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IMPACT OF EMBODIED CARBON IN THE LIFE CYCLE OF BUILDINGS ON CLIMATE CHANGE FOR A SUSTAINABLE FUTURE

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ABSTRACT

According to the literature approximately 40% of global energy in 2007 has been using in the buildings which is responsible for 30% of total carbon emission. This human induced carbon emissions cause climate change by increasing global temperature. In this sense, energy consumption in the life cycle of buildings results in two different components: embodied carbon and operational carbon. Embodied carbon, encompasses extraction and processing of raw materials; manufacturing, transportation and distribution; use, reuse, maintenance, recycling and disposal. Operational energy is consumed in operating the buildings, e.g. heating and cooling systems, lighting, and home appliances which accomplish some household functions. A number of measures and targets have been introduced, including various fiscal and regulatory instruments to handle climate change and move towards low and zero carbon buildings. Overall, the increase in efficiency of energy use is as vital as production of energy and results in direct or indirect energy savings, and subsequently mitigates high energy cost. The aim of this paper is to highlight the impact of "different strategies" on embodied energy and ultimately on the environment. This concern provides a more integrative approach to calculate a building's embodied carbon in the housing life cycle assessment considering the following strategies: (1) Choice of construction materials such as wood and glass etc… When designing buildings, (2) Minimizing distance between building and raw

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material supply, (3) Choosing recyclability in building materials and parts, (4) Minimization of building-related waste during the construction processes, and (5) Planning in accordance with recent efforts for standardization of embodied carbon in the buildings.

Key words: Sustainability, Life Cycle, Housing, Embodied Energy, Buildings

Introduction

The construction industry largely uses natural resources and annually produces 40 % of total energy in their life cycle stages of buildings in the World [1]. (Figure 1) shows increasing world energy consumption (quadrillion Btu) between 1990 and 2040 (Figure 1a) [2]. This mainly arises from the expected global population growth from 6.9 billion in 2010 to approximately 9.0 billion in 2040 (Figure 1b) [3].

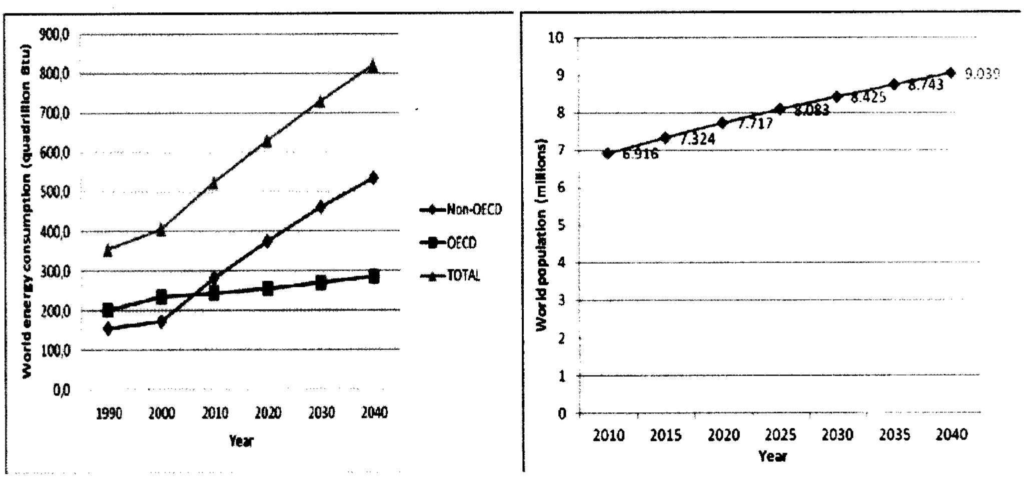

Figure 1 : (a) World energy consumption (quadrillion Btu) between 1990 and 2040 (Source [2]); (b) World population (millions) between 2010 and 2040 (Source [3])

Additionally, increased human needs and developing efforts of countries lead to more construction activities and world energy demands. Thus, the construction sector, in particular, is one of the largest consumers of commercial energy in the form of electricity or heat by directly burning fossil fuels (Figure 2) [4]. The need for a re-design of processes in the construction sector after the global crisis in the Western Countries calls the stakeholders to develop a strategy lead to rethink the process of producing buildings in a more efficient way, saving scarce resources and researching to find product and process technologies to deliver efficiency in the system. Carbon

Footprint is a standard and easy to use measurement system of the absolute impact of a product and its use; life cycle in the context denotes the process based approach of the method and enables the stakeholders to work for continuous improvement, being supported by a standard method to deliver quality and efficiency. In addition to this we should consider the great potential of these approaches into green marketing of products, delivered with an eye on sustainability measured with standard parameters.

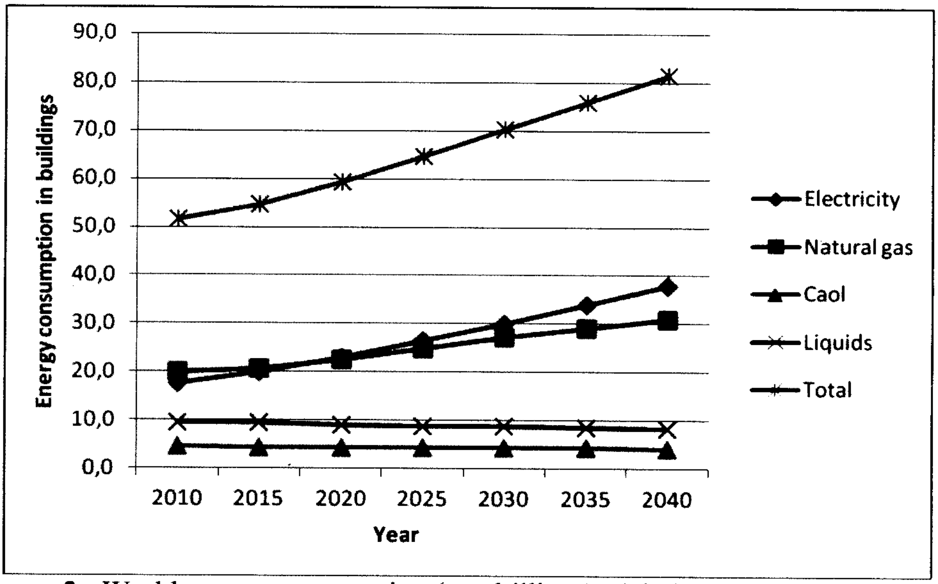

Figure 2 : World energy consumption (quadrillion Btu) in buildings between 2010 and 2040 (Source [4])

The building sector accounts for approximately 30–40% of national CO_2 emissions from the use of fossil fuels. As construction activities both consume energy and cause environmental pollution/emission of greenhouse gases they consequently lead to climate change [5].

Environmental pollution has been forcing western countries to protect world environment since the 1980s and to find concrete solutions to unbalances between economic growth and environment with an increasing concern. Report of the World Commission in 1987 on Environmental and Development revealed the importance of sustainable development diverting some attention from economic growth [6]. A sustainable development generally refers to members of one generation acting to conserve resources for future generations and also meeting the needs of the present [7]. One of the biggest threats to this sustainable development is carbon dioxide emissions. Therefore, it is crucial that the building construction industry achieves sustainable development in the society.

Sustainable development is stated as development with low environmental impact, and high economical and social levels. Achieving of these aims depends on a multi-disciplinary approach with a number of properties such as energy saves, improved use of materials including water, reuse and recycling of materials and emissions [8]. As buildings consume large amount of energy; they need to be analyzed for sustainability in the lifecycle perspective to develop strategies to minimize their energy use and associated environmental impacts.

Embodied Energy

The housing materials consume energy during their life cycle stages, such as raw material extraction, transport, manufacture, assembly, installation as well as its disassembly, removal of the waste of demolition and disposal. The energy consumed in housing stages is collectively stated as embodied energy which has two main components, direct energy and indirect energy [7]. This divided assessment is called Life Cycle Energy Analysis (LCEA) [9].

Operational Energy

Operational energy is defined as the total energy which is used to run the building and to support building performance for different functions, more specifically in heating, cooling, and lighting. Life cycle energy use of buildings is based on the operating energy (80–90%) and the embodied energy (10–20%) (Figure 3) [7].

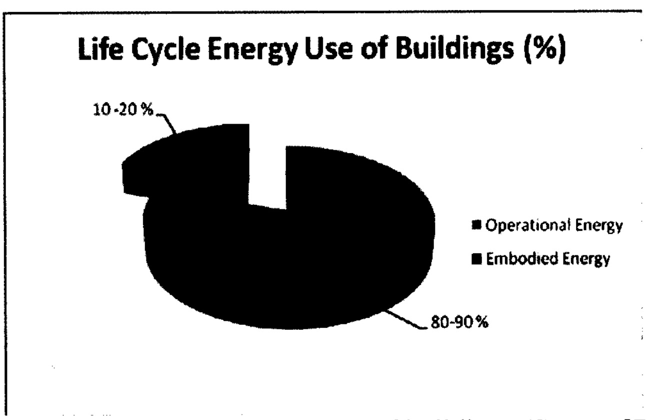

Figure 3 : Life cycle energy use of buildings (Source [7])

Compared to embodied energy, operational energy constitutes a relatively larger proportion of a building's total life cycle energy. However, recent research has pointed the significance of embodied energy and has acknowledged its growing proportion in total energy due to the emergence of more energy efficient buildings [10].

Life Cycle Assessments of Buildings

Life cycle assessment (LCA) is a method used for the quantitative assessment of a material used, energy flows and environmental impacts of products according to UNI ISO/TS 14067 [8]. Buildings are one of the main factors of energy use and greenhouse gas emissions. Therefore, it has a big impact on environment protection and sustainable development reducing energy consumption and carbon dioxide emissions arising from buildings.

LCA encompasses the analysis and assessment of the environmental effects of housing materials, components and assemblies throughout the entire life of the building construction, use and demolition. Prediction of carbon emissions is essential and crucial from global sustainability for an accurate and reasonable life-cycle [11].

Life Cycle Energy Analysis in Buildings

Life cycle energy analysis approach accounts for all energy used in building`s life cycle. This approach is mainly composed of manufacture, operation, and demolition phases (Figure 4) [12].

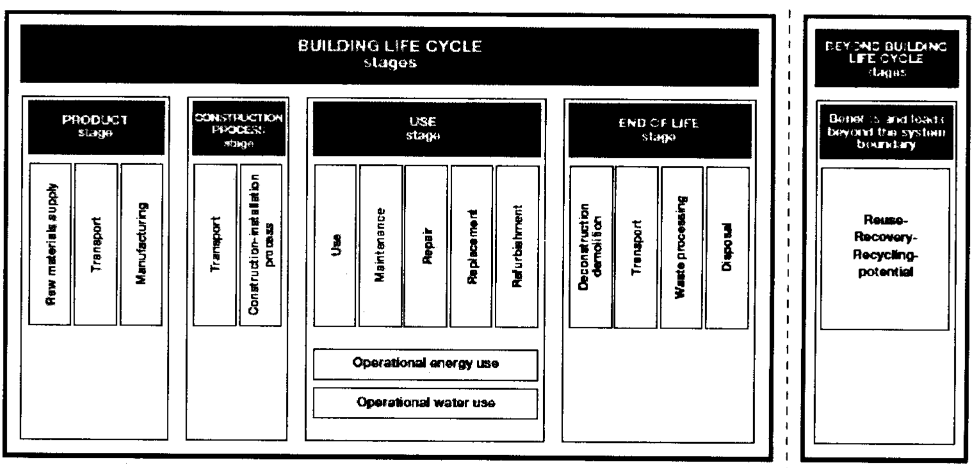

Figure 4 : Building life cycle stages (Source [12])

Manufacture phase includes manufacturing and transportation of building materials and technical installations used in new building and renovation of the buildings while operation phase refers to all activities related to the use of the buildings over its life span such as water use and powering appliances. Finally, demolition phase includes destruction of the building and transportation of dismantled materials to landfill sites and/or recycling plants. Life cycle energy analysis calculates embodied and operational energy in the whole life cycle of a building [13] and it is composed of different parts as shown in Figure 5.

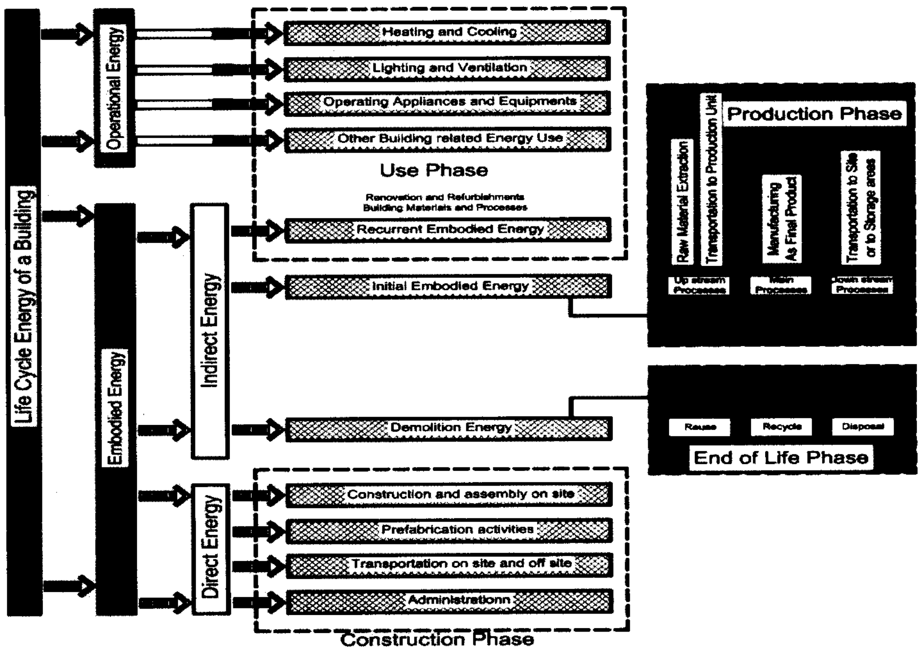

Figure 5 : Life cycle energy of a building (Source [10])

<u>Embodied energy model for a building</u>

The energy consumed during life cycle stages of a building, such as raw material extraction, transport, manufacture, assembly, and installation as well as its disassembly, demolition and disposal is collectively interpreted as embodied energy. More specifically, embodied energy is mainly divided into two categories: direct and indirect energy. Direct energy is consumed in various on-site and off-site operations like construction, prefabrication, transportation and administration. Indirect energy is mostly used during the manufacturing of building materials, in the main process, upstream processes and downstream processes and during renovation, refurbishment and demolition [10].

<u>Operational energy model for a building</u>

Operational energy is the energy required for maintaining conditions and the daily life maintenance of the housings such as heating, ventilation and air conditioning, and domestic hot water, lighting, and for running appliances. Operational energy largely varies according to the locations materials in housings and built of construction techniques [7].

Different Strategies On Embodied Energy

Choice of Construction Materials

The environmental impact of materials is caused during the complete life time, from cradle to grave. It is very important to select those lowest environmental impact building products at the design stage and designing proper processes is the way to lead improvement into the system. The low carbon and low embodied energy materials in buildings design is important to create more sustainable building environment. That concern helps designers to predict which decisions are more or less critical on determination or selection of a building's material in terms of embodied impact. The LCA method has been developed to take advantage of the environmental impact of single products or production processes. However, since appropriate data bases and users interface are not completed it is still difficult to apply LCA to compare alternatives in a design process of buildings [14]. As a result of for low carbon materials the use of modern building materials should be carried out paying attention to the energy intensity of materials the natural resources and raw materials consumed carbon identity of the material the recycling use of equivalent materials and safe disposal and the impact on the environment [15].

Minimizing Distance Between Building and Raw Material Supply

The case studies have stressed out that 2% of embodied carbon is a result of transportation of construction materials [16]. In the light of the researches, transfer of raw materials to construction field and bringing of those treated materials to construction field and choice of local domestic and easily accessible materials, being easily removable and reusable, and generation of less waste should be critical points to minimize embodied carbon.

Choosing Recyclability in Building Materials and Parts

There is a rising demand nowadays on Building Information Modeling (BIM), which allows use of recycled materials for housing construction, including the fabrication of housing elements and also recycling of housing elements at the end of their life cycle or after housing's dismantling [17]. It would be worth to consider the following principles in the choice of the building materials from the recycling point [18];

i. use materials with high proportions of recycled content reducing their overall embodied energy.
ii. reuse products saving large amounts of embodied energy compared to that used new products.
iii. reduce construction waste for embodied energy saving.
iv. select long life products or design for a long life adding value to their initial embodied energy

It is clear how a well-designed process of the supply chain and logistic cycle of materials can improve the environmental efficiency of the building materials supply.

Minimization of Building-Related Waste During the Construction Processes

A large amount of waste is generated during transformation of building materials in the construction process. Energy embedded in construction waste could be important and could carry adverse environmental impacts as long as it is not properly handled [18]. Raising awareness of embodied carbon is a start and by performing BIM more housing components could be assessed for waste generation. BIM also works well with prefabrication where the housing design can use standard panel sizes and so on and waste therefore can be limited [18].

Planning in Accordance with Recent Efforts for Standardization of Embodied Carbon

Embodied energy limits

The system limits define the number of energy, transport, workmanship, design and material inputs that are considered in the embodied energy calculation. Stages, such as raw material extraction in remote upstream, and demolition and disposal in the farthest downstream, should be included in system boundaries [4]. As a result of research studies with different system boundaries their measurement figures vary and cannot be compared with each other [1].

Methods of embodied energy measurement

Major parts of embodied energy analysis are process analysis, statistical analysis, input/output analysis and hybrid analysis (process-based hybrid analysis and input/output-based hybrid analysis). The Process-based analysis is one of the most widely used one of embodied energy analysis, as it delivers more accurate and reliable results [21]. Results of disparate embodied energy and LCA methods differ widely and their level of accuracy is not high. As a result, their embodied energy conclusions can be differed [10]. Process analysis is accurate, as it takes into account energy and material input in each process. A different of LCA tools, along with data sets of environmental impacts of building materials such as ATHENA (Database + Tool), Bath data (Database), BEES (Tool), Gabi (Database + Tool) provide approach to determine life cycle impacts of a housing. However, most of these do not cover all steps of a building's life cycle [20].

Geographic location of the constructions

Research studies performed in different countries differ from one to another in terms of data relating to raw material quality, traditionally used materials, depending on the climate of the materials used, production processes, level of economic development, delivered energy generation, transportation distances, energy tariffs, energy use (fuel) in transport, and human labor. This eventually affects the determination of energy consumption significantly, subsequently embodied energy [4, 10].

Updates in database of measurement

Research studies based on previous and current data sources could differ significantly as a result of the changing technology of manufacturing and transportation. Technological developments such as change of fuel type and old transportation methods could affect energy values. Any study based on such different data sources could be captious and uncertain, and thus the end results could vary considerably [10].

Technology of manufacturing processes

Differing technologies of material manufacturing possess assorted levels of energy consumption, as advanced technology could consume less energy due to energy efficient processes and developed energy management methods. As an example, in the same location and same period, two studies could generate different results if they are extracting information from two different material manufacturers using different technologies [10]. Technology used in manufacturing process can cause an important difference that should be taken into account in order to eliminate unreliable and variability of results [20].

Conclusion

Buildings are responsible for % 40 of total energy in their life cycle stages of buildings in the world and for one third of global greenhouse gas emissions as well, in developed and developing countries. Life cycle energy usage of buildings is based on the operating energy (80–90%) and the embodied energy (10–20%) which ultimately has an increasing unfavorable effect on climate change. Proper technologies and strategies would play main role to reduce embodied carbon. Besides, quality of raw material, production processes, design of buildings, development level of countries, use of local materials, transportation of produced materials, type of energy in transport and calculation methods of embodied energy can show a wide variety from one geographical region to another one and calculated embodied energy without considering those parameters cannot be compared with each other and therefore any standardization of embodied energy generated in buildings cannot be obtained. These concerns provide a more integrative and accurate approach to calculate a building's embodied carbon in the housing life cycle assessment considering all relevant aforementioned parameters.

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