**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

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📖 **Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**
➡️📄 *(introduction...)*
📄 **Foreword**

**UNITED NATIONS CENTRE FOR HUMAN SETTLEMENTS (Habitat)**
**Nairobi**

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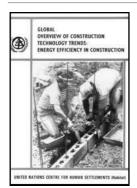
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 **Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**
➡️ ☐   **Annex**
   📄 **Solar timber seasoning in Sri Lanka\*\***

**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**Annex**

**Solar timber seasoning in Sri Lanka\*\***

> **\*\* This Annex is an edited and summarized version of an unpublished draft report entitled: "Development of an Efficient Solar Kiln for Seasoning Structural Timber for use in Building Trade", and prepared by R. H. B. Exell, Professor, Division of Energy Technology, Asian Institute of Technology (AIT), Bangkok, Thailand. This research work was subcontracted to AIT by UNCHS (Habitat) for the National Building Research Organization (NBRO), Sri Lanka.**

**Introduction**

**The Asian Institute of Technology (AIT) of Thailand on behalf of the National Building Research Organization (NBRO) of Sri Lanka and supported by UNCHS (Habitat) undertook**

a research study on solar seasoning of secondary species of timber for use in the building construction as a replacement to the primary species which are becoming scarce in the market and are of high cost. The secondary species identified for promotion and suitable for building construction (after taking into consideration strength, economy and availability) are: Selinga, Alstonia, Ginisapu, Domba, Coconut and Rubber.

These species cannot be used immediately for structural purposes due to their high moisture content. The cost of seasoning these timbers through conventional means, using oil-fired kilns, is very high and renders these timbers uncompetitive in the building market. It is for this reason that NBRO and AIT undertook this research project to design and construct an efficient solar kiln for seasoning these secondary species of timber to make them accessible to low-income house builders.

Earlier solar kilns in Sri Lanka

Prior to the start of the NBRO-AIT project, two types of solar kilns were existing in Sri Lanka. The first type having capacities of 3.0 and 13.5 m of timber is in operation since 1983.

Both kilns have drying chambers made of concrete blocks, and the solar collectors are on the ground to the south of the drying chambers. The collectors contain charcoal on the floor to absorb solar radiation and are covered with glass. Air is circulated by means of fans.

The collector of the 3 $m^3$ kiln is 1,8 m wide by 7,2 m long whereas the 13.5 $m^3$ capacity kiln has a collector of 10.8 m wide by 15 m long the width of the collector being nearly equal to the length of the wood stack inside the kiln. Many fans are used to control airflow through somewhat complicated ducting. There is automatic control of the humidity by means of vents to the outside air. A wood burner is used to supply supplementary heat at

night and on cloudy days.

These solar kilns are well researched and engineered systems, however, because of their high installation cost, they are not suitable for small business but a good option for the larger companies. In contrast, the NBRO-AIT project was to develop a more economical unit for the smaller users, and for this purpose, an improved greenhouse type solar kiln (described next) seemed to be the best.

The second type of kiln introduced into Sri Lanka was designed like a portable greenhouse having an aluminium frame covered with clear plastic sheet. It was developed by the Intermediate Technology Group (ITDG) United Kingdom, and was installed at the Wood Technology Section of the State Timber Corporation at Kaldemulla (1). The kiln is in two halves clamped together, the front half housing the fan motors and switchgear for air circulation, and the back half covering the timber stack. Both halves have lifting handles and can easily be moved by, as few as, four people and placed around an air dried timber stack on any level site. This avoids having to move the stack, which is a long and laborious job without heavy equipment.

The new project

Local investigation revealed that the target group of users for the proposed solar-timber kiln would be small sawmills in urban areas rather than the very small cottage or large-scale industries. Seasoning would be mainly for secondary species of timber for building construction (not primary species, and not timber for furniture making) and the two main species would be rubber and coconut wood.

The capacity of the kiln would be about 7 $m^3$ of timber. It would be designed to accommodate planks of coconut wood, which are longer than usual (up to 5 m). The design would be such that the kiln is portable and could be erected around stacks of

timber that have been built in advance. These stacks of timber would be air-dried initially, and would then be dried in the solar kiln. The air inside the solar kiln would be moved by means of fans since it would be assumed that the users would have electric power available. If the drying period proved to be too long, the addition of an auxiliary wood-burning heater would be considered.

**Design and construction of the kiln**

The basic design concept is shown in figure 1. The stack of timber is supported 0.6 m above the floor of the kiln on a 3 × 6 array of brick pillars 0.9 m and apart. The stack is built up with the support of crossbearers at the bottom-stickers between the layers of planks.

The height of the stack is 1.2 m making the height of the kiln 1.8 m above the floor.

The floor of the kiln is made of brick and cement, and is slightly convex so that any rain that may leak through the cover of the kiln does not remain in puddles. The floor extends from below the wood stack out to a distance slightly more than 5.4 m from the front of the stack. It is painted with bituminous paint, so that, besides being waterproof to prevent moisture entering the kiln from the ground below, its black colour absorbs solar radiation.

**Figure 1. The basic design concept of kiln**

**The wood stack is protected from direct solar radiation by a cover of aluminium sheet and the black floor serving as solar collector is covered by clear plastic sheet (of a type that can withstand deterioration by ultraviolet solar radiation) supported by an aluminium frame. The frame is in three sections: I at the end of the solar collector; II in the middle; and III over the wood stack.**

**The air is circulated inside the kiln by means of fans built into section II of the frame.**

After being blown from the solar collector through the wood stack by the fans, the air returns via an airspace behind the wood stack and the space under the stack. Clear plastic sheet stretched horizontally inside the kiln from the bottom of the wood stack to the centre of the solar collector separates the return air from the solar heated air passing through the fans. There is no airspace between the ends of the stack and the sides of the kiln.

Air vents, which can be opened and closed by varying amounts, are provided at the end of the solar collector and behind the wood stack for humidity control inside the kiln.

Provision is made for building two identical wood stacks side-by-side, and the total brick and cement floor area is double that required for a single solar kiln. With this arrangement it is possible to have one stack being air-dried while the other is being solar-dried. When the solar drying is finished, the frame and plastic sheet coverings that form the solar kiln are dismantled and re-erected over the air-drying stack. The solar-dried timber is then taken away for use, and another stack is built in its place to be air-dried. Thus, a succession of wood stacks can be seasoned, each passing through an air-drying stage followed by a solar drying stage.

**Performance calculations**

The following calculations which are not fully precise because of uncertainties regarding the actual drying process of rubber wood are made to establish the duration of drying and the amount air flow required. Different samples of wood-cut to a variety of sizes are expected to have different drying properties. Other species of wood will also behave in a variety of ways. The principles of the calculations are based on studies by Eckelman and Baker (2) and Exell (3).

An estimate of the expected drying time may be made as follows assuming that:

(i) the kiln capacity is 7.1 m$^3$;

(ii) the density of the undried wood is 680 kg/m$^3$;
(iii) the change in moisture content (dry basis) is 40 to 12 per cent;
(iv) the air temperature change in the kiln is 27° to 42°C; and

(v) the mean daily solar radiation is 15.3 MJ/m$^3$.

Then one finds that:

(i) the mass of wet wood in the kiln is 4800 kg;
(ii) the mass of water to be removed is 960 kg; and
(iii) the heat energy required to vaporize the water is 2760 MJ.

The collector area is 26 m$^2$. If the efficiency of the collector is 40 per cent (an optimistic figure) the solar-heat energy available per day on the average is 160 MJ, and so it will take about 17 days to dry the timber.

The estimation of the airflow required is as follows:

Assuming an ambient air temperature of 27°C, and ambient air humidity 77 per cent, and assuming the air is heated in the kiln to 42°C, one finds from the psychometric chart that the moisture carrying capacity of the air is $6.2 \times 10^{-3}$ kg of water per kg of dry air. Therefore, the volume of air required for drying is $1.5 \times 10''$ m. If the drying is to be done in 14 days, working 10 hours per day, the flow rate would be 18 m$^3$/min.

The smallest fans available were 30 cm in diameter and with a power of 35 W and a flow rate of 5 m$^3$/min. Three such fans were used in the design to give surplus air flow and to overcome the resistance of the stack. The fans can be kept running in the evening to utilize the heat stored in the floor of the collector and the wood stack, and provide extra

drying after sunset.

**Summary of experimental results**

Table 1 shows the results obtained in five separate test runs of the solar seasoning kiln. The first test run was done during a wet period when rain and cloud hindered the drying of the timber; 38 days were required to dry rubber wood from the exceptionally high moisture content of 70 per cent down to 11 per cent. This long drying time is inevitable at certain times of the year. The other test runs show that the performance of the kiln is satisfactory when the weather is favourable; at such times it takes about two weeks to dry timber that is one inch thick from moisture content about 40 per cent to about 14 per cent.

**Table 1. Experimental results from NBRO-AIT kiln in Sri Lanka**

| Species | Rubber | Mahogany | Coconut | Ginisapu | Albezia |
|---|---|---|---|---|---|
| Thickness (cm) | 3,8 | 2,5 | 5.0 | 2,5 | 1,9 |
| Initial m.c. (percentage) | 70 | 45 | 34 | 40 | 40 |
| Final m.c. (percentage) | 11 | 14 | 13 | 9 | 11 |
| Wet days | 13 | - | - | - | - |
| Clear days | 25 | 16 | 18 | 14 | 12 |

**Proposed modifications in the design**

Various tests carried out on the prototype kiln revealed that a number of modifications in the design should be made in future kilns in order to improve its performance of this type. These modifications are detailed as follows:

Experience has shown that better drying is obtained if 5 × 5 cm stickers are used instead

of 2.5 × 2.5 cm stickers which would reduce the resistance to air flow. Obviously, this would reduce the volume of timber stack in the kiln. Therefore, an enlargement of the space for the wood stack should be considered in future.

Figure 2 shows an outline how the structure could be improved. It is envisaged that future kilns should be fixed permanently in position (although it should be possible to dismantle them and transport them from one site to another). Therefore, the brick and cement floor need to be large enough for only one collector and stack instead of two as in the present design. This is because it was found unnecessary to carry out predrying in the open air in some cases, and even when open air predrying was done it was considered easier to transfer the wood from one stack to the other using unskilled labour than to move the kiln itself (with increased risk of damage). It takes four unskilled labour a day (4 hours) to move one full stack of timber, i.e. 4 more days to unload and reload the kiln.
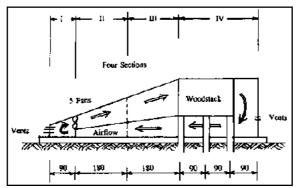


Figure 2. Proposed new structure. Fans are fixed to section I which are removable

It will be noted that the proposed new structure is in four sections instead of two for ease of construction. Section I at the front of the solar collector is shorter than in the existing

design; it appears that there is little flow through the narrow part of this section so it could be eliminated without much loss in performance of the system. This section should also be made easily removable to facilitate maintenance of the fans. The fans are further away from the wood stack in order to improve the uniformity of air distribution through the stack, and also to simplify the mounting of the fans. There could also be an optional addition of two more fans, making a total of five, to increase the airflow. These fans should be shaded from the direct rays of the sun by means of opaque covers in the roof of the collector just above the fans in order to avoid overheating in bright sunlight. This will lengthen the life of the fans.

It is suggested that, the compartment behind the wood stack should be enlarged to a width of 90 cm to improve the airflow, and also to make it easier for personnel to enter the kiln for inspection of the wood. The floor of this compartment might be painted black to obtain a little more absorption of solar energy.

In stormy weather the plastic sheet on the top of the collector may flap about vigorously. To alleviate this problem, bars should be fixed to the frame over the plastic sheet to hold the sheet down.

Finally, the feasibility of adding an auxiliary heating system to give better drying in cloudy weather and at night should be considered. During the present tests there was a period of 16 days without sunshine, therefore, auxiliary heating might have been useful at this time. Figure 3 shows how this could be done at a relatively low cost. Air-ducts are run between the pillars supporting the wood stack. At the entrance to the ducts tins containing sawdust, rice husks or some other locally-available combustible-waste material supply hot air when the fuel is burned.
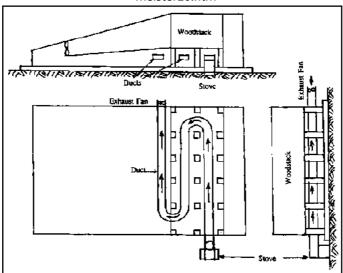
**Figure 3. Idea for auxiliary heating system**

**At the other end, a small fan draws the heat through the ducts. The main fans in the kiln are used to circulate the air heated by the ducts through the wood stack.**

**There appear to be no difficulties in introducing such an auxiliary heating system beyond the obvious one of securing a supply of fuel. The design calculations to be done would include sizing of the fuel-burning stoves, the sizing of the ducts, and the choice of a suitable fan.**

**Test and results**

**For all except one test, a full stack of timber was loaded into the kiln. One inch thick**

stickers were used to separate layers of planks for Rubber, Mahogany and Coconut wood and two inch ones were used in the case of Ginisapu and Albezia. The exception to the full stack was Mahogany, where only 1.60 m$^3$ of timber were available instead of the usual 6 to 7 m. sampling was done in the following manner (see figure 4). Sample planks from the front upper, rear upper, middle, front lower and rear lower parts of the stack were selected, as shown in the figure. A section of each selected plank 90 cm long was cut out as sample and was weighed periodically during the testing period to determine the changes of moisture content with time. Small pieces of 2.5 cm long at the ends of the sample were taken out and weighed to find the initial moisture content of the wood at the beginning of the test run. They were first weighed wet. Then they were dried in an oven at temperatures 100 to 105°C for 2 hours, kept for another 4 hours, and finally weighed again to determine the dry weight. Moisture contents in this report are expressed on the dry basis (weight of water in the wood divided by the weight of oven dried wood). The ends of the 90 cm long samples were painted to prevent drying through the ends (and also to reduce end-splitting).
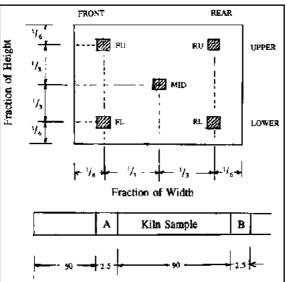
**Figure 4. Sample diagram. Upper diagram, is a cross section of stack showing positions of samples. Lower diagram is a method of cutting sample plank. Pieces A and B are oven dried to find initial moisture content. Kiln sample is weighed periodically to find change of moisture content with time.**

**The wet and dry-bulb temperatures within the kiln and outside in the ambient air were recorded. It was found that the ambient conditions were rather constant with time, while inside the kiln the conditions varied due to changes in the weather. The temperature of the air emerging from the stack was typically 5° to 10°C cooler than the air entering the stack from the solar collector. This was due to the cooling effect of the evaporation of the water from the wood, and also due to the fact that the area of the stack was shaded from sunlight. Typical temperatures and humidities observed are shown in table 2.**

**Table 2. Typical temperatures and humidities observed**

|  | Dry bulb | Wet bulb | Depression | Rel. Hum. (percentage) |
|---|---|---|---|---|
| Ambient (C°) | 32 | 28 | 4 | 70 |
| Collector (C°) | 40-50 | 30-40 | 7 | 50 |

**Table 3 shows the results obtained in five experimental runs. Except in the case of the test using rubber wood, which was done during a period of very wet weather, it took about two weeks to dry timber from about 40 per cent moisture content to 14 per cent moisture content in this solar kiln.**

**Table 3. Experimental results on moisture contents of different types of wood at Dankotuwa**

| Type of wood | Stage | Moisture content (MC) (Percentage) | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
|  |  | FU | FL | MID | RU | RL | AVG |  |
| Rubber, V: 6.75 | Initial | 72 | 67 | 82 | 59 | 69 | 70 | Planks of 3.75 cm thickness |
| CD: 25 | Final | 7.8 | 8.3 | 13.5 | 12.4 | 13.5 | 11 |  |
| WD: 13 | Drop | 64.2 | 58.7 | 68.5 | 46.6 | 55.5 | 59 |  |
| Mahagoni, V:1.6 | Initial |  | 54.0 |  |  | 36.0 | 45 | Planks of 2.5 cm thickness |
| CD: 16 | Final |  | 13.7 |  |  | 13.8 | 14 |  |
| WD: 0 | Drop |  | 40.3 |  |  | 22.2 | 31 |  |
| Coconut, V: | Initial | 43.0 | 20.0 | 44.0 | 41.0 | 23.0 | 34 | Rafters 5.0 × 7.5 cm |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Coconut, V: 5.4 | Initial | 45.0 | 20.0 | 44.0 | 41.0 | 23.0 | 34 | Rafters 5.0 × 7.5 cm |
| CD: 18 | Final | 12.1 | 11.9 | 13.6 | 13.3 | 12.5 | 13 | |
| VD: 0 | Drop | 30.9 | 8.1 | 30.4 | 27.7 | 10.5 | 21 | |
| Ginisapu, V: FK | Initial | 30.7 | 34.5 | 54.2 | 30.0 | 50.4 | 40 | Planks of 2.5 cm thickness with 2.5 cm stickers |
| CD: 14 | Final | 13.8 | 5.6 | 1.6 | 11.3 | 12.6 | 9 | |
| WD: 0 | Drop | 16.9 | 28.9 | 52.6 | 18.7 | 37.8 | 31 | |
| Albezia, V: FK | Initial | 43.8 | 34.0 | 36.0 | 35.0 | 53.0 | 40 | Planks of 1.9 cm thickness with 5 cm stickers |
| CD: 12 | Final | 12.0 | 3.0 | 10.0 | 10.0 | 17.0 | 11 | |
| D: 0 | Drop | 31.8 | 31.0 | 26.0 | 25.0 | 36.0 | 29 | |

*Note:*

> **CD means clear days**
> **WD means wet days**
> **V means volume in m$^3$**
> **FK means full kiln**
> **FU, FL, MID, RU and RL mean front upper, front lower, middle, rear upper, rear lower of the stack respectively (refer to figure 4)**

**Use of the vents and fans**

**During some of the test runs it was observed that some water was condensed on the inside of the plastic sheet at night. This water must come either from the moisture in the air or from the moisture in the timber. If it is from the air, then closing the vents at night can ensure that no moisture is added to the interior of the kiln at night and there is no**

gain or loss in the performance. If it is originated from the timber, then gain has been made by utilizing the temperature difference between the warm-wood stack and the cold-plastic sheet (cooled by longwave radiation at night) which removes further moisture from the wood.

The procedure adopted to meet this circumstance is to close the vents at night, and leave them fully open during the day to allow the condensed moisture to escape. Although it may take some time for the condensation on the plastic sheet to disappear, the decision of having the vents fully open from 8 a.m. to 5 p.m. was found to be satisfactory.

The fans are used all day. There is a question as to whether they should be used at night. If they are, there could be more drying (due to the condensation on the cooler plastic sheet as observed above), but the main advantage might be the securing of more uniform drying throughout the wood stack. On the other hand continuous operation of the fans will shorten their life. Therefore, it seems better to turn them off at night and have them, fully on during the day.

In summary it is recommended that:

   (a) during the day the vents should be open and the fans should be on; and
   (b) at night the vents should be closed and the fans should be off.

Air flow in the kiln

A special experiment was performed to map out the air flow inside the kiln. Light pieces of thread were suspended at many points inside the kiln: small currents of air were able to deflect the thread and show the direction of flow. The experiment was entirely qualitative because no instrument for measuring the air velocity was used. Instead the observed flow was simply classified as *zero, light* or *strong.* The currents were noted on the empty kiln and in the kiln with a full stack of timber, with and without the fans running, and with and

**without the vents open.**

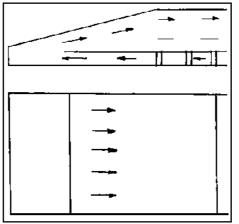**The results are shown in figures 5, 6, 7 and 8.**
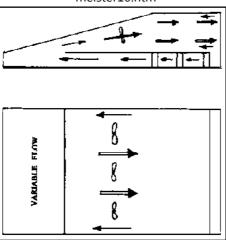


**Figure 5. Kiln empty. Fans off. All airflows light**

**Figure 6. Kiln empty. Fans on. Heavy arrows show strong flow. Note counter-flows. Opening vents make no difference to internal flow.**
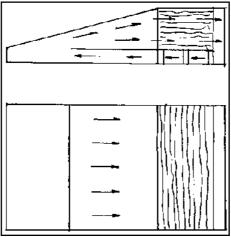
**Figure 7. Kiln full. Fan off.**
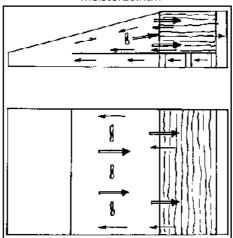
**Figure 8. Kiln full. Fans on. Circulation of counter current fans and near wood stack**

**It can be seen that when the fans are off there is a natural circulation of air in the proper direction produced by free convection. This confirms expectations during the design stage, and ensures that electrical energy is not wasted in making the fans force the air against the natural flow. The observations also show that when the fans are running, there is a counterflow (against the proper direction) at the sides of the large space containing the fans, and also in the top and bottom of the wood stack itself.**

**The counterflow in the space containing the fans may be eliminated by filling in the panel holding the fans with plastic sheet so that the counterflow is locked. The counterflow in the wood stack appears to occur because the fans are too close to the stack and fail to give a uniformly distributed current of air through the stack. This could be corrected in future designs by positioning the fans farther away from the stack as proposed earlier (see figure 2).**

The opening and closing the vents seems not to have a significant effect of the flow inside the kiln. The flow through the front vent is always inwards, while that through the rear vent is indefinite. Undoubtedly, the wind outside the kiln has an effect on the flow through the vents.

The random motion of air in the narrow front end of the solar collector suggests that this part of the structure does not heat the air very effectively, in all probability little would be lost if the sides of this section were reduced (see figure 2).

*Note:*

For more detailed treatment of solar timber seasoning refer to "Solar Heated Timber Drying Kiln. A manual on their design and operations" 1996. ISBN 1 900510006 by R. A. Plumptre and D. L. Jayanetti. Published by TRADA Technology Ltd for the Overseas Development Administration (ODA), The United Kingdom.

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📖 **Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**Acknowledgement**

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 **Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**Foreword**

**In the closing decade of this century, as the world strives for a better quality of life,**

millions of poor are fighting for life itself. Already more than 600 million people in cities and towns throughout the world are homeless or live in dilapidated houses. Unless a revolution takes place in solving the shelter problem, this shocking statistic will triple by the year 2025. Providing decent shelter for this huge number of people will no doubt be the major challenge of the construction sector well into the next century.

Traditionally, technological development in the construction sector has always influenced social and economic development, including human settlements development. Technological advancement has contributed to the higher productivity and lower cost of construction and has even reduced the adverse effects of construction on the environment in some countries. But the benefits of technology has yet to be fully harnessed by developing countries to enable them meet the increasing demand of shelter for their low-income population.

As part of its efforts in addressing the problems of shelter delivery in developing countries, the United Nations Centre for Human Settlements (Habitat), over the past decade or so, has been promoting the development of appropriate, energy-efficient and environmentally-sound construction technologies which rely, mainly, on locally-available resources. The establishment of the "Network of African Countries on Local Building Materials and Technologies", a decade ago, which has the objective of strengthening local technological capacity through information flow, regional cooperation and technology transfer is an example of the Centre's activities in this important sector.

Recognizing the importance of the construction sector in improving the shelter condition of millions of low-income population, a distinct section on construction has been included in the Habitat Agenda adopted by the Second United Nations Conference on Human Settlements (Habitat II). The Agenda, among other things, emphasizes the need for increased use of energy-efficient and environmentally-sound technologies in construction so as to ensure its sustainability. The present publication, in line with the

recommendations of the Habitat Agenda, attempts to bring together recent advances in construction technology which are suited to low-cost construction using locally-available resources. Particular emphasis has been given in this publication to energy efficient and cleaner technologies and recycling for the production of basic building materials and components. In view of the importance of architectural design in reducing the energy requirements in buildings, selected energy efficient building design concepts have also been incorporated.

This publication represents another significant step in the continuing efforts of the Centre to contribute to the improved performance of the construction sector in developing countries. It is hoped that both policy-makers and professionals will find the contents of this document interesting and useful in their work and that the "strategies for optimizing the use of energy in construction" outlined in the last chapter of this publication, will help national and local decision-makers and managers in their efforts to improve human settlement conditions in their countries.

**Dr. Wally N'Dow**
**Assistant Secretary-General**
**UNCHS (Habitat)**

**Home**"" """> **ar**.**cn**.**de**.**en**.**es**.**fr**.**id**.**it**.**ph**.**po**.**ru**.**sw**

📖 **Global Overview of Construction Technology Trends: Energy**

**Efficiency in Construction (HABITAT, 1995, 210 p.)**

**1. Introduction and overview**

Several studies have revealed that, during the periods of national economic growth, construction activity grows at a faster rate than the economy as a whole. In many developing countries, the basic indicators of underdevelopment are related to gross inadequacies in shelter, infrastructure and amenity delivery systems which result from the constraints of the construction sector. Thus, the construction industry can be said to be the backbone of national economic and social development.

Despite the strategic importance of the construction sector, it still operates with major

inadequacies in many countries. For example, construction costs are relatively high, basic inputs, particularly building materials, are scarce and expensive, the sector is import dependent amidst availability of unexploited indigenous resources. In short, the construction sector's outputs do not fulfil the demands for shelter and infrastructure especially the demands of low-income population.

There are several reasons for this anomaly but the most fundamental ones are: lack of sound planning and policies; lack of finance; and use of inappropriate and outdated technologies which are not suitable for local conditions, and are wasteful in terms of energy inputs. This publication addresses some of the latter problems.

The rapid pace of technological changes in the past couple of decades has radically impacted the nature of construction practices in developed countries and this has brought the technology-related issues in the forefront in various sectors including the building materials industries. Changing technological needs of the construction sector necessitates that the developing countries rectify their past deficiencies and enhance capacities to enable them to face the new challenges. Regardless of its level of development, each developing country should possess such capacities as to be able to monitor and assess the implications of the advances taking place around the world. It should further ensure that, the domestic construction sector is able to respond positively to changing technological environment.

In this context, absorption and adoption of "innovative" and "appropriate" technologies for developing human settlements in general, and for improving the construction sector in particular, play a vital role in any programme related to social and economic development. Adoption of "innovative" and "appropriate" technologies is not limited to setting up a mechanism to react to the above mentioned changes but also comprises the continuous acquisition of new information on construction processes in order to induct innovations.

No doubt information on available technological options is an important input for improving the performance of the construction industry, but final diffusion of technology goes beyond it and takes care of technological know-how, sources of technologies and finally establishes a mechanism and a framework for the modernization of existing industries.

The importance of the construction sector was recognized at HABITAT: United Nations Conference on Human Settlements, held in Vancouver, Canada in 1976 and the Commission on Human Settlements in its fifteen sessions over the past twenty years has underscored the significance of the sector by adopting special resolutions and by recommending selected programme areas to be implemented by UNCHS (Habitat). Owing to the vital role of the indigenous construction sector in the achievement of national economic and social goals, most of the activities of the Centre, in the construction sector, have focused on strengthening the domestic capacities of developing countries to enable them to meet the increasing demand of the construction sector outputs-housing and infrastructure facilities.

Agenda 21, adopted by the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil, in June 1992, has underscored the direct relationship between sustainable human settlements development and the sustainable construction-sector activities. In so doing, it has included a separate programme area entitled "Promoting sustainable construction industry activities" in its recommendations on "Promoting sustainable human settlements" (Chapter 7 of Agenda 21).

The basis for action for promoting sustainable construction activities as stated in Agenda 21 reads as follows:

"The activities of the construction sector are vital to the achievement of the national socio-economic development goals of providing shelter, infrastructure and employment. However, they can be a major source of environmental damage

through depletion of the natural resources base, degradation of fragile eco-zones, chemical pollution and the use of building materials harmful to human health"

and the objective for these actions as stated in the Agenda reads:

"The objectives are first, to adopt policies and technologies to exchange information on them in order to enable the construction sector to meet human settlements development goals while avoiding harmful side-effects on human health and on the biosphere, and, second, to enhance the employment-generation capacity of the construction sector. Governments should work in close collaboration with the private sector in achieving these objectives"

Recognizing the crucial role of the construction-sector activities in providing shelter for millions of poor and low-income population, the Habitat Agenda of the Second United Nations Conference on Human Settlements (HABITAT II), held in Istanbul, Turkey in June 1996, has also included in its "Global Plan of Action" a distinct section on construction sector and has devised a comprehensive set of action areas to be taken by Governments and other stake holders in the sector.

It is worth mentioning that both "Agenda 21" and the "Habitat Agenda" lay special emphasis on environmentally-sound construction practices to ensure sustainable use of natural resources; reduce the polluting impact of construction on the environment; reduce the cost of construction outputs in order to render them affordable to low-income population; and make the construction practices compatible with the local conditions (use of appropriate technologies). Both Agenda, among other things, stress the importance of improving energy efficiency and the application of low-energy, environmentally-sound and safe technologies in the construction.

The purpose of this publication, in line with the above mentioned recommendations, is to address some of the prevailing and critical setbacks of the construction sector in

developing countries. It demonstrates how environmentally-sound construction practices can be developed and how and through which measures can the sector meet the local demands in a sustainable manner. Bearing in mind that energy is one of the costly and most vital input to the construction and the building materials industry and the fact that excessive use of energy increases the cost of production and causes environmental degradation, special emphasis has been given to energy related aspects of production. Attempt has been made to demonstrate and analyze different approaches and modalities on how energy use in the construction sector can be optimized and how high-energy content materials can be easily replaced with low-energy content materials for the purpose of low-cost housing construction.

The publication starts with an analysis of high-energy content materials such as cement, lime, bricks etc. and then proceeds to discuss recent innovations to traditional technologies such as soil construction, use of timber and bamboo, alternative cementitous materials and the use of organic and inorganic wastes in the construction. The publication also includes some energy efficient house design options namely: passive solar heating and natural cooling of buildings. Finally, the publication concludes with a chapter entitled: "Strategies for optimizing the use of energy in construction". It should be mentioned here that, the technologies and any other information presented in this publication are inexhaustive. They can, however, serve as a basis for further study and research through the references and bibliographies given therein.

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📖 **Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**
   ▸ ☐ **2. Energy efficiency in the production of high-energy content**

**building materials**
- 📄 **2.1. Cement**
- 📄 **2.2. Lime**
- 📄 **2.3. Clay bricks**
- 📄 **2.4. Ceramic wall and floor tiles (2)**

**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**2. Energy efficiency in the production of high-energy content building materials**

**2.1. Cement**

**Cement production is an energy-intensive industry and the cost of required energy constitutes approximately 25 per cent of the price of the finished product (1). The total cement production in the world was about 1200 million tons in 1993 which used about 8 × $10^9$ GJ of primary energy which is more than 1 per cent of world's total primary energy consumption. Thus, the potential impact of energy savings in cement industry is considerable. One of the characteristics of cement industry is that different production technologies consume different amounts of energy for the same amount of output.**

**The important stages of cement production include:**

**(i) Raw material winning;**

**(ii) Raw mix preparation (grinding);**
**(iii) Firing the raw mix (producing clinker); and**
**(iv) Clinker grinding and mixing.**

All these stages require energy with various intensities, however, the most vital energy consuming stages are mechanical processing of raw material and clinker (grinding) and firing the raw mix (kiln process).

Cement production is basically a choice between rotary kiln technology and vertical shaft kiln technology. The rotary kiln is more popular, due to several technical advantages. However, on account of energy consumption alone, the shaft kiln is more efficient - as illustrated in table 1.

Table 1. Typical energy consumption patterns of cement manufacturing processes in Europe (fossil fuel only)

| Type of kiln | Energy consumption in kcal/kg of clinker |
|---|---|
| *Shaft kiln* | 750 |
| *Rotary kiln types* | |
| Dry (long kiln) | 860 |
| Wet (long kiln) | 1300 |
| Dry (suspension pre-heater) | 790 |

*Source:* Spence, R. J. S., Reference No. 6

There are two basic types of cement production technology in the rotary kiln process: dry and wet processes. But intermediate processes are also used: semi-dry and semi-wet. In the dry process, all raw material grinding and blending operations are done with dry

materials and the resulting powder is fed into the kiln system. In the wet process, the raw mix is wet ground and then in the form of slurry containing 30 to 40 per cent moisture is pumped to homogenization tanks where the final mixing is accomplished. In the past, wet process in cement manufacture was very common, but today the global trend is towards the dry process.

Comparison of the two basic cement manufacturing processes from the viewpoint of energy requirements shows the following:

|  | Wet process | Dry process |
|---|---|---|
| Electric power | 85-105 kwh/ton | 105-125 kwh/ton |
| Fuels | 5,000-6,000 kJ/kg | 3,000-3,600 kJ/kg |

Energy consumption depends not only on specific conditions prevailing in each factory but also on the choice of suitable equipment and proper technology, on the condition of the equipment and on its professional maintenance and operation (2).

Table 2 shows some representative figures for the energy requirements of the different kiln processes, and typical values for power consumption in the form of electrical energy. These are process-energy rather than gross-energy requirements. However, they are a reasonable approximation to gross-energy requirements and they indicate the relative-energy requirements of the different processes (3).

Table 2. Process-energy requirements in various processes of cement manufacture

| Process | Process energy requirement (MJ/ton) | Source of data |
|---|---|---|
| Dry process (kiln energy) suspension | 3300 | NATO (Europe) |

| | | |
|---|---|---|
| Dry process (kiln energy), suspension preheater | | |
| | 3300 | ETSU (United Kingdom) |
| | 3600-4000 | Rai (India) |
| Semi dry | 5074 | Ming-yu (China) |
| Wet process (kiln energy) | 5400 | NATO |
| | 6100 | ETSU |
| | 5700-6500 | Rai |
| Vertical-shaft (kiln energy) | | |
| Europe | 3150 | NATO (Europe) |
| India (mini-cement) | 4180-4600 | Sinha |
| China | 4850 | (ave) Ming-yu |

*Source:* **UNCHS (Habitat), Energy for Building, reference No. 1**

**Energy requirements for the preparation of raw mix to be fed into the kiln are rather substantial. Electric power is primarily used for crushers, grinding mills and for transporting materials. In some cement plants using dry process production, the moisture of raw materials should be removed before grinding. Removing the moisture in such cases is done by hot air from special furnaces or using heat from the waste gas of the cement kiln. The amount of heat required for drying raw materials is low as compared to the heat requirements of the cement kiln which is the major consumer of energy in cement plants. Clinker burning, in general, accounts for about 90 per cent of heat energy used in cement making (4).**

**The thermal energy consumption of the rotary kiln ranges widely depending on the type of**

process used, the quality and type of clinker required, kiln insulation, the effectiveness of the operation control system, etc. As a result, the actual specific heat consumption varies from about 3 to 7.5 GJ/t of clinker (4).

**Wet and semi-wet processes**

The advantages of the wet process, such as a simpler technological scheme for raw mix preparations and its control, lower-labour input and less pollution of the environment, led to its early extensive use in many countries. The basic disadvantage of this process as compared to the dry process has been a higher consumption of heat for clinker burning, as the water added to the raw mix has to be driven off in the kiln. Various efforts have been made to increase energy efficiency in the wet process kiln through design improvements, particularly by installing different types of heat exchangers in the kiln to improve the heat transfer (4).

In the semi-wet process, the water content of the slurry is reduced before feeding it into the kiln. Different types of filters can be used to reduce the water content to about 20 per cent. The resulting mass is fed into the kiln, which can be equipped with a pre-heater. The nodules obtained by filter-pressing of slurry and a shaping process are fed into the kiln. The preheater-kiln system consumes 5 to 5.4 GJ/t of clinker (4).
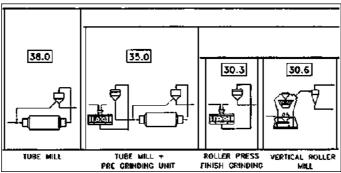
**Figure 1. Energy consumption in cement grinding (kwh/t of cement). Courtesy Holtec Engineering Private Ltd., India**
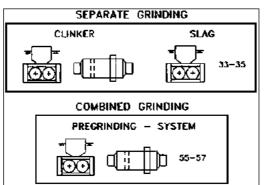


**Figure 2. Specific power consumption (kwh/t of cement). Courtesy Holtec Engineering Private Ltd., India**

**Dry and semi-dry processes**

Dry process kilns came into existence along with wet process kilns. The major development in dry process kilns was the introduction of external pre-heaters installed before the kiln inlet. This has led to better heat economy, increase in kiln capacity and, particularly in connection with the application of pre-calciners, making it possible to use smaller kilns for a given capacity. The main advantage of dry process kilns with pre-heaters is that the kiln gases pass over the raw mix thereby transferring their heat to the raw mix before it enters the kiln. Thus, the raw mix undergoes the final drying and partial calcination by using waste heat (4).

The four-stage cyclone suspension pre-heater-kiln system reduced specific heat consumption to 3.3 to 3.6 GJ/t of clinker and allowed the creation of large-scale units of upto 5,500 tonnes per day of clinker. The relatively high temperature of the raw mix entering the kiln permits a significant reduction of the size of the rotary kiln. Both the operation and maintenance of the cyclone suspension pre-heater are relatively simple, because the pre-heater does not have any moving parts. The four-stage cyclone suspension pre-heater-kiln system is today the most widely used conventional dry process kiln in the cement industry. Further developments in clinker production have been achieved by the introduction of the cyclone suspension pre-heaters with pre-calciners (4).

Although the reduction in specific heat consumption by adding pre-calciners to the suspension pre-heater-kiln system is modest, namely, about 0.084 GJ/t of clinker, this development has some advantages, which have led to its increasing use in developed and developing countries. The main advantage is increased output per unit of kiln volume. For a given capacity, the volume of the kiln can be reduced by approximately 60 per cent as compared to the suspension pre-heater-kiln system, because the raw meal is decarbonized up to 90 per cent in the pre-calciner. Another advantage, which is particularly important from the energy point of view, is that low-grade fuels can be burned in the pre-calciner thus saving high-grade fuels such as fuel oil, gas and high-grade coal. A third positive factor relates to the environment: NOx emissions are significantly decreased (4).

**Energy-saving opportunities**

Bearing in mind that about 85 per cent of the gross energy requirements in the production of cement, is consumed in the kiln process where temperatures of about 1450°C are reached (1), the potential for energy saving in the kiln process is remarkable. Considerable improvements in energy efficiency are possible through the replacement of wet-process with dry-process plants, through the installation of suspension heaters and through improved kiln insulation. Studies have shown that the variations for energy consumption between wet and dry process in rotary kilns could reach up to 86 per cent (a wet process could consume 1400 kcal/kg of cement compared to 750 kcal/kg of cement in the dry process) (5).

Small-scale plants using vertical-shaft kiln process are also better in terms of energy-efficiency compared to wet-process, but less efficient than the best and modern dry process plants.

Vertical shaft kilns have the lowest energy consumption, although they are smaller (in general 20-200 t/d) than the large-scale rotary kilns (1000 to 4000 t/d). In India, for example, it was established that while a vertical shaft kiln consumed around 750 kcal/kg of clinker, a rotary kiln consumed up to 2000 kcal/kg of clinker. In addition to the advantage of lower fuel consumption, the vertical shaft kilns are known to have operated efficiently on a variety of solid fuels, sometimes with an ash content as high as 50 per cent (6). Small-scale cement plants with vertical shaft kilns have inherent advantages of being located in the rural areas of developing countries meeting local demand resulting in reduced energy consumption for transportation. For a detailed treatment of the small-scale production of cement see UNCHS (Habitat) "small-scale production of Portland cement", reference No. 7.

As mentioned earlier, the improvement of heat-use efficiency and the reduction of heat

losses are of great importance in reducing the energy consumption in cement plants. To that effect some important measures include (4):

**(a) Energy savings in heating processes**

A significant reduction of specific heat consumption in rotary kilns is achieved by using modern dry process kilns with suspension pre-heaters or more advanced kilns with both suspension pre-heaters and pre-calciners, where the heat of the exhaust gas of the kiln is used for pre-heating the kiln feed. This can be realized when building new plants and/or when expanding existing ones.

Another useful method to economize on fuel is changing the mineralogy in the cement and utilizing mineralizers. Low-melting slags, fluoride and calcium sulphate are a few of the numerous substances that render a mineralizing effect on clinker formation. A reduction of clinker formation temperature, when utilizing the latter, leads eventually to saving of energy.

The specific fuel consumption for calcining clinker could be reduced by approximately 10 per cent by changing the clinker mineralogy. Since the clinker produced by this process features a high grinding ability, the specific consumption of electric power decreases considerably and the capacity of the cement mills increases.

Significant attention is given to the development of industrial production of cement by low-temperature technology with the use of calcium chloride, wherein the reaction in mineral formation is completed at temperatures lower than in currently utilize technologies.

Among the measures widely applied to improve heat use in rotary cement kilns are the use of internal heat exchangers, e.g., chain systems used in wet and dry process kilns and different thinners permitting reduction of the slurry moisture in the wet process that was

described above.

Substantial reductions in heat losses from the kiln can be achieved by proper maintenance of the kiln seals, control of combustion and improved refractories and cooling of the kiln shell.

Losses from the wall of the rotary kiln make up a substantial share of total energy lost. The heat transfer is reduced when the surface is insulated, but at the same time the temperature of both the metal jacket and the lining rises. Thus, external insulation may be detrimental to operating safely. One way of overcoming this is to utilize heat losses rather than minimizing heat transfer. To this end, a recuperator is fitted at the top or on the side of the rotary kiln. It is heated by some of the radiation emitted by the kiln.

Another opportunity for decreasing heat utilization in a cement plant is to use waste heat from clinker coolers. This waste heat can be used in a number of ways, particularly to dry raw materials, to dry coal when it is used for firing the kiln, or to generate steam and power if necessary.

(b) Electric power savings

Cement mills are the major consumers of electric power at cement plants, accounting for 40 per cent of total electric power consumption. Therefore, primary attention is given to improve efficiency in electric power utilization in these units as well as in the raw material grinding mills, which are in second place in terms of consumption of electric power in cement plants. Currently, clinker is ground mainly in ball mills whose energy efficiency is low - only 5 to 9 per cent.

The basic method for reducing energy consumption in ball mills is their adjustment to establish an optimum operating regime and to ensure maximum output with minimum energy consumption while preserving the predetermined fineness of grinding. Another

possibility of reducing the consumption of electric power is to improve the technology of grinding in ball mills by pre-engagement of the crusher-drier. Preliminary crushing may save energy in grinding up to 6 kwh/t raw material or 9 kwh/t of clinker.

To further increase the efficiency of the grinding process, it is necessary to employ grinding units of other designs such as roller mills. But, when developing new methods of grinding, it is necessary to ensure that economy in energy use does not cause offsetting increases in capital and operating costs. Evidently, cement will be ground in the future mostly in vertical mills.

The utilization of grinding intensifiers also ensures a certain energy saving. During recent years many cement plants have started using grinding aids for clinker grinding as a means of reducing electric power consumption and achieving increased output in the cement mill.

At present, roller mills appear to have some basic advantages in raw material grinding. The use of a roller mill in raw material grinding can reduce electric power consumption by about 20 to 25 per cent compared with that of a tube mill. However, a roller mill is in general not suitable for processing abrasive raw materials.

**(c) Substitution of fuels**

Energy conservation means not only reduction of specific energy consumption per unit of finished product but also preservation of scarce fuels such as fuel oil.

Many countries started reversing to coal after sharp increase in prices for oil-based fuels in the 1970s. Even countries possessing significant oil deposits like Indonesia aim at switching their cement plants from oil to coal and other low-grade fuels.

Widespread opportunities for using low-grade fuels for clinker burning were opened up by the development of systems with cyclone pre-heaters and pre-calciners. Pre-calcining or

secondary firing, apart from the possibility of achieving higher outputs, has also opened the way for the saving of high-grade fuels and combustible industrial wastes such as wood chips and bark, waste tyres, urban wastes, etc.

This is possible because the pre-calciner operates at a temperature of about 900°C which is needed for decarbonation of the raw mix.

Only about a quarter of the total amount of heat used for clinker burning is consumed in the kiln itself. Therefore, it is possible to feed up to 75 per cent of the fuel into the secondary furnace in kilns with pre-calciners (in practice normally up to 60 per cent is burnt in the pre-calciner). This allows the differentiation of fuel for calcining the clinker: higher calorific fuel for ensuring high temperatures in the sintering zone of the rotary kiln and less calorific fuel for ensuring decomposition of the carbonate component in the pre-calciner.

In addition, many of the substances harmful to the environment are introduced into the process together with the fuel and are bound almost completely in the cement clinker without impairing its quality. Moreover, low-grade fuel can normally be used in the process directly, i.e., without pre-treatment.

The potentialities for saving energy in the production of cement by utilizing energy-saving technologies and measures are given in table 3.

Table 3. Potentialities for saving energy in the production of cement

| Energy-saving technologies, equipment and measures | Potential savings |
|---|---|
| *Calcination of clinker* | *Fuel (percentage)* |
| Utilization of predehumified slurry, including the use of diluents[a] | 1-1.2 per one per cent of moisture |

| | content reduction |
|---|---|
| Production of cement by dry method in kiln with decarbonizer:[b] | |
| as compared with kilns with cyclone pre-heaters | 5-7 |
| as compared with the wet method | 40-50 |
| Intensification of the calcining process, including reduced suction of ambient air, utilization of mineralizers, automatic control systems, efficient heat exchangers, fuel combustion systems etc. | 10-15 |
| Utilization of ashes, slags and other materials, containing CaO, calcium silicates or aluminates[c] | 10 or more (depending on additive) |
| Utilization of combustible industrial waste and domestic garbage | equivalent to amount of waste used as fuel |
| Utilization of fluidized kilns for calcining clicker (as compared with rotary kilns)[d] | 25-35 |
| Utilization of secondary energy for electric power generation, raw material drying | 8-20 |
| *Clinker grinding* | *Electric power* |
| Milling cement in roller mills (as compared with ball mills)[e] | 15-25 |
| Utilization of milling intensifiers, optimization of granulometric composition, etc. | 10-15 |

**Source: UNIDO/former CSSR Joint Programme, reference No. 2**

**[a] Increase of kiln capacity by 1.5-2 per cent of moisture content decrease.**

**b Increase of specific capacity by 2.5 and 7.5 times, respectively and decrease of specific consumption of refractories by 4 and 5 times.**

**c Savings in raw materials components.**

**d Reduction of capital investments by 20-30 per cent, potentiality for burning shale and low-grade coal.**

**e Reduction in capital investments for construction, potentiality for additional cooling of clinker in milling processes.**

**In addition to the above opportunities, other studies provide more information on measures and possibilities for optimizing the use of energy in cement production. Table 4 is one of such compilation of information which provides examples from some countries.**

**Table 4. Selected examples of improvements in energy conservation and in specific energy consumption in cement production**

| Plant type/location | Energy savings | Measure taken |
|---|---|---|
| A. Energy conservation | | |
| Wet Process | Savings of 150 kcal/kg | Adding a vent air recirculation system to clinker cooler thereby reducing dust wastage and increasing heat recuperation. |
| Dry Process | Savings of 14 kcal/kg | Addition of new kiln seal at end discharge end to cut out air infiltration. |
| B. Lowering specific energy consumption | | |
| Wet Process | 10 per cent (from | Recirculating clinker cooler air. |

| | | |
|---|---|---|
| Wet Process (Canada) | 10 per cent (from 1,416 kcal/kg to 1,280 kcal/kg) | Recirculating clinker cooler air. |
| Wet Process (Canada) | 9 per cent (from 1,441 kcal/kg to 1,280 kcal/kg) | Thinner to lower slurry moisture from 35.8 per cent to 31.2 per cent with increase in clinker production by 9 per cent. |
| Wet Process (USA) | 17 per cent (from 1,876 kcal/kg to 1,560 kcal/kg) | Reduction in slurry moisture, new seals and closing holes, new cooler grates, and fans, new chain systems. |
| Wet Process (Brazil) | 11 per cent (from 1,841 kcal/kg to 1,637 kcal/kg) | Changing clay component, modifying chain system. |
| Wet Process (USA) | 15 per cent (from 1,617 kcal/kg to 1,381 kcal/kg) | Slurry water reduction, adding lifters, insulating bricks, raw feed chemistry control, chain maintenance, and cooler modification. |

*Source:* **Fog, M. H. and Nadkarni, K.L., reference No. 5**

**Another innovation regarding energy-savings in cement production is the technology of blended cements. The blending of certain carbonaceous materials such as granulated slag, fly-ash and other pozzolanas with cement makes it possible to produce more cement from the same amount of clinker and, thus, reduce the final consumption of energy per ton of cement produced. Experience has shown that up to 25 per cent by blast furnace slag without changing the performance of blended cements in comparison to Portland cement for general application in construction. In some countries, this mode of production has led to an estimated 20 to 40 per cent savings in fuel consumption. It has been estimated that at least one half of all Portland cement used in developing countries is used in applications for which a material of much lower strength would be adequate (8).**

*Note* For a detailed treatment of small scale cement production refer to UNCHS (Habitat), "Small
*1.*    scale production of Portland Cement", reference No. 7


*Note* For a detailed treatment of blended cements and other types of binding materials see UNCHS
*2.*    (Habitat), Endogenous Capacity-Building for the Production of Binding Materials in the
        Construction Industry-Selected Case Studies, reference No. 9.

## 2.2. Lime

**The production process of lime, like cement production, is highly energy-intensive, but
energy requirements in lime production are lower than cement and the types of fuels
required could be a variety of low-grade fuels.**

**Quicklime is manufactured by calcining limestone at temperatures around 900°C which is
almost 35 per cent lower than the heat required for cement clinker production. A high
proportion of the total energy requirement in lime production is used in kiln for calcining
the limestone. Thus, as in the case of cement, the principal means of achieving energy-
efficiency lies in improving the performance of the kilns. In industrialized countries,
production of quicklime is done by burning the limestone in large and fully automated
rotary kilns. However, in most developing countries, a vertical shaft kiln, using simple
masonry for the wall of the kiln is more common.**

**Rotary kilns are similar to those used in the cement industry. Rotary kilns have evolved
into short rotary kilns with separate pre-heaters, resulting in lower waste gas
temperatures. The original design had a specific energy consumption of 6.6 to 8.4 GJ/t
and capacities up to 560 tonnes per day. The short kiln can be made more energy efficient
with specific energy consumption as low as 5.0 GJ/t, though there are instances of such
kilns which do not capitalize on this energy-saving potential. Capacities of the short kiln
range from 200 to 1,000 tonnes per day (2).**

**Vertical-shaft lime kilns, however, have, proved to be one of the most suitable and economical methods of small-scale lime production in many developing countries (3 to 10 t/d capacity). For example, a vertical-shaft lime kiln can burn lime on a continuous basis resulting in considerable savings in heat losses. The kiln, having three distinct zones of operations (preheating, calcining and cooling), is attractive and efficient in terms of use of fuel. Further efficiency can be achieved by incorporating insulation in the wall of the kiln. These are only a few characteristics that make the use of the vertical-shaft lime-kiln technology more advantageous than the other traditional methods. For a detailed treatment of the vertical-shaft lime-kiln technology see UNCHS (Habitat), Vertical-shaft Lime-kiln Technology, reference No. 10.**

**Energy use in quicklime production**

**As mentioned earlier, the main energy requirements for the production of quicklime is in burning the lime stone in the kiln. The other energy inputs are required for limestone quarrying, grinding, and hydrating/slaking the quicklime. Table 1 shows the energy requirements for quicklime production in various types of kilns and countries.**

**Table 1. Energy requirements of quicklime production from various sources**

| Process and scale | Scale of production (ton/day) | Energy requirement (GJ/ton) | Efficiency (percentage) | Source of data |
|---|---|---|---|---|
| Traditional intermittent kiln, India | Very small | 12.6 | 25 | Rai |
| Conventional shaft kiln, India | 10-20 | 9.03 | 35 | Rai |
| Improved shaft kiln, India | 10-20 | 6.24 | 51 | Rai |
| Improved shaft kiln, Malawi | 20-300 | 6.92 | 46 | Spiropoulos |

| | | | | |
|---|---|---|---|---|
| Mechanized vertical | 20-100 | 4.76 | 67 | Rai |
| Rotary kiln | <100 | 6.71 | 48 | Rai |
| National studies | | | | |
| Argentina | | 3.8 | | |
| Germany | | 8.8 | | |
| India | | 6.34 | | |

*Source:* **UNCHS (Habitat), Energy for Building, reference No. 1**

**Table 2. Fuel consumption in lime production using different technologies**

| Country | Type of kiln | Proportion of production cost | Primary energy consumption MJ/kg quicklime |
|---|---|---|---|
| Federal Republic of Germany | Traditional vertical kiln | 35 | 4.760 |
| | Ring annular kiln | 22 | 4.865 |
| | Rotary kiln | 20 | 6.715 |
| | Traditional kiln | - | 12.60 |
| | Conventional | - | 9.03 |
| | Improved shaft kiln (CBRI) | - | 6.24 |

*Source:* **UNCHS (Habitat), Technical Note No. 12**

**As can be seen, traditional intermittent kilns can be very wasteful of fuel, with only 25 per cent of efficiency. Whereas the improved kilns can have an efficiency of up to 50 per cent even if in small-scale.**

Fuel consumption in alternative technologies for production of hydrated lime tends to show the importance of choice of technology in achieving energy efficiency. Using the case study of the Federal Republic of Germany in table 2, an energy saving of about 40 per cent is achieved when rotary kiln technology is adopted in place of a traditional vertical kiln.

**Energy-saving opportunities**

In vertical-shaft small-scale lime production, almost 60 per cent of the production cost is constituted by the cost of fuel alone.

The main fuel sources for lime-burning are coal, coke, cinder, wood, oil, gas etc. With the depleting resources of fossil fuel, it has become necessary to reduce the consumption of energy for the production of quicklime. Therefore, any saving in the consumption of energy will result in lowering the cost of production (10).

Energy savings could be achieved by changing the design parameters of the kiln. Studies and experiments carried out indicate that heat-energy savings could be achieved to the tune of 50 per cent by changing the design only. This indicates a potential for further savings by continuous research and development in limekilns (10).

An example of the energy savings achieved by improved limekiln design is illustrated in table 3 (10).

**Table 3. Average energy inputs for 1 kg quicklime (CBRI limekiln)**

| Constituent of energy consumption | Energy consumption (kcal/kg) | | |
|---|---|---|---|
| | Country type kiln | Conventional shaft kiln | CBRI improved kiln |
| Theoretical heat requirement for calcination for | 750.0 | 750.0 | 750.0 |

| Theoretical heat requirement for calcination for pure limestone | | | |
|---|---|---|---|
| Sensible heat loss through exhaust | 1050.0 | 850.0 | 850.0 |
| Heat loss due to underburnt limestone | 500.0 | 200.0 | 100.0 |
| Wall heat loss | 75.0 | 75.0 | 5.0 |
| Sensible heat loss from quicklime | 250.0 | 25.0 | 25.0 |
| Radiation losses from top surfaces | 150.0 | 125.0 | 75.0 |
| Heat loss due to incomplete burning of fuel | 100.0 | 75.0 | 10.0 |
| Excess air loss | 125.0 | 50.0 | 25.0 |
| Gross energy input (kcal/kg CaO) | 3000.0 | 2150.0 | 1660.0 |

*Source:* **Central Building Research Institute (CBRI), Roorkee, India**
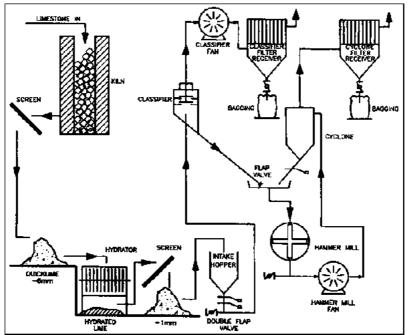
**Figure 1. Flow chart of vertical-shaft lime kiln production in Balaka, Malawi. Courtesy Brian Jones**

**The CBRI improved shaft kiln has been achieved through the principles of uniformity of heat distribution over the cross section of the kiln plus the provision of a good draught system. In detail, the CBRI kiln is a tall cylindro-conical structure constructed of masonry material with an internal lining of fired-clay bricks. The effective height of this kiln for a 10 tonne per day capacity is 11m and the calcining zone maintains a temperature of 950°C to 1100°C (11).**

**Figure 2. An improved shaft kiln developed by KVIC, India**

In rotary kilns, the highest losses are waste gases leaving the plant at a temperature of 250° to 350°C. These gases are always mixed with secondary air getting in at the interface between rotary kiln and pre-heater. If the plant were completely sealed, the waste gas temperature would rise to 430°C. This would not affect the balance sum of waste gas losses, because the over-all amount of waste gas would be reduced accordingly (4).

All energy-saving opportunities seem to be already realized in the most efficient shaft furnaces, particularly in the parallel-flow-counterflow-regenerative furnace. Waste gases emitted from this furnace range between only 60° and 140°C; further reduction would risk condensation and corrosion of equipment (4).

When a new kiln is constructed, the preferred kiln types are of the regenerative shaft kiln type. Specific heat consumption as low as 3.5 kj/kg is possible in this type of kiln.

However, an exception to this may occur if, for example, the disintegrating property of chalks and some coarsely crystalline limestones results in the shaft kiln being choked off by dust formed from the complete disintegration of these materials during burning. In this situation, the rotary kiln, fitted with a heat exchanger to recover waste gas heat, would be the most energy efficient solution (4).

For further information on lime production and some case studies see UNCHS (Habitat), "Endogenous Capacity-Building for the Production of Binding Materials in the Construction Industry-Selected Case Studies", reference No. 9 as well as UNCHS (Habitat), Vertical-shaft Limekiln Technology, reference No. 10.

**2.3. Clay bricks**

As in the cement and lime industry, most of the energy used in brick manufacture is required to fire the bricks - typically more than 95 per cent of all energy use. There are considerable differences between the energy requirements for different types of brick kilns, depending on whether the firing is continuous or intermittent, on the size and heat-transfer efficiency of the kiln and on whether the brick-earth used contains combustible materials (12).

Experience has shown that, beyond a daily output of 10,000 bricks, economies of scale are small and that low-capital-cost kilns, such as the Indian Bull's trench kiln, can have a fuel efficiency comparable with the expensive covered Hoffman kilns used in European countries. A recent study of the brick industry in Delhi (13) showed that detailed differences in the design of the trench kiln contributed to significant variations in energy efficiency. Overall, the bricks produced by the process had an average fuel consumption of 1.8 MJ per kg of bricks produced, but with individual kilns' fuel consumption varying from 100 to over 300 kilograms of coal per 1000 bricks. Research on the kiln process at the Central Building Research Institute (CBRI), Roorkee, India, has led to the development of

an improved but more expensive high-draught kiln design which is reported to reduce energy consumption by 25 per cent, compared with a typical trench kiln (13).

The scarcity and rising prices of coal, the predominant fuel used for brick-firing, are forcing brick producers to look for cheap fuel substitutes as well as energy economies. The study of the Delhi industry showed that increasing numbers of producers were using a proportion of unconventional fuels, such as fuelwood, rice husks, sawdust and agricultural waste, and that these producers were able to lower costs without it being detrimental to the quality of the bricks, though at the cost of a small lowering of energy efficiency. A small number of producers had eliminated coal entirely, with a resulting increase in energy consumption of only 14 per cent compared with producers using coal alone (14).

The theoretical energy requirement for firing clay bricks in small-scale kilns is about 20 to 35 per cent of the actual energy consumption in production practice. Thus, most existing brick production technologies are by definition energy-inefficient. Table 1 shows some examples for energy requirements related to the size of plants.

Since transportation of bricks from the point of production to the point of use accounts for a significant amount of energy consumption, it could be argued that the scale of production is a critical determinant of efficiency in energy utilization. Large-scale production technologies predetermine high-energy consumption for distribution because a single plant often has a wide catchment zone, sometimes an entire country. Large scale brick industries are examples of prevailing error in choice of scale of technology as far as energy-efficiency in transportation is concerned.

Table 1. Energy consumption in brick-making technologies

| Technology | Scale of production | Labour required (man-hr for 1000 | Over-all energy consumption |
|---|---|---|---|

| | (No. of bricks) | solid bricks) | (MJ/1000 solid bricks) |
|---|---|---|---|
| Small-scale production, all manual methods, clamps, stoves, scotch kilns | 2,000 | 20 to 30 | 7,000 to 10,000 |
| Small-scale production, all manual methods, up draught and down draught kilns | 2,000 | 30 to 40 | 10,000 to 15,000 |
| Medium-scale production, all manual methods, Bull's kilns | 20,000 | 30 to 40 | 4,000 |
| Medium-scale production, semi-mechanized method, Hoftmann on zig-zag kiln | 30,000 | 30 to 35 | 3,000 to 3,500 |
| Large-scale production, full mechanized tunnel kiln | 150,000 | 10 to 15 | 3000 to 4000 |

*Source:* **UNCHS (Habitat), Technical Note No. 12**

**In addition to the size of kilns, the actual amount of fuel required to burn a given amount of bricks would depend, among others, on the following factors:**

**(a) characteristics of raw material (clay);**
**(b) porosity of bricks;**
**(c) volume of water (moisture) to be evaporated;**
**(d) quality of the carbonaceous matters in the bricks;**
**(e) temperature to be attained;**
**(f) reuse of hot air generated in the kiln;**
**(g) quality of fuel.**

**Table 2 shows fuel requirements of intermittent and continuous kilns which is based on a study carried out in Pakistan (15).**

**Table 2. Typical fuel requirements of kilns**

| Type of Kiln | Heat Requirement (MJ/1000 Bricks) | Quantity of Fuel Requirement (Tons/1000 Bricks) | | |
|---|---|---|---|---|
| | | Wood | Coal | Oil |
| Intermittent | 7,000 to 15.000 | 0.50-1.0 | 0.25-0.6 | 0.15-0.35 |
| Continuous | 2,000 to 5,000 | 0.15-0.3 | 0.10-0.2 | 0.05-0.1 |

*Source:* **Mohammed Khalid Farooq, Pakistan, reference No. 15**

**Due to scarcity of coal in many developing countries (which are not covered in high priority segment for allotment of coal or railway wagons for its transportation) and rising prices of electricity or petroleum products, the introduction of modern technology in the industries manufacturing bricks, lime, ceramics, etc is a difficult task. Summary of a study carried out by UNIDO and ILO on the average fuel requirements for kilns is given in table 3.**

**Table 3. Fuel requirements for brick-making using different kiln types**

| Type of kiln | Heat requirement (MJ/1,000 bricks) | Quality of fuel required (tons/1,000 bricks) | | |
|---|---|---|---|---|
| | | Wood | Coal | Oil |
| Intermittent | | | | |
| Clamp | 7,000 | (0.44) | 0.26 | (0.16) |
| Stove | 16,000 | 1.00 | 0.59 | 0.36 |
| Scotch | 16,000 | 1.00 | 0.59 | 0.36 |

| Downdraught | 15,500 | 0.97 | 0.57 | (0.35) |
|---|---|---|---|---|
| Continuous | | | | |
| Original Hoffmann | 2,000 | 0.13 | 0.07 | 0.05 |
| Modern Hoffmann | 5,000 | 0.31 | 0.19 | 0.11 |
| Bulls's Trench | 4,500 | 0.28 | 0.17 | (0.10) |
| Habla | 3,000 | 0.19 | 0.11 | (0.07) |
| Tunnel | 4,000 | (0.25) | (0.15) | 0.09 |

*Source:* **UNIDO/ILO, Technical Memorandum No. 5**

**Similarly the continuing rise in the cost and shortage of wood as a source of energy for brick-making has forced many producers to switch to low-grade fuels such as agricultural wastes and cow dung. The change-over to these residues has been taking place despite their several disadvantages in comparison to fuelwood of those having lower calorific values and lower heat intensity and more difficult to feed in furnaces. Table 4 shows the price range of different fuels in India together with their respective heating values.**

**Table 4. Comparison of heating value and prices of different fuels**
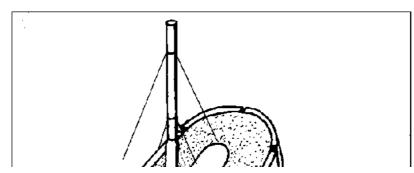
| Fuel type | Unit | Price in Rs./unit | Heat value (air dry) | MJ/Rs. total heat | Conversion efficiency (percentage) | MJ/Rs. useful heat |
|---|---|---|---|---|---|---|
| Fuelwood | kg. | 0.50-0.70 | 19.7 MJ/kg | 28.1-39.4 | 10-30 | 2.8-3.9 7.9-11.0 |
| Agri-residue | kg. | 0.04-0.09 | 14.7 MJ/kg | 163-268 | 8-12 | 13.0-29.4 19.6-44.2 |
| Dung | kg. | 0.30-0.40 | 8.8 MJ/kg | 22.0-29.3 | 8-12 | 1.8-2.3 |

| | | | | | |
|---|---|---|---|---|---|
| Cake | | | | | 2.6-3.5 |
| Charcoal | kg. | 2.50-3.00 | 29.0 MJ/kg | 9.7-11.6 | 23-30 | 2.2-2.7 2.9-3.5 |
| Soft Coal | kg. | 0.40-0.50 | 24.2 MJ/kg | 48.4-60.5 | 20-30 | 9.7-12.1 14.5-18.2 |
| Kerosene | ltr | 1.80-2.55 | 38.2 MJ/ltr | 17.0-21.2 | 37-52 | 6.3-7.8 8.8-11.0 |
| Electricity | kwh. | 1.50-2.00 | 3.6 MJ/kwh | 1.8-2.4 | 45-50 | 0.8-1.1 0.9-1.2 |
| LPG | kg. | 4.05 | 24.5 MJ/kg | 11.2 | 60-65 | 6.7-7.3 |
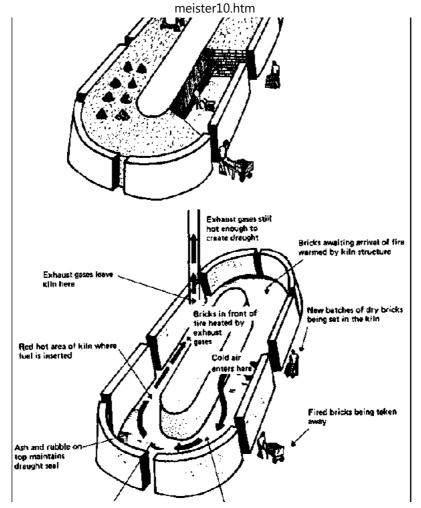
*Source:* **Adapted from Energy Conservation Book, Utility Publication, 1988**

**Due to large variety of processes and the wide range of fuel types and products, it is almost impossible to fix a standard value for the total energy input in brick-making. For example, intermittent kilns consume twice as much energy, in general, as continuous kilns.**

Exhaust gases still hot enough to create draught

Bricks awaiting arrival of fire warmed by kiln structure

Exhaust gases leave kiln here

Bricks in front of fire heated by exhaust gases

New batches of dry bricks being set in the kiln

Red hot area of kiln where fuel is inserted

Cold air enters here

Ash and rubble on top maintains draught seal

Fired bricks being taken away

Bricks in chamber
cooling down

Air warming up as it passes
by hot bricks

**Figure 1. Working method of the Bull's Trench continuous kiln. Courtesy BRE, U.K.**

It is, therefore, advisable to establish necessary measures which should be based on trial firing in each case and/or replicate identical processes as far as it is possible. Obviously, maintaining uniformity of raw materials and fuel types and continuous maintenance of kiln operation would lead to reduced deviations in the amount of fuel required in a given plant. Hence, reasonably accurate forecast of fuel consumption for a foreseeable future of plant operation.

**Energy-saving opportunities**

As mentioned earlier, one of the major energy-saving opportunities lies in converting, where possible and feasible, the intermittent kilns such as clays or simple updraught kilns, to continuous kilns: the latter include the Bull's trench kiln, the Hoffman kiln and the tunnel kiln. Experience has shown that a coal-fired Bull's trench kiln, of the type common in India and Pakistan, is several times more efficient as a sophisticated oil-fired clamp one and almost as efficient as a sophisticated oil-fired tunnel kiln. In China, Fuyin, Y., and others have developed a small-scale continuous updraught kiln, fired on coal, wood or agricultural waste, which has excellent efficiency.

Where it is considered necessary to use intermittent kilns, improvement may be made to enhance fuel efficiency by:

- ensuring that even temperatures are obtained throughout the kiln;

- reducing heat losses through the sides and top surface of the kiln; and

- recovering heat from the combustion gases. This can be achieved through use of

scotch or updraught kilns with permanent sidewalls rather than open clamps, and improvement of insulation of clamp kilns.

where continuous kilns are used, strategies for energy savings can be achieved by:

- increasing chimney heights;

- adopting a fixed rather than the traditional moving chimney design; and

- careful control of the levelling of the kiln floor. Process control such as sealing the kiln, adequate drying of the green bricks, and uniform feeding of the fuel also contribute to energy saving.

The Central Building Research Institute in Roorkee, India, has carried out extensive research on kiln processes and has found out that a reduction of 25 per cent on fuel consumption can be achieved by improvements in the high-draught kiln designs compared with the typical trench kilns. But the capital requirements of such a kiln is almost 10 times that of the traditional kiln which is a major bottleneck for small-scale brick producers to afford such an initial investment (3).
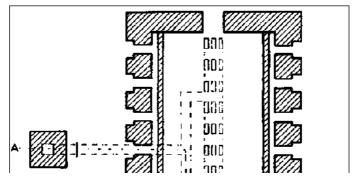
Changes in fuel type and addition of solid-fuel particles such as coal dust, sawdust, coffee or rice hulls or, even, plastics such as polystyrene, to the clay can increase energy efficiency but affect the characteristics of the brick, e.g., porosity, strength. This is not necessarily a disadvantage, but it is necessary to take these different properties into consideration during design and construction stages. Similarly, hollow bricks will save energy (5 to 6 per cent per 10 per cent of hollowness) but will have different properties from solid bricks. Several of the improvements noted above have been implemented in brick-making in Indonesia, as part of a Technical Assistance Programme, and include:

(a) introduction of perforations in hand-made and extruded bricks;

**(b) use of combustible filler (e.g., rice husk) in the clay body;**

**(c) improved body-clay preparation; and**

**(d) control of air supply and waste gas in kilns. The results of this programme have not yet been assessed (16).**

Waste engine oil can be an alternative fuel in some areas. Waste engine oil is often disposed of in such a way that it causes serious water pollution, and using it as a fuel would greatly reduce this problem. Waste engine oil can be utilized in simple gravity drip-feed flat-plate burners which vaporize the oil: such a method has been successfully used to fire a 35 cubic-foot pottery kiln at Arusha, the United Republic of Tanzania. Alternatively, sophisticated forced-air burners can be employed which use blowers to atomize the fuels. To use waste oil most effectively, a combination of fuels is required. Moreover, to start the firing using flat-plate burners, wood or other biomass can be used (17).

Another opportunity for saving energy in the overall process of brick-making is the use of solar energy for drying the green brick in countries with dry and warm climate.
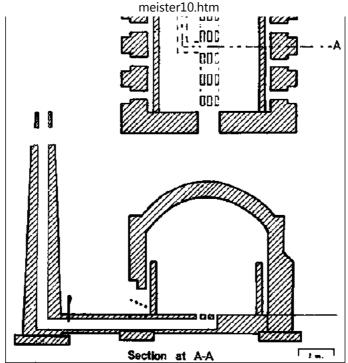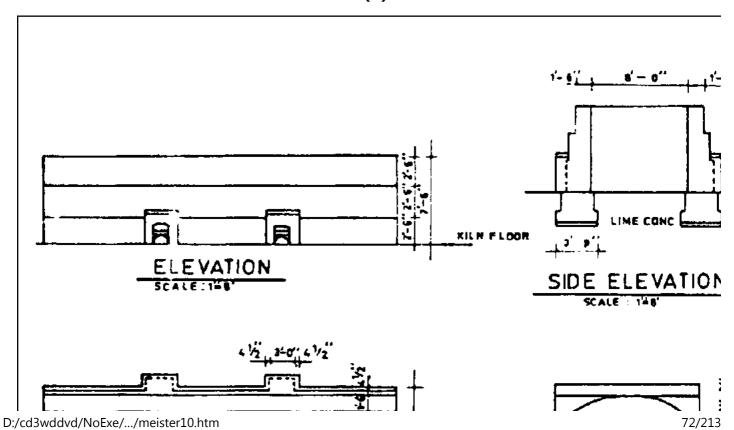
Section at A-A

**Figure 2. A rectangular down-draught kiln. Courtesy UNIDO/ILO, Small-scale brick making**



**Figure 3. Sun drying of green bricks is common in dry and warm climates. Courtesy BRE, U.K. (a)**

**Figure 3. Sun drying of green bricks is common in dry and warm climates. Courtesy BRE, U.K. (b)**



ELEVATION
SCALE:1=8'

KILN FLOOR

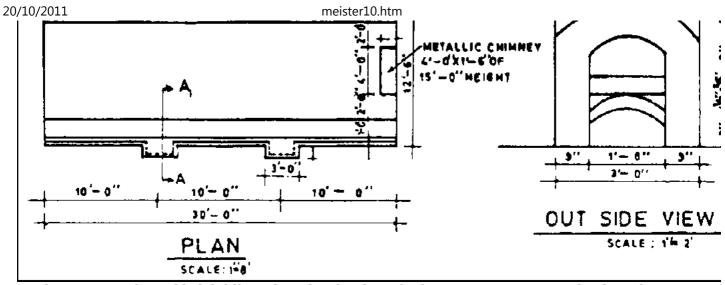LIME CONC

SIDE ELEVATION
SCALE : 1=8'

**Figure 4. Design of brick kiln using rice-husk as fuel. Courtesy Satya Prakash and F. U. Ahmed, CBRI, Roorkee, India**

**2.4. Ceramic wall and floor tiles (2)**

**Ceramic products for interior and exterior protection and decoration of all types of commercial and residential buildings are of great importance. Earthenware, tiles and mosaics are included in this group. Energy consumption of both glazed and unglazed products is high and covers a broad range depending on the individual product.**

**Energy consumption in ceramics production is concentrated in the following processes and activities:**

**   - Dressing and shaping;**

- Handling and internal transport;
- Drying and firing, which together account for about 85 per cent of energy consumption.

**Wall tile**

The traditional manufacturing process consists, with the exception of body preparation and pressing, of three phases: drying, bisque and glost firing after glazing.

The traditional manufacturing process, based on kaolinitic-clay, semi-silicious or feldspar body composition, requires bisque firing temperatures in the range of 1,230°C to 1,280°C. Glazed bisque is fired at 1,080°C to 1,120°C. Decreased firing temperatures, of 1,050-1,080°C for bisque firing and 960-1,040°C for glazing, can be achieved by replacing those bodies with lime-silicious, dolomite-silicious and certain other raw materials. Significant energy savings are possible through the lower-temperature firings, which newer materials allow.

**Ceramic glazes**

Properties of ceramic glazes have to correspond to the ceramic body properties and to quality and appearance requirements.

The last 50 years of technological progress in the production of ceramic glazes has paralleled that of ceramic bodies. Opaque zircon glazes based on potash feldspar are fired at temperatures of about 1,120°C. These glazes are for glazing kaolinitic-clay bodies. The application of calcium-silicious body in the manufacture has allowed the development of new types of glazes with sodium-lime feldspar and lead content, which are melted at firing temperatures of only 960° to 1,040°C.

Further development of glazes should result in single ceramic processes at temperatures

**as low as 900°C.**

**Opportunities for energy conservation**

**There exist several possibilities for energy conservation in the ceramic floor and wall tile industry. The most important among these are the following:**

**- Further reduction of firing temperatures through the application of fluxes and corresponding glazes;**

**- Replacement of the double firing by the single firing process for energy savings of 40 to 50 per cent;**

**- Proper adjustment of existing kilns to reduce energy consumption usually by 10 to 20 per cent;**

**- Use of waste heat from the cooling zones of kilns, for example, to pre-heat combustion air;**

**- Use of waste heat from flue gases in technological processes;**

**- Use of modern equipment for drying and firing where about 85 per cent of total energy in the overall production process is consumed.**

◀                                                                    ▶

**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**3. Innovative technologies related to the increased utilization of low-energy building materials**

**3.1. Soil construction**

**Unlike energy-dependent building materials which consume predominantly thermal energy resources, the energy requirements for modern soil construction are mainly in the form of electrical and mechanical energy to run a variety of mixing, extrusion, ramming and compaction of soil blocks. In this context, it could be argued that soil construction, even in its most technologically-sophisticated form, is capital-intensive and hardly energy-demanding. There is a wide range of soil construction technologies that utilize capital items in one form or another. One important asset in these technological trends is that there are different scales of capital intensity and, by implication, energy expenditure, including technologies with no energy requirement. In fact, in most small-scale operations, every stage of the soil construction process is manual, utilizing simple tools,**

and the only energy requirement is related to transportation of materials. However, where appropriate soils are obtainable near the construction site, there is hardly any expense in transportation and, perhaps, this is the greatest potential in soil construction as an indigenous low-cost material (18).

The selection of building materials, in general should aim at providing the most desirable levels of climatic comfort. In countries with harsh weather conditions, especially where there are extreme seasonal or daily variation in temperature, climatic comfort and, by implication, the thermal characteristics of the building materials used, are as important as their durability.

Climate conditions of countries such as the Middle East and the Arabian Peninsula although, generally, hot and dry, tend to vary sharply between summer period and winter months, thus making climatic conditions of utmost importance in the choice of materials for low-cost housing.

In this connection, it should be mentioned that soil, in comparison to several other materials, has a relative advantage due to its good capacity to store heat. Soil has a latent inertia related to its absorption capacity and has a significant ability to delay thermal variations and external thermal inflows. These properties are valuable in areas, characterized by highly variable climatic and atmospheric conditions. Perhaps the greatest asset of soil in relation to its thermal performance, is the ease with which its specific gravity can be altered for construction. This is particularly noticeable when soil blocks are made of clay and straw. With the soil-straw technique, it is possible to produce blocks with a bulk density as low as 300 kg/m$^3$ and a corresponding high insulation value of 2.80 m$^{2 \cdot \circ}$C/W, while solid concrete blocks have a bulk density of 2,400 kg/m$^3$ and an insulation value of 0.24 m$^{2 \cdot \circ}$C/W (19).

### A brief review of soil construction technologies

The most predominant examples of soil construction are the outcome of traditional practices but, unfortunately, technological errors are common in these constructions. The underlying principles of modern soil technology are a response to the defects of the traditional practices. A great deal of technological achievements in soil construction are replicas of other building materials technologies, notably fired-clay bricks and concrete. The three most common modern soil construction technologies are rammed earth, adobe construction and compressed-block technology. In several aspects, rammed earth technology is similar to monolithic concrete techniques, adobe is close to unfired-clay brick, while the production of compressed-soil blocks follow the same principles of concrete-block manufacturing.

**(a) Rammed earth**

The quality of soil is an important criteria for good quality rammed earth construction. The suitable soils should have adequate cohesiveness and should contain sandy aggregates to the point that they attain characteristics similar to those of lean concrete. When the available soils are clayey (have high plasticity index-PI), they should be mixed with soils containing a high percentage of gravel and sandy fraction. In the preparation of soil for rammed earth construction, depending on the location and size of construction projects, both manual and mechanical methods can be applied. The mechanical process, which obviously, would require some energy input, vary from simple technologies to sophisticated automated equipment. One important advantage of rammed earth technology is that its use in movability wall construction allows for a variety of forms such as round corners. In temperate climates, it is not advisable to carry out rammed earth construction less than three months before or during the frost period. In hot-humid climates, the rainy periods should be avoided, while in hot-dry climates, the hottest season should be avoided.

Owing to the similarity between rammed earth construction and *in situ* concrete

technology, most of the machinery used in concrete works are directly applicable to rammed earth. However, the two most distinguishable and important activities in rammed earth construction are formwork and ramming.

One weakness of rammed earth construction is that the walls are liable to crack after a period of time if not properly constructed. These negative aspects can be minimized by means of putting the walls on strong foundation, using soil stabilizers, surface protection or patching up the cracks as a remedial measure.
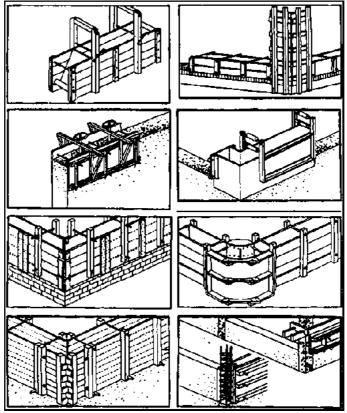
**Figure 1. Different types of formwork for rammed earth construction**

**Formwork**

Formwork for rammed earth must be solid and stable in order to resist the pressure and vibrations resulting from ramming. In addition, it should be made of lightweight material and it must be easy to assemble and dismantle. The formwork must also be capable of accommodating changes for the height, length and thickness of walls. A broad range of materials, such as timber, glass fibre, steel and aluminium, can be used for manufacture of formwork. Depending on the type of building, available workforce and equipment, formwork can be organized as either a system consisting of small units or an integral formwork. Integral formwork is normally used when the design to be executed is relatively simple and it is presented in a simple format adopting modular dimensions.

Movement of formwork on site can be done by gantry formwork. This technique is best suited for the erection of columns or wall sections. Such formwork should be light, consisting of simple planks, plywood panels or even billets, which should be kept in position by wooden supports driven into the ground and secured at the top. Other techniques for movement of formwork on site are the use of rollers and sliding formwork as in modern concrete practice.

**Rammers**

The performance of a building made of rammed earth depends largely on the efficiency of the ramming technique. Ramming is the most tedious process in the entire operation and, depending on the choice of technique, there could be some minimal energy required. There are two types of rammers - manual and mechanical. The key elements for manual ramming are:

(a) an effective striking face: a striking angle of 60° or more with detailing in the shape to cater for difficult angles in the formwork;

(b) a striking area of not more than 225 sq cm;

(c) a durable material for the striking head, preferably solid metal;

(d) a handle of about 1.4 m; and

(e) the total weight of the rammer should range between five and nine kilograms.

There are two types of mechanical ramming, i.e. impact and vibrating ramming. Impact ramming consists of pneumatic rammers which have been adapted from the foundry industry. Their function is similar to that of manual rammers except for a higher impact frequency (up to 700 strokes per minute). Pneumatic rammers must not exceed 15 kg in weight and should not be too powerful, otherwise they tend to destabilize the formwork causing the earth to bulge or rather the rammer might penetrate the soil. Vibrating rammers are powered by combustion engines or electric motors and are heavy, cumbersome and expensive yet not proven to be effective particularly, in remote areas.

(b) Adobe technology

Adobe technology is equivalent to that of fired-clay bricks except for the fact that while fired-clay technology relies on a kiln process with high energy requirement, adobe technology replaces this process with open-air sun-drying. The soils used for adobe should be plastic or cohesive in texture. Clayey soils are thus the most suitable for adobe manufacture, but it is important to select those clays which are not generally expansive. Sometimes sandy soils have to be added to the clay to achieve the right quality of soil.

The first step of adobe blocks is pugging the clay. Because of the cohesive nature of soils, the pugging of clays could sometimes be a long operation. Traditionally, the clayey soil is mixed with water and sometimes with bare feet until a consistent mixture is obtained. Animals are sometimes used to knead the soil with their hooves. The manual processes of kneading clay are extremely labourious and thus make mechanized options easily attractive. Mixing is the most important operation in the production process if the soils

used require an admixture such as sandy soils or stabilizers. Standard concrete mixers can be adapted to this practice but there are other technologies which are particularly suited for soil mixing. Vertical mixers can be fabricated on the site using planks, timber sections, ropes and steel wire with animal-driven power. There are also standard vertical mixers on a commercial scale capable of handling 10 cu m per day. Similar linear mixers adapted from the ceramic industry are available with rated capacities of up to 50 cu m per day.

**Manual moulding**

To produce good quality, dense, and resistant adobe bricks, it is advisable to use a clay mixture that is semi-solid in texture which implies the use of the sand-moulding technique. Small-scale moulding tables from the brick industry can be adapted to this technique. A typical example is the ITDG moulding table with an output of about 500 bricks per day (20). The manual technique of adobe production can be adapted to large-scale production. The key item is the multiple mould. The clay mixture should be liquid in consistency so that it can be easily spread manually to fill all the moulds in one single operation. It is important to ensure that the multiple mould can be handled by two persons and that blocks can be easily demoulded. With this technique it is possible to produce 8,000-10,000 blocks per day using a team of five or six workers.
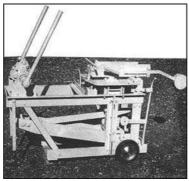
**Figure 2. A heavy manual earth block press, developed by Appro-Techno, TERSTARAM, Belgium**

**Mechanized presses**

**The simplest form of mechanized production is an adaptation of the manually-operated multiple-mould production. The moulds are mounted on wheels with or without a mobile hopper to feed the clay mixture into the moulds. An output of 7,000-10,000 blocks per day can be expected from such a technique. There is a similar technology in which the mechanized multiple mould is replaced by a manually-operated set of cutter discs. The latter technique can produce 15,000 blocks per day. The extrusion technology is the most popular form of mechanized production. The vertical extruder consists of a vertical mixer fitted with an extrusion nozzle. The system can be motorized or animal-driven. Small vertical extruders are estimated to have an output of 1,500 blocks per day. Horizontal extruders, as used in the ceramic industry, require a high level of investment but are more efficient and versatile than the vertical ones. Owing to the fact that the soils used for adobe have to be sandier than those for fired-clay bricks, a high degree of wear and friction occurs in the extruding machines, hence the importance of versatile extruders.**

The energy content of unstabilized manually-made soil blocks is so low as to be almost negligible, by comparison with the energy content of fired bricks or of concrete blocks. When machine compaction is used, the compaction energy required is still very low, but, when the energy cost of the block press used is included the total energy consumption rises to 50-100 MJ/ton (14).
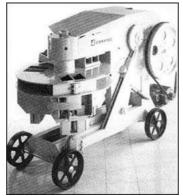


Figure 3. A motorized earth block press, developed by CERATEC, Belgium

(c) Stabilized soil blocks

Unlike rammed earth and adobe technology, the production of compressed soil blocks allows the use of a more flexible range of soil types because adjustments can be made in the production process to counteract any deficiencies in the soil characteristics. However, good quality compressed soil blocks require the use of soils containing fine gravel and sand as well as some clay and silt to bind the sand together. At least 50 per cent of the soil should have a grain size of less than five mm.

The production process involves pulverization of soil, screening, mixing with stabilizer and

compaction. Pulverization is required for lumpy soils and can be done manually or with machines. Screening is essential for removing large particles and organic matter, especially if no pulverization has been done. The pulverized and screened soil - with or without additives - should be mixed in the dry state before mixing it with water. A conventional concrete mixer may not be useful for mixing wet soils because of the tendency of composite materials to stick on the inside of the rotating drum and because of the formation of lumps in the soil.

Based on extensive studies and experiments, it has been found out that blocks stabilized with 5 per cent cement have a strength and durability comparable with ordinary clay bricks and concrete blocks. The energy requirements for this type of blocks with only 5 per cent cement is about 150 to 300 MJ/ton. However, blocks having 10 per cent cement, which would have adequate strength and durability, would increase the energy requirement of soil blocks to only 300 to 500 MJ/ton, still substantially less than the figure for any other type of alternative walling materials (4).
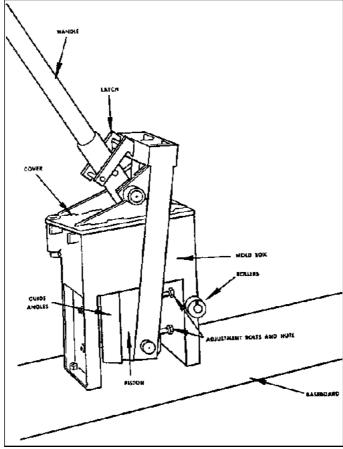
**Figure 4. A CINVA-RAM block-press. Courtesy IBEC Housing Corporation, New York**

**Soil block presses**

The mode of compaction is the key to a durable and cost-efficient compressed soil block. The strength of a block increases with the intensity of compaction to a limit of about 4 to 10 MN/sq m, beyond which the effect is reversed. Even though the strength of a block depends on the compressive capacity of the machine, it is equally important to ensure the appropriate use of the machine. Blocks with different strengths could be produced by the same machine if the production parameters are changed. Compaction machines can be classified by the moulding pressure - measured in MN/sq m - they generate, namely (a) low pressure: 0 to 4, (b) average pressure: 4 to 6, (c) high pressure: 6 to 10, (d) hyper-pressure: 10 to 20, (e) mega-pressure: 20 to 40.

Some of the compaction machines available in the market were developed especially for soil construction but others were adapted from the concrete block industry. Soil compaction machines can be further divided into manual and motorized units. In all cases, presses can be distinguished by their weight and their transmission principles-mechanical or hydraulic presses.

**Appropriate soil construction technology**

Few programmes formulated in response to the shelter needs of low-income populations have considered soil construction as a viable option. The legacy of unsafe and non-durable construction, reminiscent of most existing low-income houses built of soil, has made soil construction technology unpopular and difficult to promote, while modern soil construction, in spite of all its improvements and advancements, poses problems of inappropriateness in the choice of technology. In fact, in a number of cases low-income housing constructed with modern soil technology has failed. These failures were often due to excessive cost of production or breakdown of machinery and led to the abandonment of entire projects. A successful soil construction programme for low-income housing should

**be based, first and foremost, on sound technical criteria. Thus, the following aspects need to be taken into account:**

**(a) Understanding basic soil science;**
**(b) General design and construction considerations;**
**(c) Surface protection of exposed walls;**
**(d) Machinery for the production of soil materials;**
**(e) Government promotional activities.**

**Figure 5. Soil identification and performance tests**

Soil construction requires an ability to identify soil types.

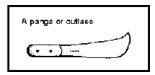Whilst a full laboratory report would be the Ideal to aim at, this Is not always possible.

The tests outlined here can be conducted in the field with the minimum amount of equipment. They will not give accurate proportions of the ingredients of a soil sample, but that is not always necessary. They will give an objective result whereby it will be possible for someone to say... "that is a sandy clay", or... "that is an expansive clay", etc. The ideal soil for soil construction will contain about one third clay, one third silt and one third sand. The proportions can be slightly different, and even totally unsuitable soil can be used, If proper precautions are taken.

Therefore, we start with a review of the equipment needed

1. EQUIPMENT

With this equipment, the following tests are designed to help you decide what are the most important materials in your soils.



A panga or cutlass

Simple field tests can be carried out using:

Eyes

**Figure**

Nose

**Figure**

Teeth

**Figure**

Fingers
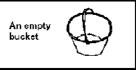
**Figure**

An empty clear glass jar with straight sides

**Figure**

An empty bucket

**Figure**

An oven dish

**Figure**

Some water

**Figure**

A ruler - any scale will do

A box of planed wood

## 2. SIEVING

A ruler - any scale will do

**Figure**
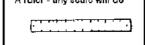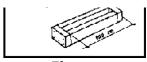
**Figure**



**Figure**

One worthwhile precaution to take is to sieve all soils which are to be used in construction. This will ensure large lumps and stones are removed, and will make remaining soil easy to use.

A useful sieve can be made from a simple wooden frame with a metal grid giving holes approximately 3 mm to 5 mm in size.
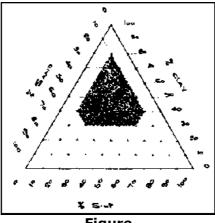
It is, incidentally, easier to let the soil fall through the sieve than to pick the sieve up with the soil on it!

## 3. CLASSIFICATION

An ideal soil type for soil construction will be in the proportions shown by the shaded area.

However, construction can go forward, even if the soil type falls outside the shaded area. It just

requires extra effort or extra precautions.



**Figure**

**Basic soil science**

**Often issues related to soil science are taken for granted or even ignored. An understanding of basic soil science, however, is essential for a successful soil construction practice. Decisions as to whether a particular soil is appropriate for construction can only be made if the characteristics of the soil are known. This knowledge will also determine the different aspects of the production process - whether to use adobe, rammed earth or compressed block technology, whether stabilization is needed and what type of stabilizer is to be used, which, if any, precautionary measures need to be taken. These considerations are of particular importance when soil construction is used for low-income housing because they have far reaching implications for the final cost of production. For instance, to use excessive quantities of a costly stabilizer or even to use one which is**

inappropriate for a given soil composition may result in an unnecessary increase in the cost of production.

For the purpose of low-cost construction, simple field tests can be undertaken to determine the characteristics and suitability of the chosen soils such as the presence of organic matter, type of soil (sandy, silty or clayey), sedimentation and shrinkage properties.

An important component of soil science is soil stabilization. Building with soil implies a choice between three main approaches:

(a) using the soil available on the site and adapting, as much as possible, the functional requirements of the construction to the quality of the soil;

(b) using another soil already suitable for the requirements of project but which has to be brought to the site from another source;

(c) modifying the local soil so that it is suited to the functional requirements of the project. This last option implies the use of stabilizers. There are three basic types of stabilization:

(i) Mechanical

By compacting the soil, it is possible to change its density, mechanical strength, compressibility, permeability and porosity;

(ii) Physical

The properties of the soil can be modified by acting on its texture through, for example, the controlled mixing of different grain fractions.

**(iii) Chemical**

**Materials or chemicals can be added to the soil to modify its properties either by a physical and chemical reaction between grains and the additive or by creating an impermeable layer which binds or coats the grains.**

**The most common stabilizers are fibers, cement, bitumen emulsion and hydrated lime.**

**Design and construction considerations**

**Appropriate design and construction practices are a prerequisite to the durability and cost efficiency of housing for low-income groups. Low-cost soil blocks produced by rudimentary techniques could prove durable and satisfactory if the correct design and construction principles are adopted. Conversely, the use of high-technology and expensive soil blocks could lead to premature deterioration and eventual failure. In this context, it could be argued that most of the existing soil housing in low-income settlements have high levels of deterioration mainly because of errors in design and construction procedures rather than because of any inherent weakness of soil as a building material. The design and construction of low-cost houses should take, at least, two items into consideration:**

    **(a) foundations and base courses;**
    **(b) walls and openings.**
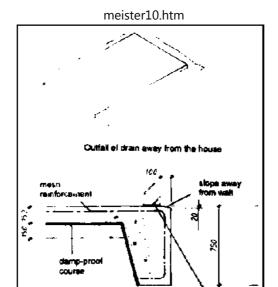
**Soil buildings are vulnerable to water penetration, especially at the ground level. Foundations not only bear structural loads but also act as barriers to ground-water penetration and thus prolong the existence of the building. It is important, therefore, to provide a damp-proof course layer between the foundation and the soil block work. For purposes of low-cost housing, simple strip foundations are suitable but stepped foundations are more effective where sloppy grounds are encountered. Foundations can be**

made of ordinary concrete rubble, concrete block masonry, stone masonry and even stabilized soil-block masonry. The base of a soil building is also vulnerable to rain water even when a foundation is provided. Water penetration can be controlled, in areas with high rainfall conditions, by a short-base course of impermeable material - a base course of about two or three layers of concrete blocks, stone or fired-bricks should be adequate for this purpose. An inexpensive alternative is to use soil blocks for the base course and protect the exposed surface at the base of the course with a rendering such as bitumen emulsion or cement mortar.

Rain water erosion and drainage shrinkage caused by sunshine can also affect exposed soil walls. It is advisable, therefore, to have overhangs of at least one meter in areas of high rainfall. Lintels are necessary above doors and windows and so is a wall plate to distribute loads on the soil wall. The corners of soil walls are particularly prone to deterioration from a combined effect of rain and wind. In fact, soil erosion is more intensive at corners than at the main body of the wall. Soil erosion at comers can be minimized by either a water-resistant rendering on the corners or by simply rounding the corners of unprotected walls. Window sills should project a sufficient distance from the wall to prevent the eroding effect of running water. The position of openings affects the strength and durability of soil walls, especially where the ground is unstable. High concentration of openings and openings near corners should be avoided.

**Figure 6. Foundations**

1. CONCRETE - RAFT TYPE

**Figure**
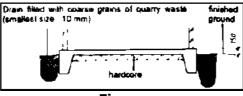
On soil types which are soft, unstable or of changing character, or are subject to heaving, houses can be built on a footing which floats on top of the soil like a raft on water. The raft acts as a footing for the walls and the floor. This footing type should be surrounded by drains which will lead water away from the house.

Mesh reinforcement for houses of different widths:

width up to 2.5 m - use 2.22 kg/m$^2$ mesh

width 2.5 to 3.6 m - use 3.02 kg/m$^2$ mesh
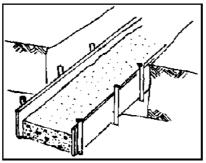
width over 3.6 m - use 3.95 kg/m$^2$ mesh

Use ordinary concrete of 1:2:4 cement - sand - aggregates
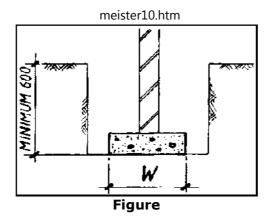


**Figure**

2. CONCRETE - STRIP TYPE



**Figure**

Concrete mix 1:2:4 strip 150 mm thick all around under all walls. Concrete must be pored between timber shutters. Top concrete struck off level.

**Figure**
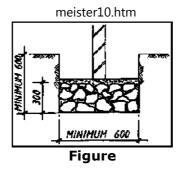
Trench to be backfilled with soil which must be well rammed in layers not more than 200 mm thick

The width (W) of the concrete depends on the soil type on which the footing sits.

| SOIL TYPE | WIDTH (W) mm |
|---|---|
| SOFT | 600 |
| LOOSE, EASILY MOULDED | 500 |
| STIFF | 400 |

3. BROKEN ROCK TYPE

**Figure**

USE THIS TYPE ONLY IN STILL OR LOOSE SOIL TYPES

Rocks approximately 100-150 mm size. Each layer must be laid and rammed, and then sand must be swept into holes. Top off with 30 mm 1:3 cement-sand mortar.
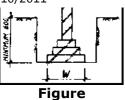
Ramming the rocks down firm Each layer of rocks must be placed carefully to fit tightly. Brush sand over the surface.



**Figure**

## 4. STEPPED-BLOCK TYPE
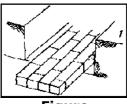
In situation where concrete footings are too expansive, stabilized-soil blocks

**Figure**
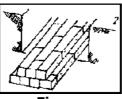
could SERVE as materials for footing.

Blockwork to be stepped out in three equal steps to width of foundation. Width of foundation (W) to be the same as for concrete footing. Backfill to be brought up equally both sides of the wall. Trench to be filled with soil which must be well rammed in layers not more than 200 mm thick.
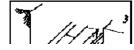
When making a stepped blockwork footing, it is most important that each layer be staggered in its jointing from the layer below. Below damp-proof course, blocks must be stabilized types only, or dressed hard building stones and burnt clay bricks may be used.



**Figure**



**Figure**

**Figure**
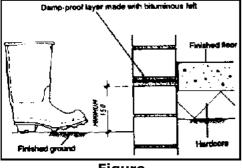
## Figure 7. Walls - Type of damp-proofing and termite-proofing

**Figure**
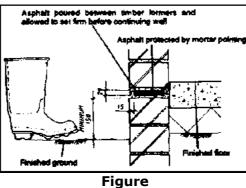
### 1. CONVENTIONAL BITUMINOUS FELT DAMP-PROOF COURSE



**Figure**

### 2. ASPHALT LAYER DAMP-PROOF COURSE



**Figure**
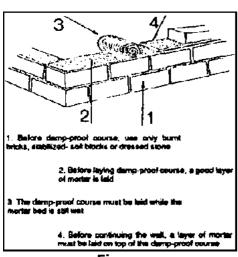
### 1. CONTINUOUS METAL-BARR TERMITE PROOFING
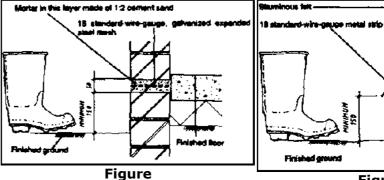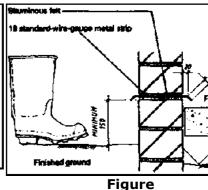


**Figure**

### 3. DENSE REINFORCED MORTAR LAYER DAMP-PROOF COURSE

### 2. STRIP METAL-BARRIER TER PROOFING



1. Before damp-proof course, use only burnt bricks, stabilized- soil blocks or dressed stone

2. Before laying damp-proof course, a good layer of mortar is laid

3. The damp-proof course must be laid while the mortar bed is still wet

4. Before continuing the wall, a layer of mortar must be laid on top of this damp-proof course

Figure



Figure



Figure
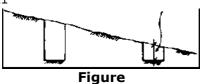
## Figure 8. Foundations - Special situations

### 1. BUILDING ON THE SIDE OF A HILL

Normal depth is 60cm

### 2. BUILDING WITH A STEPPED FOUNDATION

**Figure**
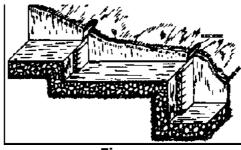
If the depth on the uphill side is more
than 1.0 m either:
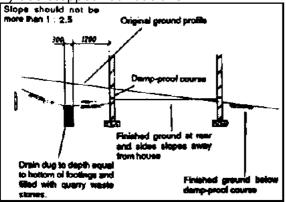
    i) cut back and put in the
    drainage, or


**Figure**

ii) use stepped foundations.
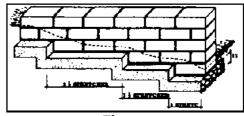

**Figure**

This is how the finished house and
ground will fit into the hillside.
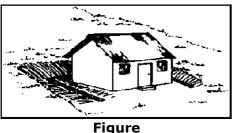
Vertical face of step must be cut straight and clean.

Concrete strip footing must be used in stepped
foundations. Make 10 cm wider than normal footings.


**Figure**

Stretcher brick must span over point from concrete
footing on to wall on lower step.

**Figure**

Backfill must than be brought up equally on both sides of wall.

Height of step must be limited to a maximum of three courses of bricks.


**Figure**
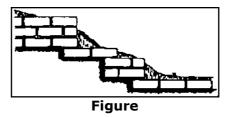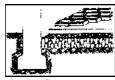
### Figure 9. Floors - In-situ construction

1. ADOBE-TYPE FLOORS


**Figure**

If an adobe-type floor is to be laid, it must be laid in at least two layers, each not more than 5 cm thick. Immediately after laying, the floor should be cut into regular blocks not more than 60 cm square. This will reduce the risk of unwanted cracks. The cuts in higher layers should be staggered from those in LOWER layers.


**Figure**

Cuts in final layer must be filled with a fine adobe mortar. One week must pass before laying successive layers. After final drying out, the surface can be treated with a mixture of turpentine and linseed oil, then waxed after that has dried out.

2. REINFORCED-TYPE FLOORS

Some soils where houses must be built may be unstable. They

**Figure**



**Figure**



**Figure**

Some soils where houses must be built may be unstable. They may heave, shrink or slip. Floors of houses in these areas must, therefore, be reinforced. Reinforcement can be done by steel bars.

However, bamboo poles up to 2 cm thick can be used and can be built into the floor as it is being laid. They should be spaced 15 cm apart and should be placed in two layers right angles to each other. Poles in one layer must be tied to poles in the other layer.
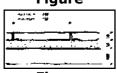
Alternatively, the poles may be laid before the floor, and the floor mix may then be placed on to and around the reinforcement. There should be at least 8 cm cover over the top of the reinforcement.

3. STONE-FLAG FLOOR



**Figure**

In situations where stones are readily available as low-cost materials they can be used for floors. Stone should be carefully cut to size.
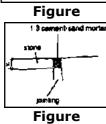
Alternatively, the poles may be laid before the floor, and the floor mix may then be placed on to and around the reinforcement. There should be at least 8 cm cover over the top of the reinforcement.

**Figure**

Stones used should be find-grained type.


**Figure**

Bedding and joints should be made with soil-cement or soil-lime-cement mortar.


**Figure**
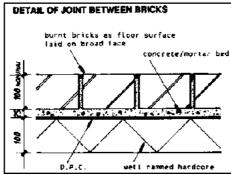
All joints should be carefully filled with 1:3 cement-sand mortar.
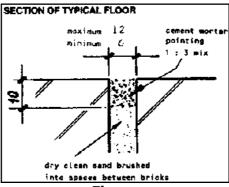
4. BRICK-ON-FLAT FLOORS

Similarly, in situations where bricks are readily available as low-cost materials, they can be used for floors
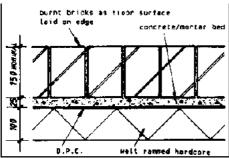
**Figure**
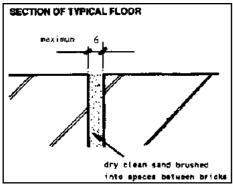


**Figure**

## 5. BRICK-ON-EDGE FLOORS

DETAIL OF JOINT BETWEEN BRICKS

burnt bricks as floor surface
laid on edge

concrete/mortar bed

150 nominal

25

100

D.P.C.          well rammed hardcore

**Figure**



SECTION OF TYPICAL FLOOR

maximum    6

dry clean sand brushed
into spaces between bricks

**Figure**

**Figure**

NOTES

BRICKS MADE WITH A FROG MUST BE LAID WITH THE FROG UNDERNEATH.

CEMENT-SOIL OR CEMENT-LIME-SOIL MAY BE USED FOR THE MORTAR BED.

BRICKS MUST BE LAID WHILE THE MORTAR BED IS STILL WET.


**Figure**

**Surface protection of buildings**

**Where low-strength soil blocks or unstabilized soil construction are used, the performance of an otherwise non-durable structure can be improved by applying a surface protection. Similarly, surface protection can be used as a technique for maintenance or upgrading existing deteriorated soil-based dwellings. Unprotected soil walls have a fair chance of durability in temperate climates, especially if good quality soils have been used and good foundations and base courses have been provided. In rainy and humid regions, however, surface protection is a basic requirement. The range of surface protection techniques for soil construction allows for several low-cost options. There are two basic techniques for surface protection which are relevant for low-cost soil construction: paints and rendering.**

**Conventional paints, distempers, slurries of lime and cement, as well as bitumen in the form of liquid cut-back, can all be used as protective coatings on soil walls. They are normally effective, however, when the soil walls have been carefully prepared prior to application of the paint. For example, if lime or cement slurry is to be applied, the soil walls must be sprayed, in advance, with water. Soil is easily the cheapest material for**

rendering. For this purpose, soil particle size should be two millimeters or less and composed of one part clay and three parts sand. Soils for rendering can be stabilized with cement, lime and bitumen. A variety of fibers, such as vegetable fibers, animal fur and even synthetic fibers, can also be used as stabilizers.

In preparing stabilized soil renderings, cement is an effective stabilizer for sandy soils. Mix proportions vary between 2 and 10 per cent of cement. It is also possible to improve the water resistance of a soil-cement rendering by adding a small amount of bitumen, i.e. 2 to 4 per cent. Lime stabilizes clayey soils when at least 10 per cent is added. By adding animal urine to the soil-lime mixture, the rendering improves shrinkage, hardness and permeability of soil walls. Bitumen should be used for soils which are both clayey and sandy. The proportion of bitumen is usually 2 to 6 per cent. If the bitumen is in the form of cut-back, it should be heated to a temperature not exceeding 100°C. Alternatively, bitumen emulsions can be used.

**Machinery for production of soil materials**

As indicated above, soil construction is liable to be a capital-intensive technology rather than an energy-demanding one. The choice of soil construction technology should be consistent with the levels of capital affordability of the respective countries. For low-cost housing, one has to bear in mind that most developing countries operate with scarce capital and may not have access to capital items from imported sources, even for seemingly basic ones. Therefore, a low-cost housing scheme should aim, as much as possible, at operating with the minimum of capital inputs.

In modern soil construction, capital items are indispensable for quality control, even in low-cost projects. Pulverization of soils, screening, mixing, compaction and testing of raw materials, as well as finished products, all require some form of equipment. The key issue is to select the appropriate machinery, consistent with low-cost criteria, bearing in mind

possibilities of improvizing and fabricating local equipment. For instance, in the area of soil compaction machinery, blocks with the appropriate compressive strength for simple low-cost houses can be produced using low technology-machines. Moreover, most of the low-technology compaction machines can be locally fabricated in several developing countries. This is also the case of item such as wheel barrows, measuring cans, sieves and a host of simple field test equipment.

The scale of the technology used is a determinant of cost and appropriateness in low-cost housing construction. Most large-scale technologies need to be imported and are subject to uncontrollable cost escalations. In addition, repair and maintenance may present major difficulties. Furthermore, the bulkiness of most large-scale machinery results in additional transport costs. It is important to promote small-scale technology to counteract these deficiencies. It must be noted that there is a distinction between the scale of output and scale of technology and that, with appropriate organization and management, large-scale output can be achieved with small-scale technology.
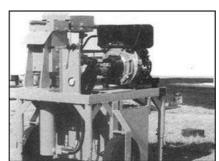


**Figure 10. A mobile block press machine, developed by "Hydroform" in South Africa (a)**

**Figure 10. A mobile block press machine, developed by "Hydroform" in South Africa (b)**

**Government promotional activities**

**The wide-scale adoption of soil construction for low-income housing will require certain institutional support to facilitate adequate production capacity of soil materials and to ensure a sustained market for them. It is essential to provide an initial activity of technology demonstration, independently of the modern soil construction technology chosen. In order to have an impact on builders in low-income communities, technology demonstration should take the form of sustained periods of on-the-job training.**

**Similar to other local building materials in developing countries, there are as yet no standards and specifications for soil construction. This could be an important factor hindering the wide-scale adoption of this type of technology. In this context, standards and specifications should adopt pragmatic and workable mechanisms. In particular, they should be complemented by training in quality-control procedures and access to simple operations for testing raw materials and finished products.**

**There are inhibitions against the use of soil construction for low-cost houses, partly as a result of technical errors in most existing traditional soil dwellings. Unfortunately, this**

**stigma cannot be overcome by simply promoting technical solutions. The main approach to this problem is for governments to actually use soil construction in on-going shelter programmes.**

*Note 1.* For further details on soil construction see UNCHS (Habitat), "Earth Construction Technology", reference No. 21 and UNCHS (Habitat), "Journal of the Network of African Countries on Local Building Materials and Technologies, Volume 1 No. 4 and Volume 2 No. 2", reference No. 22.

*Note 2.* This section has been produced based on a study prepared by UNCHS (Habitat).

### 3.2. Building stone, sand and aggregates

**Building stone, sand and aggregates are the oldest, widely available and durable building materials. These important and widely used materials, by themselves, could be considered as no-energy materials, however, for the purpose of their processing and transportation, some energy would be required which will make them low-energy materials. The energy used is, principally, for mining, crushing and transporting. In the case of dimension stone, in addition to energy requirements for quarrying and transportation, some energy is required for cutting and polishing stones which are done in stone cutting factories with sophisticated machinery and the use of electrical energy. In the case of sand and aggregates, which are the main ingredients for concrete and mortar making additional energy is used for screening them, thus, making them suitable for the purpose of their use.**

**In most developing countries and depending on the local circumstances most operations related to the use of stone in building construction are carried out manually. Some values for the energy requirements from different sources are given in table 1 below. These values are exclusive of transporting of materials to the site and do not include the energy of manual work involved.**

### Table 1. Energy requirements of some stone-based materials

| Material | Energy requirement (GJ/ton) | Source |
|---|---|---|
| *Sand and aggregate:* | | |
| Sand, the United Kingdom | 0.03-0.3 | Gartner and Rankin |
| Crushed aggregate, India | 0.22 | Rai |
| Building sand, India | 0.015 | Rai |
| Stone rubble, India | 0.1 | Rai |
| *Building Stone:* | | |
| Building stone, Kenya | 0.1 | Spence |

### 3.3. Low-cost binders

**Binders are important materials for any type of construction activity. They are used for plastering walls of buildings, for making mortars in masonry and foundations for soil stabilization, etc. Among the various types of binding materials used in construction, Portland cement is the most attractive one because of its superior characteristics. However, because of its high energy content and, consequently, high cost, is not accessible to many low-income house builders. Low-cost binders, on the contrary, have great potentiality and adequate technical characteristics to meet the requirements of low-cost construction. The most important low-cost binders include: lime gypsum, pozzolanas and blended cements. Lime was already discussed in the previous sections, therefore, in the following parts, only gypsum, pozzolanas and blended cements will be briefly discussed.**

### (a) Gypsum

Gypsum is a traditional material made from heating mineral gypsum stones. It is used for plastering walls, manufacturing gypsum-based plaster-boards and many other applications. The energy requirement for manufacturing building gypsum, compared to cement and lime is very low.

Depending on the quality of gypsum stones the heat required for gypsum kiln ranges between 150° and 170°C, much lower than for cement (1450°C) and lime (900°C) production.

Similar to lime production, a high proportion of total energy for gypsum production is used in the kiln. The raw material, is calcined directly either by mixing it with the fuel, or it is burnt indirectly by burners. Indirect heating offers better control, produces better quality gypsum and is suitable for small-scale-operations. Most production processes in developing countries are intermittent and not energy-efficient. Rotary kilns, however, offer more energy efficiency but require more capital.

Comprehensive data on the energy consumption of gypsum plaster production at all scales are not available. Some examples of the energy consumption using different kiln types and scales of production are given in table 1. Even the least efficient processes use substantially less energy than either cement or lime production. However, a direct comparison between the three materials is not possible, because they all have slightly different properties (1).
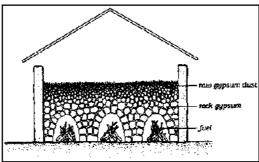
**Figure 1. A walled kiln for burning gypsum. Courtesy IT, U.K., Gypsum and Plaster**
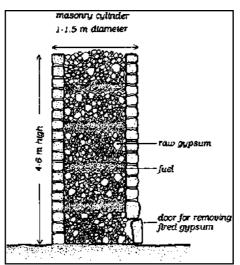


**Figure 2. A shaft kiln with masonary cylindrical wall. Courtesy IT, U.K., Gypsum and Plaster**
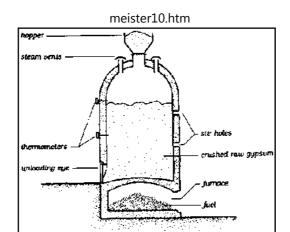
**Figure 3. Hopper-fed furnace-heated batch kiln. Courtesy IT, U.K., Gypsum and Plaster**

**Table 1. Comparative energy requirements for gypsum production**

| Process | Energy requirement (GJ/ton) | Source of data |
|---|---|---|
| Large-scale production, United Kingdom | 0.8 to 1.0 | Coburn and others |
| Calcined gypsum, India | 1.5 | Rai |
| Plaster of paris, Germany | 1.5 | Rai |
| Small-scale production, North Africa | 2.7 to 4.6 | Coburn and others |

**(b) Pozzolanas**

**Pozzolanas are siliceous materials which can be either natural or artificial. Pozzolanas on their own have little or no binding property, but when finely ground and mixed with lime**

will set and harden, in the presence of water.

The most commonly occurrences of natural pozzolanas are volcanic ashes and pumice powder. These pozzolanas, depending on the expected strength of the mortars, can reduce the use of lime by 20 to 30 per cent, but if mixed with cement, the substitution to cement can even be higher. Thus, considerable amount of energy saving can be achieved through using less cement or lime while obtaining an acceptable result.

Artificial pozzolanas are produced from a number of industrial and agricultural wastes which are highly siliceous. These include:

(i) fly-ash obtained from coal burning power plants

(ii) ground blast furnace slags resulting from iron plants

(iii) burnt clay powder and

(iv) rice-husk ash from burning the rice husks in specially designed incinerators. As in the case of natural pozzolanas, the artificial pozzolanas are processed and mixed either with lime or cement to be used as binding material in low-cost construction or soil stabilization.

**Figure 4. Lime sludge/rice husk balls laid out to dry. Courtesy IT, UK, Rice Husk Ash Cement**

**Even though processing pozzolanas and producing them in a usable form, to be mixed with lime or cement, requires some energy, experiment and extensive research work have shown that the sum of energy used in this process is less than the energy used in the substituted cement or lime. Needless to emphasis that the environmental impact of the use of industrial and agricultural wastes is another reason which makes the use of pozzolanas attractive.**

**(c) Blended cement**

**Manufacturing blended cement (also called pozzolanic cement) is one of the promising trends in the reduction of energy use in construction. Blended cements are either produced directly in cement plants (e.g. by mixing certain types of pozzolanas with**

**cement clinkers and grinding them together) or they can be produced on site by mixing ordinary Portland cement (OPC) with finely ground pozzolanas. In producing blended cements, almost all types of common pozzolanas can be used. However, among the different types of pozzolanas, furnace slag has been widely used in the process of producing blended cement, which is very popular in both developed and developing countries and for which relevant standards have already been established. The replacement percentages of pozzolanas vary from 15 to 50 per cent resulting in an energy saving of up to 40 percent. Table 2 shows some energy saving examples from India.**

**Blended cements can be used not only for making mortars for masonry or plastering purposes but also for structural concrete, particularly for foundation and/or mass concreting purposes. It can be also used in block-making for use in load and non-load bearing walls.**

**Table 2. Energy-saving opportunities using pozzolanas as replacement of cement**

| Type of blended cement | Composition (percentage) | Energy (kj/kg) | Saving (percentage) |
|---|---|---|---|
| Portland burnt clay pozzolanas cement | Portland cement: 75 | 5945 | |
| | Burnt clay pozzolanas: 25 | 335 | 20 |
| Portland fly-ash pozzolanas cement | Portland cement: 75 | 5945 | |
| | Fly-ash: 25 | Nil | 25 |
| Portland blast furnace slag cement | Portland cement: 60 | 4773 | |
| | BFS: 40 | Nil | 40 |
| Masonry cement | Portland cement: 50 | 3970 | |
| | | | |
| | Mineral tailing: 50 | Nil | 50 |

**Source: Government of India, "Use of energy by household and in production of building materials". Unpublished paper prepared for the 13th session of the Commission on Human Settlement, Harare, May 1991.**

*Note:* For a detailed treatment of low-cost binders, see UNCHS (Habitat), "Endogenous capacity-building for the production of binding materials in the construction industry-Selected case studies", reference No. 23 and UNCHS (Habitat), Journal of the Network of African Countries on Local Building Materials and Technologies volume 1, No. 1, 1989 and volume 2 No. 1, 1992.
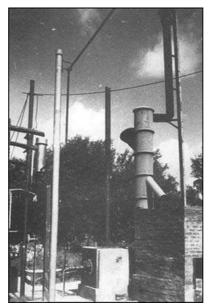


**Figure 5. Calcination kiln for powdery lime sludge to be used in production of blended**

**cement**

### 3.4. Timber and bamboo

### 3.4.1 TIMBER

Timber is the most important and widely accepted organic material used for centuries in building construction and if extracted from managed forests and used in a sustainable manner it can be used for ever. It can be used at any level of technology for a wide range of purposes ranging from its uses in rural areas to being processed in high-tech factories for manufacturing structural and non-structural building elements as well as furniture.

As a natural and renewable resource, it is also a very low-energy material with superior characteristics which makes it quite attractive for many construction purposes. Various studies have shown that even though using timber as a building material involves the use of energy for logging, transportation, seasoning, cutting, processing etc., the sum of all energy used in all these processes per weight basis is much less than any other energy-intensive structural material such as steel, aluminium, concrete, bricks etc. Table 1 shows some examples of the primary energy requirements for some timber products.

**Table 1. Energy requirements fur timber production**

| Product | Energy requirement (GJ/ton) | (GJ/m$^3$) | Source of data |
|---|---|---|---|
| Softwood framing, USA[a] | 0.7 | 0.34 | Stein |
| Timber at site, Australia[a] | 2.0 | | Lawson |
| Timber processing, Argentina | 0.4 | | Rai |

| | | | |
|---|---|---|---|
| Timber, Germany | 1.04 | | Rai |
| Timber (concrete formwork), UK | 1.6 | | Haseltine |
| Timber products, UK | 5.4 | | Gartner and Rankin |
| Particle hoard, India | 3.1 | | Rai |
| Particle hoard. USA[a] | 9.2 | 4.6 | Stein |
| Plywood. USA[a] | 13 | | Stein |

[a] **Includes transport to site**

**The advantages of timber as a low-cost construction material are first and foremost technical. Timber, after certain processing, can be used for almost the entire structure of a house as load bearing and non-load bearing elements. Timber has a unique combination of both thermal efficiency and superb sound insulation qualities. It has a high ratio between structural resistance, resilience and weight and is, therefore an excellent material to be used in building structures in earthquake-prone areas. For example, in Southern California, about 80 per cent of all residential buildings of up to four storey high are constructed with timber which include: walls, floors, roofs and even outside cladding of the buildings.**

**In principle, production of commercially accepted timber from tropical forests can be made sustainable, but in practice, a combination of commercial interests, lack of information, population pressure and mismanagement is leading to a rapid loss of forests in most worlds tropical regions.**

**One way of tackling the problems associated with deforestation is encouraging the use of commercially less-accepted species (CLAS) and industrial tree plantation species (ITPS). If properly managed and exploited, these species can serve as abundant and renewable resources of building materials that can be afforded by the vast majority of the population.**

There are currently no significant examples of use of CLAS and ITPS as a walling material or roof-cladding material in developing countries. In some cases, the wood elements are only restricted to internal partitioning (24).

The use of CLAS and ITPS for construction, especially for walling purposes and as shingles for roofing, is slowly showing potential in industrially-processed wood products where the CLAS and ITPS serve as raw material. The use of wood chips, pulps and excelsior for composite boards in some countries relies on timber species which are less suitable as sawn wood due mainly to their irregular form. There is potential for using chips and excelsior from CLAS and ITPS to manufacture wood-cement boards. In some countries, where these products are on commercial sale, there is an unfavourable market trend probably due to the unattractiveness of the finish of the boards.

The Second Consultation on the Wood and Wood Products Industry, organized jointly by UNCHS (Habitat) and UNIDO and held in Vienna in January 1991, underscored the importance of greater utilization, on a sustainable basis, of wood, including CLAS and ITPS, as a renewable source of indigenous building materials in housing and construction. The Consultation, while focusing on environmentally-sound management of forests, devised a set of recommendations addressing the industry, governments and the international community on ways and means for popularizing the use of CLAS and ITPS in the construction sector (24).

**Seasoning timber**

Although timber is considered as being "no-energy" material, for processing purposes, there is a need for certain amount of energy. Among the various stages of processing, seasoning the timber, particularly, when it is done in heated kilns, requires the highest amount of energy compared to other processing stages such as cutting, shaping, transporting, etc.

The purpose of seasoning timber is to remove the extra moisture of green timber under controlled conditions. Timber has a tendency to change dimensions in response to changes in moisture content, therefore, a proper seasoning bringing the timber to its final dimensions and making it stable for use in structures is one of the most important and energy demanding stages of timber processing.

For structural work, timber should be dried to within 5 per cent of equilibrium moisture content (EMC). This value refers to the moisture content which would be attained in service. EMC depends upon the relative humidity and the temperature of the surroundings and the following may be considered a rough guide (25).

Table 2 shows some examples of EMC for various climates.

Table 2. Equivalent moisture content of timber

| Region | Equilibrium moisture content (percentage) |
|---|---|
| Hot dry regions (desert, semi-desert and savannah) | 10-12 |
| Tropical highlands (above 1500m) | 12-14 |
| Tropical lowlands, rain forests | 14-18 |

(Other climate conditions are not included)
*Source:* UNCHS (Habitat), reference No. 25.

Seasoning timber can be carried out in two ways, air drying and kiln seasoning.

Air drying

Green timber is stacked in open sheds using spacers made of wooden sticks for air

circulation. The thickness of spaces vary between 15 mm to 40 mm depending on the timber species and outside temperature. The stacks would be put on solid-base and raised above the ground.

The time required for seasoning depends on the species and the climate (humidity and temperature) of the surroundings. In tropical climates some soft woods require at least six weeks, while denser hardwood would need 25 weeks or more.

## Kiln seasoning

Green timber is placed in a kiln or a chamber in which temperature, humidity and flow of air can be controlled. Kiln seasoning allows timber to be dried to any desired moisture content appropriate to its end use. The technology of kiln seasoning is well advanced in both developed and developing countries and there exist quite a number of types and methods including special treatments of timber such as reconditioning and sterilization.

## Solar seasoning

Solar seasoning is the most energy efficient method for drying timber. This method uses the sun radiation to heat the air inside a chamber where timber is stacked. Over the past decade, considerable research into this method has been carried out in some developing countries such as India and Sri Lanka and in some cases it has been introduced in commercial use. Figure 1 shows a solar kiln designed in the Central Building Research Institute in Roorkee, India and figure 2 shows a Bangladesh kiln designed by M. A. Sattar. It is made up of three main parts namely:

    (a) solar-energy collector;
    (b) seasoning chamber; and
    (c) chimney.

Experiments on this kiln has shown that the time taken in seasoning three different types of wood, e.g. mango (Man giferaindica), Jamu (Eugenis jambolana) and haldu (Adina cardifolia) from green stage to 10 per cent moisture content for a thickness of 3.75 cm would require 17, 27 and 18 days respectively, while seasoning the same specimen under a shed in open air would need 35, 62 and 40 days (25). The number of different designs of solar kilns has increased rapidly in the last few years with a tendency towards better insulated structures and more sophisticated control of humidity, venting and air circulation (26), (27) and (28).
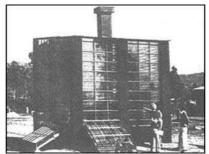


Figure 1. Solar kiln designed in Central Building Research Institute (CBRI), Roorkee, India.

The attached Annex presents, in a summary from, a research project carried out on solar timber seasoning in Sri Lanka. It demonstrates the advantages and technical feasibility for drying some secondary species of wood including the rubber and coconut wood.
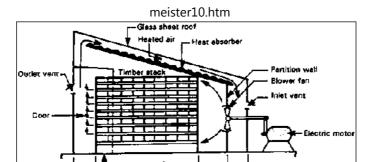
**Figure 2. Bangladesh kiln. Courtesy TRADA and ODA, reference No. 29**

**Timber protection (25)**

**In order to protect timber against hazardous attacks such as fungi, insects and marine borers, timber used in structural work should be treated by special preservatives. A successful treatment of timber depends upon the type of chemical used, as well as the type of timber and treatment. With the exception of diffusion treatment, the moisture content of the timber to be treated should not exceed 30 per cent. The maximum permiceable moisture content depends also to some extent upon the process, type of preservative chemical and the kind of timber.**

**In general, there are three types of wood preservatives: tar oil; water-borne; and organic solvents.**

**Tar-oil compounds or creosotes are suitable for exterior work, in water or in ground contact. The principal advantages of creosotes are their high toxicity against fungi, insect and marine borers. Tar-oil preservatives may be applied by vacuum-pressure, hot and cold open tank, brushes, spraying or immersion. For exterior work the recommended methods are either vacuum-pressure or hot and cold open tank.**

Water-borne preservatives require special methods of application to ensure deep penetration and are not suitable for brush treatment. Contrary to tar-oil treatment the treated timber is odourless and can be painted over when it is dry. Water-borne preservatives are applied to seasoned timber by vacuum-pressure methods, whilst boron compounds are applied to green timber by diffusion. They can be used in wet and dry conditions, including ground contact.

Organic solvent preservatives are readily absorbed by the timber and so may be applied by brush, spray or immersion. For a deeper penetration, methods such as double vacuum may be used. They do not cause the timber to swell. Treated timber may be painted and is not corrosive to metals.

Extensive research over the past few years, has revealed that most of the common and commercially-produced preservatives are toxic, and hazardous to human health, even though they are the most effective means to protect timber from all types of destructive agents. In fact the higher the toxicity of preservatives the higher their effectiveness. As a result of new experiments, the manufacturers of timber preservatives have developed alternative products some of which are also suspected to be harmful and the use of a series of preservative substances (such as aldrin, chlordane, dieldrin and some arsenic compounds, to name a few) is officially prohibited in several countries. The use of substances like pentachlorophenol (PCP) and lindane (gamma-hexachloro-cyclohexane or just y-HCH) is also greatly restricted, and likely to be forbidden in due course (30).

Unfortunately, despite their high toxicity, most of these chemicals are still being officially recommended and widely used in almost all the developing countries, a serious problem that requires urgent attention. The main drawbacks of chemical treatment are: (30)

- Fungicides and insecticides have to be sufficiently toxic to be effective, and cannot differentiate between harmful and harmless organisms, which are destroyed

likewise. Some destructive organisms develop resistance to toxic chemicals, which thus fail to serve their purpose, but destroy useful creatures (e.g. bees, spiders, birds).

- The chemicals affect animals and humans by way of inhalation, skin contacts or through contaminated food, causing various health problems, ranging from headaches, nausea, dizziness, aggressions, depressions, rash, etc. to diseases of the lungs, heart, liver, kidneys and other organs, malformations, paralysis and even cancer.

- The production, application and disposal of biocides all contribute to serious environmental pollution. The toxic chemicals and their poisonous by-products, many of which are extremely persistent (the most well-known example being DDT), enter the food chain and accumulate in ever increasing concentrations in the bodies of all living organisms, most of all in human beings. The production and handling of biocides endangers workers and users of treated products. Solar radiation, high temperatures and humidity, atmospheric pollutants and other factors can transform certain preservatives into other, more dangerous substances (for instance, PCP produces dioxin, a so-called ultra-toxin).

**Figure 3. Preservation of timber by dip diffusion**

**3.4.2 BAMBOO**

**After timber, bamboo is the second important organic product which requires much less energy for its processing and seasoning than timber. In fact, many researchers and professionals call bamboo as a "no-energy" material with very good structural property to be used in low-cost construction, particularly, in bamboo growing countries. Bamboo is a very fast growing plant and some species can reach their full height within 6 months (up to 35m height). However, it takes 3 to 6 years to develop adequate strength for use in structures. There are, in principle, two main types of bamboo, namely: "Sympodial" or clump forming bamboo, found mainly in warmer regions, and "Monopodial" or running bamboo, found in the cooler areas.**

**Well-matured culms have greater resistance to deterioration than younger ones, however, a proper preservative treatment can double or triple the resistance and the durability of bamboo. Like the treatment of timber, chemical preservation of bamboo is very important**

to reduce the attacks of termites, but again most of the available chemicals are toxic and harmful to human health and the environment. Based on extensive research, it has been found out that preservatives derived from borax, soda, potash, wood tar, beeswax and in seed oil are less harmful than other commercial chemicals. The effectiveness of these preservatives are, normally, less than those poisonous chemicals, but can be equally effective in conjunction with good building design and construction (for example, avoidance of contact with soil, exclusion of moisture, good ventilation, accessibility for regular checks and maintenance, etc.) (31).

The areas of application of bamboo include: frames (beams and columns), trusses for roof, grids (spare trusses), seaffolding, fencing, bridges, etc. Sometimes, for special purposes, full culms are halved to produce two U-shaped cross-section for using in gutters, walls, purlins, etc. Split bamboo strips can also be used for matting and woven panels, fencing, ornamental screens, etc. Even the bamboo fibres and chips can be used for manufacturing fibre boards, particle boards and fibre concrete.

Even though use of bamboo, as a very low-energy and low-cost material, has considerable advantages, it has a number of setbacks such as: (31)

- Low durability, especially, in moist conditions, as it is easily attacked by biological agents, such as insects and fungus;

- Bamboo catches fire easily;

- The low compressive strength and impact resistance limit its application in construction. Wrong handling, bad workmanship and incorrect design of bamboo structure can lead to cracking and splitting which weaken the material and make it more vulnerable to attack by insects and fungus. Nails cause splitting;

- The irregular distances between nodes, the round shape and the slight tapering of

the culms towards the top end makes tight-fitting construction impossible, and therefore, cannot replace timber in many applications;

● Bamboo causes greater tool wear than timber;

● Bamboo preservative treatments are not sufficiently well-known, especially the high toxicity of some chemical preservatives recommended by suppliers and official bodies.

If compared with timber, bamboo has quite a number of advantages. It is an abundantly available material which is low-cost and renewable. Its handling and treatment can be done with specific tools and traditional methods. Its strength characteristics, particularly its high tensile strength makes it an ideal material for frames and roof trusses. Having very low weight and high ductility, structure made of bamboo, if well designed and constructed are earthquake resistant.

For example, in Costa Rica, the powerful earthquake of April 1991 which damaged many buildings, did not affect those houses which were built in bamboo. In fact, the emergency reconstruction programmes supported by the Government of the Netherlands after the earthquake focussed mainly on the use of bamboo for new housing schemes. (32)

Furthermore, it is worth mentioning that based on a UNCHS (Habitat) supported project in Costa Rica it is expected to construct some 7000 houses per year after 1995 using bamboo as structural elements. For this purpose necessary planning and arrangements have been put in place to plant and harvest sufficient quantities of bamboo in the country. The expertise and experience gained by this project is now widely sought in the Latin American region where interest in bamboo technology is steadily growing (32).
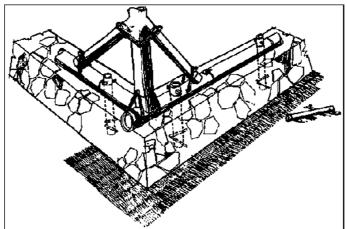
**Figure 4. Column placement in continuous foundation. Courtesy UNDP/UNIDO, RENAS-BMTCS, Manila**
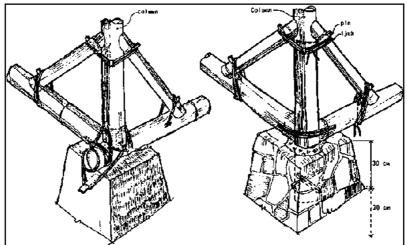
**Figure 5. Column placement in square footing. Courtesy UNDP/UNIDO, RENAS-BMTCS, Manila**
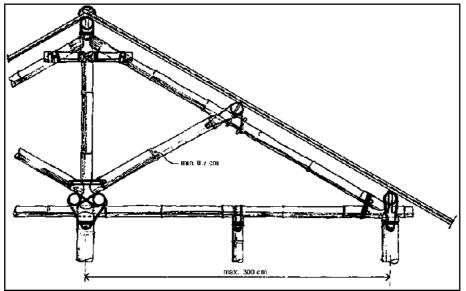
**Figure 6. Bamboo roof trusses. Courtesy UNDP/UNIDO, RENAS-BMTCS, Manila**

◄                                                                              ►

 **Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**
  ➡️ **4. Innovative technologies related to recycling of materials**
     *(introduction...)*
     **4.1. Organic wastes**

🖹    **4.2. Inorganic wastes**



**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**4. Innovative technologies related to recycling of materials**

### USE OF ORGANIC AND INORGANIC WASTES

In the context of this section, "wastes" are meant to be "by-products" or "residues" of organic or inorganic nature which are accumulated as a result of agricultural and industrial processes. Organic wastes are, generally, agricultural or forestry by-products, while inorganic wastes are mainly obtained from industrial processes.

As a result of rapid population growth and industrialization, the generation of organic and inorganic solid wastes has increased several fold during the last few years causing considerable disposal problems and environmental pollution. It has become common sight to find large dumps of solid wastes near industrial units causing air, land, and water pollution. It is for this reason that a proper use of large-scale wastes such as rice husks, coffee hulls, fly-ash, phosphogypsum, bauxite wastes, furnace slags, etc. has become a

matter of concern, as there is considerable scope for better management of these wastes.

As it was mentioned earlier, by using these wastes, particularly, in the production of blended cements, energy savings of up to 50 per cent can be achieved which is quite attractive. The use of some agricultural wastes such as rice husks, bagasse and coffee hulls can also contribute directly to the energy requirements of kiln processes, thus reducing the need for higher grade fuels. It is for these reasons that many countries have already started taking effective measures to utilize these wastes in the building industry.

### 4.1. Organic wastes

**Rice husk**

Rice is cultivated as a major agricultural food crop in 75 countries of the world. About 400 million tons of paddy rice are produced annually in these countries. Based on various studies and research work, it is established that 1 ton of rice husk is generated from every 5 tons of paddy; thus, there should be about 80 million tons of rice husk available annually worldwide of which 64 million tons are produced in the Far East countries (33)

The increasing demand for rice by the growing populations in the rice-eating regions of the world creates an upward trend in the annual production of paddy rice. Due to the improvement in the milling process, there is also an expected increase in the amount of rice husk to be generated. The disposal of this low value by-product-rice husk-will continue to pose as a problem to the 75 countries where rice is grown. Apart from the construction potentials of rice husk its conversion into ash cement is, therefore, a better alternative to the present-day dumping and burning methods of disposing it 33. Table 1 shows rice husk availability in some African Countries.

**Table 1. Rice husk availability in some African countries**

| Countries with 10.000 tons/year (or more) | Estimated quantity (1.000 tons) | Countries with 10.000 tons/year (or more) | Estimated quantity (1.000 tons) |
|---|---|---|---|
| Egypt | 470 | Zaire | 49 |
| Madagascar | 422 | United Rep. of Tanzania | 43 |
| Nigeria | 218 | Mali | 25 |
| Sierra Leone | 103 | Mozambique | 14 |
| Cte d'Ivoire | 102 | Senegal | 12 |
| Guinea | 70 | Ghana | 12 |
| Liberia | 49 | Malawi | 8 |

*Source:* **UNCHS (Habitat) and Commonwealth Science Council (CSC), Journal of the Network of African Countries on Local Building Materials and Technologies Vol. 1 No. 1, April 1989**
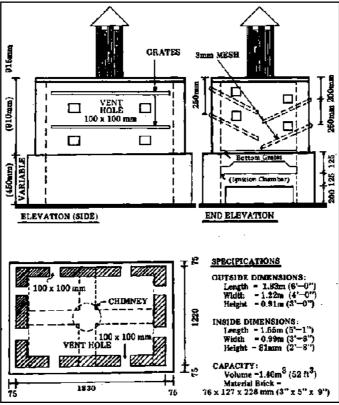
**Figure 1. Demonstration unit of incinerator installed in Dhaka, Bangladesh. Courtesy UNDP/UNIDO, RENAS-BMTCS, Manila**

**Apart from its potential use as low grade fuel, insulation material and filler, rice husks can be used (after having incinerated to produce reactive ash) as a pozzolana to replace,**

**partially, cement and also to be used in block-making.**

**In view of its abundant availability, many research institutions have undertaken considerable research over the last two decades, and the results and findings have been well documented. Table 2 gives an example of results of the average compressive strengths of mortar cubes made of Portland rice-husk ash cements.**

**Table 2. Average compressive strength of the RHA/OPC mortar cubes**

| Sample No. | Composition of the cementitious material (percentage) | Number of specimens tested | Age (days) | Compressive strength | Remarks |
|---|---|---|---|---|---|
| $C_1$ | 100 OPC | 30 | 7 | 12.4 | Control samples 100 per cent OPC |
| P/C/10 | 10 RHA 90 OPC | 60 | 7 | 14.3 | 115.3 per cent of controlled samples strength |
| P/C/20 | 20 RHA 80 OPC | 60 | 7 | 12.9 | 104.0 per cent of controlled samples strength |
| P/C/30 | 30 RHA 70 OPC | 60 | 7 | 11.7 | 94.0 per cent of controlled sample strength |
| P/C/40 | 40 RHA 60 OPC | 60 | 7 | 10.5 | 84.7 per cent of controlled strength |
| P/C/50 | 50 RHA 50 OPC | 60 | 7 | 10.2 | 82.3 per cent of controlled strength |
| A/L/30 | 30 RHA 70 Lime | 90 | 7 | 8.2 | Samples were at 50°C for 4 days |
| A/L/40 | 40 RHS | 90 | 7 | 10.2 | Strength for such accelerated |

| | | | | | |
|---|---|---|---|---|---|
| A/L/40 | 40 RHS 60 Lime | 90 | 7 | 10.2 | Strength for such accelerated curing is equivalent to the strength of 28 days normal curing |
| $C_1$ | 100 OPC | 30 | 28 | 17.85 | Control samples 100 per cent OPC |
| P/C/10 | 10 RHA 90 OPC | 60 | 28 | 19.41 | 108.7 per cent of controlled samples strength |
| P/C/20 | 20 RHA 80 OPC | 60 | 28 | 16.88 | 94.6 per cent controlled samples strength |
| P/C/30 | 30 RHA 70 OPC | 60 | 28 | 15.33 | 81.1 per cent of controlled samples strength |
| P/C/40 | 40 RHA 60 OPC | 60 | 28 | 14.29 | 80.1 per cent of controlled samples strength |
| P/C/50 | 50 RHA 50 OPC | 60 | 28 | 12.24 | 68.6 per cent of controlled samples strength |

*Source:* **UNCHS (Habitat), Endogenous Capacity Building for the Production of Binding Materials in the Construction Industry - Selected Case Studies, reference No. 23**

**Besides the use of rice-husk ash for producing blended cements and for block-making, a recent research work has proved that rice-husk ash can be used in manufacturing sodium silicate (waterglass) solution. Waterglass can be used as water proofing agent if applied, as a paint to the external walls, foundation plinths, etc. It has also been used in the manufacture of adobe blocks to increase the durability of walls. For detailed treatment of this subject refer to the UNCHS (Habitat), Journal of the Network of African Countries on Local Building Materials and Technologies, Volume 1 No. 1, 1989 and Volume 2. No. 1 June**

**1992.**

**Natural fibres**

**Natural fibres such as asbestos, sisal, hemp, kenaf, coir, bamboo, and begasse are natural products, which, with no or very little processing, can be used in building materials. The most significant use of these fibres is in the production of roofing tiles or sheets - fibre concrete roofing (FCR). Among the above mentioned fibres, asbestos is the most attractive one, which until recently was extensively used for producing corrugated and flat roofing sheets and tiles, pipes etc.**

**However, the serious health risks (lung cancer) associated with mining and processing asbestos have led to the gradual abandoning of this material and replacing it with other fibres.**

**In the absence of asbestos, other fibres such as sisal, coir (coconut fibre), Jute etc. are attracting more attention in the FCR technology and among them the sisal has proved to be the most suitable one for small-scale FCR technology. Fibres are chopped to lengths of 15 to 40 mm and added to a mortar of cement sand. A 6 to 10 mm thick layer is laid onto a flat surface for being vibrated and then placed on a mould (corrugated) for drying. After drying, tiles are removed from the mould and water cured for at least 2 weeks.**

**A high proportion of energy required for the manufacture of FCR tiles is the amount of energy which is embodied in the cement used. The attractiveness of FCR-tiles, vis-a-vis concrete tiles, obviously lies in its thickness. An FCR-tile has an average thickness of 7 mm, whereas a concrete rooftile should be at least 12 mm thick. Table 3 shows some comparative energy requirements of four common roofing elements. As it can be seen, a standard concrete roof tile requires about 60 per cent more energy than FCR tile and a corrugated-iron sheet would require almost 13 times more energy than FCR-tiles to cover the same roof area.**

**Table 3. Comparative energy requirements of alternative roofing assemblies for a pitched roof**

| Roof assembly | Embodied energy requirements (MJ/m$^2$) |
|---|---|
| Corrugated-iron sheets on timber | 605 |
| Clay tiles on timber | 158 |
| Concrete tiles (12.5 mm) | 72 |
| Fibre-concrete tiles (7 mm) | 46 |

*Source:* **UNCHS (Habitat), Development of National Technological Capacity for Environmentally-Sound Construction, reference No. 34**

**Coconut wastes include fresh husks, coconut shells and waste from the coir industry. The husk consist of 15 - 35 cm long fibres (about 60 per cent of husk), with high tensile strength, which is affected by moisture. The fibres, and more so the pith (soft cork-like material), are chemically reactive, as along as they are kept dry. During the retting process (softening by soaking in water) they become inert. The difference in reactivity between retted and fresh husks necessitates different methods of conversion into building materials.**

**Unretted husks, hot-pressed (at 150°C, 1 MP a pressure for 15 to 25 minutes) without any additives, produce strong particle boards. Unretted pith, obtained by defibrating mature husks, hot-pressed without additives, produces strong, moisture resistant boards. Lighter, resilient boards are made in the same way, but with addition of retted pith (low density, highly-elastic granular material)**

**The incineration of unretted pith produces an ash, which has pozzolanic characteristics,**

similar to those of rice husk ash, and can be used for making lime-pozzolana binders.

Retted pith mixed with cashew-nut shell liquid resin (rubbery substance) produces an expansion joint filler, which is resistant to temperature and moisture fluctuations and to insect and fungal attack. Its granules as an aggregate in concrete are useful for thermal insulation

Unretted fibres, mixed with paraffin wax and hot-pressed, make strong and flexible hardboards (fibres boards).

Coir shearing waste, containing fibre, pith and dust, bonded with an adhesive, produces particle boards with an attractive mottled appearance.

Coir waste, mixed with Portland cement and moulded under compression, produces large corrugated roofing sheets. (This process, developed at CBRI, Roorkee, requires a hydraulic press and drag mould, together with a set of forms, in which the cast sheets are kept pressed for 4 hours, before demoulding and curing).

Coconut shell chips and conventional adhesives make good quality particle boards.

Coconut shell tar, obtained during the destructive distillation of the shell, is slightly viscous liquid with anti-microbial properties(35).

4.2. Inorganic wastes

As indicated earlier, inorganic wastes are originated mainly from industrial processes. Inorganic wastes with adequate technical and economic potential to be used in building industry include:

   (i) Fly-ash generated from coal burning power plants;

**(ii) Steel and blast furnace slag generated from iron and steel producing plants;**

**(hi) Phosphogypsum generated from phosphoric acid, ammonium phosphate and hydrofluoric acid plants;**

**(iv) Red mud generated during extraction of non ferros metals such as aluminium (bauxite waste) or copper; and**

**(v) Lime sludge generated from fertilizer plants, sugar and paper factories, tanneries, soda-ash and calcium carbide industries.**

**Table 4 shows sources, quantities and areas of application of some industrial wastes in India.**

**Table 4. Sources, quantities and areas of application of industrial wastes.**

| Item | Source | Qty Available in M.T./Yr. | Application as Building Material |
|---|---|---|---|
| Flyash | Thermal Power Stations | 40.00 | Portland Pozzolana Cement, Bricks, Lime Pozzolana Mixture, Lightweight Aggregate, Cellular Concrete |
| Blast Furnace Slag | Steel Plants | 7.41 | Production of Portland Blast Furnace Cement, Super Sulphated Cement, as an aggregate in concrete, as substitute for sand, lightweight concrete |
| Cinder | Thermal Power Stations and | 3.00 | Manufacture of lime cinder mortar, production of concrete building blocks, production of bricks from black cotton soil |

| | Railways | | |
|---|---|---|---|
| Coal Washery Waste | Coal Mines | 3.00 | Manufacture of bricks, tiles, lightweight aggregates, fuel substitute in the burning of bricks |
| Copper Mine Tailing | Copper Mines | 0.55 | For manufacture of stabilized and high stress bricks, cellular concrete and masonry cement |
| Gypsum Mine Waste | Gypsum Mines | 1.50 | Gypsum building plaster, ready-made plaster with lime |
| Iron Tailing | Iron Ore Mines | 11.25 | For making stabilized and burnt clay building bricks, high strength bricks |
| Kiln Dust | Cement Plant | 2.00 | In the cement industry, as a hydraulic binder |
| Lime Stone Quarry | Lime Stone Quarry | 50.00 | For production of Masonry cement and activated lime pozzolana mixture |
| Lime Sludge | Sugar, Paper, Fertilizer, Calcium Carbide Industries | 4.80 | For the manufacture of portland cement, masonry cement, sand lime bricks, building lime pozzolana mixture |
| Paper Waste | Paper, city garbage | | For manufacture of pitch fibre pipes, Asphaltic corrugated Roofing sheets |
| Phosphogypsum | Phosphoric Acid, Ammonium Phosphate, Hydrochloric Acid Industries | 11.00 | For making Gypsum Plaster, Fibrous Gypsum Boards and blocks, cement clinker, as a solid retarder and for making super sulphate cement |

| Red mud | Aluminium Extraction Plant | 2.00 | For production of building bricks and tiles, lightweight structural blocks, roofing sheets and as an additive to concrete |
| Waste Glass | Glass Plant | | In the manufacture of Massic and glaced lightweight aggregate, brick making |

*Source:* **Government of India, Building Materials and Technology Promotion Council (BMTPC), India, 1994, reference No. 36**

**In the following section attempt is made to describe some technologies related to the use of major agricultural and industrial wastes developed in India. Most of these technologies have been tested in field conditions and a large number of buildings have been put up by housing agencies in different parts of India using these new materials. For some of these new technologies, materials and components, standard and specification have already been formulated and have also been codified by BIS (36).**

**Fly-ash-sand-lime bricks (36)**

**Fly-ash-sand-lime bricks can be used as an alternative material for burnt clay bricks which is one of the important building materials used for construction of housing and buildings. Good quality and high strength bricks can be produced from fly-ash sand and lime as binder. The mixture of fly-ash sand or bottom ash and binder in suitable proportion is moulded into bricks under pressure which is further cured by autoclaving. The fly-ash building bricks are usable in all types of brick masonry works and can substitute the conventional burnt clay bricks in nearly all application. The quality of fly-ash bricks are found to be superior to conventional burnt clay bricks in some respects such as water absorption, crushing strength etc. The bricks are also lighter compared to burnt clay bricks.**

**Advantages of fly ash-sand-lime bricks over burnt-clay bricks are related to:**

**1. Lower mortar required in construction;**
**2. Plastering on outside wall eliminated;**
**3. More resistance to salinity and water.**
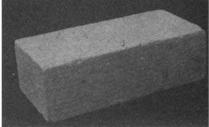


**Figure 1. The process of producing fly-ash-lime-brick. Courtesy BMTPC, India (a)**

**Figure 1. The process of producing fly-ash-lime-brick. Courtesy BMTPC, India (b)**

**Figure 2. The process of producing fly-ash-lime-brick. Courtesy BMTPC, India**

**Project cost**

**A brief description of the technology (36) for making fly ash-sand-lime bricks is given below:**

1.  Process                              - Semi mechanized (CFRI process)

2.  End use                              - Construction of load bearing/ non-load bearing walls/partition

3.  Installed capacity                   - 30 million solid brick per annum
                                         - 6250 bricks/hr

4.  Shift per day                                    - 2 (300 working days per year)

5.  Capacity utilization(expected)                   - 80 per cent

6.  Saleable products                                - 24 million solid bricks

7.  Land area                                        - Total = 15000m$^2$

                                                     Covered = 2500 m$^2$

8.  Fixed capital                                    - (i) Land and Building -
                                                     Rs 2,1 million
                                                     (ii) Infrastructure -
                                                     Rs 0.6 million
                                                     (iii) Plant and Equipment -
                                                     Rs 15,0 million

9.  Working capital                                  - Rs 3,080 million

10. Preliminary and preoperative                     - Rs 0.56 million
    expenses
    Total investment                                 - Rs 21,34 million


11. Manpower

11. Manpower

|  |  |
|---|---|
| Managerial | - 16 |
| Technical | - T12 |
| Others | - 30 |

12. Inputs (per 1000 nos. of bricks)

   (a) Raw materials

|  |  |
|---|---|
| Fly ash | - 2880 Kg |
| Lime | - 280 Kg |
| Sand | - 432 Kg |
| (b) Chemical accelerator | - 26 Kg |
| (c) Process water | - 300 Lts |
| (d) Fuel-coal | - 66 Kg |
| (e) Electrical energy | - 50 kwh |

13. Equipment/Machinery

   (i) Hydraulic press

   (ii) Boilers

   (iii) Auto-clave curing chambers

   (iv) Pulverizer

   (v) Mixers

   (vi) Electrical hoists with monorail

   (vii) Automatic tipping type buckets

   (viii) Portable belt conveyers

   (ix) Winch-based scrapping hauler mechanism

(x) Handling items like wheel barrows, curing trolleys, transfer cars, cycle carts etc.

14. Process outline

The fly ash, sand and lime with a small quantity of a chemical accelerator in a derived proportion is mixed dry in a mixer. In the second stage about 8 to 10 per cent water, 0.2 per cent chemical accelerator are added and is mixed thoroughly. The mix is then subjected to a pressure of 250 kg/cm$^2$ in suitable hydraulic press. The green bricks are then exposed to natural drying for about 48 hours, followed by curing in autoclave.

15. Properties

| | |
|---|---|
| (i) Size | - 230 × 11 Ox 70 mm |
| (ii) Colour | - Cement gray |
| (iii) Bulk density | - 1550 kg/m$^3$ |
| (iv) Unit weight | - 3.0 - 3.2 kg |
| (v) Water absorption | - 15 - 20 per cent |
| (vi) Crushing strength | - 100-120 kg/cm$^2$ |
| (vii) Free-lime content - | Less than 0.2 per cent |

16. BIS standard

IS - 12984 - 1990

17. Advantages

(a) Uniform size, require less quantity cement mortar.
(b) Can be used as facing bricks without any external plastering.
(c) Lower bulk density.

(d) More resistant to salinity and water seepage.

(e) Utilization of waste and conservation of soils

(f) Saving in fuel.

18. Profitability

    (i) Estimated cost of production    - Rs 760/1000

    (ii) Estimated sale price    - Rs 950/1000

    (iii) Total sale proceeds/annum    - Rs 22.8 million

    (iv) Break even point    - 44.18 per cent

    (v) Gross annual profit    - Rs 4.56 million

    (vi)Percentage return on capital    - 21.3 per cent

19. Market

Within 50 kms radius from location of the plant.

20. Source of Technology

    (i) Indigenous: CFRI, NRDC, CBRI, NTPC. NLC, NCB, BMTPC

    (ii) Foreign: The United Kingdom, West Germany, Sweden, Denmark, Poland, Netherlands, China, France, former Czechoslovakia.

21. Consultant

BMTPC, NRDC, CFRI, CBRI, NLC, M/s Development Alternatives, NCB

22. Information and Guidance

BMTPC

**Cellular concrete components (36)**

**With the increasing multistoreyed construction, the need for reduction in dead loads on the structure is being increasingly recognized. One of the materials which can be used for this purpose in load bearing construction is aerated concrete or cellular concrete blocks and slabs.**

**The manufacture of Cellular Concrete involves mainly:**

    **(i) Mixing of various raw materials in the mixer in predefined proportions;**

    **(ii) Setting the mineral materials in the moulds;**

    **(iii) Cutting the set cellular concrete to the desired sizes and conveying the cut concrete to the autoclave for curing;**

    **(iv) Autoclaving the cellular concrete in the autoclave for 14 to 18 hours at temperature of 185°C under pressure of 10 to 12 kg/cm.**

**Aerated concrete is a light weight material used for masonry and for roofing as a composite construction with concrete. Maximum quantity of fly ash to the tune of 80 per cent by weight of the end product can be used in the production of aerated concrete. Using fly ash will not only reduce the cost of production in respect of power consumption for grinding but also will reduce the quantity of binder and solves the problem of disposal of fly ash at the power station.**

**Besides utilisation of fly ash, the production and use of aerated concrete has several advantages:**

1. Fifty per cent saving in construction time in case of aerated concrete block masonry walls as compared to brick masonry work;

2. Eighty per cent saving in consumption of mortars;

3. Aerated concrete requires only 20 per cent of coal in manufacturing process as compared to the requirement of coal for brick-burning;

4. Saving of agricultural land used for brick making and recycling of waste;

5. In reinforced concrete frame structured multi-storeyed buildings the use of aerated concrete in place of bricks will reduce the dead load of the buildings considerably thereby effecting considerable saving of steel and cement;

6. Saving of 80 per cent of water required at the construction site;

7. Better thermal insulation and sound absorption properly as compared with brick work.

**Figure 3. Cellular concrete component (brick). Courtesy, BMTPC. India**

**Project cost and inputs**

1.  Installed capacity          - 150,000 cu.m. blocks/slabs per annum (300 working days)
                                  (Blocks: Slabs = 30:70)

2.  Saleable Product            - 120,000 cu.m.

3.  (i) Fixed capital           - Rs 264 million (with imported machineries).
    (ii) Working capital        - Rs 28 million

4.  Employment potential        - 125

5.  Land area                   - 60,000 m$^2$ (Total)

5. Land area                         - 60,000 m$^2$ (Total)
                                     - 15,000 m$^2$ (Covered)

6. Manpower                          - Managerial - 45
                                     - Technical - 50
                                     - Others - 30

7. Raw material and input (per 0.15 million cu. m of product)
   (i) Fly Ash                       - 49,500 tons
   (ii) Sand                         - 21.000 tons
   (iii) Lime                        - 12,000 tons
   (iv) Al-Powder                    - 75 tons
   (v) Steel                         - 900 tons

8. Annual (average) cost of          - Rs 118.90 million
   production

9. Sale proceeds                     - Rs 177.20 million

10. Gross annual income              - Rs 58.40 million

11. Return on investment             - 20.28 per cent

12. Break even point                 - 66.7 per cent

**Properties**

(i)   Sizes: For block     - 50-62 × 25 × 10 to 30 cm
      For slab             - 600 × 50-62 × 10 to 30 cm
(ii)  Colour               - Grey white to white
(iii) Dry density          - 600 to 750 kg/m$^3$
(iv)  Compressive strength - 2.5 to 7.5 N/m$^2$
(v)   Thermal conductivity - 0.15 to 0.27 kcal/sq.m.h
(vi)  Water absorption     - Not exceeding 45 per cent by volume in 48 hours

**Plant and equipment**

(i)    Filter for silos*
(ii)   Mixing equipment*
(iii)  Moulding equipment**
(iv)   Cutting and unloading equipment**
(v)    Storage equipment*
(vi)   Milling plant*
(vii)  Sand milling and slurry preparation equipment**

(viii) Handling and storage equipment*

*      May be procured locally
**     To be imported

**Figure 4. Clay-fly-ash burnt brick. Courtesy BMTPC, India (a)**



**Figure 4. Clay-fly-ash burnt brick. Courtesy BMTPC, India (b)**

**Additional information**

**1. Market-Cities with major construction activities**
**2. Source of Technology-CBRI, BILT, Y-Tong (Germany), Polymexcekov (Poland), Siporex (Sweden)**
**3. Information/guidance-BMTPC, CBRI**

**Clay fly-ash burnt bricks (36)**

**The process involves mixing of 30 to 60 per cent of fly ash with moderately plastic to highly plastic clays, depending upon the quality of both fly ash and clays, followed by mixing with water, moulding, drying and firing of bricks in the usual way.**

**The clay bonded fly-ash bricks can be manufactured by hand moulding or by semi-mechanized process using extrusion machine. The other operations are similar to that of manufacturing process of burnt-clay bricks. Firing of the green bricks is carried out in continuous type Bulls trench kiln at temperature of 950 to 1050°C.**

**Fly ash generally contains 5 to 6 per cent of unburnt carbon. Incorporation of fly ash, therefore, results into a better burnt product together with an economy in fuel consumption. It has been experimentally verified that saving of about five tones of coal per 100,000 bricks could be achieved by mixing 40 per cent fly ash by volume with the clay for making bricks. Other advantages of clay fly-ash bricks are reduction in the drying shrinkage and about 15 to 25 per cent of the weight of the bricks with better thermal insulation. The properties of bricks are not affected by mixing fly ash with the clay and the bricks can be used for load bearing as well as non-load bearing walls.**

**Project cost and inputs (Manual method)**

1. Installed capacity          - 7.2 million bricks/annum (300 working days)

2. Saleable product          - 6.12 million

3. Capital

   (i) Fixed capital          - Rs 294,000 (For manual operation)

(ii) Working capital          -Rs 661,000

4. Employment potential      - 146

5. Raw material and inputs (for 100,000 bricks)
   (i) Clay                  - 280 tons
   (ii) Flay ash             - 50 tons
   (iii) Sand                - 200 tons
   (iv) Fuel-coal            - 14 tons
   (v) Process water         - 1000 Lit
   (iv) Electricity          - 50 kwh

6. Annual cost of production  - Rs 4,5 million

7. Gross annual income(sale) - Rs 5,5 million

8. Return on investment      - 38.53 per cent

9. Break even point          - 59.91 per cent

**Plant and equipment**

(i)    Moulds
(ii)   Double shaft mixer/blender for mechanical process
(iii)  Extrusion machine
(iv)   Bull's Trench Kiln/High draught kiln

(v)   Kiln equipment

(vi)  Tube well

(vii) Electrical equipment/fittings

(viii) Water pipes and fittings

**Properties**

(i)   Size                  - 19 × 9 × 9 cm or 230 × 110 × 70 mm

(ii)  Colour              - Red

(iii) Bulk density        - 1700 to 1900 kg/m$^3$

(iv) Water absorption  - 12 to 18 per cent

(v)  Unit weight         - 2.5 to 3 kg

(iv) Crushing strength  - 75 to 100 kg/cm$^2$

**Additional information**

    1. **Source of technology-CBRI, Roorkee; CPRI, Bangalore, India**

    2. **Information and guidance-BMTPC, NRDC, CBRI, CPRI**

**Phosphogypsum-based building materials (36)**

**Phosphogypsum is generated as a by-product in the manufacture of phosphoric acid fertilizer industry by the interaction of ground phosphate rock with sulphuric acid. For every ton of P$_2$O$_5$ produced as phosphoric acid about 4 to 5 tons of phosphogypsum containing 10 to 40 per cent free moisture is obtained. It poses a problem in disposal and causes pollution. At present, small quantities are being used as retarder in the manufacture of cement, soil amendment and ammonium sulphate fertilizer etc.**

Phosphogypsum contains impurities of phosphates, fluorides, organic matter, alkalies etc. which adversely affect the setting and development of strength of plasters/cements produced from this. For effective utilization of phosphogypsum, it is essential to make them innocuous to enable proper and effective utilization of phosphogypsum in manufacture of building materials.

**Advantages of utilization of phosphogypsum as a building materials and components:**

(i) Conservation of clay used for agriculture purposes;
(ii) Conservation of scarce and costly materials like steel, cement and timber;
(iii) Low energy requirement for production of gypsum panel;
(iv) Utilization of industrial wastes;
(v) Environmental pollution control and reduction of disposal cost.

**Building materials and components from phosphogypsum:**

(a) Gypsum plaster;
(b) Gypsum ceiling tiles;
(c) Gypsum board;
(d) Gypsum panels;
(e) Gypsum marbles/blocks.

**Project cost**

1. Installed capacity                - 7.5 million sq.m. Plaster board or equivalent

2. Investment                        - (a) Land and building Rs. 13,2 million
                                     - (b) Plant and equipment Rs. 85 million

                                     - (c) Infrastructure Rs. 23.3 million

3. Technical know-how fees                    - Rs 25,0 million

4. Training and expenses on foreign technicians - 4,5 million

5. Preliminary and pre-operative expenses     - Rs 19,2 million

6. Working capital                            - Rs 8,6 million

7. Contingencies                              - Rs 5,7 million
   Total investment                           - Rs 184,5 million

## Inputs

(i) Phosphogypsum - 250 tons/day (dry form)
(ii) Lime            - 7.90 tons/day
(iii) Additives      - 156 tpa
(iv) Pigments        - 296 tpa
(v) Glass fibre      - 8.20 tpa
(vi) Power           - 20 million Kwh/annum
(vii) Water          - As per requirement

## Manpower

Managerial - 17
Technical   - 38
Others      - 158

**Machinery and equipment**

(i)    Cyclone separator
(ii)   Vacuum filter
(iii)  Rotary feeder
(iv)   Mixer
(v)    Screw conveyer
(vi)   Moulds
(vii)  Block making machine
(viii) Panel making machine
(ix)   Mill
(x)    Silos for storage

(xi)   Materials handling equipment
(xii)  Workshop equipment
(xiii) Purification/calcination plant

**Additional information**

**1. Market Urban centres**
**2. Source of technology CBRI, IDL-Salzbau, Germany**
**3. Information/guidance BMPTC, HUDCO, NHB, SIDBI, SICOM, State financial corporations**
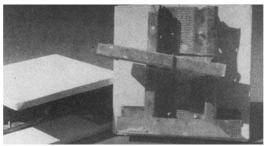
**Figure 5. Phosphogypsum-based boards. Courtesy BMTPC, India**

**Concrete fibre roofing sheets (36)**

**Coir waste, wood wool or sisal fibre can be utilized in combination with cement as a binder for production of corrugated or plain roofing sheets.**

**Shearing waste (baby fibre) and coconut pith account for a large amount of agro-industrial wastes. Unlike other cellulosic materials, coconut fibre is free from water soluble polyphenols and makes a strong board with ordinary Portland cement as binder.**

**Wood wool used largely as packing material is obtained mostly from soft-wood such as 'fir', 'chir', 'kail', 'dodar' which yields good quality fibre of suitable length and width. Sisal fibre is another suitable fibre available from sisal plant and are being extensively used in many countries for making board and roofing sheets.**

**For manufacturing corrugated sheets, fibre is soaked in water for sometime and then mixed with cement thoroughly. The cement coated mixed stuff is uniformly spread on the drag mould and is pressed by hydraulic press. The wedged mould assembly is then rolled out of the press and is cured for 3 to 4 hours in the curing yard. Water proofing paint is applied on top side of the sheets after de-moulding.**

**Salient characteristics of concrete fibre roofing:**

**1. Coir fibre/wood wool corrugated sheets require 30 per cent less cement as compared to asbestos cement sheet;**

**2. The sheets are light and can be carried over hilly and rough roads without any breakage;**

**3. The sheets are strong and possess good bending strength. A man can safely walk over them;**

**4. The sheets possess good thermal insulation and are expected to provide greater comfort in tropics as compared to AC/CGI sheets;**

**5. Their preparation needs neither heavy machinery nor high capital investment. The sheets are 50 per cent cheaper than AC/CGI sheets;**

**6. These can be laid on roofs like AC/CGI sheets;**

**7. The roofs made do not require any further finishing or waterproofing treatment.**

**Project cost and inputs**

1.  Installed capacity                    - 30,000 sheets/ year of size 2 m × 1 m × 7 mm

2.  Saleable Product                     - 24,000 sheets/year

3.  Capital

   (i) Fixed capital                      - Rs 2,66 million

    (ii) Working capital                           - Rs 0.6 million

4.  Employment potential                     - 28 persons

5.  Raw material and inputs
    (i) Cement
    (ii) Coir waste/sisal fibre/wood-wool
    (iii) Additive
    (iv) Power
    (v) Water

6.  Cost of production                        - Rs. 127/sheet

7.  Selling price                            - Rs. 165/sheet

8.  Gross annual profit                       - Rs. 0.912 million

9.  Percentage return on Investment (before tax) - 28 per cent

10. Break even point                          - 58 per cent

**Technical properties**

(i)   Pitch of corrugation, mm.              - 150
(ii)  Depth of corrugation, mm.              - 55
(iii) Length of the sheet, m.                - 1.5 to 2.0
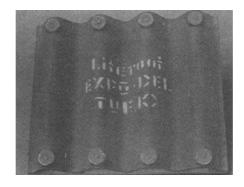
(iv)   Width, m.                                    - 1.0
(v)    Thickness, mm.                               - 7
(vi)   Weight kg/sq. m.                             -11.0 to 12.0
(vii)  Water permeability through the coated side   - Nil
(viii) Water absorption in 24 hours, per cent at 250C -
(ix)   Breaking load, kg/cm
        (a) at 1m span                              - 2.5 to 2.7
        (b) at 50 to 60 cm span                     - 5.0
(x)    Thermal insulation, k Cal cm/m0h0c           - 0.09
(xi)   Fire resistance                              - Very good

## Addition information

1. **Market-Rural and Urban areas**
2. **Source of technology-CBRI, RRI, (Bhopal), Development Alternatives**
3. **Information/guidance-BMTPC, CBRI, NRDC**

**Figure 6. Fibre concrete roofing sheets. Courtesy BMTPC, India (a)**



**Figure 6. Fibre concrete roofing sheets. Courtesy BMTPC, India (b)**

**Aluminium red-mud bricks (36)**

**Aluminium red mud or bauxite waste is a material obtained in large quantities from the aluminium producing plants. The huge reserves of about 250 million tons of bauxite in India suggest a manifold expansion of aluminium industry in future. Thus, alumina red mud is going to create serious problems due to pollution and indiscriminate disposal in the near future.**

**The physical properties of red mud like colloidal nature of particles, plasticity, water absorption and mouldability and chemical composition showing the presence of alumina, iron oxide and fluxes indicate the suitability of this material to be used in manufacturing building brick (or flooring tiles).**

**To reduce transportation costs, manufacturing facilities have to be set up near the aluminium plant where red mud and clay are easily available. In calculating the cost of**

production, two possibilities have been considered. In the first instance, the kiln is situated near the red mud storage tank from where red mud slurry directly reaches through drains or pipes in the clay pits and is mixed with the clay manually. In the second instance the kiln is far away from the storage tank and red mud is to be transported by trunks in lump form to the kiln site situated at about 1 km. Here the lumps are mixed with clay in a mechanical pan mill grinder. This mix, after wetting can be either used for making hand moulded bricks or can be extruded by a pugmill for making wire cut bricks. The process is not much different than that adopted for making normal clay bricks. However, red mud brick slurry or lumps are to be mixed with clay thoroughly in clay pits or in a mechanically-operated pan mill grinder.

## Advantages

(a) When the clay used is inferior in quality the addition of red mud improves the quality of bricks product;

(b) Red mud gives the bricks pale brown, orange or golden yellow colour depending upon composition of raw material and firing temperature. They have, therefore, good architectural value as facing bricks;

(c) The presence of 4 to 5 per cent of alkali in red mud provides good fluxing action resulting into good plasticity and better bond in the bricks.

## Production rate

(a) 36,000 bricks per day of three shifts
(b) Size: 22.5 × 11.25 × 7.5 cm

## Land and building requirements

1. Land                                   - 8.25 acres
2. Shed                                   - 100 sq.m.
3. Building Office cum-store   - 100 sq.m.

## Machinery and equipment

1. Mixer                                  - 1
2. Pug mill and extruder        - 1
3. Tubewell                            - 1
4. Pan mill                             - 1
5. Weigh batcher                   - 2
6. Handling equipment           - 3-4

## Raw materials (per annum)

1. Clay                                  -0.75 acre (18000 m$^3$)
2. Alumima red mud               - 13,500 tons

## Utilities

1. Electrical power                 - 86,400 kwh

2. Coal                                  - 1152 tons

3. Water                               - 7200 kl

4. Wood                          - 20 tons

## Manpower

1. Manager                    - 1
2. Operators                  - 2
3. Supervisor 4. Labour       - 2-60

## Project cost

Fixed capital                 - Rs. 5,4 million
Working capital               - Rs. 0,7 million
Average cost of production    - Rs. 710 per thousand
Average sale price            - Rs. 860 per thousand
Gross annual profit (pre      - Rs. 108 million
tax)
Return on investment          - 18 per cent
Break even point              - 56 per cent

## Additional information

1. Market                     - Rural and semi-rural areas as near as possible to an aluminium
                                factory
2. Information technology      - CBRI, BMTPC
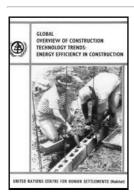
**For further details refer to UNCHS (Habitat) Journal of the Network of African Countries on Local Building Materials and Technologies, Vol. 2, No. 4, 1993.**

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📖 **Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**
➡️ 🗀 **5. Energy conservation in construction**
   📄 **5.1. Reducing transport energy**
   📄 **5.2. Reducing on-site energy use**
   📄 **5.3. Labour-Intensive Methods**

**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**5. Energy conservation in construction**

**5.1. Reducing transport energy**

**Transport plays a vital role in the entire construction process. Transport is required both for delivering raw material to the building materials plants and also for bringing the finished products to the construction sites. Being itself a high energy-intensive process,**

the extensive transportation involved in construction, constitutes greatly to the energy content of any construction output. Transport, not only consumes considerable energy, which increases the ultimate cost of construction, is also very harmful to the environment. Emission generated from road transport (particularly the $CO_2$ emissions) are major pollutants and contributors to global warning. It has been estimated that transport by truck generates approximately four times more $CO_2$ emission than the equivalent transport by rail or water. Similarly, the amount of $CO_2$ generated by truck transport (which is approximately 1.6 grams per ton and kilometre) is 20 times more than the amount generated by water or rail transport (38).

In many developing countries, the roads for efficient transport is often inadequate. This can directly affect the construction process, as supplies of materials can be unreliable with regard to delivery time and quantities required. There are proven evidence, in many countries, that the retail price of some materials are 10 times higher than the ex-factory price, just because of high energy costs involved in transport and distribution. Usually, the larger the scale of building materials production, the longer is the transportation and the higher is the fuel consumption rate.

**Energy-saving opportunities**

As mentioned earlier, the large-scale building materials production factors, such as cement, brick, lime factories etc. require a great amount of energy to transport these end-products to the construction sites which are, generally, scattered all over the country. Despite the fact that large-scale facilities are being located, normally, near the raw materials sources (to reduce the cost of transporting the raw material to the factory), the actual transport implications associated with the movement of end-products are being often ignored in the feasibility studies of the factories. This issue is, obviously, very critical and a reliable forecasting and prediction of the locations of the end users of the products for a foreseeable future is, often, not possible to make. However, studies over

the past decades indicate that the only viable solutions to the problem of excessive transport and distribution of building materials lies in the expansion of the small-scale sector.

One of the principal arguments in favour of small and medium-scale building materials plants is that by locating the plants near the users, large quantities of energy could be saved through reduced transport of both raw materials as well as the finished products. A study of lime industry in India reveals that for distances up to 200 kilometres, transport costs constitute 30 per cent of the consumer retail price. The maximum delivery distance is 10 kilometres for small lime plants of 3 tons per day, and 25 kilometres for a 10-ton per day plant. The larger plants (20 tons per day and above) have longer market ranges of 500 to 1000 kilometres, and consequently the impact of the transport cost is greater compared with small scale plants (39).

## 5.2. Reducing on-site energy use

On-site energy use is much lower than energy use for the production of building materials. Studies indicate that the contributions of on-site energy use is about 15 to 25 per cent of the total embodied energy of buildings (34). The major areas of energy-uses in the on-site construction activities are related to the use of mechanical devices and machinery such as cranes, bulldozers, loaders, graders, compactors, welding machines, mixers, lifters etc. Energy is also used in the running and maintaining temporary buildings and other facilities which the contractors use for their site operations. In addition to the routine energy use in any construction site, it has been observed that, in many sites, considerable amount of energy is being wasted because of lack of sound site management including unnecessary movement of materials, mistakes in planning the site operation and ineffective use of machinery and equipment.

## Energy-saving opportunities

It is essential to monitor continuously the on-site consumption of energy which is part of the overall management of construction. Energy auditing to ideally optimize energy-use patterns should also be conducted.

In order to optimize the use of energy in the on-site operations, a range of techniques such as critical - paths method (CPM) bar charts and arrow diagrams can be used for programming and scheduling activities. A contribution to energy conservation can be made by improving methods of construction activities, particularly avoidance of double-handling and unnecessary use of heavy machinery (16).

Continuous maintenance and examining the energy-efficiency of all mechanical-plant use, replacing inefficient parts of machinery can also contribute to energy efficiency.

It is important to examine the extent of use of transport of materials etc. to and within the site, with a view to reducing journeys and utilizing the most energy-efficient means of transport available. It is also important:

- to select, where possible, only local sources of materials supply;

- to examine the embodied energy in temporary works and replacing high-energy materials with lower-energy materials in temporary works where possible, for example the use of timber and bamboo rather than steel for scaffolding and formwork;

- to look for opportunities to save wastage of materials, such as excessive concrete in foundations, excessive cement in concrete mixes;

- looking for ways to reduce materials use by the use of closer supervision and quality control; and

**- to recycling (34).**

## 5.3. Labour-Intensive Methods

**In many developing countries, particularly in the sub-Saharan Africa, there is abundant work force which if utilized in a proper manner can contribute in saving energy in both on- and off-site construction operations. The productivity of labour-intensive technologies, in the context of developing countries, can not be over-emphasized. Applying labour intensive technologies in construction will not only facilitate decreasing the use of energy in machinery, it will generate employment and will contribute to the overall socio-economic development. Furthermore, it will develop capacities through acquisition of new skills which is a valuable asset for every country.**

**Appropriate and labour - intensive technologies are already in existence and many countries are using them, in their low-cost housing construction schemes to effectively make use of this great potential.**

**One way of tackling the problem would be to encourage and support the initiatives of the communities, the informal sector and women groups (for example by provision of attraction incentives) to actively participate in all stages of construction sector activities in their communities and neighbourhoods.**

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**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

➡️ 🗀   **6. Energy efficient building design**

**Global Overview of Construction Technology Trends: Energy Efficiency in Construction (HABITAT, 1995, 210 p.)**

**6. Energy efficient building design**

**6.1. Natural cooling of buildings (40)**

**Introduction**

**It is widely recognized that governments in most developing countries find it increasingly difficult to meet the rising costs of fossil-fuel supplies. In addition, there is a growing awareness of harmful impacts of current energy technologies and the positive cost implications of ecologically-improved systems. Maintaining comfort in the hot period of the year is a problem in many developing countries where, often, buildings become overheated inside while outside conditions are comfortable.**

**Avoidance of cooling loads**

Environmental-cooling loads are due to several sources: sunshine through windows or on the outside of the roof or walls, hot outside air entering the building, heat conducted from hot outside air to the inside.

Cooling loads due to solar gains generally represent the main problem, but these can usually be avoided through good design. Shading of the windows from direct sun is essential, especially on the east and west facades. Protection from diffused sunlight and reflected sunlight is also important. Solar loads conducted through walls and the roof can be largely avoided by using white or light colours on the exterior and by insulation. Shading by vegetation is particularly effective because the building and surrounding ground are both shaded and the surrounding air is cooled by transpiration. The knowledge of avoiding cooling loads is well-developed but is unfortunately not yet effectively practised in many countries.

**Natural cooling - basic techniques**

Several natural sources or a combination thereof, can be used to provide cooling energy in buildings e.g., initial cooling of the outdoor air by long-wave radiation before using it for convective cooling. These cooling systems will be briefly described in relation to their applicability in different climates for different building types.

**(a) Convective cooling**

Convective cooling implies cooling the structural mass of the building at night and utilizing the cooled mass during the following day as a sink, to absorb heat penetrating into or generated inside the building. During the day, interior ventilation is deliberately kept as low as possible to avoid bringing in hot daytime air. As a result, the indoor temperatures remain lower than those in a similar building without such convective cooling.

*Climatic applicability*

This type of cooling is applicable in regions with vapour pressure below approximately 17 mm HG and a large diurnal temperature range (above approximately 10° C), where the day-time temperature is above the comfort limit and the minimum temperature is below approximately 20°C. Under these conditions, daytime ventilation is not desired (as it will elevate the indoor temperature) and also not required for physiological comfort.

Convective cooling is also pertinent to regions with a vapour pressure above 17 mm Hg* and below 20 mm Hg. In regions with somewhat higher vapour pressures (up to approximately 20 mm Hg) convective cooling can be applied and the building be kept closed during the hot hours, if indoor air velocity is enhanced by a fan - e.g., a ceiling fan - in order to neutralize the physiological effect of the higher humidity.

    * mm Hg = millimetres of mercury

*Building design requirements*

In order to secure effective convective cooling, the envelope of the building should be well-insulated (average U value below approximately 0.67 $W/m^{2}{}^{\circ}C$)** and have sufficient mass "protected" by the insulated envelope and the maximum ratio of surface area to mass.

    ** $W/m^{2}{}^{\circ}C$ = Watt per square metre centigrade

*Expected performance*

The daytime temperature of a building, cooled during the previous night by convection, would be lower by 2° to 4°C than the temperature of that building when its mass is not cooled convectively. Daytime ventilation in such climate conditions will elevate the indoor temperature and nullify the cooling effect.

***Status***

Convective cooling is being applied successfully in many regions with suitable climate conditions. It is a proven cooling technique, but it is essential that the required building design characteristics are achieved.

**(b) Radiant nocturnal cooling**

Cooling of the building by outgoing long-wave radiation during the night can be achieved by two systems:

> **(i) Direct nocturnal cooling of the mass of the roof, and, subsequently, protection of the upper surface from the sun and outdoor air during daytime by external insulation. The cooled ceiling services as a radiant convective cooling panel for the space below; (see figure 1)**

> **(ii) Radiant cooling of a specialized radiator, usually made of a metallic plate above the insulation with an air space in between. Outdoor air circulated at night under the long-wave radiator is cooled by contact with the cold metal. The cooled air can be blown into the building or through a gravel-bed, thus transferring the "cold" to a mass which serves during the following day, as a cold heat sink, counteracting heat penetrating into or generated inside the building.**

Direct radiant cooling of the roof's mass: The temperature of a massive roof during the night is close to the ambient air temperature, while the temperature of a specialized radiator is lower by approximately 4° to 8°C. As the rate of heat radiant loss during the night increases with temperature, the heat loss from an exposed massive roof is maximized. On clear nights it can be approximately 70 watts/m$^2$. However, if the roof is not effectively insulated during day, heat-gain due to the solar radiation and/or the

**convection of hot air may exceed nocturnal heat loss. Therefore, efficient movable insulation (white on the upper surface) is a prerequisite for such cooling systems.**
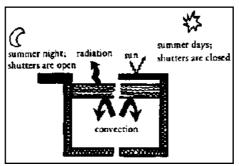


**Figure 1. Direct nocturnal cooling**

*Climate applicability*

**Radiant nocturnal cooling of a massive roof can provide effective cooling in almost all climates, except in humid cloudy regions.**

*Building design requirements*

**This system can be applied only to one-storey buildings, with a roof of high mass and high conductivity.**

*Expected performance*

**With radiant heat loss of approximately 70 watts/m$^2$, during 10 hours the roof can lose 700 W-hours/m$^2$ per night.**

Heat gain during the day depends on the effective thermal resistance of the insulation. Even with insulation having R = 1 m$^2$. C/W. (U Value = 1W/m$^2$ degrees centigrade) and an average temperature difference of 10°C, the heat gain of the roof during the daytime would be 140 W-hours/m$^2$. The resulting daily net heat loss is 560 W-hours/m$^2$ per day, a useful contribution to cooling.

Until effective and practical movable insulation becomes available, the use of this cooling system is not recommended. When, however, cost-effective movable insulation systems are developed, this cooling system would appear promising. Trials could be promoted using single-storey test buildings with concrete roofs. Existing buildings could then be retrofitted.

**(c) Evaporative cooling**

Cooling of buildings by water evaporation can be either direct or indirect, active (using mechanical equipment) or passive. In direct evaporative cooling, the air is humidified while its dry-bulb temperature drops and the wet-bulb temperature remains constant. Direct evaporative cooling is a well-established technology and can be applied wherever the ambient average summer wet-bulb temperature is below approximately 18°C. Commercial "desert coolers" are available in many countries and may be used in developing regions with suitable climatic conditions. Inexpensive, passive, evaporative cooling could be provided by utilizing the natural air flow by wind force through windows by installing "moist" elements in them - such as permeable water jars. Passive evaporative cooling can also be provided by shaded roof ponds in direct thermal contact with the roof. This cooling system is particularly applicable to single-storey buildings with flat concrete roofs or to the upper storeys of multi-storey buildings. (see figure 2)
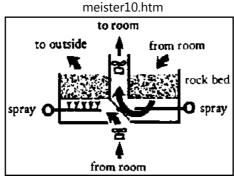
**Figure 2. Evaporative cooling**

## *Climatic applicability*

**Indirect evaporative cooling can be applied in regions where the summer average wet-bulb temperature is below approximately 20°C. The ceiling acts as a radiant convective cooling panel for the space below, so that the indoor humidity level is not elevated.**

## *Design requirements*

**The pond should be effectively shaded from solar radiation. Considering the winter conditions, the shading should also have high insulation, and the ventilation openings between the shading and the water should be approximately 30 to 50 cm high. In winter, the pond should be closed and the water drained off the roof. The roof itself should be as conductive as practical, as the insulation in winter is provided by the pond's cover. Brackish water can also be utilized in roof ponds, though treatment of the water to prevent biological activity and insects is required.**

## *Expected performance*

The pond water's average temperature follows the average ambient wet-bulb temperature (about 1°C above it) with swings depending on the pond's depth. If the roof is a good conductor - e.g., reinforced concrete - and the building itself is well-insulated, then the indoor average temperature in suitable climates will be below the average outdoor air temperature (dry-bulb temperature) by approximately 3°C. The indoor temperature swing depends on the building's heat capacity.

Research has demonstrated the potential of shaded roof ponds to serve as a cooling system in arid regions. No field experience is available.



**Evaporative cooling.**

**Photo credit: Ersin Alok**

**(d) Earth cooling**

The earth under and around a building can serve in many climatic regions as a natural cooling source for the building, either in a passive or an active way. It is possible to lower the earth temperature within a confined area well below its "natural" level, by eliminating its heating by the sun while enabling evaporation from the earth surface. (see figure 3)
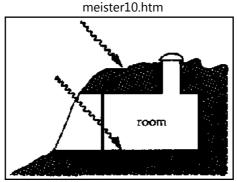
**Figure 3. Earth cooling**

To date, two methods have been tried to lower the earth temperature:

   (a) raising the building off the ground and encouraging evaporation from the surface either by irrigation or by feeding summer rains into the area below the building; and

   (b) covering the soil with a layer of gravel, at least 10 cm thick and, in regions with dry summers irrigating it.

*Expected performance*

Experiments in Israel and the U.S.A. (Arizona and northern Florida), have demonstrated that it is possible to lower the earth surface temperature by approximately 8° to 10°C below the summer temperature of exposed soil. The difference between the "treated" and "untreated soil" is reduced with depth, reaching about 60°C at a depth of 60 cm. The difference between the outdoor maximum temperature can be up to about 15°C (in mid-summer), providing the potential for a heat sink for the building.

While research has established the great potential of cooled soil to serve as a source of cooling, no research on the performance of practical building systems, utilizing this potential, has yet been done.

**Climatic analysis for various passive cooling systems**

**Comfort ventilation**

Comfort (daytime) ventilation is desirable in warm humid regions with a small diurnal temperature range and daytime temperatures not exceeding approximately 30°C. Indoor daytime temperatures are usually raised by ventilation, but physiologically the higher air motion compensates for it. Indoor daytime temperatures are close to the outdoor temperature. (see figure 4)
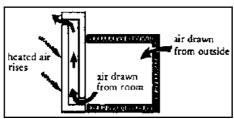


**Figure 4. Induced ventilation**

*Convective cooling*

Convective cooling is applicable in regions with a large diurnal temperature range, with the night minimum temperature not exceeding approximately 20°C and vapour pressure below approximately 17 mm Hg. The range may extend to an upper vapour pressure limit of about 20 mm Hg, if fans are available to circulate the air internally. The building is ventilated during the evening and night hours, but closed during the day. The structural

mass which is cooled during the night serves as a heat sink during the day, thus lowering the indoor maximum air and mean radiant temperatures below the outdoor maximum temperature by up to 10°C.

*Radiant cooling of the roof mass*

Radiant cooling is applicable in almost all climatic regions, except those with a cloudy night-sky in the summer. The roof should be well-insulated during the day and exposed to the sky during evening and night hours. Therefore, the system, must have movable insulation. The rate of nocturnal heat loss is higher than in other cooling systems; if the roof is well-insulated during the day and made of conductive materials such as reinforced concrete, it serves as an effective heat sink for the space below.

*Passive evaporative cooling by shaded roof ponds*

Such cooling is applicable in all regions where the average summer wet-bulb temperature is below about 20°C. The roof should be made of a conductive material. The pond should be shaded by insulated cover above an air space, with ventilation opening on opposite sides. In winter, these openings are closed and the water is drained. Average indoor temperatures in arid regions may be lower by as much as 3° below the outdoor average.

*Earth surface cooling*

Shading the soil and encouraging evaporation, either of summer rain water or of irrigation water, can lower the earth surface temperature by up to 10°C below the "natural" temperature of the earth in a given region. The cooled soil can then be used as a heat sink for the building if either air or water flow is channelled through it.

*Seasonal storage of coolness*

The section on cooling systems using natural energies was limited to the short-term (several hours) storage of coolness. Winter coolness may, however, be stored over long periods in suitable materials to be used for summer cooling purposes. The sources of coolness are the ambient air, sky and water vapour. Depending on the winter climate, one or more of these sources may have to be utilized. The suitable materials and processes for storage of coolness are deep soil storage; water (in aquifers); ice production; and freezing of water-saturated soil.

The soil in the ground may be cooled in winter by circulating ambient air or chilled water through it. The soil should be insulated on top. Relatively large volumes are needed for the storage.

Aquifers may be charged with chilled water in winter and the stored-cold water can be utilized in summer.

In areas with suitable winter conditions, ice may be produced as a means of storing winter coolness for summer applications. In these areas, it is also possible to freeze saturated soil as a means of storing winter coolness. In both systems, the storage has to be well-insulated to reduce the loss of coolness. For a given summer cooling need, ice production requires the least volume, and in many applications it may be the least expensive. In all of these systems, pumps or fans have to be employed for the storage or retrieval of the coolness.

*Other storage techniques*

It is generally agreed that many of the new storage techniques under development have not lived up to their promise, and systems such as latent-heat storage and phase-change materials have now shown many advantages compared to storage in masonry, water or rock. In some cases, the deterioration and chemical changes with cycling and the controllability of the operating properties of the storage materials have posed problems

which have yet to be reliably solved. The use of masonry for storage of heat and cold is considered more economical and operationally more stable than most experimental solutions now being tested. The problems associated with the use of water walls may lead to solutions being more expensive than the use of conventional masonry storage.

In buildings with an air-conditioning plant, the production of ice and chilled-brine during off-peak hours and the use of the stored coolness during peak hours are, however, promising.

Conclusions

Natural cooling and cooling-load avoidance will not only help to conserve energy and help reduce the adverse environmental impacts of fossil-fuel use but also satisfy bioclimatic comfort requirements within the buildings. Therefore, they should be used extensively in developing countries. Methods to promote cooling load avoidance are very advanced. To promote the use of these technologies, priority should be given to the dissemination of information on these methods. Sets of minimal meteorological data as well as information on thermal properties of indigenous building materials are required. There is a need to study the performance of natural cooling systems in the field in various parts of the world, and to pay attention to design methods and appropriate techniques of control, such as day-time shading. Cost-effective storage systems using earth capacity, ice or other new concepts have to be investigated and developed. The adaptation and improvement of traditional passive cooling and storage systems may offer useful solutions if adequate research and development effort is put into the study of the subject.

In view of the fact that very large populations in the developing countries living in hot-dry and in hot-humid conditions have to suffer serious discomfort for considerable parts of the year, the search for effective solutions for low-cost cooling is a target area where new basic concepts and designs are urgently needed.

**Improvement of the comfort levels in these regions will contribute not only to a better quality of life but also to higher economic productivity. A research programme with clearly formulated objectives needs to be identified in this area. The problem of achieving cost-effective techniques for dehumidification is particularly crucial for assisting the hot-humid regions. Promoting the use of local materials for natural cooling systems will also require considerable research and development efforts. A systematic programme for the construction of demonstration buildings and training are important steps to promote the use of natural cooling and cooling-load avoidance techniques.**

**Glossary**

| | |
|---|---|
| aquifer | layer of rock or soil able to hold or transmit much water |
| ambient (air) temperature | temperature of the surrounding air |
| comfort ventilation | use of ambient air for cooling |
| convective cooling | cooling heat storage mass, generally during the night by outdoor air and utilizing the cooled mass during the following day as a sink for heat penetrating inside the unventilated building |
| cooling load | the heat gain to a building in a designated period (watts) |
| dry-bulb | the temperature of a gas or a mixture of gases indicated by an accurate thermometer |

| | |
|---|---|
| dry bulb temperature | the temperature of a gas or a mixture of gases indicated by an accurate thermometer after correction for radiation |
| evaporative cooling | employs latent heat of evaporation of water. Evaporative coolers are considered direct if the evaporative cooled air is exhausted into the conditioned space and otherwise considered indirect |
| heat sink | any sort of surrounding which has a lower temperature than air, and which is used to dump the extra heat |
| long-wave radiation | transmission of heat through space by long-wave motion (e.g. heat loss from a roof to the sky) |
| passive system | system in which the energy flow is entirely by natural means |
| radiant cooling | cooling effects resulting from long-wave net heat loss to the sky during the night |
| radiant cooling with | cooling by long-wave net heat loss specialized radiators to the sky through a metallic plate |
| roof pond cooling | evaporative cooling of roof water pond and utilization of the cooled roof as a convective-radiative cooling panel for space below |
| solar load | heat gain to a building in a designated time by solar radiation (watts) |

| vapour pressure | pressure exerted by a gas, particularly one near to equilibrium with the liquid phase of the substance |
|---|---|
| wet-bulb temperature | temperature at which water by evaporating into air can bring the air to saturation adiabatically (without heat extraction or addition) at the same temperature |

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## 6.2. Passive solar design

Buildings need to be heated, cooled and ventilated in almost all regions of the globe, if an adequate indoor climate and comfort has to be provided to the occupants. Proper architectural design, depending on climatic conditions, can help in providing them comfort with no or extremely limited use of energy.

Depending upon the architectural design and geographical location of buildings, the energy requirement for heating and cooling buildings can be considerable. It is in this context that the concept of passive solar building design as a significant measure for energy saving during the life time of any building has attracted great attention over the past two decades, particularly after the global oil - crisis of 1974.

While the professional community with its research efforts is in search for new energy sources, the sun is transmitting continuously, vast amount of energy. Although only one trillionth of the energy reaches the Earth, this is still about 10,000 times the total commercial energy used, so that even very modest progress in utilizing solar energy could

provide a large part of mankind's energy needs. For example, on a clean day, a surface directly facing the sun receives about 1 KW of solar radiation per square metre (41).

Passive-solar design can be described as satisfying the thermal needs of building occupants by using sun's energy and other natural means. Buildings designed on the principles of passive solar architecture are those which use the structure of the building (walls, ceiling and floor) as a collector, storage and transfer mechanisms with a minimum amount of mechanical equipment, while active design systems are generally those that are very visible with collectors on roofs, pumps, plumbing, control systems and storage tanks.

**6.3. Passive solar heating of buildings (42)**

**Relevance of passive-solar heating**

Passive-solar space heating can be most effective in temperate climates, where there is sufficient sun to make it work-well and where winter temperatures are cold enough to make it cost-effective. It is useful to separate temperate zones into two different climatic regions for purposes of this discussion: those with mild winter climates and those with severe winter climates. The demarcation between the two is at the average monthly midwinter temperature of about 8°C. In mild climates it seldom freezes in the winter, and in severe climates it usually freezes every night for several months of the winter.

In regions of mild winter climate, buildings normally have low thermal resistance and are uncomfortably cold throughout most of the winter. Supplementary heating, if used at all, is makeshift and erratic; extra clothing is often the primary means of maintaining comfort. In these climates, passive-solar heating alone, without added insulation, can markedly improve the inside winter climate. By such techniques alone, the average temperature inside, in mid-winter can be raised 5° to 10°C, and the need for supplementary heating can be reduced by 60 to 90 per cent. This is not to say that conservation strategies are not appropriate in regions with mild climates. Added insulation and reduced air leakage would

not only make the building more comfortable but reduce the size of passive-solar collection-area needed.

In regions with severe winter climate, passive-solar strategies taken alone are inadequate; insulation must be added to achieve reasonable comfort levels. It is recommended that insulation be preferably placed on the outside of the wall, protected by a weather-proof outer sheathing, or in a cavity inside the wall. Extensive insulation should be added to the roof, and all cracks should be sealed to reduce air infiltration. These strategies will typically, reduce the heating requirements to about one-third or one-quarter of the uninsulated value. Passive-solar strategies can then be implemented, as in mild climates, to maintain comfort during most of the winter. Some supplemental heat will still be required to maintain comfort during extended cloudy periods, but the net effect is a building that will require only 10 to 20 per cent as much heat as buildings without conservation or solar measures. Note, however, that the coldest temperature conditions in many climates almost always occur during clear weather when passive solar heating copes very well. Without back-up heating, the inside temperature would likely never drop below 5° to 8°C, even under the most severe winter conditions. This inherent protection against freezing is a considerable advantage.

**Design considerations**

Passive-solar technology is basically design-oriented. The orientation of buildings is such that, it takes maximum advantage of environmental conditions to enhance thermal comfort. The choice of passive-solar design-strategy should be based on a balance of factors such as:

   (a) socio-cultural characteristics of the users and use patterns of the building;
   (b) construction techniques and materials available.

Severity of climate will determine the level of conservation, the design of details, and size

of elements used for passive heating.

The tendency for buildings in the formal sector in urban areas to be of massive construction in developing countries is an advantage for passive solar applications. The mass provides heat storage to carry over daytime solar gains into the evening hours. There is normally ample mass in buildings of adobe, brick, concrete block, stone, however, a few adjustments in the use of such materials will result in the greatest heat-storage effectiveness (such as using north/south partition walls between direct gain spaces).

Types of passive heating

The three passive-solar strategies of primary importance are direct gain, thermal storage walls and sunspaces.

Direct gain is simply the use of windows on the equatorial side of the building. The direct gain glazing area should be limited to no more than about 10 per cent of the floor area of the building to prevent excessive temperature swings, degradation of materials within the building by ultraviolet rays and glare. In mild climates, this may be a sufficient passive-solar glazing area to meet heating requirements (see figure 1).

Thermal storage walls either Trombe walls, (figure 2) or water walls (figure 3) can be used to balance heat delivery into the building. If the building is already of massive construction, a Trombe wall can quite easily be built simply by painting or staining the outside of the wall with a dark colour and glazing the wall outside. The incremental cost of such a modification is relatively small. In severe winter climates, double glazing should be used; in mild winter climates, one sheet of glazing is usually sufficient.

Another option, that of utilizing water in containers for thermal storage (a water wall), is reasonable if suitable containers can be obtained at low cost. Containers should be painted a dark colour on the side facing the window, but can be any colour on the room side.

Sunspaces can either be attached to the building or incorporated in atria. A sunspace consists of a direct gain room placed on the equatorial side of the building, separated from the main living or working area of the building by a wall with openings that can be closed, such as doorways or windows (figure 4). The sunspace has a large area of solar glazing compared with the surface of the mass used for heat-storage and, thus, temperature swings will typically be large (10° to 20°C). During the day, warm air is transferred from the sunspace to the rest of the building, primarily by convection of warm air through the connecting doors and windows which are left open during the day and closed at night The temperature in the sunspace will drop somewhat below room temperature at night but remain well-above outside temperatures. The use of an atrium within a building has proven to be a very successful passive-solar design-strategy. If properly designed, an atrium can provide passive-solar winter heating, daylighting and passive summer cooling within a building and at the same time can serve as a useful living, working or public area. Such atria have been included in the design of many commercial buildings and have also been successfully used in several residential buildings.

**Performance features**

Used correctly, all three of these passive-solar design-options have comparable performance and will save 160 to 320 kWh of auxiliary heating energy per year per sq. m. of glazing surface. Any one of the three might be most suitable in a particular instance, or a mixture of two or the three systems might be employed. A particular advantage of the direct gain approach is its provision of daylighting in the building, reducing the need for artificial lighting. The Trombe wall or water wall approach achieves both the most effective carryover of heat from day to night and the best thermal comfort. The advantage of the sunspace is its provision of an additional area within the building which can be used as an air-lock entry, a traffic way or a greenhouse. Both flowering plants and vegetables can be grown year-round in a properly constructed sunspace.

**Relating design strategies to climate**

**Local climatic conditions will affect both the design and the effectiveness of passive solar heating strategies. Specific temperature climate zones can be commented on as follows:**
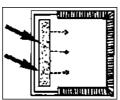


**Figure 1. Direct gain**



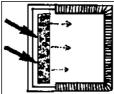**Figure 2. Thermal storage wall (Trombe wall)**



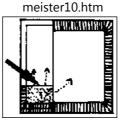**Figure 3. Thermal storage wall (water wall)**

**Figure 4. Attached sun space**

**Upland continental climates tend to have sunny, cold winters, making passive solar heating very attractive and cost-effective. If the climate is cold (less than 8° C, average midwinter temperature), special care must be taken to prevent excessive heat loss from the passive system, by means such as double glazing, use of selective surfaces (on a thermal storage wall) or night insulation. The required passive solar glazing area might be large (20 to 30 per cent of building floor area); thus a combination of direct and indirect passive strategies is usually desirable. These regions also tend to have hot summer conditions; in this case, special care must be taken to shade or cover completely the passive glazing, so that overheating does not occur.**

**At moderate latitudes (25° to 50°) it is very important to orient the building so as to allow maximum beneficial use of winter sun and maximum exclusion of summer sun. The most effective configuration is a building long in the east-west direction and short in the north-south direction. Windows and other passive solar glazing elements should be located on the equatorial-facing side of the building. However, small windows might have to be located on the opposite side and the east and west ends of view, emergency egress and summer ventilation; they should certainly never be eliminated altogether. Suitable overhangs used above equatorial-facing windows should exclude the direct summer sun totally.**

**At low latitudes (0° to 75°) upland regions needing heating (such as the altiplano of South**

America) present the need for entirely different passive solar heating methods. A central courtyard covered by horizontal glazing is effective, as is the use of east-or-west facing passive solar glazing.

At very high latitudes (50° to 70°), there is usually insufficient solar energy to make a solar system work in midwinter. A passive system can be cost-effective only if justified, based on energy savings during the autumn and spring months. In new constructions, added insulation might shorten the heating season to the point that passive solar is not very cost-effective. However, in some retrofit situations, passive solar systems might be a practical option.

Maritime temperature climates often have low-solar energy availability owing to fog and cloud. However, the climate is usually mild, and the heating season very long so that passive-solar heating can still be cost-effective. However, it is necessary to minimize heat losses to ensure net positive gain. This might indicate that double glazing or selective surfaces should be used. Sunspaces also tend to be especially successful in these situations.

Short winter climates, often make it economically difficult to justify passive-solar heating-strategies. With a heating season of only two or three months, even if it is sunny, it is difficult to recoup the investment.

Climatic analysis for passive solar heating

The effectiveness and the design of passive-solar heating-systems depend both on the winter heating needed and the solar energy available during the heating season. Figure 5 identifies four general zones according to these conditions:
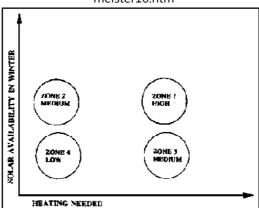
**Figure 5. Suitability of passive heating according to solar availability and heating need**

**The heating needed increases as the outside temperature decreases, as the length of the heating season increases, and as the inside temperature desired by the building occupants increases. Solar availability in winter decreases as cloudiness increases and decreases as latitude increases.**

**Zone 1: Passive heating effectiveness is greatest in Zone 1, as is the added investment in double glazing, movable insulation or selective surfaces which can be justified to achieve high performance.**

**Zone 2: Passive heating is very easy in this zone, as the size of system needed is generally modest. Furthermore, locations having a Zone 2 winter climate frequently also have a hot summer climate. Thus the passive-heating system must be carefully-designed to avoid potential adverse effects in summer. This usually means that the passive-heating apertures must be carefully-shaded in summer and, in extreme cases, should be completely covered to prevent diffuse solar gains.**

**Zone 3: Passive-solar heating is difficult in climates having cold, cloudy winters. Where the heating season is very long, energy savings are often greatest in the spring and autumn months, in which case passive heating can usually be justified. However, passive strategies for reducing heat loss from the passive system - such as double glazing, movable insulation and selective surfaces - are generally necessary.**

**Zone 4: The incentive for passive heating is lowest in zone 4. The degree to which passive heating is included in the design should usually be limited to low-cost options, for example, relocating windows from other facades to the equatorially-facing facade and the use of appropriate building shape and orientation.**

**The need for conservation strategies of insulation and reduced infiltration can be ranked according to zone as follows:**

Greatest need: Zone 3, Zone 1 and Zone 4
Least need:      Zone 2

**The need for summer sun protection is usually greatest in Zone 2 and least in Zone 3, although this will vary from case to case.**

**Good design practice is to combine passive-solar heating-techniques with energy conservation in order to achieve a well-balanced (and economically-optimal) design. The following insulation levels can be used as a rough guide:**

| Average sol-air temperature during the coldest winter month (°C) | Maximum coefficients of transmission (U-value) recommended (Watts/°C, sq. m.) | |
|---|---|---|
| | Walls | Roof |
| 12 | 0.78 | 0.52 |

| 8 | 0.60 | 0.40 |
|---|------|------|
| 0 | 0.45 | 0.30 |
| 8 | 0.37 | 0.25 |

**Infiltration should also be carefully controlled, consistent with maintaining adequate indoor air quality.**

**In applying passive-solar heating-techniques, two points should be kept in mind. The first is to avoid embellishing the system with unneeded (and usually counter productive) gadgetry. The second is to make multiple use of elements where possible. For example, a trombe wall can support the roof and serve as an acoustic barrier between a room and a noisy street. A sun space can in addition serve as an airlock entry or a passageway. This, passive-heating techniques are architecturally versatile, simple, reliable and economical.**

**The overcost of passive-solar heating-techniques is usually very nominal, normally not more than 5 per cent of the cost of the building, and should never exceed 10 per cent. Costs can be kept low following the advice given above, in which case the overcost can be shared among the multiple functions that the passive element serves.**

**Design methods**

**Methods for the passive-solar design of buildings are based on bioclimatic analysis, which is a systematic procedure for the assessment of thermal comfort in relation to external climate. Its purpose is to identify desirable adaptations of structure to meet human comfort needs under specific climatological conditions. Both bioclimatic analysis and passive-solar heating-design require certain climatological data such as out-door air temperature, humidity, wind strength, direction and frequencies of solar radiation, sunshine and cloud distribution and precipitation. There are simple but validated methods of thermal analysis used by practising architects and engineers. Therefore, it is not usually**

necessary to use cumbersome modelling and simulation techniques requiring large computers. It is, however, necessary to evaluate the materials available in a specific locality, the construction techniques of in-use and any socio-cultural constraints. A preliminary design can be prepared using information in the form of general guidelines, but detailed local climatic data will then be required to permit specific application. There are three levels of analysis, namely:

| | |
|---|---|
| Level 1 | Guidelines useful at the beginning of the design. |
| Level 2 | Simple analysis procedures which can be used to check performance as schematic design proceeds. |
| Level 3 | Complex analysis procedures to check performance towards the end of the design process. |

It is extremely desirable that these procedures be amenable to rapid checking of calculations by hand.

For levels 2 and 3 in the above list, the analysis should provide four key pieces of information: the average inside temperature for the building each month, the clear-day temperature swing inside the building in midwinter, the annual auxiliary heat needed to maintain a given minimum temperature throughout the winter, and the average and peak daily inside temperatures in hot weather.

Average inside temperatures and temperature swings pertain to the comfort which would be obtained in an unheated building. This is relevant to situations where space heating is not used in any case, and the purpose of passive-solar heating is to improve the inside

environment. Annual auxiliary heat needed identifies the energy savings potential of the passive system in situations where a backup heating system is employed. Average and peak daily inside temperatures enable the year-round performance to be checked, so that excessive overheating does not occur in summer.

**State of the art-passive solar-water heating**

The most cost-effective solar-water heating-systems are currently found in those areas of the world where conditions are suitable for combining flat-plate collectors with a passive movement of the water into the storage tank. They have the advantage of supplying hot water without the need for any connection to an electricity supply. Such systems are easiest to devise in climates without risks of freezing. Most of these systems are passive thermosyphon water heaters. Encouragement should be given to the development of this industry at the local level, and the problems of effective integration with local-building techniques should be evaluated.

**Conclusions**

Passive-solar heating will not only save energy and help reduce the adverse environmental impacts of fossil-fuel use but also vastly improve the comfort and livability of buildings. To promote the use of passive-solar design of buildings, priority should be given to the dissemination of information on the methods and materials for passive design, e.g. through the preparation of national and regional design handbooks setting out design methodologies. Sets of minimal meteorological data, as well as information on thermal properties of indigenous building materials, are needed to make the use of passive-solar technologies possible. A systematic programme for the construction of demonstration buildings is an important step to prove that solar-heated buildings are successful in conserving fuels while providing comfort. Training and education in passive solar design would increase the interest of professionals and users alike in passive solar

**design technologies.**

**Glossary**

| | |
|---|---|
| Airlock entry | a vestibule enclosed with two air-tight doors for permitting entrance without significant air or heat exchange |
| Atrium | a central-courtyard type of space within a building, either open to the sky or roofed over the whole or in part with glass or other transparent material |
| Clerestory | a vertical window placed high in a wall near the eaves and used for light, heat-gain and ventilation |
| Direct gain | energy collection through windows or other glazing into occupied space, with heat storage within the confining surfaces and other materials of the building |
| Glazing | materials which are translucent or transparent to short-wave solar radiation, including glass and plexiglass |
| Infiltration | uncontrolled air flow into or through a building via such openings as gaps under doors, chimneys without dampers and badly-fitting windows |
| Insulation | materials which conduct heat slowly, such as particle board, perlite, cellulose fibres, mineral wool and fibreglass |
| Night insulation | insulation used only at night, in the form of shutters, curtains, etc. |

| | |
|---|---|
| Passive system | system in which the energy flow is entirely by natural means |
| Retrofit (v) | add a solar heating or cooling system to an existing building previously-conventionally heated and/or cooled |
| Selective surface | one which has a high absorptivity and a low emissivity; such surfaces are commonly used on flat-plate solar collectors and on storage walls |
| Sol-air temperature | an imaginary temperature of the layer of air adjacent to the surface being considered and the equivalent of the combined effect of solar radiation and air temperature |
| Supplementary heating | auxiliary or back-up heating-system; a constantly available source of heat energy which is brought into operation when the solar system storage has been exhausted and the need for heat exists |
| Temperature swing | fluctuations in temperature |
| Thermosyphon | heat and mass transport by natural convection of a fluid; in air thermosyphon the fluid is air, in water thermosyphon it is water, e.g. in a thermosyphon water heater |
| Thermal Storage wall | a wall in which heat storage material is located closely behind solar collection glazing, e.g. a Trombe wall |

| | |
|---|---|
| Trombe wall | thermal storage wall of masonry (concrete, brick, adobe, rock, etc.) |
| U-value | heat transfer coefficient; the capability of a substance to transfer the flow of heat (used to describe the conductivity of a material or composite of materials used in construction) |

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