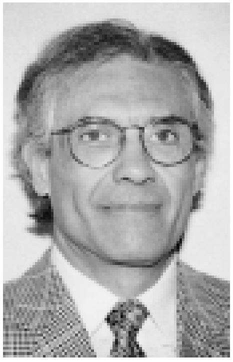
Construction and Environment
– Improving energy efficiency

by Baris Der-Petrossian and Erik Johansson



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He has worked for the United Nations since 1985: three years at the United Nations Industrial Development Organization (UNIDO) in Vienna and then at the United Nations Centre for Human Settlements (Habitat) in Nairobi, where he was in charge of research programmes for low-cost housing and environmentally sound technologies. In 1999 he organized a Habitat workshop in Vienna entitled Housing and Environment *that was attended by over 140 participants from 35 countries.*

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1 Introduction

Problem

The construction sector plays a significant role in economic development in every country. It provides the direct means to the development and expansion of economic activities and is, at the same time, a major consumer of physical and natural resources and a polluter of the environment. Over the last 30 years, the environmental impact of human settlements development, including construction activities, has grown dramatically due to the sheer increase of the world population and greater industrial and human activity.

There are numerous environmental impacts of construction activities. Building construction accounts for 25% of the forest wood and 40% of the raw stone, gravel and sand used in the world each year. Globally, buildings consume 16% of the world's fresh water and 40% of the energy used annually. Close to 70% of the sulphur oxides produced by fossil fuel combustion are produced through the generation of electricity used to power our homes and offices. Some 50% of carbon dioxide emissions – mainly in industrialized countries – are a result of the operation of buildings[1].

Regrettably, these statistics have not been taken very seriously by the construction industry and those involved in it. However, there is growing awareness of the problem worldwide. International intervention and actions in recent years[2] make clear that to ensure sustainable development, the activities of the construction sector must be controlled and managed in a way that the natural resource base is not depleted and environment not degraded irrevocably. The real challenge lies in ensuring sustainability without reducing the rate of construction activities or bringing some of them to a halt.

The environmental problems of the construction sector in developing countries are at different levels. Material producers and builders often use traditional, less enrgy-efficient techniques or old-fashioned, highly polluting equipment. There is often a lack of knowledge about how to make production clean and energy efficient. Improvements might also be hindered by lack of capital or, if the equipment has to be imported, lack of foreign currency. There is often weak management, both in materials production and at construction sites.

In many countries energy use, and consequently air pollution, due to heating and/or cooling of buildings is very high. To some extent this is unavoidable, since the indoor climate would otherwise become unbearable, but energy use could be much lower if buildings were better adapted to the outdoor climate. Architects and engineers are often not aware of new building design techniques that require less operational energy.

Laws and regulations, for example regarding the use of ecologically sensitive areas in nature and limits for pollution, are often not respected, and in some cases there are no regulations. Normally there are insufficient government policies or enforcement mechanisms to encourage designers and builders to adopt environment-friendly technologies in construction, and standards and building regulations are often inappropriate. National and local governments and authorities are key actors in reducing the negative impact of construction activities on the environment. Their role however is not specifically treated in this report. For further studies refer to UNCHS (1993a), UNCHS (1997a) and WRI (1994).

Other environmental issues related to construction are waste treatment, water use, noise, indoor air pollution and health hazards of building materials. These topics are also not covered in the report. For further studies on the latter subject refer to Berry et al. (1995) and UNCHS (1997b).

This study outlines some key concerns regarding the environmental impacts of the construction industry. Most of the pollution from the construction sector comes from energy intensive activities, such as material production, construction and operation of buildings. The study therefore focuses on energy use, and recommendations are given on how to improve energy efficiency in construction. The report is aimed mainly at designers, builders and small-scale material producers.

Method

The report was written as a desk study. It is based on the authors' experience and knowledge of building design, construction and building material production in developing countries. The applied research conducted earlier, and the results achieved, at UNCHS (Habitat) were important sources and background material for the preparation of this report. Recent literature on aspects relevant to the theme of the report was also reviewed.

Organization of the report

The report consists of three chapters. Chapter 1 gives a background to environmental problems in the construction sector. Chapter 2 provides an overview of pollution and energy use in the construction sector, and Chapter 3 gives recommendations on improving energy efficiency in construction and operation of buildings, as well as in small-scale building materials production.

1 B. Dimson 1996, *Industry and Environment*, vol 19, no 2, p 19.

2 Particularly as a result of the *Habitat Agenda* by the second United Nations Conference on Human Settlements (Habitat II) in 1996, and the *Agenda 21* by the United Nations Conference on Environment and Development (UNCED) in 1992.

2 General considerations

Activities in the construction sector are complex, highly dispersed and resource demanding. The sector contributes to the loss of important natural assets and imposes severe stress on the environment. Agricultural land is often lost through urbanization and extraction of raw materials. Forest timber is harvested for construction and as fuel for manufacturing building materials faster than it can be replaced by planting new trees or by natural growth.

Many raw materials used in construction are limited resources. For example the reserves of some metals will be gone in less than 30 years, if the current rate of exploitation continues. Fossil fuels, which are used extensively in kiln processes to produce building materials and energy generation for building operations, also have limited reserves. The consumption of fossil fuels contributes to increased air pollution and emissions of greenhouse gases. Construction-related activities contribute also to the release of ozone depleting substances that damage the ozone layer.

This Chapter will outline some of the key areas of environmental degradation caused by construction activities.

The impact of construction on land, water resources and forests

Degradation of land

Land use conflicts are a growing threat to the environment in many countries. These conflicts, particularly in developing countries, arise largely because of the lack of coordinated national land-use policies. Each sector, such as mining and forestry, views the production areas as the best resource-base for its development objectives, resulting in intense competition for the land, without a mechanism to set priorities among competing uses.

In terms of using land for quarrying and extraction of raw materials, many national policies are more concerned with licensing exploitation and charging fees to collect revenues. They are seldom concerned with the appropriateness of how such land is used. For example, in some countries areas were licensed for clay or stone quarrying at the expense of the agricultural and livestock sector. Most of these actions were carried out without prior environmental planning or cost-benefit analysis. There is a growing concern, in many countries, about increasing land dereliction, caused by the extraction of sand, gravel and clay, etc. which ultimately reduces the land available for human settlements development.

Destruction of land can be avoided by applying more sustainable methods of quarrying, such as restoring agricultural land after clay winning.

Apart from land degradation in the form of quarries and lost land, extraction and refining processes sometimes use toxic substances, such as heavy metals, that might spread into the soil and could cause damage to the eco-system.

Box 1
Loss of agricultural land due to brick making

In the city of Aligarh (0.6 million inhabitants) in the northern Indian state of Uttar Pradesh, it has been estimated that the rate of spreading of the boundaries of the city, caused by an increase of 36,000 per year in the population, leads to the loss of 100 hectares of fertile land at the boundary of the city each year. But, in addition, approximately 1 million cubic metres of soil in the form of bricks is needed to construct the new houses built, plus a further 0.5 million cubic metres of soil and other fill materials used as base materials for the roads and building plots. The bricks are supplied from 49 existing brick kilns, located at an average of 15 km from the city. The clay pits associated with these brick kilns are relatively shallow, but after use are nevertheless totally lost to agriculture. Farmers also sell soil directly, because of the high price it fetches, leading to total degradation of the land.

Source: UNCHS (1993a).

Degradation of coastal areas and water resources

Construction activities can be detrimental to coasts and water resources, which can become critical in some areas. The extraction of sand and gravel from riverbeds and beaches can have serious environmental consequences, increasing soil erosion.

The degradation of the marine environment, caused by removing coral and shells to produce building lime and for use as aggregates, is attracting increased attention. Dredging away marine coasts for extraction of aggregates has begun to replace quarrying in some countries, as the most accessible land quarry sites are used up; this is obviously less damaging to the environment, but causes increased rates of erosion of the nearby coast. In parts of India, removal of coral and shells from the coasts to produce lime and cement is common, because of their high chemical purity. The use of coral as an aggregate or building stone is also common in parts of India and is a particular problem in the Maldives.

Logging practices can also cause damage to water resources. Heavy logging can cause increased erosion; increased sediment loads then affect habitats for plant and river organisms downstream. Debris from logging and saw milling can also increase the input into streams of organic material, whose decomposition reduces the amount of oxygen in river water, jeopardizing the life of fishes.

Industry and mining are the principal sources of freshwater pollution by the heavy metal and synthetic organic chemical industries. Galvanizing and plating, and manufacture of paints and plastics, are among the construction-related sources of heavy metals.

Construction projects such as dams and irrigation schemes can jeopardize coastal waters by blocking migration of fish, reducing the supply of nutrients to estuaries, and altering salinity. All these can have serious, often unforeseen, consequences for coastal fisheries.

Deforestation

Forests are an important natural resource-base, which play a crucial role in the conservation of watersheds, prevention of soil erosion and balancing the eco-system. Forests are sources of domestic energy supply, such as wood for cooking and heating, and of fuel for brick and lime production in rural areas. Timber is not only a crucial building material but is also vital to the economies of many developing countries. Timber-producing countries earn foreign exchange by exporting timber. Therefore, any loss of forests, for any reason, may provoke potential human, economic and environmental disasters.

Inefficient commercial logging operations and the use of wood as fuel have resulted in deforestation in many regions. There is also increasing concern about the destruction of the tropical forest and the adverse impact of this on the environment. Managing the forests in a sustainable manner, so as to minimize the rate of deforestation, is therefore imperative and should be given highest priority.

The Second Consultation on the Wood and Wood Products Industry, organized by UNCHS (Habitat) and UNIDO in 1991, underscored the importance of greater utilization of wood on a sustainable basis, as a renewable source of indigenous building materials in housing construction. This includes 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, which can be afforded by the vast majority of the population.

CLAS and ITPS are slowly showing their potential as raw materials in industrially processed wood products for construction, especially for walling and roofing shingles. Timber species that are less suitable as sawn timber due, mainly, to their irregular form can be used as wood chips, pulps and woodwool (excelsior) in composite boards, and to manufacture wood-cement boards.

Box 3
Declining production of bamboo in Bangladesh

In Bangladesh, bamboo is the most important building material. It is the principal building material used for walls and roofs in about 60% of all dwellings. In 1981 there were about 1.8 million metric tons of mature bamboo culms in the village forests of Bangladesh, which was adequate for a continuous supply to meet an annual demand of about 0.8 million metric tons. With the growth of population, urbanization and the need to replace houses lost in flood disasters, demand had grown to 1.4 million metric tons in the early 1990s. This was coupled with an apparent decline in bamboo production as a result of which most parts of Bangladesh are already experiencing a shortage. The principal reason for the decline in production is pressure on land, leading to over harvesting and the use of immature culms, and to poor crop management.

Source: SKAT (1992), Building materials in Bangladesh.

Box 2
Deforestation and unsustainable forest management

The greatest concentrated forest deterioration is occurring in the large rain forests of Amazonia, West Africa and South-east Asia, which are currently being “mined” for extraction of selected high-value timber species by international concessionaires with little concern for sustainability. In Africa, the 43 million hectares of closed forest which is being logged (20% of the total closed forest) is disappearing at more than 1 million hectares per year. In Kalimantan, the Indonesian area with largest timber production, there is now estimated to be an economically harvestable area of only 12 million hectares, as compared with the previously believed 26 million, and in few years time this is expected to be down to 10 million hectares.

It has been estimated by the International Tropical Timber Organization that less than 0.2% of tropical moist forests are being managed sustainably for commercial production; and even this small extent of sustainability has recently been questioned. The World Bank estimates that in few years time, the 33 developing countries that are now net exporters of forest products will be reduced to fewer than 10, and the total developing country exports of industrial wood products are predicted to drop to about 1/3 of their current level.

In Africa, the woodlands outside the closed forests had an area of 486 million hectares in 1986, and were declining at 2.3 million hectares per year. This does not include the equally serious but difficult to measure progressive degradation of the woodlands through the thinning out of forest cover.

Sources:
P. Harrison (1987), The greening of Africa. London: IIED.
D. Pearce et al. (1990), Sustainable development. London: Earthscan.

Consumption of non-renewable resources in construction

Non-renewable resources used in construction include fossil fuels, metals and minerals such as stone and clay. Supplies of some of these resources might last only a few more decades as shown below. Although more pockets of these resources are discovered, and new technology might extract more than is possible today, the rate at which the reserves of oil, natural gas and some metals are decreasing means consumption must be controlled. Other, preferably renewable, resources must replace these traditional materials. Some renewable resources are also threatened, such as the forests mentioned above, and may eventually disappear if they are not exploited in a sustainable way. Pollution of air, soil and water resources is also a threat to many renewable resources.

Resource consumption is increasing steadily in both developing and industrialized countries. It is already very high in industrialized countries, which consume by far the largest part of the world’s existing resources. Thus, if the world is not going to run out of non-renewable resources in the near future, more efficient use of these assets and greater use of renewable resources will be necessary.

Use of metallic minerals
The construction industry is a major consumer of metals such as iron, aluminium, zinc, copper, etc. According to geological studies, the existing exploitable reserves of met-

als are very different. Aluminium (bauxite) and iron have a life index[3] of about 200 years, whereas copper, lead and zinc have a life index of between 20 to 30 years at the current rate of extraction (WRI 1994). The world's economically exploitable resources of some metals commonly used in construction are shown in Table 1, together with production patterns and life indices. (Note the figures show the total production, including those related to construction.)

It follows that serious consideration should be given to replacing these metals in construction, to extend the life of existing reserves. For example, copper for cables is being replaced, to some extent, by other materials. However, zinc, which is used for galvanizing steel products such as roofing sheets, is still used extensively.

Table 1
Annual production, reserves and life index of some metals

Metal	Production/year (million metric tons)	Reserves (million metric tons)	Life index (years)
Bauxite/ aluminium	104	23,000	222
Copper	9.3	310	33
Iron ore	930	150,000	161
Lead	3.4	63	18
Nickel	0.9	47	51
Zinc	7.1	140	20

(Source: WRI 1994).

Use of fossil fuels
Construction sector activities in general and the manufacturing processes of basic building materials such as cement, steel, aluminium, glass, bricks and lime require large amounts of fossil fuels. The reserves of oil (petroleum) and natural gas are shrinking; in 1991 they had a life index of about 40 and 60 years respectively (WRI 1994). It should be noted that the life index of plastic and bitumen products is consequently also only 40 years, since these materials are based on oil products. Coal reserves are expected to last about 300–400 years at current production.

Industrialized countries consume high amounts of fossil fuel per capita (Figure 1). Since the energy crisis in the 1970s, the per capita, as well as the total, consumption has been fairly constant. The major increase during the last decades was in developing countries, although most of this is due to population growth. Nonetheless, the consumption per capita is rising as a result of industrialisation, urbanization and improved economy. In 2010 developing countries are expected to account for 40% of the world's energy consumption (WRI 1998).

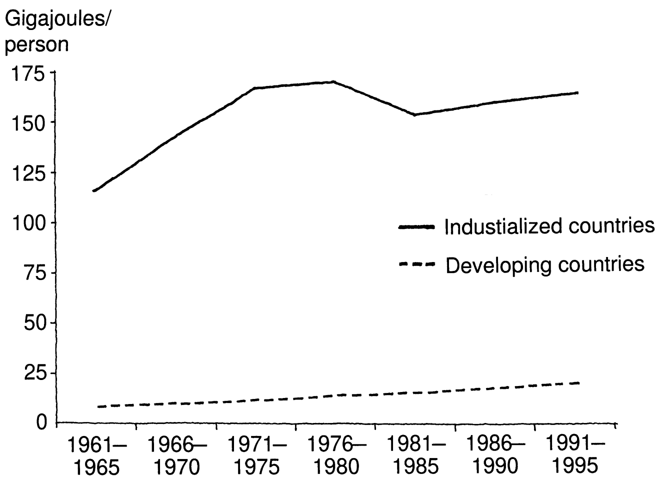

Figure 1 Fossil fuel consumption per person.
(Source: WRI 1994).

Use of energy in construction

The construction sector is a major user of energy. Energy is required for manufacturing materials, for transport and for construction of buildings. Apart from this initial energy use there is also need for energy to operate buildings.

Since energy is one of the most costly inputs to the construction industry and the source of most of their polluting effects, improving energy efficiency is one of the most urgent tasks to be addressed. This will call for efficient use of energy-intensive materials, greater use of low energy-content materials, improving the energy efficiency of production processes, increasing the use of recycled and waste materials and applying low-energy architectural design principles.

Embodied energy in buildings
The embodied energy in buildings and civil engineering facilities is defined as the total energy used at all stages of the production of these physical assets. These stages start with the extraction of raw materials, production of building materials and components, transportation, on-site construction and completion of the buildings.

Most of the embodied energy in buildings is related to the production of materials, while construction activities and transport account for a smaller proportion. If medium and high-energy materials such as ceramics, concrete, and steel are used, typically 70% or more of the embodied energy comes from the manufacturing processes of these materials.

On the basis of the gross energy requirement for manufacturing a unit weight of building materials, these can be classified in three categories: low, medium and high energy content materials. Table 2 shows a classification of major building materials used in construction in terms of energy requirement for their production.

High and medium energy-content materials require kiln processes for production, which often depend on fossil fuels. Note that there might be a considerable difference in energy requirement for the same material. The lower values in Table 2 correspond to more energy-efficient production. During the last decades, efficiency has improved considerably, especially in developed countries, resulting in even lower figures than the minimum values shown in the table. For some materials, such as metal and glass, recycling can further decrease the energy requirement. See Figure 2.

Table 2 shows that the amount of energy used to produce a unit weight of a high energy-content material can be more than 100 times that needed for low energy-content materials. However, the comparison of energy requirement per kg of material has limited interest, as the densities of

3 The life index tells the number of years a resource will last if the current rate of production remains.

building materials vary greatly and as they are used in completely different ways. It is far more interesting to compare different types of building elements – such as roofs, walls, etc. – with similar performance. Tables 6–8 in Chapter 3 compare the energy requirements for different roof and wall assemblies. Similarly, different types of construction systems can result in considerable differences in the total embodied energy requirements in a complete house system. Table 3 shows a comparison of three houses using different materials.

Table 2 Comparative energy-requirements of building materials and binders

Material	Primary energy requirement (MJ/kg)
High energy	
Aluminium	130–270
Polystyrene	100–140
Copper	≥100
Stainless steel	≥100
Galvanized steel	≥60
Polyvinyl chloride (PVC)	50–90
Zinc	35–70
Steel	20–60
Lead	≥25
Mineral wool	16–20
Glass	12–25
Medium energy	
Cement	4–8
Lime	3–10
Autoclaved aerated concrete	3–5
Woodwool slabs	3–5
Ceramics, bricks and tiles	1.5–8
Gypsum plaster	1–4
Concrete, blocks and tiles	0.9–1.6
Sand-lime bricks	0.7–1.2
Concrete-in-situ	0.6–2
Lime/cement mortar	0.5–1
Cement-stabilized earth blocks	0.3–0.8
Timber	0.1–5
Low energy	
Natural stone, sand, aggregate, soil	≤0.3

(Sources: UNCHS 1991a, b).

Table 3 Comparative energy requirements for three single-storey houses in Argentina

House type	Embodied energy (MJ/m²)
House made primarily with manufactured materials (hollow brick walls, concrete frame and roof)	1580
House made partly with manufactured materials (clay brick walls, concrete frame, steel sheet roof)	1310
House built primarily with local materials (adobe walls, timber frame, steel sheet roof)	590

(Source: UNCHS 1991b).

Operational energy in buildings

A considerable amount of energy is used in buildings during their lifetime. This energy is required for heating, cooling, ventilation, lighting, cooking and other domestic activities. The energy-use patterns inside buildings vary a great deal according to occupants' behaviour, type of structure and location of buildings. In residential buildings, urban and rural patterns tend to be very different. Household income and climate have major influences both on the type of energy sources and end-use patterns.

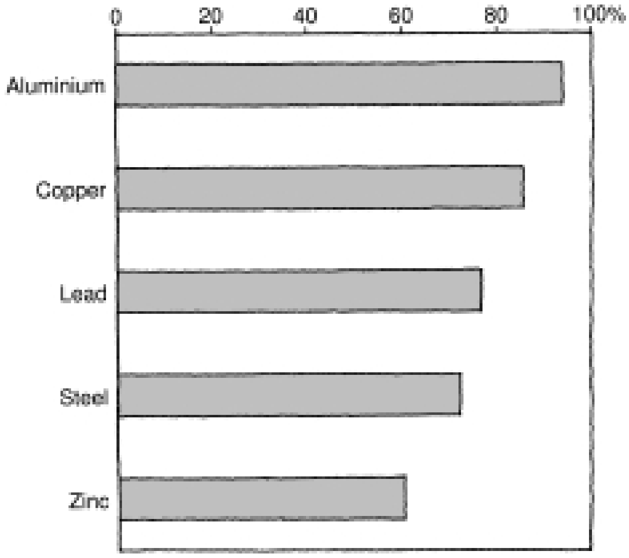

Figure 2 Possible energy savings of recycled metals. *(From UNCHS 1991a).*

Although there is little information on how households in developing countries use energy, the use of operational energy in buildings is increasing steadily, and in some countries rapidly. Many households, which previously endured a poor indoor climate, are going to install equipment for active climatization as soon as they can afford it. This trend is especially obvious in urban households, which tend to have a better economy and a modern life style.

Architects and engineers have a crucial role to play in designing buildings to minimize energy use for active climatization and lighting. A good approach is to take advantage of natural means such as solar radiation and winds and use the building as a collector, storage and transfer mechanism. These so-called passive techniques might be so efficient that in some regions no energy will be needed for heating or cooling. The knowledge of passive techniques is well developed, but is unfortunately not yet effectively practised in many countries.

Many existing buildings were never designed for active climatization through heating or air conditioning. The energy performance of such buildings can be improved significantly by increasing air tightness through sealing of windows and doors, and by adding thermal insulation materials to the building envelope. The additional cost of such measures is normally paid back in a few years.

Seen over a building's lifetime, the ratio between embodied and operational energy will vary considerably, depending on factors such as type of construction, climate and user behaviour. For example, if a building is constructed with medium and high-energy materials and no heating or cooling is used, the portion of embodied energy will be very high. But if a building has high annual use of energy for heating and/or cooling, the portion of operational energy will be very high, especially if the building is badly adapted to the climate.

Construction and air pollution

The construction industry is a major polluter of the atmosphere. Air pollution occurs at different levels:

- Local level: emissions of dust, fibres, particles and toxic gases.
- Regional level: emissions of sulphur and nitrogen oxides
- Global level: emissions of greenhouse gases and ozone-depleting substances.

Local level

At local level – mainly close to a factory or a construction site – the most serious air pollutant is particulate matter – soot, dust and fibres. Larger particles will settle out close to the emission source, whereas smaller particles – so-called suspended particulate matter (SPM) – can stay in the air for days and may be moved further away. The primary source of particulate matter is the burning of fossil fuels, but building material industries are other sources. Woodworking industries and cement and lime production are all potential generators of dust and fibres unless abatement methods are used. Construction site activities and transportation also add to emissions of particulates.

Toxic gases such as carbon monoxide and hydrocarbons result from incomplete combustion of fossil fuels. All combustion processes emit these gases, but the main concern is from motor vehicles where incomplete combustion is common.

Burning coal and oil results in emissions of sulphur dioxide (SO_2) and nitrogen dioxide (NO_2), which are irritants to humans. Building material production is a major source of these gases, but heating buildings with coal or oil is also a great source. In low-income settlements where there is a substantial annual heating requirement, coal and firewood stoves are often used to heat indoor spaces and domestic water, and the combustion products add considerably to indoor and ambient air pollution.

International standards define acceptable levels of SPM and sulphur dioxide, but these are already exceeded in many cities. More than 500 million urban dwellers are exposed to unacceptable levels of SPM and some 730 million are exposed to unacceptable levels of sulphur dioxide[4].

Regional level

Air pollution can spread within a larger region in certain atmospheric circumstances. The most common regional effect is acid rain from emissions of SO_2 and nitrogen oxides. These gases can travel long distances from the source, even across country borders, before being brought back to the ground with rain. Acidification harms forests, agriculture and lakes.

Global level

Although not toxic, carbon dioxide (CO_2) is the major greenhouse gas and thus contributes to global warming. The global contribution of CO_2 from construction and building materials production is believed to be 10–20% including 2–3% from cement and lime production. World CO_2 emissions from fossil fuel combustion and cement manufacture increased nearly four-fold from 6,000 metric tons per year in 1950, to more than 22,000 metric tons in the early 1990s (UNCHS 1993a).

A further contribution to global emissions of CO_2 is the operational energy in buildings heated with fossil fuels, especially if insulation is poor. District heating is often poorly controlled and hence inefficient; for example in China about 90 million metric tons of coal is burned per year for urban heating[5].

Table 4 shows the annual CO_2 emissions from fossil fuel consumption in four countries.

Table 4 Carbon dioxide (CO_2) emissions and the estimated contribution of construction, cement manufacture and operation of buildings

Country	*Total CO_2 production (1,000 metric tons)*	*Construction industry (%)*	*Cement manufacture (%)*	*Operation of buildings (%)*
Argentina	118,000	7.6	1.9	39
Germany	641,000	11.8	2.1	51
India	652,000	17.5	3.2	18
Kenya	5,000	11.9	11.7	25

(Source: UNCHS 1993a).

The amount of CO_2 emission depends on the type of fuel, shown in Table 5. It should be noted that trees and other plants absorb carbon dioxide during growth, so if trees are continuously replanted, this will compensate for the emissions from burning wood.

Table 5 Approximate carbon dioxide (CO_2) emissions per gigajoule (GJ) for selected fuels (including overheads for generation and distribution).

Fuel	*CO_2 emissions (kg/GJ)*
Electricity from coal	230
Gas from coal	130
Coal	90
Oil	85
Fuel wood	80
Natural gas	55

(Source: UNCHS 1991b).

At global level there is particular concern for chlorofluorocarbons (CFCs), used in refrigerators, air-conditioning units, foamed plastics and fire-extinguishing systems, and that destroy the earth's ozone layer. An international plan to replace CFCs, which also act as greenhouse gases, by other products started in 1987 (Box 4), and since then consumption has diminished by more than 70% (WRI 1998).

Since air pollution affects the environment regionally and globally, worldwide reduction of emissions calls for global action. Some examples of such work are shown in Box 4.

4 Inter-governmental Panel on Climate Change (1990): *Climate Change*. Cambridge University Press.

5 Tu Fenxiang (1992), *Energy use in buildings in China*, Chinese Building Research Institute.

Box 4
International action to reduce greenhouse gases and ozone-depleting emissions

Following a number of international interventions, serious actions are being taken by many nations to reduce the greenhouse gas and ozone-depleting emissions. However, even with the current declining emissions, greenhouse gases continue to accumulate.

The Montreal Protocol, ratified by 170 countries in 1987, provides guidance and procedures to eliminate the use of ozone-depleting substances such as CFCs. During the last decade over US$ 1 billion has been allocated for industrial projects in developing countries to assist them to meet their obligations under the protocol. For example, the UN Industrial Development Organization (UNIDO) is rendering its assistance in close to 600 projects in the relevant industrial sectors.

The most recent international intervention was the Kyoto Protocol in 1997, which represents a vital step forward in nations' efforts to address global warming. The Protocol sets out binding limits on the total greenhouse gas emissions of industrialized countries and establishes an emission reduction target of 5.2% below the 1990 emission levels.

Life cycle approach

The analysis of the impact of the construction industry on the environment is very complex. To assess how different materials and operations influence the environment over a longer period of time, it is worth considering a life cycle approach to materials and buildings.

Life cycle assessment of products

To compare the environmental impact of different materials, life cycle studies of building materials have become very popular, mainly in the developed countries. The goal is to help designers and users chose environmentally friendly materials. The approach, often called life cycle assessment or life cycle analysis (LCA), considers the entire lifetime of the products and their impact on the environment during that time. This includes the following phases: extraction and transport of raw materials, production, use, demolition and waste treatment.

The environmental impact of the products is evaluated within each phase. The environmental parameters that are considered normally include:

- Resource depletion: energy, materials, water, etc.
- Human health: consequences of toxic emissions, impact on work environment, etc.
- Global and regional pollution: global warming, depletion of the ozone layer, acidification, etc.
- Impact on animals and vegetation: biological diversity, etc.

To evaluate a product, its different environmental impacts are scored, and the sum from all phases is added. One difficulty with LCAs is how to weigh different environmental impacts against each other. Existing LCA methods all have different points systems and a comparison between materials often turns out differently depending on the method. Most methods have been developed nationally, and tend to focus on local circumstances and national political decisions.

Another problem with life cycle assessments is that no method considers the complete life cycle, which, of course, is linked to the complex nature of the task. It is also not always possible to obtain the necessary data, as they are often confidential.

Products achieving good ratings in life cycle assessments are based on renewable raw materials, are produced with methods using low amounts of energy and having low pollution, are sound and non-hazardous for the users, etc. If there is a possibility to reuse or recycle the product when a building is demolished, or if the product can be used as fuel, this is considered positive and reduces the total environmental impact considerably.

Many industrial countries have developed so-called eco-labelling schemes to promote production of environmentally friendly products. Products that meet the requirements get the eco-label, which works as a "guarantee" to consumers that the particular product is environmentally sound. Given the increasing awareness among consumers of the importance of protecting the environment, eco-labels have become important tools to market products.

Apart from being used to compare building materials, life cycle assessments have long been used by material producers to improve their products. LCAs are performed to compare alternative production processes, to look into the possibilities of reducing inputs such as raw materials and energy, and to identify and reduce the wastes and polluting effects. In many cases LCA is an excellent tool for material producers to make their products more environmentally friendly.

Life cycle studies of entire buildings

A limitation with product life cycle assessments is that they normally concentrate on the product itself, and do not include its influence on the energy use in the building during operation. Many thermal insulation materials, which are resource-consuming and would not be considered good options in most product life cycle assessments, may reduce energy use in buildings considerably.

Useful approaches when studying energy use in entire buildings are life-cycle cost or life-cycle energy analyses. Since energy-use is largely linked to environmental impact, the life cycle energy use of buildings, taking into account both the embodied energy in the building and its operational energy requirement, can be considered a measure of a building's environmental friendliness.

In a few countries eco-labelling systems for whole buildings exist. In the United Kingdom, the Building Research Establishment developed an "Environmental Standard" to issue a certificate if a building fulfils the requirements of the scheme (Atkinson et al. 1996).

3 Recommendations

In this chapter, recommendations are given on how to reduce the environmental impact of construction activities. The recommendations aim mainly at improving energy efficiency, but measures are suggested to reduce atmospheric pollution, increase the use of renewable resources and arresting depletion of land and water resources.

Several recommendations in this section are interlinked and may achieve more than one environmental benefit simultaneously. For example, using recycled and waste materials will often reduce both utilization of primary materials and embodied energy.

The recommendations are aimed mainly at the following target groups:

- Designers,
- Builders,
- Small-scale building material producers.

The recommendations are directed towards actors within the formal sector, which is the main consumer of natural resources. It is hoped that improvements in the formal sector will influence and be beneficial to the informal sector.

Designers

Designers have a crucial role in specifying the materials to be used and the technical performance standards required for the operation of buildings. In their key position they have also the possibility to influence clients. Therefore, it is important to increase knowledge in energy efficiency and environmentally sound construction among architects and engineers.

The environmental impact of the construction sector is manifold and complex. For designers it is important to have a holistic approach and not to focus on an isolated issue. To consider only the initial embodied energy in buildings might be wrong, since the operation of buildings sometimes is much more energy consuming over a building's lifetime. A life-cycle approach is therefore recommended.

Below are recommendations aimed at designers such as architects and engineers.

Selection of building materials

Materials, systems and designs that require less non-renewable resources and that have low embodied energy are preferable. Similarly, locally available building materials should be specified in order to reduce transportation.

In some cases, however, trade-offs are required. A low-energy material might be less appropriate if it implies high-energy use during the building's lifetime, e.g. if the material has low durability and has to be replaced often, or if it causes high operational energy. Timber is one of the structural materials with the lowest energy content, so using timber will reduce embodied energy. On the other hand, it may increase deforestation. Similarly, a material found far away might sometimes be more energy-efficient and more environmentally friendly than a local one, if its production is more efficient. The appropriate strategy will therefore depend on local and regional circumstances and priorities and on economic factors.

Roofing materials

The embodied energy of some common pitched and flat roof types are shown in Tables 6 and 7.

Table 6 Comparative energy requirements of some common roofing materials for pitched roofs. The calculations are based on average values from Table 2. (Tiles require more wood in the roof structure than sheets, but the energy requirement for the wood structure is of no significance compared to the roofing materials.)

Roofing material	Weight (kg/m^2)	Energy requirement (MJ/kg)	Energy requirement (MJ/m^2)
Corrugated aluminium sheets, 0.8 mm	3.1	190	580
Corrugated galvanized steel sheets, 0.4 mm	4.4	60	270
Ceramic roofing tiles, 12 mm	35	4	140
Concrete roofing tiles, 12 mm	45	1.3	60
Micro concrete roofing tiles, 8 mm	30	1.3	40

Galvanized steel sheet, the most common roofing material in developing countries, requires a very high amount of energy to be produced, see Table 6. Furthermore, the world's resources of zinc, which is used for galvanization, are very limited (Table 1). The material has poor thermal and acoustic properties. Alternative materials should be used if possible.

Asbestos cement sheet is a medium-energy material with good durability, but since its production is hazardous for health, its use is not encouraged. Similar products where the asbestos fibres have been replaced by non-hazardous fibres are good options.

Thatched roofs require virtually no energy and have no negative impacts on the environment. This option however requires skilled labour and regular maintenance. Thatched roofs are not recommended in areas where termites or other insects attack the roofs, or in urban areas because of the fire hazard.

It is recommended to use materials such as concrete tiles, micro-concrete roofing (MCR) tiles and burnt clay tiles. These are all very durable materials. Concrete and MCR tiles require little energy and can be produced on a small scale, which reduces transportation. Clay tiles are only recommended if the production is energy-efficient and does not lead to deforestation. Since roofing tiles are small they require more wood in the roof structure, which is a disadvantage compared to sheets.

Aluminium sheet is a high-energy material. The durability is, however, much better than for galvanized steel sheets, and it has better thermal properties because of its low emissivity. In warm climates where there is strong solar radiation it might be an option, especially if produced with recycled material.

Although steel is a high-energy material, roof structures of steel can be energy-efficient since the amount of material needed is small. Where timber is scarce it might be an option, especially if produced with recycled material.

A flat roof consisting of a reinforced concrete slab has a high energy requirement, see Table 7. Instead it is recommended to use a T-structure of reinforced concrete combined with hollow blocks of either burnt clay or concrete. This will improve the thermal insulation of the roof as well. For further improvements of the thermal insulation, the hollow blocks can be replaced with woodwool slabs or polystyrene blocks, see Figure 3.

Table 7
Comparative energy requirements of some flat roofs. The calculations are based on average values from Table 2. Note that neither waterproofing nor ceiling plastering is included.

Roof assembly	Weight (kg/m²)	Energy requirement (MJ/kg)	(MJ/m²)
Reinforced concrete slab, 180 mm			
180 mm concrete	420	1.3	550
Steel reinforcement (0.5% by vol.)	7	40	280
Total	427		830
Concrete slab with fillers, 180 mm			
Concrete, 40% by vol.	170	1.3	220
Steel reinforcement (0.5% by vol.)	7	40	280
Concrete hollow blocks, 60%	110	1.3	140
Total	287		640
Elements of autoclaved aerated concrete (AAC), 150 mm			
150 mm AAC elements	90	4	360
Steel reinforcements (0.2%)	2	60	120
Total	92		480
Timber roof, boarding on joists, 200 mm			
25 mm timber boarding	150	3	450
175 × 50 mm timber joists	5	3	15
Total	155		465
Earth on branches and round timber joists, 350 mm			
250 mm compacted earth	450	0.1	45
Branches, leaves, etc		0	0
Round timber joists	5	0.5	2
Total	455		47

Flat roofs with load-bearing elements of aerated concrete are a good option, especially when thermal insulation is required.

Flat roofs using a timber structure, or a combination of timber and earth, are a low-energy solution. These types of roofs should not be chosen if there is a shortage of suitable timber or if there is risk of termite attack. Earth roofs require regular maintenance.

In areas where timber is scarce, vaults and domes can be an alternative to flat and pitched roofs. The energy requirement will depend on the masonry unit used. For example, a semi-circular vault of burnt clay bricks requires around 1,000 MJ per m^2 covered surface, whereas the same vault with cement-stabilised earth bricks would require about 200 MJ/m^2 (the same values for energy requirement per kg as in Table 8 have been used). The construction of vaults and domes requires skilled labour, and in areas where these roofs do not exist traditionally, their introduction will require training programmes. See also *Building issues* 2/97.

Walling materials

The embodied energy of some common wall types is shown in Table 8.

A very common wall type around the world is a column and beam structure of reinforced concrete with infill of burnt clay or concrete hollow blocks. This is unnecessarily strong in many cases, except for high-rise buildings or where earthquake-resistant structures are required. In low-rise construction the concrete skeleton can be omitted and load-bearing building bricks or blocks can be used.

Walls made of adobe (sun-dried earth blocks) or rammed earth (pisé) require almost no energy. Since the construction process is manual, the only energy requirement is related to transportation of materials. If buildings are correctly designed, protecting the walls from rain, and if the rendering of the walls is regularly maintained, earth walls can last very long. A problem is that earth as a material often has a low status. Therefore, earth walls are mainly recommended in regions where they are traditionally used and likely to be accepted.

Compressed earth blocks, stabilized with cement or lime, are another low-energy option. They can be recommended where suitable soils and cheap labour are available. It should be noted though that the embodied energy in a cement-stabilized earth block wall is only slightly lower than for a concrete hollow block wall, see Table 8.

Where thermally insulated walls are needed, it is recommended to use lightweight concrete – either as blockwork of aerated concrete or in-situ cast foamed concrete – or in-

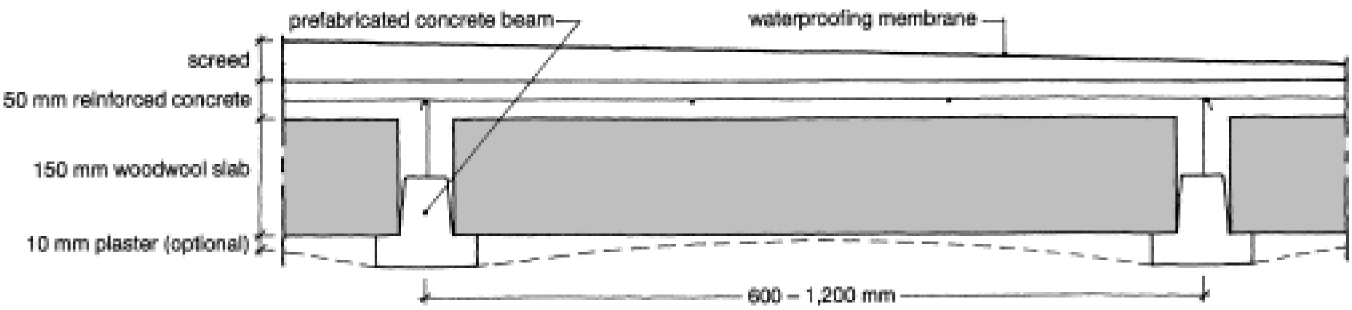

Figure 3 Flat concrete roof with fillers of woodwool slab.

sulating wall panels of woodwool slab or aerated concrete. These options are more energy efficient than cavity walls. Adobe walls also have fairly good thermal insulation.

Table 8
Comparative energy requirements of some common walls. The calculations are based on average values from Table 2. Plastering is not included. A lime/cement plaster applied internally and externally would add another 40 MJ/m².

Wall assembly	Weight (kg/m²)	Energy requirement (MJ/kg)	(MJ/m²)
Solid clay brickwork, 150 mm			
120 mm solid clay brick	150	4	600
Lime/cement mortar	50	0.7	35
Total	200		635
Hollow clay brickwork, 180 mm			
120 mm hollow clay bricks	110	4	440
Lime/cement mortar	50	0.7	35
Total	160		475
Hollow concrete blockwork, 180 mm			
150 mm hollow concrete blocks	120	1.3	160
Lime/cement mortar	50	0.7	35
Total	170		195
Brickwork of cement stabilized earth bricks, 180 mm			
150 mm compressed earth brick	220	0.5	110
Lime/cement mortar	50	0.7	35
Total	270		145
Adobe blockwork, plastered on both sides, 450 mm			
400 mm adobe plus earth mortar	480	0.1	50

Design for recycling

Reuse and recycling of building materials and wastes can drastically reduce the embodied energy in buildings. Furthermore, recycling has proved to be effective as a principle of material and energy conservation and employment generation in most developing countries.

Architects and engineers should design buildings to enable recycling of materials when a building is to be demolished. Structures with joints that are easy to disassemble are preferable. Choosing weaker mortars such as lime or lime/cement mortars, which are strong enough for most applications, greatly increase the possibilities to recycle building bricks and tiles.

Construction of new buildings is often preceded by demolition of old buildings on the construction site. The possibility of reusing building materials from the existing buildings should be carefully studied.

Low-energy building design

Buildings should be passively adapted to the climate as much as possible; that is, the building should provide a reasonable indoor climate with little or no energy input. The best use should be made of the thermal properties of materials. The placement and orientation of buildings is crucial to make best use of solar energy and other natural characteristics, such as topography and trees, to control wind and shade.

Solar heat gains are generally the main problem in hot regions. Shading of windows from direct sun is essential, especially on the east and west façades. Protection from diffuse solar radiation and reflected sunlight is also important. Solar loads conducted through walls and the roof can be largely avoided by using light colours on the exterior and by thermal insulation. Shading by vegetation is particularly effective because both the building and the surrounding ground are shaded.

In temperate or cold climates, the building design should allow passive heating from solar radiation during the cold season. To limit heat losses the building envelope should have sufficient thermal insulation and windows and doors should be sealed.

Passive climatization of buildings is thoroughly treated in *Building issues* 1/2000 and in UNCHS (1996a).

Energy conscious design is extremely important in actively cooled and/or heated buildings. The main difference from the passive design techniques mentioned above is that it is even more important to decrease heat losses and gains through the building envelope, and hence air-tightness and thermal insulation is more important. The use of thermal insulation materials in buildings will normally increase the embodied energy, but will help reduce the operational energy demand, and is likely to reduce the building's life cycle energy use.

Design of air-conditioned buildings in warm-humid climates is treated in *Building issues* 1/93.

Windowpanes are not only a high-energy material, they are often a weak point from an operational energy perspective. In warm climates unwanted solar radiation penetrates through windows, and in cold climates energy escapes through windows. In hot climates, heat reflecting glass should be considered if shading devices cannot be used. In cold climates double-glazing or coated windowpanes with low-emissivity may be beneficial.

To reduce the energy required for lighting, buildings should be designed for adequate daylight, although improved daylighting can increase energy demand for cooling and/or heating.

Existing buildings may use a considerable amount of energy if they are badly designed. Improved sealing of windows and doors, installation of shading devices and additional thermal insulation can prevent unwanted heat gain or loss. In hot-humid climates installing louvers can improve the ventilation.

Heating domestic water requires a considerable amount of energy, and where the climate is suitable it is recommended to install solar collectors. In temperate and cold climates with sunny winters, solar collectors can even contribute to the heating of buildings during the cold season. Designers should also encourage clients to choose low-energy household appliances.

Builders

Since there is a clear link between costs and energy use, it should be in the interest of all construction companies to improve energy efficiency. An energy-saving approach will also help reduce air pollution from site operations.

Below are recommendations for builders on how to increase energy-efficiency and reduce pollution on the construction site.

Site management
Considerable energy savings can be achieved by increasing efficiency on the construction site. Project planning is important to avoid double handling and rework, for example. Adequate project planning includes scheduling of activities, effective communication among all parties involved, and training of the personnel in efficiency and energy consciousness.

A large part of the energy consumption on construction sites comes from site deliveries and on-site handling of materials. Selecting materials available nearby could reduce transport to the site, and good planning of the site layout would reduce transport on site. Improper delivery, such as materials not arriving in time, or too much material on the site, leads to inefficiency. Therefore scheduling of deliveries is important. To minimize waste of materials on the site, there should be appropriate storage facilities. Waste products from the site should be kept in a separate place to facilitate reuse and recycling.

Considerable amounts of energy can be saved through efficient use of machinery and labour. Newer machines are generally more energy efficient. Maintenance of machines is not only important from an economic point of view, but it will also help improving energy efficiency. If labour is cheap, replacing machines by workers can save energy and raise employment. However, some operations should be done by machine; for example, even a simple mixer will improve the quality of concrete.

Recycling
Construction work often starts with demolishing existing buildings. Many materials can be reused, e.g. roof tiles, roof sheets, windows, doors and building bricks and blocks. To some extent materials such as timber, building boards, metal beams, floor and wall tiles can also be reused, or be recycled into new products. Metallic materials such as tubes and electrical cables are suitable for recycling. Waste from bricks, blocks and tiles can be recycled into concrete with low quality requirements.

Concrete production
Concrete production on the site is often characterized by large variation in quality due to either under or over consumption of cement and also poor batching, mixing and curing conditions. To optimize the use of cement in concrete it is necessary to improve production control. The following measures are recommended:

- Use high quality aggregate with a suitable gradation curve. Test the aggregate regularly, especially if it is taken from different sources and bought from different suppliers.
- Batch by weight (batching by volume is less exact and can give large strength variations).
- Use mechanical mixing.
- Careful monitoring of the amount of mixing water (too much water gives a weaker product with greater risk of cracks). The moisture in the aggregate has to be measured and compensated for.
- Keep newly cast concrete damp, especially during the first days, and never expose it to direct solar radiation.
- Do regular checks of the concrete strength on test specimens to verify the recipe used.

Water reducing agents can further reduce the amount of cement. These products are normally expensive, but the quantity needed is small and the amount of cement in the mix can be reduced 10–20%.

If available, it is recommended to use pozzolanic materials such as fly ash and rice husk ash to further reduce the cement content. See Table 11. However, before use test mixes have to be made to check that the quality of the concrete remains acceptable.

The most efficient way to save cement is to use ready-mix concrete. In ready-mix plants quality control is much higher than on construction sites, which strongly increases the possibilities to save cement.

Further recommendations on how to reduce the amount of cement in concrete as well as a thorough description of how to measure concrete quality based on statistics are given in *Building issues* 2/94.

Mineral construction wastes, such as crushed concrete products or bricks, etc, can be used as aggregate in concrete where there are low requirements on quality and strength.

Large amounts of concrete can be saved by simply being more careful in levelling the ground and installing formwork before casting.

Mortars for masonry and plastering
In many developing countries there is a tendency to use pure cement mortars. These mortars not only consume a lot of cement, they are also unnecessarily strong for most applications. As a rule of thumb, an appropriate mortar should be as strong as, or slightly weaker than, the masonry units or, in plastering, the previous coat. Mixing lime with Portland cement gives a better product. Lime/cement mortars are recommended over pure cement mortars since they:

- have less embodied energy,
- are more compatible with the masonry blocks, and
- have better workability.

If the surface will not be exposed to excessive wear, pure lime mortar can in many cases be used. Concerning aggregate, mixing and curing, the same recommendations that apply for concrete production (see above) apply for mortars.

The choice and application of mortars for masonry and rendering is thoroughly treated in *Building issues* 3/95.

Other cement-saving additives include natural pozzolanas such as volcanic ashes and industrial by-products such as fly ash and rice husk ash. See Table 11.

For internal plastering in rooms that are not exposed to high humidity, gypsum plaster mixed with sand, which is normally less energy consuming than lime mortar, should be considered.

To avoid wasting mortar it is important that masonry walls be as straight and vertical as possible. A leaning or uneven wall that has to be evened out with plaster will cause over-consumption.

Building material producers

The following recommendations are mainly for small and medium scale building material manufacturers. Large-scale production of metals, plastics and cement is not considered.

A key measure in improving building material production is to increase energy efficiency. A well managed, energy efficient production will reduce both production costs and the environmental impact of the production. Improving the production efficiency will often require initial investment costs. However, these extra costs are normally paid back very soon. In fact, the payback period is likely to decrease in the near future, since fuel and electricity prices are increasing rapidly.

Even if there are no strict regulations for air pollution, it is recommended to use the most environmentally friendly production technique possible, since the international trend is towards cleaner production and sharpened regulations concerning atmospheric pollution. Clean production will increase the possibilities to get loans for investment in new equipment. An environmentally friendly production may even be used in marketing the product. In industrialized countries the building material industry has reduced pollution considerably in recent years to comply with stricter pollution requirements and, not the least, the demand from consumers for ecologically friendly products.

These recommendations are on how to improve energy-efficiency and to reduce the environmental impact for some common building materials.

General recommendations

Land for quarrying should be chosen with care. Extraction of raw materials from ecologically sensitive areas should stop, and aggregate sources such as riverbeds and coastal areas should be changed if possible. Since such areas will surely be protected in the future it is better to look for other sources immediately, rather than be surprised by coming regulations.

Reduction of air pollution from fuel combustion can be achieved in different ways. First, choose good quality fuel. The fuel might have to be cleaned before combustion. Making the combustion process more efficient can reduce emissions, mainly carbon dioxide. Finally, emissions of toxic gases and particulate matter should be reduced as far as possible by installing filters and dust collectors.

Changing fuel can reduce emission of greenhouse gases. For example, a conversion from coal or oil to natural gas will lower production of carbon dioxide, see Table 8. However, in order to minimize the use of non-renewable fuels, it is recommended to use alternative fuels, such as agricultural wastes, where possible. The change from conventional to alternative fuels might cause a slight increase in energy requirement, but will be environmentally and economically beneficial.

A key measure to increase energy-efficiency and to reduce environmental impact in any building material industry is to improve the management. The following measures are recommended:

- Introduce monitoring systems and equipment
- Record the quantities of energy and materials used
- Conduct pollution-emission audits
- Train production personnel to increase awareness of the importance of energy savings
- Improve maintenance of the production equipment
- Reduce transportation distances by appropriate locating and scaling of production plants.

A good way to improve production efficiency is to perform a life cycle assessment of the product as discussed in Chapter 2.

Ceramics

As mentioned in Box 1, the production of ceramics such as bricks and tiles often contributes to the degradation of land. To reduce damage to arable land, it is important to restore the ground for agricultural after clay winning. This can be done by removing a thick layer of topsoil, say 200 mm, before winning the clay. If too thin a layer is removed, it will be unsuitable for planting. Immediately after clay winning, the bottom of the pit should be evened out and the topsoil replaced. The ground can then be used immediately for planting.

Table 9 Energy requirements in megajouls (MJ) per kg burnt material for different brick kilns.

Kiln type	*Fuel*	*Energy requirement (MJ/kg)*
Simple clamp kiln	Wood	3.5–8.0
Fixed wall clamp kiln	Wood, coal or agricultural wastes	2.3–6.5
Continuous	Coal or oil	1.0–2.5

(Sources: Barriga et al. 1992, UNCHS 1991a).

Most of the energy used in production of ceramics is required to fire the material in kilns – typically more than 95% of all energy used. There are considerable differences between the energy requirements for different types of kilns, depending on whether the firing is continuous or intermittent, on the size and heat-transfer efficiency of the kiln, and on whether the clay used contains combustible materials. Table 9 shows the energy needed to produce 1 kg of burnt clay bricks for different kiln types.

The main measures to make the firing process more energy-efficient are:

- Ensure that even, and not too high, temperatures are obtained throughout the kiln. Too high temperatures cause both higher energy demand, and also poorer quality.
- Recover heat by using flue gases from the combustion process to dry green bricks and by using waste heat from the cooling of newly burnt bricks to preheat the combustion air.
- Reduce heat losses through the sides and top surface of the kiln. This is mainly done by using properly sealed, airtight walls, and can be further improved by adding thermal insulation.

Intermittent kilns, such as the clamp kiln, not only use a lot of energy, they often have a negative impact on the environment since they normally use firewood, which is often a scarce resource. Therefore it is recommended, where possible and feasible, to convert intermittent kilns to continuous ones. The latter have the advantage that they recover a great part of the heat from the firing. Examples of continuous kilns are the Bull's trench kiln, the Hoffman kiln and the tunnel kiln. The Hoffman and, especially, the tunnel kilns are advanced kilns requiring huge investment costs. Bull's trench kilns are recommended as they have a fairly simple design. Where traditional trench kilns are used, it is recommended to improve the design to further save energy. Improvements include increasing chimney heights, adopting a fixed rather than the traditional moving chimney design, and careful levelling of the kiln floor. Up to 25% energy savings of can be achieved by these improvements.

Continuous kilns require considerably higher investment costs. Where clamp kilns are the only option, it is recommended to modify them to make them more energy efficient. Clamp kilns with fixed walls are recommended. The walls should be properly sealed and preferably thermally insulated. Uniform feeding of the fuel also contributes to energy savings. Where firewood is scarce it is important to adapt clamp kilns to alternative fuels.

Where firewood is used as fuel, large energy savings can be achieved by mixing layers of green bricks and firewood in the kiln. This mixing strongly improves the heat recovery. For permanent clamp kilns with mixed fuel and bricks, a kiln energy requirement below 2 MJ/kg is possible. The heat recovery also improves with increased height to surface area ratio of the kiln.

Addition of solid-fuel particles such as coal dust, sawdust, coffee or rice husks or, even, plastics such as polystyrene, to the clay can increase energy efficiency. This will change properties such as porosity and strength, which is not necessarily a disadvantage; for example, more porous bricks will be lighter and have better thermal insulation. Similarly, perforated and hollow bricks will save energy, typically 5–6% per 10% of hollowness.

A suggestion of an energy efficient kiln is shown in Figure 4. For more detailed information, see for example *Building issues* 2/90 and Barriga et al. (1992).

Box 5
Recycling of industrial wastes into building materials

In India, 8 million metric tons of fly ash are produced annually by the country's thermal power stations, a good proportion of which is dumped. The significance of this for the construction industry is that much of this waste has potential for being recycled in construction materials, which could simultaneously reduce the amount of land required for waste disposal, and reduce the need for quarrying.

Source: UNCHS (1993a).

Cementitious products

Cementitious products such as concrete blocks, roof and floor tiles and wood based building boards can be produced on small scale. Almost all the energy needed to produce these products is related to the cement production. Consequently, it is important to keep the amount of cement to a minimum. A more economical use of cement however requires improved production control and less quality variability of the products.

In general, the same measures as described in Concrete production on page 14 are recommended. In concrete product plants the following recommendations can be added:

- Cure products in closed rooms – curing chambers – where a humid environment is created by the evaporation during curing. If this is not possible, at least a shade protecting newly cast products from sunshine should be provided and the products preferably covered by plastic sheet.
- Establish a test laboratory for regular quality testing of the product. This can consist of sieve analysis equipment and a simple machine for strength tests.

A number of waste products can be recycled into concrete products to further reduce the embodied energy, see Table 11.

Lime

As for ceramics, almost all energy in lime production is used in the kiln process, where limestone is transformed to quicklime. The energy required varies considerably with the type of kiln, which can be batch, vertical shaft or rotary. The latter is unusual in developing countries since it requires large investment costs and is not treated here.

Table 10 illustrates how great the differences in energy required to produce quicklime can be for different types of kilns. Note that the energy required for hydrated (slaked) lime, used in construction, is 75–80% of that of quicklime. [6]

The improved or mechanized vertical shaft kiln is recommended. Since the burning process enables the use of waste heat to preheat the limestone, considerable savings in heat losses can be achieved compared to batch kilns. The heat recovery efficiency increases with increasing height to diameter ratio of the shaft, a ratio ≥6 is recommended. To further reduce heat losses the walls of the kiln should be thermally insulated.

Table 10
Energy requirements in megajouls (MJ) per kg to produce quicklime for some different kilns in India

Kiln type	*Production capacity (metric tons/day)*	*Energy requirement (MJ/kg)*
Traditional batch kiln	1–3	13
Conventional shaft kiln	10–20	9.0
Improved shaft kiln	10–20	6.2
Mechanized shaft kiln	20–100	4.8

(Source: UNCHS 1991b).

6 Slaked lime is produced by adding water to quicklime and this gives slaked lime about 30% higher density.

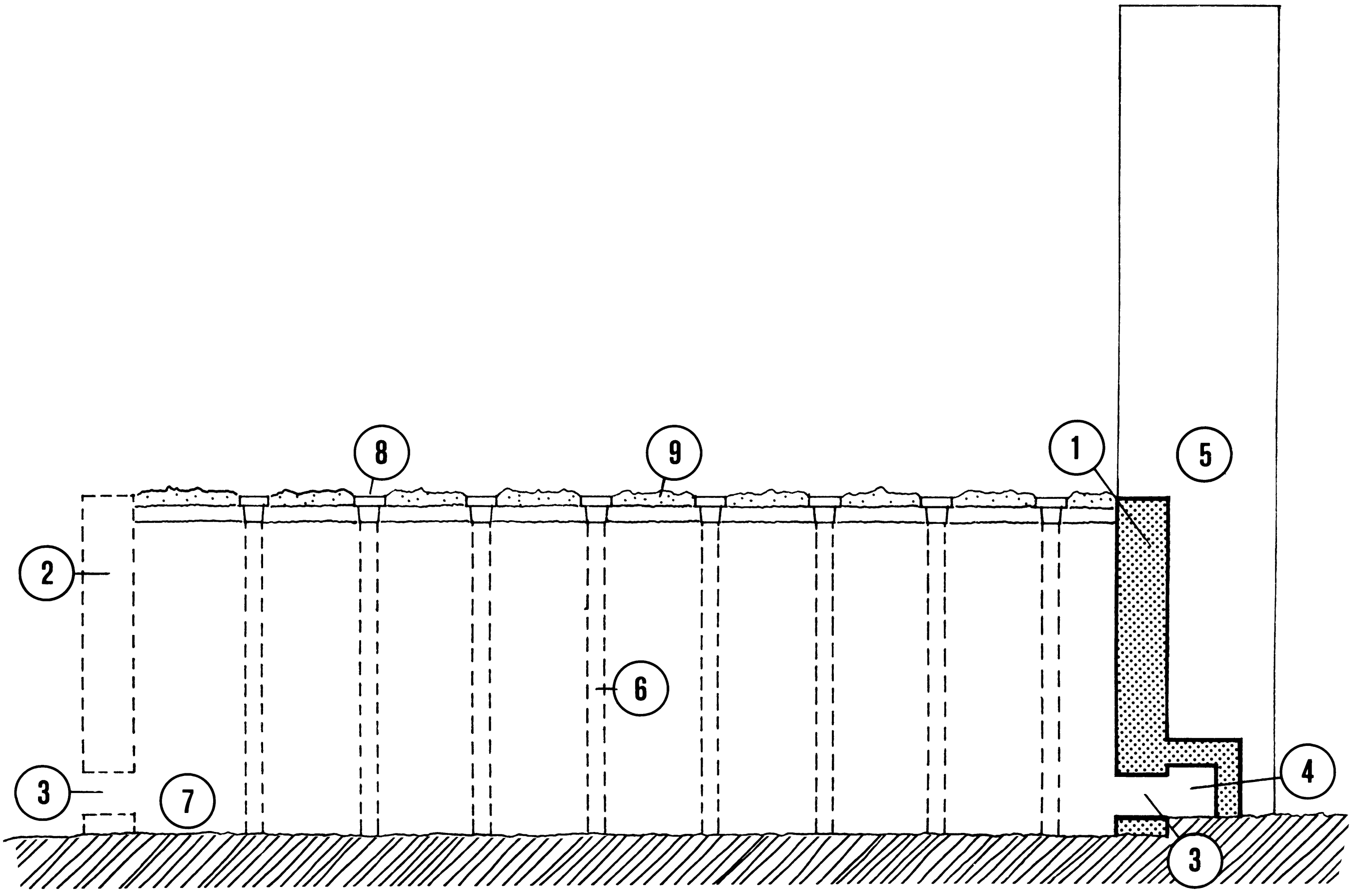

Figure 4
Example of an energy-efficient, top fired kiln. The kiln has three permanent walls and one temporary. Burning starts at the temporary wall and waste heat from that end is used to preheat green bricks in the rest of the kiln. Possible fuels include coal, sawdust, shells, briquettes and oil. (Peterson and Sandin 1990).

1 Hollow walls filled with insulation: for example, bricks + 200 mm special mineral fibre + bricks.
2 Temporary wall built of bricks and sand/clay. The teles can be moved in and out of the kiln when the wall is removed.
3 Opening, around 250 × 250 mm with cast iron damper.
4 Ventilation duct, around 400 × 400 mm leading to a chimney.
5 Chimney with internal dimensions around 250 × 250 mm, 7–10 m high.
6 Hole, around 300 × 300 mm, left in the mass of tiles during packing.
7 Fire place for about 1 m^3 of wood to start the firing.
8 Cast iron hatches for firing.
9 Packing and insulation on top, for example old tiles laid on the tiles to be fired and covered with clay.

Shaft kilns can use different fuels. It is recommended to reduce air pollution by incorporating a scrubber, which filters suspended particulate matter.

The vertical shaft kiln technology for lime production is treated in Barriga et al. (1992), Smith (1993) and UNCHS (1993b).

Gypsum products

As for lime, the energy required to produce gypsum plaster is mainly related to the kiln energy. Large-scale production is energy efficient using less than 1 MJ/kg, but requires large investments. A medium scale production such as a vertical shaft kiln or a rotating pan, requiring about 1–2 MJ/kg, is often appropriate. Small-scale production in pits or heaps is very fuel consuming and should be avoided.

To further reduce energy and costs in gypsum plaster production it is recommended to recycle old gypsum products such as partition wall blocks and panels. Nowadays about 10–30% of the raw material in production of gypsum boards in Europe and North America is recycled. Gypsum blocks can also be made from phospho-gypsum, a bi-product of fertilizer manufacture. A disadvantage with phospho-gypsum products is, however, that they can contain high amounts of radon – a radioactive gas.

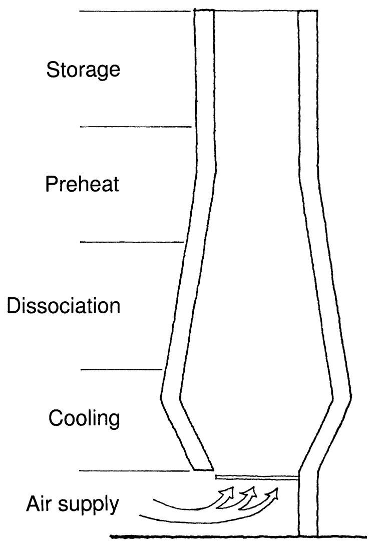

Figure 5 Example of a vertical shaft lime kiln.
(Source: Wingate, M (1985): Small-scale lie-burning, IT Publications).

Timber and wood products
The main energy requirement for timber is related to sawing and seasoning. It is recommended to use low-energy kilns for seasoning, e.g. solar driers.

Wood-based products such as chip boards, plywood and glue-laminated timber are resin-bonded and pressed which makes them more energy requiring per kg material. In board production it is recommended to minimize the use of resin by improved production control. Using sawmill or agricultural wastes, such as bagasse and coconut husks, as raw materials can reduce the energy required further. See Table 11.

Table 11 *Examples of current use of wastes in building materials.*

Type of waste	*Source*	*Application in building materials*
Bagasse ash	Sugar industries	Blended cements, mortars
Blast furnace slag	Steel plants	Blended cements, super sulphate cements, in-situ concrete, concrete blocks
Banana leaves/stalk	Banana plantations	Building boards
Burnt clay powder	Ceramic plants	Mortars
Cinder	Thermal power stations	Mortars, concrete blocks, bricks from black cotton soil
Coal washery waste	Coal mines	Ceramics, lightweight aggregate, fuel
Coconut husks	Coir fibre industry	Building boards, roofing sheets, lightweight concrete
Cotton sticks	Cotton plantations	Building boards
Fly ash	Thermal power stations	Blended cements, mortars, concrete blocks, lightweight concrete
Ground nut shell	Ground nut mills	Building boards, roofing sheets
Iron tailing	Iron ore mines	Stabilized and ceramic bricks, high strength bricks
Jute stick	Jute industry	Building boards
Kiln dust	Cement plants	Mortars
Limestone waste	Limestone quarry	Masonry cements, mortars
Lime sludge	Sugar, fertilizer, calcium carbide paper	Portland cements, masonry cements, sand lime bricks, mortars
Paper waste	Paper garbage	Pitch fibre pipes, bitumen sheets
Phospho-gypsum	Fertilizer plant	Gypsum plaster, blocks and panels, super sulphate cements
Red mud	Aluminium extraction plant	Ceramics, lightweight blocks, roofing sheets, concrete additive.
Rice husk ash	Rice mills	Blended cements, mortars
Saw mill wastes	Saw mills	Cement and resin-bonded building boards
Sisal fibres	Sisal plantations	Mortars, roofing sheets
Straw (wheat, rice)	Agriculture	Building boards

(Sources: various brochures and information materials from BMTPC (Building Materials and Technology Promotion Centre, India). 1997).

Box 6
Habitat II and the construction sector

In June 1996, at the second United Nations Conference on Human Settlements (Habitat II), heads of governments and officials from countries around the world, agreed that in order to improve the living condition of millions of poor and low-income people of the world, there is need for concerted effort by all stakeholders to provide adequate shelter and to ensure a sustainable human settlement development in an urbanizing world. It was also concluded that urban areas are suffering serious problems such as homelessness, poverty, pollution and overall environmental degradation, to mention only a few.

The Habitat Agenda adopted by Habitat II (UNCHS 1997a) proposes a practical and integrated approach, based on achievable targets and realistic courses of action formulated on the basis of an understanding of the prevailing situation. The Global Plan of Action of the Habitat Agenda offers guidelines and actions, which can be interpreted in the context of each country and used to formulate innovative national policies and strategies as well as actions to be taken by the international community.

The Habitat Agenda advocates (as far as environmentally sound and cleaner technology in construction is concerned), *inter alia,* a new approach, which is based on:

(a) Harmony with environment – "…the impact of construction industry should be brought in harmony with the environment and its contribution towards economic growth should be exploited, all to the advantage of society at large…". (from paragraph 88)

Habitat II also committed itself to the obligation of:

(i) "promoting locally available, appropriate, affordable, safe, efficient and environmentally sound construction methods and technologies in all countries, particularly in developing countries, at the local, national, regional and sub-regional levels, that emphasize optimal use of local human resources and encourage energy saving methods and are protective of human health". (paragraph 40f)

(ii) "Promoting more energy efficient technology and alternative/renewable energy for human settlements, and reducing the negative impacts of the energy production and use on human health and on the environment ". (paragraph 43o)

(b) Institutional support – "…Institutional support should be provided in form of industrial standards and quality control, with particular attention to energy efficiency, health, accountability and consumer safety and protection…". (from paragraph 88)

(c) Research and development – "Intensify and support research efforts to find substitutes for or optimize the use of non-renewable resources and to reduce their polluting effects, paying special attention to recycling, reuse of waste materials and increased reforestation". (paragraph 92a)

(d) Exchange of information – "Promote information exchange and the flow of appropriate environmentally sound, affordable and accessible building technologies and facilitate the transfer of technology". (paragraph 91c)

(e) Regulatory measures – "Encourage and promote the application of low-energy, environmentally sound and safe manufacturing technologies backed by appropriate norms and effective regulatory measures". (paragraph 92b)

The full version of the Habitat Agenda is available at UNCHS (Habitat)'s homepage: http://www.unchs.org

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Http://www.hdm.lth.se
The web-site of Housing Development & Management at Lund University, Sweden, contains some links to other relevant sites such as international energy organizations, courses and conferences.

Http://www.unchs.org
This homepage provides information about UNCHS (Habitat), its activities, programmes and projects, publications and events.