixtures, faucets with aerator, water level controllers, pressure regulating devices	Low flow fixtures	Energy efficient motors, dry toilets, low flow fixtures
Waste management			
Segregation of waste	mandatory waste segregation, dry and wet waste segregation of kitchen		
Resource recovery from organic waste			
Resource recovery from recyclable waste	All waste recycled and reused		

9 Policy Guidelines to promote Green Affordable Housing

This section proposes policy guidelines for Neighbourhood/Habitat level as well as a few minimum required mandatory regulations for Habitat scale, which could be considered by State Governments and Centre Government.

Policy guidelines and minimum mandatory regulations for housing unit level are also proposed for consideration by municipalities/State Governments/Centre Government.

It is important that for mainstreaming green features in affordable housing sector, that the States / developing agencies should prioritise policy goals for integration of green initiatives and sign an agreement to achieve the chosen goals with a time line with the Central Government or the funding agency. It is also very pertinent to note that the green initiatives require enormous technical support and skill up-gradation to enable steady supply of quality /skilled labour in large numbers and Government's support in enabling the training and skill up gradation would be a major trigger to scale up the green building movement. It is also proposed that **minimum 2 out of 6 policy guidelines should be enacted between the year 2014 – 2017 and the remaining within 2022.**

For eg. STATE A may choose Item No 2 & 3, which needs to be mandated by revising the Existing Building Codes, introducing the Item in the State Schedule of Rates.

9.1 Policy guidelines for Neighbourhood / Habitat Level

Table 9.1: Policy guidelines for Neighbourhood / Habitat Level

S. No.	Policy Goal	Policy Guidelines	Assessment/Appraisal Parameter	Cost implication to implement/ Life cycle cost
1.	Healthy local micro climate by respecting the site's nature	Preserve existing trees Plan along the contours Design as per solar path and predominant wind direction. Master plan to integrate existing site features.	Case studies show this helps in sedimentation control, microclimate and enhanced biodiversity.	No incremental cost to implement
2	Improve site porosity	Pervious pavement in pedestrian areas of landscape Pervious flooring (pavements) for parking areas (surface parking)	Helps in rain water harvesting and reduction of heat island effect.	Cost of pervious pavers Rs.295/m2 in comparison to concrete pavers which is Rs.350/m2. Cost of pervious concrete pavers that can take vehicular load is Rs. 400/sq.mts.

S. No.	Policy Goal	Policy Guidelines	Assessment/Appraisal Parameter	Cost implication to implement/ Life cycle cost
3.	Conserve Energy Promote Renewable Energy alternates	Energy Efficient Street Lighting Solar based outdoor street lighting.	Reduces electricity bills and carbon footprint.	Life Cycle Cost Analysis show payback period is within 3 years
4.	Conserve Water	Source of landscape water from recycled treated water being generated on site or rain water harvested. Use of efficient irrigation equipment like drip or sprinklers. Use of treated water for flushing in toilets.	Reduces dependence of water from external sources and is cost effective.	Cost of STP is comes to be Rs.30,000/unit for a development of 96 units in 7.5 acres of development. In another development it caused only Rs. 8000/unit, where total number of units are 148 in the development.
5	Enable Solid Waste Management	Provide separate bins for waste segregation. Allocate space for storage and disposal. Resource recovery from organic waste on site.	Reduces waste management at municipality level. Helps maintain cleaner cities Resource recovery from waste.	Minimal cost

9.2 Mandatory Regulations for integration of Green building features in Affordable Housing

a) A must for all publicly owned or funded by public agencies

b) For all affordable housing developments which seek incentives/concessions or quickening procedures for project approvals and permits under Green Affordable Housing

Table 9.2: Mandatory regulations to support the above set policy guidelines at the Neighbourhood/ Habitat Level

S. No.	Policy Goal	Mandatory Regulation	Assessment/Appraisal Parameter	Cost implication to implement/ Life cycle cost
1.	Healthy local micro climate by respecting the site's nature	1.1. Top soil preservation if nutrient rich 1.2. Rain water	The case study analysis shows it is more economical to store top soil than to buy rich soil from nursery post	Rs.17/cubic mt for top soil preservation, to purchase nutrient rich soil Rs.228/cubic mt.

S. No.	Policy Goal	Mandatory Regulation	Assessment/Appraisal Parameter	Cost implication to implement/ Life cycle cost
		harvesting along with storm water management 1.3. Use of native species vegetation in landscape.	construction landscape. Use of native species supports biodiversity of a locality, after maturity trees consume no water.	Cost for rain water harvesting and storm water management is Rs.5000-10000/dwelling. No additional cost for using native species.
2	Improve site porosity	Minimum 10% of the open to sky space (space not occupied by building footprint) to be porous.	Helps in rain water harvesting and reduction of heat island effect.	Cost of pervious pavers Rs.295/m2 in comparison to concrete pavers which is Rs.350/m2.
3.	Conserve Energy Promote Renewable Energy alternates	Use of energy efficient outdoor lighting. (Example Metal Halide)	Reduces electricity bills and carbon footprint.	Considering lamp life and efficiency Metal Halide lamps are more affordable than commonly used sodium vapour lamps. Cost of one fixture Rs. 1900, in comparison to Sodium Vapour which is Rs. 1750/fixture.
4.	Conserve Water	Installation of waste water treatment plant on site		Case study analysis show, Less than 1% of total project cost. Rs.7500-8500/dwelling unit in a group housing project.
5	Enable Solid Waste Management	Management of organic/kitchen waste on site.	Reduces waste management at municipality level. Helps maintain cleaner cities Resource recovery from waste.	Minimal or no additional cost.

Table 9.3: Recommendations / policy guidelines for House unit Level

S. No.	Policy Goal	Policy Guidelines	Assessment/Appraisal Parameter	Cost implication to implement/ Life cycle cost
1.	Optimize building design with respect to climate and site conditions	Orient the buildings to maximise thermal comfort and natural lighting.	Reduces dependence on artificial mechanical devices which consume high electricity.	No incremental cost to implement
2.	Use alternate efficient construction technologies	Use of precast/prefab structural members.	Low embodied energy Less construction time	In certain cases initial cost of alternate technologies is low. In case of Prefab technologies, the system

S. No.	Policy Goal	Policy Guidelines	Assessment/Appraisal Parameter	Cost implication to implement/ Life cycle cost
		Use of technologies that consume less time like RCC wall construction. Use of technologies that use less material like Jack Arched Roof		becomes economical with more number of dwelling units.
3.	Conserve Energy Promote Energy Conservation Building Code	Use of efficient lighting fixtures and lamps and ceiling fans inside the house. Meet ECBC mandatory requirement.	LCCA show savings after 1st year, pay back is within 1 year.	One CFL (15W) costs Rs.200, one incandescent lamp (60W) costs Rs.15/.
		Use of local materials as they have low embodied energy. Installation of Solar Thermal Hot Water System	LCCA shows Solar water heating systems are more economical for climates which need hot water shower. Pay back is within 3 years.	Investment of Average Rs.35000/200Lts capacity/unit.
4.	Conserve Water	Efficient water fixtures like dual flush Water Closets, low flow faucets	Life cycle cost analysis show huge potential of water and capitol saving. Annual 75% water saving/family.	Initial cost per fixture could be 30% higher. Example, conventional W/C is Rs.5000, while dual flush W/C is Rs. 6500/.
		Rain water harvesting and waste water treatment to be reused for flushing in bathrooms.		Cost of reusing water after on site treatment is Rs. 7500-Rs.8500/dwelling in group housing. The cost of reuse of rain water is higher – case study shows Rs.14000-Rs.42000/dwelling depending upon the density.
5	Enable Solid Waste Management	Waste segregation at individual house level.		

Table 9.4: Mandatory regulations for House unit Level

S. No.	Policy Goal	Policy Guidelines	Assessment/Appraisal Parameter	Cost implication to implement/ Life cycle cost
1.	Optimize building design with respect to climate and site conditions	Follow at least 50% of solar passive architectural design strategies recommended for climate zone.	Reduces dependence on artificial mechanical devices which consume high electricity.	No incremental cost to implement
2.	Conserve Energy Promote Energy Conservation Building Code	Top floor terrace/roof to be either insulated/high reflective finish/shaded/green roof	Case studies show Green roof, insulated roof and reflected roof help in maintaining comfortable indoor conditions and reduce fluctuations.	Green roof cost is Rs. 409/sq.mts in comparison to brick coba which is Rs.540/sq.mts. Green roof is 25% more economical.
3	Conserve Water	Efficient water fixtures like dual flush Water Closets, low flow faucets		

9.3 Green Building Initiatives in the State of Karnataka

Zonal plans, building bye laws, Schedule of Rates used in Karnataka were reviewed to assess the penetration of green building features in the State of Karnataka.
Green initiatives integrated in the Revised Master Plan for Bangalore are described below.

9.3.1 Revised Master Plan 2015, BANGALORE, 2007, Volume – III*(ZONING OF LANDUSE AND REGULATIONS)*

Rain water harvesting: Provision of Rain Water Harvesting is mandatory for all plots which are more than 240 sq.m in extent. A 5 % rebate on the property tax is offered for residential property and 2 % for non-residential buildings for the first 5 years, when rain water harvesting is made as an integral part of the building constructed.

Solar energy: Solar lighting and solar water heating is recommended for all new development/constructions. If the solar lighting and solar water heating is adopted, then refundable security deposit on fulfilling the conditions shall be returned along with 2 % interest.

Tree Planting: Planting of minimum one tree is mandatory for a site measuring more than 2400 sq.ft. and minimum of 2 trees for a site measuring more than 4000 sq ft. The concerned authorities shall ensure that the trees are planted before approval of building plan and tax shall be accessed only after confirming the existence of trees in the site in question. The trees shall be planted only in the rear set back area.

Redevelopment Scheme:

Following regulations shall apply for all redevelopment schemes taken up by Karnataka Slum Clearance Board/BDA/BBMP/KHB within the local planning area of Bangalore:

Redevelopment schemes (including slums) may be allowed in the following Land uses:

Residential (Main), Residential (Mixed), Commercial (Central), Commercial (Business), Industrial (General) & Industrial (Hi-tech).

- Maximum plot coverage is allowable up to 60%.
- Maximum FAR is allowable up to 3.
- In case of Layout/Group housing, minimum of 10 % of area for Park and 5% of area for C.A shall be reserved and maintained by the respective authorities.

Subdivision regulations

RESIDENTIAL - Parks / Open spaces and Playgrounds: Parks / Open spaces and Playgrounds shall not be less than 15 % of the total land area. This shall be relinquished to the Authority (free of cost and free of encumbrance) and if required, the authority may handover the area for maintenance to the resident's welfare association. If the land is not maintained up to the satisfaction of the authority, it shall be resumed back by the authority.

Regulations for Residential Development Plan:
1. 10 % of the land shall be reserved for Park & Open space. The open space (park) shall be relinquished to the authority free of cost and the same may be allowed to be maintained by the local residents association (registered), if the Authority so desires.

Regulation for Integrated Township

10% of the total area shall be reserved for parks & open space. It shall be handed over to the authority free of cost & shall be maintained by the developer to the satisfaction of the authority.

9.3.2 Electronic - City Industrial Township Area Bangalore, Building Byelaws-2013-2015 (ELCITA)

Following are the green initiatives integrated in the building bye laws:

Lighting and ventilation requirements

a) **Natural ventilation*:***

Rooms shall have, for admission of light and air, one or more openings, such as windows and ventilators, opening directly to the external air or into an open veranda. Doors are not counted towards the area of openings in walls for lighting and ventilation purposes.

b) **Artificial ventilation*:***

Where the light and ventilation requirements are not met through daylight and natural ventilation, the same shall be ensured through artificial lighting and mechanical ventilation, as per Part VIII Building Service section I, Lighting and ventilation of National Building Code of India brought out by the Indian Standards Institution. The provisions contained in the latest version of the Code shall be made use of at the time of enforcement of the bye-laws.

c) **Area of openings*:***

Minimum aggregate area of openings excluding doors shall not be less than 1/6th of the floor area in the case of residential buildings. In the case of other public buildings like business houses, educational buildings, offices, institutional and hospital buildings, the minimum aggregate area of openings shall be not less than 1/5th of the floor area. The area of openings shall be increased by 25% in the case of kitchen. No portion of a room shall be assumed to be lighted if it is more than 7.5 m from the opening. In case of bath rooms and water closets, minimum area of window or ventilator shall be 0.9 sq. m. with one side being not less than 0.3 m.

Facilities at the construction premises

Temporary lavatories shall be provided for the use of workers within the construction premises where the floor area is more than 250 Sq.m.

Facilities for physically handicapped persons – All buildings (except individual residences) shall be designed and constructed to provide facilities to the physically handicapped persons as prescribed in the Schedule IV of these bye-laws.

***Rain water harvesting*:**

a) Provision of Rain Water Harvesting is mandatory for all plots which are more than 240 sq.m in extent. For plots less than 240 sq.m in extent, provision shall be made for ground water recharge.
b) The Rain Water Harvesting structures shall have a minimum total capacity as detailed in Schedule V.
c) Provided that the Authority may approve the Rain Water Harvesting structures of specifications different from those in Schedule V, subject to the minimum capacity of Rain Water Harvesting being ensured in each case.
d) The owner of every building mentioned in the Schedule V shall ensure that the Rain Water Harvesting structure is maintained in good repair for storage of water for non-potable purposes or recharge of groundwater at all times.
e) The Authority may impose a levy of not exceeding Rs. 1000/- per annum for every 100 sq. m of built up area for the failure of the owner of any building mentioned in the byelaw 3.4.7 to provide or to maintain Rain Water Harvesting structures as required under these byelaws.

Solar energy:

Solar lighting and solar water heating is mandatory for all new development/constructions as per Table 10 for different categories of buildings. If Solar Lighting and Solar Water heating are adopted, then refundable security deposit on fulfilling the conditions shall be returned along with 2% interest.

Tree planting:

Planting of minimum two trees is mandatory for residential sites measuring more than 500 Sq.m and minimum four trees for Public & Semi-public / commercial / Industrial sites measuring more than 1000 Sq.m. The trees shall be planted only in the rear / side setback area. The Authority shall ensure that trees are planted at the time of giving occupancy Certificate.

Construction practices and safety

The various construction activities like; demolition, excavation, blasting, actual construction from foundation level upto completion shall be in accordance with Part VII Construction Practices and Safety of the National Building Code of India. The safety measures to be adopted during the various construction operations, including storage of materials on the construction site and Corporation / public land shall be in accordance with Part VII Construction Practices and Safety of the National Building Code of India.

9.3.3 Schedule of Rate for Karnataka State

The schedule of Rates were checked for Karnataka, and it was found out that are no specific green building features integrated in the Schedule of Rate.

10 Conclusions

Literature review and detailed case studies helped in identifying and assessing the impact of green building features incorporated in various climate zones of India since traditional times to modern current practices.

The impact of some of the green building features were analysed through on site monitoring of environmental parameters like air temperature, Relative Humidity, light level, surface temperature. Electricity bills and water bills were collected in a few case studies where available, to assess the Energy Performance Index and Water consumption in comparison to conventional buildings, without any green building feature.

The affordability and replicability analysis was carried out by comparing the thermal performance and embodied energy of green building feature in comparison to conventional features.

Affordability analysis was carried out by undertaking Life Cycle Cost Analysis (LCCA) to find out the payback period and overall savings expected by incorporating green features on the overall life cycle of the dwelling unit.

A summary of green features for 5 climate zones that are affordable and replicable in affordable housing projects is collated below.

10.1 Summary of green features for 5 climate zones

Table 10.1: Summary of green features for 5 climate zones

Sl. No.	Green Building Feature	Climate Zones of India				
		Moderate	Warm-humid	Cold	Hot-dry	Composite
1.	Orientation and Siting of buildings	Longer façade oriented towards North and South direction.				
2.	Climate responsiveness	Small windows, courtyard planning, daylight integration, natural ventilation.	Larger openings, shaded windows and verandas, courtyards, daylight integration, natural ventilation	Small openings, solar heat gains from concepts like Trombe wall, green house, daylight.	Small openings on East /West and large openings on North/South, shading, thermal mass, Integration of cooling towers, water bodies, evaporative cooling.	Small openings on East /West and large openings on North/South, thermal mass, cooling towers, earth air tunnels, evaporative cooling, South windows to allow winter sun come inside the living spaces.
3.	Building materials & Structural systems	Roof treatment shaded/insulate/reflective, use of local materials like Stabilized Earth Blocks, Laterite blocks.	Roof treatment shaded/insulate/reflective, shaded windows, jalis, hollow blocks for walls, use of local materials. New construction technologies like Reinforced Concrete Walls which need no plastering.	Insulated envelope comprising of walls and roof, locally available materials like stone, bamboo, stabilized earth	Roof treatment shaded/insulate/reflective, shaded windows, jalis, Use of local materials like Fly ash bricks, lime, stone, stabilized earth blocks, AAC blocks.	Roof treatment shaded/insulate/reflective, shaded windows, jalis, Use of local materials like stone, stabilized earth blocks, AAC blocks.

Sl. No.	Green Building Feature	Climate Zones of India				
		Moderate	Warm-humid	Cold	Hot-dry	Composite
				blocks.		
4.	Sustainable site planning	Pervious pavement, top soil conservation, tree preservation, protection of contours, rain water harvesting, use of native species in landscape to enhance the local biodiversity.				
5.	Energy efficiency	Use of CFL, LED lamps inside the dwelling, use of efficient outdoor lighting by use of efficient lamps like Metal Hallide and LED, use of efficient ceiling fans.				
5.	Water management	Use of efficient fixtures inside the building, efficient design of landscape, use of harvested rain water for landscape and building domestic use, treat waste water and reuse in landscape and toilet flushing.				
7.	Renewable energy integration	Integration of solar water heating panels and outdoor solar lighting.				
8.	Waste management	Segregation of solid waste, storage of segregated waste, resource recovery from waste like compost from wet kitchen waste.				

11 Way Forward

Green building initiatives in affordable housing has huge potential in India. The current study helped in initiating the dialogue with a few stakeholders; however, due to limitation of time, the research was limited to only a few field studies in 5 cities of India.

It is intended to take forward the documentation and field analysis to other regions of the country falling in the spectrum of 5 climate zones. For example, under cold climate, the present study covered Kashmir, however, North East part of India falling under cold climate was only covered through literature review. Physical checks and field studies in that part of the country were not carried out due to limitation of time. Similarly under Warm-humid climate, one of the cities in South India was covered; however Eastern part of India was not covered. Thus, it is important to extend this research to all regions of India, so as to bring forward the local materials and regional aspects of green buildings in affordable housing projects. This will help the Government in issuing guidelines that can be followed by the various regions for seeding green initiatives in majority of the Govt supported programmes and projects.

Secondly due to limitation of time, performance monitoring of environment parameters to assess the impact of green features on temperature, RH, light levels was carried out only for one day. The current monitoring reflects the performance; however, the analysis is complete by monitoring one full year of environment performance, such that impact of all seasons is captured. For example, a Mud house may be very comfortable in summers, however, may or may not be so comfortable in winters. Thus it is important to take forward the current study into a second phase of a detailed study further for an extended period.

Thirdly, monitoring the cost aspects is an ongoing process and will vary from Region to Region and time to time. This can be taken up progressively across Cities/towns to qualify for affordability and also to introduce in all the State SORs certain items which are green and affordable. Only on such introduction in the State SOR, these elements and features could become part of a contracting document ensuring a step towards on site implementation.

Fourthly, the Development Control Norms (DCRs) of the States can also be improved upon to modify the set back requirements conforming to ECBC norms for adequate lighting and ventilation and also to improve more on site percolation of water.

12 Annexures

Annexure 1

The below list of green housing has been collected through discussions with senior colleagues in TERI, practicing architects and from the database of GRIHA and IGBC rating systems. From the rated projects the below mentioned list comprises only those projects which are already operational and certified. However, from the database of GRIHA and IGBC certified projects it is found out that further to the below list, under GRIHA there are about 170 GRIHA Pre Certified homes, and under IGBC there are about 198 Pre-certified IGBC homes in the country.

Table 12.1: List of Affordable Housing Projects with Green Features in Warm-Humid Climate Zone

Sl. No	Building	Typology	Location	Architect	Source
1	GFRG Demonstration Building	House	Chennai	IIT Madras	http://www.businesswireindia.com/news/news-details/iit-madras-unveils-%E2%80%98gfrg-demonstration-building-showcase-its-rapid-aff/35575
2	Visala	House	Trivandrum	Shailaja & Sajan	http://www.newindianexpress.com/cities/thiruvananthapuram/article1338279.ece
3	TATA Subh Griha	Housing	Mumbai	HOK, Toronto	http://www.tatavaluehomes.com/shubh-griha-vasind/index.php
4	Marg Swarnabhoomi	Housing	Chennai		http://www.margswarnabhoomi.com/about-green-building.php
5	VBHC Vaibhava	Housing	Chennai	VBHC	http://articles.economictimes.indiatimes.com/2012-06-12/news/32194922_1_affordable-homes-budget-housing-jerry-rao
6	Hiranandini Palace Gardens	Housing	Chennai, Mumbai	Hiranandini	
7	Govardhan Village	Housing	Thane	Chitra Viswanath	
8	The wall house	House	Auroville	Anupama Kundoo	http://www.indian-architects.com/en/anupama-kundoo/projects-3/wall_house-29254
9	Chandrashila Budget House	House	Kerala		http://archnet.org/sites/6776/publications/2400
10	Auroville Earth Institute	Housing	Auroville	Satprem Maini	

	Vikas Apartments	Housing	Auroville	Satprem Maini	Energy efficient buildings in India by Ms.MiliMajumdar
11	Rabirashmi	Housing	Calcutta	Bengal DCl	http://www.downtoearth.org.in/content/kolkata-highrises-get-rooftop-solar-panels
12	Net Zero energy town homes	Housing	Florida, USA	Planet green group	http://inhabitat.com/florida-eco-village-will-be-the-first-affordable-net-zero-townhome-development-in-the-us/
13	Barnes family house	House	New Orleans, USA	Kimberlake	http://www.ecobuildingpulse.com/prefab-design/aiadesign--all-the-right-moves.aspx
14	Pou del Merli settlement	Housing	Martorell, Spain		http://tzb.fsv.cvut.cz/projects/resset/files/resset-spain.pdf
15	Punggoal Eco town	Housing	Singapore		http://edition.cnn.com/2012/09/02/world/asia/singapore-punggol-eco-town/

Table 12.2: Green Building Initiatives for Affordable Housing: Moderate Climate Case studies

Sl. No.	Name of the building	Architect	typology	RESOURCE	Siting of Building
1	Zed earth Villa		Residence	http://www.grihaindia.org/index.php?option=com_fabrik&view=list&listid=3&Itemid=0&resetfilters=0	Bangalore
2	Par Xpress		Residential	NHB	Pune
3	BCIL ZED Woods		Residential	NHB	Bangalore
4	BCIL ZED Collective		Residential	NHB	Bangalore
5	Ganga Skies		Residential	NHB	Pune
6	Suvidha – Retirement Village	Ar Jaisim		Jaisim fountainhead	Bangalore
7	Rohan Ashima	Mind Space			Pune
8	Rohan Ashima	Mind Space			Bangalore
9	Faculty Housing	Mind Space			Bangalore

Sl. No.	Name of the building	Architect	typology	RESOURCE	Siting of Building
10	Residence for Mary Mathew	By Ar Mathewan d Ghosh	House	Energy efficient building in India, Ms. Mili Majumdar	Bangalore
11	Good Earth Malhar Terraces		housing	http://www.goodearthhomes.net/Terraces.html	Kengeri, Bangalore
12	laterite house of Indradev Babu	Anup Naik	House	http://www.prismma.in/architect-bangalore-2/, http://www.thealternative.in/lifestyle/bangalores-greenest-homes-the-red-laterite-house-of-indradev-babu/	Townsend, Yelahanka, North Bangalore
13	House of Subbu Hegde	Chitra Viswanath	house	http://www.thealternative.in/lifestyle/bangalores-greenest-homes-how-mud-bricks-helped-the-hegdes-go-sustainable/	Classic Orchards, Bannerghatta Road
14	Kanavi residence	Chitra Vishwanath and Deepak Godhi	house	http://www.thealternative.in/lifestyle/bangalores-greenest-homes-hombelaku-abode-of-the-kanavis/	HSR Layout, Bangalore
15	Five Seasons House		house	http://www.thealternative.in/lifestyle/bangalores-greenest-homes-dutts-five-seasons-house-home-seasons/	RT Nagar, Bangalore
16	Ashok Kamath's Residence		house	http://www.thealternative.in/lifestyle/bangalores-greenest-homes-ashok-kamath-2/	Yelahanka New town, Bangalore
17	Ganapathy home	Natasha and Jeeth Iype	house	http://www.thealternative.in/lifestyle/bangalores-greenest-homes-living-on-good-earth-at-the-ganapathy-home/	Good Earth, Kengeri, Bangalore
18	Muthiah home		house	http://www.thealternative.in/lifestyle/bangalores-greenest-homes-it-is-allsun-and-earth-at-the-muthiah-home/	Classic Orchards, Bannerghatta Road
19	ZED Earth	BCIL	Villas and Townhouses	http://www.zed.in/bangalore/zed-earth	Dodabellapur Road, Bangalore
20	Sandhya Subbaramaiah Residence		House	http://www.thealternative.in/lifestyle/bangalores-greenest-homes-made-lovingly-by-hand/	3rd cross, phase 4, Dollor Colony, JP Nagar

Below are some rated housing projects, out of these which are affordable in nature will be identified in the next step.

Figure12.1: Green Building Initiatives in affordable housing for cold climate zones

SN	Name	Architect	Typology	Location	Resource
1	Tata power Carbon Neutral Eco-Hut in India at Walwhan Garden	N/A	Individual	Lonawala	http://www.tatapower.com/media-corner/pressrelease-2013/press-release-08-july-2013.aspx
2	GERES project	N/A	Individual	Ladakh	http://www.geres.eu/en/energy-efficiency-and-bioclimatic-architecture-in-india
3	The Hill Haven	Ankita Mittal	Individual	Saattal (Uttarakhand)	

Table 12.3: Green Building Initiatives in affordable housing for Hot & Dry climate zones

SN	Name of the building	Architect	Typology	RESOURCE	Location
1	Rajsamadhiyala House	BPS Architects	Single house	Buildotech Magazine	Rajkot
2	Solar passive hostel	Vinod Gupta	Housing	Energy efficient buildings in India by Ms. Mili Majumdar	Jodhpur
3	Integrated Housing and Slum Development Programme Phase - II	Shunya Consultants	Housing	HUDCO Design awards 2012	Lonar

Table 12.4: Case study of Composite Climate

Sl. No.	Name of the building	Architect	typology	RESOURCE	Location
1	IGNCA, Matighar	Sanjay Prakash		http://www.sanjayprakash.co.in/ignca.html	New Delhi
2	Habitat Housing	Ashok B Lall	Housing	http://www.ashoklallarchitects.com/projects/housing.htm#habitat	New Delhi
3	NHPC Group housing, Noida	Ashok B Lall	Housing	http://www.ashoklallarchitects.com/projects/housing.htm#habitat	New Delhi
4	Bidani		Reside	http://arvindkrishan.com/?p=590	Faridabad,

Sl. No.	Name of the building	Architect	typology	RESOURCE	Location
	House		nce		Delhi
5	Redevelopment of property at civil lines	Ashok B Lall	Residential	TERI publication	Delhi
6	Bamboo Housing Prototype- Nagpur India	Wonder grass			Nagpur
7	Juanapur slum settlement scheme	Anil lall		http://www.worldhabitatawards.org/winners-and-finalists/project-details.cfm?lang=00&theProjectID=127	Delhi
8	Avani residence				Hyderabad
9	Mud house	Chitra Vishwanath	Residence	http://biomesolutions.blogspot.in/2010/11/mud-house-in-jubilee-hills-hyderabad.html	Hyderabad
10	Chimes Legend	Mindspace	residential	http://www.legendindia.co.in/chimes.html	Hyderabad
11	City of dreams row housing	Mindspace	Residential		
12	Monama House		Residence	http://www.cpas-egypt.com/pdf/MarianAzmyNessim/Ms.c/3%20%20Chapter%205-6.pdf	Hyderabad
13	National Media Centre Co-operative Housing Scheme	Vinod Gupta	Residential		Delhi
14	Residence of Anirudh and Madhu	Anant Man, Siddhartha wig	Residence	TERI publication	Panchakul
15	Residence of Sudha and Atam Kumar	Sanjay Prakash	Residence	TERI publication	Delhi

Table 12.5: Case study of Composite Climate which are rated

Sl. No.	Name of the building	Place	Source
1	YEIDA affordable housing	Noida, Delhi	
2	Govardhan Ecovillage	Thane, Maharashtra	
3	5 masters residences, Doon School	Dehradun	GRIHA 4 star
4	Common wealth Games Village	Delhi	GRIHA 2 star
5	Sahara Lucknow	Lucknow	
6	Sahara Nagpur	Nagpur	
7	Lotus Zing	Noida, UP	IGBC LEED green homes
8	Lotus Panache	Noida, UP	IGBC LEED green homes
9	Lotus Boulevard	Noida, UP	IGBC LEED green homes
Case study of Composite Climate which are rated			
S. No.	**Name of the building**	**Place**	**Source**
10	Lotus 300	Noida, UP	IGBC LEED green homes
11	Greenopolis	Gurgaon	
12	Spire South	Gurgaon	
13	Spirewoods	Gurgaon	

Annexure 2

Questionnaire filled during field visits

Questionnaire for the User Group

Sl. No.	Basic Information			
1	Name			
2	Age			
3	Male/Female			
4	Occupation			
5	Highest education in the family			
6	Additional details any			
	Occupancy Information			
1	Unit Type			
2	Single/Duplex/Triplex			
3	No of occupants			
4	No of families living			
	Financial Information			
1	Income Source			
2	Occupation type	Govt	Private	Business
3	Identifying the Income group (*to be filled by TERI*)	EWS	LIG	MIG
4	Number of people earning (at unit level)			
5	Net monthly/annual income (at unit level)			
6	House occupancy type	Owned	Rented/Leased	On Loan
	If Owned			
	a. Purchased price			
	b. Purchased year			
	c. Current value			
	d. Idea of selling			
	If Rented			
	e. Monthly Rental			
	f. Deposit/advance paid			
	If on Loan			
	g. Monthly Interest			
	h. Value of mortgage			
	i. Source			
	j. Time period			
7	Maintenance fee			

User Group Interview

1. Does your monthly income match to your monthly expenses

2. Do you consider your house is at affordable range? Reasons.
3. What is the preferred price range that you would call as affordable:
4. Is the space/area sufficient:
5. Is the area/space worth for its cost (owned/rent/loan):
6. Reasons behind in acquiring the property at this particular housing project (one or multiple options can be selected):
   a. Affordable:
   b. Sustainable/green in nature:
   c. Location:
   d. Any other reasons:
7. Is the housing located well (considering public or private transportation, facilities, amenities, hospital, schools etc)
8. Are all living spaces thermally comfortable?
   a. Effectiveness of solar passive features if integrated eg: PDEC system:
   b. Effectiveness of any active technology features if integrated eg: Chilled beams etc:
   c. How many AC rooms:
   d. How often AC is required/used:
   e. How often ceiling fan is required/used:
   f. Is the home comfortable throughout the day? If not when?
   g. Is the home comfortable in all seasons? If not when?
9. Are all living spaces visually comfortable?
   a. Daylight sufficiency:
   b. Artificial lighting quality:
10. Indoor Air Quality
    a. If IAQ is good:
    b. Is your home naturally well ventilated?
11. Any there any health issues in family like dust allergies etc caused by poor IAQ, headaches etc caused by glare, Vitamin D deficiency or any bone alignment issues (typically caused due to improper exposure to day lighting)(identify if any of these diseases are hereditary):
12. How comfortable the Water and Waste recycling methods/practices are at
    a. Unit level:
    b. Community level:
13. Issue:

a. Green features:

b. Maintenance of green features:

c. General maintenance:

d. Water availability:

e. Communal/social:

f. Any other:

Questionnaire for the Developer

Sl. No.	Basic Information			
1	Name			
2	Designation			
3	Company/organization			
4	Address			
5	Mobile			
6	Email			
7	Project/Development name			
8	Location			
9	Target group	EWS	LIG	MIG

Interview questions

1. History of your company/organizations in providing Affordable housing
2. Your definition of
   a. Affordability:
   b. Green building:
   c. Green affordability:
   d. Specific green features designed for affordable housing:
3. From when 'sustainability' is considered along with the 'affordability' concept.
4. Preferred locations/regions/cities for affordable housing development
5. Project Details
   a. Total built up area and floor unit area:
   b. No. of Units:
   c. Type of units(eg: Duplex, triplex, MIG, LIG, mixed etc):
6. Considerations taken in account while proposing the affordable housing development
7. What parameters are preferred while selecting the land for the development
   a. Govt
   b. Private
   c. NGO

d. Other

8. Budget
   a. Initially planned budget:
   b. Finally arrived budget:
   c. How is the cost difference adjusted:
   d. Technologies used to make the project affordable:
   e. What is the extra budget allocated for green features in the project:
   f. Total budget of the project
   g. Price of individual unit sold at
      i. EWS: LIG: MIG:
   h. Rent of individual unit:
      ii. EWS: LIG: MIG:
9. What benefits would account to a developer for going to an affordable &/or green project instead a conventional development
10. Timelines of the project:
11. Information on demand of affordable housing projects and are these easily sold out
12. Targeted results/objectives of the development
13. Project operation /maintenance
    a. Being handled
    b. Handed to the community
    c. Handed to third party

Reasons:

14. Financial benefits from Government
    a. Land subsidy
    b. Incentives (eg. stamp duty exemption)
    c. Tax benefits
    d. FSI (floor space index) Relaxation
    e. Transfer of Development Rights (TDR) benefits
    f. Other (please specify)
15. Financial bodies support
    a. Project Finance
    b. Project Finance on lower rate of interest
    c. Any other Incentives/ Subsidies

d. Tax benefits

e. Others (please specify)

16. Green Affordability:

a. For going green concept

i. Benefits

ii. Challenges

b. For going affordable concept

i. Benefits

ii. Challenges

c. Legal issues faced any:

d. Operational/maintenance challenges:

i. Benefits:

ii. Challenges:

iii. Issues:

17. Experiences/lessons to be carried to future projects:

Questionnaire for the Architect

Sl. No.	Construction Details: Site Planning/ Landscaping			
1	Site Area (Sqm)			
2	Built up Area (Sqm)			
3	Floor Area Ratio (FAR)			
4	Landscape Details	Soft scape	Soft Area including Lawn, bushes, shrubs and trees (Sqm)	
			Names of Native species	
		Hard Scape	Pervious Paved Area (Sqm)	
			Construction/ Material	
			Cost of pervious pavement	
			Impervious Area (sqm)	
			Construction/ Material	
			Cost of impervious pavement	
5	Details of any local materials used for landscaping and irrigation (including drawings and photos)			
6	Source of landscape water and approximate quantity			

Sl. No.	Construction Details: Civil works			
1	Building Plan Form (please tick)		H- Shape Rectangular Circular	L-Shape Square Irregular
2	Surface to Volume Ratio			
3	Window to Wall ratio (Approx)			
4	Envelope Details (Thermal, Recycled content, Embodied Energy) with drawings	Roof along with cost		
		Wall along with cost		
		Window & Frames and cost		
		Window Grill specs and cost		
		Window shades and cost		
		Door materials & Frames along with cost		
		Floor details and cost		
		Staircase and cost		
		Staircase railing and cost		
5	Details/ List of any local materials/ construction technology used (with drawings)			
1	Cost rate for local materials/construction technology			
2	Details of any passive/ low energy cooling technologies integrated with building envelope (with drawings)			
3	Cost of passive technologies integrated			
4	BOQ or quantification of green building design features			

Questionnaire for the Contractors

	Basic Information about the project		
1	Name of the Building		
2	Year of Construction		
3	Location & Address		
4	Contract Type	Landscape, Civil, MEP	
5	Total Cost of Construction		
6	Total Built up Area (Sq. mts)		
7	Total site area (sq. mts.)		
8	Cost/ Sq. mts		

1. BOQ for green features installed in the project along with rates (please fill on the empty page side).

2. Green features installed by the contractor.
3. Challenges if any faced during implementation of green features

4. Would you be willing to replicate the green features in other residential projects based upon the current project experience?

5. Cost of labour for installation of green design features

6. In case of Pre Fab technologies, what is the impact on construction cost and time.

7. Did you quote higher or lower during tendering time, knowing the project is green and affordable.

8. Profit margins expected by the contractors

Questionnaire for the MEP consultants

Sl. No.	Building Services: Plumbing			
1	Total project water demand (Lts/day)			
2	Total Building Water Demand excluding drinking water(lts)			
3	Sources of Water	**Source**	**Quantity (lts per year)**	
		Ground water		
		Municipal (from water bills)		
		Filtered Rainwater		
		Recycled Water		
4	Details of Water Efficiency	Flow rate of the plumbing and sanitary fixtures (LPF or LPM)	Shower heads	
			Faucets	
			Water Closet	
5	Details of Irrigation Efficiency	Type of Irrigation System (please tick)	Flooding	
			Sprinkler	
			Drip Irrigation	
			Any other	
6	Details of Rain water harvesting system	Roof Area (sqm)		
		Size of rain water tank (lts)		

Sl. No.	Building Services: Plumbing		
		Recharge System details/ Construction details	
7	Details of Water Treatment & recycling system	Capacity (lts)	
		System details/ construction details	
8	Details of Drinking water system		
9	Any other water saving features (with drawings)		
10	Cost of waste water treatment system		
11	Cost of installation of rain water harvesting system		
12	Water bills	-	

Sl. No.	Building Services: Electrical				
1	Total Connected Load (kW)				
2	Source of Power		**Source**	**Capacity (kW)**	
			Grid		
			Solar Photovoltaic (SPV)		
			Any other		
3	Details of Electrical Efficiency		**Fixture**	**Star rating/ Efficiency**	**No.s**
		Lighting (including outdoor lighting)	FTL		
			LED		
			Incandescent		
			Sodium Vapour		
			Any other (please mention)		
		Cooling	Ceiling Fans		
			Desert Coolers		
			Window AC		
			Split AC		
			Packaged AC		
			VRF		
			FCUs		
			Any other (please mention)		
		Water Heating	Geyser		
			Solar Water Heater		
			Any other (please		

Sl. No.	Building Services: Electrical				
			mention)		
		Ventilation	Exhaust		
			Any other (please mention)		
		Pumps/ Motors			
4	Details of Energy consumption		Annual Electricity consumption (kWh)		
			Energy Performance Index(EPI)		
5	Monthly electricity bills (12 months)				
6	Details of any passive/ low energy lighting technologies (with drawings and costing)				
7	Details of any passive/ low energy cooling technologies (with drawings and costing)				

Questionnaire for the Operation & Maintenance

Sl. No.	Waste Management		
1	Total Waste Generated (Approx in Kgs)		
2	Total Waste Recycled (in Kgs)		
3	Details of Waste Management System (with drawings)	Dry	
		Wet	
Sl. No.	**Energy**		
1	Electricity bills and annual energy consumption from various sources including back up		
2	Tariff rate per unit of electricity and per unit for other sources		
3	Maintenance of green/energy efficient features, any issues, limitations, recommendations along with maintenance cost		

Sl. No.	Water	
1	Water consumption with break up if possible	

Sl. No.	Water	
2	Rain water harvesting system maintenance experience and recommendations if any	
3	Waste water treatment maintenance plan and cost	

Questionnaire for the Manufacturers

Resource utilization of green features

After green features have been listed and identified in case studies this data sheet will be sent to product manufacturer

Product supplied	Raw material required for final product	Quantity of raw material required per unit of final product	Manufacturing site of final product	Source of raw material (site of raw material extraction	Embodied energy of product (if available)	Percentage of recycled material in final product
Environmental awareness/ certificates	We have environmental management system in place (ISO 14000 or other formal process): Our product has/have environmental certificate/certificates (if yes please mention what certifications are obtained):					Yes/No Yes/No

Note: If product itself is a raw material please mention N/A at relevant places

Annexure 3

Manufacturers of Green products, materials& systems from various case studies

Following table lists down the name of manufacturer of materials used in case studies.

Table 12.6: Manufacturer of materials used in case studies

Sl No	Material	Application	Manufacturer/supplier name	Manufacturer/supplier contact	Recycled content
1	Stabilized Earth Blocks	Walls (Ext &int)	Good earth	Good earth	Red mud from aluminium manufacturing as 2%
2	Rammed earth	Compound Wall (Upper half)	Good earth	Good earth	On site soil
3	Random Rubble Masonry – Sadaralli stone	Compound Wall (Lower half)	Local vendors	NA	
4	Ashlar Masonry-Sadaralli stone	1. Plinth & sill level (most residential units). Complete ground level (Few residential units). 2. Shear wall	Local vendors	NA	
5	Stabilized Mud Blocks	Above sill level (For most residential units)	Good earth	Good earth	Red mud from aluminium manufacturing
6	Finished walls (with stabilized mud blocks + cement plastering)	Applied for some residential units in random for architectural aesthetics	Good earth	Good earth	Red mud from aluminium manufacturing in CSEB
7	Hollow clay blocks	Curbing			-
8	Cuddapah stone	Pervious landscaping	Local vendors	NA	-
9	Wood	- Indoor stairs	Parvathi Timber & Ply	Jithesh Patil-9741822265	

Sl No	Material	Application	Manufacturer/supplier name	Manufacturer/supplier contact	Recycled content
		- Door/Window frames (Recycled Teak)	Parvathi Timber & Ply	Jithesh Patil-9741822265	Recycled wood
		-balcony/shading structure - Rafters and Columns (Recycled Teak)	Parvathi Timber & Ply	Jithesh Patil-9741822265	Recycled wood
		- Flush doors (Recycled Teak)	Parvathi Timber & Ply	Jithesh Patil-9741822265	Recycled wood
10	Terracotta tiles	Indoor flooring (for some residential units), Pathways and pervious areas	PrashaliConmats (P) Ltd	Venaktesh-9448379553	clay
11	Jaisalmer marble	Indoor flooring (most residential units)	MaheshwarImpex	Rishab-8050065000	-
12	Athangudi Tiles	Indoor flooring (most residential units)	Sri Ganapathi tile Works	Ayyappan-09443403382	-
13	Distemper paint	Interior walls (preferred instead of No/Low VOC paints)	Thottathil Traders	Deepu-8050536776	-
14	Iron	Grill for windows, GI sheet between RCC slab and Onduline sheet, hand railing (not recycled)	Sri Menhi Traders	9845124127	no
15	Sadarhalli stone	Landscaping elements, pervious areas, compound wall	Meccano Granites	Krishnamurthy-9341252580	no
16	Mud Concrete	Paving (Mud + Cement + Aggregate) (Mud instead of sand)	SKS Enterprises	Sandeep-8880175827	Site soil
17	RCC	Roof			
18	Onduline	Outermost layer of roof for heat reflection, solar panel fixing provision and water proofing	OFIC Building Materials India Pvt Ltd	Kiran-9342182229	No
19	Polycarbonate sheet	Skylight	OFIC Building Materials India Pvt Ltd	Kiran-9342182229	no

Sl No	Material	Application	Manufacturer/supplier name	Manufacturer/supplier contact	Recycled content
20	Clear glass	All windows	Varna Glass	Vijay Kumar-9535066687	Mostly contains recycled materials
21	Autoclaved Aerated Concrete Blocks	Walls (Ext & int)	Kansal Building Solutions Pvt. Ltd.	Mr. Ashwani Aggarwal 509/5, Anand Mai Marg, Govind Puri, New Delhi - 110019 011-26212028, 26436009, 26466666, +91-8130793001 FAX:011-26212028 Email-ID(s):info@kansalindia.in	Minimum 60% flyash
22	Concrete Pavers	Landscape	NITCO	Mr. Pawan Talwar, Director Jindal Trust Building 1/8B, Asaf Ali Road, New Delhi-110002 Contact Number(s)-011-24633686 FAX-011-24633687 Email-ID(s):pawantalwar@nitcotile.in	-

Table 12.7: Details of Manufacturer for Green Building Systems

Sl No	Application	Manufacturer/supplier name	Manufacturer/supplier contact
1	Building components	Manufacturer/supplier name	Manufacturer/supplier contact
2	Plumbing fixtures	white closet of Parry ware or equivalent make	No. 797, 12th Main, 1st Cross, HAL 2nd Stage, Indiranagar, Bengaluru – 560008 Tel: 91-80-25213368/32968735, Fax: 91-80-41207706.
3	Irrigation fixtures (spray and drip)	SS irrigation systems- local in Kengeri	
4	Rain water harvesting	Good earth have designed and installed. Local pipes were bought	Good-earth Eco – Developments(P) Ltd., Boulevard 15, Good earth Orchard, Doddabelle Road, Kengeri, Bangalore – 60, Office +91 80 28485120/ 28485121
5	Dewats	Consortium for DEWATS Dissemination (CDD) Society	CDD Society I Bangalore Survey No.205 (Opp. Beedi Workers Colony), Kommaghatta Road, Bandemath

Sl No	Application	Manufacturer/supplier name	Manufacturer/supplier contact
			Kengeri Satellite Town, Bangalore 560 060, Karnataka, India., +91-(0)80-28486700 +91 8064532829, +91-(0)80-28482144 bangalore@cddindia.org
6	Solar hot water system	Tata BP Solar	Tata Power Solar Systems Limited, 78, Electronics City, Phase I , Hosur Road Bangalore - 560 100 India, Tel: 91 80 6777 2000, 3000
7	Indoor lighting	Only specification mentioned for clients to buy any brand	-
8	Outdoor lighting	Havells	Havells India Ltd 5th Floor, The Estate, # 121, Dickenson Road, Bangalore 560042 Email : Bangalore.Office@havells.com, Tel:080-49075000, Fax-No:080-25582663
9	Stand-alone solar P V based LED street lighting	Avni Energy Solutions Pvt. Ltd.	# 39/5, 8th Cross, Govardhan garden, Opp Delhi Public School, JC Industrial Area, Near Kanakapura Road Metro,Bangalore - 560 062 Phone :91-80-26860337 Fax : 91-80-26860556 Email : purchase@avnienergy.com

Annexure 4

BASIC Technical data on Compressed Stabilised Earth Block

PROPERTIES	SYMBOL	UNIT	CLASS A	CLASS B
28 day dry compressive strength (+20% after 1 year)	σ d 28	MPa	5 -7	2 - 5
28 day wet compressive strength (after 24 hours immersion)	σ w 28	MPa	2 - 3	1 - 2
28 day dry tensile strength (on a core)	τ 28	MPa	1 - 2	0.5 - 1
28 day dry bending strength	β 28	MPa	1 - 2	0.5 - 1
28 day dry shear strength	S 28	MPa	1 - 2	0.5 - 1
Poisson's ratio	μ	-	0.15 - 0.35	0.35 - 0.50
Young's Modulus	E	MPa	700 - 1000	-
Apparent bulk density	γ	Kg/m^3	1900-2200	1700-2000
Coefficient of thermal expansion	-	mm/mºC	0.010-0.015	-
Swell after saturation (24 hours immersion)	-	mm/m	0.5 - 1	1 - 2
Shrinkage (due to natural air drying)	-	mm/m	0.2 - 1	1 - 2
Permeability		mm/sec	1.10^{-5}	-
Total water absorption	-	% weight	5 - 10	10 - 20
Specific heat	C	KJ/Kg	~ 0.85	0.65 - 0.85
Coefficient of conductivity	λ	W/mºC	0.46 – 0.81	0.81 – 0.93
Damping coefficient	m	%	5 - 10	10 - 30
Lag time (for 40 cm thick wall)	d	h	10 - 12	5 - 10
Coefficient of acoustic attenuation (for 40 cm thick wall at 500 Hz)	-	dB	50	40
Fire resistance *	-	-	Good	Average
Flammability *	-	-	Poor	Average

Sources: http://www.earth-auroville.com/compressed_stabilised_earth_block_en.php

BIS code details:

The performance specification of CSEB are based on BIS code IS 1725 -1982 and tested in accordance with IS 3495 – 199,

Source: Final Report on Low Cost Housing Using Stabilised Mud Blocks

Soil suitability and stabilization for CSEB

Sources: http://www.earth-auroville.com/compressed_stabilised_earth_block_en.php

Not every soil is suitable for earth construction and CSEB in particular. But with some knowledge and experience many soils can be used for producing CSEB. Topsoil and organic soils must not be used. Identifying the properties of a soil is essential to perform, at the end, good quality products. Some simple sensitive analysis can be performed after a short training. Cement stabilisation will be better for sandy soils. Lime stabilisation will be better suited for clayey soils.

Good soil for compressed stabilised earth blocks

The selection of a stabilizer will depend upon the soil quality and the project requirements. Cement will be preferable for sandy soils and to achieve quickly a higher strength. Lime will be rather used for very clayey soil, but will take a longer time to harden and to give strong blocks.

Soil for cement stabilisation: it is more sandy than clayey	Gravel = 15%	Sand = 50%	Silt = 15%	Clay = 20%
Soil for lime stabilisation: it is more clayey than sandy	Gravel = 15%	Sand = 30%	Silt = 20%	Clay = 35%

The average stabilizer proportion is rather low:

	Minimum	**Average**	**Maximum**
Cement stabilisation	3 %	5 %	No technical maximum
Lime stabilisation	2 %	6 %	10%

These low percentages are part of the cost effectiveness of CSEB.

Annexure 5

Soil suitability for pervious pavement, percolation and recharging:

Sources: Manual on artificial recharge of ground water, Government of India, Ministry of Water Resources, Central Ground Water Board, September 2007

Hydrological Soil Groups: There are four soil groups that are used in determining the hydrological soil cover complexes, which are used in a method for estimating the runoff from rainfall. A generalised soil found in India giving the broad classification of all the major soils in India is shown below:

Soil Group	Description
A	Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material.

The classification is broad but the groups can be divided into sub-groups whenever such a refinement is justified. The infiltration rates and permeability of soils in different groups are shown in below. In these tables, infiltration rate is the rate at which water enters the soil at the surface and which is controlled by surface conditions and permeability rate is the rate at which water moves in the soil, which is controlled by the nature and characteristics of soil horizons.

Infiltration Rates

Sl.no	Class	Rates / hr		Remarks
		Inches	millimeter	
1	Very low	Below 0.1	Below 2.5	Highly clayey soils
2	Low	0.1 - 0.5	2.5 - 12.5	Shallow soils, clay soils, soils low in organic matter
3	Medium	0.5 - 1.0	12.5 - 25.0	Sandy loams, silt loams
4	high	Above 1.0	Above 25.0	Deep sands, well aggregated soils

Conclusion

It can be concluded from above data that, pervious paving can be recommended on any soil but design might vary based on the permeability of the soil. Pervious paving with objective of high percolation and recharging are preferred in deep sands, well aggregated soils, sandy loams & silt loams which has medium to high permeability of water.

Annexure 6

Comparison between Planted Gravel Filter & Anaerobic Baffled Reactor

DEWATS stands for "Decentralized Wastewater Treatment Systems". DEWATS represents a technical approach rather than merely a technology package. DEWATS applications are designed to be low-maintenance: most important parts of the system work without technical energy inputs and cannot be switched off intentionally. DEWATS applications provide state-of-the-art technology at affordable prices because all of the materials used for construction are locally available.

Typical DEWATS combine the following technical treatment steps in a modular manner:

- primary treatment – in sedimentation ponds, settlers, septic tanks or bio digester
- secondary treatment – in anaerobic baffled reactors, anaerobic filters or anaerobic and facultative pond systems
- secondary aerobic/facultative treatment – in horizontal gravel filters
- post-treatment – in aerobic polishing ponds

Following figure highlights DEWATS configuration schemes as mentioned above

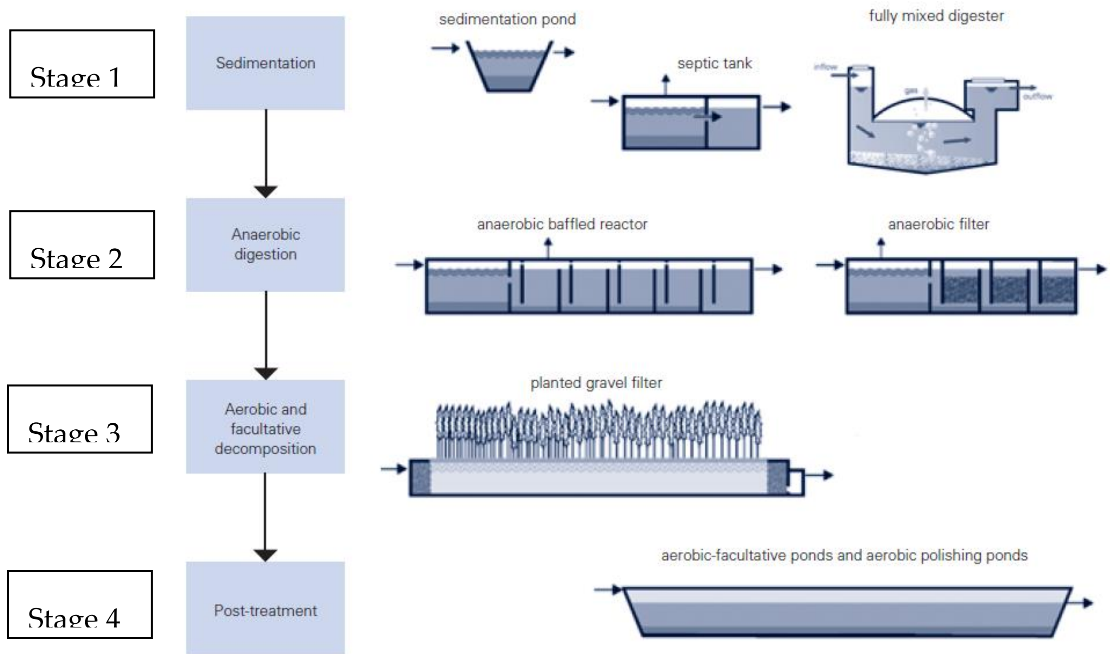


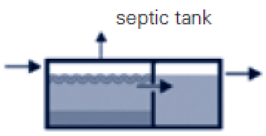
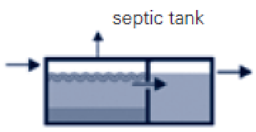
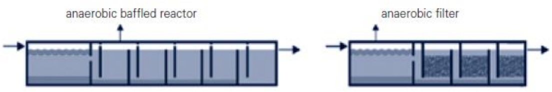
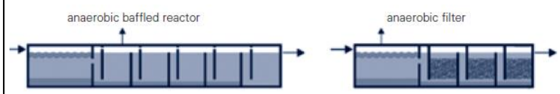
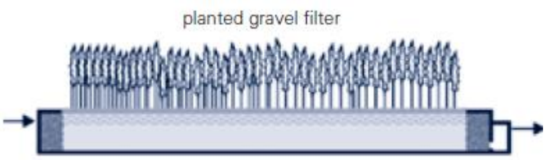
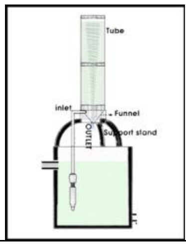
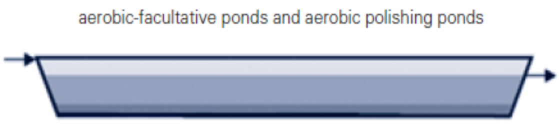
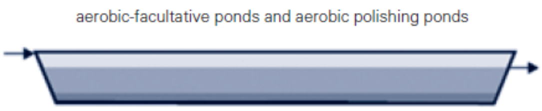
Figure12.2: DEWATS configuration schemes

In reference to the above image, we can observe that, anaerobic baffled reactor and planted gravel filter occur in subsequent stages, 2 & 3, respectively designed for two different processes. The design of DEWATS system varies depending upon the requirement

- volume of wastewater
- quality of wastewater
- local temperature
- underground conditions

- land availability
- costs
- legal effluent requirements
- cultural acceptance and social conditions
- final handling of the effluent (discharge or reuse)

A comparative scenario has been presented below, between the Dewats system at Malhar Footprints & another DEWATS system which uses Planted Gravel Filter in the tertiary stage as highlighted below. Treatment capacity of 10000 litres/day has been considered for both the cases. The comparison of treatment processes has been described below:

	DEWATS Type 1	**DEWATS Type 2**
Stages	DEWATS with Planted Gravel Filter	DEWATS with Vortex
1		
2		
3		
4		

As observed from, stage 3, in both the case are different, where forced aeration has replaced planted gravel filter.

Parameter	**DEWATS Type 1 Planted gravel filter (in third stage)**	**DEWATS Type 2 Using Anaerobic baffled reactor (in Malhar footprints in 2nd stage)**
Capacity of treatment	10000 litres/day	10000 litres/day
Manufacturer	CDD Society-BORDA	CDD Society-BORDA-CSR
Treatment process	All stages are similar except stage 3, where PGF	All stages are similar except stage 3, where Forced aeration using

Parameter	DEWATS Type 1 Planted gravel filter (in third stage)	DEWATS Type 2 Using Anaerobic baffled reactor (in Malhar footprints in 2nd stage)
	has been used	pumps has been used
Modules	Settler, ABR+AF, **PGF**	Settler, ABR+AF, **Vortex**
Pros and cons	• Larger area • No energy • Odourless	• Compact area • Energy is required • Odourless
Initial cost of investment (Materials for construction + labour charges)	INR 11,39,526 (Settler, ABR+AF, **PGF) +**) + INR 5,00,000 (Filtration + UV tube) + INR 7,00,000 (Pumping + Accessories) +Consultancy cost	INR 5,20,000 (Settler, ABR+AF)+ INR 2,00,000 (Vortex)+ INR 30,000 (Plumbing Accessories) + INR 5,00,000(Filtration + UV tube) + INR 7,00,000 (Pumping + Accessories)+ Consultancy Cost
Total cost of investment including consultancy cost	Rs. 25,00,000	Rs. 29,00,000/-
Annual cost of Desludging Settlers	Rs. 5000	Rs. 5000
Annual cost of Desludging ABR+AF	Rs. 5000	Rs. 5000
Annual Cost of Maintenance of PGF(For PGF, cleaning/replacing filter materials, andFor Vortex, pump maintenance)	Rs. 10000	INR 5000
Annual cost of Electricity	0	INR 3000
Annual cost of Human Resource (Salary of Operator)	0	INR 48,000
Total maintenance cost for **1 year**	INR 20,000	INR 66,000
Total cost for 10 year	**INR 27,00,000**	**INR 35,60,000**

Conclusion: Hence it's concluded that, the DEWATS system type in Malhar Footprints is higher in cost than the DEWATS type 1

General advantages of DEWATS technology:

- Provides treatment for domestic and industrial wastewater
- Low initial investment costs as no imported materials or components are needed
- Efficient treatment for daily wastewater flows of up to $1000m^3$
- Modular design of all components
- Tolerant towards inflow fluctuations
- Reliable and long-lasting construction design
- Low maintenance costs

Annexure 7

Embodied energy calculations

Components	Specific embodied energy [1,2,3,4]	Total Embodied energy for house (KWh)	Comments
Concrete blocks	0.153 kWh/Kg	1332.36	Standard wall size: 17'*9' 11"; actual window cut out: 4'6"x4'9"
Double glazed windows	4.167 kWh/Kg	1341.567	Glass area: 17 feet*9feet 11 inch
Cement Plaster	555.56 kWh/m3	220.94	1" plaster
Mud wall	0.1 MJ/ton	1.05	double layered mud wall 20" thick
	Total	**2895.917**	

Energy savings calculations

Fuel	Savings (Kg/House/year) [5]	Calorific value (kWh/kg) [6,7]	Energy savings (kWh/year)
Wood	261.16	5.3	1384.148
Dung	496.96	4.3	2136.928
Bush	323.81	4.07	1317.9067
		Total	4838.9827

Energy Payback time = (Embodied energy of building)/ (Energy savings per year)

= 2895.917/4838.9827

= 0.59 years

Glossary

CFL	-	Compact Fluorescent Lamp
EPI	–	Energy Performance index
GRIHA	–	Green rating for Integrated Habitat Assessment
IHSDP	–	Integrated Housing and Slum Development Programme
JNNURM	-	Jawaharlal Nehru National Urban Renewal Mission
NBC	–	National Building Code
TERI	–	The Energy and Resources institute
U-Value	-	Heat Transfer Coefficient

Athangudi tiles: Athangudi tiles are basically cement tiles like mosaic, but unlike the machine pressed and produced mosaics; they are handmade over glass surfaces.

Attached greenhouse (AGH): one of the PSH design wherein attached green house is constructed next to the room which is required to be kept warm. AGH traps the heat during the day time and dissipates it during night time to the adjacent room.

Bukhari: Traditional heating technology used by Ladakhi people.

Carbon Foot print is the sum of all emissions of CO2 which are induced by burning fossil fuels, normally for supporting human activities. It is expressed in equivalent tons of carbon dioxide (CO2).

Compressed Stabilised Earth Blocks (CSEB) Masonry units made by compressing soil mix manually or mechanically operated press. A stabiliser (usually Cement) is required to increase the compressive strength and water resistance of the block. The proportion of Cement would vary from 5-10%, which makes the material cost effective and low energy.

Daylight Factor: The ration between the illuminance in an indoor space to its light in immediate outdoor space. It is generally mentioned in percentage.

DEWATS with Syphon is a decentralised waste water treatment system which consist a vertically positioned tube with a funnel shaped bottom element. Sewage after passing through various chambers for anaerobic treatment goes into the tube, where a natural self-purification effect from the effluent takes place during the continuous swirling moment without affecting the quality of water. This system requires much less energy compared to a complete mechanical treatment system.

Direct Gain (DG): One of the PSH designs wherein southward facing room is covered with double glazing glass. The double glazed glass traps in heat which is stored in south wall and is later used to keep room warm during night time.

Dual Flush Toilet is a type of flush toilet that uses two buttons to flush different levels of water of different usages of toilet. It has an ability of saving water by using only limited amount of water for flushing as required.

Dual Plumbing System is a system of plumbing installation, which is used to supply both potable and recycled water in a building. Under this system, two completely separate water piping systems are used to deliver water to the user. This system prevents mixing of the two water supplies, since recycled water is usually not used for human consumption.

Earth air tunnel (EAT): An innovative technology air conditioning technology which uses stable earth temperature of the place to maintain comfortable air temperatures during both summers and winters. This technology is at infant stage and requires additional support system for air treatment (mainly to control humidity of air).

Embodied energy: Embodied energy is the amount of energy consumed to extract, refine, process, transport and fabricate a material. It is often measured from cradle to (factory) gate, or cradle to site (of use). Likewise, embodied carbon footprint is the amount of carbon (CO2 or CO2e emission) to produce a material.

Jikki: Jikki is a lime and marble ground dust mixed to get a fine paste. It has very low embodied energy. The availability of marble is high in Rajasthan and Gujarat regions.

Lapti: It is a less viscous finish layer of Jikki.

LED Lamps: An LED lamp is a light-emitting diode (LED) product that is assembled into a lamp (or light bulb) for use in lighting fixtures.

Lighting power density (LPD): LPD is a lighting power requirement defined for a particular space to maintain appropriate visibility.

luminous efficacy: It is the ration of luminous flux (lamp lumen output) to the power consumed by the lamp, expressed in unit lumen/watt

Lux: It is the unit of light illuminance

Markalak clay: Locally available clay which acts as binder in the sun dried block as well as is water resistant thus helps in water proofing the roof.

Mean Radiant Temperature (MRT) is uniform temperature of an imaginary enclosure that characterises the behaviour of radiant heat transfer between the human body and enclosure. It is represented as the average temperature of the surrounding surface elements, each weighted by the solid angle it subtends at the measurement point (human body).

Mud concrete: Plain cement concrete made from soil/clay, cement and aggregate (soil replaces the sand in PCC)

Mulch: It is a protective layer of a material that is spread on top of the soil for stabilization by using grass, hay, straw, wood chips etc.

Nimaj Stone: It is a local stone available in parts of Rajasthan and Gujarat. The material is low in embodied energy if transported locally and has high thermal capacity.

Onduline sheet: ONDULINE® sheets are manufactured by impregnating organic cellulose fibres with bitumen under high temperature and pressure. The sheets are pre pigmented with special purpose resins. The impregnation of colour into the sheets is done using patented techniques that enable the sheets to retain their colour over a longer period of time even under harsh conditions. The patented manufacturing process ensures uniform bitumen penetration into the sheets providing an excellent dimensional stability to the product and thereby preventing delamination.

Passive solar house (PSH): These are passively designed houses engineered by NGO GERES to be installed in cold climate regions of India. There are three main designs of PSH, i.e., direct gain (DG), attached greenhouse (AGH), solar wall (SW).

Power Conditioning Unit (PCU) is a setup that provides conditioned voltage to support electricity load that comes from an energy source. It typically consists Maximum Power Point Tracking (MPPT) charge controller and a bi- directional inverter to supply continuous power to the dedicated local load with the power load coming wither from the solar array, battery bank or grid in that order of preference.

Precast Jack Arch Roof Is a roofing system constructed with pre cast panels made with burnt clay tiles places on pre-cast concrete beams. The panels serve as a lost formwork for the finished roof, after concrete is laid over them. Usually these panels are casted before and transported/ lifted to site for roof construction. This type of construction doesn't need a plaster or paint; used 40% less steel as reinforcement, thus become cost effective and low energy.

Ready Mix Concrete (RMC) is concrete that is manufactured in a factory or batching plant according to the concrete design, then delivered to a work site by truck mounted in-transit mixtures. This is a customised concrete product which gives a large flexibility in concrete mixing that reduces the onsite work.

Reed System is a waste water treatment system; sewage is passed horizontally through a bed of soil or gravel media where reed species are grown. The roots of the plants create conditions for existence of dense bacteria settlement on roots that decomposes/ breaks the solid particles, absorbs toxic concentrations in waste water to a large extent. This is a cost effective and low energy technique where there is no mechanisation required, except pumping of grey water.

Reinforced Concrete Wall is a cast in-situ reinforced concrete shear wall; usually present is high rise construction, satisfies the code compliance in earth quake prone areas. These shear walls are the main vertical structural element with a dual role of resisting both gravity and lateral loads. This system doesn't require or requires minimal intermediate columns and beams that make the construction uniform looking. Structural modifications are very minimal in this type of construction. It makes the construction to complete much faster but requires more mechanisation.

Solar wall (SW): One of the PSH designs wherein southward facing room is covered with double glazing glass. The double glazed glass traps the heat in the room making it warmer during the day time. This design is only effective during the day time.

Specific heat capacity: It is the amount of heat that will be absorbed by the material before the 'steady state' condition is reached. It is the product of the mass of the material and specific heat.

Surkhi: Surkhi is a burnt red brick waste, used as a substitute for sand for concrete and mortar, and has almost the same function as of sand but it also imparts some strength and hydraulicity. Surkhi makes cement mortars and concretes more water proof, more resistant to alkalies and to salt solutions than those in which no surkhi is used

Swale is a storm drainage channel with required slope to channelize and collect the rain water at a collection point or a recharge well.

U-value: It is the thermal transmission through unit area of the given building unit divided by the temperature difference between the air or other fluid on either side of the building unit in 'steady state' conditions. It is reciprocal of total thermal resistance. Its unit is W/(m2K). This is correct

VDF-vacuum dewatered flooring: The Vacuum Dewatered Flooring or VDF Flooring is a system for laying high quality concrete floors where the key is Dewatering of Concrete by Vacuum Process wherein surplus water from the concrete is removed immediately after placing and vibration, thereby reducing the water: cement ratio to the optimum level.

Wind catcher: A very traditional technology used in arid regions. These are similar to Passive Downdraft Evaporative Cooling systems used in Iran, Egypt etc. The technology is now resumed in many modern and contemporary constructions as an alternative to air conditioning. The cooling tower does not have evaporative system. It helps in catching cool air/wind above building level and supplies to living spaces. When outside temperatures are high it acts as a stack by removing hot air.

Yakzes: A shrub which grows locally in Ladakh and has insulating properties.

Bibliography

A F Sherwani, J A Usmani, Varun and Siddhartha (2011), Life cycle assessment of 50kWp grid connected solar photovoltaic (SPV) in India Volume 2-1 pp 49-56.

Abeysinghe, Tilak and Jiaying, Gu (2011) "Lifetime income and housing affordability in Singapore" Urban Studies, 48, 1875-1891

Adobe brick technique. http://www.solidearth.co.nz/. (http://www.solidearth.co.nz/adobe-brick-technique.php). Accessed on 30th September, 2014.

Ali, Asif. "Passive Cooling and Vernacularism in Mughal Buildings in North India: A Source of Inspiration for Sustainable Development." 2nd International Conference-Workshop on Sustainable Architecture and Urban Design (ICWSAUD) organized by School of Housing, Building & Planning, University Sains Malaysia, Penang, Malaysia. 2013.

Aranya Community Housing, Aga Khan Award for Architecture.

Architecture and Development association de solidarité international. Case studies (http://www.archidev.org/spip.php?article1151).As retrieved on 13th August 2014.

B V V Reddy & K S Jagadish (2003), Embodied Energy of common and alternate building technologies, Energy and Buildings, Vol 35, pp 129-137

Bangalore cops get strong and sleek houses, made in 15 days (http://www.dnaindia.com/bangalore/report-bangalore-cops-get-strong-and-sleek-houses-made-in-15-days-1627541). As retrieved on 17th September 2014.

Bangalore opens the doors to a Greener tomorrow with 'PRANA', 2012. (http://www.lookbangalore.com/bangalore-open-the-doors-to-a-greener-tomorrow-with-%E2%80%98prana%E2%80%99/). As retrieved on 1st September 2014.

BIEC. (http://biec.in/green_project).As retrieved on 1st September 2014.

CALORIFIC VALUE OF FUELS. http://www.indiasolar.com/cal-value.htm. As retrieved on 28th September 2014.

Carlye Jones, 2014. The Advantages of Terra-Cotta Roofing (http://www.ehow.com/info_8044867_advantages-terracotta-roofing.html).As retrieved on 19th September, 2014

Census report. (http://censusindia.gov.in/), 2011.

Central Public Works Department (2013), A handbook of planning of office buildings, 2013, New Delhi

Central Public Works Department (2014), CPWD Guidelines for Sustainable Habitat, 2014, New Delhi

Clottes Franck (December 2012). L.E.C. Integration Design Manual. GERES.

Dalkia (2010), Practical CO2 equivalences guide, http://www.dalkia.ie/ireland-energy/ressources/documents/1/20202,Guide-equivalences-CO2.pdf

Development Alternatives, Energy directory of building materials, Project Sponsored by Building Materials and Technology Promotion Council, BMTPC, 1995

Dili, A. S., M. A. Naseer, and T. Zacharia Varghese. "Passive environment control system of Kerala vernacular residential architecture for a comfortable indoor environment: A qualitative and quantitative analyses." Energy and Buildings 42.6 (2010): 917-927.

Dili, A. S., M. A. Naseer, and T. Zacharia Varghese. "The passive environment control system of Kerala vernacular residential architecture: an experimental investigation on wind flow and thermal comfort." International Journal of Earth Science & Engineering 2 (2009): 264-271.

Dissemination of Passive Solar Housing in the Cold Desert of the Indian Himalayas. (http://www.worldhabitatawards.org/winners-and-finalists/project-details.cfm?lang=00&theProjectID=D8045D7F-15C5-F4C0-998DD42602A7C533). As retrieved on 19th august 2014.

Dormer. (http://en.wikipedia.org/wiki/Dormer). As retrieved on 19th September, 2014.

Dowerah. Abode perhaps the northeast way. http://www.livemint.com/. (http://www.livemint.com/Politics/YL7JpYRcFCN0D5qo52uX5O/Abode-perhaps-the-northeast-way.html). Accessed on 30th September, 2014.

Energy efficiency and bioclimatic architecture in India, 2009. (https://no.myclimate.org/fileadmin/images/ksp/ksp_international/716_greenhouses_and_hydro_himalaya/Himalaya_Press_Kit_Ashden_Awards.pdf). As retrieved on 20th August 2014.

Energy for building, Improving energy efficiency in construction and in the production of building materials in developing countries, United Nations Centre for Human Settlements (Habitat), Nairobi, 1991

Environmental Protection Agency. Retrieved on 19th August 2014.

Eurostat, EU statistics on income and living conditions (EU-SILC). (http://epp.eurostat.ec.europa.eu/portal/page/portal/microdata/eu_silc). Retrieved on 19th August 2014.

Film on the heritage pol's of Ahmedabad. Ahmedabad Mirror. http://www.vaarso.com/. (http://www.vaarso.com/pols-of-ahmedabad.html).Accessed on 30th September, 2014.

Gary Emmett (2012), International construction cost survey, Turner & Townsend, Brisbane, Queensland, 2012.

GBI (http://www.greenbuildingindex.org/why-green-buildings.html). Green Building Index. Retrieved on 20th August 2014.

GBL (http://twgbqanda.com/english/e_features.php?Type=1&menu=e_features_class). Green building label. Retrieved on 20th August 2014.

GFRG demonstration (http://www.businesswireindia.com/news/news-details/iit-madras-unveils-%E2%80%98gfrg-demonstration-building-showcase-its-rapid-aff/35575). As retrieved on 25th August 2014.

Govardhan Eco village activities. (http://ecovillage.org.in/our-activities). As retrieved on 26th August 2014.

Green building. (http://www.epa.gov/greenbuilding/pubs/about.htm). United States Environmental Protection Agency. Retrieved 20th August 2014.

GREEN CITIES: Sustainable Low-Income Housing in Brazil. The World Bank Group (2011). (https://openknowledge.worldbank.org/bitstream/handle/10986/12786/701870ESW0P1180e0Low0Income0Housing.pdf?sequence=1). As retrieved on 26th August 2014.

Green features. (http://viaverdenyc.com/green_features). As retrieved in 25th August 2014.

GRIHA case studies (GRIHA case studies). (http://www.grihaindia.org/images/casestudies/pdf/GRIHA%20Flyers_Case%20studies.10.pdf). As retrieved on 26th August 2014.

GRIHA manual 4, Page number: 32.

Guide to maintenance charge in apartments, http://apartmentadda.com/blog/2012/01/10/guide-to-maintenance-charge-calculation-in-apartments/

H. J. Holtzhausen (2007), Embodied Energy and its impact on Architectural Decisions, Sustainable Development and Planning, WIT Press, Southampton, UK, 2007

http://www.akdn.org/architecture/pdf/1242_Ind.pdf.As retrieved on 31st August 2014 Hot & Dry climate.

http://www.aqua-calc.com/page/density-table/substance/glass-coma-and-blank-window. As retrieved on 28th September 2014.

HUDCO (2012).HUDCO Design Awards 2012.New Delhi, India & TERI reports

ICAEN; 2004; Vol. 2 Design Manual: Sustainable Building; New Delhi; TERI

IGBC. (http://igbc.in/site/igbc/index.jsp). Retrieved on 20 august 2014.

India Global Building performance Network. (http://www.gbpn.org/activities/india). Global Building Performance Network. Retrieved on 20th august 2014.

Information on http://bangalore.citizenmatters.in/articles/4566-tanker-water-prices-up-apartments-in-distress

Jain and Singh. Construction sustainability and traditional buildings. July 2007 ARCHITECTURE - Time Space & People. http://www.coa.gov.in/. (http://www.coa.gov.in/mag/july07/Sustainability-Minikshi%20Jain.pdf). Accessed on 30th September, 2014.

Jali wall. http://www.costford.com/. (http://www.costford.com/architecture_technology_13.htm). Accessed on 30th September, 2014.

Janson, Ulla. Passive houses in Sweden-Experiences from design and construction. Energy and Building Design, 2008.

Johad. http://en.wikipedia.org/. (http://en.wikipedia.org/wiki/Johad). Accessed on 30th September, 2014.

Johnson. Advantages of a thatched roof. http://www.slideshare.net/. (http://www.slideshare.net/thatchroofnet/thatched-roof). Accessed on 30th September, 2014.

Kakkad, Maulik D., and Capt CS Sanghvi. "Comparative study of bamboo (ikra) housing system with modern construction practices." National Conference on Recent Trends in Engineering & Technology. 2011.

Kalra, Ripin, and Roger Bonner." Addressing Climate Change with Low-Cost Green Housing." Washington, DC: World Bank (2012).

Kati. Uses for bamboo in Sustainable Building. http://www.greenbuild.org/. (http://www.greenbuild.org/new-construction/uses-for-bamboo-in-sustainable-building/). Accessed on 30th September, 2014.

Khanna P (2011), Material and Technology- An inventory of select materials and technologies for building construction. Project report to CDKN, 2011, Development Alternatives Group, New Delhi

Krikke, (14th May 2003). Bio Solar House (http://www.architectureweek.com/2003/0514/environment_1-1.html). As retrieved on 28th August 2014.

Krishna A Joshi &K A Kambekar (2013), Optimisation of Energy in Public buildings, International Journal of Research in Engineering and Technology

Kumar, Ashwani. "Vernacular practices: as a basis for formulating building regulations for hilly areas." International Journal of Sustainable Built Environment (2014). Accessed on 30th September, 2014.

Lautman. India's forgotten Step wells. http://www.archdaily.com/. (http://www.archdaily.com/395363/india-s-forgotten-stepwells/). Accessed on 30th September, 2014.

Layout plan, dwelling plan and section, TERI Reports:

Lochiel Park- Case study on Green village. (http://www.garnautreview.org.au/CA25734E0016A131/WebObj/Casestudy-GreenVillage-LochielPark-SouthAustralia/$File/Case%20study%20-%20Green%20Village%20-%20Lochiel%20Park%20-%20South%20Australia.pdf). As retrieved on 26th August 2014.

Mahindra life spaces forays into affordable housing with 'Happinest.' (http://www.thehindubusinessline.com/multimedia/archive/01952/Click_here_for_pdf_1952398a.pdf). As retrieved on 26th August 2014.

Mahindra lifespaces launches its first Happinest project in Chennai. (http://www.mahindra.com/News/Press-Releases/1407322867). As retrieved on 26th August 2014.

Mahindra lifespaces ventures into affordable housing. 2014. (www.dailyexcelsior.com/mahindra-lifespaces-ventures-affordable-housing-segment/). As retrieved on 26th August 2014.

Mamata Varma. Karnataka State Police Housing Corporation Ltd. (https://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&ved=0CDoQFjAF&url=http%3A%2F%2Fwww.greenbuildingcongress.com%2Fsite%2Fmmbase%2Fattachments%2F375484%2FMadhav.pdf&ei=UiEZVML_GpaJuASE04LwDQ&usg=AFQjCNHg_V6vEY

GPJ4XeOEMBZ-RFdSItMg&bvm=bv.75558745,d.c2E&cad=rjt). As retrieved on 17th September 2014.

Mangalore Tiles. http://en.wikipedia.org/. (http://en.wikipedia.org/wiki/Mangalore_tiles). Accessed on 30th September, 2014.

Manual for Restoration and Retrofitting of Rural Structures in Kashmir, Rural architecture of Kashmir,Chapter 2. http://kashmirdivision.nic.in/. (http://kashmirdivision.nic.in/Disaster_Management/Man_res_retro_kmr_Chpt2.pdf).Accessed on 30th September, 2014.

Manual for Solar Passive Building, TERI report

Mehta and Gohil. Traditional Circular House-form (Bhunga) in Kutchh, Gujarat. http://aina.wikidot.com/. (http://aina.wikidot.com/documentation:traditional-circular-house-form-bhunga-in-kutc). Accessed on 30th September, 2014.

MNRE." Green Building Movement". Akshay Urja, Vol. 4, No. 5, 2011, p. 11

Mohammed Arif, 2012. Life cycle analysis and carbon credit earned by solar water heating system, International Journal of Research in Engineering & Applied Sciences, Vol 2-2, pp 1884-1905

Naseela P M (2010), Study on Alternate construction materials for housing construction, M Tech Thesis 2010, Building Technology & Construction Management Division, IIT Madras

P S Chani, Najamuddin, and S K Kaushik.October-2003.IE (I) Journal-AR-Page 47-50, vol 84.

Passive Homes in Glumslöv, Sweden. Skanska Sustainability case studies. (http://skanska-sustainability-case-studies.com/pdfs/7/07_Zero_v001.pdf).As retrieved on 24th August 2014.

Prana The Life Force, 2013. Inside Outside. (http://www.insideoutside.in/inside-outside/issue-magazine/2316/prana-life-force). As retrieved on 1st September 2014.

Proceedings of the institution of civil engineers-Engineering sustainability, vol 164, no. 4, pp. 249-260., 10.1680/ensu.2011.164.4.249

Rautela, Joshi, Singh, Lang. Timber-reinforced Stone Masonry (Koti Banal Architecture) of Uttarakhand and Himachal Pradesh, Northern India. http://www.world-housing.net/. (http://www.world-housing.net/WHEReports/wh100168.pdf). Accessed on 30th September, 2014.

Residential Energy Efficiency. Buildotech, 2013.

RICS report on making urban housing work in India. (http://www.rics.org/in/knowledge/research/research-reports/a-report-indicating-how-to-make-affordable-housing-work-in-india/), 2010.

Sagwan. http://navnirmanagro.com/. (http://navnirmanagro.com/sagwan.html). Accessed on 30th September, 2014.

Satish Kumar. R (2010),Comparison of Windows made with different type of materials- A case study, International journal of civil engineering, Vcol1, No.3, pp 565-575

Satish, BK, Brennan, J & Pedreschi, R 2011. "Influence of affluence on sustainable housing in Mysore, India."

Shah. Kath-khuni architecture of Himachal Pradesh. http://www.slideshare.net/. (http://www.slideshare.net/mansiarch/kath-khuni-of-himachal-pradesh-autosavedpdf-low). Accessed on 30th September, 2014.

Shankar. Laterite as a building material. http://www.prismma.in/.(http://www.prismma.in/laterite-as-a-building-material/). Accessed on 30th September, 2014.

Singh, Manoj Kumar, Sadhan Mahapatra, and S. K. Atreya. "Solar passive features in vernacular architecture of North-East India." Solar Energy 85.9 (2011).

Skanska sustainability-case study. (http://www.skanska-sustainability-case-studies.com/Case-Studies/Coldharbour-Lane-UK.html). As retrieved on 22nd August 2014.

Stauffer, Vincent. Solar greenhouses for the Trans-Himalayas: a construction manual. ICIMOD, 2004.

Study of Traditional Dwelling in Jaipur. http://www.archinomy.com/. (http://www.archinomy.com/case-studies/665/study-of-traditional-dwelling-in-jaipur).

Subhankar and Amol. Architecture of North East India: Vernacular Typologies. http://www.academia.edu/

Suresh V., Alternative building materials and technology dissemination, Proc. National workshop on alternative building methods (Ed. K.S. Jagadish and K.S. Nanjunda Rao), January 16 – 18, IISc., Bangalore, 2002, pp.163 – 170.

Sustainable Development Concepts. Building research institute, Singapore. (http://www.bri.sg/showcase/treelodgepunggol-2/sustainable-development-concepts/optimized-maintenance-solution/). As retrieved on 24th August 2014.

Suvasini Sridharan, 2013. Floored by tradition (http://www.thehindu.com/todays-paper/tp-features/tp-propertyplus/floored-by-tradition/article4983162.ece) . As retrieved on 19th September, 2014.

Talakondula Ramesh, Ravi Prakash, Karunesh Shukla (2013), Life Cycle Energy Analysis of a Multifamily Residential House: A case study in Indian context, Open Journal of Energy Efficiency, 2013, 34-41

Tata Power inaugurates first Carbon Neutral Eco-Hut in India at Walwhan Garden, Lonavala. (http://www.tatapower.com/media-corner/pressrelease-2013/press-release-08-july-2013.aspx). Press release. As retrieved on 23rd August 2014.

The BoKlok project. (http://www.boklok.com/about-the-BoKlok-concept/). As retrieved on 22nd August 2014.

The costs and benefits of green affordable housing. Cambridge (MA): New Ecology, 2005.

The Sustainable Housing Complex for ACC, 2011. (http://initiativeforgreenhabitats.blogspot.in/2011/05/sustainable-housing-complex-for-acc.html). As retrieved on 2nd September 2014.

The vernacular architecture of Rajasthan. http://www.archinomy.com/. (http://www.archinomy.com/case-studies/1992/the-vernacular-architecture-of-rajasthan). Accessed on 30th September, 2014.

Tipnis; 2012; Vernacular Traditions Contemporary Architecture; New Delhi; TERI

Traditional Dwelling in Delhi. http://www.archinomy.com/. (http://www.archinomy.com/case-studies/677/traditional-dwelling-in-delhi). Accessed on 30th September, 2014.

Traditional Dwelling in Malkaganj, New Delhi. http://www.archinomy.com/. (http://www.archinomy.com/case-studies/690/traditional-dwelling-in-malkaganj-new-delhi). Accessed on 30th September, 2014.

Traditional Dwelling in Uttar Pradesh (Muzaffarnagar). . http://www.archinomy.com/. (http://www.archinomy.com/case-studies/673/traditional-dwelling-in-uttar-pradesh-muzaffarnagar). Accessed on 30th September, 2014.

Traditional house in Jharkhand. http://www.archinomy.com/. (http://www.archinomy.com/case-studies/686/traditional-house-in-jharkhand-india). Accessed on 30th September, 2014.

UNCHS (1991). Energy for Building: Improving energy efficiency in construction and in the production of building materials in developing countries. Page 37.

Value & Budget Housing. (http://www.vbhc.com/construction-technology). As retrieved on 26th August 2014.

Value & Budget Housing. (http://www.vbhc.com/uploads/Oragadam_Brochure.pdf). As retrieved on 26th August 2014.

Value & Budget Housing. (http://www.vbhc.com/uploads/Vaibhava-Oragadam.pdf?/projects/vaibhava-oragadam/pricing-sheet). As retrieved on 26th August 2014.

Varanashi. 2011. A thatched over your head roof. http://www.thehindu.com/. (http://www.thehindu.com/todays-paper/tp-features/tp-propertyplus/a-thatched-roof-over-your-head/article2722092.ece). Accessed on 30th September, 2014.

Volker Quaschning (2003). Specific Carbon Dioxide Emissions of Various Fuels. http://www.volker-quaschning.de/datserv/CO2-spez/index_e.php. As retrieved on 28th September 2014.

Wells, Walker (2007). Blueprint for Greening Affordable Housing. Washington DC: Island Press.

What is sandstone used for. http://www.worktopfactoryy.co.uk/. (http://www.worktopfactoryy.co.uk/Whatis/WhatIsSandstoneUsedFor/tabid/1823/Default.aspx). Accessed on 30th September, 2014.

What is whitewash? http://www.wisegeek.com/. (http://www.wisegeek.com/what-is-whitewash.htm). Accessed on 30th September, 2014.

Why build green?" (http://www.epa.gov/greenbuilding/pubs/whybuild.htm). United States

Why do houses built in Rajasthan have thick walls and flat roofs? http://www.answers.com/.

Why lime? http://www.lime-green.co.uk/. (http://www.lime-green.co.uk/knowledgebase). Accessed on 30th September, 2014.

Why Sky City? (http://en.broad.com/uploads/pdf/tkcswsm201307.pdf). As retrieved on 1st September 2014.
(http://www.answers.com/Q/Why_do_houses_built_in_Rajasthan_have_thick_walls_and_flat_roofs). Accessed on 30th September, 2014.

Why use lime. http://www.buildinglimesforum.org.uk/. (http://www.buildinglimesforum.org.uk/why-use-lime). Accessed on 30th September, 2014

Wilson, Alex. "Building Green on a Budget" (http://www.buildinggreen.com/auth/article.cfm/1999/5/1/Building-Green-on-a-Budget/).Environmental Building News. Retrieved 1 December 2011.

You, Jia, Hao Wu, and Sun Sheng Han. "What is affordable housing in China? Evidence from Nanjing, China."

ZED Collective (http://www.siliconindia.com/rec_project/zedhomes/page3.html). As retrieved on 18th September 2014.

ZED Earth Villa (http://www.zed.in/bangalore/zed-earth). As retrieved on 13th August 2014.

ZED.Trans Indus (http://www.zed.in/homes/completed-projects). As retrieved on 13th August 2014.

About Housing and Urban Development Corporation Ltd. (HUDCO) & Human Settlement Management Institute (HSMI)

Housing and Urban Development Corporation Ltd. (HUDCO) a premier techno-financing company was set up in 1970 by the Government of India to accelerate the pace of housing and urban development in the country. Apart from the financing operations, HUDCO offers consultancy services, promotes research and studies and help propagate use of local building materials, cost-effective and innovative construction technologies. A Public Sector Company, under the Ministry of Housing & Urban Poverty Alleviation (MoHUPA), HUDCO has been a key partner with the Government in building assets for the Nation. In its operations, HUDCO lays a considerable emphasis on the housing need of the 'deprived' i.e Economically Weaker Sections (EWS) and Low-Income Groups (LIG).

Human Settlement Management Institute (HSMI) established in 1985 as Research and Training Wing in the Housing and Urban Development Corporation (HUDCO) for providing training support to professionals and to serve as a forum for interaction of administrators, professionals, researchers and other engaged with the issues and day to day practice of human settlement development has taken the lead in addressing capacity, knowledge-building and R&D deficits in four focus areas: Sustainable Habitat; Affordable Housing; Urban Poverty, Slums & Livelihoods and; Project Development Management. While strengthening the borrowing agencies through training, HSMI helps in generating viable projects to improve HUDCO's lending operations directly as well as indirectly. This gives the institute a rare twin character of an R&T Wing for internal capacity building, while also operating as a sector specialist institute. Through its capacity building research and documentation activities, HSMI strives to fulfil the role of a facilitator for healthy debate on key issues in the habitat sector, act as catalyst to stimulate innovative policy operations and implementation strategies and facilitate the participation of all in the dream of achieving sustainable habitat. It currently supports a range of capacity and knowledge initiatives in the areas.

About The Energy and Research Institute (TERI)

Sustainable Building Science: Overview

One of the prime areas of activity within the Energy Environment Technology division is adoption of efficient and environment-friendly technologies in new and existing buildings. The activities of this area focus primarily on energy and resource use optimization in existing buildings and design of energy efficient sustainable habitats.

The Centre for Research on Sustainable Building Science (CRSBS) comprising architects , planners, engineers , environmental specialists, specialised in urban and rural planning, low energy architecture and electro-mechanical systems, water and waste management and renewable energy systems has been offering environmental design solutions for habitat and buildings of various complexities and functions for nearly two decades. The group also undertakes LEED facilitation for buildings.

The Green Rating for Integrated Habitat Assessment (GRIHA) cell, also comprising professionals from the above-mentioned fields is actively involved in facilitation of green rating for buildings under the GRIHA framework. Inputs from CRSBS feed into the processes undertaken at GRIHA cell. The different services offered by the Sustainable Building Science (CRSBS and GRIHA) are as follows:

Environmental design consultancy

Specialised environmental design consultancy and building performance analysis are conducted. A wide range of computations and simulation tools including DOE2, TRNSYS, ECOTECT, RADIANCE, FLOVENT, AGI32, LUMEN DESIGNER, BLAST, Phoenics, RETScreen are used to assess the environmental and cost impact of the design decisions.

LEED and GRIHA facilitation

The team has experience in technically facilitating LEED accreditation [LEED India for New Construction (LEED India NC) and LEED India for Core and Shell (LEED India CS)] for buildings. The group also assists and administers GRIHA, an indigenous green building rating system for buildings, developed at TERI. GRIHA has now been now endorsed by the Ministry of New and Renewable Energy, Government of India, as the national building rating system for India.

Energy audits and energy management programs

Energy conservation studies for a large number of buildings are conducted. There exists a vast experience in conducting energy audits and evaluating a whole range of building upgrade options including envelope retrofit and system retrofit or changes in operational patterns. In addition to establishing operating efficiency of electrical, HVAC, lighting and thermal systems, recommendations to improve upon the same by suitable retrofit measures or by refinement of operational practices are also offered. The group also has expertise in development of energy management programs for service industries like hotels and the corporate sector.

Capacity building

Capacity building for architects, building developers and service engineers on issues such as energy efficiency in building envelopes and systems has been undertaken. Over 1000 architects, developers and engineers in the area of green buildings, energy efficiency and sustainability aspects of built environment have been trained through training programmes, refresher courses, seminars and workshops.

hudco

Housing and Urban Development Corporation Ltd.

www.hudco.org

teri

The Energy and Resources Institute

www. teriin.org