Sustainability and Energy Saving Though Proper Construction Practices and Materials Selection

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Abstract - Energy consumed during the construction of buildings and structures, including the embodied energy of the concrete and other construction materials, represent a considerable percentage that may reach 40% of the total energy consumed during the whole service life of the structure. Reducing energy consumed in the construction practices along with reducing the embodied energy of concrete and building materials, therefore, are of major importance. Reducing concrete's embodied energy represents one of the major green features of buildings and an important tool to improve sustainability, save resources for coming generations and reduce greenhouse gas emissions.

In this paper, different methods to reduce concrete's embodied energy are discussed and their effect on demand side energy are assessed. Using local materials, pozzolanic blended cements, fillers, along with specifying 56 days strength in design are discussed and assessed. Proper mix design, quality control and proper architectural design also affect and reduce embodied energy. Improving durability, regular maintenance and scheduled repair are essential to increase the expected service life of buildings and hence reduce overall resources consumption and reduce energy. These effects are discussed and quantified.

Construction practices also consume considerable amount of energy. The effect of transporting, conveying, pouring, finishing and curing concrete on energy consumption are also discussed.

Keywords--Sustainability, Energy, Cement, Concrete, Construction, Pozzolanic

I. Introduction

THE built environment accounts for approximately 40% of all energy consumption. It was always believed that about 1% of this is consumed during construction, 84% accounted for during the lifetime use and 15% is embedded in construction materials.

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In a more recent study, however, the embedded energy was found to reach or sometimes exceed 40% of the total lifetime energy. Figure 1, shows the relation between the embodied energy and the cumulative energy consumed over the service life of the structure [1]. Embodied energy is defined as the energy consumed by all of the processes associated with the production of a building or a material. This includes energies required to extract raw materials, to process raw material, to manufacture the product and to transport of product from source. As can be seen, the energy consumed in materials production decreases as a percentage of total consumed energy with the increase in service life. At 40 years, for example, the embodied energy represent 40 % of cumulative energy, while at 100 years this percentage is reduced to 15% while the operation energy accounts for 85% of the cumulative energy.

The main objective of this paper is to investigate ways to reduce the amount of cement, reduce embodied energy in cement manufacturing and investigate ways to improve sustainability and reduce energy consumption in the building industry.

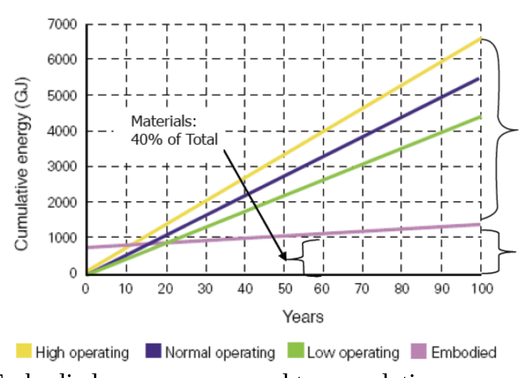


Fig. 1 Embodied energy compared to cumulative enrgy

II. ENERGY DURING CONSTRUCTION

The construction-related energy consumption required to complete a project is proportional to the project size and the nature of the work involved. For projects of a specific type, the energy required for construction is proportional to the project cost, as the project cost is directly related to the project size. As a result, energy consumption for a specific project can be expressed as a function of cost and type [2]. Table 1, for example, shows the relation between energy consumed in highway construction compared to the cost of the project for different types of highways. These construction energy consumption factors represent a simplified relationship between project size and energy consumption. The results obtained from their use are not exact, but provide a basis of comparison between alternatives.

Cranes, trucks, mobile equipment, and power tools will all consume energy during project construction. This energy is about 1% of the total lifetime energy of the structure. It must be noted, however, that this figure does not include the embodied energy of the materials used in the manufacture and fabrication of the equipment used in the project. Equipment, therefore, should be durable and should be used wisely. Avoiding over vibration of concrete and over curing will reduce construction energy along with selecting the right time for casting to avoid the unnecessary precautions required for hot weather concreting. The utilization of recyclable forms will also contribute to the energy reduction. The main objective of this paper, however, is to reduce the demand side energy embodied in the materials used for construction with emphasis on concrete. As mentioned before, this may reach 40% of the total energy consumed during the lifetime of the structure.

TABLE I. CONSTRUCTION ENERGY CONSUMPTION FACTORS (2002 DOLLARS)

Facility Type	**Factor (MBTU / thousand dollars)**
Rural Freeway	26.5
Rural Conventional Highway	25.2
Rural Freeway Widen	16.5
Rural Conventional Highway Widen	17.8
Urban Freeway	10.5
Urban Conventional Highway	9.6
Urban Freeway Widen	9.4
Urban Conventional Highway Widen	8.9
Interchange	26.8

III. ENERGY IN CONCRETE PRODUCTION

Concrete is second only to water as the most consumed substance in the world. Every tear almost one ton of concrete is produced for every human in the plant. Proper selection of building materials, therefore, plays an important role in achieving and improving the sustainability of buildings and structures and, hence, contributes to the environmental sustainability of our planet. According to the Leadership in Energy and Environmental Design [3], LEED, rating system, 13 points may be awarded for the proper selection of materials. Kim [4] placed the Economy of Resources as the first principle of sustainable design and pollution prevention. The strategies for achieving this principle includes use of low embodied energy materials, material conserving design and construction, proper sizing of building systems, rehabilitation of existing structures, use of reclaimed or recycled materials and components and use of non-conventional building materials.

It goes without mentioning, that global warming may jeopardize our existence and the existence of our planet. Nations are currently joining hands in order to control global warming. Global warming is mainly attributed to the excessive emission of greenhouse gases. Carbon dioxide accounts for 85% of green house gases. The CO_2 concentration has increased to reach 390 ppm and is still increasing [5]. Cement production accounts for a considerable portion of CO_2 emission, as amount of cement consumed in concrete has reached 2.77 billion tones in 2007 [6]. Reducing the amounts of cement consumed in the building industry is, therefore, of great importance.

Table II shows the embodied energy requirements for a typical concrete mix [7] consists of 500 lbs (226.4 Kg) of cement. 1400 lbs (634.2 Kg) of sand, 2000 lbs (906 Kg) of crushed stones and water to cement ratio of 0.52 by weight.

Table II.
Embodied Energy for Cement and Concrete Production

	% by weight	Btus per ton Materials	Btus per ton Hauling	Btus/yard concrete	Energy %
Cement	12%	5,792,000	504,000	1,574,000	94%
Sand	34%	5,000	37,000	29,000	1.7%
Crushed Stone	48%	46,670	53,000	100,000	5.9%
Water	6%	0	0	0	0%
Concrete	100%	817,600		1,700,000	100%

It was found that 94% of the embodied energy comes from cement. This number, however, depends on the case. In this example it was assumed that cement was hauled 50 miles to the ready mix plant, aggregate hauled 10 miles and concrete hauled 5 miles to the building site. It was also assumed that water has no embodied energy. This value should be modified in Kuwait as the desalinated water consumes a considerable amount of energy. Coarse aggregated in Kuwait are imported as local aggregates have been banned. The embodied energy requirements for concrete in Kuwait, therefore, is expected to be higher.

IV. ENERGY IN CEMENT PRODUCTION

Cement manufacture causes environmental impacts at all stages of the process. These include emissions of airborne pollution in the form of dust, greenhouse gases, noise and vibration when operating machinery and during blasting in quarries, and damage to countryside from quarrying. Equipment to reduce dust emissions during quarrying and manufacture of cement is widely used, and equipment to trap and separate exhaust gases are coming into increased use. Environmental protection also includes the re-integration of quarries into the countryside after they have been closed down by returning them to nature or re-cultivating them.

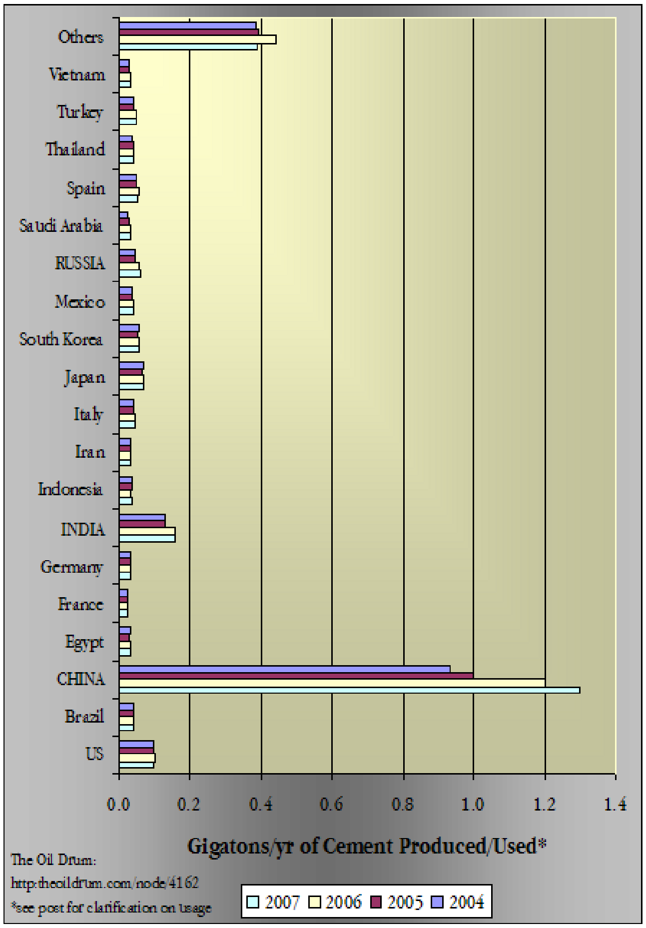


Fig. 2 Annual production of cement by country in billions of metric tons

Cement production is a highly energy intensive production process. The energy consumption by the cement industry is estimated at about 2% of the global primary energy consumption, or almost 5% of the total global industrial energy consumption. Due to the dominant use of carbon intensive fuels, e.g. coal, in clinker making, the cement industry is also a major emitter of CO2 emissions. Cement industry contributes 5% of total global carbon dioxide emissions. The non-metallic mineral sub-sector accounts for about 9% of global industrial energy use, of which 70 to 80% is used in cement production.

Figure 2, shows the quantities and distribution of cement production around the world. The total amount produced in 2007 is 2.77 billion tons.

The high temperature needed for cement manufacturing makes it an energy-intensive process. The average energy input required to make one ton of cement is 4.7 million Btu—the equivalent of about 418 pounds of coal. The U.S. cement industry uses energy equivalent to about 16 million tons of coal every year. According to the Department of Energy, U.S. cement production accounts for 0.33 percent of energy consumption.

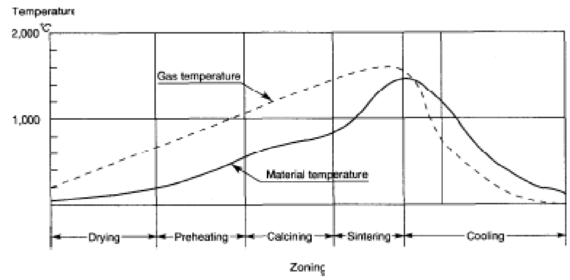
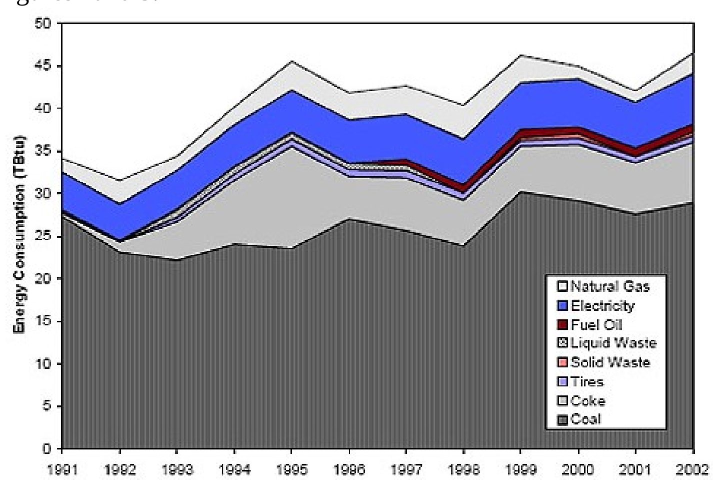


Fig. 3 Temperature variations in cement production

Finding ways to reduce both energy needs and reliance on fossil fue petroleum coke, and other fossil fuels have been traditionally burned in cement kilns, many cement companies have turned to energy-rich alternative fuels. Today, many plants meet between 20-70% of their energy requirements with alternative fuels. And many of these alternative fuels are consumer wastes or byproducts from other industries. Recovering their energy value in cement making is a safe and proven form of recycling.

Fuels like coal and coke contain carbon and release tremendous quantities of heat when they're burned. But coal and coke aren't the only fuels that contain carbon. Tires are also a great source of hydrocarbons (carbon and hydrogen). Using tires for combustion in a cement kiln produces 25% more energy than coal and it can also result in lower emissions. In fact, any material with high carbon content could be used as a fuel. Paper, packaging, plastics, saw dust, solvents… all are suitable for use as alternative fuels. Because of the extremely high temperatures (well above 3,000 °F), these materials burn quickly and extremely efficiently.

Burning alternative fuels in cement kilns offers several environmental benefits. This type of energy recovery conserves valuable fossil fuels for future generations while safely destroying wastes that would otherwise be deposited in landfills. From the PCA publication [8] 15 plants used waste oil, and 40 plants in 23 states used scrap tires. Solvents, unrecyclable plastics, and other materials are used as well, Figures 4and 5.



Source: Hendrick van Oss, U.S.G.S.

Fig. 4 Use of alternative energy in California

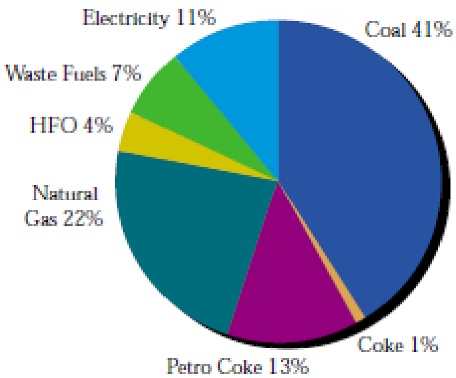


Fig. 5 Production fuel use in Canada

TABLE III.
ENERGY CONSUMED IN KILNS

	Rotary Kilns				Shaft Kiln(China)
	Wet	Lepol	Long dry	Short dry kiln	
Fuel use (MJ/kg)	5.9	3.6	4.2	2.9 - 3.4	3.7 - 6.6
Power use (kWh/kg)	0.025	0.030	0.025	0.022	
Primary energy (MJ/kg)	6.2	3.9	4.5	3.5 - 3.7	

As may be seen in Table 3, shifting from wet to dry or semidry kiln will reduce energy required for cement clinker production.

The energy consumption in cement industry in the middle east is higher than average. The energy index(SEC stands for Specific Energy Consumption) for cement industry in Iran is currently 105lit/ton, while this value for the world is 80 and the target for Iran is 95 in 10 years. So saving potential of 10% can be achieved during this period, equivalent to 29.3 million $ per year [9]. Figure 6 shows the energy consumption in Iran compared to the international average.

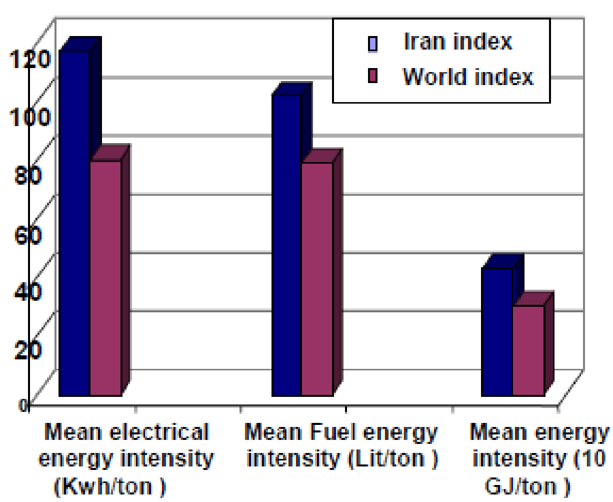


Fig. 6 Energy intensity in cement industry

In Iranian cement factories, the intensity of electricity and fuel oil are 117 KWh/ton and 105 lit/ton respectively. Altogether the energy intensity in cement will be 4.319 GJ/ton. (1.31 greater than mean world energy intensity in cement production) [9].

In another study **[**10**],** however, World average primary energy intensity was 4.8 MJ/kg cement, with the most energy intensive regions being Eastern Europe and the former Soviet Union (5.5 MJ/kg), North America (5.4 MJ/kg) and the Middle East (5.1 MJ/kg).

V. REDUCING ENERGY IN CEMENT PRODUCTION

The use of blended cements has a major effect on reducing energy in cement production. Pozzolanic materials may be mixed with cement to produce blended cements. ASTM C618 defines pozzolan as : "Siliceous or siliceous and aluminous materials which in themselves posses little or no cementitious value, but in finely divided form will react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties". Pozzolanic materials are either natural, wastes or byproducts of other industries. Natural pozzolana, fly ash, ground granulated blast furnace slag, silica fumes, rice-husk ash, grind glass are examples of pozzolanic materials. Fly ash is a byproduct of coal used in electricity stations, slag is from the steel industry, silica fume is a waste from the silicon industry, grind glass is from recycled waste glass and rice-husk is waste from rice. The amount of pozzolanic material that may be used depend on its type and may exceed 70% without reducing concrete strength for slag and fly ash. Thus, reducing the cement amount and the energy consumed in its manufacturing by the same ratio. Figure 7 shows the pozzolanic or supplementary cementitious materials (SCM) replacement required for zero increase in CO_2 production per region [11]. The use of pozzolanic materials has also environmental benefits as it utilizes some waste materials that may otherwise, increases the solid waste problem.

In fact the use of pozzolanic materials is essential in Kuwait as it produces concrete with suitable resistance to both chlorides and sulphates available in Kuwait. The use of normal cement will result in concrete susceptible to sulphates which cause cracking in concrete; while the use of sulphate resisting cement will result in concrete with low resistance to chloride induced corrosion. The effects of sulphates and chlorides are magnified by the high temperature in Kuwait. Utilization of pozzolanic materials, therefore, will result in more durable concrete which will result in prolonged service life of buildings. This will result, in turn, in reducing cost and energy consumed in extensive repairs and/or replacement of deteriorated structures.

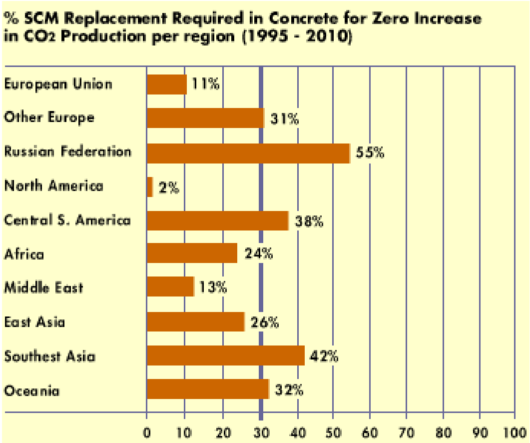


Fig. 7 SCM Replacement Requirements

The use of fillers is another method to reduce the utilized cement in construction. With the recent trends to reduce water to cement ratio and improve compaction, there is no enough space or water for complete hydration of cement. This means that actually, a portion of mixed cement acts as expensive filler. Replacing this portion with cheaper filler that requires less energy to produce is, therefore, beneficial..

Crushed limestone is the most promising filler. In 2004 ASTM C150 allows for 5% cement replacement. In 1983 Canada allowed for 5% and in 2009 allowed for 15% as per CSA A3001 and CSA A23.1. EN 197-1 allows CEM II to contain up to 35% lime. ASTM is currently discussing increasing the percentage to 15% .

VI. REDUCING AMOUNT OF CEMENT IN CONCRETE

Proper and elaborate methods of mix design – selecting proportions of constituent materials – are essential to produce concrete that satisfy the required characteristics with minimum cement. Admixtures are essential in this regard. Increasing workability, for example, which is a requirement for narrow congested sections or for pumped concrete used for high rise buildings, may be achieved by using high range water reducers with less cement instead of increasing the amounts of cement and water. Concrete members are designed for specific strength that is usually specified as the 28 days strength. Concrete strength, however, continue to increase considerably after this age. Specifying strength after 56 days will result in avoiding overdesign and allows for more reduction in the amounts of utilized cement.

The relation between the age of concrete and strength is given by:

$$f_{cm} = f_{cm(28)} \; (t/ 4 = 0.85 \, t) \qquad (1)$$

Where f_{cm} is the concrete compressive strength, $f_{cm(28)}$ is the strength at the age of 28 days and t is the age in days [12]. According to this equation the strength at 56 days will be 10% higher that at 28 days. This equation is for concrete made with type I cement. For concrete containing pazzolanic materials this value will be about 15%.

VII. REDUCING AMOUNT OF CONCRETE IN STRUCTURES

Overdesign is very common in practice. This may be due lack of knowledge and confidence or due to lack of trust in materials properties, supervision and workmanship. Hiring experienced engineers, qualified supervisors and well trained workers along with using certified materials allows for proper design and hence, reduction in the amounts of concrete and cement.

Instead of the common skeleton concrete system, other structural systems and materials may be investigated and utilized. Load bearing masonry systems may be used. Using aerated concrete or load bearing brick systems reduces the amounts of cement and hence energy. The use of lime-silica bricks, produced from 100% recycled rubbles was investigated by the author [13]. This resulted in considerable reduction in consumed energy.

Using steel, light gauge steel or composite structural systems should be considered and investigated for both cost and energy consumption at the pre-design phase of the construction project.

Architectural design plays a major role in reducing the amount of cement. Architects should avoid complicated design, avoid non-structural members and allow for reduction in member sizes where possible.

VIII. PROPER CONCRETING PRACTICES AND QUALITY CONTROL

Proper concreting practices such as using proper mixing, transporting, conveying, placing, compacting and curing concrete are essential. Using proper form systems and considering hot weather concreting precautions should also be followed. Properly designed quality control program including testing of constituent materials, mix design, testing properties of fresh concrete, applying proper supervision during concreting, testing properties of hardened concrete, applying statistical methods to quantify significance of deviation in properties and specifying and taking actions when necessary is of great importance. Quality control will allow designers to avoid overdesign and will also result in increased durability and service life. The service life of structures in Kuwait is quite short compared to other countries. Doubling the service life of structures will result in reducing the need for new buildings to 50%, hence reducing the need for cement and for energy consumed in building industry by the same ratio.

IX. ENERGY REDUCTION IN KUWAIT

Besides the energy that may be saved in cement production, considerable additional savings may be achieved through the proper use of cement and the use of supplementary materials. As mentioned before the quality control and proper concreting practices may will increase the service life of buildings. Buildings in Kuwait last for 30 to 40 years while design for 70 to 80 years is achievable. Increasing the life from 40 to 70 years will reduce the cement for concrete by about 40%. The combined use of pozzolanic materials and crushed limestone fillers will reduce the amount of cement by another 40%. While the specification of 56 days strength instead of 28 days will reduce the amount of cement by about 10%. The combined effect of these conservative estimation will be the savings of 68% of the current cement use in Kuwait. About 4 million tons of concrete are consumed in Kuwait annually with about 15% cement. The amount of cement, therefore, may be estimated as 600000 tons. As mentioned before the energy consumption in cement industry in the middle east may be estimated as 5.1 MJ/Kg. The cement utilized in Kuwait, therefore , requires 3.06 PJ, (PJ = 10^{15}J). The savings of 68% will mean the savings of 2.08 PJ.

X. CONCLUSIONS

Remarkable reduction in energy consumption and in CO_2 emission may be achieved through reducing embodied energy of cement and reducing the consumed amounts of cement utilized in constructions. This may be achieved through using blended cements, reducing the amount of cement in concrete through proper mix design and reducing the amounts of concrete in construction through proper structural and architectural design.

Proper use of blended cements and admixtures along with following recommended construction practices for the hot environment in Kuwait, will considerably prolong the service life of buildings and hence reduce future need for new constructions and hence energy.

The reduction in Kuwait due to the extended service life, the use of blended cement and the specification of 56 days strength is estimated to be 2.08 EJ.

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