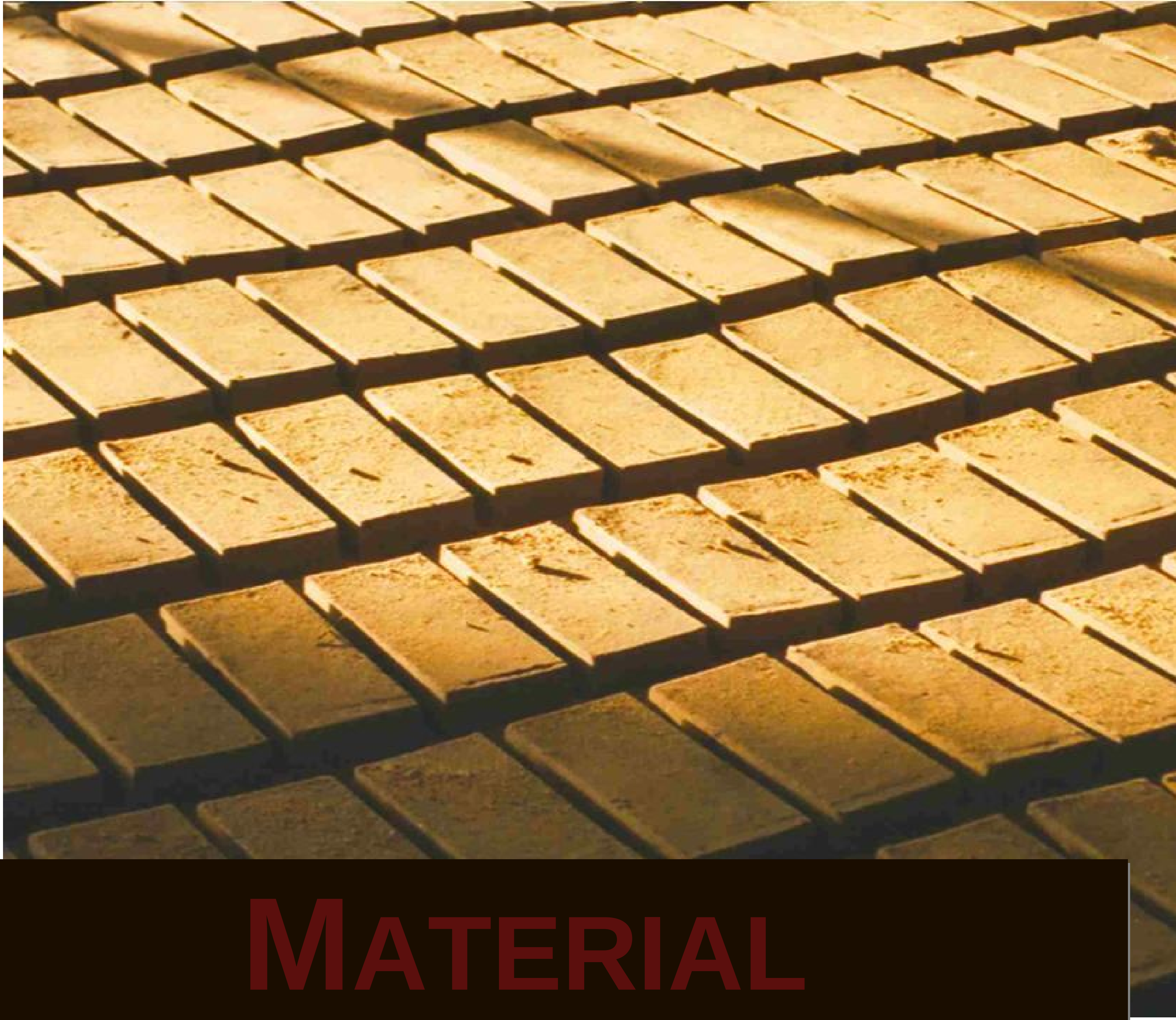

Material And Technology

An inventory of select materials and technologies for building construction

Supported by: Climate and Development Knowledge Network
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TARA / DA RESEARCH TEAM

Core

Pankaj Khanna

Support

Kriti Nagrath
Amol Mangrulkar
Tanu Bhatt
Akanksha Rathee

Advisors

Shrashtant Patara
Zeenat Niazi

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CONTACT DETAILS

Technology and Action for Rural Advancement
B-32 Tara Crescent
Qutub Institutional Area
New Delhi – 110016, India
Tel: 91-11-2613 4103, 2689 0298
www.tara.in
www.devalt.org

Contents

List of Figures

Foreword

With rising temperatures and erratic weather patterns, climate change is one of the most pressing problems facing the world today. Threats associated with climate change are further compounded by the increasing pressure the exponentially growing population is placing on our natural resources. The construction sector, especially, has been identified as a high priority sector for action on this front.

The construction sector registers an annual growth of 9%, contributes 8% to the GDP and generates direct employment for 18 million people in the country. However, it is also responsible for 22% of the total national CO_2 emissions and, hence is intricately linked with looming climate hazards. On the other hand, the impacts of the changing climate like rising sea levels, increased occurrence of severe weather events and natural disasters, severe water shortages, etc. are also felt keenly by the sector and warrants immediate response. At the same time nationally and internationally, construction has been identified as a sector where large savings in energy and carbon emissions are possible.

To tap into this opportunity, there has arisen a need for requisite tools and customized knowledge to enable action at levels from policy to implementation. This inventory presents a range of technologies that can be used in different geo-climatic zones. The eco-friendly technologies in the inventory have been structured according to the components in a building.

- Wall Technologies
- Roof Technologies
- Construction Systems
- Flooring
- Insulation
- Water and Sanitation
- Energy systems

The inventory includes both alternate materials and technologies that offer benefits in terms of the environment and economics, while maintaining efficiency and quality parameters. The technologies have been chosen based on the following key parameters

- Reduced embodied energy and fuel consumption hence reduced carbon emissions
- Reduced environmental damage through optimal resource use and waste utilization
- Better Thermal efficiency and comfort
- Resistant to natural disasters
- Aligned to local production in terms of material and skill availability
- Cost efficiency

The inventory has been designed as a reference guide to designers and habitat practioners in order to assist them in choosing appropriate technologies.

1. Wall Technologies

1.1 Rat-Trap Bond

The Rat-trap bond is a masonry technique in which the bricks are laid in such a manner that a discontinuous cavity is formed between two faces of the wall. Typically, a 75 mm cavity is formed in a 230 mm thick wall. This is done by placing the bricks on edge in a modular fashion (as shown). For the purpose of housing, this system can be used for in-fill walls (in an RCC frame) in multi-storied housing or for single storied row housing. It is also possible to construct single storied housing in reinforced load-bearing Rat-trap masonry, as certified by Anna University in Chennai.

Figure 1: Rat-trap bond wall construction – cavities are left in the wall by a typical arrangement of bricks

Unique Features

- Reduces the number of bricks used, by at least 20%. Together with at least 30% saving in mortar, this technique can reduce the overall cost of wall by at least 25%
- Offers a CO_2 emission reduction to 35 kg CO_2/m^3 of masonry compared to a value of 48 kgCO_2/m^3 for a wall using conventional English bond masonry
- Better insulating capacity because of the cavity

The system requires bricks of good quality with a minimum compressive strength of 50 kg/cm^2 and neatly formed edges. The system can be used wherever burnt brick masonry is predominantly practiced and where the above quality conditions are met.

1.2 Cavity Wall

A cavity wall consists of two layers of masonry, separated by a cavity of varying dimensions ranging from 50 mm to 100 mm. The masonry layers may consist of solid brick, structural clay tile or concrete masonry units. They are bonded together with stainless steel or PVC masonry ties, normally positioned at 900 mm x 450 mm in a staggered fashion (2.5 ties per m^2) The isolation of the exterior and interior layers by the air space allows heat to be significantly absorbed and dissipated in the outer layer and cavity before reaching the inner layer and building interior. The cavity, ranging from 50 mm to 75 mm in width, may or may not contain insulation. It requires larger floor space – a 260 mm cavity wall which replaces a 230 mm thick wall reduces the carpet area of a typical bedroom (3.5 x 4.5 m) by 2%, considering only the 2 outer walls are replaced. However, this quantum of reduction can result in significant improvement in the building envelope, particularly, if applied on the unfavourable west orientation, which will cut into the major part of radiation that falls on building.

Figure 2: Cavity wall with waste thermocol infill

Unique Features

- Significantly improved thermal performance because of the cavity and hence is effective against the climate extremes. The performance of walls can further be enhanced by adding insulation.

The technique is well suited for both wet and hilly and semi-arid regions where extreme heat or cold are common. Although, it may not be feasible for rural houses, it has good potential for use in public buildings, where significant savings in operational energy can be realized.

1.3 Energy Efficient Brick Technology

Most brick kilns in Asia still operate as traditional units with limited investment and awareness about cleaner production systems. Batch-fired clamp kilns are the most widespread kilns in rural areas. These are labour intensive units with low energy efficiency and high carbon emissions. Typically, only a small part of heat is utilized for firing and drying operations while most of the heat is lost, resulting in increased fuel use and emissions, besides the non-uniform quality of bricks. Being a predominant building material in the Indian building sector, it is critical for low carbon construction to include cleaner brick production, through improvements in the technology.

1.3.1 Vertical Shaft Brick Kiln

The Vertical Shaft Brick Kiln (VSBK) is an energy efficient technology for fired clay brick production. It essentially consists of one or more rectangular, vertical shafts within the kiln structure, which functions like a chimney. The green bricks are loaded from the top platform and move slowly down to the central firing zone before being unloaded at the bottom in batches. This technology relies on the principle of counter-current heat exchange between the upward moving hot air and the downward moving green bricks in order to achieve high thermal efficiency and cut down on fuel use.

Figure 3 : VSBK Kiln

Unique Features

- Clean technology - Saves 30% to 50% on fuel as compared to other brick firing technologies
- Significant reduction in pollution levels when compared to other conventional technologies
- High quality production and less breakage percentage

1.3.2 Alternative Fuel for Brick Firing

Many alternative sources of fuel can replace coal and firewood, the most common fuels used to fire a kiln. Alternative fuels can be used to partially replace these conventional fuels by more than 50% of the total fuel quantity. In areas where firewood is already scarce, they can help reduce pressure on the resource. Alternative fuel materials range from agro/ bio-waste like sawdust, husks from coffee and rice, coconut shells, dry stalks; to industrial waste for instance, from the sponge iron industry. Bio-briquettes are another alternative fuel which can be produced through high pressure compression of a mix of locally available coal/ lignite with up to 30% by weight of different biomass.

Finer fuels such as sawdust, husks and coal powder can be added directly to the clay mix. The fuel will burn completely within the kiln and also help reduce the chances of cracking during the drying process. Another way to use alternative fuel is to charge conventional fuels like coal, where the fuel will burn and release a sudden burst of high energy.

1.4 Perforated Burnt Clay Brick

These bricks save the amount of clay used and provide better thermal insulation due to the presence of air cavities. Hollow or perforated brick when provided with reinforcements, can be used for structural applications such as flooring, roofing and walls and also in the form of filler blocks to replace concrete in reinforced cement concrete applications.

Unique Features

- Lower embodied energy as amount of soil per unit volume is reduced by 25 to 40%
- Better thermal efficiency due to cavity in unit

The technology for perforated bricks is in the introductory stages and has not yet been anchored in the Indian market. It can be used in regions where burnt brick masonry is predominant. Although technically, they can be fired in conventional kilns, it needs good research and development support. Also policy support is required so brick kilns are incentivised to invest in the technology.

Figure 4: Perforated burnt clay Bricks

1.5 Earth Based Construction

1.5.1 Compressed Earth Blocks

These are masonry units, made with earth / soil by compressing the soil mix in a manually or mechanically operated press. Depending on the soil press, they are available in various sizes, including the conventional burnt brick size of 230 mm x 115 mm x 75 mm. Given the same thickness of wall, a CEB wall (with internal plaster) has slightly better thermal performance than a burnt brick wall (both sides plaster). CEB walls also enable better humidity control, especially if exposed. The variable nature of soil makes this a sensitive material to work with, but with an appropriate soil mix and adequate production quality control, CEBs are a high quality viable walling option. The Stabilised CEB is well suited for load bearing houses of a scale normally witnessed in rural areas. It is a more durable option than the conventional earth based technique of sun-dried adobe blocks common in rural areas.

Figure 5: CEB blocks

1.5.2 Rammed Earth

Traditionally, rammed earth buildings have been constructed in Himachal Pradesh as a response to the local material availability and comfort requirements in the given climatic conditions. This involves ramming earth, typically in layers of 60-100 cm between wooden/ metal formwork and shifting the formwork up as wall construction proceeds. The potential of this technique has not been realized fully outside a few rural locations where these houses were built more than 50 years ago. This technology can be adapted to present conditions and made more durable by improvised ramming techniques

Figure 6: Traditional rammed earth house in Himachal Pradesh

Unique Features

- Lower embodied energy and CO_2 emissions due to minimal use of high energy materials like cement and non-requirement of firing, unlike the burnt clay bricks
- Least environmental impact as they don't use top soil, which can be restored after extracting lower layers of earth
- Aesthetically appealing due to their superior finish and good blending with traditional building practices in rural areas
- Thermally more efficient than other masonry options

Earth based construction is best suited for regions where the appropriate soil is available and there is trained manpower with a good understanding of the soil properties. Apart from Himachal Pradesh where earth based techniques are used traditionally, SCEB are suitable also for the semi-arid region.

1.6 Stone Masonry

Natural building stones have been extensively used for the building construction in India. They are used most commonly as random rubble stone masonry for foundations and in some parts, also additionally for wall construction. Another form of their use is as dressed stones – ashlar masonry – for walls. The major challenge for stone masonry is its design to resist seismic forces. This involves the use of stones in a particular manner which holds the wall together and also their anchorage with the roof and walls (in case of stone foundations).

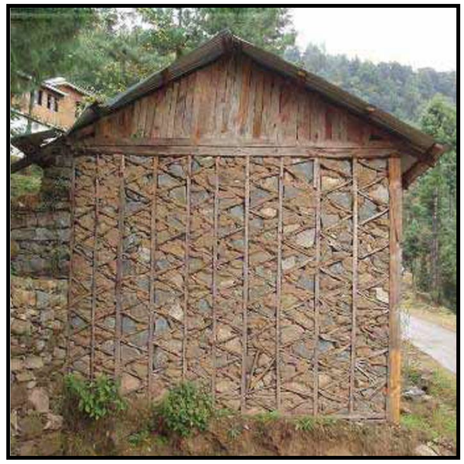

Figure 7: A typical Dhajji Wall

In some parts of Himachal Pradesh, there is a popular use of the Dhajji wall construction. In this construction system, the walls are made of timber frames within-fills of light thin panels made by close packaging of mud mortar, stone and ballast. In case of an earthquake, the small panels distribute the energy evenly. The traditional Dhajji wall (framed wall) construction mode of the region was subsequently improvised by the British for making their colonial edifices. It is an excellent example of vernacular building construction technology which is suitable to Hilly regions and seismic risks zone.

1.6.1 Laterite blocks

Laterite stone have traditionally used after directly extraction from the naturally occurring laterite sources, after which they are cut into brick like shapes for use as walling units. Recently, there has been advancement in using laterite in the form of interlocking bricks used to construct walls without the use of cement mortar. Laterite stone is ground and filtered using a sieve, which is then mixed with 5% cement mixture and a chemical setting agent. This mixture is then machine compressed to form high density interlocking bricks. They are manufactured in two widths of 6 inches and 8 inches; and are also available in varying lengths. Each interlocking brick has grooves and locks on its sides which can be fitted with each other to form a block wall that does not need cement mortar for bonding.

Figure 8: Interlocking laterite blocks for wall construction

Unique Features

- Lower embodied energy due to use of natural locally available materials- stone and wood. The only energy spent is in transportation of materials
- High recyclability factor – specially in case of interlocking blocks which don’t use connecting mortar
- Improvement over a traditional building practice which has proven itself over the years
- Laterite blocks are a good alternative for regions where sand is a scarce material

1.7 FaL-G Bricks

Fal-G bricks are manufactured from a mix of fly ash, lime and calcined gypsum (a by-product of phosphogypsum or natural gypsum). The mix capitalizes on strength augmentation of fly ash-lime mixtures in the presence of gypsum. The bricks are manufactured by mechanically compressing the raw material and do not need firing or autoclaving for curing. Lime and gypsum are both normally obtained as by-products from other industries, the former from acetylene plants and lime stone quarrying and the latter from fertilizer plants, Freon gas plants, etc. Fal-G bricks can be used in all traditional applications of burnt clay bricks and even in cavity walls. They utilize industrial waste like fly ash; have good compressive strength with less water absorption property. Fly ash bricks now have a fairly high acceptability in the construction sector, having been promoted by the government as a mandatory material to be adopted, at least in a 100 km radius of a thermal power plant.

Figure 9: Fal-G Bricks

Unique Features

- Utilization of waste - the predominant advantage of using fly ash bricks is reduction in the embodied energy of building envelope through masonry which incorporates an industrial waste to the extent of at least 50% by weight
- The bricks of superior quality and finish can be made as compared to conventional bricks and can be left unplastered

The bricks are best suited for regions where fly ash is available, preferably in a radius of 100 km, which makes their production economically feasible. It is best suited for the coastal region of the project where it is abundantly available and its feasibility should also be explored for the semi-arid region.

1.8 Sand Lime Bricks

These bricks are produced using a mix of finely ground sand and lime. The mix is moulded under pressure and the green bricks are steam cured. Certain bricks also incorporate fly ash in the mix. Like the fly ash bricks, the advantage of using sand lime bricks is their low embodied energy value as compared to clay bricks. In India, they are available in sizes 190 x 90 x 90 mm and 190 x 90 x 40 mm.

Unique Features

- Save 30% to 50% on fuel cost when compared to other brick firing technologies
- Being of uniform size and shape, they have superior finish and can be left unplastered

Sand-lime bricks need a capital intensive production infrastructure and therefore can be used only where the same can be facilitated. It is preferable to use them in regions where fly ash is available which can then be used in their production.

Figure 10: Sand lime Bricks

1.9 Concrete Block Masonry

Concrete blocks are masonry units made with cement, fine and coarse aggregate used in a lean mix- 1:9 to 1:13 (1 part of cement: 13 parts of sand and stone aggregates) –; mechanically compacted and vibrated. Typically, they are at least 4 times the size of a burnt clay brick and common wall thicknesses possible with concrete blocks are 300 mm, 200 mm, 150 mm and 100 mm. For blocks of given strength, wall masonry is 15-20% stronger than masonry with brick walls, because of reduction in the number of mortar joints. Typically, the blocks produced and cured conventionally would be good only for non-load bearing construction. However, it is also possible to engineer load-bearing low rise buildings with blocks which are produced in tighter quality control regimes, commonly in semi-automatic facilities and then steam cured.

Unique Features

- Low embodied energy compared to conventional burnt brick masonry due to a rationalized use of the critical ingredient – cement. Also, there is good potential to use waste materials such as fly ash, stone dust (from stone crushers), which further lowers the embodied energy
- Their strength can be engineered as per structural requirement, so the quantity of high energy material like cement can be rationalized by using stronger mix for ground floor as compared to upper floor

Figure 11: Concrete blocks

The blocks can be produced wherever cement and aggregates are available, so it has a wide application. However, they are more preferable in regions where good quality clay is not available for burnt bricks. Because of the general easy availability of their ingredients, their use should ideally not be in conflict with long-standing traditional building practices.

2. Roof Technologies

2.1 Micro Concrete Roofing

MCR tile is a cement based roofing material and a high grade alternative to conventional high energy and low durability options such as burnt clay country tiles (khaprail), CGI sheets, etc. Micro concrete is a type of cement concrete which uses fine aggregate – typically less than 6 mm size for the concrete. This is then moulded as a roofing tile which can be used as a cladding material for sloping roofs. With an appropriately designed under structure, MCR roofs can be used for a variety of applications in low cost housing, institutional buildings, factories, parking areas, etc. The tiles are securely tied to the under structure with wires and therefore can also meet performance requirements of roofing in regions of high velocity winds like the coastal belt.

Figure 12: MCR tile roof in semi-arid Bundelkhand as an alternative for burnt clay country tiles

Unique Features

- Low energy and highly durable alternative for sloping roofs
- Can utilize waste materials such as stone dust
- Very well suited to local production through micro-scale production facilities

The technology is particularly well suited for sloping roof applications in the semi-arid and the coastal belt. It already has a presence in the semi-arid region of Madhya Pradesh but needs greater percolation into the building sector as a low carbon alternative material.

2.2 Ferrocement Roofing

Ferrocement comprises of a uniform distribution of reinforcement by use of chicken wire mesh and welded mesh encapsulated in rich cement mortar, thereby achieving significant reduction in both steel reinforcement and dead weight of roof. This composition provides a more uniform distribution of strength as compared to RCC. The roofing system uses pre-cast ferrocement roofing channels of a segmental arch profile which are placed adjacent to each other and spanning over two supports. After partly filling the valley between channels with concrete, the channels form an idealized T-beam and are able to carry the load of a roof or an intermediate floor. As per span of the channel and loading conditions, ferrocement elements can be designed and produced in a variety of profiles. Typically, a channel of bay width 85 cm and rise at centre 30 cm can be used for a span of up to 6 metres.

Figure 13: Ferrocement roofing channel roof in an institutional building (above) and disaster resistant Core house in coastal Orissa

Unique features

- Low embodied energy primarily because of significant reduction in the quantity of steel
- Pre-casting of roof leads to substantial reduction in construction time.

- 20% saving in cost possible because of reduction in steel quantity and elimination of coarse aggregates and shuttering.

It can successfully be used in any geo-climatic region where flat roofs are to be used, but it is most suited to applications where the economies of scale of use can justify the setting up of a decentralized production facility.

2.3 Funicular shells

A Funicular Shell is a 3 dimensional catenary on a rectilinear base. The roofing system consists of doubly curved shells made with materials of good compressive strength such as waste stone pieces and brick tiles, supported on reinforced concrete edge beams. A series of these shells in variable geometric configurations supported on a grid of concrete beams, identical to a coffer slab, provides an attractive roof for small to medium spans.

Figure 14: Funicular shell – various small shell segments can be cast on a grid of beams

Unique Features

- Utilises waste stone to provide a roof which can be very well adapted to structural requirements
- Low embodied energy due to virtual elimination of steel in the slab portion
- Aesthetically pleasing ceilings which can incorporate traditional motifs and don't need plastering/ painting

It is suitable for areas where waste stone is available for utilization. It is particularly well suited for large spans, for instance in community buildings/ halls where a grid of beams can support a variety of funicular shells

2.4 Plank and Joist (Precast RCC)

Plank and Joist is a building system, in which pre-cast RCC slabs – planks- are supported over pre-cast RCC beams – joists- placed across walls. To complete the roof, concrete is then poured over the gaps between slabs and beams, which ties all pre-cast elements together. This technique can easily be adapted by masons who are familiar with similar techniques of placing stone slabs over girders to construct roofs. The pre-cast planks are typically 30 cm wide x 1.5 m long, although the length can vary from 1.2-1.8 m, depending on the size of room. Due to its small size, the plank needs only nominal MS reinforcement; typically 6 mm bar to meet the structural requirements. For joists, a 15 cm x 15 cm section can be used for a span of up to 4 metres.

Figure 15: Precast planks and joists (to be finished with in-situ concrete to finish the roof)

Unique Features

- Low embodied energy because of reduction in steel
- 20% saving in cost possible because of no shuttering and reduction in steel quantity.
- Simple technology – the components can easily be produced using moderate infrastructure

This technique can be used in any geographical region where a flat roof is to be constructed. It is especially well suited, because of the similarity in construction procedure, for places where stone slab roofs are used, like the semi-arid region.

2.5 Pre-cast Arch Panel Roof

Arch Panel roofing is a building system, in which the roof is constructed with pre-cast panels made with burnt clay tiles placed on pre-cast reinforced concrete beams. The arch profile imparts lateral or transverse strength to the panels for distributing the roof load through compressive forces. The panels serve as a lost formwork for the finished roof, after topping concrete has been laid over the pre-cast components. It can be used economically till a span of 5 metres beyond which the beam section becomes uneconomical and it becomes difficult to manually lift the beam.

Figure 16: Precast arch panels in community building (above), view of the ceiling

Unique Features

- Simple technology to replace conventional RCC roof for moderate spans
- Low embodied energy because of 40% less steel- however, the energy content is ultimately determined by the embodied energy of the brick tiles
- Finishes like plaster and paint are not needed

Recommended for areas where burnt clay products are commonly used and produced in good quality – both the semi arid and coastal study area.

2.6 Brick Jack Arches over RCC Joists

Jack arch roof is an old form of roof construction in which the roof consists of shallow (low rise) vaults made with compression materials like burnt bricks or compressed earth blocks, supported on intermediate supports in the form of beams. Unlike regular arches, jack arches are not semicircular but have the profile of a segmental arch. Normally, optimal spans of a jack arch are 1 – 1.5m, with the rise at the centre being 1/4th of the span. The arch is constructed with a formwork unit which slides along the length of the jack-arch as construction proceeds. The series of jack-arches which constitute the roof are usually filled in the valley spaces between them with cement concrete to provide a plane surface above, that can serve as a floor to another level, a terrace or the protective covering for the building. Again to create this kind of roof innovations such as the use of hollow blocks and precast beams can be utilized.

Figure 17: Jack arch roof with burnt clay bricks

Unique Features

- Recyclability
- Low embodied energy
- Locally available resources
- This particular approach can be very cost effective

Recommended for semi arid areas (can be used where good quality bricks are locally available)

3. Construction Systems

3.1 Timber Frame Construction

Figure 18: Traditional composite construction of timber frame and masonry in Himachal Pradesh

Timber framed construction is another traditional building practice of constructing light-weight structures which incorporate a range of infill materials- bricks, stone, earth. It is the method of creating framed structures of heavy timber jointed together with various joints, most commonly with lap jointing, and then later pegged mortise and tenon joints. Diagonal bracing is commonly integrated into the structure to impart structural stability with regard to resisting seismic stresses or other natural hazards. However, due to indiscriminate cutting of forests and presently costly availability of timber, these practices have been made discontinuous in many parts of the country and masonry has taken their place. However, there are traditional composite models of timber frames and masonry which are good low carbon alternatives and also rationalize the pressure on a particular natural resource. Timber under structures for roofing can also be promoted as alternatives to high-energy steel structures.

Unique Features

- Lower embodied energy due to use of natural materials- stone and wood, which are locally available. The only energy spent is in transportation of materials
- High recyclability factor – specially in case of interlocking blocks which do not use connecting mortar

3.2 Bamboo

Figure 19: Bamboo frame and cladding for a community building (above)
A bamboo prototype house developed by Wondergrass

Bamboo is also a traditional building resource in many parts of India. Composites are good alternative to conventional housing component in no. of areas such as non-load bearing wall fill, roof under structure, rafters and purlins. Roof covering, doors and Windows's shutter panels etc. in fact some prototype building systems has been developed which comprises even foundation, columns and floor. The materials include bamboo mat board, Bamboo Mat Corrugated Sheet, Treated Bamboo Post and systems such as roof trusses, wall infill panel, post and beam.

Bamboo and bamboo composites have immense potential to serve as a green building material in housing and construction. Bamboo based housing technology is very much suitable for construction of cost effective houses in earth quake prone areas. Technological support from building professionals and local building artisans are required to put bamboo at its deserving place. Sustainably managed plantation and harvesting in bamboo rich regions can ensure the use of bamboo on a large scale.

Unique Features

- Low embodied energy because of natural material – the main energy component comes from the bamboo treatment or processing into sheets
- Lightweight building material capable of resisting seismic forces through appropriate designed structural connections
- Both the wet hilly regions as well as the coastal region have good bamboo resource and are appropriate for bamboo based construction techniques

3.3 Timber Reinforced Stone Masonry – Hybrid System

Despite being located in a high seismic risk area, certain regions in Himachal Pradesh – Kangra-Kullu area- and Uttarakhand exhibit an elaborate tradition, more than 2 centuries old, of constructing multi-storeyed houses. This tradition represents the traditional knowledge and understanding of earthquake effects on buildings and their earthquake resistant design and have been known to survive many damaging earthquakes in the last century. Generally, ornate multi-storeyed houses with abundant use of wooden beams are characteristic of this form of construction, traditionally known as 'Koti Banal'. For buildings of the Koti Banal architecture, locally available building materials such as long thick wooden logs, stones and slates were judiciously used. The height of these structures varies between 7 and 12 m above the base platform which consists of dry stones. The buildings are characterized by a number of advantageous design features such as regular plan shapes, the sensible use of locally available building materials, and the integration of wooden beams over the total height of the building as well as small openings and the arrangement of shear walls.

Figure 20: Koti Banal architecture – Wooden logs as ring beams between layers of stone, external verandas resting on massive columns

Gravity loads from the floor construction (dead loads) or from live loads on the roof (e.g., snow) are transferred to the massive wall system which basically consists of a hybrid timber-reinforced stone masonry system. In the lower parts of the walls the timber logs are interconnected establishing a very solid cribbage while the timber elements on the upper parts are mainly of a reinforcing purpose. The walls further transfer the loads to a stone-filled base platform which is the continuation of the stone foundation. The system of horizontally pairs of wooden logs which are connected to each other by wooden shear pins/tenons act like a wooden frame which is braced by well-dressed flat stones in between the logs increasing the bearing and lateral capacity of the construction.

Unique Features

- A traditional system designed using principles of earthquake resistant design – very good potential for incorporating the design and construction principles into contemporary rural buildings
- Low embodied energy because in principle the system uses only locally available materials
- The system is best suited for Himachal Pradesh, since it originates from there and uses the naturally occurring materials of the region.

3.4 Disaster Resistant Construction

Resistance to natural disasters is a very important criteria for building design and construction to avoid sudden needs of massive reconstruction after such disturbances. The wet and hilly region and coastal region are prone to earthquakes and cyclones respectively. Such events result in a huge wastage of material resources and also cause a surge of resource exploitation in order to meet the reconstruction requirements. Given a range of locally available building materials in different regions, it is possible to design buildings keeping in mind key aspects of structural strengthening for disasters. Today, there is a reasonably good awareness of the need for disaster resistance of buildings, which needs to be emphasized in the mainstream building design. The approach should be to avoid collapse of buildings, even though they might suffer damage depending on the intensity of the hazard.

Earthquakes

- Tying of walls at corners and by providing horizontal bands at critical levels such as the lintel levels to ensure that individual walls do not suffer out of pane failure due to seismic forces during earthquake, which is commonly the reason for roofs to collapse eventually. The bands can be provided in timber (including bamboo splits) or reinforced concrete and
- Structural connections between basic elements of a building- foundation, walls, columns and floor slab/roof should be such so as to allow safe transfer of the inertia forces generated by the earthquake through the different elements, by imparting the required ductility to them. While the floor slabs and beams receive due attention, it's mostly the vertical elements such as walls and columns which fail under the stress and cause damage to the building.
- The overall shape, size and geometry of a building play a critical role in performance during earthquakes. Simple plans with structurally correct distribution of columns and walls behave the best and irregular shapes have the highest risk of twisting during earthquake and subsequent damage.
- Particularly, in case of rural non-engineered buildings built with local materials, it is critical to ensure that commonly used materials like stone and bricks are suitably reinforced to increase their resistance to earthquakes

Cyclones

Cyclones cause damage to buildings in the coastal belt of India almost every year. Typically, the damage in case of cyclones is caused by components of houses being pulled apart by winds moving swiftly around and over the building. This lowers the pressure on the outside and creates suction on the walls and roof, effectively causing the equivalent of an explosion. Whether or not a building will be able to resist the effects of wind is dependent not so much upon the materials that are used but the manner in which they are used. It is a common belief that heavier buildings, such as those made of bricks and concrete blocks are safer in cyclone prone areas. While it is true that heavier and engineered masonry house offers a better margin of safety than other types of buildings, safe housing can also be provided by a variety of other materials including wood and many others.

- While masonry houses are regarded as safe, in many cases cyclonic winds blow away the roofs, followed by collapse of un-reinforced masonry walls. The walls must be tied together or be suitable reinforced to prevent this.
- In light-weight timber/bamboo houses, the connections between various components are the most critical

- Roofing is the commonest area of failure in cyclones, where in the upward thrust caused by high velocity winds creates a suction effect which lifts the roof. This should be addressed with the right slope of roof adequate fastening devices, adequate sheet thickness and sufficient frequencies of fasteners which tie the roofing to it's under structure.
- Location of buildings is an important factor influencing the thrust of wind on the building. Settlements should be planned and sited so as to preferably be shielded by natural features, such as hills, trees, etc. Also, the site for building should be above the likely inundation level. In case high level natural ground is not available, then construction should be done on stilts with no masonry or cross bracings up to maximum surge level.

4. Flooring

4.1 Terrazzo In-Situ Flooring and Tiles

Terrazzo consists of a topping of stone ships fixed to a binder, which is most commonly cementitious. These are highly durable in nature and low maintenance and have been in common use. However, significantly, because of the stone topping, terrazzo floors can incorporate a high percentage of recycled materials which could be ships of marble, quartz, glass or other suitable hard material. Out of a typically 40mm thick floor, the top 6-8mm layer can be recycled stone chips, while the remaining is cementitious mortar and the base concrete. The terrazzo layer is tamped, trowelled and ground for a smooth finish.

Figure 21: Different types of terrazzo floors

Unique Features

- Utilizes waste
- Low embodied energy
- Locally available resources

Terrazzo flooring is suitable for areas where waste stone is available and can be recycled into the floor – this is possible both in the semi-arid and hilly areas where waste from stone quarries is readily available.

4.2 Wooden Flooring

Wooden flooring is a natural and low carbon option and can be provided in various forms – 100% wood or composite wood floorings which includes various reconstituted wood or other lignocellulose material based products, such as MDF (medium density fibre), HDF (high density fibre) with laminate or veneer. They can incorporate a large recycled content from agricultural/industrial wastes. Wood ply construction ("sandwich core") uses multiple thin plies of wood adhered together, wherein stability is attained from using thin layers of wood that have little to no reaction to changes in the immediate environment.

Also, reclaimed (salvaged) wood can be used for flooring which usually provides a more durable floor than using freshly harvested wood. This is one of the best options for low carbon construction, however, procuring of the same from other building sites is not a mainstream activity and needs to be organized such that recycling of used wooden elements can be practiced more commonly.

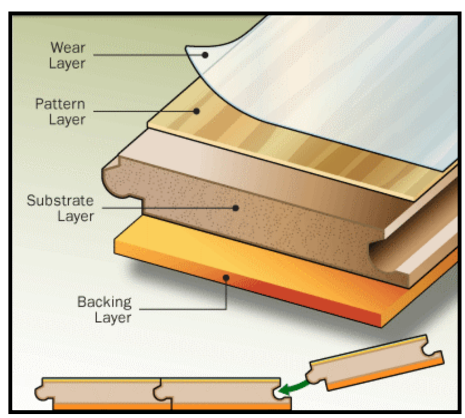

Figure 22: Recycled wooden flooring (above), wooden panel flooring

Unique Features

- Low embodied energy, specially if reclaimed wood is used
- Thermal efficiency – wooden floors provide a thermally more comfortable flooring option than most other flooring materials

It is suitable for use in areas with large reserves of forest, such as the wet and hilly region.

4.3 Bamboo Flooring

Bamboo flooring and bamboo board are relatively new products developed by using modern scientific methods from superior quality bamboo. Bamboo flooring is an attractive alternative to wood or laminate flooring if the bamboo has been locally sourced and also harvested in a cycle which ensures high quality of the product. Bamboo flooring tiles, being produced in India come in a plank dimension of 920 x 92 mm and thicknesses of 12, 15 and 18 mm. A tongue and groove mechanism is used to install the tiles, contributing to easy and quick installation. Bamboo flooring can be solid (made with only bamboo) or engineered (bamboo plus other woods). The benefit of engineered bamboo flooring over solid bamboo is that it uses a fraction of the surface species as compared to the solid bamboo flooring. The National Mission on Bamboo Application (NMBA) is a premier agency at the forefront of developing and standardizing new bamboo based value added products and has stabilized the bamboo flooring technology which is available for commercial production.

Figure 23: Bamboo flooring tiles

Unique Features

- A natural and renewable material, which can be made available for processing in a cycle of 4-5 years and a good alternative to wooden hardwood floors
- Supports sustainable livelihoods and income generation through production of bamboo floor tiles

Bamboo flooring is suitable for both the wet and hilly region and the coastal region, where bamboo is abundantly available.

5. Insulation

5.1 Inverted Earthen Pot Insulation

Figure 24: Inverted earth pots on roof

Maximum ingress of solar heat in tropical climates is from the roof. Covering flat roofs with inverted earthen pots is an easy and cost effective method to reduce solar gain. In this method, roof is covered by inverted earthen pots, placed abutting each other and the intervening space can be filled with cement/ lime mortar and finished with the terracing material. The pots provide increase the insulating value of the roof by virtue of the air gap created by them. Pots made with earth are recyclable and regionally available.

Unique Features

- A low tech and low cost method of increasing the insulating capacity of the roof
- Earthen pots are locally made and boost employment generation

5.2 Mud Phuska

This is a traditional insulating technique for flat roofs where high thermal mass of mud is used to insulate the roof. Suitable earth for this treatment should not contain excessive clay or sand and should be free from stones and organic matter. In this system, the roof is first prepared by cleaning, painting the surface with residual type petroleum bitumen of penetration 80/100 and immediately spreading coarse sand and levelling it while the bitumen is still hot. Subsequently, a layer of puddled mud is applied to slope, maintaining an average thickness of around 100mm, followed by a 25mm thick coat of mud plaster which should be ideally allowed to mature for 7 days before application. This is finished with a coat of cow dung to fill any cracks that may have developed in the mud plaster. Typically, terracing is done over this with burnt clay brick tiles laid in mud mortar till half the tile thickness and the remaining joint is grouted with a 1:3 cement-sand mortar.

Unique Features

- Low cost and highly thermally efficient technique very effective for insulation of roofs
- Low embodied energy technique as compared to all other insulation options

5.3 Broken China Mosaic Terracing – Cool Roof

Terracing is most commonly done with materials of high emittance and low reflectance such as burnt brick tiles, plain cement screed. Thermal performance of roofs can be enhanced further by using roofing finishes with high solar reflectance or ‘albedo’, combined with high emissivity. The primary purpose is to reduce the amount of heat absorbed by the roof surface – a ‘cool roof’ will typically reflect 80% of the incident solar energy as compared to 20-40% by a conventional roof. Using broken china mosaic, typically a post consumer product can be used as a cost effective external roof finish to reflect the incident solar radiation. Well-graded broken pieces of glossy glazed tiles, preferably white, are embedded in wet mortar to provide a smooth surface that does not undulate. The joints are then grouted using cement mortar

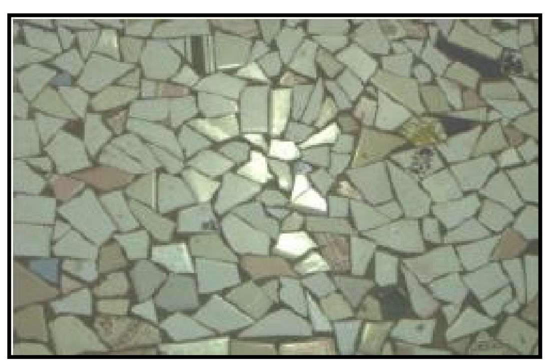

Figure 25: China Mosaic terracing

with waterproofing material. Broken China or light-colour tiles with high SRI (solar reflective index) of 50 percent or more reflect heat off the surface because of high solar reflectivity which prevents heat gain.

Unique Features

- Recycles waste gazed tiles – low energy cool roof technique

6. Water and Sanitation

6.1 Twin Pit Water Seal Toilet

Figure 26: Twin pit toilet

The “Twin Pit Water Seal Toilet” is a system where in the excreta is transferred to two leach pits under the ground. The pits are made in honey-combed brickwork for the leaching action and are used alternately, while one is being used, the other is left unused for the excreta to decompose. So, after a cycle of about 1.5 to 2 years, one pit can be emptied and the decomposed matter can be used as organic humus/ natural manure, which is safe for manual handling. The main components of such a toilet are the water seal pan/ trap arrangement, squatting platform, junction chamber, two pits and a superstructure. The squatting platform is a raised pucca floor constructed with appropriate plinth and foundation. The pan has a steep bottom slope which allows easy flushing of excreta. The junction chamber, located just outside the toilet structure, has one inlet connected to the P-trap and two outlets connected to the 2 leach pits.

Unique Features

- Simple technology for ecological on-site disposal of human waste
- Low cost technology

The technology is most suitable for regions with sandy soils which are conducive for leaching of wastewater from the pits – can be applied in all the three regions, depending on the sub-soil strata.

6.2 Eco Sanitation

Figure 27: (Above) Ecosan toilet on a raised platform with waste storage below
(Below) Ecosan pan for waste separation designed by Biome

Ecological sanitation, or Ecosan, is a new paradigm in sanitation that recognizes human excreta and water from households not as a waste but as resources that can be recovered, treated where necessary and safely used again. Tailored to local needs, ecological sanitation systems, ideally, enable a complete recovery of nutrients in household wastewater and their reuse in agriculture. In this way, they help preserve soil fertility and safeguard long-term food security, whilst minimizing the consumption and pollution of water resources.

The basic principle of the Ecosan toilet is separation of faeces and urine and separate storage of the two wastes and then application of the nutrients contained in human waste as manure and fertilizer in agriculture. Typically, the toilet is built on a raised platform, about 1m high, to create storage space at the ground level for the waste. The faeces are stored and decomposed for a period of around 6 months and urine is diluted with water before use. The toilet has a special pan to separate the solid and liquid waste. The major challenge in the success of Ecosan is the social and habitual change which the user should be comfortable with during use of toilet and later, to recycle the nutrients.

Unique Features

- Promotion of recycling by safe, hygienic recovery and use of nutrients, organics, trace elements, water and energy.
- Appropriate sanitation solution for areas of high water table or soil types where leaching of waste is not feasible.

6.3 DEWATS

Decentralised Wastewater Treatment System is both an approach and technology to provide on-site treatment of wastewater through a combination of aerobic and anaerobic techniques, without the energy requirements of conventional sewage treatment plant. It is capable of treating wastewater flows from 1 to 500 m3 per day from both domestic and industrial sources. Systems are small, individual or cluster type wastewater facilities to provide wastewater treatment services to residents. In the decentralised wastewater treatment systems, essentially, the black water from toilets/urinals and the grey water from washing areas/bathrooms are separately collected and treated through different modules of the treatment system.

Figure 28: Anaerobic baffled reactor and root zone treatment module in the DEWATS system

Typically, there are four treatment modules in the system – 1. Sedimentation and primary treatment in sedimentation ponds or septic tanks, 2.Secondary anaerobic treatment in fixed bed filters or baffled septic tanks, 3.Secondary and tertiary aerobic/anaerobic treatment in constructed wetlands (sub-surface filters wastewater is treated by passing through root zones of plants) and finally, 4.Secondary and tertiary treatment in polishing ponds. There is also a possibility of utilizing biogas from the anaerobic modules such as the baffled septic tank. The space requirement for this system is approximately 5-10m2 per m3 of wastewater to be treated.

Unique Features

- Natural wastewater treatment technique without any mobile parts or operational energy requirements
- Appropriate sanitation solution for areas where skilled and responsible operation and maintenance cannot be guaranteed

The system is most suitable for community based sewage treatment requirements such as a housing settlement and institutional buildings and can be used wherever the space required is made available.

Figure 29: Community assisted rainwater harvesting tanks in Jhabua, Madhya Pradesh

6.4 Rain Water Harvesting

Rain water harvesting has a range of techniques for storage of rainwater or recharge of groundwater aquifers with rainwater. Most of these techniques are simple in concept and implementation and have a rich traditional base in India, which has eroded over the years in the wake of unsustainable exploitation of ground water resources. The collected rainwater can be either be stored or recharged depend upon the suitability of the region, geological strata and rainfall distribution in the region. It is better to recharge collected water to the areas where rainfall occurs only 3-4 months of monsoon and its better to store where rain falls throughout the year.

Typical elements of a rainwater harvesting system are the 1.Catchment which receives rainfall directly, 2. Conduits which are pipelines or drains that carry rainwater from catchment to the harvesting system, and 3. Storage/ recharge facility. The recharge can be done through any suitable structures like dug wells, bore wells, recharge trenches and recharge pits. The semi-arid regions of India, which face water stress today, have traditionally harvested water through different community assisted and maintained structures which were part of the larger planning of settlements with respect to their geographical locations.

Figure 30: Rooftop rain water harvesting in a government school building

Unique Features

- Fulfils needs of drinking and other household needs of water without creating a negative balance of underground water resources
- If implemented on the right scale, water harvesting has great potential to reverse the downward spiral of water scarcity
- Typically, water harvesting structures are low cost and therefore have a very favourable cost-benefit ratio.

Water harvesting is applicable to all the study regions, wither in the form of storage or recharge

7. Energy systems

7.1 Smokeless Stove

Cooking in rural areas, using conventional firewood based stoves is highly polluting with CO2 emissions and also causes respiratory damage to health of users, particularly women. Smokeless stoves are the improved version of conventional stove which, typically has two cooking chambers (usually also integrating the steamer) and a vent pipe in provided at the side or rear of the stove for letting smoke out. By confining combustion to an insulated and enclosed area, the stoves increase the core temperature and thereby achieve more complete combustion of the fuel, thereby allowing a smaller amount of fuel to burn hotter, while producing less ash and smoke. Depending on the stove model, this can reduce indoor air pollution up to 90% and cut down firewood consumption by more than 50%. The technology can further be enhanced by using biomass based briquettes as fuels instead of firewood. Although, the stoves can be made with locally available materials, but in order for large scale adoption which would need organized manufacturing and distribution from a production facility, material options need to take into account reducing the weight of the stove.

Figure 31: One of the models of a smokeless stove

Unique Features

- Reduces indoor air pollution in rural households
- Environmentally sound due to reduction in fuel consumption and resultant CO_2 emissions
- Can be made easily with locally available inexpensive materials

The technology is suitable essentially for all rural areas, wherever stoves are used for cooking.

7.2 Solar Technologies

Being a tropical country, India has abundant solar energy throughout the year – 1500-2000 clear sunshine hours in a year, which can be harnessed for solar power. The Govt. of India's National Solar Mission aims to deploy at least 20 gigawatts (GW) of solar projects by 2020. This strategic initiative is part of the country's plan to provide power to millions of citizens lacking access to energy sources, as well as to combat climate change. Solar photovoltaic and solar thermal collectors are two primary solar based applications which can be used to displace firewood and fuels like kerosene and offset carbon emissions in the process.

7.2.1 Solar Photovoltaics (PV)

Solar PV technology uses PV modules composed of a number of solar cells containing a photovoltaic material, most commonly Silicon. The dominant application for solar PV is the solar home system (SHS). Apart from SHS, solar home lighting and PV-battery charging are prominent application of the technology in the buildings sector. Battery charging programs allow rural residents to purchase or rent batteries to provide electricity to their homes, and then recharge them at PV-powered charging stations.

Figure 32: Solar lantern with the accompanying solar PV module

Solar Home Systems involve the installation of PV systems of 30 to 50 peak watts (Wp), each, in individual homes, mainly in rural areas. For instance, a typical solar-home-system sold by SELCO in India has a 35 Wp PV module and a 90 Ah/12 V battery to power four 7 W

DC fluorescent lights for about four hours per day and a socket. Although, the technology is still expensive, but through the available credit systems, it can be feasible, considering a typical solar PV system is equivalent to buying a 25 year supply of electricity.

Kerosene lamps or other fuel based devices are the most common means for lighting in areas without access to electricity. These are not only polluting in nature, but also a fire hazard and costly to operate with rising fuel prices. Solar lanterns are rechargeable lighting devices which combine a PV module (power rating 0.3 to 1.5 Wp), battery and a charge controller in a single compact unit. This can provide 4-15 hours of lighting from a day of charging and can be used both for task lighting and ambient night lighting.

7.2.2 Solar Thermal Collectors

A solar thermal collector is a device which provides hot water by collecting solar heat onto a closed collector compartment through which water required to be heated is run. For use in buildings, it is available either as a 'Flat plate' collector or an 'Evacuated tube' collector which has significantly higher capacity than flat plate collector. This is a commercially viable and technologically mature product which has been in the Indian market for many years. However, it is still far from meeting its potential in the country, particularly in the residential building sector. The commercial and institutional sector comprising of hotels and hostels have been more forthcoming in adopting this technology.

Figure 33: Evacuated tube type solar thermal collectors at a hospital in Dharmsala, Himachal Pradesh

A single collector system typically provides water at 40-50oC and replaces an equivalent of 5-6 kWh of heat on an average (conventionally provided by one to two geyser installations). It may save an energy equivalent of 900-1800 KWh at the minimum per year. The smallest solar water heating system will have a saving in equivalent of coal burning of 1350 to 2700 Kg per year of use. 1 m2 of collector area, on an average, provides 60 litres of hot water per day.

Unique Features

- Solar based technologies are a clean emissions-free option with a massive potential to replace non- renewable and polluting fuels like coal and kerosene.
- Although solar PV is expensive, solar thermal technology is affordable with an attractive payback.

Although the suitability of solar technologies depends on the available solar energy, solar PV is suitable for all the three regions. Solar thermal is best suited to Himachal Pradesh's climate where the hot water requirement is higher than semi-arid and coastal region. However, for the service sector such as hotels and hospitals, solar thermal is also suitable for all regions.