Sustainable building technologies

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The paper addresses certain issues pertaining to the energy, environment, alternative building technologies and sustainable building construction. Brief history of developments in building materials is discussed. Energy consumption in manufacture and transportation of some common and alternative building materials and the implications on environment are presented. Brief details of some of the energy-efficient alternative building technologies developed by ASTRA are provided. Impacts of alternative building technologies on energy and environment are discussed. Some thoughts about utilizing industrial and mine wastes as well as recycling of building wastes for meeting the demand for buildings in a sustainable fashion have also been presented.

BUILDING materials and technologies, and building practices have evolved through ages. Housing and building conditions reflect the living standards of a society. Stones, mud, thatch/leaves and timber represent the earliest building materials used for the construction of dwellings. Hardly any energy is spent in manufacturing and use of these natural materials for construction. Durability of the materials, directly derived from natural materials like soil, thatch/leaves, timber, etc. is questionable. Quest for durable building materials is an ongoing phenomenon ever since man started construction activity. Brick burning represents one of the earliest examples of using energy (other than animate energy) to manufacture durable building materials from the soil/earth. Firewood was the main source of energy for burning bricks. Use of metal products represents the next energy consuming, manufactured material for the construction, after bricks. Then comes the manufacture of lime and lime-based products. Burnt bricks, metal products and lime are the manufactured materials (using external energy sources) commonly used for construction by our ancestors for a very long period of time.

Discovery of natural inorganic binders like pozzolanic materials lead to the use of lime-pozzolana (LP) cement for construction purposes. Experience of using LP cement paved the way for the invention of Portland cement in 1824. Portland cement and steel brought revolutionary changes in the construction practices from early part of 20th century. Then plastics and plastic products entered the construction industry. Chronological sequence of developments in building materials and products is listed in Table 1.

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Bricks, cement, steel, aluminium, plastic products, paints, polished stone, ceramic products, etc. are the commonly used materials of construction today. These materials are energy intensive and are transported over large distances before being used for construction. The following points require attention, regarding the use of modern building materials: Energy consumed in the manufacturing processes – energy intensity; Problems of long distance transportation; Natural resources and raw materials consumed; Recycling and safe disposal; Impact on environment, and Long-term sustainability.

Thus the issues related to energy expenditure, recycling, biodegradable, environmental and sustainability with respect to future demand need to be addressed during the manufacture and use of any new building material.

Some issues on energy, environment, sustainable construction and buildings

Indian construction industry is one of the largest in terms of economic expenditure, volume of raw materials/natural resources consumed, volume of materials and products manufactured, employment generated, environmental impacts, etc. Large variety of materials are manufactured and consumed in the construction industry. Production levels and energy expenditure of some of the building materials consumed in bulk quantities are given in Table 2.

Total energy expenditure on bricks, cement aluminium and structural steel consumed in bulk quantities is 1684×10^6 GJ per annum. It has been estimated that 22% of green house gas (GHG) emissions is contributed by the construction sector in India[1]. There is an ever-increasing demand for building materials. For example demand for

Table 1. Historical development in building materials

Material	Period
Mud, stones, wood/thatch	Prior 8000 BC
Sun dried bricks	6000 BC
Pottery products	4000–8000 BC
Burnt bricks	4000 BC
Lime	3000 BC
Glass	1300 BC
Iron products	1350 BC
Lime-pozzolana cement	300 BC–476 AD
Aluminium	1808 AD
Portland cement	1824 AD
Plastics	1862

Table 2. Volume and energy consumption of building materials in India (2003)

Material	Volume of materials manufactured per annum (2000)	Thermal energy (MJ per kg)	Total energy (GJ)
Bricks	150×10^9 Nos	1.40	630×10^6
Cement	96×10^6 tonnes	4.20	403×10^6
Aluminium	0.80×10^6 tonnes	236.8	189×10^6
Structural steel	11×10^6 tonnes	42.0	462×10^6

houses has doubled in about two decades from 1980 (Figure 1)[2]. Projected demand for the building materials like bricks, steel and cement consumed in bulk quantities is given in Table 3. Compounded growth rates of 2.5%, 5% and 5% has been assumed for bricks, steel and cement respectively to compute the projected demand. In case of brick-making activity, at present topsoil equivalent of 300 mm from 100,000 hectares (1000 sq km) of fertile land, 22×10^6 tonnes of coal and 10×10^6 tonnes of biomass are consumed annually. We have an arable land area of 1.62×10^6 sq km comprising alluvial soils, black soil, red soil, laterite soil and desert soil. Alluvial, laterite and red soils are suitable for brick making. Area under the soils suitable for brick making may not exceed 50% of the arable land. Brick-making activity to meet the present and future demand can result in consuming the 300 mm depth fertile topsoil of arable land in about 90 years (assuming 2.5% compounded growth rate). Similarly the pressure on raw materials like limestone to manufacture cement and energy requirements to produce these materials has to be addressed.

Production of building materials has slowly and steadily moved from highly decentralized and labour-intensive methods and processes to centralized, machine-dependent industry mode. Centralized mode of production necessitates hauling of raw materials and distribution of finished materials over great distances. These activities again require expenditure of fossil fuels for transportation. Transportation of raw and finished building materials is another key issue that can contribute to cost of materials, increased energy requirements and environmental issues. Energy (fossil fuel energy) spent in transportation of some of these building materials using trucks is given in Table 4. Sustainability of the present mode of production, consumption and distribution of building materials and currently adopted construction practices is questionable.

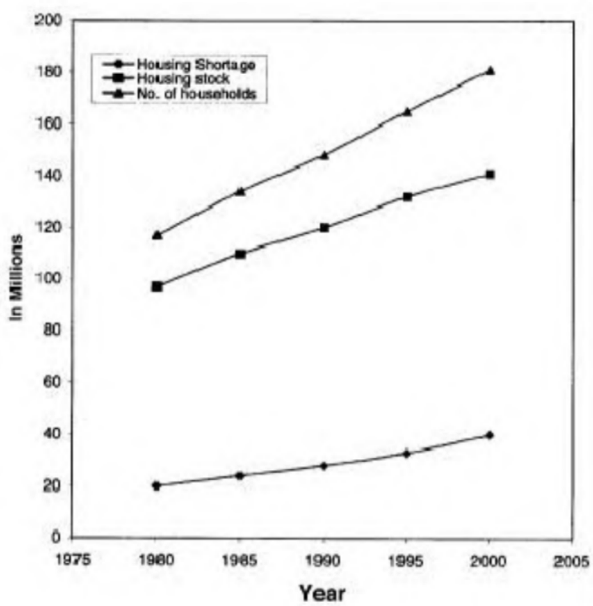

Figure 1. Housing demand and existing housing stock.

Table 3. Projected demand for building materials

Material	2000	2020
Bricks (Nos)	150×10^9	246×10^9
Structural steel (tonnes)	11×10^6	30×10^6
Cement (tonnes)	96×10^6	255×10^6

Table 4. Energy in transportation of building materials

Building material	Unit	Energy in transportation for 100 km (MJ)
Bricks	m^3	200
Sand	m^3	175
Cement	Tonne	100
Steel	Tonne	100

Need for sustainable alternatives

Steel, cement, glass, aluminium, plastics, bricks, etc. are energy-intensive materials, commonly used for building construction. Generally these materials are transported over great distances. Extensive use of these materials can drain the energy resources and adversely affect the environment. On the other hand, it is difficult to meet the ever-growing demand for buildings by adopting only energy-efficient traditional materials (like mud, thatch, timber, etc.) and construction methods. Hence, there is a need for optimum utilization of available energy resources and raw materials to produce simple, energy efficient, environment friendly and sustainable building alternatives and techniques to satisfy the increasing demand for buildings. Some of the guiding principles in developing the sustainable alternative building technologies can be summarized as follows: Energy conservation; Minimize the use of high energy materials; Concern for environment, environment-friendly technologies; Minimize transportation and maximize the use of local materials and resources; Decentralized production and maximum use of local skills; Utilization of industrial and mine wastes for the production of building materials; Recycling of building wastes, and Use of renewable energy sources.

Building technologies manufactured by meeting these principles could become sustainable and facilitate sharing the resources especially energy resources more efficiently, causing minimum damage to the environment.

ASTRA's initiatives and developments in sustainable building technologies

Centre for ASTRA (Application of Science and Technology for Rural Areas) was formed in 1974 at Indian Institute of Science (IISc), Bangalore, to cater to developing technologies for sustainable development. Recently, this centre has been renamed as 'Centre for Sustainable Technologies'. Developing environment friendly, energy efficient, simple and sustainable building technologies utilizing maximum local resources and skills, is one of the thrust areas of ASTRA's activities. R&D and dissemination of building technologies became an interdisciplinary work, where the Department of Civil Engineering actively pursued this work since over 2.5 decades of time. Large number of building technologies were developed and successfully disseminated. ASTRA's approach to develop sustainable building technologies was not confined to laboratory work. Field trials and laboratory work went hand in hand to develop viable technologies. ASTRA's efforts in alternative building technologies since 1976 on issues of R&D, dissemination, training and establishing mechanisms for spreading the technologies and the recent developments are given in Table 5. The table indicates that considerable amount of time has been spent initially at the Ungra Extension Centre (UEC) in field experimentation of building technologies initially. There was a need for some buildings at UEC for carrying out other activities of ASTRA and this need had thrown up an open ground for the buildings research group to experiment. This opportunity gave scope for experimenting and monitoring long-term performance over a period of several years. Important lessons on building technologies were learnt during the initial period. A large number of viable alternative building technologies have been developed and disseminated over a period of 2.5 decades. Some of these building technologies are: Stabilized mud blocks, Steam cured blocks, Fine concrete blocks, Rammed earth blocks, Mud concrete blocks, Lime–Pozzolana cements, Soil-lime

Table 5. Sequence of developments in alternative building technologies at ASTRA

R&D work/technology or concept developed	Period	Demonstration of technology or concept/technology transfer/manpower training
Soil–cement block, use of CINVA RAM press and ferrocement roof	1976	Construction of biogas laboratory, IISc campus
Compacted pure mud blocks, part stabilized blocks, development of ASTRAM block machine, soil compaction, soil stabilization and durability studies: Bamboo–polythene–stabilized soil roof LP mortar, lime production	1977–1982	Construction of demonstration buildings at UEC and surrounding villages and central school buildings at IISc Bangalore, field testing of soil block machines
Pozzolana cement, lime–soil plaster Lime stabilized blocks and steam curing Ferrocement, RB panel roofs Prefabricated beam and panel roofs Soil–cement blocks and masonry studies Developing new soil block press	1983–1990	Pozzolana kilns, LP cement field trials, lime soil plaster Commercial production of soil block machines Demo of 2-storey soil block buildings, ferrocement roofs
Developing precast roofing systems, filler slab roofs and ferroconrete tile roofs Studies on long-term behaviour of stabilized blocks and quality assessment methods, and stabilized block masonry Developing steam-curing techniques for lime-stabilized block technology	1991–1995	Training professionals in alternative building technologies for effective dissemination Construction of about 1500 buildings in private sector using stabilized blocks Small scale LP cement plant
Studies on fly ash and industrial wastes for steam cured block production, design and development of small-scale steam cured block production system Studies on solar passive architecture Investigations on properties of blocks using ash modified soils Studies on composite mortars and stabilized block masonry Studies on energy in buildings	1996–2000	Construction of a large number of buildings using alternative techniques in private sector Construction of 3-storeyed building using steam-cured blocks at IISc, Bangalore Self-financing courses on alternative building method for architects and engineers
Developing earthquake-resistant building techniques using the concept of containment reinforcement Developing building materials from mining wastes Studies on composite mortars Development roofing tiles from industrial and mine wastes	2001–2003	Construction of > 5000 earthquake-resistant buildings using stabilised blocks in Gujarat state Technology transfer for the production of steam cured blocks

plaster, Composite mortars for masonry, Composite beam and panel roofs, Reinforced brickwork/tile-work roof, Ferrocement and ferroconcrete roofing systems, Unreinforced masonry vaults and domes, Ribbed slab construction, Filler slab roofs, Rammed earth foundations, Reinforced block-work lintels and precast chejjas, Solar passive cooling techniques and Containment reinforcement for earthquake-resistant masonry.

A large number of buildings (> 12,000) have been built using these alternative building technologies, (Figure 2). Figures 3 to 5 show some of the buildings built using sustainable building technologies. Salient features of some of these technologies are highlighted below. More information on the alternative building technologies developed by ASTRA can be found in references 3–32.

Stabilized mud blocks

These are dense solid blocks compacted using a machine with a mixture of soil, sand, stabilizer (cement/lime) and water. After 28 days curing, the stabilized mud blocks (SMB) are used for wall construction. Two block sizes (305 × 143 × 100 mm and 230 × 190 × 100 mm) have been standardized. These blocks are 2.5 to 2.8 times bigger in volume when compared with locally available conventional burnt clay bricks. Compressive strength of the block greatly depends upon the soil composition, density of the block and percentage of stabilizer (cement/lime). Sandy soils with 7% cement can yield blocks having wet compressive strength of 3–4 MPa. Higher strength for the block can be obtained by increasing the quantity of stabi-

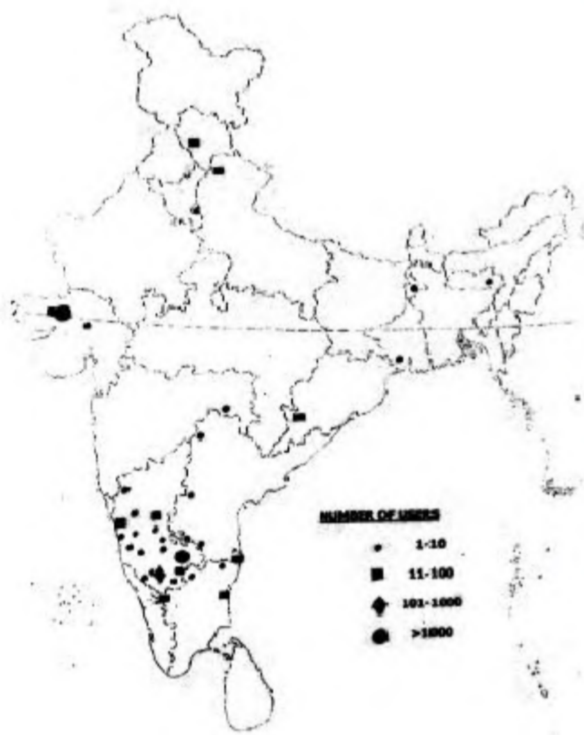

Figure 2. Spread of alternative building technologies in India.

Figure 3. ASTRA office complex (stabilized mud blocks walls and precast beam panel roofs) 1985–86.

Figure 4. Soil–cement block residential building, Bangalore.

Figure 5. Stabilized mud block residential building, Himachal Pradesh.

lizer. Major advantages of SMB are: (a) energy efficient, do not require burning, 70% energy saving when compared to burnt bricks, (b) economical, 20–40% savings in cost when compared to brick masonry, (c) plastering can be eliminated, and (d) better block finish and aesthetically pleasing appearance. Figure 6 shows production of SMB using a manual press.

Fine concrete blocks

The concept and process is similar to the one employed for SMB production except that instead of soil, some fines are added to the mix. Fines like fly ash, polished stone waste, etc. are mixed with either sand or stone quarry dust, along with cement and water. The mixture is then compacted into blocks using a machine (manual or mechanized) and then cured for 28 days. Fines (like fly ash, polished stone waste, etc.) in the range of 20–25% by weight of sand can result in a good grading for the mixture and with 6–7% cement good quality block with wet strength > 3 MPa can be achieved. In addition to fines, about 10% red loamy soil addition can result in good natural mud colour for the block. The major advantage of fine concrete block is the utilization of waste products like fly ash, polished stone waste, mine wastes, etc. which otherwise cause pollution and environmental degradation.

Steam cured blocks

A mixture of lime, industrial waste products like fly ash or expansive soils like black cotton soil and sand can be compacted into a high-density block. Lime reacts with fly ash/clay minerals forming water insoluble bonds imparting strength to the block. These reactions are slow at ambient temperatures (~ 30°C) and hence steam curing for about 10 h at 80°C can accelerate these reactions leading to high strength for the block. The process involves: (a) mixing of raw materials like lime, cement, fly ash or black cotton soil, sand and water in a mixer, (b) converting the mixture into a dense block using soil block press, (c) Stacking the blocks in a steam chamber and steam curing for 10–12 h. Blocks of any convenient size can be manufactured. Compressive strength of the block depends upon the composition of the mix, density of the block and percentage of stabilizer (cement/lime). A combination like 25% fly ash, 6% lime and 2% cement can yield blocks having wet compressive strength of > 6 MPa. This kind of strength will be sufficient to construct 3–4 storey load-bearing buildings with spans in the range of 3–4 m. Blocks of higher strength can be easily achieved by adjusting the mix proportions. It should be noted here that the block quality is much superior when compared to local burnt bricks and SMB. Advantages of using these blocks are: (i) Ideal process for a small-scale or cottage industry, (ii) utilization of industrial waste products like fly ash and problematic soils like black cotton soil and high clay soils, (iii) energy efficient and environment friendly, and (iv) higher strength for the blocks.

Composite beam and panel roofs

This concept exploits the efficiency of beam and slab construction. The roofing system consists of partially precast or cast-*in-situ* ribs/beams at certain spacing covered with panels. A typical composite reinforced tile-work panel roof is shown in Figure 7. The panels and beams are connected through shear connectors to achieve composite action. Varieties of options are available for the beams (precast reinforced concrete, rolled steel sections, trussed steel members, timber, steel, concrete composite, etc.) and panels (precast concrete, reinforced brickwork, stone slabs, hollow hourdi tile, reinforced SMB panel, etc.). The profile for the panels could be curved, folded plate or flat. Use of curved shape panels results in a composite jack-arch roof. The beam cross section can also be adjusted to minimize the material consumption. The major advantages of this type of roofing system are: (i) possibility of

Figure 6. Production stabilized mud blocks using a manual press.

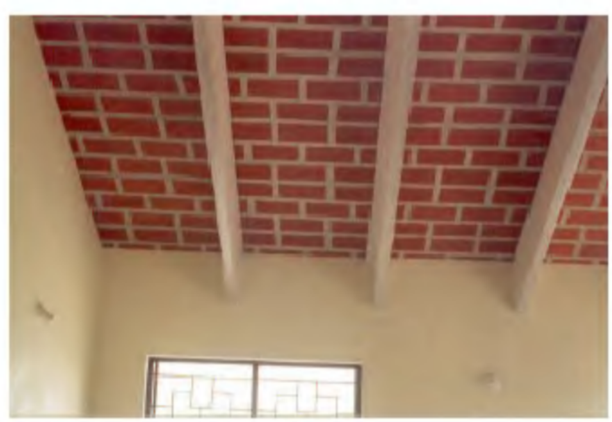

Figure 7. Composite reinforced tile-work panel roof.

prefabrication and quick erection, (ii) better quality assurance due to prefabrication, (iii) savings in volume of materials and hence cost effectiveness, and (iv) possibility of using hollow panels to increase thermal comfort.

Filler slab roofs

Filler slab roofs are basically solid reinforced concrete slabs with partial replacement of the concrete in the tension zone by a filler material. The filler material could be cheaper or cheaper and lighter. A number of alternative materials can be thought of: (a) brick or brick panel, (b) Mangalore tile, (c) stabilized mud block, (d) hollow concrete block, (e) hollow clay tile/block, etc. Figure 8 shows ceiling of a typical filler slab roof using SMB filler. Quantity of concrete in the tension zone of the slab that can be replaced by a filler material depends upon the shape of the filler material and the thickness of the solid slab. For example in a solid concrete slab of 125 mm thickness, a filler block of 60–70 mm thickness can be easily accommodated. In a typical situation, by using a stabilized mud block, 25% of the concrete can be replaced by a material, which costs one third the cost of concrete. This means that 15–20% of the cost of concrete can be saved by this operation.

Unreinforced masonry vaulted roofs

Vault and dome constructions using unreinforced masonry are known in India for more than six centuries. Due to the advent of steel and reinforced concrete these techniques were abandoned during the British period. Because of the advantages like aesthetics, cost, durability and savings in energy, vaults and dome constructions have been revived. Recent work and expertise developed at IISc has shown that unreinforced masonry vaults can be constructed using the concept of moving formwork. A metal formwork of about 1 m width defining the vault shape can be repetitively used to construct such vaults. Various shapes can be adopted for the vaults. Catenary-shaped vault is the most efficient. The thickness of the vault is dependent on the span of the vault. A vault thickness of about 100 mm can be used for spans up to 4 m. It is also possible to construct the intersecting vaults as well as hipped vaults.

Figure 8. Ceiling of a typical filler slab roof using stabilized mud block filler.

Lime–pozzolana cement

The Lime–pozzolana (LP) cement is made by mixing calcium hydroxide (lime) and pozzolana in the ratio of 1 : 1.5 or 1 : 2. Secondary grade lime available locally in many areas can also be used by adjusting the mix proportions. Variety of pozzolonas like burnt clay pozzolona, rice husk ash, good quality fly ash or combination of pozzolonas can be used. Ideally lime and pozzolana have to be interground in a ball mill. But such mixtures have poor shelf life (15 days). Volume proportions of 1 : 3 or 1 : 4 (LP cement : sand) can be used. The strength of the mortar mix can be easily manipulated by adjusting the proportions of various materials. LP cements are low energy-consuming materials and can be used for a majority of secondary applications except for reinforced concrete works.

Containment reinforcement for earthquake-resistant masonry structures

History of earthquake damages indicates that greater damage to buildings and loss of life take place in one- and two-storeyed masonry buildings. Unreinforced masonry walls have poor flexure strength and very little ductility. Earthquake ground motions generally lead to out of plane bending failure of unreinforced masonry walls. Reinforcing such walls properly can prevent out of plane failures and impart ductility to the wall. An innovative way of providing vertical reinforcement to masonry wall has been developed, which is called 'containment reinforcement'. The method consists of wrapping the thin reinforcing bars in vertical direction on both the faces of the wall and are held together by ties provided in the bed joints. Containment reinforcement is anchored to RC bands at roof and plinth level. Such reinforcement is provided at 1 m intervals along the length of the wall and at door and window jambs. This new technique has been validated through a large number of shock-table studies on scale models. This technique is simple and cost effective. About 1000 buildings have been built using SMB walls and containment reinforcement in Gujarat state after the Bhuj earthquake.

Energy in common and alternative building technologies and buildings

Energy consumption in buildings can take place in two ways: (i) energy capital that goes into production and transportation of building materials and assembling of the building (embodied energy), and (ii) energy for the maintenance/servicing of a building during its useful life. The second one greatly depends on the climatic variations in a particular region. The first one is a one-time investment, which can vary over wide limits depending upon choice of building materials and techniques. Energy in conventional (common) and alternative building technologies and buildings, their implications on sustainable building construction practices are discussed in the following sections.

Table 6 gives the details of energy content in various types of common and alternative walling and roofing systems. The table indicates that: (a) Energy content of SMB masonry and steam-cured block masonry are about one fourth and two thirds of that required for the commonly used burnt brick masonry respectively, (b) Alternative roofing systems like SMB filler slab, composite panel roof, ribbed slab roof, etc. can be used in place of conventional reinforced concrete roof saving about 20–40% of energy, and (c) Ferroconcrete tile roof consumes 30% less energy when compared to conventional Mangalore tile roof. Thus it is clear that use of alternative building technologies results in reduction of considerable amount of embodied energy in building systems.

Impact of alternative building technologies

The energy values of different components of buildings discussed earlier can be integrated into computation of total embodied energy of a building. Total embodied energy of three types of buildings using conventional and alternative building systems is given in Table 7. Embodied energy is computed based on the actual measurements of quantities recorded while constructing these buildings. Energy per 100 m^2 of built-up area of the buildings is considered for the purposes of comparison. A multi-storeyed reinforced concrete framed structure building is most commonly used for building flats in urban areas. Also, it is very common to find 2–3-storeyed load-bearing brick and concrete slab roof buildings. The multi-storeyed building consumes highest amount of energy at 4.21 GJ per m^2 of built-up area, whereas the energy consumed by the load bearing conventional 2-storeyed brickwork building is 2.92 GJ/m^2 (30% less than that used by multi-storeyed framed structure building). Two-storeyed building using alternative building materials like SMB walls, SMB filler slab roof, etc. is highly energy efficient. The energy consumed by this building is 1.61 GJ/m^2, which is about 40% and 55% of that consumed by multi-storeyed building and conventional brick wall building respectively. This clearly indicates that use of alternative building technologies results in considerable amount of reduction (~ 50%) in embodied energy, thus paving the way for efficient utilization of energy resources and simultaneously reducing GHG emissions, thereby protecting the environment.

Major features/impacts of the alternative building technologies discussed in the previous sections can be highlighted as follows:

- Energy efficient, consuming less than half of the energy required for conventional building methods leading to energy conservation
- Techniques are simple and employ maximum local resources and skills
- Decentralized production systems and small-scale operations that generate local employment
- Reduce cost and energy involved in transportation of building products.

Table 6. Embodied energy in various walling and roofing systems (after Reddy and Jagadish)[13]

Building element	Unit	Energy per unit (MJ)
Walling systems		
Burnt brick masonry	m^3	2141
SMB masonry	m^3	550
Steam cured block masonry	m^3	1396
Roofing systems (for 3.6 m span)		
Reinforced concrete slab	m^2	730
SMB filler slab	m^2	590
Composite panel roof	m^2	560
Ribbed slab roof	m^2	490
Brick masonry vault roof	m^2	575
SMB masonry vault roof	m^2	418
Mangalore tile roof	m^2	227
Ferroconcrete tile roof	m^2	158

Use of industrial/mine wastes and recycling of building wastes

Need for building materials will grow at an alarming rate in future, in order to meet the demand for new buildings. Manufacturing of building materials like bricks/blocks,

Table 7. Total embodied energy in a building (after Reddy and Jagadish)[13]

Building and specifications	Number of storeys	Total built-up area of the building (m^2)	Total embodied energy per 100 m^2 of built-up area (GJ)	Equivalent amount of coal per 100 m^2 (tonnes)
Reinforced concrete framed structure with infilled burnt brick masonry walls	8	5120	421	21
Load-bearing brick masonry walls, reinforced concrete slab roof, mosaic tile floor	2	149.5	292	15
SMB load-bearing walls, SMB filler slab roof, terracotta tile floor finish	2	160.5	161	8

cement, steel, aggregates, etc. consumed in bulk quantities, puts great pressure on natural resources (raw materials) and energy requirements. As already mentioned, the top 300 mm layer of fertile soil will be used for brick manufacture in due course of time, if we do not use alternative materials for bricks. In order to sustain the construction activity in future, it becomes inevitable to explore the following possibilities:

- Use of energy-efficient alternative building technologies
- Efficient utilization of natural resources/raw materials
- Optimal designs and planning practices
- Recycling of building wastes
- Utilization of industrial/mine wastes for the manufacture of building materials
- Adopting energy-efficient process in manufacturing processes of building materials
- Use of renewable energy sources and technologies.

Majority of the large-scale industries and thermal power plants generate solid wastes in bulk quantities. Red-mud, coal ash, slag, fly ash, etc. represent such wastes *unutilized* for several decades. For example, $> 100 \times 10^6$ tonnes of fly ash is produced annually in India (from thermal power plants) and only 2–3% of it is being utilized. Similarly millions of tonnes of red-mud is stored near aluminium manufacturing units ($\sim 20 \times 10^6$ tonnes of red-mud is heaped into hillocks at the aluminium manufacturing unit at Belgaum in Karnataka state). Such huge heaps of wastes concentrated in certain specific localities cause environmental and pollution hazards. Such wastes can be utilized for the manufacture of bricks/blocks, substitute for fine aggregates in concrete, partial replacement of cement in concrete, lime–pozzolana cements, etc.

Huge quantities of solid wastes (generally known as mine tailings) are produced by the mining industries. Generally, mine tailings are accumulated in heaps near the mines resulting into huge hillocks. For example Bharat Gold Mines Limited at Kolar Gold Fields (KGF) has created 33×10^6 tonnes of tailings (which are non-toxic) heaped into 13 hillocks. Similarly, the iron-ore tailings of the Kudremukh Iron Ore Company in Karnataka, amounting to $\sim 150 \times 10^6$ tonnes are stored in huge dams created for collecting the iron-ore slurry washings. Coalmines, copper mines, etc. generate and store huge quantities of solid wastes.

There is a large scope for utilizing mine wastes for the manufacture of building materials and products. For example 33×10^6 tonnes of gold mine tailings at KGF can be converted into bricks/blocks, which can satisfy the demand for bricks at Bangalore city for the next 30 years or more. Similarly utilizing the 150×10^6 tonnes of iron ore tailings can meet the requirement of sand and bricks and blocks of Karnataka State for decades. Thus there is a great potential for utilizing industrial and mine wastes for the manufacture of building materials and products.

Reuse and recycling of demolished building wastes is another area/aspect of efficient utilization of materials and resources. Recycling of materials like steel, stone and timber from demolished structures takes place to some extent. But the recycling of bricks, concrete, aggregates, mortar, etc. is still not done in an organized fashion. Such materials can be crushed and processed to utilize them in new constructions.

Concluding remarks

Certain issues concerning embodied energy in buildings and its implications on environment and sustainability of currently used methods of construction are discussed in some detail. Construction industry contributes 22% of GHG emissions into the atmosphere. It is difficult to sustain the building activity in the long-term to meet the future demand for buildings by using the currently available energy-intensive materials and building techniques/technologies. Alternative building technologies developed by ASTRA are energy efficient and the embodied energy of buildings using these technologies is less than half of the energy consumed by conventional buildings. It becomes inevitable to steadily switch over to the use of energy-efficient building materials and technologies and devise methods and mechanisms to utilize industrial/mine wastes and recycling and reuse of building wastes for the manufacture of building materials and products for the sustainable construction practices.

Currently R&D efforts in developing sustainable building technologies are limited in the Indian context. There is a large scope for R&D efforts in developing alternative building technologies, addressing the following issues.

- Clear understanding of the sector-wise demand and growth of the Indian construction scenario.
- Estimating current building stock and the contribution of unorganized sector in manufacturing and supply of energy intensive building materials.
- Assessing the availability (regionwise) of local resources, raw materials/traditional materials for developing and manufacture of building products.
- Developing alternative building technologies to meet the region-specific needs/demands for buildings.

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