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Designing a Net-Zero Energy House with Sustainable Materials and Smart Building Technologies

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ABSTRACT

This project aims to design and construct a self-sustainable house that prioritizes sustainability throughout its life cycle. It will incorporate renewable energy sources, such as solar panels, and water conservation systems like rainwater harvesting and greywater recycling. Efficient insulation, ventilation, and lighting systems will be used to reduce energy consumption and enhance occupant comfort. Sustainable materials with low embodied energy, low toxicity, and high durability will be preferred. Smart building technologies will be employed to optimize operations and minimize resource consumption. The project will also focus on promoting occupant well-being by incorporating green spaces, natural lighting, and healthy materials. In summary, this project will showcase the potential of sustainable building design in creating a greener future by utilizing renewable resources and minimizing environmental impact throughout the building's life cycle.

Introduction

This project aims to address the urgent need for sustainable buildings in the face of climate change. It will design and construct a self-sustainable house that prioritizes sustainability throughout its life cycle. By integrating renewable energy sources, conserving water, using sustainable materials, optimizing building operations, and promoting a healthy lifestyle, this project will demonstrate the potential of sustainable building design to contribute to a greener future. It will set an example for future practices by reducing energy consumption, utilizing renewable energy sources, conserving water, and promoting occupant well-being. The project will prioritize sustainability from material sourcing to end-of-life re-use and will utilize smart technologies for efficient operation. Overall, this project is crucial in achieving global net-zero emissions and combating climate change by showcasing sustainable building design practices.

Problem Statement

This project aims to address the urgent need for energy-efficient buildings to combat climate change and achieve global net-zero emissions by 2050. It focuses on designing and constructing a self-sustainable house that considers sustainability throughout its life cycle. The project aims to utilize renewable resources, reduce pollutants, and promote a sustainable lifestyle for occupants. By doing so, it aims to contribute to a greener future and demonstrate the potential of sustainable building design in achieving global sustainability goals.

Project Objectives:

1. To design and construct a self-sustainable house that utilizes renewable energy sources and reduces pollutants to combat climate change and achieve global net-zero emissions by 2050.

2. To source building materials and products with low embodied energy, low toxicity, and high durability to promote sustainability throughout the building's life cycle.

3. To manage the building's operation, maintenance, and upgrades through smart building technologies and sensors to minimize energy and resource consumption.

4. To prioritize the well-being and health of occupants by incorporating green spaces, natural lighting, and healthy materials that promote a healthy indoor environment.

Methodology

A blended research methodology combining literature review, qualitative data collection and investigation, and quantitative data collection and analysis was utilized in this study. This approach has proven effective in researching complex processes and systems in various fields, including the architecture, engineering, and construction (AEC) industry. The qualitative data helps inform and guide the quantitative data collection and analysis, leading to a better understanding and generalization of findings. The initial step involved reviewing existing literature on sustainability parameters and identifying any gaps or additional variables to be considered. Design provisions and quantitative variables were then established, using standard codes and estimation methods. The findings of this project will be analyzed in relation to conventional practices and their potential impact on societal issues.Analysis and Design

Building Plan and Materials

The building is a house with; Hall, Kitchen, Two (2) bedrooms and bath with toilet.

In this aspect the following were the aspects considered as per passive thermals is concerned:

I. **Shape of building**: It's made in square shape for even distribution of thermals in the building.

II. **Orientation**: The orientation of the building is made into consideration to align the building with direction of the incoming sun rays for lighting and solar heating of the building (considering the rooms requiring much lighting)

III. **Building Material**: The walling of the constructed with thermal insulating material that are more readily and easily available. The walling material and insulation material are selected basing on

- Their thermal conductivity as per IS Code 3792. Availability on the locality
- Cost effectiveness of material

Thermal Conductivity of material (IS 3792)

Burnt brick = 0.75 W/mK, Concrete = 1.74 W/mK, Timber = 0.144 W/mK

Asbestos = 0.245 W/mK

The walling material and insulation material are selected basing on

- Their thermal conductivity as per IS Code 3792.
- Availability on the locality

IV. **Floor finishes:** the floor is provided with concrete (has high thermal conductivity) covered by wooden tile (since timber has lower thermal conductivity compared to concrete)

V. **Roofing**: the roof will be made up of Asbestos cement tiles

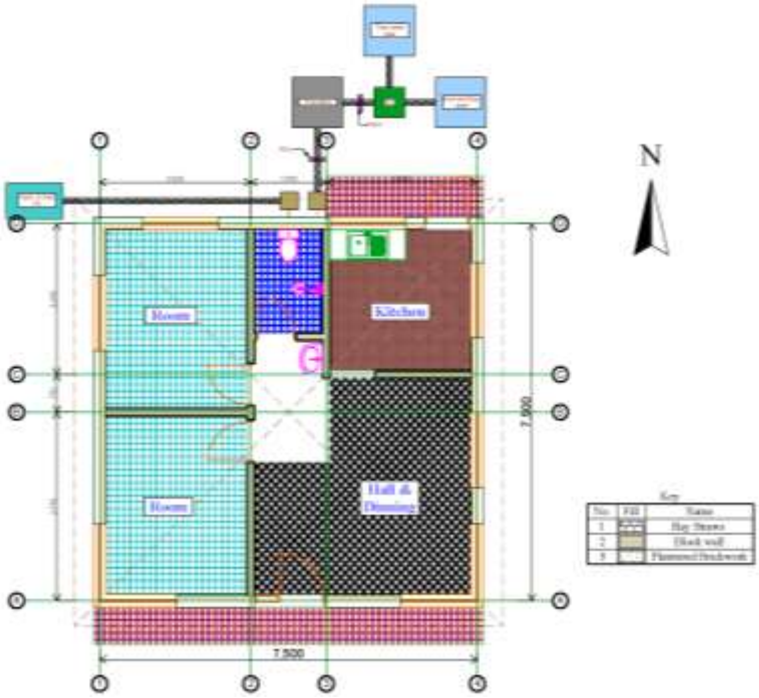

Figure: Proposed floor plan

Solar Power

1. Electric load calculations

Table : Electrical loading

S/No	Appliance	Rating (W)	Qty	Total wattage (W)	Usage (W)	Power (Wh)
1	Indoor Bulbs	24	6	144	6	864
2	Outdoor Bulbs	40	4	160	10	1600
3	Fan	100	2	200	6	1200
4	Refrigerator	700	1	700	12	8400
5	Television set	300	1	300	12	3600
6	Iron	1000	1	1000	1	1000
			Total	**2504 W**		**16664 Wh**

Total = 16.66 kWh

Total wattage = 2504W

2. Inverter Sizing

Total Watt of all appliances is 2504W

For safety, the inverter should be considered 30% bigger. Therefore 1.3 x 2504 = 3255.2W

The inverter should be 3300 or greater for safety.

3. Solar Panels

Assume 12V battery:

Power

$I = \frac{P}{V} = \frac{2504}{12} = 208.67$ A

Battery Size, Ah =Watt(hrs/volts)

$= \frac{16664Wh}{12V} = 1388.67$ Ah

Current required to charge the battery =1/10 of Ah

$$= \frac{1}{10} X\ 1388.67\ Ah\ = 138.87\ Ah$$

Total Current = 208.67 + 138.87

= 347.54 A

Solar plate power = VI

Power = 15V X 347.54A =5,213.1W

Assume 400W solar panels are used, Number of solar panels required:

Np = (5213.1/400) = 13.0327

Round value is 13

Solar panels required are 13

Considering 400W panels, we can also calculate as;

(16,660W/3.2(A standard USA panel generation factor)) = 5206.25W

Number of panels= 5206.25w/400w

= 13.0156

Round figure is still 13 panels.

4. Area required for installation

Area of one 400W panel is 22.75 square feet by 13 panels = 295.75 sq. Feet.

Approximately 27.476 square meters are needed for installation of the panels.

5. Considering cloudy days,

Total appliances use is 16.66KWh

Therefore 16.66kwh

Battery voltage 12V

3 days autonomy

$$= \frac{16{,}660w\ x\ 3\ days}{0.85\ x\ 0.6\ x\ 12} = 8166.67Ah$$

So, the battery is rated at 12v, 8500Ah, for three days autonomy.

Solar lighting

While lights can be provided using electricity, this design uses passive lighting. Strategically placed large windows catch daylight as the sun moves through the sky, lighting the home during daytime hours with no additional energy. Using the sun to light homes directly during the day has a number of advantages as well as using solarr LED bulbs during the night. Below are some of the benefits accoording to Greentech;

Water collection and recycling

Water Requirement

As per IS Code 1172, per capita water demand per person per day is 135lts per. Assume the two room house with 4 people, then the water requirement shall be 540lts per day

Rain water harvesting: Rain water is collected using gutters and sent to collection tank for use. The tank provided for rain water is 2000lts

Grey water (non-toilet plumbing fixture) accounts for more than 50% of waste water in a household. Therefore, from 400lts, 200lts of wastewater can be recycled and used for flushing, washing and irrigation.

Analysis and factors for this consideration

Qualitative analysis

Black water is director to sewer (septic tank). This can not be recycled due to presence of organic matter.

Greywater is considered from laundry use, baths, and hand wash sink. Wastewater from these plumbing fixtures is directed to cleaning through first filter (coarse filter) then to second filter (fine filter) before directed for use. It can only be used for flash in toilet and laundry. Irrigation water can also be satisfied by greywater. Greywater is much considered since it is produced in high amount compared to other waste water and easier in treatment that blackwater

Water supply to be the system shall be injected by two means:

- Water supply from the mains by the distribution company. This will be directed to the main tank
- Rain water harvesting (RWH) will also be directed to the main tank via a simple filter system before injecting to the tank since it is usually hard water.

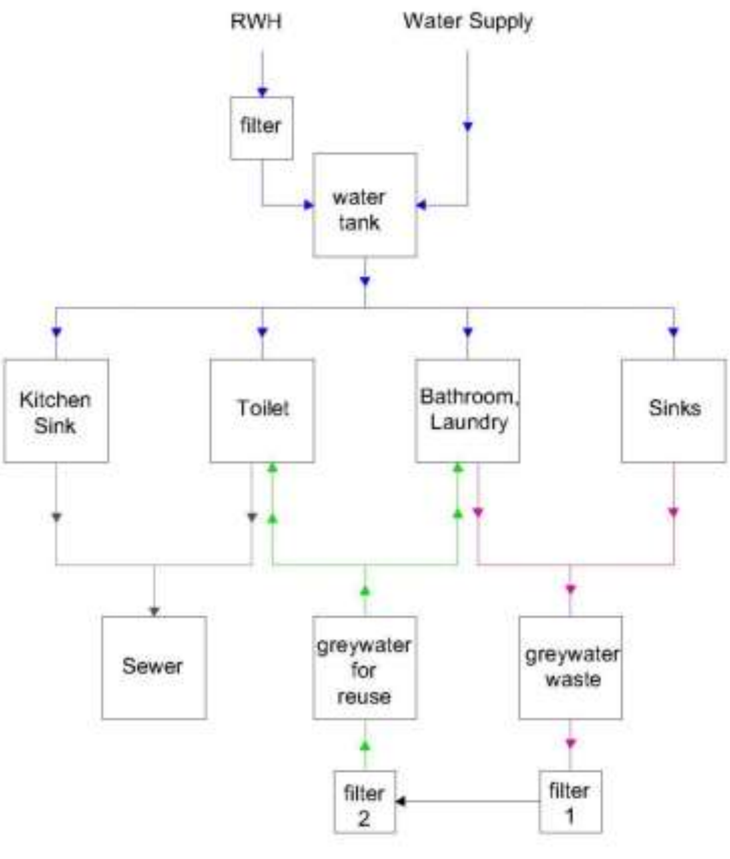

Figure: System mechanism for recycling

Quantitative analysis

Table: Approximate amount of wastewater produced by one person each day in an average home

Wastewater type	**Wastewater source**	**L/person/day**
Greywater	Shower	63
	Hand basin	6
	Washing machine	13
	Laundry tap	2
	Total greywater	**84**

Blackwater	Toilet	20
	Kitchen tap	12
	Dishwasher	5
	Total blackwater	**37**
Total wastewater		**121**

Assume 80 litres/person/day is directed for recycling; and half of the water is redirected back to the plumbing system as in the water supply layout. Therefore, this means 40 litres/person/day can be save by recycling of water. This accounts for 160 litres/person/day for four people in the house.

Solar pump

Since the house/home will be self-sustained, it will not have supply of outside water. Residents will be getting water from the water main distributors / borehole. An approximated quantity of water requirement per day is used to calculate the amount of power that will be needed to pump water from underground. These calculations use values for depths of wells, as locations affect depths of boreholes, or wells. They can be adjusted to suit whichever area the plan can be located. Designing solar water pump system.

Step 1: Determine the daily water requirement in (m^3/day)

Daily water requirement = 0.5m^3/day

Step 2: Calculate the Total Dynamic Head (TDH) required for pumping the water.

Total vertical lift = Elevation + Standing Water Level + Drawdown

Total vertical lift = 6m + 6m + 3m =15m

Frictional loss = 5 % of the total vertical lift = 15 x 0.05 = 0.75m

Total Dynamic Head (TDH) = Total vertical lift + Frictional loss

Total Dynamic Head (TDH) = 15 + 0.75 = 15.75m

Step 3: Calculate the total hydraulic energy required per day (Watt-hour/day) for pumping the water.

Hydraulic energy required = Mass x g x TDH

Hydraulic energy required = (1000 kg/m^3 x 0.5m^3/dav × 9.8m/s^2 x 15.75m) / 3600

= 21.44 Wh/day

Step 4: Calculate the solar radiation available at the site.

Solar radiation available at the site

(No. of hours of peak sunshine per day) = 5h.

Peak sun hours are most commonly used as they simplify the calculations.

Step 5: Calculate the size and number of PV modules required, the motor rating, its efficiency, and losses.

$$\text{Total wattage of PV panel} = \frac{\text{Total hydraulic energy}}{\text{No. of hours of peak sunshine per day}}$$

$$\text{Total wattage of PV panel} = \frac{21.44}{5}$$

$$= 4.2875\text{W/day}$$

Total wattage of PV panel considering system losses

$$= \frac{\text{Total wattage of PV pane}}{\text{pump efficiency x Mismatch factor}}$$

$$= \frac{4.2875\text{W}}{0.40 \text{ x } 0.80}$$

= 13.40W

Total wattage of PV panel considering the operating factor of the PV module

$$= \frac{\text{Total wattage of PV panel considering system losses}}{\text{Operating factor}}$$

$$= \frac{13.40\text{W}}{0.60}$$

$= 22.33$ W

No. of PV panels required of 36Wp

$$= \frac{\text{Total wattage of PV panel considering the operating factor of the PV module}}{36}$$

$$= \frac{22.33}{36}$$

$= 0.62027$ (1 Pv module) rounding figure

Power rating of the DC motor = Total wattage of V panel considering operating factor of the PV Module

= 22.33/746W = 0.0299 hp motor

(1hp Round figure)

= 1hp.

Results

The house area of 56 square meters, two rooms, hall and kitchen. Insulated wall area of 90 square meters. The front side of the house which comprise the hall and one of the rooms that will receive much of the light as this side faces south side. Water supply is dependent on distribution main/borehole, and recycling of grey water. It is expected to save more than 35 liters per person per day. One horse power pump is required

For power supply, the power consumption per day is 16.67 kWh which bring up to 500 kWh per month. battery size 8500 Ah rated 12V is required for the system (3day autonomous) and Solar Panels required are 13 panels each at 400W

Conclusion

This project demonstrates the potential of sustainable building design to combat climate change and contribute to a greener future. By considering sustainability throughout the entire life cycle of a self-sustainable house, including energy efficiency, renewable energy sources, and sustainable materials, we can reduce energy consumption, minimize waste, and promote a healthy lifestyle. The project emphasizes the importance of taking action towards a sustainable future and provides a blueprint for future sustainable building designs. It highlights the role of the building industry in reducing greenhouse gas emissions and stresses the need to prioritize sustainability throughout all stages of a building's life cycle. Overall, sustainable building design plays a crucial role in achieving global net-zero emissions by 2050 and building a sustainable future.

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