5 EVALUATION OF TECHNOLOGY OPTIONS: KERALA

5.1 Introduction

This chapter presents a comprehensive evaluation of the prevailing building process in Kerala and proposes two sustainable building alternatives. The evaluation has been done using a methodology based on the conceptual framework from chapter 2. The analysis and discussions on the public housing schemes in Kerala (chapter 3 and 4) urge the need for feasible technological options for affordable housing. This argument also confirms the findings of Gopikuttan (2002, 2004), who argues that a clear understanding of the technology suitable to the specificities of the state is inevitable for meaningful public intervention in the housing sector of Kerala. Above all the inter-relationship between technology and wider socio-cultural, economic and environmental factors need more attention in the context of sustainable development. All this necessitates a thorough evaluation of the technological options based on the concepts of sustainable development.

This chapter is organized in six sections. Section 5.2 presents the evolution of the present building process in Kerala. This is followed by (Section 5.3) an overview of the popular technological options in housing. The succeeding section deals with the analysis of these building alternatives (Section 5.4). It has been done in two stages. The first phase is an evaluation of the prevailing building alternatives based on the conceptual framework. However, in the second phase, a categorization or grading of basic building materials and technological alternatives based on embodied energy has been done. On the basis of this, section 5.5 comes up with certain specific considerations for the selection of new building alternatives and proposes two sustainable building alternatives. They are (i) Rice husk ash (RHA) Pozzolanas; a partial replacement for cement and (ii) Straw bale (SB) construction; an alternative technique for walls. Basic details of straw bale construction and few examples from the Netherlands and India are presented as appendix 5.2 of this chapter.

5.2 Evolution of the present building process: Kerala

This section presents an overview of the evolution of the prevailing building processes in Kerala followed by a quick insight into the history of present technology.

5.2.1 *Traditional building process*

Traditional Kerala architecture is based on the principles of Vastu Sasthra (science related habitation). It considers the astrological placement of the Sun, Earth, and other planets during the actual construction along with the location of the site, its shape, the proposed building's shape, the facing direction of the building, the location of gates, entry doors, doors to each room, windows, and the general design of the building. The basic theories of Vastu Sasthra are closely connected with astrological principles. Therefore, deviation from the accepted rules was believed to cause detrimental effects to those who use the building or the artisans who had constructed it. Thus the technology demanded highly skilled craftsman and precision in the entire work. The whole process was under the control of a head craftsman. Also the building process was based on caste-related social customs and traditions. It had a great influence on the overall building process, such as the type of buildings, materials used for construction, technologies employed, labour involved etc. Absence of wage labour relations and the supremacy of the caste system was a distinguishing characteristic (Harilal et al., 2000; 2002). Houses belonging to each caste had a common name of identification revealing their appearance and technology used. The quality and size of houses diminish as we go down to the caste scale. The "Pulaya's" (lowest division of caste) hut was considered as the smallest unit of accommodation (Government of India, 1891). The caste system provided the framework for occupational division of labour. Only the upper class enjoyed the privilege of employing the services of artisans, and the poor people used to build their houses with self-help or mutual help using locally available materials. This situation continued till the early 1970s.

5.2.2 *Modernisation of the building process*

The social reform movements and the larger process of modernisation of Kerala since independence and later the formation of Kerala state had effectively overcome many social and caste-based restrictions in all sectors of life including the building process. Following the 1973 hike in oil prices, the majority of youth from Kerala migrated to the gulf countries in search of better employment opportunities and there was a significant inflow of remittances to the state from the Middle East. Income windfalls and exposure to the outside world brought out greater changes in their aspirations, desires and preferences. A major part of the investment at that time was in the housing sector. Average prices of indigenous building materials (sand, clay) increased by about fifteen to twenty times during this period (1978-80). Free access to the natural materials was denied and traditional practice of community co-operation in house building became non-practicable. At the same period, the factory-produced materials (cement, steel) showed an increase of less than ten fold (Gopikuttan, 2002). The share of construction sector in the gross domestic fixed capital formation of Kerala for the last two years of 1970 was more than 90% (Gopikuttan, 1988).

The number of new residential buildings has also showed a steady increase. This housing boom was the combined effect of economic, social, institutional and cultural changes occurring during those days. Land reforms conferred ownership on land to those who had earlier been landless labourers. Also the popularity of One lakh housing scheme generated the importance of having own houses, even among the economically weaker sections. These social changes and subsequent investments in housing favoured the excessive use of energy-intensive building materials like cement, steel and bricks, replacing the traditional materials. Table 5.1 gives a picture of the changes in the material use pattern from 1961 to 2001.

Table 5.1 Changes in material use pattern in Kerala (in percentages)
Source: Census of India 1961, 1991 and 2001

Building elements	**Traditional materials (Lime, mud, grass, thatch, bamboo, wood)**			**Modern materials (Burnt bricks, stone, tiles, concrete, GI and other metal sheets)**		
	1961	1991	2001	1961	1991	2001
Roof	74.1	25.2	11.2	25.9	74.8	86.1
Wall	63.7	35.4	30.4	36.2	62.7	68.5

The modernisation of the building process during those periods opened up a new era of technology in the housing sector of Kerala. It resulted in the vanishing of environmentally-friendly Kerala architecture. The most adverse effect of this process was the excessive dependence on energy-intensive building materials. Only 0.1% of houses had concrete as roofing material in year 1961, but the latest census reports shows figure of 26.5% in 2001 (Government of Kerala, 2004). These changes in the technology consequently generated changes in the employment sector and the wage structures, especially in the rural areas, and intermediaries or agents emerged for all sectors of the building process, including supply of materials and labour. As a result, even for small constructions except kutcha houses, the households are forced to depend on these intermediaries, and this further increased the cost of construction. Wages of skilled labourers increased many-fold. Also this modern technology with its undue stress on costly and energy-intensive materials like steel and cement is not affordable to the majority of the population. In addition to this, these materials consume large amounts of non-renewable natural resources like energy, minerals, and topsoil affecting the environment. In order to overcome these problems and to solve the urgent housing demand, the government of Kerala promoted cost effective construction techniques and innovative materials.

5.2.3 *Emergence of Cost Effective and Environmentally Friendly (CEEF) technology*

The paradigm shift in the housing policy from a public housing approach to the one based on aided self-help during the beginning of 1980s also facilitated the introduction of cost-effective technology in the housing sector of Kerala. Several non-governmental organizations sprung up in early 1980s with affordable technological options. Mr. Laurie Baker, a well known British-born architect, settled in Kerala, took the lead in this effort. Based on his principles, Alternative Technology (AT) initiatives and institutions like Centre of Science and Technology for Rural Development (COSTFORD) and Nirmithi Kendra came up in the eighties to save the poor from the exploitative tendencies of the intermediaries (Gopikuttan, 2004).

5.2.3.1 Centre of Science and Technology for Rural Development (COSTFORD)

COSTFORD is registered as a non-profit voluntary organization in 1984 under the chairmanship of Mr. Laurie Baker. It has a taskforce of people from different disciplines such as architects, engineers, economists, geo-physicists, scientists, advocates, accountants, doctors, industrial consultants, educationalists and social workers. COSTFORD, in general, has two main foci of activities, namely, social activities and construction activities using appropriate building technologies. The focus is to empower and enable the weaker sections of the society to improve their living conditions by the application of appropriate and people-friendly technologies. Promotion of non-commercial building practices, which discourage the role of intermediaries from the building process, is also among their priorities.

For their core activities, COSTFORD is supported by the Central Government departments like Department of Science and Technology and the department of Rural Development together with the department of local Self Government, Government of Kerala and Housing and Urban Development Corporation (HUDCO). For activities such as training they get funding from the State Department of Science and Technology.

5.2.3.2 Nirmithi Kendra

The devastating flood during the year 1985 and the consecutive rehabilitation works connected with it in the coastal areas of Kollam district opened up a new era of cost-effective and environmentally-friendly (CEEF) building technology through Nirmithi Kendras. India's first "Nirmithi Kendra" (Building Centre) was set up in Kollam for bringing out affordable solutions for housing. Arising from the success of the Nirmithi movement in Kerala, the ministry of urban development and HUDCO decided to start a national programme of setting up a net-work of building centres through out the country. Later in 1989, the Kerala State Nirmithi Kendra (KESNIK) was established as an apex body to all the District Kendras. At present there are now twenty eight centres in the State with nine centres under State Government, Fourteen under District administration and five under the control of different non Governmental organizations. These Kendras were started with the following objectives.

- Technology transfer from 'lab' to land
- Dissemination of these technologies to the masses
- Skill up-gradation and training for artisans in innovative and cost-effective technology options
- Production of cost-effective building components using local resources and making these available through local sales outlets
- Construction of housing and public buildings using the trained workforce and the components produced by the building centres
- Provision of guidance, information and counselling to people on proven, innovative and cost-effective building materials and technology options.
- Effective utilization of locally available building materials.

Box 5.1

Cost Effective and Environmentally Friendly technology (CEEF)
(Source: Collin, 1999)

The appropriate technology propagated by the Nirmithi Kendras emphasizes cost effectiveness and environmental friendliness in the building process and is popularly known as Cost Effective and Environmentally Friendly (CEEF) technology. It is distinctive in (i) the use of locally available materials, (ii) minimizing the use of energy intensive materials like cement and steel, (iii) ensuring local participation, (iv) combining traditional architecture with modern styles and (v) designing the building according to the lay out of land.

CEEF technology buildings in Kerala are characterised by brick masonry walls (without plastering) with rat-trap bond or Flemish bond, filler slab roofs and pre-cast cement concrete door/window frames. Pre-cast lintels and use of brick arches or corbelling is a common feature of CEEF buildings. Natural ventilation in the rooms is facilitated through artistically designed brick jalis (small openings in the brick walls) and there by reducing the use of glass.

The organisational structure of Nirmithi Kendras is in the form of a charitable society registered under the Scientific and Charitable Societies Registration Act 1955 (ACT XII). Their financial needs were met by tying up with various training, employment generation and rural development schemes for production of building materials and construction of low-cost houses. Each Kendra gets an initial grant of Rs 200,000 (roughly € 4000) the from central government through HUDCO in addition to the state government allotted grant and 1.5 to 2 acres of land for setting up the centre.

International recognition was accorded to Nirmithi Kendra when the United Nations Commission for Human Settlements at its fourteenth session in Nairobi (May 1993) adopted a resolution recommending governments to set up institutions modelled on the Building Centres at the national, provincial and grass root levels. Later in 1996, Nirmithi movement was declared as a Global best practice by UNCHS at the Second United Nations International Conference Convention on Sustainable Human Settlement which held in Istanbul.

In line with the initiatives of COSTFORD and Nirmithi Kendra several other appropriate technology organisations also came into active involvement in the building scenario of Kerala. Habitat Technology Group established in 1987 as a charitable agency, committed to the concept of green and humane architecture is a major organisation among them.

The National Housing and Habitat Policy of 1988 encouraged all the state governments to facilitate the training of construction workers by administering development programmes through Building Centres, and promoting the decentralised production and use of low-cost building materials from local resources.

The appropriate technology initiatives in Kerala are based on the assumption of abundant supply of labour and availability of indigenous building materials. Their focus is to create maximum employment opportunities and to provide livelihood security to the poor by constructing their own houses. The government of Kerala supported the AT initiatives in the state through financial assistance and providing facilitative environments. Most of the public housing schemes are also formulated with a concept of utilizing the options of CEEF technology. The evaluation of the public housing schemes in Kerala (chapter 4) shows that despite the continued efforts of CEEF technology institutions in the state, the dissemination of these technologies to those houseless people who are in need of affordable solutions has not been very successful. It clearly points towards the difficulties of the poor households in accessing affordable technological options. These aspects urge the need for modifying the present CEEF technology options to suit the needs of end users. Selection of materials and technologies for the building construction should satisfy the felt needs of the user as well as the development needs of the society, without causing any adverse impact on environment (Reddy et al., 2001).

5.3 Popular building alternatives in Kerala

A mixed mode of construction can be seen in the traditional buildings of Kerala. The stonework was restricted to the plinth and laterite[1] was used for the walls. The roof structure in timber frame was covered with palm or coconut leaf thatching for most buildings and rarely with tiles, only for palaces or temples, till the mid of twentieth century. The exterior of the laterite walls were either left as such, or plastered with lime mortar. Mud construction was also one of the most common methods of making cost effective and sustainable habitat in the ancient days in Kerala. Since earth or soil is readily available everywhere, it can be utilized for constructing a very good monolithic, sustainable structure. The indigenous adoption of the available raw materials was the dominant feature of traditional constructions in Kerala.

The natural building materials available for construction in Kerala are stone, laterite, timber, clay and palm or coconut leaves. Granite is a strong and durable building stone; however its availability is restricted mostly to the highlands only. However, laterite is available in most parts of Kerala. The quarrying and extraction of these two are less energy intensive, and it does not require much skilled labour. So it can be used for foundations and superstructure, in places where it is locally available. Cement, steel, and bricks are the other popularly used building materials in Kerala for the last three decades. The CEEF technology initiatives in the state since 1980 opened up the market for alternative materials such as ferro cement, hollow and solid concrete blocks, rubble filler blocks and most recently, for interlocking blocks. The recent interest in promoting traditional mud construction is a positive sign towards sustainable building process in Kerala.

5.3.1 Foundation and basement

The superstructure of a conventional residential building in Kerala with 23 cm thick brick wall is usually constructed by keeping the wall centrally over stone or laterite masonry basement of 45 cm (both width and thickness) in normal soil conditions. The cost-effective construction techniques promoted by Laurie Baker put forward the suggestion of keeping the brick wall flush with the outer side of basement. This arrangement can not only enhance the inside room area but also prevent the entry of rain water to the foundation through the joints between basement and wall.

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[1]Laterite is a surface formation in tropical areas which is enriched in iron and aluminium and develops by intensive and long lasting weathering of the underlying parent rock.

According to Central Building Research Institute (CBRI), New Delhi, a 30 cm thick stone foundation can be an affordable option instead of a 45 cm thick foundation, without compromising the strength. Utilization of mud mortar instead of cement mortar in foundation is a popular cost effective option adopted for low rise buildings in Kerala. Reinforcing the soil in the foundation trench with layers of bamboo can be an alternative foundation in places were stone is not locally available and bamboo is plenty. This technology is widely practiced by COSTFORD.

Sand piles (load bearing), arch foundation and stub foundation are the other alternative options for foundations. Arch Foundation can be either made of brick or stone masonry depending on the availability of material and the load to be transmitted. In this type of foundation the walls are supported on arches springing from a series of square cement concrete bases. The load from the superstructure is transmitted through these arches and distributed to the ground through the foundation bases. Stub foundation consists of a series of brick or stone masonry stubs resting on cement concrete bases. At the plinth level they are tied by a grade beam. Both arch foundation and stub foundation are labour intensive and suitable for good soil conditions and low rise buildings.

5.3.2 Walling or superstructure

The conventional technology for walls in Kerala is brick masonry in English bond• or laterite masonry. Rat-trap bond masonry is an innovative and popular technological option in brick masonry introduced by Laurie Baker. It is like a cavity wall construction and has got the following peculiarities (Becker, 1993c).

- Strength of this masonry is equivalent to standard 23 cm wall, but consumes 20% less number of bricks
- Good thermal comfort due to the cavity in between the bricks
- Good appearance
- The overall saving cost of this wall compared to the 23 cm conventional brick wall is 26%
- Labour intensive technology

• English bond is made up of alternating courses of stretchers and headers. This produces a solid wall that is a full brick in width. It is fairly easy to be laid and is the strongest bond for a one-brick-thick wall.

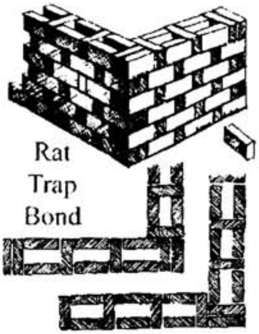

Figure 5.1 Schematic representation of rat trap bond masonry (Source: Baker, 1993c)

CEEF technology also promoted other technological options such as stabilized mud blocks, hollow or solid concrete blocks, Ferro cement, rubble filler blocks, interlocking blocks as affordable choices for walling.

Stabilized mud blocks (SMB) – Mud, sand and appropriate stabilizer (cement or lime) is compacted using a machine to form a building block. After twenty eight days of curing, the stabilized mud blocks are used for wall construction. Major advantages of SMB are energy efficiency (70% energy saving compared to burnt bricks), economy (20-40% savings in cost compared to brick masonry) and pleasing appearance (Reddy, 2004).

Ferro cement - Ferro cement is a composite material consisting of cement-sand mortar (matrix) reinforced with layers of small diameter wire meshes. It has wide range of application in housing as wall panels, roofing channels, tiles, trusses, door shutters, cup boards, lintels, sunshades and water tanks. Ready availability of materials, architectural flexibility, low level production technology and better utilisation of available human resources are considered as the advantages of Ferro cement construction.

Hollow and solid concrete blocks - These are the widely accepted CEEF technology walling options in Kerala. As the Ferro cement products, these blocks can also be produced on site without much skill and know-how.

Rubble filler blocks – This is an alternative technological option for superstructure prevailing in Kerala. Instead of coarse aggregates of specified sizes using in solid concrete blocks, stone or brick ballasts of different sizes according to their availability can be used. They are placed in different layers in the mould in a matrix of cement sand mortar and compacted using a machine.

The scarcity of timber is a major problem making it inaccessible to the poor. Hence the present CEEF technological options in the building process in Kerala make minimum use of it. Timber is mainly used for the door and window openings as shutters and frames. Pre-cast concrete door and window frames are being used widely in Kerala as alternative choices. According to Baker (1993a), one square foot of window can cost up to ten times the cost of the simple brick or stone wall it replaces. A honey combed wall (*jally* work) can be an affordable option in many of the cases to replace a window.

Lintels and beams are usually made of cement and steel. Very often lintel is not at all necessary for a door or window opening up to 1.2 m width. Ordinary bricks placed on edges can also serve the purpose of a lintel in that case. Brick arch are less expensive and more aesthetic than concrete lintels (Baker, 1993a).

Replacing lintels and beams with arches and corbelling is a common practise adopted by the CEEF houses in Kerala. Brick arches can replace beams over a span of up to 4.5 m. Corbelling is also a type of arch in which one brick is slightly projected (maximum length of projection is one fourth of the length of brick) outwards from the bottom coarse of bricks and this arrangement is followed to span an opening. Pre-cast reinforced concrete lintels can also be an alternative affordable option to conventional lintel. They are usually 7.5 cm thick and 23 cm wide with 3-10 mm mild steel bars for openings up to 1.8 m. Use of pre-cast lintel considerably speeds up construction of wall, besides eliminating the work of shuttering and centring.

Mud is the most environmental friendly sustainable building material available in almost all places. The CEEF technology initiatives in Kerala are constantly advocating the promotion of mud construction as an affordable alternative. Adobe or sun dried bricks and stabilized mud blocks are the widely accepted technology in mud construction in Kerala. Most of the soils available in Kerala are suitable for mud construction and if otherwise stabilizers can be used for making it suitable to the purpose. Lime and other local materials like straw, cow dung, sugar, molasses, tannic acid, coconut oil etc can be sustainable options as stabilizers based on availability.

5.3.3 Roofing

The scarcity of timber and the safety concerns with respect to theft and natural calamities diminished the popularity of tile roofing and promoted concrete roofing (Table 5.1). Filler slab construction, shell roofing and other pre-cast roofing techniques are the popular CEEF technology options against the expensive reinforced concrete slab.

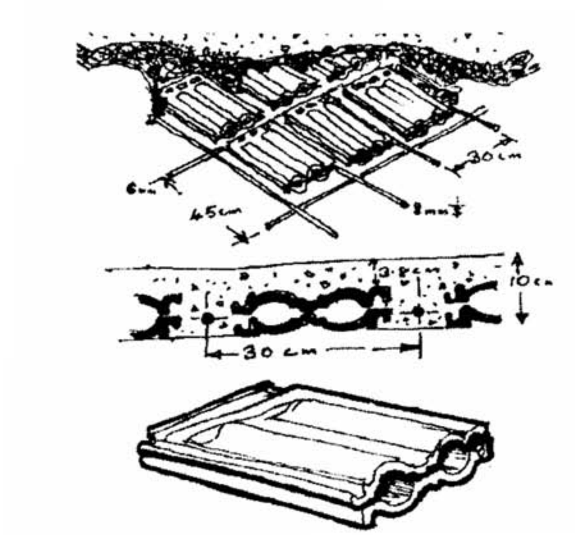

Figure 5.2 Schematic representation of filler slab with M.P tiles as filler material (Source: Baker, 1993a)

Filler Slab – This roofing technique is more popular in Kerala than any other technological alternatives due to the economical advantages and comfort with respect to other prevailing roofing options. They are basically solid reinforced concrete slabs with partial replacement of concrete in the tension zone by a filler material. Use of such filler material can result in reduction in dead weight of reinforced concrete slab, savings in cost as well as energy of the roof or floor system (Reddy et al., 2001). In Kerala, Mangalore pattern (M.P) roofing tiles are used commonly as the filler material.

Pre-cast concrete funicular shells, pre-cast concrete ribbed slab and pre-cast 'L' panels are other CEEF technology option in roofing. Pre-cast 'L' panels are very economical and do not need any shuttering.
Funicular shells are doubly curved shells under the action of uniformly distributed loads. Usual size of a funicular shell is 1m x1m and weight 65 kg. These shells can be cast by simple masonry moulds.

Pre-cast concrete ribbed slab can be used for floors, and roofs (flat as well as sloping) in single and multi-storeyed buildings. This roofing technique requires simple shuttering. The overall saving compared to the conventional reinforced concrete slab is 22 to 30% (North East India Regional Databank).

Table 5.2 gives a list of alternative technological options available in Kerala. Even though there is a number of sustainable options available in India, only very few are in practice in Kerala.

Table 5.2 Technology for different phases of construction

Building elements	Traditional materials or Technology	Conventional materials or Technology (Presently in use)	Prevailing CEEF technology options			
			Commonly used in Kerala		Available in India and not popular in Kerala	
			Building materials	Technology	Building materials	Technology
Foundation and Basement	Laterite Rubble	Laterite Rubble Concrete		Sand Piles Mud with bamboo reinforcement	Latoblocks Sand – lime bricks Mud- concrete blocks Steam cured lime stabilized bricks	Brick arch foundation Stub foundation
Building blocks or superstructure	Wood Laterite Mud Rubble	Bricks Solid /hollow concrete blocks	Adobe Stabilized mud blocks. Rubble filler blocks Ferro cement Solid concrete blocks Hollow concrete blocks Interlocking blocks	Rat trap bond Flemish bond	Building blocks from industrial and agricultural wastes	Straw bale technology Rammed earth wall Ferro cement wall panels
Binder	Mud/ clay Lime Gypsum Cow dung	Cement Lime	Mud Combination mortar (cement-lime-sand)		Lime or cement pozzolana Stabilized mud mortars Cement/Lime soil mortar	
Roofing	Wood Palm leaves Thatch Tiles(since 1759 only)	Concrete Tiles Aluminium sheets Asbestos Cement sheets Galvanised Iron sheets FRP sheets Asphalt sheet		Filler Slabs Funicular shells Pre cast concrete ribbed slab Ferro cement Channel or shell units L Panel roofing	Ferro cement tiles Bamboo mat corrugated roofing sheet	Pre-cast brick panels Micro concrete roofing (MCR)tiles Fly ash MCR tiles Jack arch with bricks and pre-cast RCC joists Corbelled brick pyramid Brick vaults and Domes Fal-G vault Fibre-cement roofing sheets and tiles
Lintels or Beams	Wood or stone lintel Brick corbelling Brick Arches		Brick	Pre cast R.C.C lintels Ferro cement lintel Brick corbelling Brick Arches		
Flooring	Cow dung			Cement plaster over brick bats Burnt clay tiles over brick bats	Fly ash terrazzo tiles	

Among them also the popularity of these alternative options is not gaining that much acceptance as that of modern building practises, especially among the poor. It may be due to the easy availability of energy intensive building materials and the popularity and acceptance of modern building process. It can also be noticed that these alternative building materials are not being produced and made available on a scale comparable to that of the modern building materials (Gopikuttan, 2004).

5.3.4 Sustainable utilization of waste materials for building process

The supply of cost-effective durable building materials is one of the major problems of technology in providing housing in developing countries irrespective of rural or urban areas. The establishment of high technology building material industries in the model of developed countries can make only limited contribution to meet their immediate and future needs (UNCHS, 1988).

Locally available waste materials can be utilized for the development of sustainable building materials and contribute in solving this problem to certain extent. Fly ash, red mud and lime sludge are the major industrial wastes utilized for the building industry in India. Fly ash or pulverised fuel ash is a waste product from thermal power plants where pulverised coal is being used as fuel. Forty million tonnes of fly ash are produced annually in India. Disposal of this waste product causes severe environmental problems. At the same time the potential of this material as an alternative building material such as bricks, blocks, Portland pozzolana cement, tiles, lightweight aggregates and hollow blocks is excellent.

Red mud is an industrial waste produced during the production of aluminium. In India about four million tonnes of red mud are produced annually. The Building Materials and Technology Promotion Council (BMTPC) of India has developed different technologies for utilization of this waste material in the production of bricks, tiles, corrugated roofing sheets and as binder for several products like doors, panels etc. One of the greatest technological opportunities available to building material industries is their potential to incorporate the agricultural and industrial wastes either as raw materials or as fuel substitutes, thus simultaneously reducing pollution and the need for the extraction of new raw materials (UNCHS, 1993). Table 5.3 gives a list of alternative technologies from agricultural or industrial wastes which are available in India.

Even though there is an active intervention by the appropriate technology institutions in the state with strong support from the government to promote alternate building materials, none of these institutions are effectively making use of the available industrial or agricultural wastes in Kerala. Lime sludge is a waste product from sugar, paper and fertilizer industry. It can also be utilized for the production of building blocks and Portland pozzolana cement. Red mud and lime sludge are the main industrial wastes available in Kerala. Rice and coconut are the major crops in Kerala and hence rice husk, rice straw and coir pith are abundantly available as agricultural residues. Even though technologies are available for utilising these wastes in building process (coir fibre for fibre cement roofing sheets, wall panels) as building blocks (straw bale technology) and pozzolanic material (rice husk ash), they are not yet introduced or widely in practise in the state.

Table 5.3 Alternative building materials

Type Of Waste (Industrial/Agricultural)	Source	Building Material
Fly ash / Pulverized fuel ash	Thermal Power plant	Portland- Pozzolana cement, Fly ash bricks, Roofing tiles
Red Mud	Aluminium industry	Bricks, Tiles, Blended cement, Fibre-reinforced panel products.
Lime sludge	Sugar, Paper, Fertilizer industry	Pozzolana cement Building blocks
Rice husk	By product from rice processing	Pozzolana cement Building blocks
Coir Pith	Coir industry	Building blocks
Rice Straw	Rice cultivation	Building blocks

The housing situation of Kerala and the present building practises in the state urge an evaluation of the sustainability and affordability of prevailing technological options. Alternative technologies and materials were introduced in Kerala with the primary objective of finding affordable housing solutions. But the present housing situation in the state reveals that sustainability of those alternatives has to be given more significance than affordability alone, since none of the options can be affordable (in the present as well as in the future) without being sustainable. Traditional technology in Kerala, based on locally available materials like wood, laterite, thatch and mud has given way to modern technology based on cement, steel and burned brick in a comparably short period of time ranging from thirty to fifty years. Even though the modern materials are more expensive than traditional materials, their easy availability and popularity made the technology more popular even among the poor. This explains why the CEEF technology innovations in Kerala could not compete with the modern building process, even though they provided many options that were more affordable.

5.4 Selection of building alternatives

The selection of sustainable technological options has been done in two stages. The first stage employs the conceptual framework from chapter 2 for a comprehensive analysis. However, in the second stage, a grading of basic building materials and popular technological options based on embodied energy has been done. Basically the second phase of grading plays a crucial role only when two alternative score equal points in the first phase analysis in making the most appropriate choice.

5.4.1 Comprehensive analysis based on the conceptual framework

This section presents a comprehensive analysis using the conceptual framework for the selection of the suitable technological options according to the requirements of Kerala. Fig. 5.3 is an adaptive version of the same framework in the context of sustainable-affordable building process.

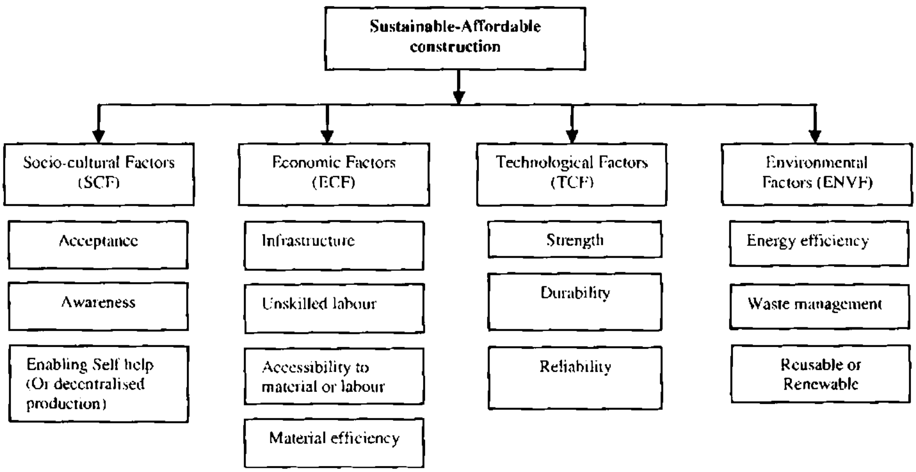

Figure 5.3 Conceptual framework: sustainable-affordable construction

As explained earlier (Chapter 2), all four aspects of sustainable-affordable habitat are closely interrelated to each other (refer Fig 2.3). In the context of sustainable housing development, sustainable construction can be considered as synonym to technological sustainability. 'Sustainable' refers to the general property of a material, building section or construction that indicates whether or not specific demands are met for affecting the air, water and soil qualities, for influencing the health and well being of living organisms, for use of raw materials and energy, and even for scenic and spatial aspects, as well as for creating waste and nuisance (Hendriks, 2001). This definition clearly indicates the relation between four aspects; such as- 'affecting the air, water and soil qualities' and 'scenic and spatial aspects, as well as for creating waste and nuisance' - refers to environmental factors (ENVF), 'influencing the health and well being of living organisms' refers to both socio-cultural (SCF) and economic (ECF) factors, and use of raw materials and energy implies technological (TCF) as well as environmental factors.

Socio-cultural Factors (SCF) - Technological innovations can be said to be sustainable only if they are accepted by the users and are beneficial to their well-being. Proper awareness of the technology is a factor which helps in making the technology acceptable. The materials or technology, those requiring decentralized production can help in enabling the users in self building and result in local level employment and income generation. This will improve the affordability of the technology and make it economically sustainable.

Economic Factors (ECF) - Technological options which demands minimum infrastructure, basic resources and unskilled labour requirements improves the affordability of sustainable constructions only if there is enough accessibility to material and labour.

Technological Factors (TCF) - The sustainability of technological options also depends on strength and durability aspects and are important criterions to be ensured particularly in the case of materials those are locally produced. Along with this, the reliability of technological innovations also adds to technological sustainability.

Environmental Factors (ENVF) - As explained through the definition of sustainable construction, environmental sustainability mainly refers to the quality of surrounding habitat. Technological innovations can be said to environmentally sustainable only if it either contributes to or maintain the quality of environment rather than degrading it by utilizing non-renewable resources or producing materials which are harmful to the environment.

This analysis adopts a methodology based on the assumption that all the four factors of sustainable-affordable construction are having equal importance and are interdependent to each other. Each technological alternative is given a score (two, one or zero) for each criterion (under the four factors of sustainable-affordable construction) based on a qualitative comparison among the different alternatives. The total sustainability score of various options are calculated as the sum of the four factors.

Tables 5.4 to 5.6 presents the analysis of prevailing building practices in the state based on this methodology. Different technology alternatives for walling, roofing, type of mortar and other miscellaneous practises currently in use in Kerala are analysed.

Walling alternatives - Table 5.4 gives an evaluation of the different walling alternatives prevailing in Kerala. Among the various alternatives, laterite wall masonry has the highest value of sustainability. Hence laterite can be suggested as the most sustainable option in places where they are locally available. Hollow and solid concrete block masonries also have fairly good scores next to laterite masonry. Even though the CEEF technology options like soil stabilized mud blocks and rubble filler block had maximum scores in technological and environmental factors, their total sustainability is comparatively low or nearly equal to that of hollow and solid concrete block masonry. This is attributed to their lower scores in socio-cultural factors as compared to other alternatives. In the same way, the lowest sustainability values of socio-cultural factors and economical factors of rat-trap bond masonry compared to other brick masonry options in Kerala making it unsustainable and unaffordable, even though it has many technological and environmental advantages over other options. These examples show that the economical sustainability of a technology or material is closely linked to the socio-cultural factors.

Table 5.4 Sustainability analysis of prevailing technology options for walling: Kerala

	Socio-cultural Factors (SCF)					Economic Factors (ECF)						Technological Factors (TCF)					Environmental Factors (ENVF)					Total score 100
Technology options for Walling	Acceptance	Awareness	Self Help	SCF	SCF (%)	Infrastructure	Unskilled labour	Accessibility to material or labour	Material efficiency	ECF	ECF (%)	Strength	Durability	Reliability	TCF	TCF (%)	Energy	Waste management	Reusable Renewable	ENVF	ENVF (%)	
Brick masonry English bond	2	2	2	6	**100**	2	2	2	0	6	**75**	2	2	2	6	**100**	0	1	1	2	**33**	77
Flemish bond	2	1	1	4	**68**	2	1	1	1	5	**63**	2	2	2	**6**	100	0	2	1	3	**50**	70
Rat trap bond	1	1	0	2	**34**	2	0	0	2	4	**50**	2	2	2	6	100	1	2	1	4	**67**	63
Laterite wall	2	2	2	6	**100**	2	2	2	1	7	**88**	2	2	2	**6**	100	2	2	2	6	**100**	**97**
Hollow concrete block masonry	2	2	2	6	**100**	1	2	2	2	7	**88**	2	2	2	**6**	**100**	1	2	1	4	**67**	89
Solid concrete block masonry	2	2	2	6	**100**	1	2	2	1	6	**75**	2	2	2	**6**	**100**	1	2	1	4	**67**	86
Adobe	1	1	2	4	**68**	1	2	2	2	7	**88**	1	2	1	**4**	**67**	2	2	2	6	**100**	81
Soil stabilized mud blocks (SMB)	1	1	2	4	**68**	1	2	2	2	7	**88**	2	2	2	6	100	1	2	2	5	**83**	85
Rubble filler block	1	1	2	4	**68**	1	2	2	2	7	**88**	2	2	2	6	100	1	2	2	5	**83**	85
Ferro cement	1	1	1	3	**68**	2	1	1	2	6	75	2	2	2	**6**	**100**	1	1	1	3	50	73

Roofing alternatives - Table 5.5 presents the evaluation of the different roofing alternatives. Mangalore pattern roofing tiles with wooden rafters has proved to be the most sustainable roofing option among the prevailing alternatives. The CEEF technology alternatives like filler slab and shell roofing has comparably lower sustainability values against their maximum scores in technological sustainability. This owes to the lower sustainability values in socio-cultural factors (compared to reinforced roofing slab), economic factors and environmental factors (compared to thatch and Mangalore pattern roofing tiles).

Table 5.5 Sustainability analysis of prevailing technology options for roofing: Kerala

Technology options for Roofing	Socio-cultural Factors (SCF)					Economic Factors (ECF)						Technological Factors (TCF)					Environmental Factors (ENVF)					Total score 100
	Acceptance	Awareness	Self Help	SCF	SCF (%)	Infrastructure	Unskilled labour	Accessibility in material or labour	Material efficiency	ECF	ECF (%)	Strength	Durability	Reliability	TCF	TCF (%)	Energy	Waste management	Reusable Renewable	ENVF	ENVF (%)	
Thatch / Palm leaves	0	2	2	4	67	2	2	2	2	8	100	0	0	0	0	0	2	2	2	6	100	67
Mangalore pattern tiles	1	2	2	5	83	1	2	2	1	6	75	1	1	1	3	50	1	2	1	4	67	**69**
Aluminium/ GI sheet	1	2	2	5	83	1	2	2	1	6	75	1	1	1	3	50	0	1	2	3	50	65
Reinforced cement concrete slab	2	2	1	5	83	1	1	2	0	4	50	2	2	2	6	100	0	1	0	1	17	63
Filler slab	2	1	1	4	67	1	1	1	1	4	50	2	2	2	6	100	1	1	0	2	33	63
Shell roofing	1	0	2	3	50	1	0	1	1	3	38	2	2	2	6	100	1	1	1	3	50	60

Table 5.6 presents an evaluation of miscellaneous building alternatives for the sustainable choice of mortars and other CEEF technology options in the building process.

Binder material - Mud is the traditional binding material from the age old days in India. Sustainability analysis also indicates it's potential as an excellent building material with a highest sustainability compared to the other prevailing options. Cement, the most popular building material has fairly good score for socio-cultural factors and maximum values for technological factors. But its cost and energy intensive production methods are making it least sustainable among the other alternatives.

Miscellaneous options - Exposed brick work with brick arches is a symbol of CEEF technology buildings in Kerala. Along with these two, the use of pre-cast reinforced concrete door and window frames and filler slab roofing is also a common feature of the

CEEF houses. The sustainability values in socio cultural factors for these alternatives give an indication of the popularity of CEEF technology in Kerala. Reinforced concrete door and window frames are widely popular in Kerala as an affordable alternative compared to conventional wooden frames. The possibility of decentralised production is also an added advantage making it affordable. At the same time, the difficulties in getting the expert labourers and proper know-how about the other technology alternatives over the prevailing technologies make them less acceptable and affordable to the users.

Table 5.6 Sustainability analysis of miscellaneous technology options: Kerala

Miscellaneous technology options	Socio-cultural Factors (SCF)					Economic Factors (ECF)						Technological Factors (TCF)					Environmental Factors (ENVF)					Total score
	Acceptance	Awareness	Self Help	SCF	SCF (%)	Infrastructure	Unskilled labour	Accessibility	Material efficiency	ECF	ECF (%)	Strength	Durability	Reliability	TCF	TCF (%)	Energy	Waste management	Reusable /Renewable	ENVF	ENVF (%)	100
Different alternatives for binder material																						
Mud	0	1	2	3	50	2	2	2	2	8	100	1	1	1	3	50	2	2	2	6	100	75
Lime	1	2	2	5	83	1	2	2	1	6	75	2	2	2	6	100	1	1	0	2	33	73
Cement	2	2	0	4	67	0	2	2	0	4	50	2	2	2	6	100	0	1	0	2	33	63
Miscellaneous CEEF technology options																						
Brick arches	2	1	1	4	67	2	1	1	2	6	75	2	2	2	6	100	2	1	1	4	67	77
R.C.C door and window frames	1	1	1	3	50	1	2	2	2	7	88	2	2	2	6	100	0	1	2	3	50	72
Exposed brick work	1	1	1	3	50	2	1	1	2	6	75	2	2	1	5	83	2	1	2	5	83	73

5.4.2 Grading of building components based on embodied energy

This part of analysis makes a grading of basic building materials and popular technological options based on embodied energy. Sustainable housing development requires materials and technologies which have less impact on the environment. Human activity has increased the levels of certain greenhouse gases in the atmosphere resulting in global warming. Greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide, troposphere ozone and chlorofluorocarbons (CFCs). Of these gases CO_2 is the most important by-product of the building material industry. Several studies have been done to identify and solve the implications of building materials industry on the environment due to emission of carbon dioxide, dumping of waste materials and excessive energy utilization during the production, processing and transportation of building materials. Construction activity contributes 17% of the carbon dioxide emission in India (Tiwari, 2001). The major energy intensive building materials, namely steel and cement are readily available in all the corners of the state, even though they need to be transported over large distances from the place of their origin. Extensive use of these materials can deplete the non renewable resources and adversely affect the environment. At the same time it is difficult to meet the alarming housing needs by adopting energy efficient traditional materials alone. Hence there is a need for optimum utilization of available resources and raw materials to produce environmentally friendly sustainable affordable alternatives (Reddy, 2004). This necessitates the choice of building alternatives based on embodied energy.

The total energy use during the life cycle of a building is an important concern and the embodied energy forms a considerable part (40%) of the total energy use in low energy residential buildings (Thormark, 2002; Chen et al., 2001). It is the energy that is used to extract, process, manufacture and transport building materials and components, and can be taken as an important index on measuring the sustainability of building alternatives. But the value of embodied energy for different materials varies from one country to another depending on the source of energy used for manufacturing. The indirect energy use in a residential building through the energy content of the materials of construction in India is about 3-5 GJ/m^2 of floor area, whereas the same indicator for an office building in Japan is 8-10 GJ/m^2. The higher value in Japan can also be attributed to the use of more energy intensive mechanised construction activity (Debnath et al., 1995). Chani et al. (2003) has calculated the embodied energy rates (EER), i.e., the embodied energy needed per unit area of different walling elements in India. Their analysis shows that traditional bricks which are most widely used for walling in India prove to be the worst choice with respect to energy input. The study of Reddy and Jagadish (2001) on embodied energy of available building alternatives in India also gives an insight into the selection of different building alternatives.

Among the basic building materials, aluminium is the highest energy intensive material. Steel and cement, the most widely used building materials for house construction are also energy intensive in nature. Lime pozzolana can be a better alternative to replace cement in this respect (see Appendix 5.1, Table 1). All the renewable materials and waste products which are being used as building alternatives are the most sustainable choices with respect to energy (zero energy).

The environmental suitability study for walling materials in Sri Lanka conducted by Emmanuel says that environmental suitability is a relative phenomenon and hence it is only possible to say that one material is either better or worse than another material rather than finding the best material (Emmanuel, 2004). The principle of DCBA method for the evaluation of building materials is also the same. Here also a comparative analysis has been done to identify the sustainable building materials. The letters show how environmental friendly an alternative is. In this method D = the normal (current or conventional) situation, C = correct the environmental damage of the normal situation, B = Limit the environmental damage to a minimum, A = autonomous situation with little or no environmental damage (Duijvestein, 2001). The scope of DCBA method has now been extended to economic and social aspects of sustainability from the initial concern on environmental aspects. The principle of 'PAGE' analysis used in this research for grading different materials based on embodied energy is also similar to DCBA method.

- 'P' refers to Poor; for highly energy intensive materials,
- 'A' refers to Average; moderate energy,
- 'G' refers to Good; low energy, and
- 'E' refers to Excellent; for zero or minimum energy material (mostly renewable).

'PAGE' is only used as additional check in the comprehensive analysis using the framework and is only used in situations when two alternatives carry equal scores in the main analysis.

Table 5.7 to 5.9 shows a comparative grading of different building components based on embodied energy. The values of embodied energy used in this grading are taken from the works of Chani et al. (2003) and Reddy et al. (2001). It is disappointing to see that the most popularly used traditional brick masonry with cement mortar is the worst choice in terms of embodied energy (Table 5.7). Hollow concrete block masonry (40×20×20) is the most appropriate selection from the prevailing alternatives.

Table 5.7 PAGE' grading based on embodied energy of different walling elements

Walling elements with (Dimensions in cm)	**Embodied energy in MJ/ m²**		
	Cement mortar (1:6)	**Composite mortar** cement: lime: sand	
		1:1:6	**1:2:9**
Traditional Brick 22.9X11.4X7.6	615 **P**	638 **P**	621 **P**
Modular Brick 20X10X10	539 **P**	562 **P**	548 **P**
Hollow Concrete Block 40X20X10	348 **A**	365 **A**	353 **A**
Hollow Concrete Block 40X20X20	193 **G**	204 **G**	195 **G**
Solid Concrete Block 30X20X15	300 **G**	312 **A**	303 **A**

P (Poor) – 450 MJ/m² and above A (Average) – 300 to 450 MJ/m², G (Good) – 150 to 300 MJ/m²; E (Excellent)- Below 150 MJ/m²

Table 5.8 'PAGE' grading based on embodied energy of different roofing elements

Roofing elements	Embodied energy in MJ/ m^2 Energy / m^2 of plan area of roof	PAGE grading
Reinforced cement concrete slab	730	P
SMB filler slab roof	590	P
RC ribbed slab roof	491	P
Composite brick panel roof	560	P
Burnt clay brick masonry vault roof	575	P
SMB masonry vault roof	418	A
Mangalore tile roof	227	G
Ferro cement roof	158	G
P (Poor) – 450 MJ/m^2 and above; A (Average) – 300 to 450 MJ/m^2; G – 150 to 300 MJ/m^2, E (Excellent)- – Below 150 MJ/m^2		

Table 5.8 presents a list of different roofing elements with their PAGE grading. From the available options, Ferro cement roof (grade G) is the most sustainable option with the lowest embodied energy. Reinforced cement concrete slab is the most energy intensive choice (grade P). Unfortunately it is the popularly used roofing technology in Kerala. Among the other available alternatives Mangalore tile roofing (grade G) can be suggested as a sustainable alternative.

Table 5.9 'PAGE' grading based on embodied energy of different types of mortars

Type of Mortar	Embodied energy in MJ/m^3	PAGE grading
Cement mortar (1:6)	1268	P
Cement mortar (1:8)	1006	P
Cement soil mortar Cement :soil :sand (1:2:6)	849	A
Cement pozzolana mortar (1:6) [Cement :pozzolana– .8:0.2]	918	A
Cement pozzolana mortar (1:8) [Cement :pozzolana – 0.8:0.2]	736	G
Cement soil mortar Cement :soil :sand (1:2:8)	773	G
Lime pozzolana mortar (1:3) [Lime :pozzolana – 1:2]	732	G
P (Poor) - 1000 MJ/m^3 and above, A (Average) - 800 to 1000 MJ/m^3 G – 500 to 800 MJ/m^3 and E (Excellent)-- Below 500 MJ/m^3		

Cement mortar is the most widely accepted and popularly using technological alternative in Kerala among the other options of this kind. But in terms of embodied energy it is the most unsustainable choice. Table 5.10 presents a list of different types of mortars with their PAGE grading. Lime pozzolana mortar (grade G) is the sustainable alternative in terms of embodied energy.

5.5 Sustainable alternatives: specific considerations in the context of Kerala

The results of the sustainability analysis can be used as a guideline for the selection of suitable technological options according to the peculiarities and requirements of Kerala. The ensuing text discusses the various factors which contribute to the sustainability of technological options in the context of Kerala.

Acceptance, awareness and feasibility of technological options can be considered as the basic criteria for socio-cultural sustainability. The un-sustainability of rat-trap bond masonry among the other brick masonry options gives a clear understanding of the importance of socio-cultural factors in sustainable technology. Rat-trap bond masonry has several advantages compared to English bond (most popular brick masonry alternative in Kerala) masonry. But the unawareness of technology and the poor acceptance make it less preferable to the users. This is the same case with filler slab; an affordable alternative to roofing when compared with the popular reinforced cement concrete slab. This also gives an indication to the relation between economic factors and socio cultural factors. Both the above mentioned technologies are considered to be more cost effective than their present popular alternatives, but the un-sustainability in socio-cultural factors makes them less affordable in practice. Along with this the increasing popularity of a few other CEEF technology alternatives (hollow or solid concrete blocks, pre-cast door and window frames) show the significance of decentralised production in enabling self-help or mutual help to improve the feasibility.

The relation between socio-cultural factors and affordability of certain CEEF technology options was explained in the previous section. An exception to this can be seen in the case of locally available alternatives like thatch and mud. Even though they have poor acceptance and inferior image (for thatch roof), their local availability in Kerala make them economically sustainable. This is also true with reinforced concrete slab roofing. Filler slab roofing is considered to be more material efficient, comfortable and economical than reinforced concrete slab. But in practice the poor awareness on this technology and availability of skilled labours make it less affordable to the users.

Although most of the appropriate technology experts advocate labour intensive technologies as sustainable options in less developed economies, the situation in Kerala is different. This can be clear from the less affordability of rat-trap bond masonry. Even though there is a considerable saving in material usage, this technology is found to be economically unsustainable in Kerala due to its labour-intensive nature. Hence sustainable construction in Kerala demands minimum labour cost and infrastructure, unskilled labour and accessibility of resources. It also demands innovations in renewable resources to make locally available materials sustainable. This can be supported by the poor technological sustainability of thatch. Even though there are technologies available to improve the durability of thatch, none of them is popular or even known to the real users.

The evaluation of the prevailing technological alternatives in Kerala points to the importance of effective policies for the dissemination of technological innovations to the real users. Also the evaluation points towards the need for innovative technological options from renewable resources.

The following points can be taken as guidelines for the selection of new alternatives:

- Alternative technological options should be capable of being produced locally using decentralised production methods and with utilisation of local resources (materials and manpower).
- The alternative technological options should be able to prove their advantages over prevailing options within a reasonable time period. (This could help in improving their acceptance and popularity).
- Technologies which demand minimum infrastructure, local resources and know-how with unskilled and less labour intensive nature should be popularized.
- Locally produced environmentally friendly alternatives in the building process which utilize local waste materials, renewable or reusable materials and less energy intensive technology should be promoted.

5.5.1 *Choice of sustainable technology options*

The above discussion based on the results of sustainability analysis on the building options in Kerala suggests the utilization of locally available renewable materials in the building process. From the analysis in the previous section it became clear that laterite, the locally available material, is the only present sustainable option for walling. Although, laterite and lateritic soils cover around 60% of the total geographical area of Kerala, there are places where laterite is not available. Hollow concrete block is the obvious option in such places. A renewable building alternative from local resources as walling option can be a good choice for affordable housing. Suzuki et al. (1995) and Andrew et al. (1994) have studied the implications of building construction on environment in the context of Japan and New Zealand respectively. Both agree that construction of wooden houses has less impact on the environment than with any other type of house, since wood is a renewable resource.

The straw bale construction (SB) might be an appropriate alternative in the context of Kerala, where rice straw is available as a local waste in most of the places. Along with rice straw, rice husk is also a waste product from the paddy fields. The potential of rice husk ash (RHA) as a cement replacement material is excellent. Utilization of both SB and RHA in the building process will be more promising in another way if it can accelerate the paddy cultivation, as this is an immediate necessity in Kerala for the balancing of local ecosystem. Declining paddy cultivation is a growing concern in the state, as it results in many of the environmental problems. The area and production of rice which was steadily increasing till the mid seventies had to succumb to economic pressure due to the promotion of cash crops like rubber, banana, and tapioca and also due to the growth of the construction sector. These factors also support the necessity of finding out more value added products from paddy fields other than rice to retain the environmental balance and protect the natural ecosystem.

5.5.2 *Sustainability analysis for new technology options*

Since straw bale construction and rice husk ash pozzolana are pioneers in the building process of Kerala, the criteria used for socio-cultural factors and economic factors in the previous section cannot be employed directly. Among the criteria for socio-cultural factors, awareness of technology options can be taken as a measure only if the technology is known to the public, but these two are purely new technology in the context of Kerala. The same is the case with 'availability of labour' criteria in technological factors. Acceptance of technology is also a criterion that is connected with awareness. But in this analysis acceptance is measured as the ability of the technological options to prove their advantages over prevailing options within a reasonable time period.

Table 5.10 presents an evaluation of the two selected alternatives using the framework. This has been done using the same methodology as in the previous section. Comparative values were assigned with respect to the popular technological options (hollow block and cement) in Kerala.

The results establish the sustainability of these alternatives in the building process of Kerala. The two sustainable-affordable alternatives proposed for rural building applications in Kerala are:

Rice husk ash (RHA) Pozzolanas - Alternative option for cement
Straw bale (SB) construction - Alternative technique for walls

However, with respect to the behavior of straw bale walls in the climate of Kerala only limited knowledge is available. Kerala falls within the realm of tropical climate and dominant feature is monsoon with an average rainfall of 3100 mm. Even though the examples of the 1938 bale mansion in Huntsville, Alabama and a 1978 building near Rockport, Washington (an area reported to receive about 1900 mm of annual rain) supports the durability of SB walls in rainy seasons; it is necessary to prove the durability and gain reliability before introducing this technique to the public. Basic details on straw bale construction, its advantages and few examples of projects are presented at the Appendix 5.2 of this chapter.

Table 5.10 Sustainability analysis for new technology options: Kerala

Technological options	Straw bale construction	Rice Husk Ash Pozzolana
Socio-cultural Factors (SCF) Acceptance	2	2
Self help or decentralised production	2	2
Total score SCF	**4**	**4**
SCF in %	**100**	**100**
Economic Factors (ECF) Infrastructure	2	2
Unskilled labour	1	2
Local materials	2	2
Less labour intensive	2	2
Total score ECF	**7**	**8**
ECF in %	**88**	**100**
Technological Factors (TCF) Strength	1	1
Durability	1	1
Reliability	1	1
TCF	**3**	**3**
TCF in %	**50**	**50**
Environmental Factors(ENVF) Energy	2	2
Waste management	2	2
Utilisation of renewable resources	2	2
Total score ENVF	**6**	**6**
ENVF in %	**100**	**100**
Aggregate score (100)	**85**	**88**

5.6 Conclusion

The analysis of the major technological options in Kerala gives a better overview on the sustainability of the present building process in the state. Among the present technologies, traditional building technology with laterite walls, Mangalore pattern tile roofing and mud mortar is found to be the most sustainable technological option for affordable housing in Kerala, where laterite is locally available. Locally produced hollow concrete block masonry can be suggested as an alternative technological option to replace laterite in other places. This choice of building alternatives has been made from the prevailing popular technologies in Kerala. At the same time, we could not consider the potential of CEEF technology options like rat-trap bond masonry, adobe, soil stabilized mud blocks, rubble filler block, filler slab and shell roofing due to their comparatively poor scores in socio-cultural sustainability and economic sustainability.

None of the technological alternatives could be affordable in practice, if it has not enough support and acceptance from the society. Hence dissemination of technological innovations is a must to make it acceptable, feasible and there by affordable to the users. This can be attributed to the present inferior image of CEEF technology against modern or prevailing energy intensive building process in Kerala.

The evaluation of present building process in Kerala also point towards the need for alternative technological options utilizing locally available agricultural and industrial wastes to replace energy intensive technology. Locally available materials, especially wastes, significantly reduce the consumption of energy and secondary resources needed for extraction, processing, fabrication and transportation. Straw bale (SB) and rice husk ash (RHA) are promising in this regard. In Kerala, straw and rice husk are abundantly available as agricultural residues. Promoting these two alternatives in building industry can certainly contribute in realizing the dream of "shelter for all" and lead to sustainable future.

Appendix 5.1

Table 1 Embodied energy of basic building materials

Basic building materials	Embodied energy MJ/Kg
Aluminium	237
Structural Steel	42
Cement	5.85
Lime	5.63
Lime pozzolana	2.33
Bricks	1.4
Laterite	0
Sand	0
Rubble	0
Fly ash	0
Rice husk ash	0
Straw	0
Mud	0

Appendix 5.2

Straw bale (SB) construction: A sustainable walling option

This technique has not been introduced in Kerala so far. But the ecological and environmental significance of straw bale along with the plenty availability of rice straw in the state supports the sustainability of straw bale construction as an affordable option for housing in Kerala. Straw is a viable and renewable building alternative, plentiful and cheap. It is the plant structure between the root crown and the grain head. The internal structure of a single straw is tubular, tough and it contains cellulose, hemi-celluloses, lignin and silica. It has high tensile strength also.

Straw bale construction is basically a wall system in which bales of straw are stacked up, pinned together, capped by an assembly to bear and distribute the roof load and then plastered with cement, lime, mud, or other materials to protect the bales. Properly constructed and maintained, straw bale walls, with exterior and interior plaster, remain waterproof, fire resistant and pest free. Environmentally, economically and in terms of efficiency, straw bale houses offer many advantages. However, careful attention to details during and after construction is crucial in order to avoid moisture problems. Providing proper site drainage is the most important factor for longevity.

Type of bales

Bales are rectangular compressed blocks of straw, bound by strings or wires. Straw bales come in all shapes and sizes. Rectangular bales are the only bales suitable for building. Three string bales (585 × 405 × 1070 mm) common in western USA has an average weight of 29 kg. The two string bales (460 × 350 × 920 mm) which are common in the rest of USA and most of the world are easier to handle and has a weight ranging from 15 to 19 kg.

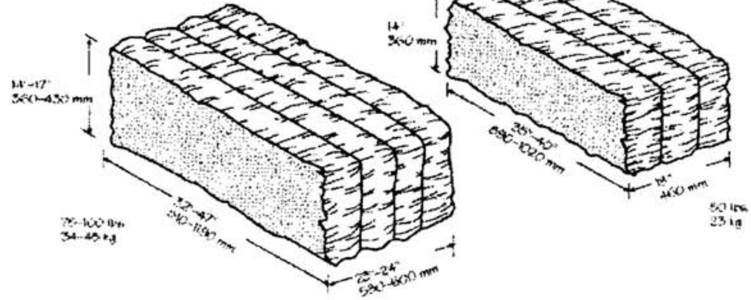

Figure 1 Three and two string bales (source:http://buildinggreen.com)

Besides these traditionally sized bales, big jumbo bales are also becoming popular. They are basically available in two sizes. The real jumbo is 1200x760x2400 mm and the mini-jumbo is 800 mm wide and available in various lengths and heights depending on the bailing machine used. The jumbo bales are appropriate for bigger industrial buildings where they show definite advantages due to their high load carrying capacity of up to 1000 kg /bale for the 1200 mm wide variety. Machine handling is only possible due to their weight. Greater stability and the bigger size of jumbo bales compared to the conventional bales favors rapid and easy construction.

SB building techniques

Basically there are two main construction methods:
- Load bearing bales
- Non-load bearing bales

Load bearing (structural) bales

Load bearing bale walls are most suited to smaller buildings not taller than two stories. The bales are stacked like bricks with the joints staggered. Traditionally the stacked bales are pinned by driving wooden or bamboo stakes vertically through the bales to increase stability during construction. Some form of pinning is still quite common but now mostly in a form of external bracing using wood or bamboo. A roof plate bond beam is placed on the topmost course of bales. This bond beam is tied down to the foundation using pre-inserted (under the foundation) packaging straps or heavy duty fencing wire. The straps are tightened down to pre-compress the bales (roughly 4%). The plaster adds significantly to the structural integrity of the wall system.

Figure 2 Structural bales

The straw bale wall is a structural sandwich where the plaster takes the load and the bales act as stiffener for the plaster. In the load bearing technique the bales function as a fully load bearing wall system. It is recommended to keep the openings for windows and doors less than fifty percent of the total surface area of the wall and the unsupported wall length less than 6m.

Post and Beam (P&B) or Non- structural bales

This technique is more appropriate for the construction of large structures. In this case, the structural loads are taken by the posts and beams of the framed structure and the straw bales act as in fill material only. Preferably the bale walls are either placed on the outside of the wooden P&B structure or within, thus simplifying the construction by avoiding complicated interfaces between the wooden structure and the bales. The bale walls are attached to the beams to create some form of rigidity. The bale walls with plaster finish only form the wall membrane and have to carry its self -weight only.

Figure 3 Non-Structural bales

Other building methods using straw

- Straw-clay building

Clay and water are stirred and mixed with loose chopped straw to form a straw reinforced clay matrix. This technique has been and is still in use in different countries especially in Europe but also in other continents. Depending on the country the technique has different names like cob (UK and India) and Leichtlehm (Germany, Austria) etc. Earlier the mixture was packed in to a double-sided wooden form between heavy posts and beams of timber frame buildings. The current practice is to use lightweight wooden ladder frames thus vastly reducing the amount of wood required.

- Mortared bales

Mortar made of Portland cement and sand is applied between the straw bales. This is plastered on the exterior and interior surfaces to protect the bales. This technique has now almost been discontinued because the mortar joints form cold bridges between the straw bales, result in condensation and leads to the decomposition of the straw bales.

- Pressed straw panels

Straw is compacted under controlled temperature and pressure. The resulting panels can be used for walls as well as roofs. These panels are not used for exterior applications but only for partition walls and for ceilings. The application is mainly due to the good acoustic property of the panels.

Construction and Practical issues

Humidity and Moisture

SB buildings are capable of surviving humid climates, only if proper attention has been given in preventing condensation before and during construction. Following points should be noted.

- Moisture content in a bale should not exceed 15% of its dry weight.
- The tops of bale walls, exposed horizontal surfaces (e.g. window sills) and joints with wooden frames must be carefully sealed and designed to drain off moisture.
- Extra care should be given to store and protect the bales from the field of origin to the completion of building. Straw left in a moist, aerobic environment (above 20% moisture content) supports the growth of fungi leading to the decay of the straw. The stacking of bales should be carefully done to prevent this. Bales may be stacked near to the place of construction on palettes or lumber to keep them adequately raised by 15 to 20 cm above ground level. If the ground is wet, the bales must be protected from rising damp by a plastic cover directly on the ground leaving a well ventilated air gap between the bales and plastic. Make the bale stack tall and narrow rather than flat and wide to minimize the flat area exposed to sun and rain and increasing the ability for good ventilation. The top of the stack should be peaked or rounded to ease water run off.
- Ensuring the permeability of wall surfaces for preventing condensation is an important measure to avoid the decay of bales after it has been constructed.

The SB house built without foundation and without exterior plastering with bales placed over plastic put on the ground, near Tonasket, Washington in 1984 has no apparent deterioration of the bales. This indicates the importance of drying out of bales and breathing (Steen et al., 1994).

Fire

Plastered straw bale walls are less of a fire risk than traditional timber framed walls. The American Society for Testing and Materials fire tests conducted on plastered straw bale wall assemblies in Albuquerque and California shows a high resistance to flame spread and fire resistance. ASTM E-119 fire testing in New Mexico found that a plastered, 450 mm straw bale wall survived fire penetration in excess of two hours, after which the flame source was discontinued; even non-plastered wall survived for 34 minutes (EBN, 1995). The National Research Council of Canada also tested plastered straw bales for fire safety and found performance better than conventional building materials. It is found that the plastered surface withstood temperatures of about 1010° C for two hours before developing cracks. These findings are also supported by real life experiences in the field. Plastered straw bale structures have survived wild fires where wooden buildings burned to the ground and steel melted. The basis for this extraordinary performance is that straw bales hold enough air to provide good insulation value, but because they are compacted firmly, they do not hold enough air to permit combustion.

Stacking and pinning

Bales of load bearing walls must be laid flat and stacked in running bond with each bale overlapping the two bales beneath it. Whereas for non-load bearing walls bales are laid either flat or on edges. The first course of bales must be laid by impaling the bales on vertical stakes extending from the foundation. Only full-length bales may be used at corners of load bearing walls.

Advantages of Straw bale construction

Straw bale construction has several advantages over other conventional building practices. They are discussed below.

Significant savings in energy use

Straw bales as building materials enable a significant reduction in energy consumption. It can be achieved in two areas.

- Energy used to make it available as a building material (embodied energy) and
- Reducing residential energy consumption for either heating or cooling.

Based on the experience of the first attempt, a second building was constructed in the year 1998. Instead of casuarinas poles, steel rods were using for that building. Pre-compressed straw bales were used instead of hand pressed straw and chicken mesh. Reinforced concrete roof was constructed with 6 mm chips and straw bales were covered over the roof with chicken mesh and lime plastered.

Figure 5 Second SB building, Trichy, India

Both these SB buildings could effectively withstand a 1m high flood that lasted for 1.5 days with out any problem.

Examples from the Netherlands

In the Netherlands, the first Straw bale building was constructed during the period of 1944-45 by the architect W. Gubbels. The choice for straw bales was based on the limited availability of other building materials in the aftermath of Second World War.

Ouwerkerk - The first SB house built with a permit in the Netherlands was in the year 1998 at Ouwerkerk. It has got the following specifications.

- Non load bearing straw bales
- Lime plastering outside
- Inner walls made of adobe
- Wooden flooring

Figure 6 SB house Ouwerkerk

Warns - This is a residential building combined with a boat workshop with the following specifications.

- Strip foundation
- Non-load bearing straw bales
- Mud plaster

Figure 7 SB building in Warns (picture during construction in 2003 October)