THE STRUCTURE OF THE BUILDING LIFE CYCLE ASSESSMENT (LCA) FOR SELECTING SUSTAINABLE MATERIALS IN RESIDENTIAL COMPLEXES IN TEHRAN

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ABSTRACT

The world is now faced with an imbalance in the biological systems. The emergence of the phenomenon as climate change in the world can seriously take at risk the biological future of the world and causes the extinction of life and organisms on Earth. Given that the main reason for this phenomenon is the greenhouse gas emissions, buildings cause about half of these emissions, as a sustainable building design will cause to reduce negative effects caused by the improper use of materials and produce wastes. Therefore, sustainability approach based on the needs of today's generation using renewables resources and in opposition to non-renewable resources can be expressed. In fact, sustainable building materials should have the lowest risk to human health. So materials should be investigated from design to implementation and operation to understand the sustainability concepts of building. The present article will review the assessment of sustainable materials to use in residential buildings in the area of Tehran, and the vision of research is to provide solutions for assessing the sustainable architecture through understanding the new way of building life cycle analysis (LCA) of materials in building as a tool to measure. So the research questions are: How much selecting sustainable materials based on LCA in the design of residential complexes in Tehran is effective in reducing energy consumption of these buildings? And it investigates how quantitative and qualitative sustainable materials based on assessment system of environmental cycle in residential complex in Tehran.

Keywords: *Sustainable materials, Life Cycle of building, Embodied Energy, LCA*

INTRODUCTION

Building materials determine a considerable part of the energy consumed by buildings. Building materials include amounted to 60 percent of the construction costs of the building (Arayela, 2005). In another study, it is referred to the percentage between 50-60% of the total construction costs, but what is clear is that this percent in developing countries (where most cases use imported technologies in the field of housing) constitute over 65 percent of total construction costs (Ogunsemi, 2010). On the other hand, various pollutions of urban spaces are also one of the negative reflections of the non-normative development of housing in cities. So considering the required development of housing and a wide range of issues created, explaining sustainable architecture by reducing pollutions caused by housing development is essential. Thus, considering that the daily production of dust and debris in Tehran is five times of municipal wastes and daily 40 tons of building waste is generated in the city (Mohammadi, 2007). In this paper, using the building life cycle analysis (LCA) as one of the new methods for assessing the environmental capacity of building methods and products (equipment and facilities) during their life cycle from raw material stage to the time of their disposal should take step in the discussion of sustainable architecture in order to respond to today's problems in the field of architecture and also in the environmental sector in Tehran. This article is composed of five parts. Thus, after the theoretical foundations that are about sustainable architecture and introducing building life-cycle analysis, the research methodology is introduced. The study area has been studied and the results and the conclusions are presented and discussed.

THEORETICAL FOUNDATIONS

In the theoretical foundation of this research in the first stage, the concepts of LCA in line with sustainable architecture is described and it focus on the method investigated and tools used in the built environment. In the second stage, sustainability assessment in buildings based on the assessment system of environmental cycle and the use of this method from the primary stages, study and design to before operation of the residential complex in the region of Tehran is discussed. Finally, the results of this work can be used by stakeholders as an important reference in the LCA, which includes update procedures in perspective and analysis methods to protect the environment and thus achieve sustainable development in the region of Tehran.

SUSTAINABLE ARCHITECTURE

Sustainability is any development that according to the requirements of environmental, economic and social to meet the structural needs of current and future societies is created. A building is sustainable that regard to its natural context is flexible, durable, and with high quality and to be formed with regard to the identity of its community and abled to create comfort and relaxation of man due to accrued performance. Stable and homogeneous design is a design that something as a part of a larger whole is well considered (Rocky Mountain, 1998). On the other hand, according to the diversity of the architectural word, it's hard to point a specific case that architecture had a minor impact on the natural environment. Environmental factors that architecture influences them, including (technology, materials, energy, water, transport) wastes resulting from construction of buildings, the resources that are consumed during the life of the building by residents, and finally the sources and various wastes that somehow connected with the surrounding environment to be included. According to available figures, energy consumption of buildings alone consumes around half of total energy consumption of the world.

Figure 1-world energy consumption in 2008 based on the different parts
American Institute of Architects (AIA) and Architecture 2030, 2009)

Figure 2. The consumption of electricity in the world in 2008

At the same time and simultaneously, buildings over the years consume a huge amount of natural resources and exchanged to the wastes and buildings wastes. Buildings consumed about 50 percent of

Figure 1. CO2 concentration in the atmosphere from 280 million in 1000 has now reached 367 million.

(Current and long term historical data compiled by Scripps, Earth Policy Institute, ESRL/NOAA, World watch)

the world's raw materials that more than 70 percent of the consumption cases are nonrenewable, and buildings are responsible for producing more than 36% of wastes in the total world (Graham, 2002). Buildings produce about a third of total world greenhouse gases (GHG) that this figure is increasing in recent years.

This amount will be increased about 8.6 billion tonnes in 2004 and due to the increasing process in 2030 in amount of doubled amount and reached about 15.6 billion tons (IPCC, 2007). A variety of factors are involved in this sector, which we refer to three of them that have a significant impact on the libertine increase:

1. Excessive increase in population and the availability of available resources;
2. Building processes and uncertain longevity of the building;
3. Technology and Materials

Figure 2. Figure 2-2 - Compare the construction sector in terms of CO2 emissions

(U.S. Energy Information Administration statistics (USDE 2008), Architecture2030)

BUILDING LIFE CYCLE ANALYSIS

One of the methods of assessing the sustainability of buildings and especially the sustainability of building materials is analysis of the life cycle of the building. LCA of 1990 was entered the

construction sector, and is an important tool to assess it (Fava, 2006; Taborianski, 2004). Life cycle analysis of building is a method for assessing the capacity of environmental of construction methods and products (equipment and facilities) during their life cycle from raw stage until their disposal (Sonnemann et al, 2003; Hobday, 2006; Warburg, 2005). Klopffer believes LCA is a very wide method, because it gathers information about the structure, analysis of environmental impacts of the building and the quality of data arising from the effects in a comprehensive review (Klopffer, 2006). In the following, how to reduce energy consumption using this approach is explained.

REDUCE ENERGY CONSUMPTION OF BUILDINGS WITH LCA APPROACH

Reducing energy consumption in buildings must be accompanied by reducing the number of sources of energy, as well as created a fundamental change in primary and secondary energy consumption (Sartori and Hestnes, 2007).

REDUCE TOTAL ENERGY CONSUMPTION

When we consider all phases related to the construction of a house, and add items such as drinking water, cooking, lighting and the use of equipment to it. The ratio of the energy consumption among the house that is built with sustainability standards and a house that is built in common form from 10: 1 to 1: 7.3 is reduced. This figure is 1:5.2 when we consider all environmental items and in terms of warming potential of earth decreases to 1:4.2. Elsewhere it is observed that when we reach to carbon footprint, this reduction shows a ration equivalent to 1: 2.2, respectively. Despite all existing aspects, architects and designers should not pay attention only to aspects related to energy consumption but also should pay attention to the materials used and remaining of the building that remains at the end of its useful life. In another study, they concluded that transport of materials to the site leaves the least environmental impact than other factors (Blengini and Dicarlo, 2010).

Table 1: Effects of transporting materials from industrial production unit to the project site

Impact category	Lorry, road m_1	Freight rail m_2	Transoceanic freight ship m_3
Primary energy demand (MJ–Eq/km)	3.266	0.751	0.170
Global Warming Potential (kg CO ₂ –Eq/km)	0.193	0.039	0.011
Water demand (l/km)	1.466	1.115	0.097

(Source: Blengini and Dicarlo, 2010)

In one study, they concluded that the primary energy for the construction of equipment of building in typical buildings and buildings with low energy consumption is approximately 45% and 60% of total energy consumption to build it. This relative increase is only due to the use of wood for making windows frame to reduce the environmental impacts. They concluded that the greatest influence in this area is related to increase the outer layers of the building, the use of windows to waste less energy, loss of energy for the construction, to stored energy of 10: 1, this means that 10 times more than what they spent energy for construction, they can provide to save in building energy (Gustavsson and Joelsson, 2010). Ferbik and Hans in 2010 with research on four houses in Belgium concluded that energy consumption due to the construction of a building with low energy consumption within a short time (less than 2 years) will be compensated. Only in houses with the least amount of energy loss (over 30 years MJ / m³ 900), the amount of energy used to manufacture them in front of their energy loss is minimal. They in recent research concluded that the return of investment on energy loss to insulate a building provides between 10 and 30 years of energy consumption of a common house (Verbeek and Hens, 2010) Baryspan, Avsen and Oscar Peliney carried out a similar study on house in Spain. In their study, it was concluded that 90% of primary energy used is consumed during the 5 years of the life of a building (Zabalza et al, 2009). In a research in the area of residential buildings, Otama and Givala concluded that the double walls to a wall in a period of 40 years have better productivity. However, the primary embodied energy of double walls and a wall in tall buildings is, respectively, 79.5 GJ / m² and 76.3 GJ / m³. This small difference in embodied energy of these two

types of wall with energy-saving that is expected is very different, the amount of energy consumed declined from 480 GJ / m² to 283 GJ / m² (Utama and Gheewala, 2000). Recently radhi in a similar study on the effect of external heating and its conductivity from the coverage concluded that the thermal conductivity depends on the heat that is stored in the structure of a building (potential) (Radhi, 2009). This explanation means that in the design, we require maximum precision in the simulation of building to achieve considered parameters for evaluation of LCA.

2.2.1.3. environmental impact of materials (IMPRO)

Environmental Improvement Products (IMPRO) includes the application of policies such as, strategies used in IPP, regulations related to environmental product declaration (EPD) and ecology. EPD is an accepted strategy that is used to international standards, and provides a guideline to reduce the environmental impacts of building products (EPD, 2005). EPD includes materials such as concrete, wood, and metals such as aluminum, which is shaped based on LCA and includes information on how to prepare raw materials, energy consumption, choice of materials, emissions in the atmosphere, soil and water and generating wastes (Askham, 2006). On the other hand, ecology refers to the relationship between a product and the surrounding environment. Ecology provides techniques to reduce environmental impacts during different stages of their life cycle. Sun and Pojari concluded that ecology include determining the environmental impact of the production – consumption chain of products that the issue included environmental influencing factors during the design of materials, process and related activities, when 60 to 80% of its life cycle has elapsed (Sun et al., 2004). Fuel and Energy Management of America (2003) collected data and statistics in the field of annual required energy consumption in residential buildings, commercial with embodied energy (cement, ceramics, glass, steel and so on). The organization based on that information specified buildings that consume a lot of energy and produced greenhouse gases.

THE ASSESSMENT OF MATERIALS IN LCA

In this section, the dominant materials used in residential buildings in Tehran will be presented and the environmental impact of them is evaluated in the LCA method.

BRICK AND TILE

Ceramic floors consume a lot of energy during production, because so much gas is burned and used to be treated product, and cause to increase primary energy consumption. Brickworks spend around 80% of total energy consumption to processing these products. In addition, the required water to evaporate ceramic flooring is 7.5 times more than the amount ceramic of wall and brick consumes. To exterior paving of building, rubble stone is suggested instead of carpet ceramic and what about MJ-Eq 13.45 (86%) in primary energy consumption is saved and reduced CO₂ emissions by as much as 0.57 kg (66%). To cover the building, Fiber- Cement is a very unsatisfactory option, however today concrete than ceramic in better. Although ceramic has energy saving equivalent 6.95 Kg / Mj (60%) than fiber- cement, and ceramic products show 1.93 MJ / Kg (42%) reduction in energy consumption compared to concrete. About brick, using light clay brick (85% clay and 15% straw) calcium silicate brick (9% limestone and 10% sand) considerably reduces negative environmental impacts. Although light clay brick has relatively high primary energy (45% of the energy produces by the natural fuel). In addition, light clay brick is neutral in terms of CO₂ emissions, so compared to typical brick (which is published 0.27 CO₂) is more cost-effective (Zabalza et al., 2010).

Table 2: LCA findings from different bricks and tiles

Building Products	Density (kg / m ³)	Thermal conductivity (W / mK)	Primary required energy (MJ-Eq / kg)	warming potential of earth (Kg CO ₂ -Eq / kg)	Amount of water needed (L / kg)
Ordinary brick	1800	0.95	3.562	0.271	1.890
Clay brick	1020	0.29	6.265	-0.004	1.415

Sand-lime brick	1530	0.7	2.182	3.009	3.009
Ceramic Tile	2000	1	15.649	0.857	14.453
Stone tile	2100	1.5	2.200	0.290	3.009
Ceramic tile of roof	2000	1	4.590	0.406	2.456
Concrete tile of roof	2380	1.65	2.659	0.270	4.104
Fiber cement of roof	1800	0.5	11.543	1.392	20.368

(Zabalza et al, 2010)

INSULATION MATERIALS

It is better to point out that, the impact of industrial products is far more than natural materials such as wood fiber, natural fiber or recycled materials such as cellulose fibers. As long as products like polyurethane with CO₂ emissions produce equivalent 7 kg and much crude oil and gas for its production, natural insulations such as wool spread CO₂ gas to a very small extent (0.987kg). Another advantage of this product is the possibility of its recycling. Due to the high volume of using natural fibers, wool sheep industry is currently declining and due to its low supply in the market, in most cases, combined materials are used in the field (Zabalza et al, 2010). Cork can be a good choice in the field of insulation materials. This is due to the cheapness and availability of this product. And the other benefits of environmentally friendly product is the extraction of it from forests in the form of every 10 years, this could help the ecosystem. However, its primary energy production is relatively high, in addition, 50% of energy from biomass sources is provided which reduces its use. Polyurethane sheets expanded and rigid polystyrene foams have the highest heating insulation. In contrast of these products, rock wool is placed that its required primary energy 4 times, the effect of its carbon 4.7 times and its moisture effect up to 8.4 times less than the above cases. However, rock wool requires relatively high consumption of coal to be combined well with basaltic rocks, and also needs to synthetic polymer resins to have a good quality. Despite all this, we need a general understanding of the design to through that, depending on the project and the costs and climate reach to a general consensus on the field of choosing materials and at the same time we can reduce the negative effects on nature.

Table 3: LCA findings from insulation materials

Building Products	Density (kg / m ³)	Thermal conductivity (W / mK)	Primary required energy (MJ-Eq / kg)	warming potential of earth (Kg CO ₂ -Eq / kg)	Amount of water needed (L / kg)
EPS sheet foam	30	0.0375	105.486	7.336	192.729
Rock wool	60	0.04	26.393	1.511	32.384
polyurethane rigid foams	30	0.032	103.782	6.788	350.982
Cork	150	0.049	51.517	0.807	30.337
Cellulosic fibers	50	0.04	10.487	1.831	20.789
Wood wool	180	0.07	30.267	0.124	2.767

(Zabalza et al, 2010)

CEMENT AND CONCRETE

Normally 40 to 60% of the total weight of the building is formed of these products, which also have significant negative environmental effects. The environmental effect of reinforced concrete is much more than non-reinforced concrete, this is due to the use of ribbed bars that is sticking to concrete and

causing building non-recyclable materials. As a result, its primary energy required is increased 700Mj-Eq / t (63%) and its CO₂ emissions by as much as 42 kg / t (31%) will increase. Notably, the use of lime mortar is instead of cement mortar that in terms of handling and transport and CO₂ emissions during construction can reduce carbon emissions to 62%. It should be noted that the environmental impacts is due to manufacturing process of clinker brick significantly high. This effect can be reduced by production using ecological and recycled products significantly. Now in most European countries, these products as alternatives of non-renewable products are used and use them is only 35% (the figure is 80% in the Netherlands) and in Spain, the figure is less than 5%. The use of alternative fuels in cement production process can reduce its environmental effects, so it can be changed waste products into recycled products using recycled materials in the process. Compare the actual amount of energy consumption in clinker furnaces that some is among 2900-3200 Mj / t and its supposed amount is equal to 1700-1800Mj / t, the figure is very high, by 2050 this rate should be (based on emissions protocol CO₂) reduced by half (Habert et al, 2010). This figure can be reduced with technology of fuel sedimentary materials (use wastes left by the furnace slag and convert them into liquid and burn them again) reduced (Zabalza et al, 2010). Concrete is one of the materials that play an important role in the field of energy. Concrete is considered as one of the sources of CO₂. To the extent, that this produces 70% CO₂ of the world (Calkins, 2009). For example, according to one study, about 99% of CO₂ emissions in three bedrooms of a house in Scotland have been due to the use of concrete walls. Blengini states that recycled concrete can be included 19% of the total volume of concrete consumed (Blengini, 2009). In another study it was observed that extract of aggregates that is used for mixing in the concrete needs to 20 kj / kg oil and 9 kj / kg electricity, breaking and demolition of the concrete needs to 120 kj oil and 50 kj electricity. In another study found that only benefit of concrete when it is recycled, which can be used its pieces instead of combination aggregates (Dodoo et al, 2010).

Figure 5: The amount of CO₂ emissions resulting from the processing and production of building materials in terms of 1 sq.m

(Cuchí et al., 2007)

Another way to reduce the environmental effects of concrete is the use of it in the replacement of natural aggregate with recycled products such as sand, brick, crushed plastic, fiberglass wastes, wood chips, etc. (Joseph, 2010). However, the integration of products is not as well as industrial and chemical products of manufacturing. As a result some of the attachments of concrete mixture that are naturally prepared not operate as well as manufacturing and industrial products. Despite all these problems, recycled concrete can be used in different places, for example Redford airport in the United States to build used 6.5 million tons of recycled concrete. Frequency of use of concrete is due to increase of its physical power against building products, which increased the use of this product (Herbert and Rouse, 2000 :). Another type of concrete that with a high performance is produced in France is ductal concrete. The concrete compared to ordinary concrete has the 65% saving in the use

of renewable materials, reducing 51% of primary energy and reducing CO₂ emissions by as much as 47%. Also its physical capacity is increased and its compressive strength is 6 to 8 times, bending strength to 10 times more and its durability is between 10-100 times better (Damtfot et al, 2008). Some researchers suggest alternative materials, for example Haberman and Pearl Mather concluded in a research on Negev desert houses that if, instead of reinforced concrete, we used the replacement materials such as foam concrete blocks, blocks of reinforced soil or sand, embodied energy is reduced by 20% (Huberman and Pearlmuter, 2008). In similar conditions, the use of refractory brick can be effective. The energy required for the production of refractory brick (657.1Mj / t) than conventional brick (4186.8Mj / t) is much less. The index shows a decline of about 6.4 times (Oti et al, 2009). This traditional building materials while are inexpensive have appropriate heating and acoustic properties. And at the end of their useful life can be used as leaven of other products or even return to nature. However, refractory brick loses its durability against water, water can deplete it, but the problem is also solved by covering this product. In some cases, the stone can also be a good alternative to concrete or ceramic. When the stone is available or could be extracted it in sufficient quantities, can reduce the environmental impact of the building to an acceptable level.

Looking at remained buildings from the 19th and early 20th century, researchers can understand their performance and durability by an accurate assessment (Calas et al, 2010; Mandell et al., 2010). Racks also can be an appropriate alternative for ceramic. Nikoltti and others in a study compared marble rock and ceramic as decking. They concluded that the environmental impacts of marble rock are less than 2.2 times ceramic (Nicoletti et al, 2002). Metals (steel, aluminum, copper, etc.) have much more embodied energy compared to concrete (aluminum 191 Mj / g, steel 32 Mj / kg, concrete 1.30 Mj / kg). As a result, if they even contain a small part of the overall volume of the building, the total amount of embodied energy will increase sharply. For example, Chen investigated a research on two high-rise residential buildings in Hong Kong. In these cases, steel and aluminum used in buildings included around 75% of the total embodied energy of building (Chen et al, 2001: ??). However, a relatively small amount of concrete was used in these two buildings; embodied energy of metal can be reduced substantially in the case of being recycled. They also pointed to the fact that the volume of energy for recycled steel is 10 Mj / kg as well as for recycling aluminum are 8Mj / kg that the figure included 31% of energy consumption for production of pure steel and 4% of pure aluminum (Blengini, 2009). Gustavsson and Sathre, 2006 achieved similar results, although their numbers with the numbers obtained was slightly different. As a result, the use of recycled aluminum and steel has the ability to reduce energy embodied about 50%. More benefits show themselves when building has reached to the end of its useful life and we want to recycle its materials. However, according to research that Dodu and others conducted, the reserves recycled of metals have increased and thereby useful return of energy recycled at the end of life of the building reduces (Dodu et al, 2010). Renewable energy potential of recycled metals has caused leading these materials, which can be used the recycled materials as a proper substitute for concrete in non-structural elements of the building. (Chen et al, 2001).

Table 4: The results of LCA from cement and concrete

Building Products	Density (kg / m ³)	Thermal conductivity (W / mK)	Primary required energy (MJ-Eq / kg)	warming potential of earth (Kg CO ₂ -Eq / kg)	Amount of water needed (L / kg)
Cement	3150	1.47	4.235	0.819	3.937
Cement mortar	1525	0.7	2.171	0.241	3.329
Reinforced concrete	2546	2.3	1802	0.179	2.768
Concrete	2380	1.65	1.105	0.137	2.045

(Zabalza et al, 2010)

WOODEN PRODUCTS

When concrete was proposed as a cost to the environment, wood had a very good reputation. Articles generally agreed that wooden structures have low required energy and less CO₂ emissions (Cole and Kernan, 1995; Borjesson and Gustavsson, 2000; Treloar, 2002; Petersen and Solberg, 2005). Wooden materials have a suitable performance as carbon storage over the life of the building and this is much more than trees that have not been cut yet (Borjesson and Gustavsson, 2000). In general, all wood-based materials have minimal impact on the environment, particularly those materials that do not require processing in industrial plants. Primary energy of all these products is supplied by biomass. The amount of CO₂ gas emissions by this category of products is almost zero. It must be considered that per cubic meter of wooden laminate absorbs 582 kg CO₂ gas, while the concrete per cubic meters releases 458 kg CO₂ gas, it is in relation to the steel is equivalent to 12.087 kg. The use of wood can reduce the running costs of the building and also reduce the environmental impacts and global warming (caused by greenhouse gas emissions).

Table 5: results of LCA from wood-based materials

Building Products	Density (kg / m ³)	Thermal conductivity (W / mK)	Primary required energy (MJ-Eq / kg)	warming potential of earth (Kg CO ₂ -Eq / kg)	Amount of water needed (L / kg)
Logs, soft wood, smooth, dry by kiln	600	0.13	20.996	0.3	5.119
Logs, soft wood, smooth, dry by air	600	0.13	18.359	0.267	4.195
Wooden laminated used in building	600	0.13	27.309	0.541	8.366
Chipboard used inside the building	600	0.13	34.646	0.035	8.788
wooden board	600	0.13	36.333	0.62	24.761

(Zabalza et al, 2010)

CONCLUSION

In this paper, in response to the increasing difficulty of building wastes in the country, producing new materials from the point of view of new resources of products and methods for product recovery after consumption was suggested, to through pay attention to ecological trends in the construction and use, environmental load reduces in producer and consumer part. In this context, eco-friendly materials in residential complexes on Tehran in order to reduce energy consumption are as follows :

Taking advantage of ceramic products to 1.93 MJ / Kg (42%) on the floor as well as rocks can be a proper alternative to ceramic.

The use of refractory brick can also be effective. The energy required for the production of refractory brick (657.1Mj / t) than conventional brick (4186.8Mj / t) is much less as well as enjoying the right clay brick (85% clay soil and 15% straw) calcium silicate brick (9% limestone and 10% sand).

Use insulations that a higher percentage of recycled and waste materials are used in their manufacture and also for filling containers, bulk rock wool and cellulose should be used that have the percent of

more recycled material than fiberglass. The use of lime mortar is instead of cement mortar that reduces handling and transportation as well as CO₂ emissions. Instead of reinforced concrete, we should use replacement materials such as foam concrete blocks, blocks of reinforced soil or sand to work. Replacement of natural aggregate with recycled products such as sand, brick, crushed plastic, fiberglass wastes, wood chips, etc. is in order to reduce the environmental impacts of concrete. The use of recycled metals (aluminum and steel recycling) as a substitute for concrete in non-structural elements of construction should be introduced. The use of wood can reduce the running costs of the building and also reduce the environmental impacts and global warming (caused by greenhouse gas emissions).

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