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DESIGN AND DEVELOPMENT OF SUSTAINABLE CONSTRUCTION STRATEGY FOR RESIDENTIAL BUILDINGS: A CASE STUDY FOR COMPOSITE CLIMATE

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Abstract

Developing cities in India like Nagpur are growing exponentially in population due to industrialization. The ever increasing demand of the natural resources leads to depletion of limited resources and also affects local environment in terms of increasing pollution emissions especially carbon emission. With recourse to composite climatic condition (Nagpur, India) the sustainable construction strategy is developed in the present paper. The developed strategy includes conservation of soil, energy, resources, material and water. It provides a systematic approach towards sustainability of building through quantification of energy consumption. Analysis of conventional and non-conventional material and technology on cost, energy consumption and carbon emission parameters helps in highlighting suitable options for sustainable construction. Strategy is validated through a case study of new construction of the residential buildings for enhanced environmental performance. The amount of excavated soil and its reutilization on site is taken into consideration. Locally available sustainable construction materials are compared for material cost, and embodied energy for selection of appropriate construction material. In order to conserve the ground water various options for the low flow devices, roof top rainwater harvesting and gray water recycling and reuse are suggested. Application of sustainable construction strategy to case study building revealed that 97% of natural soil is conserved through backfilling. Estimated carbon emission reduction due to recommended construction materials (sustainable bricks, cement, and steel) with respect to conventional options is of the order of 60%. Recommended water conservation options resulted in 57% reduction in ground water demand. However suggested sustainable construction strategy options estimated in increase in project cost by 13% whose effect can subsequently be reduced over the design life span computations. The developed strategy can further be applied to the larger residential township areas with varying building types for conserving the natural resources as well as reducing the impact of environmental pollution.

Keywords: *Sustainable construction strategy, natural resource conservation, techno-economic feasibility, environmental pollution control, carbon emission reduction*

1.0 Introduction

Construction industry is a major consumer of natural resources. Construction related activities account for quite a large portion of energy consumption and CO_2 emissions. This energy is consumed at pre-occupancy state in manufacturing and transportation of building materials and components, which is termed as embodied energy (EE), and at occupancy state which corresponds to the running of the appliances when it is occupied. Construction sector in India emits about 22% of the total annual emission of CO_2 resulting from the Indian economy. Out of the emissions from the construction sector, 80% are resulting mainly from the products/industrial processes of energy intensive building materials, i.e. cement, lime, steel, bricks and aluminum [1]. Further, sustainability 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 [2]. A sustainable construction strategy ideally should include all those parameters which reduce energy consumption and atmospheric carbon emission. Degree of sustainability of a building is judged by comparing it to a benchmark construction. Comparison benchmarks can be set according to building characteristics. Development of these reference building benchmarks requires some assumptions and data collection. While some factors such as activity, occupancy data, building area, number of pupils, age of building, etc. can be easy to obtain by means of questionnaires, other vital information for evaluation for energy performance of the building, such as construction details and type and efficiency of heating systems are often not known by respondents [3]. This information has to be collected from all stakeholders involved in planning and designing stage of building.

A strategy for sustainable construction is presented in this paper which takes in to account soil, resources, material, and water conservation. It helps in rational utilization of non-renewable resources with an increase in use of renewable resources, elimination of wastes, reduction of waste formation, customs management of consumption, utilization of equipments and materials, more efficiency and/or increase in quality of productive processes. Each parameter affects overall sustainability of building. Development and environmental performance of building is location specific. Proper control at all stages of building development such as construction, fitment, outdoor facility construction, transportation, operation, waste treatment, property management, demolition, and disposal, with related material, equipment, energy and manpower inputs improves environmental performance of building [4].

It is comparatively easy to construct a new building with an approach to sustainability. It is because in new buildings control over all actions can be easily planned than existing buildings. Quantification and comparison of resource consumption in building construction tends to minimize the consumption. Building energy labeling systems help in this. There are several voluntary energy labeling systems prevalent across the globe viz. BREEAM (Building Research Establishment's Environmental Assessment Method), GB Tool, LEED (Leadership in Energy and Environmental design), CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) Green Globes, GRIHA (Green Rating for Integrated Habitat Assessment) [5]. Voluntary building-assessment scheme helps in encouraging owners greater in energy-reduction effort [6]. Researches carried in the area of improvement in environmental performance of building suggest that policy formulation, assessment and monitoring, life cycle analysis and simulation, and building material selection are major controlling factors [7]. In the strategy to improve overall performance of buildings, approach of authority [8-11], economy of nation [12, 13], availability of local energy sources [14], state of technology [15-17] and behavior of consumers [18, 19] have been identified as major parameters.

A sustainable building in its basic form is energy efficient and water efficient. In most of the sustainable construction practices take energy conservation in building occupancy state into account. Whereas research shows that the embodied energy of residential buildings can contribute up to 40% of the life-cycle energy use in residential buildings. The initial embodied energy of a building is the energy used in producing a building whereas the recurring embodied energy is the energy used in maintaining and repairing of the building over its effective life. [20]. EE data depends on 10 parameters viz. system boundaries, methods of EE analysis, geographic location of study area, primary and delivered energy, age of data sources, source of data, completeness of data, technology of manufacturing processes, feedstock energy consideration and temporal representativeness [21]. Present study takes in to account embodied energy of building material as one of the strategic parameter.

Uncontrolled exploitation of ground water resources results in to scarcity of potable water. Rain water harvesting is an apt answer to such situation. Even though initial investment in such technology is considerable it proves to be cost effective in long run. Efficiency of rainwater harvesting depends on the materials used, design and construction, maintenance and the total amount of rainfall. Cement tiles are used as a roofing material, the year-round roof runoff coefficient is about 75%, whereas clay tiles collect usually less than 50% depending on the harvesting technology. Plastic and metal sheets are best with an efficiency of 80-90% [22]. A combination of water management options results in decrease in water consumption up to 50%, thereby reducing the pressure on the scarce water resources. This reduction can be achieved because the water is recycled for different usage reducing the use of fresh groundwater. Environmental and financial impacts can be reduced similarly; the annual environmental impact of the in-house water use can be reduced by 8% when using low-flow shower heads, and up to 38% when using rainwater harvesting systems. These options are financially viable in long term use such as faucet aerators, low-flow shower heads and dual flush toilets [23].

Similarly during a building's life cycle, operational energy services including Heating ventilation and air conditioning (HVAC), lighting, equipment and appliances etc. contribute to approximately 80% of total building energy consumption [24]. Improvement in thermal performance of building envelope also leads to reduction in carbon emission. Retrofitting, reconstruction and selection of appropriate U-factors for building materials lead to a saving of carbon emission up to 31– 36%. Reuse, recycling and regeneration energy through combustion together can save up to 10% of total energy and subsequently emission [25]. However, energy consumption pattern in domestic application varies over geographic location with occupant's behavior. In order to design the sustainable construction strategy for the residential building in composite climate various labeling and rating systems are reviewed. Different parameters associated with sustainable construction practices are identified. The data is collected by field survey. The developed strategy for the sustainable construction is applied. The economic viability of the developed sustainable construction strategy for the considered case study of the residential building is estimated on the annual basis.

2.0 Developed sustainable construction strategy

Strategic planning is a decision-making process involving diverse objectives which requires a systematic approach. In the present paper the design process for new buildings is addressed. To validate the effect of strategy a case study of cluster of eighteen residential buildings located in composite climate is taken up and results are quantified. Present strategy includes;

1. Conservation of excavated soil by various means such as backfilling and landscaping.
2. Use of low embodied energy, natural materials, and recycled building materials.
3. Reduction in per capita consumption of water in the home through various measures such as rain water harvesting, use of low flow devices.
4. Reuse of waste water and reducing consumption of municipal water.

3.0 Design Data

Proposed site is located at Nagpur city, Maharashtra in India. Case study building is a cluster of 18 individual residential bungalows. The building is located at nonagricultural land and is sanctioned by local town planning authority. Each bungalow is a four bedrooms, hall, and kitchen house with approximate total occupancy of 5 to 6 persons. Plot area of each proposed building is 11.15 m x 19.10 m i.e. 212.96 m^2. Proposed area of construction of one bungalow is 237.00 m^2. Thus, for 18 bungalows total area is 3833.28 m^2. Orientation of building is 0° towards North and the short wall of the building is facing East–West. Sizes of openings are 20% of wall area. The longer window provides better light with better penetration and spread, so as to reduce lighting load. Outer walls are 0.23 m thick & inner walls are 0.115 m thick. Reinforce concrete roof is proposed for the construction of building. Roof insulation is proposed with the aid of false ceiling to reduce the heat gain through roof. Around 28% of the plot area is covered by landscaping on front and rear side of building. Soil used for landscaping is partially excavated dump and garden soil. The building is designed as a framed reinforced concrete structure which has M-20/M-25 concrete as primary building material

3.1 Reuse of excavated soil

Soil it is collected in process of excavation for foundation pits and is used for landscaping, refilling and leveling of low level areas. Total Quantity of excavation is estimated 36.50 m^3 for each bungalow. Excavated soil for total 18 buildings is 657.00 m^3. Out of this soil 430.20 m^3 is used in filling in plinth and floor, 74.68 m^3 is utilized in garden top soil replacement in landscaping and remaining 131.40 m^3 is used for leveling internal roads surface

3.2 Cost analysis of building materials

To calculate embodied energy of buildings estimate of material quantity has been prepared. Construction cost is calculated on the basis of quantity estimate. Rates have been taken from current schedule rates of Central Public Work Department (CPWD), India 2009-2010. For non-conventional material cost data has been collected at source. Major conventional building materials have been compared to non-conventional building materials. Several building material options for each conventional building material have been proposed. For masonry clay bricks have been compared to Fly ash bricks, Autoclaved aerated concrete blocks (A A C blocks), and Stabilized Mud Block (SMB). Ordinary Portland cement (OPC) is compared with Portland Pozzolana cement (PPC). Cost of conventional building material has been considered as base value and percentage saving in cost has been estimated for non- conventional building material. Details of cost of various options have been given in Table 1 below.

3.3 Estimation of embodied energy of building materials

Embodied energy of basic building materials has been calculated. Unit embodied energy data has been derived from various literatures [1], form source calculations and market survey. Fly ash bricks, Autoclaved aerated concrete blocks (A A C blocks), and Stabilized Mud Block (SMB) are compared with clay bricks. These materials use waste material as raw material and least energy in manufacturing process and thus have lower embodied energy. Portland Pozzolana cement uses fly ash in the process of manufacturing in as a replacement to costly and energy intensive cement clinkers. Thus PPC has lower embodied energy as compared to OPC. Steel being energy intensive material is compared with recycled steel. Table 2 gives comparative analysis of embodied energy for basic building materials

Table 1: Comparative analysis of cost of conventional and energy efficient materials

Description	Quantity	Unit	Rate (Rs.)	Cost (Thousand Rs.)	Cost Saving %
Clay Brick	520895	No.	3.90	2031.490	…..
Fly Ash Brick	520895	No.	3.75	1953.356	3.85
AAC block	73800	No.	28.00	2066.400	-1.72
SMB	520895	No.	3.80	1979.401	2.56
OPC	15120	Bag	290.00	4384.800	…..
PPC	15120	Bag	260.00	3931.200	10.34
TMT steel	109.930	Ton	46000.00	5056.780	…..
Recycled steel	109.930	Ton	42000.00	4617.060	8.70

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

Table 2: Comparative analysis of embodied energy for basic building materials

Description	Quantity	Unit	energy (MJ/ unit)	Total energy in MJ	% Savings
Clay Brick	1132.38	Cum	4050.00	4586139.00	…..
Fly Ash Brick	1132.38	Cum	1100.00	1245618.00	72.84
AAC block	1132.38	Cum	1920.00	2174169.60	52.59
S M B	9846.78	Sqm	110.00	1083145.80	76.38
OPC	524.66	Cum	852.00	447010.32	…..
PPC	524.66	Cum	507.00	266002.62	40.49
TMT steel	109930.00	Kg	32.00	3517760.00	…..
Recycled steel	109930.00	Kg	10.10	1110293.00	68.44

3.4 Estimation of carbon emission of building materials

Carbon emission for bricks, cement and steel has been calculated. Unit carbon emission data has been collected from various literatures, form source calculations and market survey. For each construction material above options have been compared and saving in emission is highlighted. Table 3 gives comparative analysis of carbon emission for building materials. Carbon emission data has been taken from Environmental Protection Agency (EPA) report and for steel it is taken from M/s Kamboj Ispat Pvt. Ltd., Nagpur, India

Table 3: Comparative analysis of carbon emission for building materials

Description	Quantity (No.)	CO_2 emission per brick (Kg CO_2 /bricks)	Total CO_2 emission (Kg CO_2)	% Savings
Clay Brick	520895	0.59	307328.05	…..
Fly Ash Brick	520895	0.11	57298.45	81.36
AAC block	73800	0.22	16236.00	94.72
S M B	520895	0.22	114596.90	62.71
OPC	15120	0.89	13456.80	…..
PPC	15120	0.60	9072.00	32.58
TMT steel	109.930	1.987	218.43	…..
Recycled steel	109.930	0.357	39.25	82.03

3.5 Water conservation through low flow devices

Nagpur lies in central part of India where average intensity of annual rainfall is 800 mm. Rest of the need of water is catered by municipal water supply and withdrawal of ground water through wells and sumps. Water is a scarce natural resource in this part and thus essentially needs to be conserved. There are two methods of water conservation reducing water use on sully side and restoring and recycling water on demand side. In this case study water conservation is achieved through deploying low water fixture which is commercially available in market, implementing rainwater harvesting and installing waste water recycling system for case study buildings. Various systems for Low flow devices (LFD) have been studied. Low-flow toilet flushing device use a maximum of 1.6 gallons of water per flush compared with about 3.5 gallons of water used by a conventional toilet. Low-flow shower heads use about 2½ gallons of water per minute compared to between four and five gallons per minute used by conventional heads. Low-flow faucet aerators can cut the water usage of faucets by as much as 40% from 4 gallons per minute to 2½ gallons. As far as cost is concerned low flow fixtures are high in cost as compare to conventional fixtures. Thus an increase in initial installation cost is there but they save considerable amount of water and thus pay off in long run of time. Table 4 gives reduction in water usage by low flow fixtures.

Table 4: Comparative analysis of conventional fixtures and low water fixture

Water consumption liter/capita/day	Conventional system	Low flow Device
Per day per person consumption of water (l)	180	108
Annually Consumption for 18 buildings (l)	7123204.8	4758004.8
Cost of water (annually) (Rs.)	427392.29	285480.28
Cost of Fixture & Fittings (Rs.)	1291770.00	2251170
Total Cost (Rs.)	1719162.29	2536650.288
Excess in cost (%)	……	47.55
Saving in water (%)	……	33.20

Rates of water supply is taken from Nagpur Municipal Corporation water tariff as 5.0 Rs/unit (1 unit=1000 L

3.6 Rainwater Harvesting

For landscaping area of 80.04 m^2 water requirement is taken as 3.5 liters /m^2 per day. Yearly water requirement with 30% evaporation losses for 18 buildings is computed as 1210204.80 liters /annum. To cater this need it is propose to have rainwater harvesting system. Roof top rainwater harvesting is analyzed for total 18 buildings. Water collected annually for 18 Building is 1243584 liters/annum. Thus harvested water totally caters the need of water required for landscaping with a 2.68% excess storage.

3.7 Recycling & reuse of wastewater

Decentralised Wastewater Treatment Systems are effective, reliable, cost-efficient and custom-built wastewater treatment systems which are perfectly suited for small to medium-size systems. The technical options within decentralised wastewater treatment system are based on a modular and partly standardized design. Decentralised wastewater treatment system is based on basic technical treatment processes: mechanical treatment (sedimentation and flotation) and biological (anaerobic and aerobic) treatment. The most common decentralised wastewater treatment system modules are septic tanks, biogas digesters, anaerobic baffled reactors (ABR), anaerobic filters (AF), planted gravel filters (PGF), and (if needed) polishing ponds. The systems can be designed to specific individual site-specific needs. In the present study a Decentralised Wastewater Treatment Systems is designed collectively for 18 buildings. Water required for washing & cleaning of house & flushing of toilets is 35 litres per capita per day thus annual water requirement for 18 buildings is 1.14 million litres. Whereas grey water collected out of bathing and cloths washing is 48 litres per capita per day. Assuming that 80% of recycling water will be available after treatment total quantity of water available is computed as 1.26 million litres. Thus requirement for washing cleaning is 100% catered with grey water recycling with a saving of 10% water.

3.8 Operating energy and related carbon emission

Household lighting typically accounts for 10% of electric bill. Alternative sources of energy are not carbon based and therefore do not release greenhouse gas (carbon dioxide) into the atmosphere when consumed. They can be designed to partially or fully satisfy the building / township's energy needs. Increasing utilization of these commercially available energy resources, including solar, wind, geothermal, and hydroelectric, is an important component in a municipal initiative to improve energy efficiency.

Compact Fluorescent Lights (CFLS) and Light Emitting Diodes (LEDs) have risen in popularity in recent years due to their longevity and energy-efficient design. These bright, compact lights are designed to reduce energy consumption without sacrificing light or productivity. Replacing CFL by LED saves cost and energy considerably.

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4.0 Results and Discussions

Selection of site is a major criterion in conservation of natural resources. Site must be a non agricultural land. Top soil must be preserved. In present study excavated stuff has been used for landscaping. Remaining soil is used for backfilling and leveling. No soil is disposed out of site.

The comparative study of construction material such as bricks, cement, and steel has been done. For bricks four options have been considered viz. Clay Brick, Fly Ash Brick, AAC (Autoclaved Aerated Concrete), and Stabilized Mud Block. These bricks are locally available within a periphery of 30-50 km. Various locally available options for above building materials have been compared for embodied energy and cost. It is observed that these options when compared to clay brick consume less embodied energy viz. Fly Ash Brick consumes 73%, AAC (Autoclaved Aerated Concrete) consumes 53% and Stabilized Mud Block (m^2) consumes 76% less embodied energy. More over Fly ash brick utilizes fly ash which is waste material and land filling. Stabilized Mud Block do not used any manufacturing energy and these are only compressed blocks. Autoclaved concrete blocks uses less concrete for given volume and thus, save scarce natural resources such as cement and aggregates. Cost of these blocks fly ash bricks and stabilized mud blocks are 4% and 3% less as compared to conventional clay bricks respectively whereas, AAC blocks are 2% costlier than conventional clay blocks.

Similarly in the comparison of Ordinary Portland cement and Portland Pozzolana Cement it is found that later is 11% cheaper than former one and saves energy to an extent of 41%. Thermo Mechanically Treated (TMT) steel is being used for the building under study and it has a potential of recycling the scrap as well as use of recycled steel as reinforcement in construction. It is found that recycled steel saves 9% energy and 68% cost as compared to conventional steel. When conventional materials are replaced by non-conventional material such as fly ash bricks or PPC cement it helps in reducing carbon emission as well as gives a solution to waste utilization. Fly Ash Brick, AAC (Autoclaved Aerated Concrete), and Stabilized Mud Block emit respectively 82%, 95%, 63% less CO_2 to atmosphere as compared to clay Bricks. Pozzolana Portland Cement (PPC) emits 33% less CO_2 as compared to Ordinary Portland Cement (OPC). It is found that recycled steel saves 82% as compared to conventional steel.

Comparative study of conventional and low flow devices shows that water consumption has been reduced to 108 liter per capita per day than 180 liter per capita per day by using the low flow device. This helps to reducing ground water load as well as municipal water bills. For the present study building cost of the RWH system is found as Rs. 113640.00. The annual collected water from the RWH system is 69088 Lit/year. The requirement of water for the landscaping and gardening is 67233 Lit/year. Hence, required water for the landscaping and gardening can be 100% fulfilled by the RWH system. More over cost of the system is mere 1% of the total cost of the building so it can be easily constructed with building itself. Similarly treated grey water caters the need of household washing and flushing. Lighting, home appliances and cooling system is the important component for human beings. Now a day's consumption of electricity is more as per the living standards, hence it is necessary to use the alternative option for the like solar, geothermal cooling system or use latest low conserving lights and star rated appliances.

Case study helps in elaborating the strategy and indicating its application. If implemented it results in to a systematic approach towards the sustainable construction. Analysis of case study clearly shows that application of the proposed construction strategy to a building results in to potential energy and emission saving. The strategy guides through each stages of construction process for quantifiable reduction in use of non-renewable resources and helps in using resources efficiently and minimizing waste by closing cycles. It further extends solution towards pollution reduction. This strategy can be implemented to a larger buildings and townships for reduction in energy and emission.

5.0 Conclusions

The conclusion of this study can be summarized as follows:

a. Conservation of natural resources by utilizing non-agricultural land for developing into residential or commercial building helps in conserving natural vegetation and reducing environmental pollution.
b. Utilization of waste material in production of construction material and minimizing conventional energy sources in material manufacture such as fly ash and stabilized mud blocks reduces energy in a range of 70-80% and saves cost up to 2-4%. Saving in energy in cement is in a range of 41% and 11% respectively
c. Water being scarce resource it is essential to reduce use of ground water and treated municipal water. Low flow fixtures save water and also reduce utility bill. Even if cost of low flow devices is quite high as compared to the conventional devices but in long turn they pay off by saving.
d. Total water calculated in the study taking standard water consumption 180 litres per capita per day which has been reduced to 108 litres per capita per day by using the low flow device.
e. Similarly sanitary water requirement may be reduced 80-90% by deploying decentralised Wastewater Treatment System and landscaping water requirement may be cut down by almost 70-80% by the rain water harvesting

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