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The role of multi-story structural building systems on reducing embodied energy consumption and carbon emissions

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Abstract. During the last decades many structural building systems were implemented in multi-story buildings production. Each of these systems consumes energy and produce carbon emissions from the early stage from the extraction of materials to the construction of a building. The selection of structural building systems with low embodied energy and carbon emissions reduces the impact of buildings on the global environment. The purpose of this research is to make a comparison in embodied energy consumption and carbon emissions between the most conventional building structural systems for multi-story building in Iraq. Through examine different solutions for structural building systems. This research aims to identify the most efficient structural building systems and materials in embodied energy consumption and carbon emissions for multi-story buildings in Iraq. Results demonstrated that the building of reinforced concrete structure has provided better results and consumed less embodied the energy and carbon emissions, as compared to the pre-cast concrete and steel structural building systems.

1. Introduction

Several recent studies have attempted to test the energy efficiency, carbon emissions in structural buildings systems and materials. Kumar et al. [1] had studied the energy efficiency for two different structural materials for small buildings samples (fire clay bricks and ash blocks) and the results for the study showed that ash blocks reduce energy for that used cooling the building. Jayasinghe [2] has studied the effect of different building materials on energy consumption from product of the material to the use and operation, this study compare between conventional and alternative building material, and also between systems of building. The result of this study appears that the alternative building and systems material have lower energy consumption according to conventional types. Bribian et al. [3] compared of life cycle assessment between common building material (Steel, aluminum, copper, PVC and glass), and recently sustainable materials (Brick and tiles, insulation materials, cement and concrete, wood products) in their energy and water consumption. The aim was to develop the guideline of selection materials for new buildings and rehabilitation of existing buildings. Lee et al. [4] have studied the impact of different building materials on the energy consumption, the results showed that concrete structure is more significant in embodied energy than that of the steel or the hybrid structure. From the review of recent researches, it can be concluded that research problem is no obvious study that compares in embodied energy consumption and carbon emissions between the most conventional building structural systems for multi-story building in Iraq. So, the research hypothesis is that "structural building systems have an effect on reducing embodied energy consumption and carbon emissions".

IOP Conf. Series: Materials Science and Engineering **518** (2019) 022031 doi:10.1088/1757-899X/518/2/022031

2. Embodied energy consumption for Building structural systems

The construction industry is one of the largest consumers of raw materials in the world. There is a general trend toward the reduction of raw materials consumption and of non-renewable resources in particular. The reduction of waste in these resources during the production and construction processes. As well as the possibility of reuse and recycling of materials after demolitions. So that the quality of the recycled material approaches the level of its original quality. The building's consumption of energy starts from its early stages of design and construction (from the extraction, classification, processing, and transfer of building materials), as well as the energy consumed by the construction activities themselves. The energy that used for the production of building materials that defined as potential embodied energy, which can be defined as the "quantity of energy required to process, and supply to the construction site, the material under consideration. In order to determine the magnitude of this embodied energy, an accounting methodology is required that sums the energy inputs" [5].

2.1 Embodied Energy consumption for building materials

Materials differ in the amount of energy needed to produce it; the energy inherent in building materials gives an indicator or a measure of energy that will enter the life cycle of the building. Thus, the selection of materials with low potential reduces the impact of buildings on the environment. The use of local materials instead of imported reduces transport capacity. The energy of the manufacture of building materials was classified on the basis of the energy consumed, which is the total energy required by the production unit weight of the material and was classified into three sections according to energy consumption, namely:

- High-energy materials
- Medium-energy materials
- Low energy materials [6].

Table 1. The energy of producing construction materials

The material	The potential energy Mj/kg
High energy material	
Aluminum	218
Plastics	80.50
Iron	25
Medium energy materials	
Cement	4.5
Asphalt	2.8
Brick	3
Reinforced concrete	1.04-1.9
Cement blocks	0.6-0.8
Thermostone Block	0.85
Concrete	0.75
Reinforced concrete	1.1
Precast Concrete	2
Low energy materials	
Sand	0.08
Gravel	0.08
Stone	1.26

2.2 Embodied Energy consumption for Building structural systems

Conventional building systems in Iraq can be divided into two basic types, load bearing construction and Skelton building construction, the second type used in multi-story building cause of the lightweight and economic considerations, and thus can be divided also into steel and concrete (reinforced and pre-cast) structural systems. Table 2 shows the amount of energy needed to produce building system types known locally [7]. (Fernandez 2008)

IOP Conf. Series: Materials Science and Engineering **518** (2019) 022031 doi:10.1088/1757-899X/518/2/022031

Table 2. The energy to produce building system types

Building system	**The potential energy GJ/m^2**
Steel structure	5.06
Concrete structure	3.8

3. Carbon emissions for Building structural systems

Carbon dioxide is a component of atmospheric gases. In recent decades, industries have increased the concentration of carbon dioxide and other greenhouse gases, such as methane in the atmosphere, from natural levels. The carbon emissions from building industry is a remarkably appears in the whole world, there is a trend towards reduction of it, with the raw material to produce it and calculate than transition to the site of building. There are several ways to measure the concentration of carbon dioxide, one of them is the embodied carbon coefficients that depends on the measurement of amounts of emissions from the construction industry, which vary according to the type of material and the method of extraction and then converted and delivered to the construction site. Table 3 shows the amount of embodied carbon coefficients that produce from building materials [8].

Table 3. The amount embodied carbon coefficients from building materials.

The material	**EC .CO^2/kg**
High energy material	
Aluminum	8.24
Plastics	2.73
Steel	2.82
Medium energy materials	
Cement	0.194
Asphalt	0.06
Brick	0.23
Reinforced concrete	0.185
Cement blocks	0.7
Concrete	0.1
Precast Concrete	0.2
Low energy materials	
Sand	0.004
Gravel	0.005
Stone	0.073

Table 4 shows the amount of Co_2 emissions that produce from building system types known locally. (Fernandez 2008)

Table 4. The amount of Co_2 emissions that produce from building system types known locally

Building system	**Co_2 emissions t /m^2**
Steel structure	0.36
Concrete floor	0.4

4. Methodology

The present research studied different types of common multi-story structural systems. The simulation was made using Rivet. The shape of sample building was rectangular. The area of floors 1000 m^2 with 5 stories levels. This sample was tested in case of being freestanding (isolated), and for different structural systems (reinforced concrete, precast concrete, and steel). Analysis was performed for embodied energy and carbon emissions.

The embodied energy consumption for a sample structure system was calculated according to the following equation.

$$EE = PE \times M \quad (1)$$

Where *EE* is the total embodied energy for a sample structure system in *Mj*, and *M* is the mass of a sample structure system in *Kg*, that can obtained through the multiple of volume of building columns and floors in $m^3$and the density of materials in Kg/m^3.

1- The Carbon emissions for Building structural systems a sample structure system was calculated according to the following equation.

$$EC = EC \times M \text{ ……..eq} \quad (2)$$

Where *EC* is the total embodied carbon for a sample structure system in *Mj*, and *M* is the mass of a sample structure system in *Kg*, that can obtained through the multiple of volume of building columns and floors in $m^3$and the density of materials in Kg/m^3.

5. Results and Discussions

The results show the effect of multi-story structural building systems on reducing embodied energy consumption and carbon emissions**,** which was different in each tested case.

5.1 The effect of structural systems on embodied energy

The tested structural systems include common multi-story structural systems (reinforced concrete, precast concrete, and steel) with a rectangular floor plan as shown in Figure 1**,** and the result is shown in Tables 5.

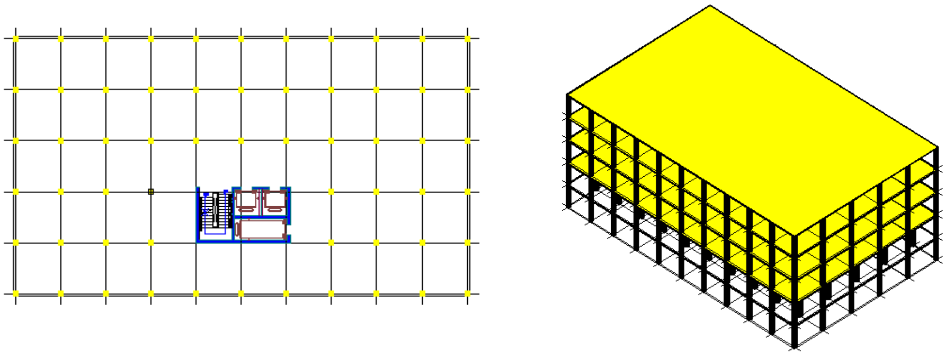

Figure 1. The floor plan and isometric for a sample building

Table 5. The effect of structural systems on embodied energy

Energy consumption for structural building systems		**The potential energy Mj/kg**	**Volume of building columns and floors m^3**	**Density of materials Kg/m^3**	**Mass of building columns and floors kg**	**Total energy Mj**
1-Concrete building			2664	2400	6393600	7032960
2- Pre-cast Concrete building			2664	2400	6393600	1278720
3-Steel building	A-Column		HP 12*84 ASTM A6 125Kg/m	7850	165000	45191942
	B-Beam		I 10*35 ASTM A6 52Kg/m	7850	62400	2202720
	C-Concrete		1200	2400	2880000	3168000
	Total energy					50562662

IOP Conf. Series: Materials Science and Engineering **518** (2019) 022031 doi:10.1088/1757-899X/518/2/022031

As shown in Tables 5, the building of reinforced concrete structural provided better results and consumed less embodied energy. Steel structural building increased consumption by 70% as compared to the concrete structural building. Respectively precast concrete structural building increased consumption by 17%, compared to the concrete structural building. Figure 2 show the embodied energy consumption for each structural building system.

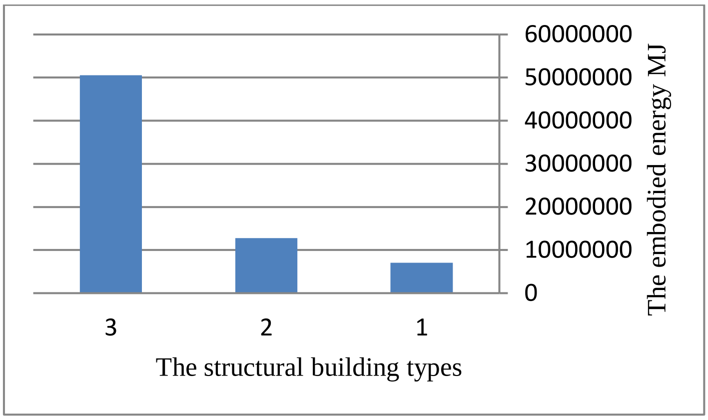

Figure 2. The embodied energy consumption for each structural building system

5.2 The effect of structural systems on embodied carbon emissions

The results of the tested samples on embodied carbon emissions are shown in Tables 6.

Table 6. The effect of structural systems on embodied carbon emissions

Embodied carbon emissions for structural building systems		**The EC CO^2/kg**	**Volume of building columns and floors m^3**	**Density of materials Kg/m^3**	**Mass of building columns and floors kg**	**Total Embodied carbon emissions in Kg**
1-Concrete building		0.185	2664	2400	6393600	1182816
2- Pre-cast Concrete building		0.2	2664	2400	6393600	1278720
3-Steel building	A-Column	2.82	HP 12*84 ASTM A6 125Kg/m	7850	165000	465300
	B-Beam	2.82	I 10*35 ASTM A6 52Kg/m	7850	62400	175968
	C-Concrete	1.1	1200	2400	2880000	3168000
	Total energy					3809268

As shown in Tables 6, the building of reinforced concrete structural provided better results in carbon emissions. Steel structural building increased carbon emissions by 68% as compared to the concrete structural building. Respectively precast concrete structural building increased carbon emissions by 10%, compared to the concrete structural building. Figure 3 shows the embodied energy consumption for each structural building system.

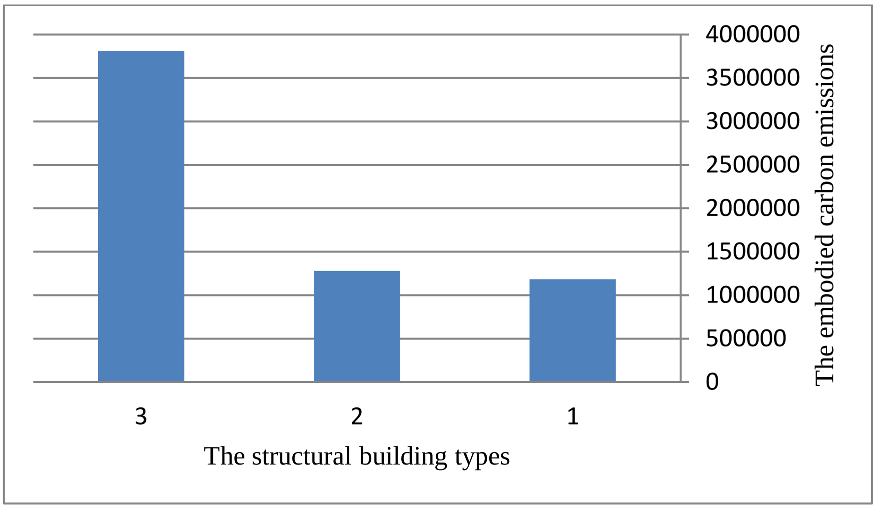

Figure 3. The embodied carbon emissions for each structural building system

6. Conclusion

The most affected conventional structural building system in Iraq that reducing embodied energy and carbon emissions is the reinforced concrete system. Steel structural building increased embodied energy consumption by 70% as compared to the reinforced concrete structural building. Respectively precast concrete structural building increased consumption by 17%, compared to the reinforced concrete structural building.

The embodied carbon emissions for steel structural building increase by 68%, as compare to the reinforced concrete structural building. Respectively precast concrete structural increased carbon emissions by 10%, compared to the concrete structural building.

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