Sustainable and Energy Efficient Housing Systems

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Abstract

The word "sustainable" is increasingly utilized in regards to many factors in daily lives from sustainable development to sustainable agriculture. In terms of housing, sustainability maintains a similar focus on future prosperity. Sustainable housing essentially incorporates homes that are designed to reduce the cumulative environmental effects caused during and after construction in such a way that the needs of the present can be met without compromising the ability for future generations to meet their own needs. Due to rapid urbanization, housing sector is facing acute shortage of raw materials such as cement, sand, limestone, etc. Moreover, there is a global effort being taken up to reduce CO2 emissions reduce greenhouse gases, etc which require an effort of reducing the cement consumption and utilization of alternate materials for manufacturing of masonry units, wall panels, wall construction, etc. This paper summarises three different housing systems with case studies such as Interlocking brick/block walls, Rammed earthwalls, Rapid wall technology which are sustainable and involve reduced usage of virgin raw materials and cement.

Keywords: Sustainability, Interlocking bricks, rammed earth walls;

1. INTRODUCTION [1,6]

According to leading scientific research, a lot of work is being taken up to substantially reduce global greenhouse gas emissions within the next decade to avoid disastrous climate change [1] [3] [5]. Curtailing the increase of greenhouse gas emissions and then decreasing emissions over the next ten years is key to keeping global warming under one-degree centigrade above today's level [8] [12] [14]. The construction and operation of buildings are a prime source of demand for oil, natural gas, and coal for heating, cooling, and lighting, which in turn produce global greenhouse gases [7] [10]. Hence, there is an urgent need for buildings to be constructed in the near future to be sustainable, and systems to be adopted must also be sustainable [9] [15] [17].

Ecologically sustainable development (or sustainability) is defined as development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends [4] [11]. The five key principles from the Foundation of Sustainability are: [13] [19] [23].

Integration— the effective integration of environmental, social and economic considerations in decision making.

Community involvement—recognition that sustainability cannot be achieved, nor significant progress made toward it, without the support and involvement of the whole community.

Precautionary behaviour—where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Equity within and between generations — fairness and equal access to opportunities both in our lifetimes as well as for future generations.

Continual improvement—the declining environmental situation means there is an imperative to take immediate action to become more sustainable and to make continual improvement.

• Sustainability is a very broad, all-encompassing concept that has implications for every aspect of society, including people of all ages and abilities. In this regard, steps need to take wherein we can cutdown the usage of virgin raw materials, consumption of cement, etc which can contribute towards better environment through reduced greenhouse emissions. In this regard, choosing housing systems which are sustainable and which aim at reduced usage of natural resources such as sand, limestone and reduced cement consumption and utilize the alternate materials or waste materials in construction which would otherwise cause many issues such as inefficient land usage, dumping etc. Housing systems such as Interlocking brick/block walls, Rammed earth walls, glass fibre reinforced gypsum walls popularly known as "Rapidwall" have been found to be popular in terms of sustainability.

1.1 INTERLOCKING BRICK/BLOCK WALLS

With the surge in material costs in the construction industry, there is a need to find more cost-saving alternatives to maintain the cost of constructing houses at prices affordable to clients [2] [6] [9]. The potential for using earth as an alternative construction material has been seriously considered, as earth has been used as a brick in house construction throughout the ages [3] [10] [12]. The methods from traditional techniques are being further developed to improve the quality of earth-stabilized blocks, which will broaden the potential for its application [5] [13] [16].

Earth construction is very cost-effective, energy-efficient (with excellent thermal properties and low energy input required for production), environmentally friendly, and safe. These qualities are particularly relevant and important with the ever-growing need for increased awareness to reduce energy consumption worldwide [7] [14] [18].

Production techniques have been developed to achieve better quality blocks and reduce production costs [11] [20] [22]. In order to do this, the following points need to be considered: [8] [17] [24].

• Mix proportions between soil and stabiliser need to be optimised, by considering the specific characteristics of the soil,

• Sufficient compaction pressure should be applied to the moist soil mix so as to produce blocks that fit its purpose,

• Smooth block surfaces produced will reduce additional surface coating or render

Figure 1: interlocking bricks [1, 1]

1.2. SHAPES AND SIZES

A variety of interlocking blocks have been developed during the past years, differing in shape and size, depending on the required strengths and uses. The system developed has the following shapes and forms:

• Full blocks (300x 125 - 150x 100 mm) for all standard walls (single or double block thick)

• Half blocks (150 x 125 - 150 x 100 mm), which can be moulded to size, or made by cutting freshly moulded full blocks in half.

• Channel blocks, same sizes as full and half blocks, but with a channel along the long axis, into which reinforcing steel and concrete can be placed to form lintels or ring beams.

• The vertical sides of the blocks can be flat or have recesses, and the vertical grout holes can be square or round.

• Inserts for electrical switch housing and conduit as well as water piping outlet can be incorporated.
• Special blocks for window sills

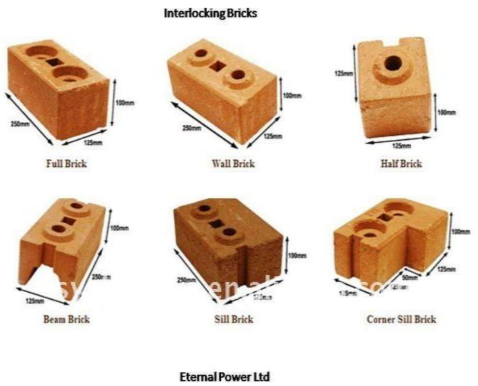

Figure 2: Different size of interlocking bricks [1,2]

1.3. WHY INTERLOCKING BRICKS?

- Can be produced at or near the site –reduced transportation cost
- Green technology –Zero carbon emission
- Energy Efficient
- Uses local available materials
- Reduces the need for skilled labour
- No limitation for the wall to be built only 1 metre in a single day of work.
- Maximize the use of unskilled labour
- Faster to build –shortens construction time
- Creates local employment
- Permits self-help construction or community based projects
- Can be used to build all types of buildings
- Construction cost can be reduced as much as 50% in comparison with conventional system depending upon the local price.

1.4. CONSTRUCTION WITH INTERLOCKING BRICKS

- Load bearing construction system
- No need for mortar between 2 layers of bricks
- Reduces reinforcements as it eliminates concrete lintels, beams and columns
- Cement based and Reinforced wall –resists fire, wind and earthquakes
- Modular -No material wastage
- Simple construction –with little training unskilled labour can be used to build the buildings
- Cost-effective construction system
- Can be used as composite structure

1.5 CASE STUDY [1a]

•Location: Baan Nam Khem Village, Phang-nga Province, Thailand
•Number of Houses: 56 units and 1 Community Center
•Sponsors: 32 units (EU) and 24 (Rotary)
•Plot Size: 120 sq. m
•House Size: 74 sq. m. (Two Storey)
•Cost per Unit: 256,200 Baht (~ US $ 7,500)
•Cost per sq. m. 3,462 Baht (~ US $ 100)
•Wall Construction: Interlocking Brick Technology
•Project Duration: 10 months

Figure-3:- Post-Tsunami Rehabilitation Project [1]

2. <u>EARTH RAMMED WALLS [2]</u>

Rammed earth walls are sometimes known as pisé walls—from the Latin origin *pisé de terre*. First used in Lyons, France, in 1562, the term applied to the principle of constructing walls at least 500mm thick by ramming earth between two parallel frames that were then removed, revealing a completed section of compressed earth wall [1] [5] [10]. While 500mm thick walls can still be constructed if desired, with or without cement, most modern rammed earth walls in Australia are built using cement as a stabilizer and are typically 300mm thick for external walls and 300mm or 200mm for internal walls [7] [12] [15].
Rammed earth walls are constructed by ramming a mixture of selected aggregates, including gravel, sand, silt, and a small amount of clay, into place between flat panels called formwork. Traditional technology involved repeatedly ramming the end of

a wooden pole into the earth mixture to compress it [8] [13] [17].

Modern technology replaces the pole with a mechanical ram [6] [9]. Stabilized rammed earth is a variant of traditional rammed earth that adds a small amount of cement (typically 5–10%) to increase strength and durability [14] [19]. Stabilized rammed earth walls need little added protection but are usually coated with an air-permeable sealer to increase the life of the material—it varies with circumstance [11] [16] [21]. Thousands of un-stabilized rammed earth buildings around the world have given good service over many centuries [20] [23].

Most of the energy used in the construction of rammed earth is in quarrying the raw material and transporting it to the site [18] [24]. Use of on-site materials can lessen energy consumed in construction [22] [26]. Rammed earth gives limited insulation but excellent thermal mass [25] [30].

Figure-4: formwork for earth rammed wall [2,1]

2.1. APPEARANCE

The colour of rammed earth walls is determined by the earth and aggregate used. The ramming process proceeds layer by layer and can introduce the appearance of horizontal stratification to the walls, which can enhance the overall appearance. It can be controlled as a feature or eliminated. Aggregates can be exposed and special effects created by the addition of different coloured material in some layers, and elements such as feature stones or objects, alcoves or relief mouldings can be incorporated into rammed earth walls, at a price. Unusual finishes can be achieved by including shapes in the formwork that can be released after the wall has been rammed.

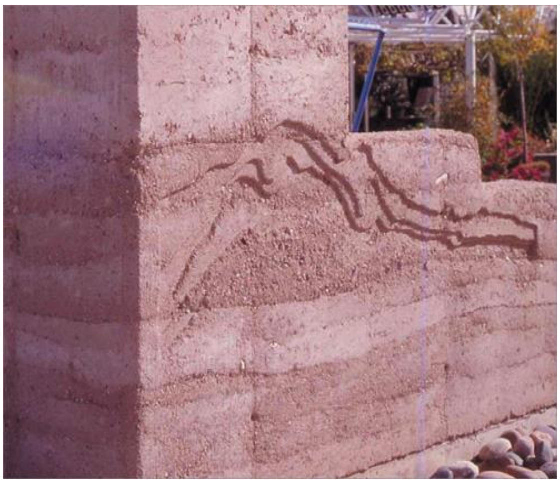

Figure 5:- Sample wall at the Environmental Research Laboratories in Tucson, Arizona[2,2]

Chamfered corners, which allow the walls to be easily released from the formwork, are visible. Brushed finishes help reduce formwork marks that can create a concrete-like appearance, but this is only necessary with fine grain size ingredients. Vertical curves can be formed by carefully ramming along a drawn guideline on the interior of the formwork. Horizontal curves are also possible but require specialised, and therefore expensive, formwork.

2.3. ENVIROMENTAL ASPECTS AND SUSTAINABILITY

Rammed-earth structures are thought to be more sustainable and environmentally friendly than popular building techniques. Because rammed-earth structures use locally available materials, they usually have low embodied energy and generate very little waste. The soils used are typically subsoil low in clay (between 5% and 15%), allowing the topsoil being retained for agricultural use. When the soil excavated in preparing the building's foundation can be used, the cost and energy consumption for transportation are minimal. The formwork is removable and can be repeatedly reused, reducing the need for lumber. Mixing cement with the earth can counteract sustainable benefits such as low embodied energy and humidity control since manufacture of the cement itself adds to the global carbon dioxide burden at a rate of 1.25 tonnes per tonne of cement produced. Partial substitution of cement with alternatives such as ground granulated blast furnace slag has not been shown to be effective, and raises further sustainability questions.

Rammed earth can contribute to the overall energy-efficiency of buildings. The density, thickness and thermal conductivity of rammed earth make it a particularly suitable material for passive solar heating. Warmth takes almost 12 hours to work its way through a wall 35 cm (14 in) thick.

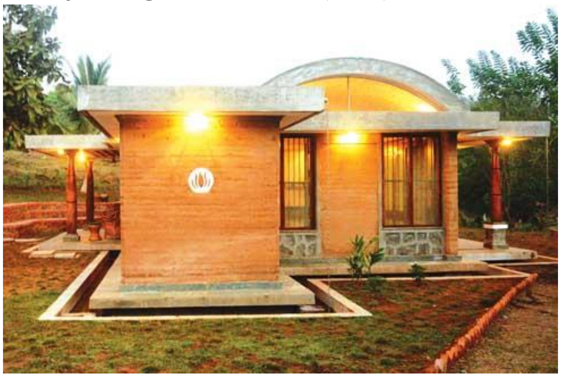

Figure -6 Housing on rammed earth [2,3]

Rammed-earth housing may resolve problems with homelessness caused by otherwise high building costs and may also help address the ecological impacts of deforestation and the toxicity of building materials associated with conventional construction methods [3] [8] [12]. There are now modern materials that incorporate the process and design of traditional rammed earth but have found new alternatives to the old dependency upon the binding properties of clay soils [5] [10]. Nowadays, companies use cross-linking styrene acrylic polymer materials replacing soil cement (with its low tensile strength), asphalt, tree resin, and ionic stabilizers [14] [18] [20]. These materials can also be used with contaminated mining materials and non-organic waste materials to incorporate the process of rammed earth but with longer-lasting and better results [7] [15] [22].

Although it is a low greenhouse emission product in principle, transport and cement manufacture can add significantly to the overall emissions associated with typical modern rammed earth construction [13] [17] [25]. The most basic kind of traditional rammed earth has very low greenhouse gas emissions, but the more highly engineered and processed variant of rammed earth has the potential for significant emissions [9] [23] [30].

2.4. FEATURES OF RAMMED EARTH WALL

Rammed earth is extremely durable. There are numerous examples of rammed earth buildings and structures that are hundreds of years old—for example, much of the Great Wall of China is made using an earlier method of un stabilized rammed earth construction [1] [5] [11]. Modern methods have improved the finished product enormously from those days [8] [12]. Today's rammed earth has the benefit of modern soil technology and testing methods, and a better understanding of the chemistry involved [4] [10] [15].

Other advances in the technology include the addition of a small percentage of cement (around 6%), better structural design methods, the inclusion of damp courses and concrete footings, mechanical compaction of the walls, regulatory controls by building authorities, and the use of water-based silicon water repellents [9] [13] [18] [22].

2.4.1 CURVED RAMMED EARTH WALLS

Curved rammed earth walls can cost a bit more depending on what is required. It may cost a little extra to have special formwork made up.

2.4.2 TERMITES RESISTANCE IN RAMMED EARTH WALLS

Rammed earth is an excellent material to use in termite areas, being most unappetising and impenetrable to termites. A very common method in rammed earth houses is simply to build on a concrete slab, as the concrete slab is an approved termite barrier as well as an excellent foundation for the rammed earth. It also means that you do not have to spray poisonous chemicals around your home.

Figure-7: -curved earth rammed wall [2,4]

2.4.3 HOW DO YOU FINISH THE WALLS?

Usually, it's a practice of leaving them smooth (an 'off-the-form' finish), or one can wire-brush them to provide an overall textured wall [3] [7] [12]. The wire-brush finish removes the formwork lines, exposes the soil texture, and gives a softer finished look [6] [13]. The off-the-form finish gives a smoother surface and a more modern look, and the formwork lines and textural changes are more evident [9] [15].

It is also possible to plaster, render, paint, or otherwise treat the walls in the same way as other masonry products [11] [16]. Some customers have used lime wash in ochre colors very effectively [8] [17] [20]. A waterproofing agent is applied to external walls and a dust sealer to internal walls [10] [18] [23].

2.5. CASE STUDY OF RAMMED EARTH WALL [2]

A number of 'green' buildings have now been constructed in Australia and throughout the world. Many of these buildings have won awards. One of these is the two-storey rammed earth 'Academic Offices Building' on the Charles Sturt University (CSU) Campus at Thurgoona in New South Wales, Australia [2] [8] [13].

The CSU office building contrasts sharply with a typical office building in almost every feature. It is a two-storey building with load-bearing rammed earth external and internal walls, and there is no steel frame [6] [10]. The windows open to permit natural ventilation [4] [9]. There is a central corridor running the length of the building on both levels with offices on either side. Each office is typically 10.5 m² in floor area [5] [15].

Hydronic heating and cooling have been installed instead of an HVAC system, and there are circulation pipes embedded in the ground floor slab and the two ceiling slabs [11] [18]. Ninety-eight square meters of flat plate solar collectors have also been installed on the roof of the building [7] [16]. It was anticipated that these panels would collect sufficient energy in winter to significantly reduce gas consumption. By circulating water through the panels at night in summer, it was also expected that radiant cooling would produce a store of cold water to reduce cooling energy requirements on the following day [12] [20].

Cooling is also achieved through a night ventilation purge in summer. Fresh air is allowed to circulate in through the louvers located under the office windows and out through the louvers in chimney ventilation stacks [14] [19]. These sets of louvers are computer-controlled, while the louvers above the office doors may only be operated manually [17] [23]. Since a hydronic system is used, there is no need for a suspended ceiling to conceal ductwork, and the concrete ceilings are exposed [21] [24]. In some places, a corrugated profile has been cast into the ceiling to increase its surface area and enhance convective heat transfer [22] [26].

The floors are carpeted [25]. The windows are single 6 mm glass with wooden frames [3] [27]. The offices have double-hung vertically sliding sash windows with weather strip sealing [9] [28]. In the stairwells and at the ends of the corridors upstairs, there are manually operated louver windows [29].

Window shading has been carefully designed to exclude all direct beam sunlight during the summer months [30] [31]. Each office has a variable-speed sweep fan controlled by the occupant, and these fans are seen as an important cooling mechanism [18] [32]. The building has woolen insulation placed underneath the roof sheeting rather than on top of the upper ceiling slab [16]. Solid-foam insulation was installed around the edge of the concrete slabs [23]. The external doors at CSU all close automatically and seal against a wooden frame [20].

3. RAPID WALL [4]

Rapid wall is a prefabricated walling panel with broad construction applications. It is suitable for load-bearing walls for individual domestic cottages as well as for multi-storey residential buildings; formwork for suspended concrete floor structures and for most other purposes for which traditional building materials are currently used. Rapid wall is manufactured in a moulding process using glass-fibre reinforced, water-resistant gypsum plaster and water proofing additives. All panels are up to 12 metres long and 3 metres high. The panels are cellular in form and 124 millimetres thick. The formed cells can be used to accommodate building services such as plumbing and electrical conduits or they can be filled with insulation, for increased thermal performance, or with concrete for increased load bearing structural capacity.

3.1. MANUFACTURING PROCESS

The casting-table, in each computer-controlled plant, comprises a flat steel epoxy-coated surface with sides that are raised to contain the plaster when in the fluid state.

Figure- 8: pre cast rapid wall [5]

Prior to the commencement of the manufacturing process the casting table is first lightly greased. Commencing from the start position the crab assembly moves over the casting-table accurately dispensing the special plaster mix comprising water, Rapid flow gypsum-plaster, water repellents and additives, over the entire table to a depth of 15 millimetres.

This plaster layer is lightly screeded after which the travelling crab assembly automatically chops and dispenses a predetermined quantity of glass-fibre rovings over the entire liquid-plaster surface. This layer of glass-fibre is then rolled into the plaster to position it centrally within the 15 millimetre thick skin to provide reinforcement to the plaster.

In every 250-millimetre length of Rapid wall a 230 millimetre by 94-millimetre cell is formed using teflon coated removable plugs that are laid at right angles to the 12-metre panel. The core-table mechanism positions all 48 plugs over the plaster and glass-fibre layer on the casting table. The final quantity of plaster is dispensed onto the casting table filling between the plugs and forming the top skin of the panel.

The travelling crab then dispenses a further layer of chopped glass-fibre over these cores and the tamping process is undertaken.

A final quantity of chopped glass-fibre is again automatically and uniformly dispensed over the entire panel surface by the travelling crab. The crab assembly then automatically returns to its cleaning and filling station to be prepared for the production of the next Rapid wall panel.

Using a mesh roller the surface of the Rapid wall panel is then rolled to position this final layer of glass-fibre centrally within the plaster top skin. Final screeding and smoothing of the cast is completed manually by two operators. To this point the process has taken only 20 minutes. After this, the panel is left to cure until the temperature and the consistency of the plaster allows final screeding.

Once the plaster has completed its initial set, a further 20 minutes, the core-table mechanism advances and locks onto the core formers and slowly withdraws them from the set panel.

To remove the panel from the casting-table three perimeter edges of the casting table are opened and two panel-supports are extended. The table is then automatically tilted to approximately 88 degrees off vertical. The entire two-tonnes weight of the wet panel is taken by the bottom supports.

Finally, a multi-directional truck, fitted with a transfer frame, removes the Rapid wall panel from the tilted casting-table and places it either in air drying racks or in the Rapid cure drying oven for final curing prior to it being stored and ultimately cut to dimensions for installation on a specific building project.

The elapsed time of the complete manufacturing process, including full curing in the Rapid cure dryer, is less than two hours for each panel.

3.2. APPLICATION OF RAPID WALL

In apartment buildings, some up to 14 storeys, concrete filled Rapid wall panels have been used very successfully in load-bearing construction to support combined lateral and vertical loads and to support vertical loads only.

3.3 DOMESTIC HOUSING CONSTRUCTION

Rapid wall panels, either unfilled or concrete filled, can be used to support domestic structures. Unfilled Rapid wall can be used to support domestic structures up to two storeys providing the suspended floor is constructed from timber.

3.4 FIREWALLS UP TO A RATING OF FOUR HOURS

Unfilled 100 millimetre Rapid wall (current panels are 124 mm) will provide an FRL of 180/120/60 and concrete filled Rapid wall an FRL of 240/240/240.

3.4 ROOF PANELS

Insulation filled Rapid wall panels have been successfully used in cottage construction as structural roof elements over which battened roof sheeting is placed.

3.5 PERMANENT FORMWORK FOR SUSPENDED SLABS

When used as permanent-formwork for suspended concrete slabs, services such as electrical or plumbing can be carried in the cells, noise attenuation between floors is improved and a finished plaster ceiling is obtained.

3.6 FENCING

Rapid wall has been used extensively for domestic fencing providing a high quality finish to both neighbouring properties. Uniquely Rapid wall can be placed directly in trenches and sand filled to provide solid foundation free fences up to two metres high.

3.7 FEATURES OF RAPID WALL

3.7.1 PROTECTION FROM ALL THE ELEMENTS.

Produced from inert gypsum plaster, Rapidwall has a 1 hour fire rating when unfilled or a 4 hour fire rating when filled with concrete.

By using a simple tie down system, the roof is secured through the cavity of the wall to the foundation giving it significant protection against high winds.

Further, Rapidwall has a high thermal insulation and when the hollows are filled with insulation even greater thermal properties are achieved.

3.7.2 SAVES ENERGY AND THE ENVIRONMENT

"Rapid wall offers huge savings in embodied energy - **66%** for domestic buildings **40%** for commercial buildings."

Rapid wall uses "fewer raw materials but doesn't compromise on load bearing capability and the total CO2 saving of Rapid wall, for residential dwellings in Australia would be about 63% or 3.91 million tonnes compared to brick."

3.8 COST SAVING

The following chart is based on the construction of a 130m² demonstration house in Mumbai, India.

Materials used	Rapidwall Building	Conventional Building	Saving in %
Cement	16 tonnes	32.55 tonnes	50.8
Steel	1800 kg	2779 kg	35.2
River sand	20 m^3	83.37 m3	76
Granite metal	38 m^3	52.46 m3	27.56
Bricks	-	57200	
Rapidwall	500m²	-	
Water	50000lt	200000lt	75
Built Area	143m²	154.45m²	8
Labour	389 man days	1200 man days	67.59
Construction Time	21 days	120 days	82
Total Weight of superstructure	170 tonnes	490 tonnes	65
Construction Cost	$US 26,800	$US 36,980	27.5
Embodied energy in kWh	82921	215400	61.5

Figure-9: cost saving table [5]

4.0 CONCLUSION

Sustainable housing essentially incorporates homes that are designed to reduce the cumulative environmental effects caused during and after construction in such a way that the needs of the present can be met without compromising the ability for future generations to meet their own needs

Sustainable housing can be accomplished through a number of pathways but focuses on three main points. The first is the efficient use of energy, water, land, and various other resources that are required to operate the general systems associated with the home. The second is promoting the health of any and all occupants residing within the home itself. The final important aspect 16 16 of sustainable housing is the emphasis on a reduction of greenhouse gas emissions, pollution, waste, and land degradation.

The housing systems discussed in this paper basically carry with them advantages such as sustainable, reduced greenhouse emissions, utilization of waste materials, reduced consumption of virgin raw materials, reduced land degradation due to utilization of waste byproducts which otherwise would have dumping and health related issues. With Rapid industrialization and rapid urbanization, there is a rapid shortage of housing which are affordable and equally sustainable and which can be executed within short period of time. Interlocking brick/block walls, rapidwall technology, rammed earthwalls can serve as systems which can also reduce the energy consumption in long run through better thermal insulation.

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