TECHNO-ECONOMIC FEASIBILITY OF INTEGRATION OF GREEN TECHNOLOGIES FOR AFFORDABLE HOUSING

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ABSTRACT

The conventional construction technology along with spiralling cost of traditional building materials makes the housing unaffordable or a distant dream for an average income salaried person. The aim of a paper is to design an affordable green building model for an Economically Weaker Section (EWS) housing scheme to compare energy, carbon footprint and water performance. In this, a single dwelling unit plan is worked out for a EWS housing scheme using the identified green materials & techniques and compared with conventional material & techniques of construction. The study reveals that the integrated sustainable technologies like application of energy efficient building construction materials, implementation of water management and energy management techniques make the housing schemes energy efficient and cost effective to the economically weaker section of urban area.

Keywords: *Affordable Housing; Economically Weaker Section; Energy Efficient Building; Sustainable Technologies.*

1. INTRODUCTION

The housing shortage affects mostly the economically weaker sections (EWS) and low income groups (LIG), and the younger group of urban-urban migrants changing cities in search of better prospects. In India at the end of the 10th five year plan the overall shortage has been estimated at close to 25 million dwelling units. Affordable houses may be taken as houses ranging from about 300 square feet for EWS, 500 square feet for LIG and 600 square feet to 1200 square feet for middle income groups (MIG), at costs that permit repayment of home loans in monthly instalments not exceeding 30% to 40% of the monthly income of the buyer (SP 7:2005). In terms of carpet area, a EWS category house would be taken as having a minimum 25 square metres and of an LIG category house would be limited to a maximum of 48 square metres. The carpet area of an MIG house would be limited to a maximum of 80 square metres (Menon, 2009). Depending on household income, different housing schemes i.e. high income groups (HIG), MIG, LIG and EWS are categorized. The cost of housing scheme mainly depends on the carpet area and rate of conventional construction. The components of building block of traditional materials such as brick, stone, natural river sand, ordinary portland cement, wood, paints, steel etc. have environmental implications during the life cycle at various stages like manufacturing, transportation, construction to demolition (Raut *et al.*, 2011). The spiralling cost of such traditional building materials makes the housing unaffordable or a distant dream for an average income salaried person. This leads to have more and more research to find out alternative low cost, energy saving, eco-friendly, recyclable solid wastes from industries, agricultures, mines for effective utilization as a partial or full replacement of such components for uses in buildings and infrastructures (Pattanaik,

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2010). Although research had been well established commercially very few materials have been used in practice.

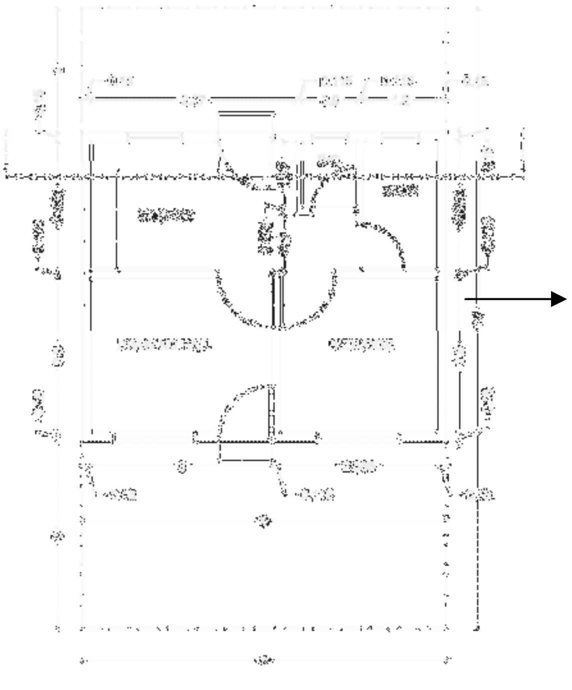
In view of developing techno-economical viable solution for affordable housing the present paper elaborates the detailed methodology for integration of locally available green materials, alternate water management and energy management techniques which are climatically appropriate. The methodology is well supported with a typical designed plan of a EWS dwelling unit over the study location.

2. METHODOLOGY

In order to design an affordable green building model for an economically weaker section (EWS) the sizing for dwelling unit is worked out (SP 7:2005). Identification and selection of green construction materials and techniques was reviewed and suitably considered for the proposed EWS housing scheme. The block budgeting for the dwelling unit along with carbon footprint reduction was estimated.

3. TYPICAL CONSTRUCTION OF A EWS HOUSING SCHEME

Figure 1 indicates typical plan of a single storied EWS dwelling unit. Considering the maximum plot area of 60 m^2 with the maximum super built-up of 30 m^2, ventilated area was considered to be 15% on the front and rear walls of the dwelling unit (SP 41:1987). A EWS housing scheme is considered with both side walls as common walls with front and rear plot margin. Dwelling cost and energy consumption calculated by using the identified green materials and techniques and compared with conventional material and techniques of construction. The appropriate green construction materials, water and energy management techniques are elaborated further.



Common wall between two dwelling units

Figure 1: Typical Plan of Single EWS Dwelling Unit

4. GREEN CONSTRUCTION MATERIALS AND TECHNIQUES

Identification and selection of green construction materials was reviewed and suitably considered for the proposed EWS housing scheme. Every year India generates around 90-100 MT of bagasse as by-product of the sugarcane industry, India is the second largest sugarcane producer in the world after

Brazil (Sengupta, 2002). Typically, as a substitute for conventional masonry, cement and sand use of sugarcane bagasse ash (SBA) is recommended as a low cost sustainable solution (Madurwar *et al.*, 2013). As a substitute for nominal size crushed aggregate use of naturally available rounded aggregates/gravels and maximum size of crushed aggregates are recommended (Mehta and Monteiro, 1993). Further, use of bamboo (BMTPC) is recommended as door & windows, flooring, roofing sheets and shuttering and scaffolding. The particle fibre board (Satta and Steve, 2008; Cristel *et al.*, 2010) made from bagasse is recommended as a sustainable false ceiling solution. Roof top rainwater harvesting (Gupta and Ralegaonkar, 2006) and application of active solar energy gadgets are recommended as the sustainable water and energy management solution.

4.1. SUGARCANE BAGASSE ASH (SBA)

Sugarcane is a major crop in many tropical countries. The production process generates bagasse as a waste, which is used as fuel to stoke boilers that produce steam for electricity cogeneration. The final product of this burning is residual sugarcane bagasse ash. Ash stands out among agro-industrial wastes because it results from energy generating processes. Tables 1, 2 and 3 show the physical characterization, particle size distribution and chemical composition of sugarcane bagasse ash.

Table 1: Physical Characterization of SBA

Properties	Specific Gravity	Mean Particle Size, D60 (µm)
SBA	2.4	45.0

Table 2: Particle Size Distribution of SBA

% Distribution	Gravel	Sand	Silt	Clay
SBA	0.61	75.15	23.04	1.20

Table 3: XRF of SBA

Elements (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
SBA	59.50	2.40	3.34	14.75	2.11	0.92	8.90

The percentage silica present indicates the suitability of SBA as pozzolanic material (IS 456:2000) for partial cement and sand replacement and also for making building bricks by mixing with cement and sand in different proportions (Suvimol and Daundrudee, 2008). The SBA-sand-cement combination had resulted in production of lighter brick material as per the recommended Indian standard. It was observed that bricks with the 10% addition of cement to SBA and sand exhibits a compressive strength of 5 MPa which is almost 1.7 more times more than the conventional clay bricks (3 MPa) and satisfies the requirements in IS 2185 (Part – I):1998 and BIS, SP 21:1983 for a building material to be used in the indoor structural applications. Apart from that, SBA building brick manufacturing process results in 60% reduction in energy consumption over the conventional building bricks.

Mortars and concretes with SBA as sand replacement were investigated by several researchers. The results indicated that the SBA samples presented physical properties similar to those of natural sand. The mortars produced with SBA in place of sand showed better mechanical results than the reference samples (Sales and Lima, 2010). The physical properties of concrete containing ground bagasse ash (BA) including compressive strength, water permeability and heat evolution were reviewed. Grounded bagasse ash from the sugar factory was used as a replacement for Portland cement at 10, 20, and 30wt% of binder. The water to binder (W/B) ratio and binder content of the concrete were held constant at 0.50 and 350 kg/m3 respectively. The results showed that, at the age of 28 days, the concrete samples containing 10–30% ground bagasse ash by weight of binder had greater compressive strengths than the controlled concrete (concrete without ground bagasse ash), while the water permeability was lower than the controlled concrete. Concrete containing 20% ground bagasse ash had

1.13 times higher compressive strength than the controlled concrete. The water permeability of concrete was observed to be reduced as the fractional replacement of ground bagasse ash was increased. For the heat evolution, the maximum temperature rise of concrete containing ground bagasse ash was lower than the controlled concrete. It was also found that the maximum temperature rise of the concrete was reduced 13, 23, and 33% as compared with the controlled concrete when the cement was replaced by ground bagasse ash at 10, 20, and 30wt% of binder, respectively (Nuntachai *et al.*, 2009). Tables 4 and 5 show the cement replacement potential of SBA in ordinary and high strength concrete.

Table 4: Cement Replacement, Water to Binder Ratio (w/b) and Compressive Strength of Various Agro-Wastes for Ordinary Concrete

Agro-waste	Cement Replacement (%)	w/b ratio (%)	Compressive Strength, 28 Days (MPa)	Source
Bagasse Ash	30	0.53	32.00	(Amin, 2011)

Table 5: Cement Replacement, Water to Cement Ratio (W/C) and Compressive Strength of Various Agro-Wastes for High Strength Concrete.

Agro-waste	Cement Replacement (%)	w/c ratio (%)	Compressive strength, 28 Days (MPa)	Design Strength, (MPa)	Source
Bagasse Ash	10	0.30	65	65	(Rukzon and Chindaprasirt, 2012)
	20	0.30	67		
	30	0.30	68		

4.2. NATURAL AGGREGATES / GRAVELS

The importance of using the right type and quality of aggregates cannot be overemphasized. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm (0.2 in.). Coarse aggregates consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm (0.2 in.) and generally between 9.5 mm and 37.5 mm (3/8 in. and 11/2 in.). Some natural aggregate deposits, called pit-run gravel, consist of gravel and sand that can be readily used in concrete after minimal processing. Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed. Crushed stone is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. Crushed air-cooled blast-furnace slag is also used as fine or coarse aggregate. The aggregates are usually washed and graded at the pit or plant. Some variation in the type, quality, cleanliness, grading, moisture content, and other properties is expected. Close to half of the coarse aggregates used in Portland cement concrete in North America are gravels; most of the remainder are crushed stones (ASTM C 637, C 638 and Guidelines for Affordable Housing in Partnership, Ministry of Housing and Urban Poverty Alleviation, GOI, 2009).

Maximum size of aggregate affects the workability and strength of concrete. It also influences the water demand for getting a certain workability and fine aggregate content required for achieving a cohesive mix. For a given weight, higher the maximum size of aggregate, lower is the surface area of coarse aggregates and vice versa. As maximum size of coarse aggregate from a mix reduces surface area of coarse aggregate required in a mix increases. Higher the surface area, greater is the water demand to coat the particles and generate workability. Smaller maximum size of coarse aggregate will require greater fine aggregate content to coat particles and maintain cohesiveness of concrete mix. Hence 40 mm down coarse aggregate will require much less water than 20 mm down aggregate. In other words for the same workability, 40mm down aggregate will have lower water/cement ratio, thus higher strength when compared to 20mm down aggregate. Because of its lower water demand, advantage of higher maximum size of coarse aggregate can be taken to lower the cement consumption. Maximum size of aggregate is often restricted by clear cover and minimum distance between the reinforcement bars. Maximum size of coarse aggregate should be 5 mm less than clear cover or minimum distance between the reinforcement bars, so that the aggregates can pass through the reinforcement in congested areas, to produce dense and homogenous concrete. It is advantageous to use greater maximum size of coarse aggregate for concrete grades up to M 35 where mortar failure is predominant. Lower water/cement ratio will mean higher strength of mortar and will result in higher strength of concrete. However, for concrete grades above M40, bond failure becomes predominant. Higher maximum size of aggregate, which will have lower area of contact with cement mortar paste, will fail earlier because of bond failure. Hence for higher grades of concrete (M40 and higher) it is advantageous to use lower maximum size of aggregate to prevent bond failure (ASTM C 637, C 638 and Guidelines for Affordable Housing in Partnership, Ministry of Housing & Urban Poverty Alleviation, GOI, 2009).

4.3. BAMBOO BASED PRODUCTS

Bamboo has a long and well established tradition for being used as a construction material throughout the tropical and sub-tropical regions of the world (Rahman *et al.*, 2011). With the rising global concern, bamboo is a critical resource as it is very efficient in sequestering carbon and helps in reduction of Green House gas emissions. In the modern context when forest cover is fast depleting and availability of wood is increasingly becoming scarce, the research and development undertaken in past few decades have established and amply demonstrated that bamboo could be a viable substitute of wood and several other traditional materials for housing and building construction sector and several infrastructure works. Its use through industrial processing have shown a high potential for production of composite materials and components which are cost-effective and can be successfully utilised for structural and non-structural applications in construction of housing and buildings (Asamoah and Owusu, 2011; Mahzuz *et al.*, 2011). Main characteristic features, which make bamboo as a potential building material, are its high tensile strength and very good weight to strength ratio. The strength-weight ratio of bamboo also supports its use as a highly resilient material against forces created by high velocity winds and earthquakes. Above all bamboo is renewable raw material resource from agro-forestry and if properly treated and industrially processed, components made by bamboo can have a reasonable life of 30 to 40 years. Various uses and applications in building construction have established bamboo as an environment-friendly, energy-efficient and cost-effective construction material. Bamboo can be used for shutters of door and windows, flooring, roofing sheets and shuttering & scaffolding. Bamboo flooring, bamboo roofing and bamboo board are developed interior designing material developed by using modern scientific methods from superior quality bamboo. Bamboo flooring is an attractive alternative to wood or laminate flooring (BMTPC).

4.4. FIBREBOARDS / PARTICLEBOARD / THERMAL INSULATOR

Bagasse can be made into soft boards, medium density fibreboards or particleboards, as well as high density hardboards. It can be upgraded by bonding with phenolic resin, producing boards and panels that are strong, durable, heat and moisture resistant, light weight, and easily transportable. Bagasse-based thermal insulation shows thermal conductivity in the range 0.047 – 0.050 W/mK (Pappu *et al.*, 2007).

Table 6: Physico-Mechanical Properties of Particle Insulation Board Made from SBA

Agro-Waste	Density (Kg/m3)	Thermal Conductivity (W/mK)	Source
Bagasse	90-140	0.047-0.050	(Krishpersad, 2006)

Pitched roof is proposed for the construction as it reduces heat gain due to radiation, in turn reduces cooling load. Considering the need for developing alternate eco- friendly, energy efficient and cost effective roofing sheets, building materials and technology promotion council (BMTPC) and Indian plywood industries research and training institute (IPIRTI) had jointly developed a technology for manufacturing bamboo mat corrugated sheets (BMCSs). These sheets were found to be resistant to water, fire, decay, termites, insects, etc. They were light but strong and possess high resilience and offer better thermal comforts (BMTPC). The pitched roof technology along with bamboo truss is suitable for the selected climatic condition. False ceiling of bagasse-cement panels is provided to the pitched roof of EWS dwelling.

4.5. WATER AND ENERGY MANAGEMENT TECHNIQUES

Community based roof top rainwater harvesting system shall be recommended for the collection and storage of rain water for flushing and gardening purpose. The design criterion mainly depends on the roof area and maximum average precipitation of that area for one day. According to EA and UKWIR, 1996 rainwater harvesting appears to be relatively more pragmatic and cost-effective option compared to grey water recycling. BSRIA, 1998 has investigated the impact of low water consuming devices and made a scenario-based assessment of potential savings in water and cost in various types of buildings. The study showed the saving potential of up to 24% as compared current consumption. This reduction saves not only on water supply costs but also on water treatment costs. Solar based water heating system along with solar lighting and cooling system shall be implemented to save the energy.

5. RESULTS AND DISCUSSION

In order to provide the techno-economic feasible solution for EWS housing scheme several green materials and techniques were scientifically examined and recommended over the study location. The optimal planning for the multiple EWS dwelling units have been demonstrated with the concept of common wall system that itself saves 50% masonry cost. Generally carbon emission is often a by-product of energy consumption; each clay brick fired with fossil fuel conservatively releases 0.4250 kg of carbon dioxide greenhouse gas into the atmosphere. The recommended SBA brick releases 0.1667 kg of carbon dioxide greenhouse gas which intern results in 2/3rd of emission reduction as compared to conventional burnt clay bricks. Along with SBA bricks the wall thickness of external wall can be modified from 9” to 6” as the compressive strength is much significant compared to clay bricks. Utilization of 6” smart SBA bricks saves around 33% of production material as well as the embodied energy and makes the masonry more economical. The recommended SBA had a potential to replace 30% of cement from all grades of mortars and concretes required for EWS housing. Proper mix & structural design also saves the cement consumption from concrete. The 20 mm down crushed aggregate from the concrete is replaced by 40 mm down locally available natural/rounded aggregates ensures minimum 20% of cement savings. The recommended alternate roofing of bamboo over the conventional RCC slab saves the entire carbon emission of reinforcement steel, cement and aggregates. The extensive use of bamboo products like bamboo roof, bamboo flooring and bamboo shutters for door and window makes the building more economical and energy efficient. The thermal insulation behaviour of SBA ceiling panel makes the built environment pleasant and saves the additional energy required for cooling. Community based Rain water harvesting System for flushing and gardening makes the dwelling unit self sustainable and saves equal amount potable water. Implementation of centralized PV solar energy system for room lighting (Solar LED lamp) and cooling (Ceiling Mounted Solar Fan) purpose saves the conventional electrical energy and makes the dwelling unit energy efficient.

6. CONCLUSIONS

Collective housing schemes incorporating raw or treated local building materials along with appropriate water and energy management techniques have the potential to provide climatically and socially viable, energy efficient, sustainable and affordable housing to the economically weaker section of the society.

Following conclusion are drawn for the suggested EWS housing scheme.

- SBA masonry products are light weight, thermally insulated, energy efficient and save 40-60% cost of masonry construction.
- Use of SBA as cement and sand replacement saves around 30% cost and carbon emission from masonry and concrete.
- Use of maximum size of locally available natural/rounded/crushed aggregates saves up to 20% of cement from concrete making the EWS housing more economical and energy efficient.
- Use of treated bamboo products in EWS housing schemes makes the building affordable.
- Suitably designed community roof top rainwater harvesting system and ultra low flow fixtures saves up to 50% of potable water.
- Climatically suitable alternate solar energy gadgets save electrical energy and makes EWS housing energy efficient.

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