MaS-SHIP

Mainstreaming Sustainable Social Housing in India Project

Comparative performance of sustainable building systems December, 2018

This document discusses the comparative performance of selected building systems that have been categorised under walling and roofing systems, as per their use in the Indian housing market.

The comparison is based on attributes that best help in evaluating sustainability of the main criteria of environmental impact, operational performance, user experience and economic impact. The comparisons have assessed both quantitative and qualitative aspects of sustainability, thus making the assessment appealing to all decision-makers. The values presented against these attributes correspond to the manufacturing and construction phase of each building system.

Building systems selection

In the recent decades, numerous new building systems that are characteristic of low cost, environmental friendly or high speed of construction have been introduced into the Indian housing market. However, not all of them have developed a huge demand in the construction sector or have highly established supply chains. Many of these have been tried and tested across pilot projects. Since the past decade, the emphasis on affordable housing, and especially social housing through various programmes of the Government of India has accelerated the introduction of new building system options from across the globe into the Indian construction industry.

The Technology Sub-Mission of the Government of India's Housing for All (urban) mission led by the Building Materials and Technology Promotion Council, is actively promoting pre-fabricated and mechanized building systems to enhance the pace of construction and possibly reduce costs of construction of social housing projects.

This study has looked across the range and identified 17 building systems for assessment, based on popular application and the push by the government.

Established building systems

Established building systems refer to those building systems that which have an established evidence of practice in the Indian housing market. These include, both the conventional buildings systems which are most commonly used and traditional building systems. As a result of the evidence of their use, qualifying data for their level of sustainability is largely available either as certified data or can be derived from the certified data pertaining to their constituent building materials. There is a small but known group of building practitioners who have applied these systems in their projects. Depending on their application process, these can be further categorized as products available in the market (such as fly ash bricks, concrete blocks, AAC blocks, etc.) or systems implemented through on-site decentralized production of components. Technologies like precast RCC plank and joist for roofing and ferrocement roofing channels fall in this category characterized by deployment of low investment semi-mechanized processes which enhance job creation due to on-site production set-ups.

Emerging building systems

Emerging building systems refer to those building systems which have been promoted by the Ministry of Housing and Urban Affairs, Government of India, through the Building Materials and Technology Promotion Council (BMTPC) as prospective solutions

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for faster and cost-effective delivery of houses to meet the target of around 12 million houses by 2022. All systems in this category are based on a 'production' approach of housing where speed of construction is of prime importance. Hence, the category involves either precast components assembled at site (such as reinforced EPS core panels, large precast concrete panels, GFRG panels, etc.) or rapid in-situ processes where large formwork systems are installed at site for construction of houses through casting the entire house in one go.

Within this group, some systems have evidence (1 or 2 projects) of use in social housing through demonstration projects backed by BMTPC and others have not been used for social housing till date. Data pertaining to sustainability attributes for this category have many gaps because of insufficient evidence of their use and performance record. Although all building systems have been evaluated for structural performance by the BMTPC Performance Appraisal and Certification System (PACS), sustainability aspects like environmental performance, thermal behaviour, job creation, etc have not been formally evaluated. The MaS-SHIP project has attempted this evaluation based on data gathered from manufacturers who are usually also the implementers of these systems.

Sustainability Assessment of building systems

The data collected was a mix both quantitative as well as qualitative in nature. This was dependent on the definition and the unit of measurement which in turn determined the calculation methodology.

Based on extensive literature review and intensive deliberations with various stakeholders through dissemination workshops on the relevance and usefulness of each attribute, 18 attributes with their units of measurement were finalized for indicating sustainability, and categorized under four main criteria as below:

Resource efficiency- defined as 'doing more with less', that is, using material resources in the most sustainable manner while minimizing their environmental impact.

Operational performance- defined as the performance of the building against set standards of thermal comfort. However in this case it is also relates to the user's convenience in maintenance.

User acceptance- defined as the user's opinion and experience in the use of certain building materials and technologies in the housing projects.

Economic impacts- defined as the external factors that affect the economics of choice of building material or technologies that are used.

Nine attributes of the above main criteria are of quantitative nature, thus involve exact values which have been used to understand the comparative performance of the 17 building systems. The other nine qualitative attributes have been normalised on a scale of high, medium and low, and have also been described in section below.

Main criteria: Resource Efficiency

1. Embodied energy

Embodied energy is the total energy expended for implementing a building system, from extraction of material up until the point of installation in a building. In this case, it has been taken as the summation of four components- 1) primary energy of materials like cement, steel, sand, etc; 2) processing energy for manufacturing of building components; construction/ installation energy and 3) transportation energy (assumed from common practice) for primary materials to manufacturing plant and finished goods to construction site. The fuel used by lifting and placing equipment, such as cranes has not been considered for precast building systems.

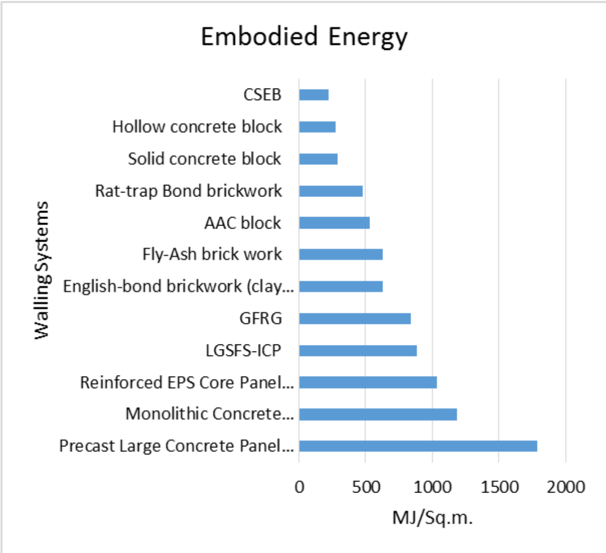


Figure 1: Embodied energy of selected walling systems

There is clear distinction in energy consumption between some of the masonry-based walling systems and emerging building systems which involve large scale pre-casting in factories. For instance, precast large concrete panels consume 8 times more energy as compared to Compressed Stabilised Earth Bricks (CSEB) (Figure 1). The CSEB building system has the lowest embodied energy among the masonry based options because of significantly lower use of industrial processed material and reduced transportation because of the possibility of production being close to the source of soil and construction site. Which is to say that in the above case, building systems with on-site production have lower embodied energy than pre-fabricated systems. An exception to this is monolithic concrete construction using aluminium formwork, which is cast on-site but has a high embodied energy due to the use of aluminium formwork.

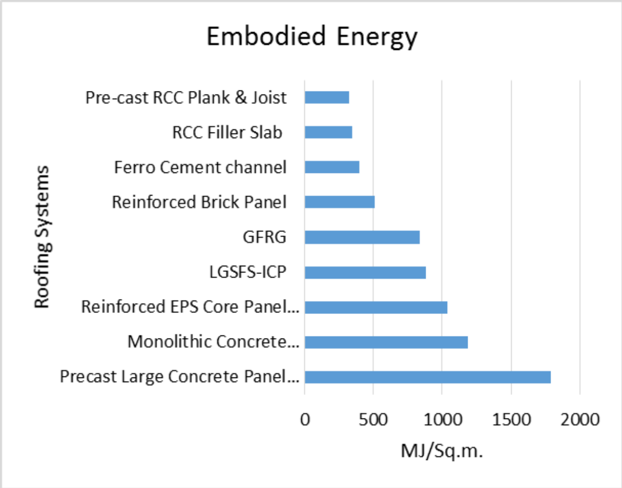


Figure 2: Embodied energy of roofing systems

The emerging building systems have a significantly higher energy requirement for their large-scale manufacturing facilities. Electricity consumption in these facilities, typically needed for an assembly line of production processes is a predominant consumer of energy. For instance, in the LGSFS-ICP building system, the energy consumed by batching plants, slip forming machines and cutters is almost 2/3rd of the total embodied energy. Similarly, Monolithic Concrete construction using aluminium or plastic frames consumes significant process energy for high level mechanization and thermal energy for drying of panels.

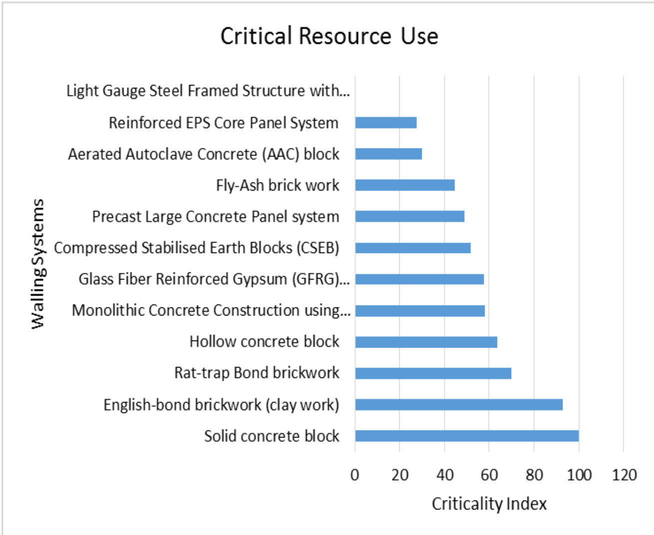
2. Critical resource use

Critical resource use is understood from the point of view of minimizing the negative impact of natural resource exploitation which is inevitable in the case of some primary materials that are commonly needed across building systems. The following six natural resources were identified for the critical resource use index. The criticality of each of these resources *(mentioned for each resource in the list below)* is taken as average of their ranking on three parameters – Resource scarcity, Environmental impact and Conflict of use on a 1(low) - 2(medium) - 3(high) scale.

- Top soil - 2.67
- Sub soil - 2.33
- Sand - 1.67
- Stone aggregate - 2.33
- Steel (Iron)- 1.67
- Cement (Limestone) – 2.0

Weight of the critical resource (as per specifications of the given building system) is calculated per m² of the wall assembly and its proportion w.r.t total weight of wall assembly. This proportion is multiplied by the respective resource criticality to arrive at a normalized index. A simple average of indices for all applicable critical resources is calculated for the final Critical Resource Use Index (critically index) for the building system. The index that emerged ranges from 0 to 100, with lower being better.

A lower value of this index would be possible through improvement measures such as more efficient use of natural resources per quantum of the building system; part-replacement of critical resources with complimentary materials or industrial wastes and/or ensuring recyclability/ re-use of building elements.



Amongst walling systems (Figure 3), English bond brickwork has a considerably high index value of 93 as a result of the predominant requirement of top-soil and also riverbed sand in its brick production and masonry work. Solid concrete block is the highest due to high amount of sand, limestone (cement) and aggregate used. Fly-ash brickwork, precast large concrete panel and CSEB perform well because of a rationalized quantity of cement which is offset by high usage of sand and stone aggregates. Fly ash brickwork performs well because of high usage of non-critical fly ash and no stone aggregates used. Despite containing petroleum based Styrofoam, EPS core panels have one of the lowest criticality values as the total quantum of material used is low.

Figure 1: Critical resource use of selected walling systems

Overall for roofing systems, the variation in critical resource use index is less than in the case of walls, with the range being 0 to 79. It is important to note that the reinforced EPS Core Panel system fares amongst the best for the same reasons as described above. RCC filler slab rationalises the usage of resources like steel and cement and uses almost 30% of waste material as filler, compares equivalent to RCC plank and joist roofing where the overall thickness is rationalised across the span.

Ferrocement channel roofing rates highest among roofing systems when the whole assembly of the roofing system is considered, with sand, aggregate and brickbat filling and screed cover, thus resulting in an overall high amount to critical resource use (Figure 4).

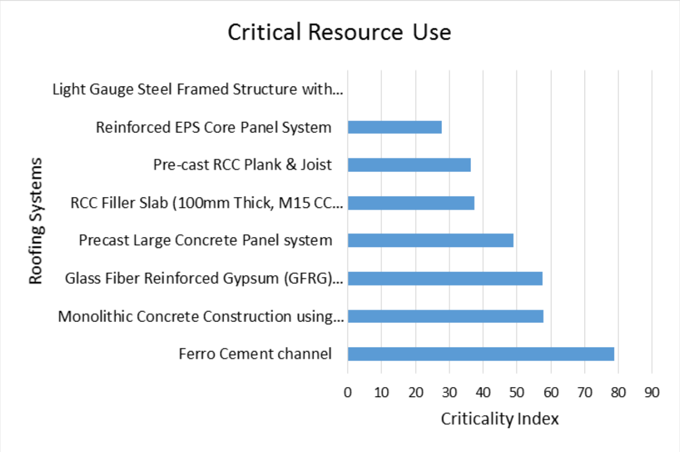


Figure 2: Critical resource use of selected roofing systems

3. Current recycled content

This attribute measures the quantum of recycled content utilized in the building system which may be achieved by usage of materials which utilize, for instance, industrial waste. The values have been segmented on a scale of high, medium and low. This scale is derived from the percentage of recycled content in the system. Low: 0-20%, Medium: 20 – 40% and High: > 40 – 100%.

The intent is to reduce the dependency on virgin materials such as top soil, sand etc. or on materials with a high environmental impact such as cement.

12 out of 17 building systems with their current composition do not involve any recycled content. The 5 which contain recycled content, GFRG, RCC filler slabs, fly-ash blocks and stonecrete blocks contain 20%-40% recycled content, thus being *Medium* on the above-mentioned scale.

Scale	Building Systems
Low	Solid Concrete Blocks, Hollow Concrete Blocks
Medium	GFRG, RCC filler slabs, Fly-ash blocks,
High	Stonecrete blocks
Nil	English bond brickwork, Rat-trap bond brickwork, CSEB, Reinforced EPS Core Panel, LGSFS, Precast Large Concrete Panel System, Monolithic Concrete Construction, Pre-cast RCC Plank and Joist, Ferro Cement Channel, Reinforced Brick Panel

4. Future Reusability

Future reusability is the ability of a material to be used in its second life cycle without any structural changes. The intent is to reduce the generation of C&D (Construction & Demolition) waste at source. The data for this attribute has been collected through manufacturer and building practitioner surveys. Materials such as steel and aluminium framework, which are recyclable and which have not been incorporated into a composite material, have been considered reusable to about 100%. The high-medium-low scale has been derived from percentage of constituent materials of the wall/roof which may be reusable.

All building systems with prefabricated elements which are assembled on-site perform well on this attribute, while established systems and all systems produced on-site are low on the scale of future reusability. The formwork for monolithic concrete construction have been taken into consideration as they allow for reuse more than 100 times.

Scale	Building Systems
Low (<20%)	English-bond brickwork, Flyash bricks,Rat-trap bond masonry, AAC blocks, CSEB blocks, Reinforced EPS core panels, precast RCC plank and joist, RCC filler slabs, stonecrete blocks.
Medium (20-40%)	Hollow and solid concrete blocks, ferrocement channels
High (>40%)	GFRG panels, Precast large concrete panels, LGSFS.

5. Water use during construction and manufacturing

The water consumption during construction and manufacturing has been calculated on the basis of embodied water co-efficient in different building materials – cement, steel, aluminium, and process water for mixing and curing of concrete.

There is a clear distinction between masonry-based systems and precast building systems (Figure 5). However, it is noteworthy that fly-ash brick masonry also needs 1928L/m^2 of water for mixing and curing processes (for instance, fly ash bricks are cured for 24 hours in a 66 °C steam bath) as compared to, 429L/m^2 for burnt clay bricks and 683L/m^2 for CSEB. Glass Fibre Reinforced Gypsum (GFRG) panel systems have the lowest water use as it is produced in a controlled environment and requires no curing on-site. In comparison, Light Gauge Steel Frame systems (LGSFS-ICP) have higher water use during construction and manufacturing due to the embodied water in the steel production (Figure 6).

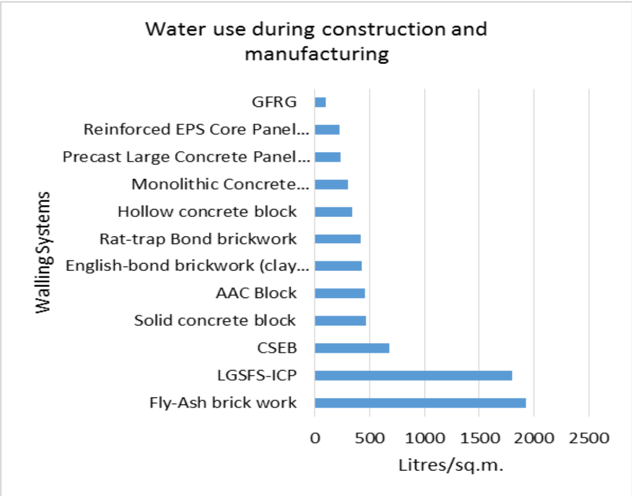


Figure 3: Water use by selected walling systems

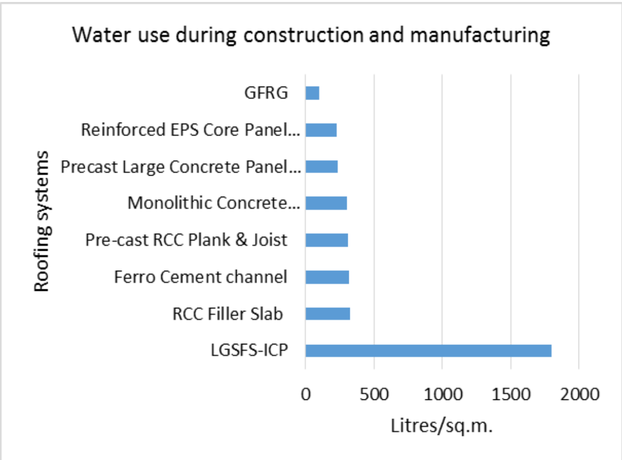


Figure 4: Water use by selected roofing systems

Main Criteria: Operational Performance

1. Durability

Durability is the period for which the building material or system is stated to last by its manufacturer under specified conditions of use. It can also be understood as the functional life period of the system and the durability of its key materials. The data for this attribute has been collected through manufacturer and building practitioner on the lifespan of the system and its components. Their responses directly inform the scale of high, medium and low.

Scale	Building Systems
Low	Nil
Medium	CSEB blocks, AAC blocks, Reinforced EPS core panels, GFRG panels
High	English bond brickwork, Flyash blocks, Rat-trap brickwork, concrete blocks, stonecrete blocks, LGSFS, Precast large concrete panels, monolithic construction, precast RCC plank and joist roofing, Reinforced brick panels, ferrocement channels, RCC filler slabs.

It must be noted that none of the systems fall under the category of "Low" since the durability of the building system depends on the quality of construction and skills of the labour. Most responses read as "High durability if built according to IS: 456-1978", referring to the relevant standards. Systems falling under medium durability were reported to have higher moisture absorption tendencies compared to the materials in the high category. For example, surveys with several AAC brick manufacturers and developers have indicated that increase in moisture content in these bricks, due to humidity has resulted in cracks and breakages in the brickwork.

2. Ease and frequency of maintenance

This attribute measures the frequency of maintenance works required (regular or occasional). It could involve the following indicators:

- Extra products required for the maintenance
- External help required
- Mandatory frequent services

Tier 3 data was collected through material specifications and catalogues regarding the maintenance of the building system. Households were questioned on the ease and frequency of maintenance required in the houses. The scale of high, medium and low comes from the responses of the householders and building practitioners towards these questions.

Scale	Building Systems
Low	Hollow and solid concrete blocks, precast RCC plank and joist, stonecrete blocks, reinforced EPS panels.

Medium	Rat-trap brickwork, AAC blocks, CSEB, ferrocement channels, RCC filler slabs, GFRG panels, LGSFS,
High	Flyash brickwork, precast large concrete panels.

3. Thermal performance

Thermal performance of a material is a measure of the thermal transmittance (also known as the U-value) which is the property of heat transmission in time through unit area of a building material or assembly, induced by unit temperature difference between the environments on each side. The lower the U-value of a material, the better is its capacity to resist flow of heat through it.

Monolithic concrete constructions of 100mm RCC walls and roofs have a higher thermal transmittance value (U-value = 3.59 W/m²k) as compared to traditional English bond brickwork (U-value = 2.11 W/m²k) and even lesser for AAC blocks, which for a 200mm thick wall has a U-value of 0.7 W/m²k (Figure 7).

In the case of standard rat-trap bond brickwork and hollow concrete block wall, both show similar performance due to the presence of the cavity in both the walling systems.

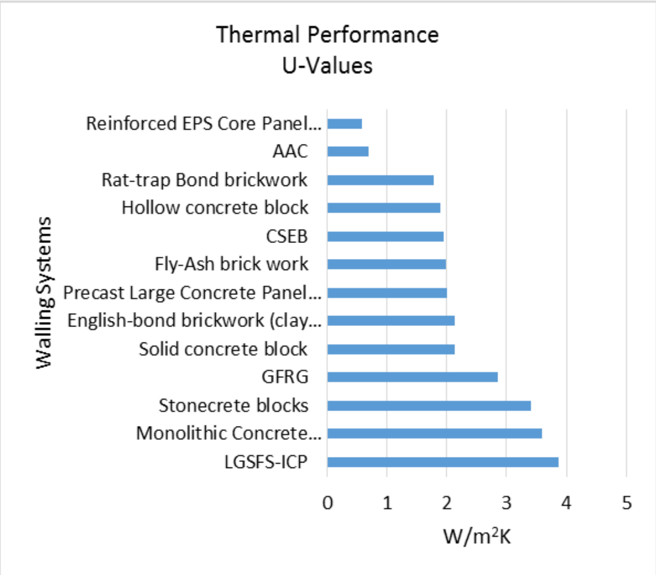


Figure 5: Thermal performance of selected walling systems

The thermal performance of LGSFS- ICP is low due to its high U-value of 3.87 W/m²k as compared to Reinforced EPS Core panels that have a much greater heat insulating factor with the U-value being low (0.58 W/m²k) as a result of a 70mm thick Expanded Polystrene (EPS) in the centre which acts as insulation. The thermal performance of LGSFS- ICP depends on the infill panel and not on the framing itself. Therefore, the U-value could vary with change in thickness and specifications of the infill panel.

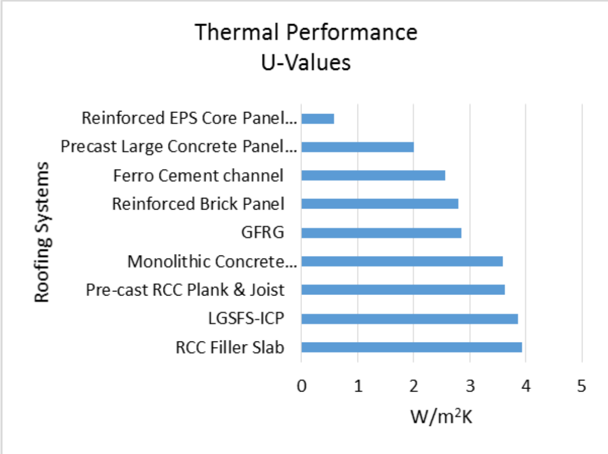


Figure 6: Thermal performance of selected roofing systems

4. Thermal Mass

Thermal mass or thermal admittance quantifies a material's ability to absorb and release heat from a space as the indoor temperature changes through a period of time. For the sake of proper comparison, the total weight of all the components per m2 of the wall/roof assembly has been calculated, as shown above in Kg per m². In climates with large diurnal swings, admittance values can be a useful tool when assessing heat flows into and out of thermal storage. Here, the density of the material has been taken as a measure for thermal mass.

It can be noted that a Monolithic Concrete construction of 100mm thickness perform similar to a 230mm rat-trap bond wall made of fired clay bricks. LGSFS-ICP performs best as the weight of the infill panel is only 36 kg per m². Since the weight of the frame itself has not been considered, the choice of panels makes a significant difference on the thermal mass of this system. It can be seen that apart from solid concrete blocks, most walling systems have lower or comparable thermal mass to English-bond brickwork (Figure 9).

In the case of roofing, the weight of the ferrocement channels roofing assembly has been calculated with a 25mm channel roof, 75mm brickbat concrete and 30mm cement screed. The assembly has a higher thermal mass compared to RCC filler slabs and precast large concrete panels, where the assembly only contains the slabs and a layer of plaster on both sides (Figure 10).

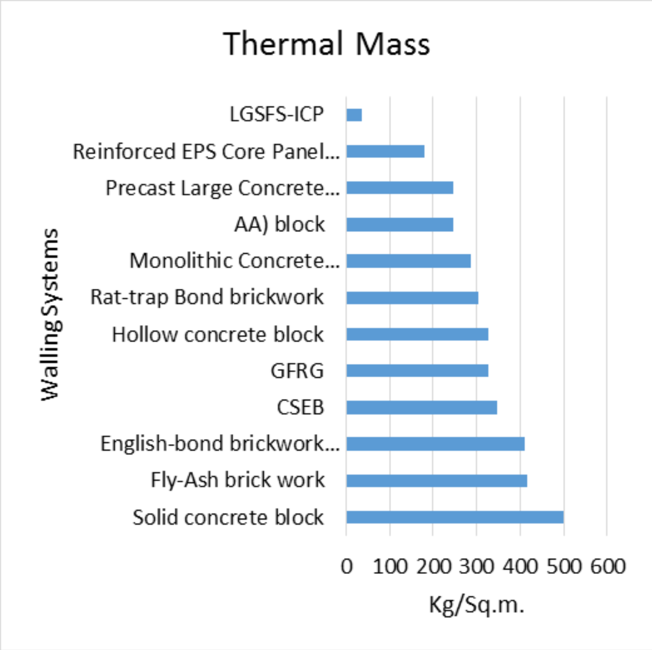


Figure 7: Thermal mass of selected walling systems

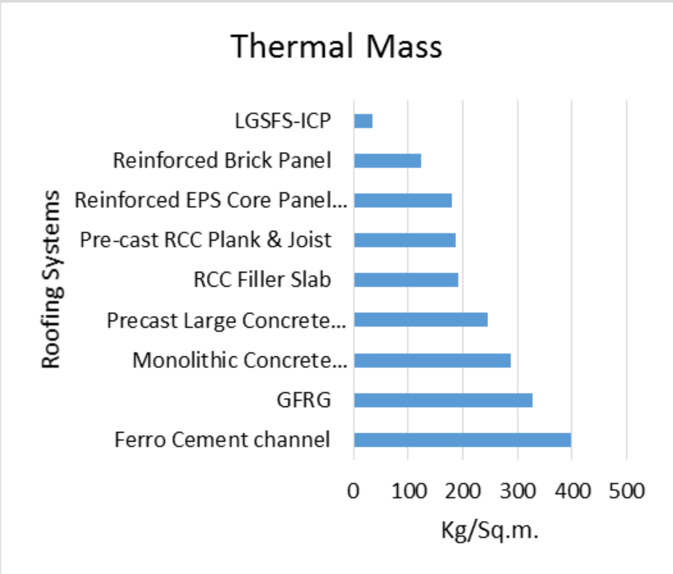


Figure 10: Thermal mass of roofing systems

5. Impact of building materials on cooling and heating loads across housing in 4 different climatic zones

To perform a comparative analysis of the cooling and/or heating energy savings potential of the selected building systems, thermal simulations were carried out to estimate the annual cooling or heating energy consumption (per unit area) of a case study social housing dwelling unit, for the five climatic zones in India. A dynamic thermal simulation engine - Design Builder which is based on EnergyPlus was used to perform the parametric analysis to compare the savings made in heating or cooling energy use by applying selected walling and roofing systems. A split air-conditioning HVAC system (COP-3.26) was modelled and the set-point for the operative room temperature was assigned in accordance with the EN 15251 standards of adaptive thermal comfort.

Occupancy and activity schedules were assumed from national standards, similar research work and homeowner's survey data collected as part of MaS-SHIP. A total of 16 existing and emerging building construction systems were assessed in comparison to the base-case. Comparative analysis between the annual cooling load per sq. m. shows the savings potential for each of these building systems as enlisted in the table below.

The below graph illustrates the saving potentials of the cooling loads that are possible due to the change in the use of walling systems. The base case that has been taken is of a walling system that comprises of 12.5mm cement plaster + 225mm burnt clay brick +12.5 mm cement plaster. Based on the simulations, the cooling energy of the alternative walling systems was calculated.

It is interesting to observe that both AAC blocks and Reinforced EPS Core Panel ensure more than 25% saving potential in all climatic zones.

Reinforced EPS Core Panel systems has the highest saving potential of 39% in the Composite climatic zone. Stonecrete block masonry and Monolithic concrete construction perform the worst with 8% more energy required in cooling than the base case in the Composite zone (Figure 11).

In the case of Warm and humid climates, the saving potential is similar, with Reinforced EPS Core Panel consuming 35% less energy for cooling. The CSEB walling system performs the poorest. With 7% more energy required to cool than the base case.

In the hot and dry zone and the temperate zone a similar case occurs. The walling systems that have the least saving potential are stonecrete block masonry, LGSFS-ICP and monolithic concrete construction.

The base case that has been taken for roofing systems is 100mm RCC + 100mm lime concrete. Based on this the simulations for other roofing systems were evaluated.

The RCC Plank & Joist roofing system is proves to have a constant energy saving of a range of 7-16% in all climatic zones. RCC filler slab on the other hand performs the worst in comparison, with more energy required to cool than the base case in all climatic zones (Figure 12).

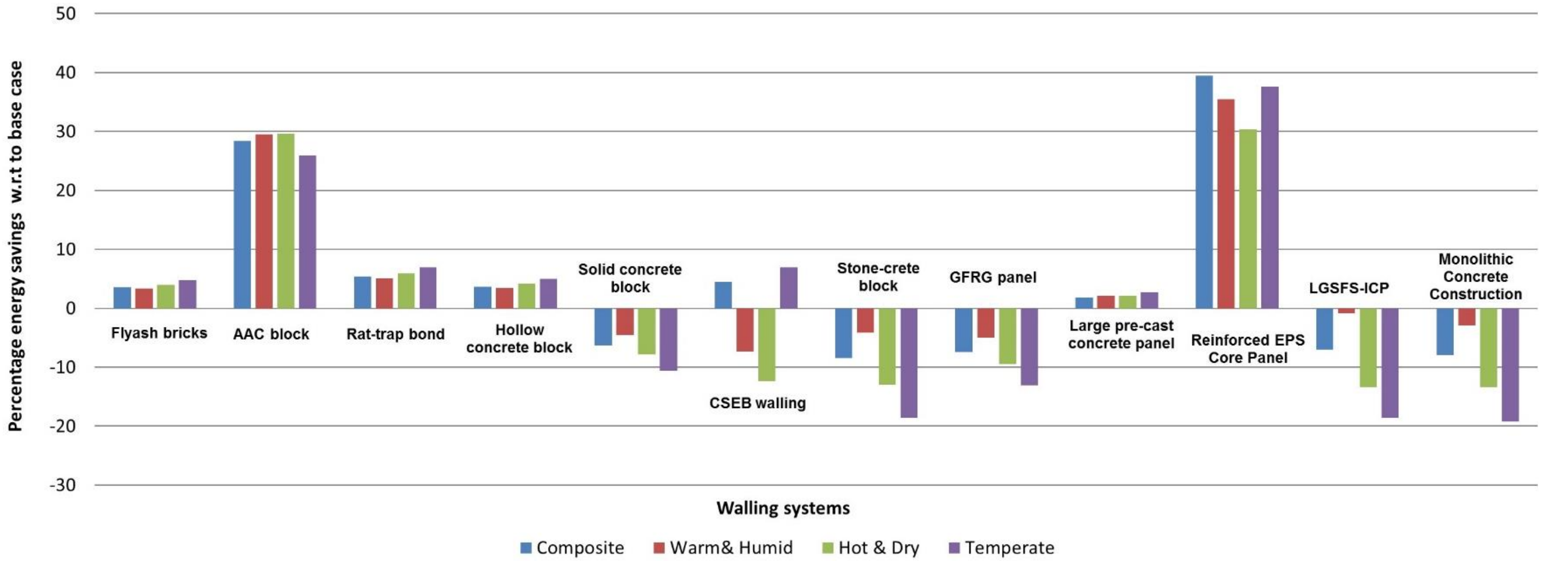


Figure 11: Impact of walling systems on cooling energy consumption w.r.t. to the base case

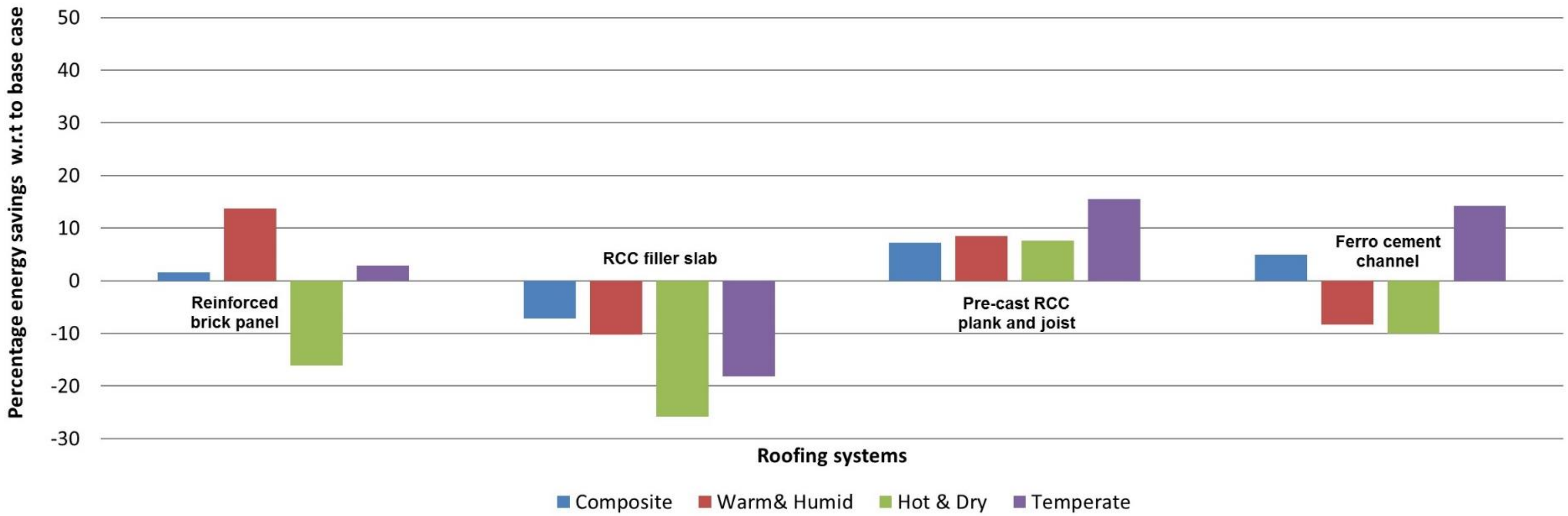


Figure 12: Impact of roofing systems on cooling energy consumption w.r.t. to the base case

Figure 13: Impact of heating loads on selected walling materials

In the cold climatic zone, the selected walling systems fair relatively poorly. LGSFS-ICP requires 66% more energy to heat the dwelling unit than the base case. The AAC in this case compares comparatively better with 13% energy required for heating (Figure 13).

Main Criteria: User Experience

1. Familiarity with the material

Familiarity with the material deals with the degree of inclination towards a building material or technology based on user acceptance. For established systems, it is majorly based on the household responses of maintenance and repair. In the case of emerging materials, only qualitative responses from manufacturers were taken who suggested from their experience, whether there would be easy acceptance of the material.

Tier 3 data was collected through household and building practitioner surveys. Householders were questioned on their experience with the building system used, while the building practitioners were questioned on their likeliness towards using a certain building system. The scale of high, medium and low comes directly from the responses of the householders and building practitioners towards these questions.

Scale	Building Systems
Low	Ferrocement channels, GFRG, Reinforced EPS core panels, AAC blocks, precast RCC plank and joist, LGSFS, monolithic concrete construction.
Medium	Hollow and concrete blocks, RCC filler slabs, precast large concrete panels.
High	English bond brickwork, Flyash brickwork, rat-trap bond brickwork, CSEB, Reinforced brick panels, stonecrete blocks.

2. Modification Ability

This attribute focuses on the suitability of constructed building for adopting changes after construction by occupant, including nail-ability. To be able to make changes like -concealed piping, electrical, and plumbing services, and provision for incorporating the mechanical, electrical and plumbing services within the proposed building component thickness. Qualitative tier 3 data was collected through material specifications and catalogues regarding the maintenance of the building system. Households were questioned on the modification ability of the materials used in the structures of the households.

Scale	Building Systems
Low	Fly-ash brick work, AAC blocks, Solid and hollow concrete blocks, rat-trap brickwork, Precast RCC plank and joist, RCC filler slabs, stonecrete blocks, reinforced EPS core panels, Precast large concrete panels, monolithic concrete construction, ferrocement channels
Medium	CSEB, reinforced brick panels, GFRG panels, LGSFS.
High	English bond brickwork

Most building systems do not allow for modifications post construction, nor perform well in terms of nail-ability. Some systems such as reinforced EPS core panels require specialised tools for creating holes, window/door adjustments and other actions, thus are also not considered easily modifiable. GFRG panels and LGSFS system allows for modularity, thus provide the promise of modifiability in the future.

Main Criteria: Economic Impact

1. Construction cost

Construction cost refers to the costs incurred in production of building components and construction process at site. These vary based on the Schedule of Rates of States[1], but also largely based on the skill requirement as well as availability of labour. However, it is anticipated that with the rising demand in the social housing market and the need for higher speed of construction, the cost of emerging building systems will considerably reduce, thus making them affordable.
In the case of CSEB, the construction cost is relatively less, as the production is usually done on site, thus saving on the transportation (Figure 14). Fly ash bricks have for many years been competing with the burnt clay bricks in terms of cost, and with several incentives as well as the implementation of bye-laws, fly ash bricks have now gradually have a comparative advantage over burnt clay bricks. In case of both walling and roofing

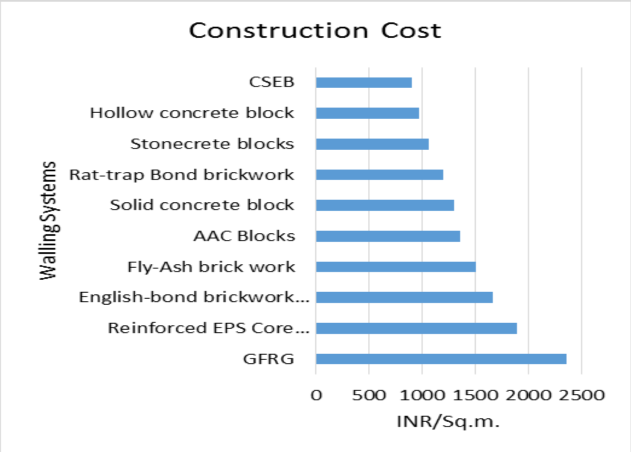


Figure 84: Construction cost of selected walling systems

[1] Please provide reference of 'schedule of rates'

systems, GFRG till date has the highest construction cost, as the market for emerging, prefabricated building systems is still at the nascent stage.

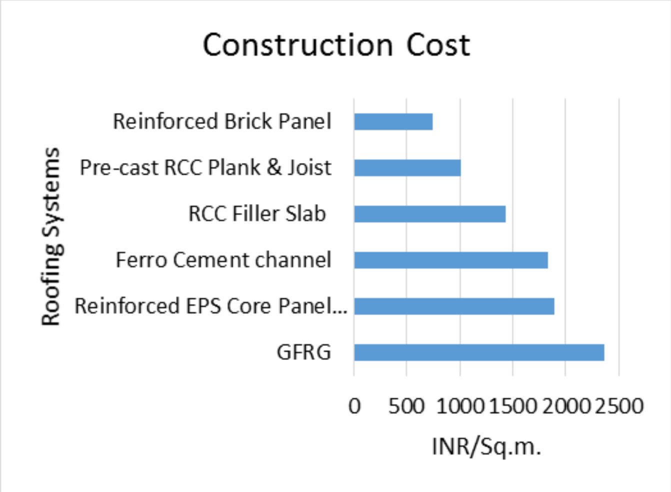


Figure 15: Construction cost of selected roofing systems

2. Skill requirement

Skill requirement looks at the level of skill needed during production and construction of a building material or system. A scale of High, Medium and Low has been established based on the percentage of skilled personnel required in the construction process.

Scale	Building Systems
Low (<20%)	Solid concrete blocks, Stonecrete blocks, Ferrocement channels, monolithic concrete construction
Medium (20 – 40%)	English bond brickwork, Fly-ash brickwork, Rat-trap bond brickwork, Hollow concrete blocks, Precast RCC plank and joist, CSEB, RCC filler slabs, GFRG, precast large concrete panels.
High (>40%)	Reinforced EPS core panels, LGSFS

The installation and set-up of Reinforced EPS core panels requires training in the use of specialised tools and the presence of trained personnel on site. Similarly, the setup of LGSF structures requires special training and supervision on site.

3. Supply Chain

Supply chain is the availability of number of reliable suppliers for a particular building material or system in the very initial stage of construction of the project and in proximity to the project site. For all systems with in-situ production except for monolithic concrete construction, the supply chain has been assumed to be high due to requirement of only constituent materials such as cement, sand, stones, earth etc. which are available pan-India. Manufacturers and suppliers of emerging materials have been mapped across India to locate the nearest sources.

Scale	Building Systems
Low	LGSFS, GFRG
Medium	Monolithic concrete construction, reinforced EPS core panels, hollow and solid concrete blocks
High	Flyash brickwork, Brickwork involving clay-fired bricks, AAC blocks, RCC filler slabs, precast large concrete panels

Building systems which require traditional, well-established building materials such as red bricks, rat-trap bond have been considered as having a well-developed supply chain (high). For systems which require on-site production of components, such as CSEB, RCC filler slabs, ferrocement channels and monolithic concrete construction, the availability to the moulds and moulding machines are the deciding factor for the supply chain (medium). Pre-manufactured components and systems such as GFRG, precast concrete panels, LGSFS etc., which have registered manufacturers and suppliers, have been mapped across India. The systems which only have presence in a few states across India have been considered to have a poor supply chain (low).

4. Duration of construction

The duration of construction has been defined as the time required on site for construction, assembly and installation of a building material or system. This attribute has been measured in sq. meter of built-up area per day from various project details, building practitioners and developers.

All established building systems involving brick or block masonry have a similar speed of construction between 6 – 8 m^2 per day. LGSFS and reinforced EPS core panel values involve the time taken in production of the panels and frames, which elevates the overall time taken per project. If only the time taken on on-site erection is taken, then the speed of construction in emerging systems is considerably higher than the traditional masonry systems.

Comparing the above-mentioned building systems with Monolithic Concrete and Precast Large Concrete panel shows a very different picture, as the systems are capable of high-speed construction, with more than 70m2 being produced and erected on site per day. It should be noted that these values are highly dependent on the production capacity and process of the manufacturing units. In Monolithic Construction, the majority of time is taken in the digital fabrication of the formwork, which is required at the beginning of each project. When formwork of the same specifications is used in multiple projects, the time taken in fabrication is also eliminated.

5. Job creation

Job creation refers to the amount of employment generated both skilled and unskilled in terms of man-days (8hours) per sq m of the built-up area. With the data provided by the manufacturers through the surveys, on number of manpower required for the manufacturing as well as on-site construction, the job creation potential was calculated for each of the building materials and systems.

As is observed from the graph (Figure 16), English bond brick work and rat-trap bond brickwork generate the maximum number of mandays/m^2 thus ensuring that there is a large labour force that is employed. On the other hand, due to high level of mechanisation in production and assembly, highly prefabricated building systems like precast large concrete panels can generate only close to 0.08mandays/m^2. There is definitely a trade-off that needs to be made in terms of speed of construction as well as local unskilled/semi-skilled employment generation. The difference ranges from the scale of production and construction to the kind of skill that is required. In the case of CSEBs, as the blocks are produced on-site, a large work force is required for production of blocks and consequently for construction purposes.

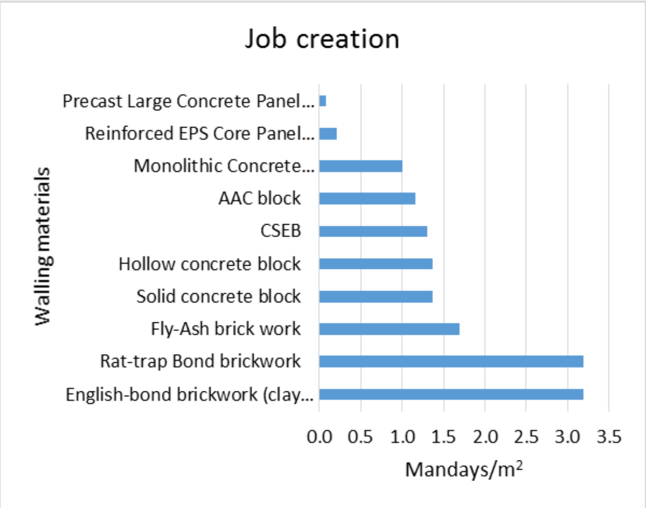


Figure 16: Job creation potential of selected walling systems

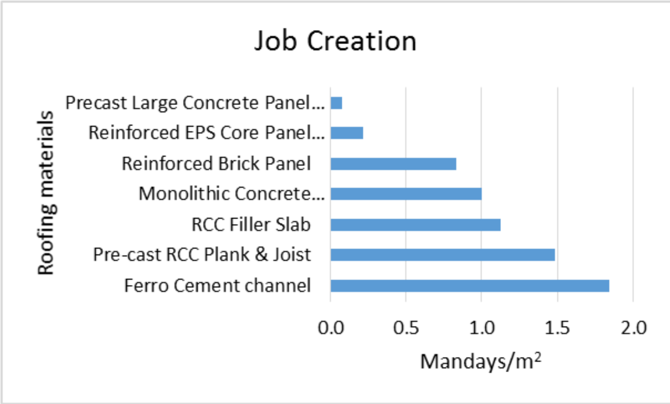


Figure 17: Job creation potential of selected roofing systems

Conclusion

Preferences under the sustainability criteria play a major role in the selection of appropriate building materials and building systems for social housing projects. With the emergence of new and emerging building systems in the Indian construction market, there has been several contentious views on their use and sustainability, especially in the context of social housing.

However, the above comparison suggests that a building system that performs well with respect to resource efficiency may not perform as well with respect to operational performance or cost economics. Even within the four broad parameters, a building system performs at different levels across the defined attributes, for example a system that performs well with respect to embodied energy may not necessarily perform very well with respect to material resource input; and one that performs well with respect to cost of construction may not have a high job creation potential.

A holistic outlook needs to be embedded in the decision-making processes when visualising future housing needs in the time of extreme natural resource depletion and climatic uncertainties. The Sustainability Assessment Tool (SAT) has been built for this very purpose based on a Multi- Criteria Decision support system. The tool provides the targeted beneficiaries with evidence-based performance information, for selecting appropriate building materials and systems, to ensure that the social housing sector grows in a sustainable manner.

MaS-SHIP

Mainstreaming Sustainable Social Housing Project in India (MaS-SHIP) is a two-year research developed to promote sustainability in terms of environment performance, affordability and social inclusion as an integral part of social housing. Funded by United Nations Environment Programme (UNEP) 10 Year Framework of Programme on Sustainable Consumption and Production (10YFP).

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