RESEARCH ARTICLE OPEN ACCESS

# Design of residential villa applying concept of 'SUSTAINABLE ARCHITECTURE' in Gotri area

Dhruv Manvar, Sahil Gupte, Saumya Mehta, Zarrar Shaikh
Guided by: Asst. Prof. Yesha Desai
*(Department of Civil Engineering, ITM(SLS) Baroda University, Vadodara*

**ABSTRACT**
This project explains design, construction planning and management of sustainable architecture. It focuses on designing a building to utilize renewable energy sources in the best way possible. It is a building with almost zero energy consumption. From its initial design to materials used in construction to relying on green energy sources after the building is habilitated, it is designed to sustain the environment throughout. The design integrates maximum utilization of sunlight and air circulation, heat and noise insulation. The materials in construction use eco-friendly materials, paint and techniques. After the project is completed, it is checked with simulation software and energy audit is done. It is designed to work with zero energy consumption with integration of solar rooftop panels, solar water heater system and rain water harvesting. This project suggests detailed planning and encourages sustainable development.
***Keywords –*** Eco-Friendly, Green Building, Sustainable, Renewable

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## I. INTRODUCTION

### 1.1 Introduction about project

- In recent years, sustainability concept has become the common interest of numerous disciplines. The reason for this popularity is to resolve current ecological problems and to perform sustainable development.
- The Concept of Sustainable Architecture, combines "Green Architecture", "Zero Energy Building" and "Green Building" with all of its components, design, construction planning and management. It is the theory, science and style of buildings designed and constructed in accordance with environmentally friendly principles.
- Green architecture strives to minimize the number of resources consumed in the building's construction, use and operation, as well as curtailing the harm done to the environment through the emission, pollution and waste of its components.

### 1.2 Aim and Objectives of the project

**Aim**

- To understand the importance of proper planning and construction techniques according to concepts of 'Sustainable Architecture'. To compare and improve conventional methods and give an ideal design for a Green home.

**Objectives**

- Design and Planning: A residential house with a design that utilizes minimum amount of natural resources available and cuts off non-renewable resources.
- Construction: Construction process with eco-friendly materials, minimal emission of harmful substances and proper usage of available resources.
- Management: Reliability of house appliances on renewable energy sources. Utilization of natural resources with minimum carbon emission and waste. Zero energy building which generates the most amount of energy it consumes.

### 1.3 Literature Review

- **Sustainable Architecture Module: Qualities, Use, and Examples of Sustainable Building Material**

Jong-Jin Kim, Brenda Rigdon, Jonathan Graves
The process of specifying environmentally friendly building products is no different than that for conventional building products:

- ✓ The type of materials needed must be determined, data must be gathered on comparable materials, and products must be evaluated.

- ✓ Environmental considerations need not be the only, or even most important, factors when selecting building materials.
- ✓ The key consideration is the material's appropriateness for the intended function. The longevity or insulation value of certain materials with high embodied energy content can sometimes justify the environmental costs of their manufacture. Overall, becoming more involved in materials and systems choices means the architect gains more control over the quality and sustainability of the finished building.

- **ROLE OF CULTURE IN SUSTAINABLE ARCHITECTURE**

Sinem Kultur, Bahcesehir University, Turkey

- ✓ Emergence of the concept sustainability concurrently leads to discussions on the methodology of sustainable architecture.
- ✓ A variety of approaches going after different logics for sustainable design appeared, one of which is eco-cultural logic. This logic keynotes the significance of sustainability of the culture to be provided through design in architecture.
- ✓ It argues that the existence of a critical interaction between culture and environment through which they continually redefine each other.

- **Sustainable Architecture: Practices and Methods to Achieve Sustainability in Construction**

Bruno Marques Carlos, Rafael Loureiro

- ✓ Sustainable architecture has currently a great visibility, so the actors in the construction sector should look for new practices that can meet the expectations of society. The scope of sustainability in architecture is to adopt different strategies, in order to reduce the energy consumption of buildings and the pollution associated with this activity.
- ✓ There are several practices enabling the optimization of construction materials, including selective demolition and waste recycling, which are certainly the most efficient, since they promote the extension of the materials life cycle, reducing the dependence of pure raw materials in the industry.

the introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

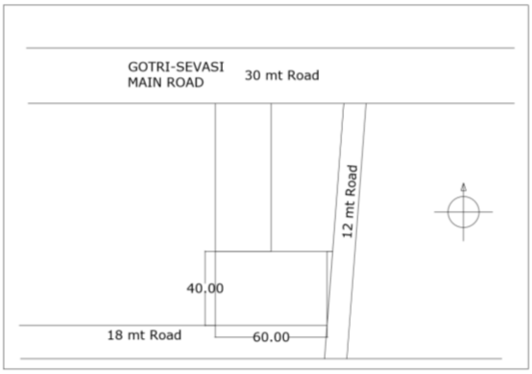
## II. DESIGN AND PLANNING

### 2.1 Key features

According to Green Rating for Integrated Habitat Assessment (GRIHA) the key design features of a green building in India:

- It preserves the natural site and surroundings as much as possible. It must have minimum hard-scape.
- It must be oriented with longer facades facing north and south.
- Window to wall ratio (WWR) between 15% to 60%.
- Well insulated walls and windows.
- It must utilize daylight to minimize the requirement of artificial lighting.
- It must have good indoor air quality and must meet thermal comfort requirement.

### 2.2 Overview of site




SITE LAYOUT

After plot searching and site survey, we selected this plot to design on.

It is located outside the crowded city areas but still nearby to all the necessary facilities selected plot is accessible by Gotri-Sevasi main road still maintaining some distance between road and actual plot to reduce effects of noise and air pollution.

It is surrounded by open plots which give clear openings to utilise most of wind and sunlight available.

Plot area: 60 X 40 = 2400 $m^2$ which gives us enough area to design an ideal villa.

### 2.3 Environmental conditions

- **Wind**

Normally wind in Vadodara comes from SW Arabian Sea during most time of the year.

So in our design we have to utilize it properly in natural cooling, ventilation, and to maintain clean and fresh environment in our villa.

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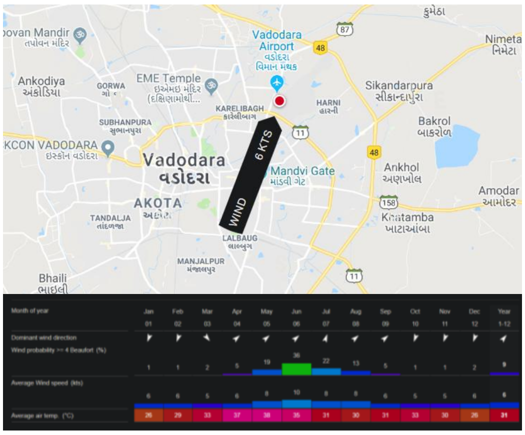



But during winter season, cold wind comes from the opposite direction NE from Himalayan mountain range.

We have to obstruct it in our design to reduce cold.

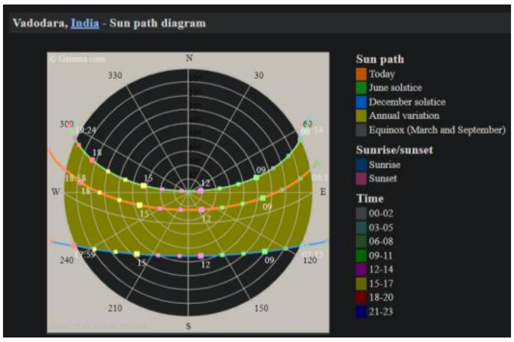
Wind statistics source: windfinder.com Vadodara Airport wind & weather statistics

- **Sunlight**

Path of the sun above Vadodara leans a little towards South side during most time of the year.

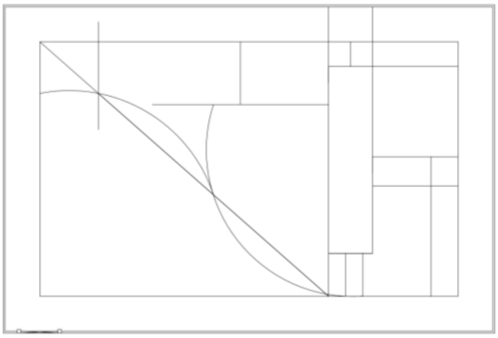
In December, during Winter season the Sun moves leaning far South than most of the year. It emits soft light and heat which we need to counter the cold atmosphere.

In June, during Summer season the Sun moves exactly above the site. We have to reduce the harsh light and extensive heat during summer season.

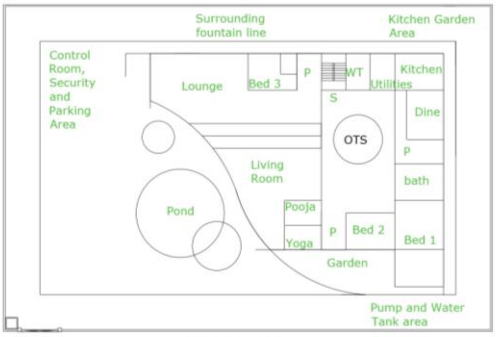



Sun path source: gaisma.com live compass view of sun path above the site

### 2.4 Design process



CONCEPT



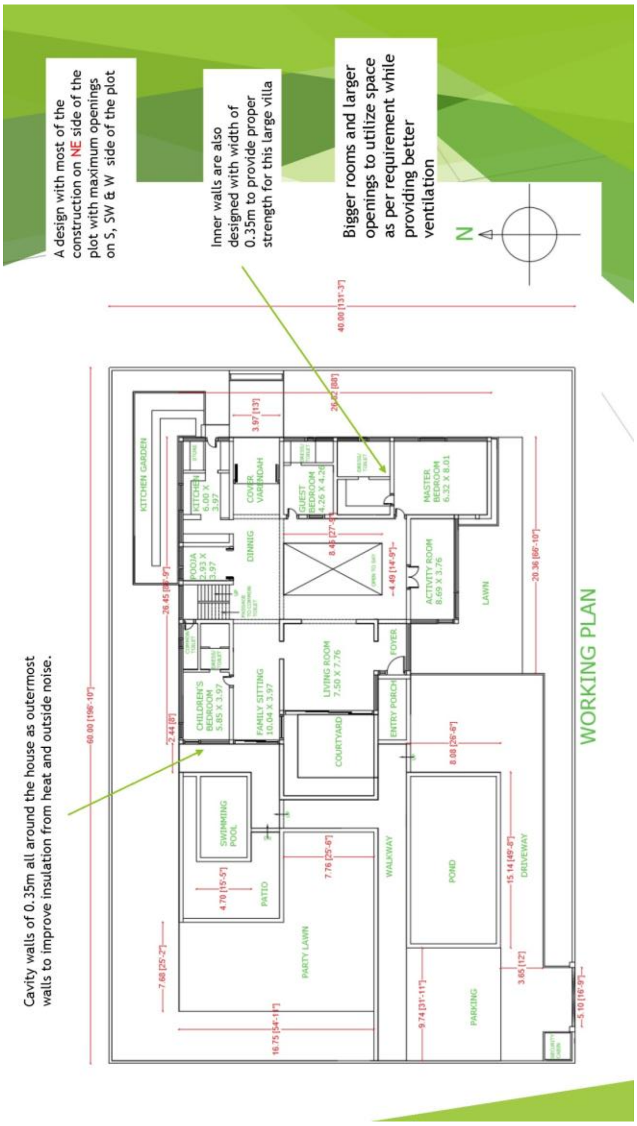

LINE DIAGRAM

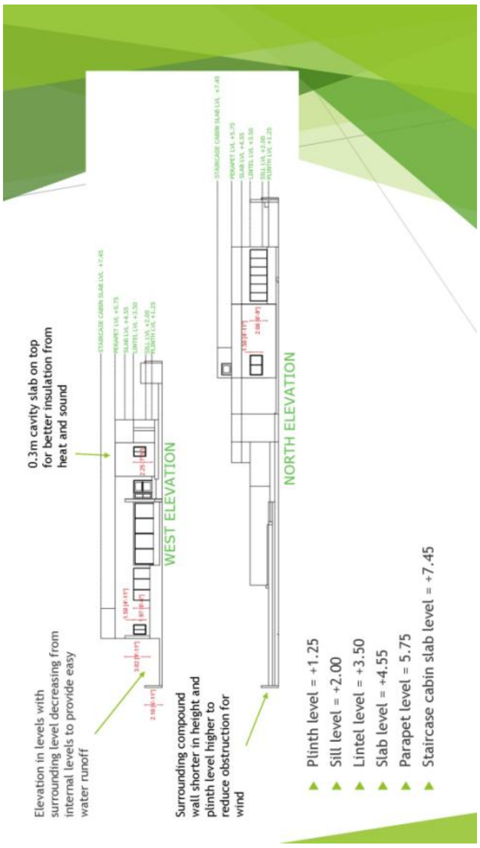
We started by outlining the shape of the villa according to the directions and plot.

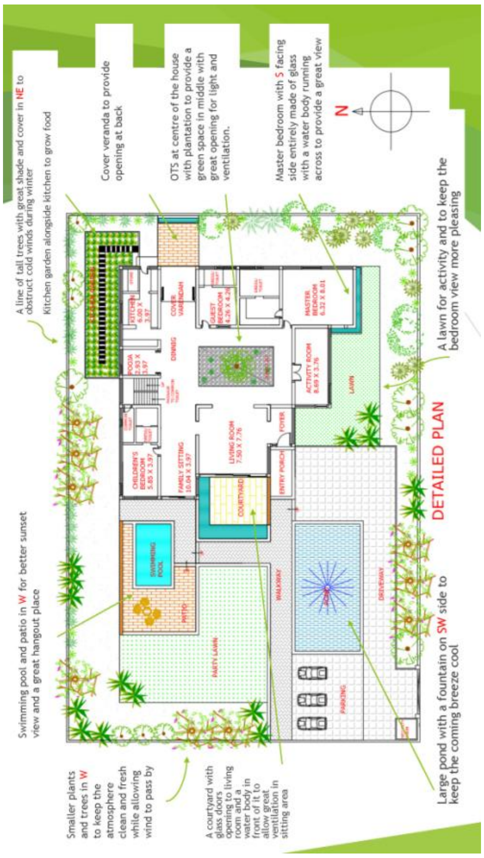
After sketching roughly on paper we moved to AutoCAD. Going through many changes and rearranging the rooms to utilize most of sunlight and wind we came up with line diagram shown above.

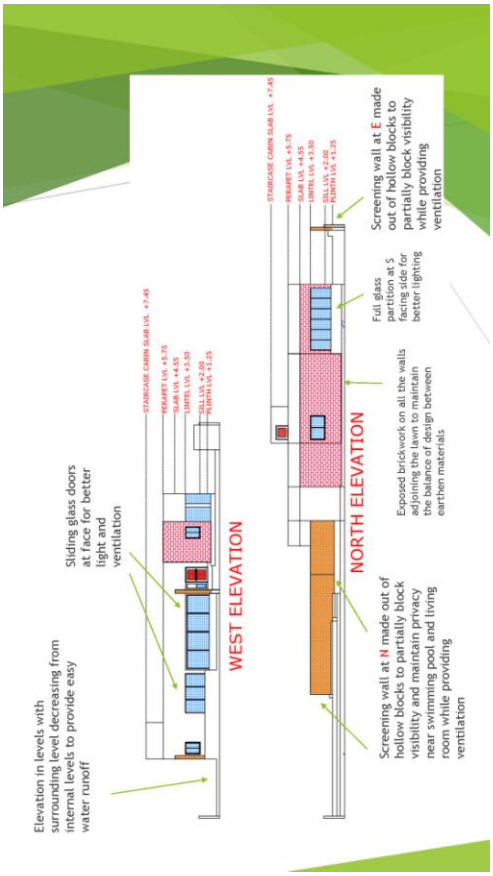
Here we have a pond which cools off the wind coming from normal SW wind direction. We have an OTS in middle to circulate the air and we have kitchen at back with a kitchen garden.

After changing this several times and improving the design we have our final plan.


A design with most of the construction on NE side of the plot with maximum openings on S, SW & W side of the plot
Inner walls are also designed with width of 0.35m to provide proper strength for this large villa
Bigger rooms and larger openings to utilize space as per requirement while providing better ventilation
Cavity walls of 0.35m all around the house as outermost walls to improve insulation from heat and outside noise.
WORKING PLAN


0.3m cavity slab on top for better insulation from heat and sound
Elevation in levels with surrounding level decreasing from internal levels to provide easy water runoff
Surrounding compound wall shorter in height and plinth level higher to reduce obstruction for wind
WEST ELEVATION
NORTH ELEVATION
Plinth level = +1.25
Sill level = +2.00
Lintel level = +3.50
Slab level = +4.55
Parapet level = 5.75
Staircase cabin slab level = +7.45


A line of tall trees with great shade and cover in NE to obstruct cold winds during winter
Kitchen garden alongside kitchen to grow food
Cover veranda to provide opening at back
OTS at centre of the house with plantation to provide a green space in middle with great opening for light and ventilation.
Master bedroom with S facing side entirely made of glass with a water body running across to provide a great view
A lawn for activity and to keep the bedroom view more pleasing
DETAILED PLAN
Large pond with a fountain on SW side to keep the coming breeze cool
A courtyard with glass doors opening to living room and a water body in front of it to allow great ventilation in sitting area
Smaller plants and trees in W to keep the atmosphere clean and fresh while allowing wind to pass by
Swimming pool and patio in W for better sunset view and a great hangout place





- Land type: NA (Non Agricultural)
- Plot area= 2400 $m^2$
- Adjacent road width= 18 m
- Plinth area= 708.63 $m^2$ (Additional= 102.82 $m^2$)
- FSI (Floor Space Index)= 0.29 (maximum permissible= 1.8)
- Carpet area= 555.63 $m^2$ (approx. 15% of Built-up area)
- Built-up area= 653.69 $m^2$
- Super built-up area= 811.45 $m^2$
- Clear height= 3.3 m
- Openings= minimum 18% varying up to maximum 42%
- Green area or vegetation= 1260 $m^2$ (53%)
- Area of water bodies= 189 $m^2$ (8%)

### 2.5 Comparison and improvement

- **Total openings:**
  - **Sunlight during daytime:**

| Conventional Design | Green Design | Increment |
|---|---|---|
| 10%-15% | 26% | +16% |

| Conventional Design | Green Design | Increment |
|---|---|---|
| 50%-60% of house area | 90% of house area | +40% |

- **Green area:**

| Conventional Design | Green Design | Increment |
|---|---|---|
| 10%-30% | 53% | +43% |

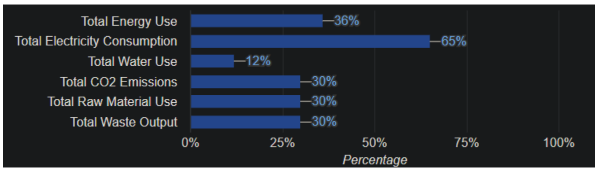
**2.6 Implementation**

- This design is an ideal design for a sustainable home with many factors considered.
- But in crowded city areas all the design considerations can't be applicable, in that case we have to focus on designing according to best ventilation available.
- Design with multi-purpose rooms
- Green area should still be there
- Put great focus on materials and construction techniques to componset the effects.

## III. MATERIALS AND CONSTRUCTION METHODS

### 3.1 Key Features

- Low impact :minimize impact on natural environment
- Minimize waste: designed and constructed in a manner that minimizes waste, pollution and environmental degradation.
- The construction material must have less embodied energy and must maximize the use of recycled content.
- It must have efficient sanitary fixtures and irrigation system that minimize the water demand. Further, all the sewage waste generated should be treated and reused on site.
- Materials from renewable sources: Materials significantly of plant origin. Can be obtained from renewable sources like solar energy, wind energy, bio-gas etc. E.g.: wood, natural fibers, polymers etc.
- Reuse from waste products as raw materials: They are typically the products of recycled matter. Materials that can be dismantled and reused again. E.g.: old plumbing, doors, crushed glass, wood chips etc.




### 3.2 Problem

Construction plays a very important role in its economy contributing on an average 6.5% of the GDP. All round the world construction materials generate million tons of waste annually. These construction materials require high embodied energy resulting with large $CO_2$ (Carbon Dioxide) emissions.

The embodied energy of steel is about 32 MJ/Kg and for cement is about 7.8 MJ/Kg Scientific and Industrial Research Organization). The highest $CO_2$ producing material is cement and a large amount of $CO_2$ is produced in the processing of construction materials and in the transport of these materials.

If the consumption of the construction materials remains the same all around the world then by the year 2050 the production of the cement in the world could reach 3.5 billion metric tons. But annually the production and consumption of the construction materials are increasing simultaneously, if this is the case then the production of cement itself annually could reach over 5 billion metric tons with approximately about 4 billion tons of $CO_2$ (carbon dioxide) emissions. Due to the abundant usage of the construction materials the impact of these materials is dominated than from the impact of the other sources.

Buildings use resources (energy, water, raw materials, etc.), generate waste (occupant, construction, and demolition), emit potentially harmful atmospheric emissions, and fundamentally change the function of land, and the ability of that land to absorb and capture water into the ground.

### 3.3 Solution

Building owners, designers, and builders each face unique challenges to meet demands for new and renovated facilities that are accessible, secure, healthy and productive, while minimizing any negative impacts upon society, the environment, and the economy.

The main objectives of sustainable design are to reduce, or completely avoid, depletion of critical resources like energy, water, land, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are livable, comfortable, safe, and productive.

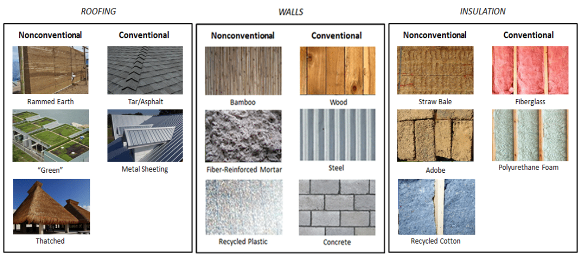
A sustainable material is any material that can be put to effective use in the present without compromising its availability for use by latter generations.

These are mainly renewable materials or the materials which can be recycled and reused.

**3.4 Materials available**

- Bamboo, bamboo based particle board & ply board, bamboo matting.
- Bricks sun dried
- Precast cement concrete blocks, lintels, slab.
- Calcined Phospho-Gypsum wall panels
- Calcium Silicate boards and tiles
- Cellular light weight Concrete Blocks
- Cement paint
- Clay roofing tiles

- Water, Polyurethane and acrylic based chemical admixture for corrosion removal, rust prevention, water proofing.
- Epoxy Resin system, Flooring, sealants, adhesives and admixtures
- Ferro- cement boards for door and window shutters
- Ferro-cement Roofing channels
- Fly-ash sand lime bricks and paver blocks
- Gypsum board, tiles, plaster, blocks, gypsum plaster sisal and glass fibrecomposites.
- Laminated Wood Plastic components
- Marble Mosaic Tiles
- MDF Boards and Mouldings
- Micro Concrete Roofing Tiles
- Particle Boards
- Polymerised water proof compound




**3.5 Materials & Techniques to be used**

**1. Stone Masonry:**
- Used in foundation for load bearing structures.
- Reduces amount of concrete.
- Better strength.
- Useful where soil bed is more hard.


**2. Rammed earth:**
- Prepared on site so no transportation cost.
- Greater strength
- Better Thermal insulation
- No need of plastering
- Less mortar required if interlocking mud blocks are used.
- Zero wastage

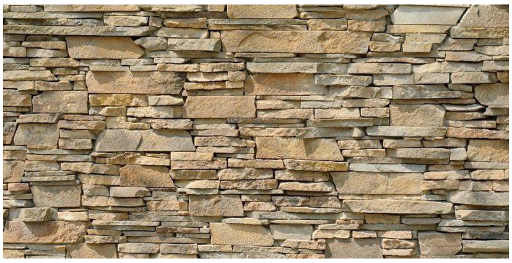
**3. Types of Bricks:**
- Regular Brick
  - Durable and easily available
  - Provides better insulation by doing rat trap bond
- Recycled Brick
  - Light in weight
  - Low cost

- Surkhi Brick
  - Durable and easy to maintain
  - Provides better insulation
  - Blends with lime mortar

- Perforate blocks
  - Strong and durable
  - High fire resistance
  - Less maintenance cost

- Stones

- Resistance to fire
- Easily available
- Great in winter as it absorbs heat during day and releases at night
- Great insulation



4. **Cavity walls:**

- Reduces weight on foundation
- Great sound insulation
- It gives better thermal insulation than any other solid wall because space is full of air and reduces heat transmission
- Heat flow rate 50% of a solid wall
- Economically cheaper
- Fire resistant

5. **Filler slabs or Cavity Slabs:**

- The heat gain from the roof is the highest, if the filler slab could be done using hollow materials, the multiple advantages – passive solar cooling where the voids reduce the heat transfer, lesser roof weight thanks to the hollowness.
- Adds aesthetic value, when seen from the room below.
- Reduced sound transmission between the floors because of the voids in between.
- Reduction of steel consumption considering greater distance between them.

6. **Lime Plaster:**

- Alternate to cement mortar
- Consists of lime, sand, jaggery, methi & other organic additives locally available (prepared by fermentation process)
- Lime is green & versatile building material with high durability.
- Produced at low temperature hence reducing carbon footprint
- Lime putty mortar absorbs CO2 during curing process
- Can be recycled
- Bricks using lime mortar can also be recycled
- Flexible & permeable
- Moves & absorbs moisture

7. **Appreciating Indian stones & techniques.**

- Kotastone (brown/green/aqua)
- Marbles (green/white)
- Jaisalmer
- Granites
- Red oxide flooring
- China mosaic

**8. Insulated glass windows:**
- Versatility
- Energy efficiency
- Noise reduction
- Heat insulation
- UV ray protection
- Great viewing experience
- Opening for sunlight

**9. Green plumbing fixtures:**
- Pressure reducing valves
- Low-flow shower heads
- Low-flush toilets
- Recirculating hot water pumps
- Efficiency faucets

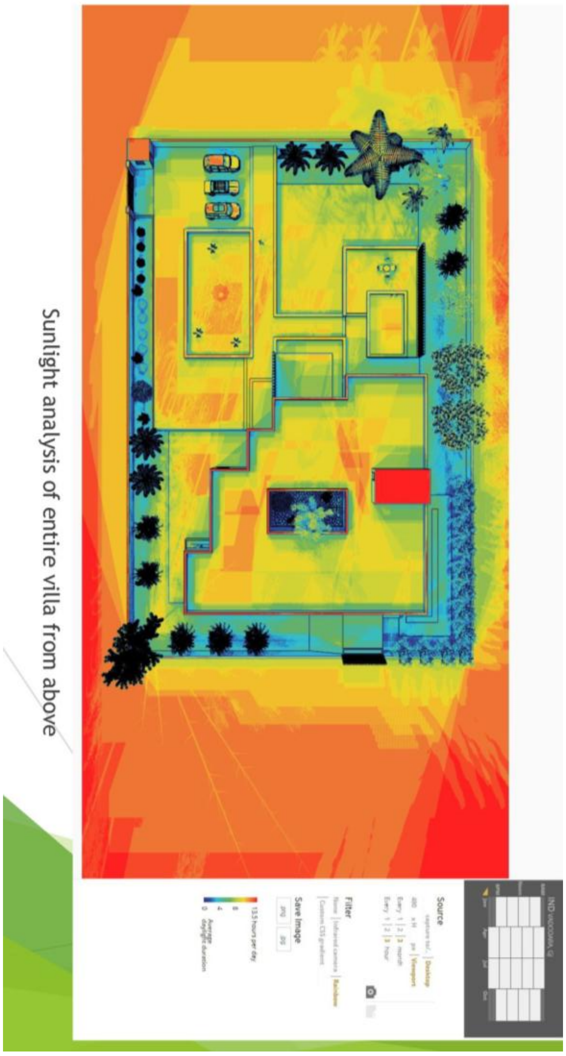
**10. Blended Cement:**
- Consumes less energy than Ordinary Portland Cement (OPC)
- Doesn't start degrading like OPC but becomes stronger with passage of time
- Blended cements like Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) uses raw materials which are waste or harmful for environment
- It contains their harmful effects and uses them for better purposes

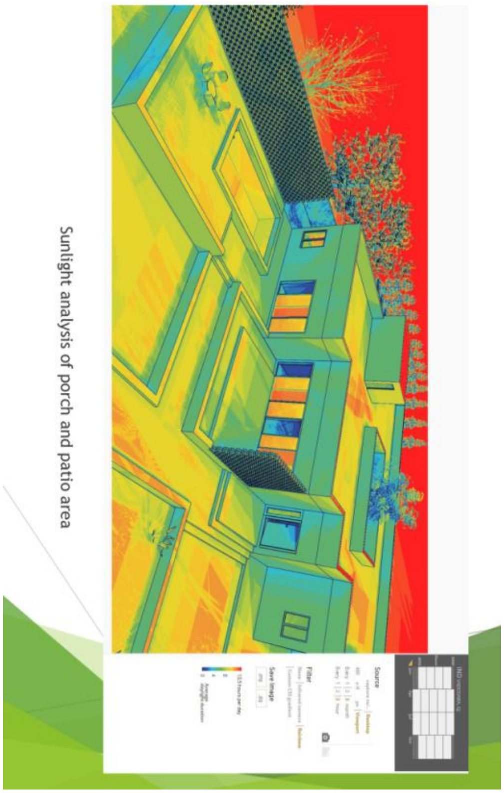
## IV. UTILITIES AND MANAGEMENT

### 4.1 Scope and Aim

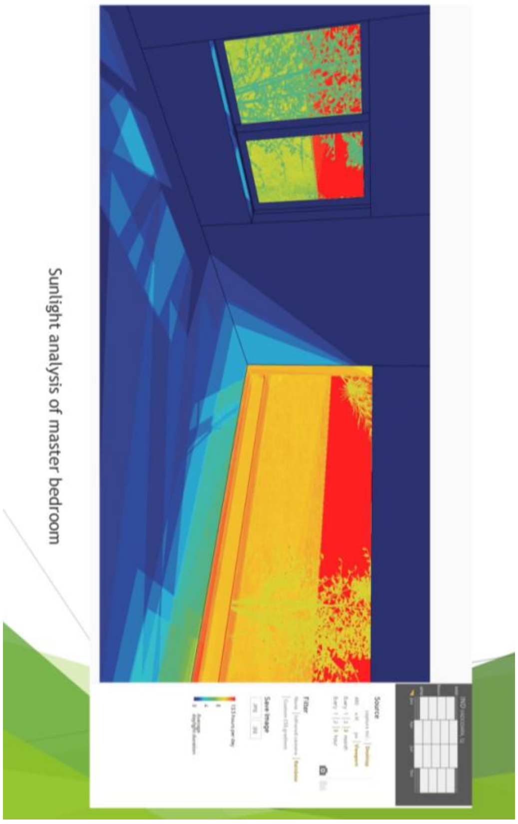
- Scope
  - o To find out if this design checks all the objectives in order to build a sustainable villa.
  - o To find out if there is any room for improvement in our design to make it more suitable for our aim.
- Aim
  - o Sunlight hours analysis for our 3D model. Prepare detailed energy audit and compare it with conventional design. Design of Sustainable Utilities. Make necessary changes and prove that our design is sustainable and better in performance.

### 4.2 Sunlight Analysis

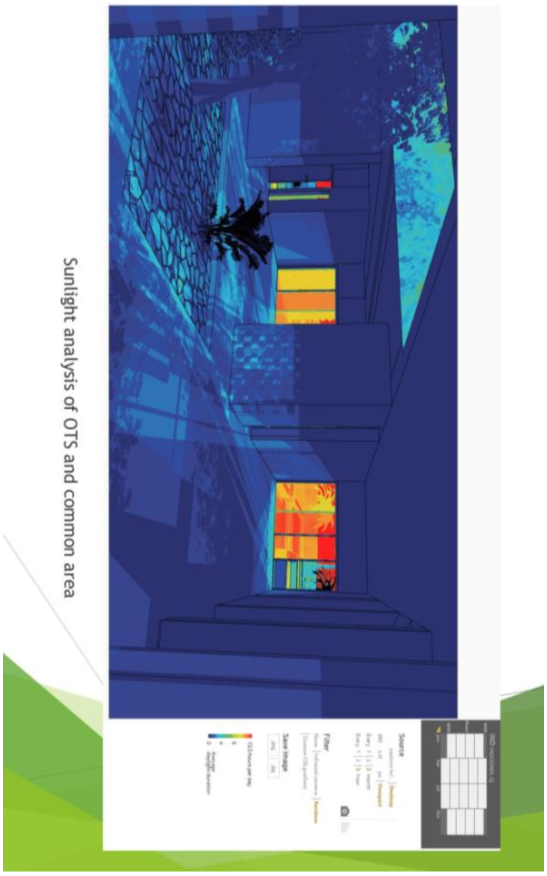




Sunlight analysis of porch and patio area



Sunlight analysis of master bedroom



Sunlight analysis of OTS and common area

- **Results of Sunlight and shadow analysis**
- Average Sunlight in porch and patio: 6 hours of direct sunlight, shaded light till noon and soft light during evening with a view of Sunset
- Average Sunlight in common area and OTS: 4 hours of direct light and shaded light for almost entire day
- Average sunlight in master bedroom: 2 hours of soft light during morning and shaded light for 6 hours in entire day
- Almost 4 hours of extra direct sunlight in common spaces and shaded light throughout entire day compared to conventional design.
- This proves that design is sustainable in terms of sunlight and will result in benefits of low usage of lights, encouraged use of natural light, perks of sunlight and better indoor environment. This will improve sustainability in energy usage and lifestyle.

### 4.3 Energy Audit


- **Detailed energy audit of Sustainable Design**

Energy audit of designed villa considering requirements according to Energy Conservation Act, 2001 and design criteria. This includes

- Calculation of required lumens flux in every room area according to available sunlight throughout day.
- Calculation of Power required in every appliance throughout a day. Calculating this data for a whole year and simplifying it in a tabular form with deriving final kWh/day value.
- Calculation of energy generation by rooftop solar panels and provision of required nos. of panels, its capacity of generating power on average throughout a year in kW.
- After calculation of usage as described in MS Excel, the energy source to be used is also renewable.
- Required solar rooftop for this household can be calculated by average energy usage and average solar radiation on site.
- Average energy usage: **11.527 kWh/day**
- Average solar radiation on site: 800-1000 watt/sq. m
- According to studies conducted by GEDA, unit per day can be generated with 1 kW rooftop, therefore here we will require **3.2 kW** total capacity generation.
- For that 10 panels of 320 watt capacity can be used.
- This will require space 10 nos. of 2x1 m for each. That will be 20 sq. m
- Initial onetime cost of this rooftop will be **Rs. 1,44,000/-** with life expectancy of 25 years.

- **Detailed energy audit of Conventional Design**

Energy audit of a conventional design of similar building with lesser openings, lesser natural light throughout a day resulting in increase in usage of electric appliances and facilities.

- Conventional design requires more usage of artificial lighting and ventilation solutions therefore resulting in more energy usage.
- In our audit, conventional design energy usage came out to be 21.034 kWh/day which is significantly more than sustainable design.
- Main reasons for this are poor design and planning of building and additionally usage of less efficient appliances.
- Comparison of conventional and sustainable design and evaluation of benefits.

- **Results and Comparison after energy audit**

| | Sustainable Design | Conventional Design | % benefit |
|---|---|---|---|
| Power Consumption | 12 units (roundup) | 22 units (roundup) | 45.45% |
| Cost per Day | Rs. 96 | Rs. 176 | |
| Cost per Month | Rs. 2,880 | Rs. 5,280 | |
| Cost per Year | Rs. 34,560 | Rs. 63,360 | 83.34% |

One time cost for Solar Rooftop of capacity 3.20 kW = Rs. 1,40,000
With life expectancy of 25 years
Assuming extra maintenance cost of Rs. 60,000
Total cost will be 2,00,000 for 25 years in Sustainable design compared to 15,84,000 for conventional design resulting in 87% cost saving.

### 4.4 Sustainable Utility Solutions

- **Solar Rooftop power generation:**
  - Capacity: 3.20 kW
  - Initial cost: Rs. 1,40,000
  - Maintenance: Rs. 60,000
  - Life expectancy: 25 years
- Total cost will be 2,00,000 for 25 years in Sustainable design compared to 15,84,000 for conventional design resulting in 87% cost saving.

| | Sustainable | Conventional | Improve |
|---|---|---|---|
| kWh/day | 11.527 | 21.034 | 45.19% |
| Total cost for 25 years | 2,00,000 | 15,84,000 | 87% |


- **Solar water heater system:**

For solar water heater system, for a normal household requirement is 50 litres per person with provided 50 litres extra. cost will be Rs. 135 per litre and life will be 12 years at least for that initial 5 years there's no maintenance cost and after that it's very unlikely but we have to consider any tank or pipe replace so Rs. 1000 per year is considered. For this 5000 litres overhead tank should be provided.

- Capacity: 300 litres
- Initial cost: Rs. 40500
- Maintenance: Rs. 7000
- Life expectancy: 12 years

Comparing to normal water heater it will save total of 6 units daily for a year which sum up to 2,190 units per year of total Rs. 10,950 per year for 12 years which is Rs. 1,31,400. Where as in solar water heater system, only motor pump usage is there.

| | Sustainable | Conventional | Improvement |
|---|---|---|---|
| Units | 0.75 | 29.91 | 97.49 % |
| Total cost for 12 years | 48,000 | 1,31,400 | 36.52 % |

- **Rainwater Harvesting system:**
- Mean annual rainfall in Vadodara: 93 cm (37 inches)
- Mean annual rainfall in mm x area in $m^2$ x runoff factor = collected rainwater in litres
- 930 mm x 499.9 $m^2$ x 0.90 = 4,18,416 litres
- Drain water from first few rainfalls for cleaning purpose = 10,000 litres
- Total water amount collected per year = 4,08,416 litres
- For a villa with 5 residents average water usage is 350 lpcd
- Therefore total water usage per year = 350 x 5 x 365 = 6,38,750 litres
- Extra water usage for a villa = 1,00,000 litres per year
- Total water usage per year = 7,38,750 litres
- Water harvesting in ideal conditions = 55.28 % of total consumption

- Provide rainwater harvesting system with water storage capacity of 20000 litres of underground and 5000 litres of overhead tank.
- A diversion arrangement (T-joint with valve) is required at the outlet of roof collected water pipe line to allow the water to be either disposed off (dirty water after initial rain) or stored in the storage tank through the filter system for use as drinking water.
- Provision of proper piping system, valves and pump to manage water circulation.
- Provide groundwater recharge structure alongside a bore well made of a 4-6 cubic metre pit filled with graded filter materials like cobbles, pebbles, gravel and sand in layers to let silt free good quality water to percolate. This will allow recharge and supply both.
- All of this will cost roughly Rs. 40,000 for construction and components.

## V. SUMMARY OF PROJECT

### 5.1 Advantages

- Best design for ventilation and sunlight availability inside house
- Better overall environment and air quality inside house
- Eco-friendly materials and construction techniques

- Energy efficient building design
- Proper utilization of available resources
- Maximum utilization of renewable resources and minimum utilization of non-renewable resources
- Maybe costly to construct but very cost efficient in long run

**5.2 Scope of future works**

- Green architecture produces environmental, social and economic benefits. Environmentally, green architecture helps reduce pollution, conserve renewable resources and prevent environmental degradation.
- Economically, it reduces the amount of money that the building's operators have to spend on water and energy and improves the productivity of those using the facility.
- Socially, green buildings are meant to be beautiful and cause only minimal strain on the local infrastructure.
- The changing climate and the importance of designing resilient buildings that reduce damage to the environment and that are capable of adaptation, leads to a crisis planning scenario in $21^{st}$ century.
- This is a holistic approach to sustainability reaches beyond buildings to encompass sustainable communities and lifestyles.

**5.3 Conclusion**

- Provision of design for a building to utilise most amount of sunlight, wind direction, rainwater. Green aesthetics like exterior design, courtyard plantation and landscaping, etc.
- Encouragement of sustainable construction methods rather than conventional methods with maximum utilisation of available materials
- Enrichment in lifestyle of residents
- Provision of proper detailed plan layout, 3D model and estimation of whole project
- Construction planning with advised construction techniques and material selections
- After the project is completed, it is checked with simulation software and energy audit is done.
- Most efficient management of resources after construction is done with Provisions for energy production systems like rooftop solar power plant, solar water heater and rainwater harvesting system

## REFERENCES

**6.1 Design**

- 'Abhyudaua House' in Ahmedabad by KNS Architects
- 'Living green: Country's top eco-friendly designs' by NDTV GoodTimes
- 'Bel-Air' Mega Mansion, California
- grihaindia.org (Green Rating For Integrated Habitat Assessment) green ratings
- teriin.org (The Energy and Resource Institute)
- windfinder.com Vadodara Airport wind & weather statistics
- gaisma.com sun path finder
- Software Used: 'Autodesk AutoCAD' for planning drawings & 'Trimble SketchUp Pro' for 3D model design and rendering

**6.2 Material**

- 'Environmental impact of construction materials and practices' by Sanket Petkar from National Institute of Construction Management and Research (researchgate.net)
- 'An approach towards sustainable design' by Graphite Space Designing Studio, Vadodara
- All about green building concept – The Hindu (thehindu.com)
- Types of walls in construction (civiltoday.com)
- Passive solar home design, Department of Energy (energy.gov)
- Building a green home using local resources and sustainable materials (sciencedirect.com)
- Sustainable materials for building construction I TERI (teriin.org)

**6.3 Utilities**

- GEDA guidance books for energy efficiency.
- Energy Conservation Act-2001 from Ministry of Power and Bureau of Energy Efficiency
- 'Rainwater reservoirs above ground structures for roof catchment' paper from iisc.ernet (Indian Institute of Science)
- Design tips for rainwater harvesting components from The Constructor
- Software Used: 'Sunlight Hours' plug-in for 'Trimble SketchUp Pro' for shadow analysis & Microsoft MS Excel for energy audit.

**6.4 Literature**

- GREEN ARCHITECTURE: A CONCEPT OF SUSTAINABILITY by Amany

Ragheba, Hisham El-Shimyb, Ghada Raghebb from Department of Architectural Engineering, Delta University for Science and Technology, Mansoura, Egypt and Department of Architectural Engineering, Pharos University, Alexandria 21311, Egypt

- Architectural Design Principles and Processes for Sustainability by David Grierson and Carolyn Moultrie first published in 2011 in Champaign, Illinois, USA by Common Ground Publishing LLC, www.CommonGroundPublishing.com

Dhruv Manvar, Sahil Gupte, et. al. "Design of residential villa applying concept of 'SUSTAINABLE ARCHITECTURE' in Gotri area." *International Journal of Engineering Research and Applications (IJERA)*, 10 (06), 2020, pp 14-27.