Design of Green Building: A Case Study for Composite Climate

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Abstract

A green building is that which uses optimum energy and puts least impact on environment. Industrialization and technological development exerts excess load on the local environment in terms of increasing energy demand and pollution emissions. It is, therefore, essential to investigate the better design options in terms of whole building system. Since there are number of parameters as construction material, lighting and cooling systems, water, etc. it is essential to apply an integrated approach toward green building design. The present study briefs the analysis and design approach for green building. A case study for composite climate is considered for green building design. Various alternatives for design parameters in terms of cost and energy saving with reference to conventional and non-conventional energy system have been estimated. Design is validated through computer simulation. It is found that with the appropriate use of green construction materials, energy efficient lighting and cooling appliances, water conservation system significant amount of cost, energy and CO_2 emission saving is achieved.

Key Words: Composite climate, CO_2 emissions, energy efficient lighting and cooling appliances, Green building, Green construction material

1. Introduction

Green buildings are designed to maintain indoor comfort conditions with respect to the local climate while minimizing the use of conventional energy, generation of greenhouse gases and the cost of operation. Common objective is to reduce overall impact of the built environment on human health and the natural environment efficiently. While the practices or technologies employed in green building are constantly evolving and differ from region to region, there are fundamental principles which have to be followed. These principles include efficiency of structural design, materials, energy, and water.

While designing a green building following parameters are taken into consideration; utilization of natural light and ventilation to maximum limit, using locally available, low embodied energy, and recycled materials for construction, using energy efficient electrical and mechanical appliances. Final energy consumption is equal to the demand of energy at user's end. This demand varies with increasing population, improvement in living standards, development in technology, and unique conditions in each individual country. It is expressed as the relation between per capita gross domestic product (GDP) and energy consumption. Energy consumption is directly proportional to GDP [1].

The energy efficiency of the built form is affected by decisions to be taken at all the design stages. The design of built form with solar passive techniques includes shape and size of built form, orientation, site planning, design of building components such as roofs, walls, openings (doors and windows) and design of building elements such as windows and shading devices.

Materials should be extracted and manufactured locally to the building site, wherever possible, to minimize the energy embedded in their transportation. Embodied energy of different construction material is dependent on its production process [2]. Wooden materials have lower embodied energy over its life cycle as compared to other construction material [3, 4]. Embodied energy in cement stabilized reinforced earth (CSRE) walls (with 8%

cement) is only about 15–25% of the embodied energy in burnt clay brick masonry [5]. Use of large amount of either natural or artificial Pozzolans makes cement low-CO_2 alternative. Embodied energy in conventional buildings can be reduced by approximately 10–15% of total through relatively simple means. Out of which the predominant part of the potential energy salvage is achieved through material recycling [6]. Prefabricated building elements or modular units, which can be joined together to create larger or smaller homes, is another sustainable construction technique [7]. In a study of mathematical model on the dynamic thermal behavior of actual green roofs it was observed that green roof act as insulation reduce heat flux through the roof [8]. Lighting load constitutes about 15% of the total electrical load of a building. During a building's life cycle, operational energy services, including HVAC, lighting, equipment and appliances etc. contribute to approximately 80% of total building energy consumption [9]. In a study on the potential energy saving, life cycle cost analysis and payback period of the lighting system in Malaysia it was found that life cycle cost for T5 fluorescent lamp system reduces upto 40% if 100% installation is done, which is considered to be low cost option compared to the standard and the other alternatives [10]. In the analysis of different cooling systems in New Delhi, India it was concluded that simple evaporative cooling system provides 12.05% saving while the regenerative evaporative cooling system provides 15.69% saving in annual power consumption of the building with indoor temperature maintained at 22˚C and 26˚C [11].

The pressures on water supplies, greater environmental impact associated with new projects as well as deteriorating water quality in reservoirs already constructed, constrain the ability of communities to meet the demand for freshwater from traditional sources. Rainwater harvesting presents an opportunity for augmentation of water supplies allowing for self-reliance and sustainability.

In a study and analysis of rainwater in a dual water supply system to supplement drinking water computer model was generated to quantify the water saving potential of the rainwater collection scheme. Author suggested that using stored rainwater for water closet flushing, 60% of the main water supply is saved [12].

TRNSYS is a transient systems simulation program with a modular structure. It recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected. The TRNSYS library includes many of the components commonly found in thermal and electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. Main applications include solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells.

Present paper briefs the design of green building for composite climate zone. Design is verified with the help of simulation model.

2. Methodology of study

Methodology adopted in the study includes;

- Deciding shape, dimensions and orientation of building on the basis of passive solar design approach
- Selection of appropriate green materials for reduction in embodied energy of building
- Selection of energy efficient lighting and cooling methods
- Estimation of rainwater harvesting system
- Estimation and comparison of cost for conventional and green alternatives in building design
- Validation of parameters by simulation for thermal performance

3. Case study

The study area for the design of green building is proposed at VNIT, Nagpur, which lies in composite climatic zone of India where maximum temperature is around 48˚C and minimum temperature is around 25˚C during sunshine hours. Area considered for proposed study is 100 m^2 with dimensions 13.50m x 7.50m having long walls in North/South direction whereas short walls in East-West direction so as to reduce heat gain. All walls are 230 mm thick whereas West and South facade walls are provided with the insulator (expanded polystyrene) which helps to prevent heat gain due to thermal mass. Sizes of openings are worked out as 15% of wall area [13]. Windows are placed on longer walls so as to get maximum glare free daylight and cross ventilation. Pitched roof is proposed for the construction as it reduces heat gain due to radiation, in turn reduces cooling load. Fig. 1 shows plan and section of proposed green building model.

Estimation of quantity of construction material is done for 13.50m x 7.50m x 3m size building. Table 1 and Table 2 show the cost estimate for bricks, cement, and electrical appliances. Where as in table 3 and table 4 total carbon emission from construction material and electrical appliances has been calculated. As quantity of steel remains same in both cases there is no implication on cost but using recycled steel saving in carbon emission is achieved. Quantity of light and cooler is worked out for 22 working days for 8 hours. Annul consumption is calculated and compared.

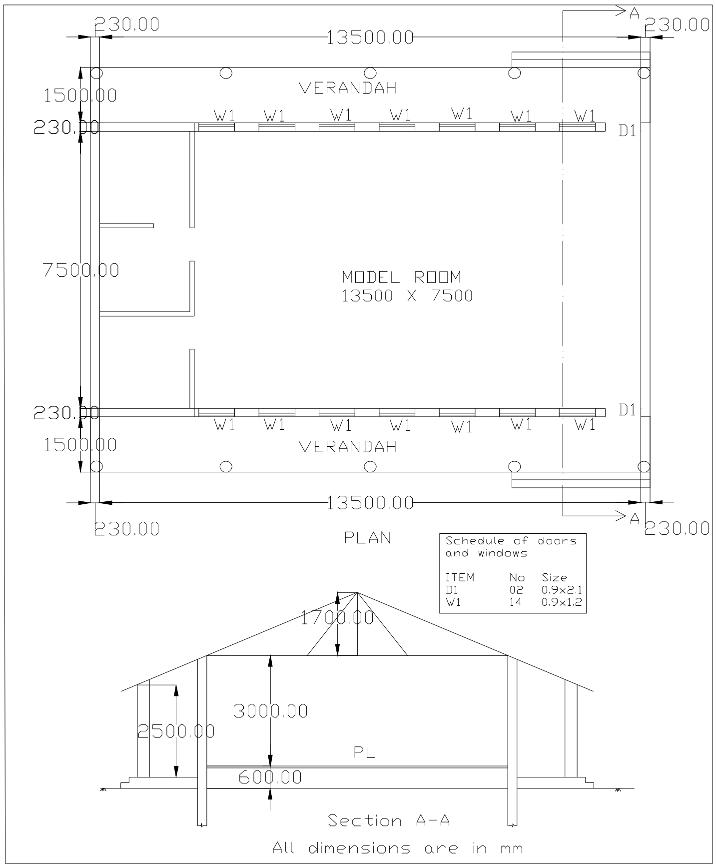

Fig. 1: Plan and section of proposed green building model

Table 1-Comparison of cost for construction materials

S No	Item	Quantity	Unit	Rate (INR)	Cost (INR)	Remark
1	Clay brick	13550	No	3.50	47425.00	-
2	Fly ash brick	13550	No	3.40	46070.00	2.86% less
3	OPC	212	Bag	350.00	74200.00	-
4	PPC	212	Bag	310.00	65720.00	11.43% less

Source: Quantity of construction materials has been worked out and rates are taken from current scheduled rates of PWD-2009.

Table 2-Comparison of energy consumption for electrical appliances

S No	Item	Qty. in No.	Installation Cost (INR)	Electricity Cost (INR)	Total Cost (INR)	Remark
1	Tube Light	81	12150.00	50550.00	62700.00	
2	CFL Light	95	11400.00	25555.00	36955.00	41.06% less
3	Cooler	6	49000.00	4702.00	61000.00	64.11% less
4	A C	6	72510.00	97459.00	169969.00	

Source: Cost of electricity as per Maharashtra State Electric Board (MSEB) tariff 2010

Table 3-Comparison of carbon emission for construction materials

S No	Item	Quantity	Unit	Kg CO_2/ per unit	Total Kg CO_2	Remark
1	Clay brick	13550	No	0.59	7994.5	
2	Fly ash brick	13550	No	0.11	1490.5	81.36% less
3	OPC	212	Bag	0.89	9434.0	
4	PPC	212	Bag	0.60	6360.0	32.58% less
5	Steel	1.62	Tonne	1.987	3220.0	
6	Recycled steel	1.62	Tonne	0.357	580.0	81.98% less

Source: Carbon emission data taken from Environmental Protection Agency (EPA) report emission data for steel is taken from Carbon emission data taken from M/S Kamboj Ispat Pvt. Ltd. Nagpur

Table 4-Comparison of carbon emission for electrical appliances

S No	Item	Qty. in No.	Total power Kwh	Tonne CO_2/ Kwh	Total CO_2 Tonne	Remark
1	Tube Light	81	570.24	0.0005883	0.34	
2	CFL Light	95	334.48	0.0005883	0.20	41.48% less
3	Cooler	6	440.00	0.0005883	0.26	85.14% less
4	A C	6	2978.00	0.0005883	1.75	

Source: Department of Energy's Energy Information Administration. Electricity sources emit 1.297 lbs CO_2 per kWh (0.0005883 metric tons CO_2 per Kwh)

3.1 Calculation of Rainwater Harvesting

For landscaping area of 30 m^2 water requirement is 3 liters /m^2 per day. Yearly water requirement with 30% evaporation losses is computed as 21600.00 liters /annum. Water required for flushing is taken as 10 liters /flush and for occupancy of 40 persons total water required for flushing on week days (excluding holidays) for a period of 10 months is computed as 8800.00 liters/annum. Total water required is 109600 liters /annum. Water tariff is taken as 5.00 Rs/1000 liters as per Nagpur municipal Corporation tariff. Therefore cost of water required for landscaping and flushing is Rs 548.00/ annum. To cater this need it is propose to have roof top harvesting provision. For the area of 100 m^2 roof top water collected annually is 36150.00 liters/annum. Therefore stored rain water is proposed to be used in flushing and landscaping thus saving water resource which clearly saves water cost for landscaping and flushing.

3.2 Simulation with TRNSYS

To verify thermal performance of designed green building proposed model has been simulated with TRNSYS. Fig. 2 shows simulation model for building and Fig. 3 shows variation in temperature for designed building throughout the year.

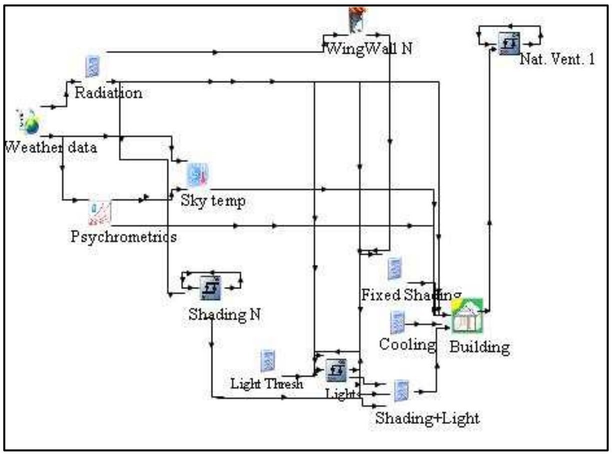

Fig. 2- Developed Model for the Building in TRNSYS simulation

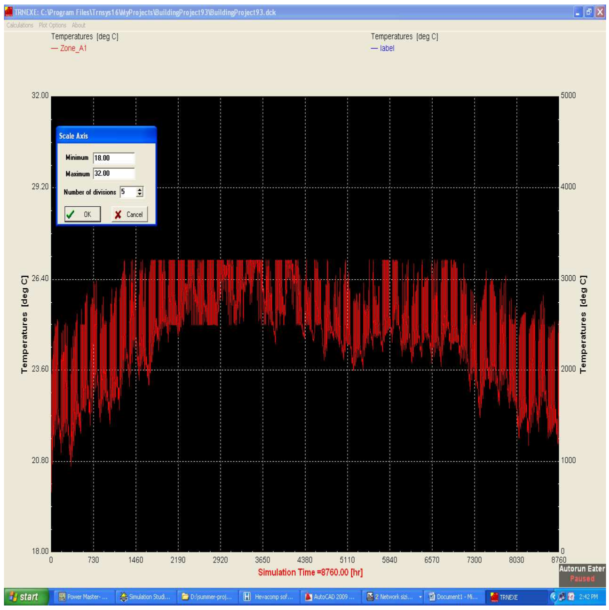

Fig. 3- Thermal performance of designed building

4. Results and Discussion

Comparative calculations for case study of fly ash bricks with clay bricks show that the cost for fly ash brick is 2.86% less as compared to later. Pozzolana Portland cement (PPC) gives 11.43% less cost than Ordinary Portland cement (OPC). As fly ash bricks and PPC contains appreciable amount of fly ash it is an alternative solution to solid waste management problem as well as helps in cost reduction of the construction.

It has also been calculated that carbon emissions from fly ash bricks is 81.36 % less as compared to clay bricks and PPC has 32.58% lesser carbon emissions as compared to OPC for the designed green building at VNIT campus.

Application of recycled steel is recommended which reduces significant carbon emissions as compared to fresh steel. It has been estimated that carbon emission from recycled steel is 81.98 % less as compared to fresh steel for the estimated quantity desired for the designed case study.

By using passive solar building design approach as well as design guidelines laid in SP: 41-1987 maximum use of natural daylight as well as appropriate ventilation rate has been achieved in the proposed green building. This has resulted in reduction in number and size of lighting fixtures. Replacing fluorescent tube lights with CFL resulted in the saving of 41.06% cost of installation as well as operation for a year, in turn savings in carbon emission has been estimated as 41.18%. Wherein, for peak summer season use of evaporating coolers is recommended as compared to air conditioner that resulted in 64.11% cost saving as well as 85.14% savings in carbon emissions.

The natural resource of water i.e. rainwater harvesting is proposed for the case study that resulted in 36150.00 liter of annual water collection for storage as well as usage for desired end use.
The designed green building is simulated in TRNSYS Simulation Environment to analyze the thermal variations in the designed built environment which resulted in the range of 20-26°C that is in thermal comfort zone.

5. Conclusion

Based on the design of green building and analysis of different construction material following important conclusions are drawn from the present work:

- Analysis shows that planning, design, and building materials have great impact on energy efficiency of building.
- With the appropriate use of green construction materials like fly ash brick, Pozzolana Portland cement and recycled steel the significant amount of cost and CO_2 emission saving is achieved.
- The operational cost reduction as well as CO_2 emission reduction for electro-mechanical appliances is achieved using low energy consuming appliances like CFL Lights, Evaporating coolers for lighting as well as cooling requirements respectively.
- Conserving rainwater and reusing it reduces excess pressure on Ground Water and is recommended for the designed green building.
- TRNSYS simulation software found useful in developing real-life built environment model along with the technical details of all the construction materials, building functional details and cooling requirements. The developed model when analyzed over a period of a year the thermal comfort has been observed well within the comfort zone.

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