JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Feasibility of Cement Stabilized Earth Blocks as a Sustainable Construction Material in Western Ghats Regions of India

Aviral Singh, Prof. Shadab Saifi
M. Arch Student, Associative Professor,
Faculty of Architecture & Planning, AKTU, Lucknow, India.

Abstract: Our home is the Earth, where we spend our entire lives. Technological advancements have wreaked effects on our environment and polluted it severely. The increased demand for construction materials worldwide has resulted in significant natural resource use in the form of building materials. Overexploitation has increasingly resulted in shortcomings and higher prices to be paid for construction supplies. Traditional unfired earthen building materials were the most popular in previous communities. Due to its durability and other desirable properties such as low environmental impact, thermal insulation, and others, this traditional material has shown to be highly good for building constructions. Buildings from the Karnataka region of India built from earth blocks have been taken as cases to study their static behavior, reliability and durability strength in a moderate climate. The assessment of this material's relevance will help contribute to the green building industry and get into the mainstream of construction. Stabilized earth blocks represent an interesting alternative to the conventional bricks and are the need of the present and perhaps the most important one in future.

Keywords: Stabilized earth blocks, Conventional bricks, Overexploitation, Static behavior, Thermal insulation, Environmental impact, Building constructions.

I. INTRODUCTION

For almost ten thousand years, rammed earth construction has been practiced. Mud blockhouses have been discovered in Turkestan, Russia, dating from 9000 to 6000 BC. Assyrian rammed earth foundations have been discovered dating back to 5000 BC. Earth was employed as a building material in all ancient civilizations, not just for homes but also for holy structures. The 2300-year-old Great Wall of China was initially constructed entirely of rammed earth, with bricks and stones added later to give it the appearance of a stone wall. The increased demand for construction materials around the world has resulted in significant natural resource use in the form of building materials(Kariyawasam & Jayasinghe, 2016)(Kariyawasam & Jayasinghe, 2016). Overexploitation has increasingly resulted in shortcomings and higher prices to be paid for construction supplies. The realization of the causes behind this has resulted in a shift toward the development of sustainable construction materials that require significantly less energy in both manufacturing and operation(Kariyawasam & Jayasinghe, 2016). Stabilized rammed earth has been identified as one such material that can improve resource efficiency while lowering carbon emissions(Kariyawasam & Jayasinghe, 2016).

Sustainability is a blend of factors. It's not just a matter of society, the economy, or the environment. All of these areas collaborate towards a better quality of life and a single justified answer. That is why it is necessary to think about the "fundamentals" of all three sectors. There are a few buzzwords that have shaped the various industries on a consistent basis.

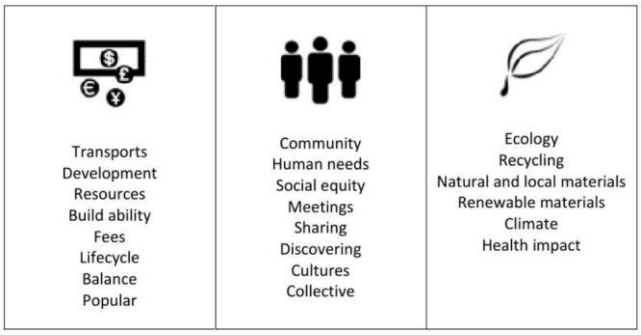


Figure 1 Approach to Sustainability
Figure 2 Different Sectors of Sustainability

Depending on what we are doing, we mostly spend our time in certain indoor types of space—for example- home to live, a job, a place for communication and etc. So since prehistoric time, man has summed up the spaces it colonized and thus have constructed different types of buildings - residential, ritual and public. Most of the famous early buildings were always built from

materials found in the surrounding areas, proceeding primarily from the ground. Materials used were earth (clay), wood, stone, leather from animals, straw and many more. Different corners of the earth have different types of geographic conditions like climate, soil, wind, water etc.

II. AIM & OBJECTIVE

This study aims assess CSEB as an alternative construction material in Western ghat regions of India by comparing the strength and energy of cement stabilized rammed earth blocks (CSEB) with that of commonly used burnt clay bricks. The study also focusses on the embodied energy and contribution to the operational energy of CSEB and outlining its various applications in various projects.

III. SUSTAINABILITY AND SUSTAINABLE MATERIALS

According to ancient religious beliefs, we are all descended from the ground. Everything in our environment is derived from the earth, and after a period of time, everything is changed back into the ground. And we must exert some effort in order to maintain the current state of our surroundings. Human activities have an impact on the environment. Some have a smaller influence, while others have a much larger one(Embodied Energy in Building Materials: What It Is and How to Calculate It | ArchDaily, n.d.). The building and construction sector is responsible for up to 30% of all greenhouse gas emissions, according to the United Nations Environment Program (UNEP). Gases such as CO2, CH4, N2O, O3, halocarbons, and water vapor are released during processing, mining, industrial operations, transportation, and the mixing of chemical products(Embodied Energy in Building Materials: What It Is and How to Calculate It | ArchDaily, n.d.). When these gases are released into the atmosphere, they absorb some of the solar radiation and redistribute it as radiation in the atmosphere, thus warming our planet(Embodied Energy in Building Materials: What It Is and How to Calculate It | ArchDaily, n.d.). The layer thickens as a large volume of gas is expelled every day, allowing solar radiation to enter and stay in the planet(Embodied Energy in Building Materials: What It Is and How to Calculate It | ArchDaily, n.d.). Today, this 'layer' has thickened to the point where humanity is beginning to suffer serious consequences, such as desertification, glacier melting, water scarcity, and the intensification of storms, hurricanes, and floods, all of which have altered ecosystems and reduced biodiversity(Embodied Energy in Building Materials: What It Is and How to Calculate It | ArchDaily, n.d.). The impact of all greenhouse gas emissions attributable to a substance during its life cycle is referred to as embodied energy or embodied carbon. Manufacturing, extraction, maintenance, construction, and disposal are all part of this cycle. Reinforced concrete, for example, has a phenomenally high embodied energy(Embodied Energy in Building Materials: What It Is and How to Calculate It | ArchDaily, n.d.). Large volumes of CO2 are emitted during the calcination step, when limestone is transformed into calcium oxide (quicklime), as well as during the burning of fossil fuels in furnaces, when making cement. When we consider the mining of sand and stone, the usage of iron for rebar, and its transportation to the construction site to be mixed in, we can see how each project decision affects the environment(Embodied Energy in Building Materials: What It Is and How to Calculate It | ArchDaily, n.d.). Other building materials, such as brick, plastic, and ceramic, also require a significant amount of energy to create since the minerals used in them must be mined and treated in an energy-intensive process(Embodied Energy in Building Materials: What It Is and How to Calculate It | ArchDaily, n.d.).

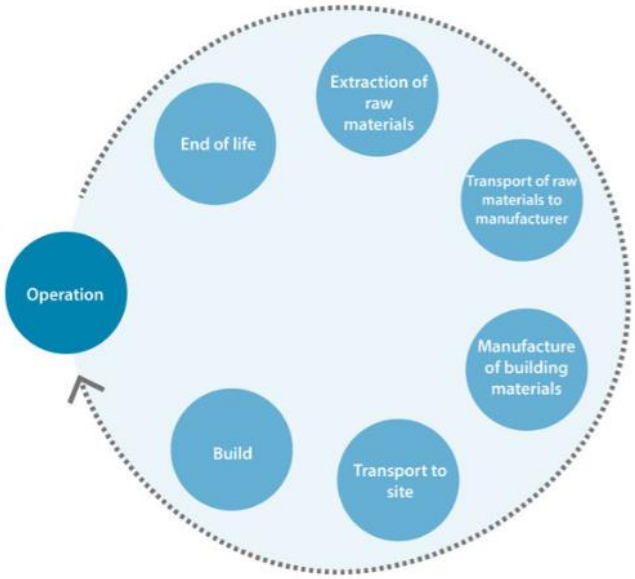


Figure 3 Lifecycle Analysis of a Material (Archdaily,2011)

IV. Earth construction

Earthen construction is one of the most cost-effective and widely used construction methods. The employment of earth construction technology is frequent in the construction of homes. Earth can also be used to construct other constructions such as stores, offices, stores, and warehouses(The 12 Techniques of Earth Construction (English) - TERRAVERSA, n.d.).Earthen structures can be found all over the world, and they use a range of techniques. These approaches surely evolved as a result of the diverse soil conditions and climates, as well as the various technology available to each culture at the time of formation(The 12 Techniques of Earth Construction (English) - TERRAVERSA, n.d.).Soils can be worked in three different ways depending on their hydration state: monolithic, unit-based, or mixed structures.

V. CEB and rammed earth (compressed)

Rammed Earth and Compressed Earth Blocks are two types of compressed earth processes; however they are fundamentally the same(The 12 Techniques of Earth Construction (English) - TERRAVERSA, n.d.). There are historic instances of Rammed Earth still standing today, a witness to its endurance and strength, and definitely one of the reasons it has been regarded as a legitimate building material by the current construction industry(The 12 Techniques of Earth Construction (English) - TERRAVERSA, n.d.). This method involves gradually moistening the soil with water to create an uniform damp mix, then layering it inside a stiff formwork and ramming it with a heavy device to remove air and enhance density and compressive strength(The 12 Techniques of Earth Construction (English) - TERRAVERSA, n.d.). Compressed Earth Blocks are made with Rammed Earth by making a homogeneous humid mix, but instead of ramming it into a formwork, the mix is poured into a mould as a substitute in a steel press and compressed manually or mechanically(The 12 Techniques of Earth Construction (English) - TERRAVERSA, n.d.). The earliest machines for compressing earth into bricks were invented in France in the 1800s, and the modern machines were invented in 1952 in Bogota, Columbia, by engineer Raul Ramirez, making compressed earth bricks one of the newest techniques in the 'wheel of earth construction(The 12 Techniques of Earth Construction (English) - TERRAVERSA, n.d.).

Figure 4 CSE Block Wall (Terraversa,2020)
Figure 5 CSE Blocks

Both Rammed Earth and Compressed Earth Blocks have achieved substantially higher compressive strength and water resistance than most other earth construction processes, making them viable challengers in the current building materials market.(The 12 Techniques of Earth Construction (English) - TERRAVERSA, n.d.).

Earth, undoubtedly is the oldest building material known. Even though building with earth once fell out of popularity when the modern building materials and methods were discovered, but then it gains its revival time following the energy crisis(Raseena et al., 2016). Moreover, growing concern and interest about environmental and ecological issue globally also increased the used of earth as a building material(Raseena et al., 2016). When compared to other building materials, CSEB had a variety of benefits. It increases the use of local materials and saves transportation costs because production takes place on-site, promotes the availability of decent housing for more people, and generates local economic activity rather than spending on imported supplies(Riza et al., 2010). Faster and easier construction methods resulted in fewer skilled workers being required, improved insulation and thermal properties, increased strength, reduced carbon emissions and embodied energy in the manufacturing phase, and produced extremely low waste that was easily disposed of, causing no direct environmental pollution throughout the life cycle(Riza et al., 2010).

Earth bricks also have the potential to absorb atmospheric moisture, resulting in a healthy atmosphere for occupants inside a building(Riza et al., 2010). Because the Earth is mostly subsoil, the topsoil can be used for agriculture. Building utilizing local materials employs locals and is more resilient in times of disaster(Riza et al., 2010). One of the disadvantages of employing earth as a construction material is its limited durability, which is directly proportional to its compressive strength(Riza et al., 2010). Because most soils lack the strength, dimensional stability, and durability essential for building construction in their native state. Soil stabilization is a technique for improving the natural durability and strength of soil. Mechanical stability, second, physical stabilization, and third, chemical stabilization are the three types of stabilizations(Riza et al., 2010)Brick can be classified in several ways. ASTM standard categorized brick as(Riza et al., 2010).

- Building brick (ASTM C 62),
- Facing brick (ASTM C 216),
- Hollow brick (ASTM C 652), and
- Thin veneer brick (ASTM C 1088)

Building bricks can be used in both load-bearing and non-load-bearing walls, as well as for insulation. Clay bricks, mortar bricks, fired or unfired bricks, and others are all types of brick(Riza et al., 2010). The production procedure of CSEB brick sets it

apart from traditional burnt bricks. For CSEB brick to obtain strength, it must be compacted using static, dynamic, or vibro-static processes, as well as the content of stabilizer added(Riza et al., 2010).

VI. Soil Suitability and Stabilization for CSEB

Not all soils, including CSEB, are suitable for earth construction. However, with a little knowledge and practise, many soils may be used to produce CSEB. Organic soils and topsoil should not be used(Auroville Institute, 2011). Identifying the qualities of a soil is necessary for producing high-quality products.

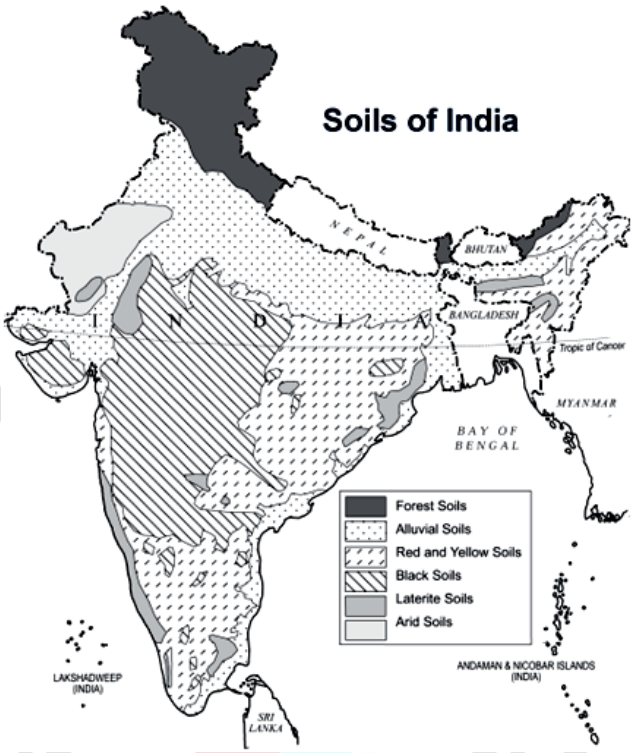


Figure 6 Soil Types of India

After a brief training, some simple sensitive analysis can be conducted. Sandy soils will benefit from cement stabilisation. Clayey soils will benefit from lime stabilisation(Auroville Institute, 2011). The CSEB stabiliser plays a significant role in the bonding of soil-stabilizer combinations(Riza et al., 2010). One of the main objectives of the stabilizing medium is to limit the soil's swelling qualities by building a solid framework with the soil mass, thereby increasing the strength and durability of the soil(Riza et al., 2010).The most extensively used stabiliser for ground stabilisation is Portland cement. Many studies have discovered that soils with a plasticity index of less than 15 are acceptable for cement stabilisation. Cement binder is often added at a rate of 4 to 10% of the dry weight of the soil(Riza et al., 2010). However, if the cement content exceeds 10%, CSEB brick production becomes uneconomical. Bricks with less than 5% cement are frequently too friable to handle easily(Riza et al., 2010). Cement can be used as a stabiliser in soils with a plasticity index of less than 15. Furthermore, lime is recommended as a stabiliser for soils with a plasticity index greater than 15 or clay content(Riza et al., 2010). To aid in the stabilisation process, lime can be added to the cement and clay mixture. Due to the presence of lime in cement and the presence of lime ascribed to the immediate reduction of plasticity, the lime-clay ratio will be raised is more apparent in soil lime mixes(Riza et al., 2010). When lime is introduced to clay soil, it is first absorbed by the clay mineral until with the addition of lime. Although the same trend occurs in soil-cement mixes, the immediate effect of change the soil's affinity for lime is established(Riza et al., 2010). However, call lime fixation, and a weighted amount of 1 to 3 percent lime is generally applied. The pozzolanic reaction that produces hydrated gel is aided by the addition of lime after lime fixation. This is a time-consuming technique in which strength is built up gradually over time(Riza et al., 2010).

Soil for cement stabilisation: it is more sandy than clayey	Gravel = 15%	Sand = 50%	Silt = 15%	Clay = 20%
Soil for lime stabilisation: it is more clayey than sandy	Gravel = 15%	Sand = 30%	Silt = 20%	Clay = 35%

VII. TYPES OF CSE BLOCKS

The development of CSEB proposes nowadays a wide range of products, from different size and shapes. To select the most adapted product to one's need, one should pay specially attention to these factors(Auroville Institute, 2011):

Module of the block	• It is the block size plus the mortar thickness. • To avoid wasting time on design calculations, choose a simple module in the decimal system. • Select the module with the thinnest mortar joint possible.
Possibilities of different wall thickness	• Which wall thickness can be achieved with easy bonds according to the module of a block? • A block's load bearing capacity can be determined by its thickness.
Area of the block	• The bigger it is, the weaker the block will be. A large area will require great compaction energy: • A manual press with 15 Tons capacity will not be able to compress properly more than 600 cm²
Plain, hollow or Interlocking blocks…?	• Each of them has different possibilities: ➢ Plain ones will be laid with a thick mortar (1 to 1.5 cm) ➢ Hollow ones will be laid with a thin mortar (0.5 to 1 cm) ➢ Interlocking blocks will require a thin mortar (0.5 cm), very special details and are meant for earthquake resistance.
Mold possibilities	• Whether a mould can do full size, 3/4 of half block. • In order to establish a good quality connection without breakage, these three sizes must be used.

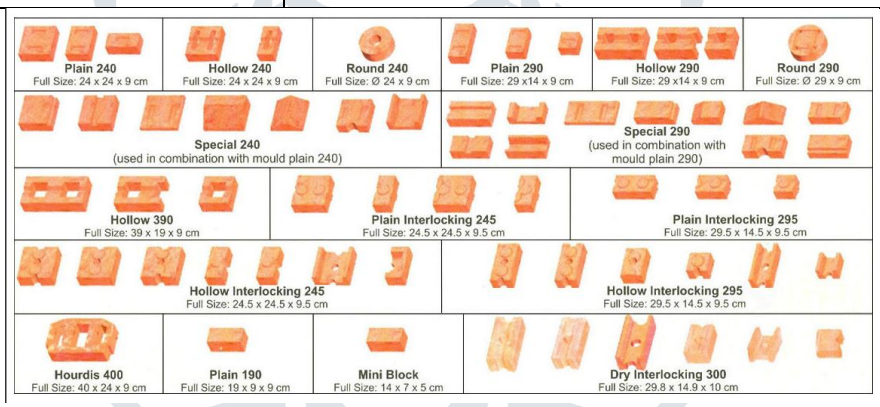


Figure 7 Variety of blocks by the Auram Press 3000

VIII. PERFORMANCE OF CSE BLOCKS

Compressive strength appears to be the most widely acknowledged metric for judging the quality of bricks. Nonetheless, it was strongly linked to soil types and stabiliser content(Riza et al., 2010). In most cases, determining compressive strength in a wet state yields the weakest strength number. The growth of pore water pressures and the liquefaction of unstabilised clay minerals in the brick matrix are responsible for the reduction in compressive strength under saturation conditions. Cement concentration, soil types (plasticity index), compaction pressure, and types of compactions are all factors that determine CSEB brick strength(Riza et al., 2010). The optimal cement content for stabilisation is in the range of 5% to 10%, with additions of more than 10% having a negative impact on the bricks' strength. The clay soil's plasticity index is normally between 15 and 25(Riza et al., 2010). Earth soils with a low plasticity index are the best for stabilising. Manual compaction is not recommended for plasticity indexes greater than 20(Riza et al., 2010). Natural fibres can be added to the CSEB to boost its strength and improve its ductility in stress. The improvement is achieved by delaying the propagation of tensile cracks after initial development, as well as shrinkage cracking(Riza et al., 2010). Because there is no standard testing for CSEB, most researches used the testing procedure for fired clay brick and concrete masonry block to assess the compressive strength(Riza et al., 2010).

PROPERTIES	SYMBOL	UNIT	CLASS A	CLASS B	CLASS C
Dry compressive crushing strength (@ 28 days, +10% after 1 year)	σ Cd	MPa	5 -7-	4-5	3-4
Wet compressive crushing strength (@ 28 days, after 24 hours immersion)	σ Cw	MPa	3 - 4	2 - 3	1.5 - 2

Tensile crushing strength, dry (on a core @ 28 days)	τ	MPa	0.5 - 1	0.5 - 1	0.5 - 1
Bending crushing strength, dry (@ 28 days)	σ Bd	MPa	0.5 - 1	0.4 - 0.8	0.3 - 0.6
Shear crushing strength, dry (@ 28 days)	τ	MPa	0.4 - 0.6	0.3 - 0.5	0.2 - 0.3
Total water absorption	-	% weight	8 - 10	10 - 12	12 - 15
Apparent bulk density	γ	Kg/m3	1900 - 2000	1800 - 1900	1700 - 1800
Poisson's ratio	μ	-	0.15 - 0.35		
Young's Modulus	E	MPa	700 - 1000		
Coefficient of thermal expansion	-	mm/mºC	0.010-0.015		
Swell after saturation (24 hours immersion)	-	mm/m	0.5 - 1		
Shrinkage (due to natural air drying)	-	mm/m	0.2 - 1		
Permeability		mm/sec	1.10-5		
Specific heat	c	KJ/Kg	0.65 - 0.85		
Coefficient of conductivity	λ	W/mºC	0.81 – 0.93		
Damping coefficient	m	%	5 - 10		
Lag time (for 40 cm thick wall)	d	h	10 - 12		
Coefficient of acoustic attenuation (for 40 cm thick wall at 500 Hz)	-	dB	50		
Fire resistance *	-	-	Good		
Flammability *	-	-	Poor		
Embodied energy (for 5% cement stabilized and produced by hand press)	-	MJ/m3	572.58		
Carbon emission (CO2/m3 raw material)	-	CO2/m3	49.37		

IX. COMPARISON OF CSE BLOCKS WITH OTHER CONVENTIONAL MATERIALS (PONDICHERRY)

Initial embodied energy (MJ/m3 of materials)	**Carbon emission (Kg of CO2 /m3 of materials)**
CSEB are consuming 11 times less energy than country fired bricks: CSEB produced on site with 5 % cement = 548.32 MJ/m3	CSEB are polluting 13 times less than country fired bricks: CSEB produced on site with 5 % cement = 49.37 Kg of CO2 /m3
Country fired bricks = 6,122.54 MJ/m3	Country fired bricks = 642.87 Kg of CO2 /m3
Concrete blocks = 3,180 MJ/m3.	Concrete blocks = 410 kg of CO2 /m3

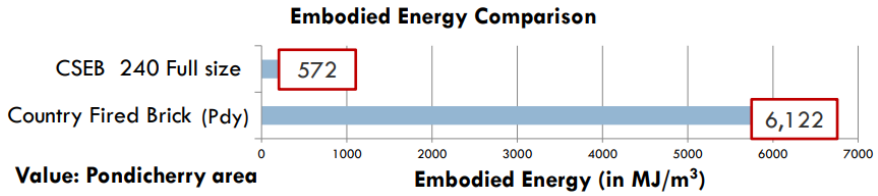


Figure 8 Embodied Energy comparison of CSE Blocks with Country Fired Brick

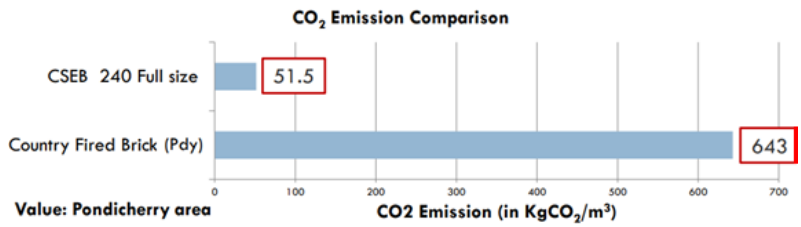


Figure 9 C02 Emission Comparison of CSE Blocks with Country Fired Brick

Another crucial component is the manufacturing process. The process's complexity isn't important right now, but the energy consumed and the costs incurred are, particularly in brick manufacturers where the bricks must be baked. Although the commercial production of concrete does not necessitate that much energy, the reaction of cement with water releases a significant amount of CO2(Rammed Earth, n.d.). This gas is the most harmful; in fact, pollution is measured in CO2, making it simple to compare the amount of pollution produced by each of these ways, as indicated in the table below(Rammed Earth, n.d.).

Material	**Density Kg/m3**	**Emission per Kg Kg of Co2/KG**	**Emission per Kg Kg of Co2/KG**
Cseb	2200	0.004	9.7
Adobe	1200	0.06	74
Concrete	2360	0.04	320
Prefabricated concrete 2% steel	2500	0.18	455
Massive brick	1600	0.19	301
Hollow brick	670	0.14	95

Most of the time, CSEB is less expensive than burned bricks and concrete blocks. A finished m3 of CSEB masonry is always cheaper than burnt bricks in the Western Ghat Region, costing between 15 and 20% less than country fired bricks(Auroville Institute, 2011).

The following is the cost breakdown of a 5% CSEB produced in Auroville with an AURAM press 3000 in July 2012:

Labour (soil sieving and block making): ~45 %	Raw materials (soil, sand, water): ~ 27 %	Cement: ~25 %	Equipment: ~3 %

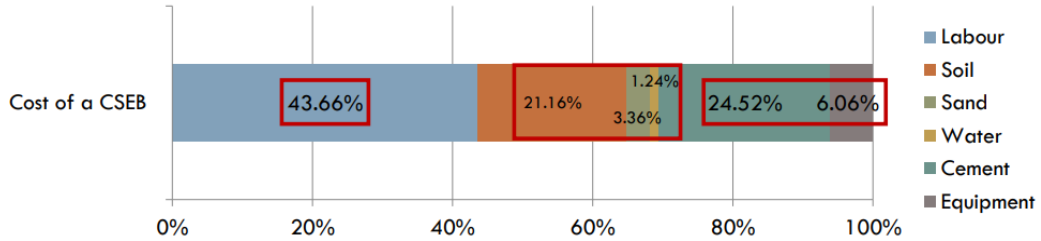


Figure 10 Cost Breakup of CSEB

The labour cost (which includes dirt digging, preparation, and block making) and the cement cost are the largest in this breakdown, however they vary greatly depending on the local environment(Auroville Institute, 2011). As a result, if productivity falls, the cost of the block will rise dramatically. In general, to lower the cost of the block, employees' productivity should be optimized, and the amount of cement used should be reduced if 5% cement is not required(Auroville Institute, 2011). Furthermore, because the cost of the equipment is not prohibitively expensive, one should not attempt to reduce the cost of the lock by purchasing low-quality machines that will not last long and will not provide strong blocks(Auroville Institute, 2011).

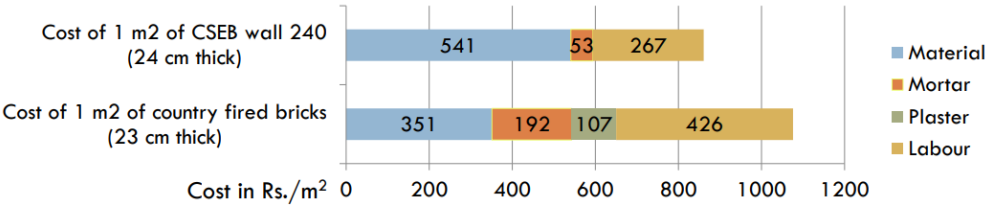


Figure 11 Cost comparison of CSEB and Fired Brick Wall (Auroville Institute,2011)

X. CASE STUDIES

10.1 Case 1 - Vikas Community, Auroville, Tamil Nadu, India

Vikas Community is located in Auroville, an international township near Pondicherry in the southern Indian state of Tamil Nadu(Tropical Buildings, n.d.-a). The weather is hot and humid, with the majority of rain falling during the North-East Monsoon (October-December) and to a smaller extent during the South-West Monsoon (February-March) (June-August). The village is situated on a plateau near the sea(Tropical Buildings, n.d.-a). Large expanses of woodland have been developed across Auroville as a result of massive reforestation efforts, considerably improving the microclimate of the area during hot seasons. Passive ventilation strategies become a particularly effective mode of cooling as a result of this(Tropical Buildings, n.d.-a).

10.1.1 Qualitative Analysis

The site's natural setting influenced its design, which preserved existing greenery and topography(Tropical Buildings, n.d.-a). Photovoltaics and a wind pump were used to harness solar and wind energy for water infrastructure. The structures were meant to respond to natural conditions such as wind direction and severe rains, as well as to reflect the community's spiritual ambitions through communal elements and the incorporation of Sri Aurobindo's symbol into the building dimensions(Tropical Buildings, n.d.-a).

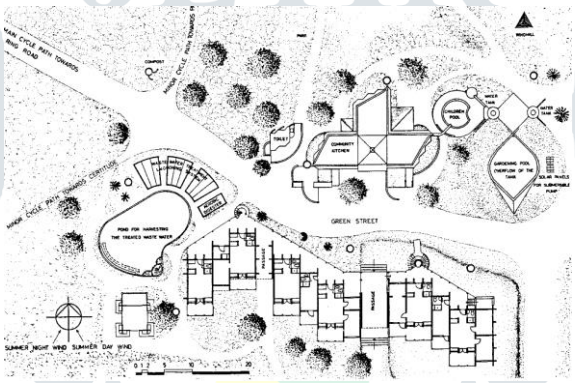


Figure 12 Site Plan of Vikas Community

Throughout the buildings, earth building technologies and ferrocement were used extensively, and dirt from the site excavation was used to make CSEB blocks(Tropical Buildings, n.d.-a).

Figure 13 Images of Vikas Community

- Structural material - Stabilized Rammed Earth Foundations and Compressed Stabilized Earth Blocks have been used to support load-bearing masonry.
- Foundation- Stabilized Rammed Earth (5% stabilization)
- Walls- Compressed Stabilized Earth Blocks (CSEB) (5% stabilization)
- Flooring- CSEB, terracotta, or ceramic tiles
- Finishing- Lime stabilized earth plasters (on selected walls)

- Roofing- CSEB vaulting with waterproofing & ferrocement channels
- Others- Composite CSEB ring-beams, lintels and columns

10.2 Case 2 - House of Bhooshan Family at Mysore

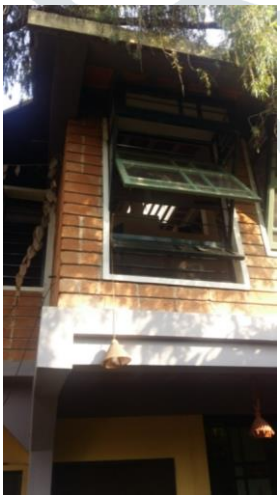
This is a little building on a small plot of land in a higher-income neighborhood in Mysore City. Built between 1985 and 1989 using path-breaking techniques such as Stabilized Mud Blocks and infill slab roofs, as well as an unusual spatial sequence and openings, all in response to the site's limited size and moderate climate(Tropical Buildings, n.d.-b). Designed for reduced energy usage with a temperature responsive design that only requires a few ceiling fans for artificial ventilation(Tropical Buildings, n.d.-b). Mysore city, which is located on the southern extremity of the Deccan Plateau, has a pleasant climate(Tropical Buildings, n.d.-b). In the summer, the temperature rarely exceeds 35 degrees Celsius, while in the winter, the temperature rarely falls below 15 degrees Celsius(Tropical Buildings, n.d.-b). It also gets nice breezes from the southwest and has a good rainy season for the most of the year. The design criteria are intended to respond to hot summer months between April and August, as well as severe downpours on a number of days throughout the year, primarily from June to December(Tropical Buildings, n.d.-b). Summer is hot and humid, with relative humidity ranging from 50 to 60 percent(Tropical Buildings, n.d.-b).

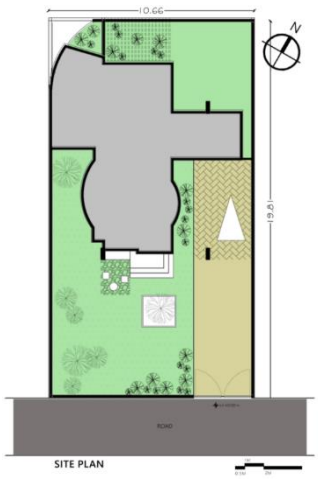
10.2.1 Qualitative Analysis

As it was part of a larger site's upper-class section, it had a lot of setback rules. It was feasible to cover around 100 square meters(Tropical Buildings, n.d.-b). This house, which was designed for two working parents and two school-aged children, tried to fit in the neighborhood and the site by leaving a bigger section of the Ground Floor unbuilt for landscape, composting, storage, and vehicle parking, as well as children's play. It was planned to be as unobtrusive as possible, hiding behind foliage(Tropical Buildings, n.d.-b).

The house was planned to be a low-cost structure. The curtain walls and internal walls are built of stabilised mud bricks manufactured on site from excavation mud. The openings were made of very thin profile steels with low-quality wood and glazed shutters. Air is diverted to lower floors using specially constructed 3D windows, which can work without a curtain in most cases. Even in strong winds, the shutter hanging vertically down may prevent raindrops from entering. The majority of the cabinetry, as well as some cladding and sliding shutters, are fashioned from recycled deal wood (pine wood) boxes. The ceiling is made of a filling slab with hollow clay hurdis, and the flooring is made of traditional clay tiles (save in the kitchen, which had to be replaced with granite after ten years) for cost reduction.

- Structural material: 8-pillared RCC frame construction. Hollow clay block fillers in RCC filler slab. Particularly with a smaller bottom floor and a larger main floor on the first storey.
- Foundation: Stabilized Rammed Earth (2.5% stabilization)
- Walls: Stabilised mud blocks, 150 mm thick or 100 mm thick. and recycled wood partition in some paces
- Flooring: 150 x 150 mm fired clay tiles. granite in kitchen where clay tiles disintegrated fast.
- Finishing: Rough composite plaster with lime and cement in interior parts. Exposed concrete or exposed mud block masonry.
- Roofing: Sloped roof with hollow clay block filler slab RCC





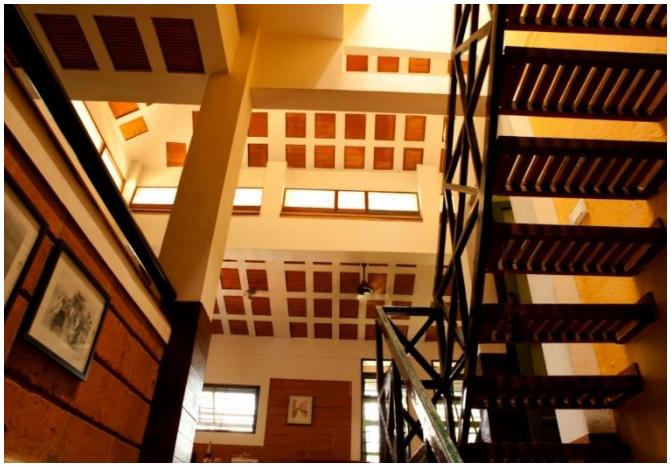


Figure 14 Images of Bhooshan House, Mysore

10.3 Case- 3 Realization community, Auroville, Tamil Nadu, India

In Auroville, Realization is a residential project with 17 units for a total of 25 persons. Many neighbours were brought together by a severe housing shortage and began a construction process that was overseen by the Auroville Earth Institute(Tropical Buildings, n.d.-c). In October 2007, the initiative became a movement. Over the years, three blocks of apartments were constructed, and the project was finished in May 2012(Tropical Buildings, n.d.-c). The site plan was created with microclimatic considerations in mind, as well as wise use of the natural resources on site(Tropical Buildings, n.d.-c). Auroville, an international township in the southern Indian state of Tamil Nadu, near the city of Pondicherry, is home to the Realization Community(Tropical Buildings, n.d.-c). The weather is hot and humid, with the majority of rain falling during the North-East Monsoon (October-December) and to a smaller extent during the South-West Monsoon (February-March) (June-August)(Tropical Buildings, n.d.-c). The village is situated on a plateau near the sea. Large expanses of woodland have been developed across Auroville as a result of massive reforestation efforts, considerably improving the microclimate of the area during hot seasons. Passive ventilation strategies become a particularly effective mode of cooling as a result of this(Tropical Buildings, n.d.-c).

10.3.1 Qualitative Analysis

The buildings were designed to maintain as much of the current greenery as possible while also taking advantage of natural ventilation provided by the prevailing wind direction(Tropical Buildings, n.d.-c). Because of the site's natural slope, less excavation was required for the foundations. All of the earth that was excavated was utilised to make Compressed Stabilized Earth Blocks (CSEB), the primary building material(Tropical Buildings, n.d.-c).

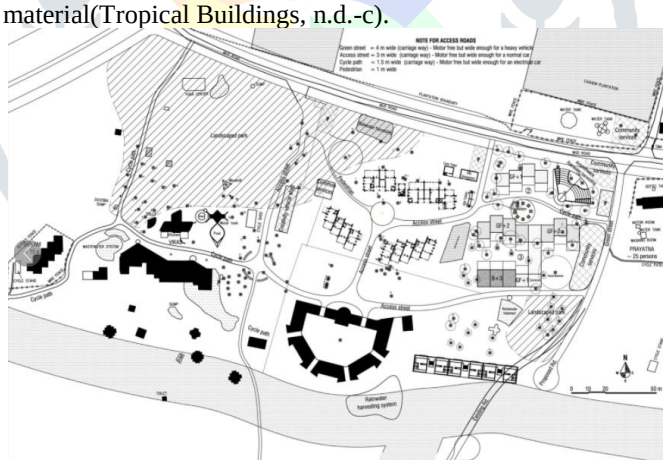


Figure 15 Site Plan

10.3.1 Qualitative Analysis

Realization apartments are multi-story structures with earthen foundations(Tropical Buildings, n.d.-c). From foundations to roofs, the structures were planned with earth as a building material, with Stabilized Rammed Earth Foundations, Compressed Stabilized Earth Block (CSEB) for load-bearing walls, and CSEB vaulted roofing with ferrocement channels to reduce the usage of traditional roofing materials(Tropical Buildings, n.d.-c). Apartments were designed in accordance with Auroville's space allocation suggestions, maximizing tiny areas. Many of the apartments were designed with double-height areas to increase ventilation and natural light, while staggered floor patterns were designed to take advantage of the prevailing winds(Tropical Buildings, n.d.-c).


Figure 16 Realisation Residence
Figure 17 Vaulted CSE Block

Almost all building systems are similarly cost-effective and low-impact on the environment: In contrast to imported industrial building materials, one important element of earthen construction is that, as labor-intensive construction technique, a large portion of the construction cost is spent in local economies of production and construction(Tropical Buildings, n.d.-c). Labor accounted for around 65 percent of the cost of construction in the case of Realization, which is roughly the opposite of cement-based construction technologies (in which generally 60-65 percent of construction is invested in material)(Tropical Buildings, n.d.-c).

Construction that minimizes initial embodied energy is the most passive solution to this building system(Tropical Buildings, n.d.-c). The construction's initial embodied energy and carbon footprint are drastically reduced by maximizing the usage of raw soil (already a zero to very low EE material) extracted from the site(Tropical Buildings, n.d.-c). As a result, the overall technical design is guided by circular ecology concepts. Because of the soil characteristics (selection of the site based on the quality of available soil), just a small quantity of cement stabilisation (5%) is required to generate load-bearing blocks strong enough to support up to four stories. The initial embodied energy was less than a quarter of that of a normal building system, according to analysis (RCC frame and country fired brick infill system)(Tropical Buildings, n.d.-c).

XI. Comparative Analysis

S. No	Parameters	Vikas Community	Bhooshan house	Realization community
1	**Location**	Auroville, Tamil Nadu, INDIA	Mysore, Karnataka	Auroville, Tamil Nadu, INDIA
2	**Climate**	Tropical	Tropical	Tropical
3	**Architecture type**	Traditional and modern	Vernacular	Traditional and modern
4	**Building Shape**	Rectangular	Organic	Rectangular
5	**Building floors**	2 and 4	2	3
6	**Net floor area**	1448sq.m	211sq.m	900sq.m
7	**Foundation type**	Stabilized Rammed Earth (5% stabilization)	Stabilized Rammed Earth (2.5% stabilization)	Stabilized Rammed Earth (5% stabilization)
8	**Wall type**	Compressed Stabilized Earth Blocks (CSEB) (5% stabilization)	Stabilised mud blocks, 150 mm thick or 100 mm thick. and recycled wood partition in some paces	Compressed Stabilized Earth Block (CSEB) masonry (5% cement stabilization)
9	**Roofing**	CSEB vaulting with waterproofing & ferrocement channels	Sloped roof with hollow clay block filler slab RCC.	CSEB masonry vaults (principal roofing);

10	**Finishing**	Lime stabilized earth plasters (on selected walls)	Rough composite plaster in interiors NO external plaster applied	Lime Stabilized Earth plasters

XII. Case Development

12.1 Introduction

In order to understand the applicability of CSE blocks as compared to other conventional materials, the development of a case has been done. Pondicherry has been chosen as the proposed location for case development so as to take "in-situ CSE block production" into consideration.

Location: Mysuru, Karnataka, INDIA
Climate: TROPICAL
Building Type: Residence
Floors: Ground floor
Net floor area: 80sq.mt

Figure 18 Floor Plan

12.2 Brick wall Estimation

S.NO	WALL TYPE	LENGTH (Mt)	BREADTH (Mt)	HEIGHT (Mt)	VOLUME (CUM.)
1	WA1	8	0.23	3.5	6.44 ~ 6.5
2	WA2	10	0.23	3.5	8.05 ~ 8.1
3	WA3	8	0.23	3.5	6.44 ~ 6.5
4	WA4	10	0.23	3.5	8.05 ~ 8.1
5	WA5	3	0.23	3.5	2.41 ~ 2.5
6	WA6	6.5	0.23	3.5	5.23 ~ 5.3
7	WA7	2.5	0.23	3.5	2.01 ~ 2.1
8	WA8	2	0.23	3.5	1.61 ~ 1.7
			TOTAL		40.8 ~ 41

12.3 Volume of windows openings (Brick wall)

S.NO	WINDOW TYPE	LENGTH (Mt)	BREADTH (Mt)	HEIGHT (Mt)	VOLUME (CUM.)
1	WN1	1.5	0.23	1.5	0.517 ~ 0.6
2	WN2	1.5	0.23	1.5	0.517 ~ 0.6
3	WN3	1.5	0.23	1.5	0.517 ~ 0.6
4	WN4	1.5	0.23	1.5	0.517 ~ 0.6
5	V1	0.45	0.23	0.75	0.07 ~ 0.1
			TOTAL		2.5

12.4 Volume of doors openings (Brick wall)

S.NO	DOOR TYPE	LENGTH (Mt)	BREADTH (Mt)	HEIGHT (Mt)	VOLUME (CUM.)
1	D1	1	0.23	2.1	0.483 ~ 0.5
2	D2	1	0.23	2.1	0.483 ~ 0.5
3	D3	1	0.23	2.1	0.483 ~ 0.5
			TOTAL		1.5

Volume of total brick wall construction = Total volume of walls – (Total volume of windows + Total volume of doors)
Volume of total brick wall construction = 41- (2.5+1.5) = 37cum.

12.5 CSEB Wall Estimation

S.NO	WALL TYPE	LENGTH (Mt)	BREADTH (Mt)	HEIGHT (Mt)	VOLUME (CUM.)
1	WA1	8	0.3	3.5	8.47 ~ 8.5
2	WA2	10	0.3	3.5	10.5
3	WA3	8	0.3	3.5	8.47 ~ 8.5
4	WA4	10	0.3	3.5	10.5
5	WA5	3	0.3	3.5	3.15 ~ 3.2
6	WA6	6.5	0.3	3.5	6.825 ~ 6.9
7	WA7	2.5	0.3	3.5	2.625 ~ 2.7
8	WA8	2	0.3	3.5	2.1
			TOTAL		52.9 ~ 53

12.6 Volume of windows openings (CSEB wall)

S.NO	WINDOW TYPE	LENGTH (Mt)	BREADTH (Mt)	HEIGHT (Mt)	VOLUME (CUM.)
1	WN1	1.5	0.3	1.5	0.675 ~ 0.7
2	WN2	1.5	0.3	1.5	0.675 ~ 0.7
3	WN3	1.5	0.3	1.5	0.675 ~ 0.7
4	WN4	1.5	0.3	1.5	0.675 ~ 0.7
5	V1	0.45	0.3	0.75	0.101 ~ 0.2
			TOTAL		3

12.7 Volume of door openings (CSEB wall)

S.NO	DOOR TYPE	LENGTH (Mt)	BREADTH (Mt)	HEIGHT (Mt)	VOLUME (CUM.)
1	D1	1	0.3	2.1	0.63 ~ 0.7
2	D2	1	0.3	2.1	0.63 ~ 0.7
3	D3	1	0.3	2.1	0.63 ~ 0.7
			TOTAL		2.1

Volume of total CSEB wall construction = Total volume of walls – (Total volume of windows + Total volume of doors)
Volume of total CSEB wall construction = 53- (3+2.1)
= 47.9 ~48cum

13. Conclusion and Recommendation

From the case development carried out in this study, the following conclusions can be made concerning the effects of using CSRE blocks compared to other conventional materials in Western Ghats region of India-

- Initial embodied energy of red brick is 226533mj/ m3 and Cement block is 152640mj/ m3. Cement stabilized earth blocks (CSEB) initial embodied energy is 26319.36mj/ m3 which is very less compared to kiln red bricks and cement blocks.
- Carbon emission by red brick is 23786.18 kg of CO2 /m3 and by cement block is 19,680kg of CO2 /m3. Cement stabilized earth blocks (CSEB) has 49.37 kg of CO2 /m3 very less compared to kiln red bricks and cement blocks.
- Cement stabilized earth blocks (CSEB production can be in-situ which therefore helps in employment for unskilled labours and also thus reduce the transportation cost of the building materials.
- Total costing for the CSE blocks is Rs. 1,42,224 while for red bricks is Rs. 1,58,839 proving that if CSE blocks is used and in-situ produced or locally transported can cost 10% - 15% less than other conventional materials.

Based on the above analysis and conclusion, it is seen that the CSE blocks plays a significant role towards sustainable construction. As firewood is not needed to produce CSEB, its initial embodied energy as well as carbon emission is way less than other conventional materials. It has been used in four storey buildings proving it to be durable enough for midrise buildings. It can withstand heavy rains or snowfall without being damaged with a minimum of maintenance hence can be used in any type of climate. If used in Western Ghats region of India, it can be cost effective in comparison with other conventional material by almost 15%-20%, as it can be in-situ manufactured.

14. Bibliography

Auroville Institute. (2011). *Building the Future With Earth Using Compressed Stabilized Earth Blocks (Cseb)*.

Embodied Energy in Building Materials: What it is and How to Calculate It | ArchDaily. (n.d.). Retrieved January 30, 2022, from https://www.archdaily.com/931249/embodied-energy-in-building-materials-what-it-is-and-how-to-calculate-it

Kariyawasam, K. K. G. K. D., & Jayasinghe, C. (2016). Cement stabilized rammed earth as a sustainable construction material. *Construction and Building Materials*, *105*, 519–527. https://doi.org/10.1016/j.conbuildmat.2015.12.189

Rammed earth. (n.d.). Retrieved January 30, 2022, from https://www.slideshare.net/michealabebe/rammed-earth-110077124

Raseena, N. ., Firozemon, Harikumar, M., Rithika, S., Sathyanathan, N., Sainabathul, S. ., & ManoharanK, J. (2016). Experimental Investigation on Compressed Stabilized Earth Block. *International Journal of Engineering Research & Technology (IJERT)*, *4*(33), 1–7. www.ijert.org

Riza, F. V., Rahman, I. A., Mujahid, A., & Zaidi, A. (2010). A brief review of Compressed Stabilized Earth Brick (CSEB). *CSSR 2010 - 2010 International Conference on Science and Social Research*, *Cssr*, 999–1004. https://doi.org/10.1109/CSSR.2010.5773936

The 12 Techniques of Earth Construction (English) - TERRAVERSA. (n.d.). Retrieved January 30, 2022, from https://terraversa.es/the-12-techniques-of-earth-construction-english/

Tropical Buildings. (n.d.-a). Retrieved January 30, 2022, from https://www.tropicalbuildings.org/case_studies/65

Tropical Buildings. (n.d.-b). Retrieved January 30, 2022, from https://www.tropicalbuildings.org/case_studies/61

Tropical Buildings. (n.d.-c). Retrieved January 30, 2022, from https://www.tropicalbuildings.org/case_studies/75