Decreasing the CO2 Emissions and the Embodied Energy during the Construction Phase in the UAE through the Selection of Sustainable Building Materials

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ABSTRACT

A great quantity of CO2 is emitted to the atmosphere during the different phases of a building's life cycle: in the production of materials and products, in the construction of the building itself, in the setting up of the site, in the exploitation, the renovations, the later rehabilitations, up to the final demolition. The present paper shows the possibility of reducing the embodied energy in building materials up to 55% and the CO2 emissions produced up to 43% in the construction phase, through a careful selection of sustainable building materials. The purpose of this study is to quantify the total amount of CO2 emissions and embodied energy that can be saved by the method presented in the particular phase of the material selection within the life cycle of a building. This material selection, as well as the bioclimatic characteristics, must be defined from the early design project phase. The research presented here has been carried out as a case study on an existing high-rise residential building in the UAE constructed in a conventional way and with no specific selection of materials. The building is compared to a hypothetically created building with similar characteristics but using sustainable building materials.

KEYWORDS: Construction CO2 Emissions, Embodied Energy, Sustainable Materials.

1. INTRODUCTION

Located in Southwest Asia on the Arabian Peninsula, the United Arab Emirates (UAE) is a federation of seven Emirates – Abu Dhabi, Dubai, Sharjah, Umm Al Quwain, Ajman, Ras Al Khaimah and Fujairah , which spans approximately 83,600 square kilometers. The UAE has an arid climate. Summers are very hot, stretching from April through the month of September, with temperatures reaching as high as 48 degrees Centigrade in coastal cities with levels of humidity reaching as high as 90% (UAE Interact, 2006). The discovery of oil in 1958 in Abu Dhabi and 1966 in Dubai transformed the economy dramatically, enabling the country to move away from a surviving economy toward a modern, industrial base. Total estimated oil reserves in the UAE are about 98 billion barrels, or nearly 10% of the worlds proven oil reserves. The Emirate of Abu Dhabi has about 94% of the UAE's total reserves. Coupled with strong government policies for liberalization of the economy, it has grown significantly into one of the most open in the Middle East. Income levels per capita today in the UAE are among the highest in the Arab world.

This economic boom has led to the development of a number of new service sectors and hubs of non-oil industrial activities. Cities like Abu Dhabi and Dubai have emerged as an active international trading center, combined with a large tourism sector and dynamic real estate markets (Initial National

Communications, 2006). As a result of this economical and population growth, industrial process and real estate boom. The UAE is considered the second country after Qatar in CO2 emissions per capita as shown in Figure 1 with annual emissions of 28,213 kilograms of CO2 per 1000 people. If the total population for the year 2003 is 4,041,000, then the total emissions of that will be 114,008,733 kilograms of CO2 (Nation Master Facts and Statistics, 2007).

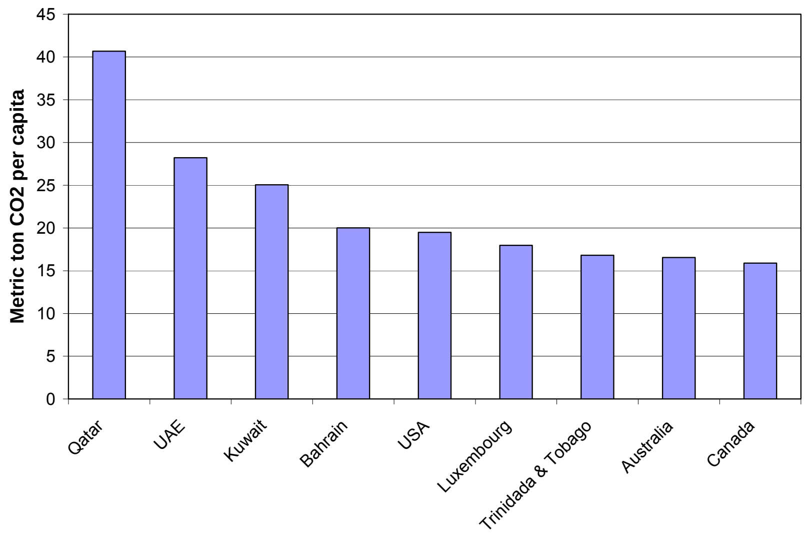


Figure 1. Top 10 countries in CO2 emissions per capita (Nation Master Facts and Statistics, 2007)

In 1994, the UAE compiled its first-ever inventory of greenhouse gas emissions. Energy-related CO2 emissions from fossil fuel production and combustion are (60,246Gg) which is about 95% of the total CO2 emitted. Also, Industrial processes account for about 4% of CO2-equivalent emissions, almost all of it in the form of carbon dioxide. Waste management activities account for about 3% of CO2-equivalent emissions, virtually all of it in the form of methane. Manufacturing and construction industries emits (24,764Gg) of CO2 to the atmosphere which is about 39% of the total CO2 emissions, throughout the different phases of a building life cycle: in the manufacturing of materials and products, in the construction of the building itself, in the setting on site, in the exploitation, the renovations, the later rehabilitations, up to the final demolition. Agricultural production, accounts for about 2% of overall CO2- equivalent emissions (Initial National Communications, 2006).

CO2 emission reduction in the construction of buildings is feasible by starting to follow different working lines in the UAE. As is known, the first one is the use of District Cooling which has proven to be a major contributor to Greenhouse Gas reduction in many cases. The use of passive solar energy; to reduce the expenses of cooling. Also, the use of photovoltaic solar energy; in the production of electric energy for consumption in buildings. All these belong to the operation phase of the building, and they are relatively known and considered in the UAE. Nevertheless, there are other ways to reduce CO2 consumption starting at the early construction stages. In the design phase, the designer can make important decisions to define a bioclimatic design and to establish the future lines in selecting construction materials for the building phase. Both items, design and construction materials, are closely inter-related, the first one depends upon the other, and vice versa. The design depends on the way the construction materials have been selected and have to be used. The correct selection of materials and products must be done in order to save energy, as well as to reduce CO2 emissions. Therefore, the aim of this research is; to assess the possible reduction in the CO2 emissions and the embodied energy produced by building materials, when hypothetically replaced with sustainable building materials. An eighteen story residential tower, built in the emirate of Abu Dhabi using conventional building materials will be the case study building because such buildings are dominant in the UAE, and building materials used in their construction result in most of the CO2 emissions and have the highest content of energy comparable with other types of buildings.

Figure 2 shows the relative contribution of the main sectors in terms of CO_2 emissions (Initial National Communications, 2006). This figure clearly shows the role of the construction industry as the main contributor to the UAE's CO_2 emissions. Thus any reduction in the emissions of this industry will be very influential. This is the main drive for this work.

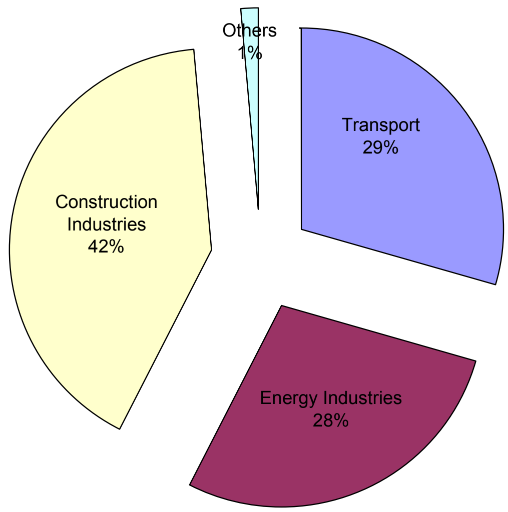


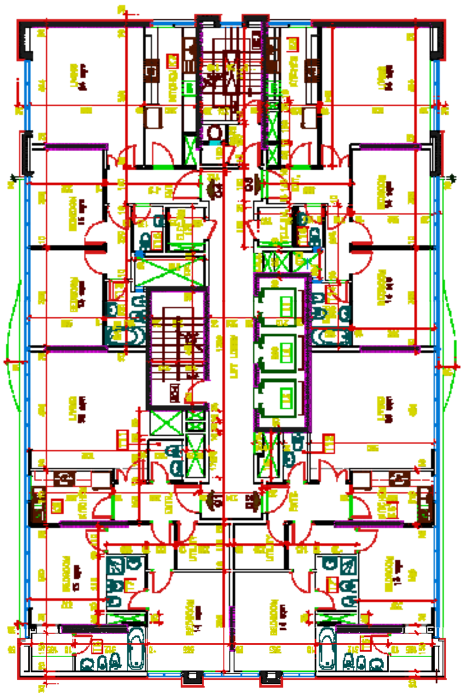
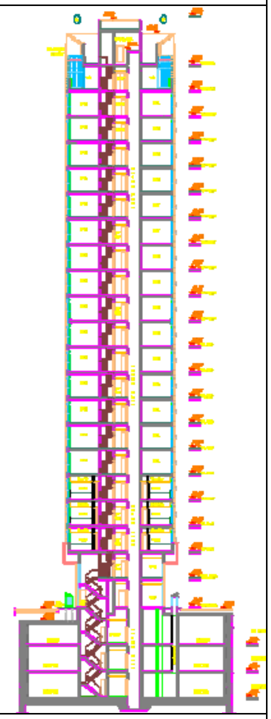
Figure 2: Relative CO_2 emissions in the UAE by sector

2. PARAMETRIC STUDY

The project was carried out following the main principles in general architecture where the design integrates typical solutions to adapt the building to the harsh climatic conditions such as: the use of mechanical air conditioning and electrical lighting. No considerations could be done towards the site location or the orientation of the building because of previous urban planning decisions, where Abu Dhabi city was planned 40years ago to a flat city with a linear plan, vertically divided it into two semi symmetrical halves with a main road in-between as the spine of this division 47. The building is similar to most buildings in the UAE where the elevations are fully glazed with aluminium cladding and other parts are covered with marble or tiles. The building materials used are the typical construction materials of similar buildings in the UAE. These materials are called “conventional” building materials. The definition of what a ‘‘conventional’’ material is, depends to a great extent on the parameters. In a systematic way, the construction of a high rise residential building in the UAE, is developed with a reinforced concrete structure, concrete blocks walling, rock wool, polyurethane or polystyrene insulation, aluminium framed double glass windows, MDF and hardwood doors, marble and ceramic floor finishing, chemical paintings and interior wood treatment in PVC. Most of these materials are imported in huge quantities to meet the tremendous growth of construction development and industry in the UAE. Sustainable strategies were not considered in the design of this building. Some energy efficiency techniques are implemented to the building services but their contribution is too small to energy saving. All the details related to the case study building such as: Location, cost and building materials used are listed in Table 1 below.

Table 1. Details of the Building used in the current Case Study.

Case Study Details	
Location	Tourist Club Area in, Sector E-13, and Plot C-55
Country	Abu Dhabi, UAE
Construction Cost	DHS 55,500,000
Construction Period	15 months, similar to the construction time period of any other conventional residential tower in the UAE
Developed by	Private developer (owner)

Typical Plan	**Elevation**	**Section**
		

Area Breakdown		
Level	Facility	Area in m2
Basement floor (4 floors)	Car Parking for 54 cars & services	1,150 x 4
	Sub Total	*4,600*
Ground floor	Show room	87
	Circulation and Services	222
	Sub Total	*309*
Mezzanine floor	Offices	220
	Circulation and Services	144
	Sub Total	*364*
Typical floors 1st, 2nd and 3rd	(12 nos.) 1 Bedroom apartment	777
	(3 nos.) 2 Bedroom apartments	252
	Circulation and Services	420
	Sub Total	*1,449*
Typical floors 4th to 18th (15 nos.)	(60 nos.) 2 Bedroom apartments	5,220
	Building Services	2,025
	Sub Total	7,245
Roof level	Building Services	365
		Grand Total: 14,332m2

In order to estimate the CO_2 emissions and the embodied energy in the building materials used, all the different work units should be measured in kilograms. For the conversion into weight measures, some of the materials were in the state of volume in cubic meter, others were measured as an area in square meter and the rest as items. With consideration to each material characteristic, the density of each material was obtained as per the international standards (Specific gravity of metals, 2007) and multiplied with the specified volume given in the projects documents or obtained manually in most cases, the result was the weight in kilograms. The calculated weight of concrete, steel, block work, wood, waterproofing, aluminium, glazing, marble and ceramic 57 tiles is shown in Table 2. Some other building materials and components that contribute to the dead load of the building were excluded such as paint, sanitary ware, electrical works and mechanical works because their weight is small in comparison with other materials such as concrete and steel. In addition, in most cases it was not possible to figure out the volume and the density to calculate the weight. Table 2 shows that concrete is the major building material that occupies 61.5 % of the total building weight. Steel comes in the second place with a percentage of 19.9% and block units in the third place with a percentage of 13.7%, the rest of the building materials has similar contribution in comparison with their actual used quantity in the building. Finally, the total building weight is approximately 22,000,000 kilograms.

Table 2. Weights and percentages of Building Materials in the case study building.

Building Material		Weight (Kg)	Percentage %
1.	Concrete	13,523,088	61.5
2.	Steel	4,366,348	19.9
3.	Block work	3,015,246	13.7
4.	Wood	209,346	0.95
5.	Roofing and Waterproofing	585,118	2.66
6.	Aluminium curtain walls + Doors + cladding	58,598.1	0.27
7.	Glass windows	53,823.73	0.24
8.	Marble	3,8651.48	0.18
9.	Ceramic tiles	128,548.5	0.58
	Totals	21,978,768	100

In order to estimate the CO_2 emissions and the embodied energy produced by the case study building. The main building materials that highly contribute to the weight of the building like: concrete, steel, and block work and the materials with high embodied energy and high embodied carbon like: aluminium will be the main focus of this study. So, the weights of these materials are multiplied first with the specific embodied energy and embodied carbon values of each material separately. the results are shown in Table 3.

Table 3: Embodied energy and CO2 emissions estimate in construction materials of the case study building.

Conventional Materials in Case Study Building	**Weight in Kg**	**Embodied Energy**		**Embodied Carbon**	
		Typical UK MJ/Kg Factor	Total (MJ)	Typical UK KgCO2/Kg Factor	Total (KgCO2)
Concrete (other)	5,710,588	1.43	8,166,141	0.211	1,204,934
Concrete (slabs)	7,812,500	1.43	11,171,875	0.211	1,648,438
Steel (others)	1,388,164	19.7	27,346,831	1.72	2,387,642
Steel (slabs)	2,978,184	19.7	58,670,225	1.72	5,122,477
Block work	3,015,246	3.00	9,045,738	0.2	603,049
Aluminium	58,598	210	12,305,601	31.5	1,845,840
Glass	53,824	13.5	726,620	0.77	41,444
Totals	**21,017,104**		**127,433,013**		**12,853,824**

This table shows a comparative relation of emissions by material type. Where, a conversion of the embodied energy was carried out, in MJ/kg units and in KgCO2 in terms of CO2 emissions. This conversion was applied to all the constructive elements. The translation of energy used in embodied energy and embodied carbon is a work of hypothesis, because it was assessed by the data obtained from The Inventory of Carbon & Energy (ICE), version 1.5 Beta by Geoff Hammond and Craig Jones, (2006), Department of Mechanical Engineering, and University of Bath, UK . Whereas, after a thorough search in literature, books, electronic documents and internet. Figure 3 shows the weight specific embodied energy and CO2 emissions for the conventional building materials. Figure 4 shows the overall embodied energy and CO2 emissions contributions of the material shown in Table 3.

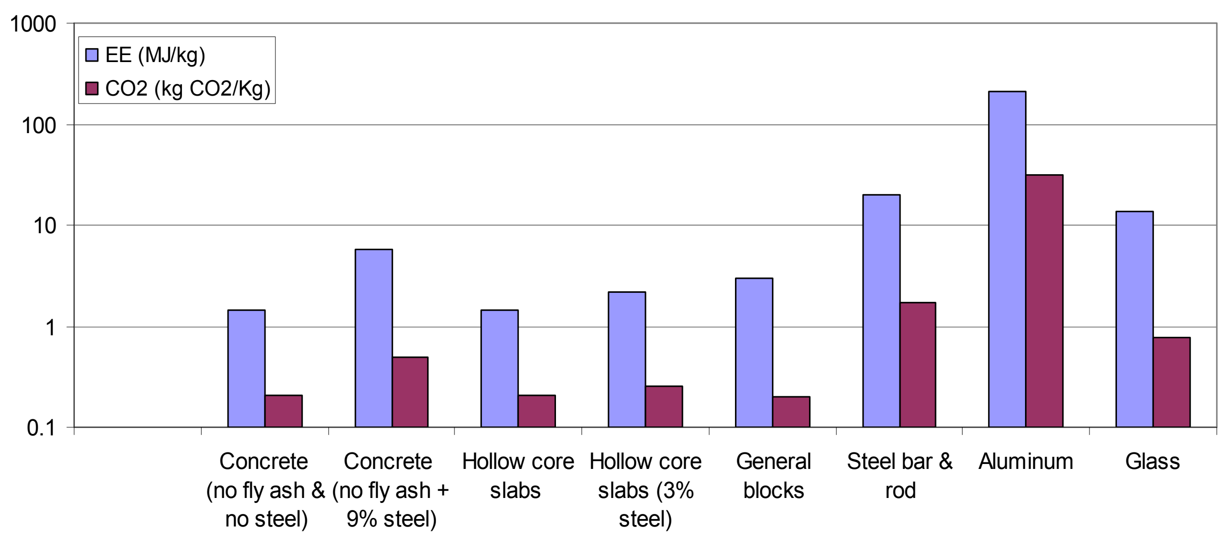


Figure 3. Comparison between the Weight Specific Embodied Energy and the CO2 Emissions Factors for the Conventional Building Materials.

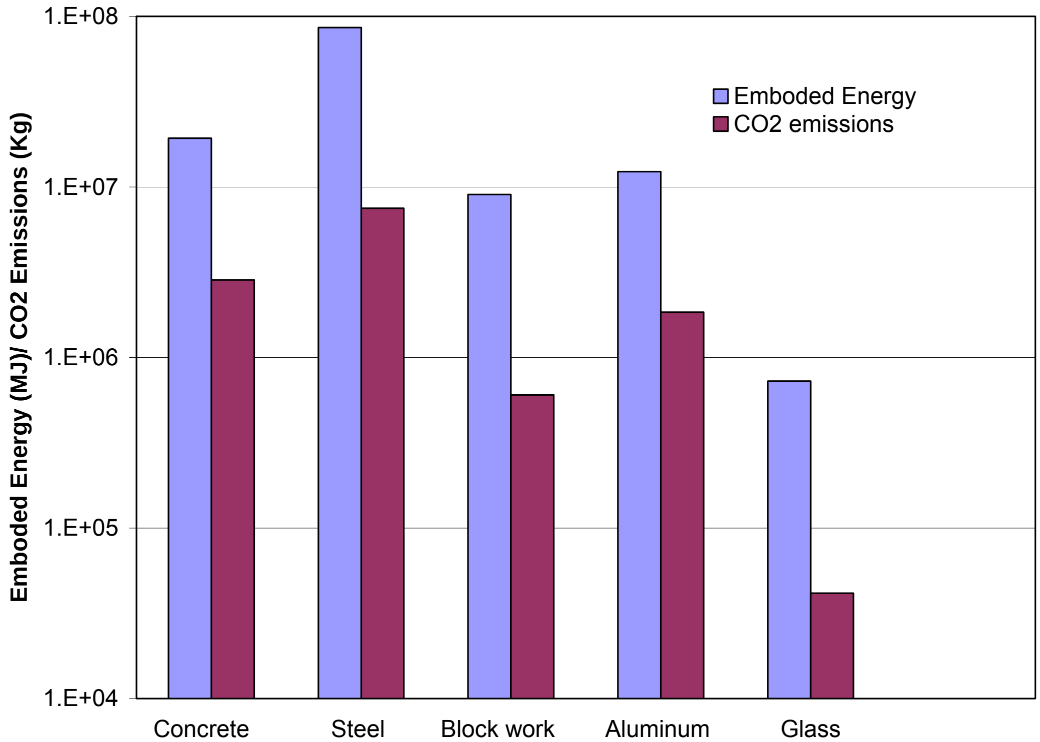


Figure 4. The Overall Embodied Energy and CO2 Emissions Contributions of the Building Material Shown in Table 3.

3. RESULTS AND DISCUSSION

There are two main scenarios of reduction a building's related embodied energy and CO_2 emissions:

1) Reduce the weight of the building, i.e. use less of the conventional building materials.

2) Use alternative building materials which has lower embodied energy/ CO_2 emissions.

These scenarios were translated to different options of alternative building materials with sustainable features for the main building materials of the case study building. Following is a list of the main alternative building materials considered in this study:

- High performance concrete with high volume fly ash replacing 15%-50% of the ordinary Portland cement (OPC), (Mehta, 2003).
- Concrete with 20% of reclaimed aggregates (Anink et al, 1996). Contains crushed concrete, brick, masonry waste and crushed glass.
- Recycled steel (steel manufactured with 20% recycled content, 14% is post-consumer) (Woolley et al, 2000).
- Pre cast hollow core slabs.
- Autoclaved Aerated Concrete-A.A.C (Delmon AAC Factory, 2007). Can be used for external walls , lightweight partition walls , roof thermal insulation tiles and floor blocks.
- Aluminium cladding with recycled Aluminium

- Glass with 50% recycles glass.
- Cork, cellulose (is a by-product of waste paper) for wall insulation (Anink et al, 1996)

Figure 5 shows the weight specific embodied energy and CO2 emissions for the alternative building materials.

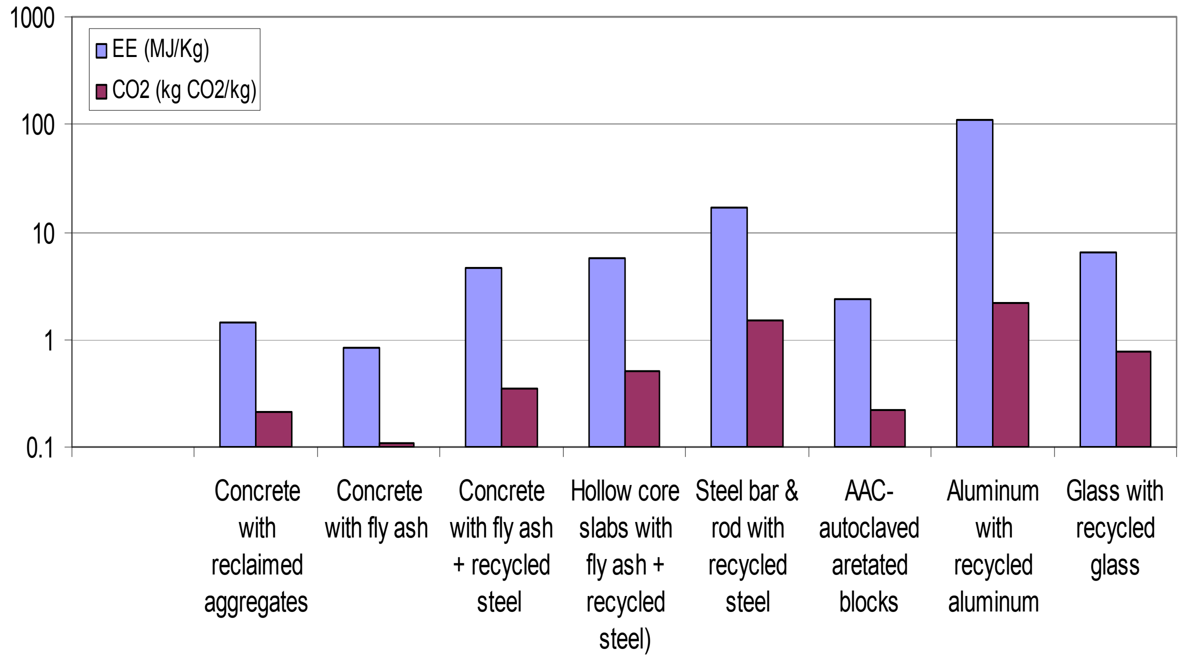


Figure 5. The Weight Specific Embodied Energy and the CO2 Emissions Factors for the Alternative Building Materials studied.

Figure 6 shows the percentage reduction in the embodied energy and CO2 emissions associated with each of the alternative building materials shown in Figure 5. Based on these values, the case study building was "virtually re-built" using the best combination of the alternative materials presented earlier. Doing so resulted in significant reduction in the building's weight (12%), total embodied energy (53%) and CO2 emissions (59%). Figure 7 compares the overall data for standard and "re-built" building. The reduction in embodied energy and CO2 is partly due to the reduction on the building's weight but mainly due to the lower weight specific embodied energy and CO2 emissions of the alternative materials used.

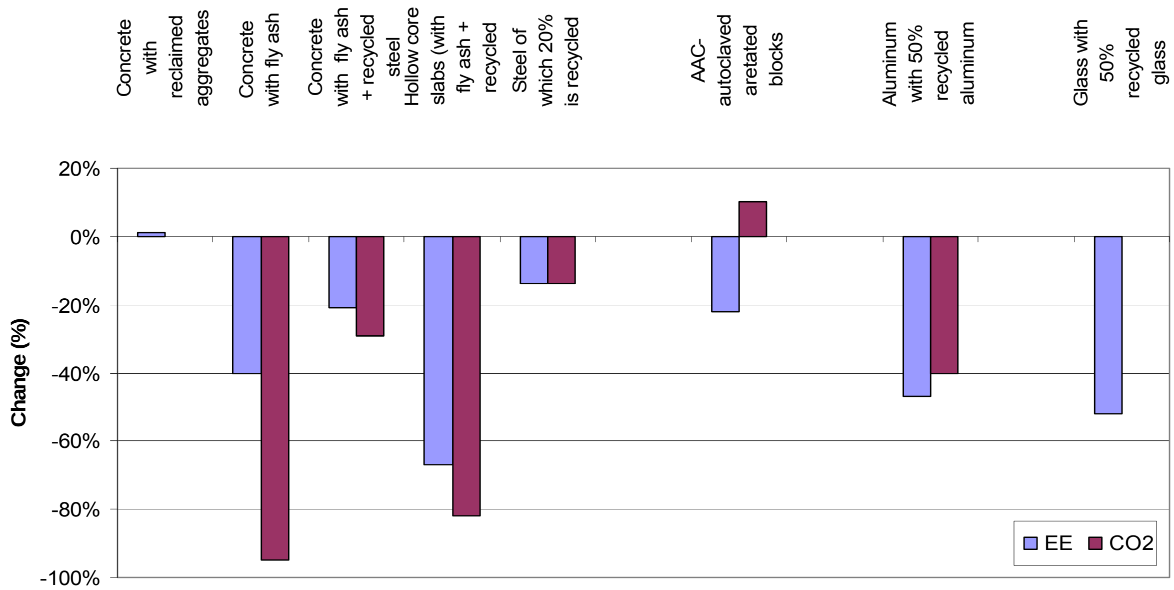


Figure 6. Percentage changes in the embodied energy and the CO2 emissions in case of using the alternative building materials.

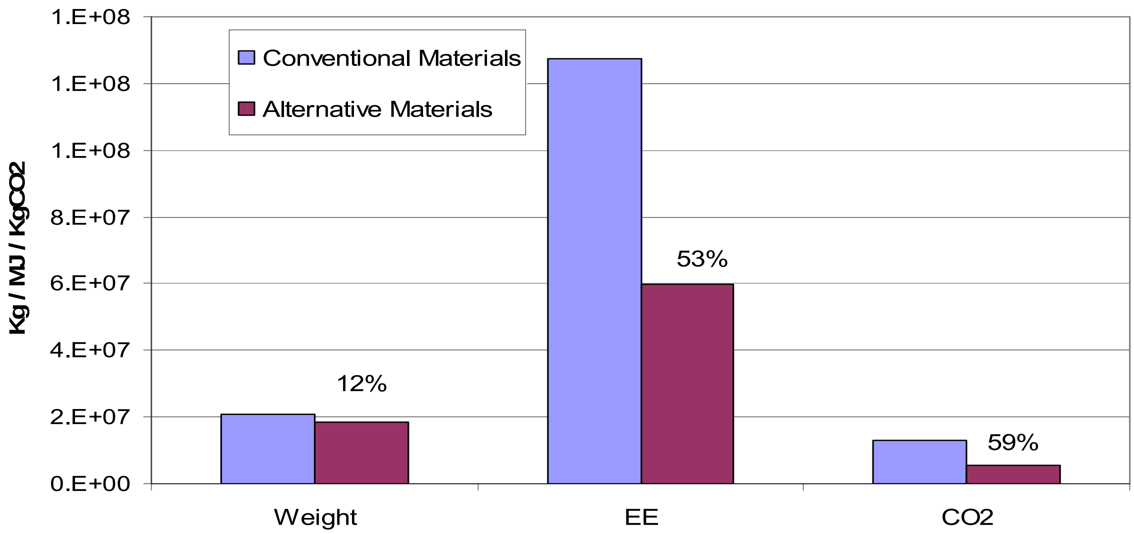


Figure 7. Overall weight, embodied energy and CO2 emissions of the building using conventional and alternative building materials, percent reduction shown for the alternative materials.

4. CONCLUSIONS

The focus of this study was to examine ways of reducing CO2 emissions and embodied energy related to building materials during the construction phase through the following strategies:

- Consider building materials that can reduce the total weight of the building, which relatively will contribute to the reduction of the embodied energy and the CO2 emissions such as concrete.

- Consider building materials with sustainable features as alternatives for materials that have high-embodied energy and embodied carbon factors such as aluminium.

The results showed:

- A total weight of the building was reduced up to 12%.
- The total embodied energy is reduced up to 53%
- The total CO2 emissions are reduced up to 59%.

These figures show great potential; in enhancing the sustainability of the building through the proper selection of alternative building materials with sustainable features. Although, they have to be revised to take into account the CO2 emissions and EE associated in the recycling process.

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