DECREASING THE CO2 EMISSIONS AND THE EMBODIED ENERGY IN THE UAE THROUGH THE SELECTION OF SUSTAINABLE BUILDING MATERIALS IN THE CONSTRUCTION PHASE

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SUPERVISED BY
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Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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Statement 1

This dissertation is being submitted in partial fulfillment of the requirements for the degree of MSc in Sustainable Design of the Built Environment.
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This dissertation is the result of my own independent work/investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references.

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Abstract

A great quantity of CO_2 is emitted to the atmosphere through the different phases of a building life cycle: in the production of materials and products, in the construction of the building itself, in the setting of the site, in the exploitation, the renovations, the later rehabilitations, up to the final demolition.

The purpose of this study is to quantify the total amount of CO_2 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. As a result, the research shows the possibility of reducing the embodied energy in building materials up to 53% and the CO_2 emissions produced up to 59% in the construction phase, through a careful selection of building materials with sustainable features.

The research presented here has been carried out on a real case study of a high-rise residential building in the UAE constructed in a conventional way and with no specific selection of materials, comparing it with a hypothetically created building with similar characteristics but using building materials with sustainable features.

………To my dear parents and my beloved daughter, Raudah

Acknowledgments

I would like to express my personal appreciation to Dr. Bassam Abu Hijleh, Head of the Built Environment Institute for supervising and directing my scientific investigation that led to this research.

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1.0 Introduction

1.1 Background

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, 2007).

The discovery of oil in 1958 in Abu Dhabi and in 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).

In 1994, the UAE compiled it's first-ever inventory of greenhouse gas emissions. Energy-related CO2 emissions[1] 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.

[1] CO2 emissions refer to Carbon dioxide, colorless, and odorless gas. Contributor to global warming, formed by combustion processes. Significant overexposure may cause headache, dizziness, restlessness, increased heart rate and pulse pressure, and elevated blood pressure. Used in manufacture of carbonates and as propellant in aerosols (Mendler et al, 2006).

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. A 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[2] produced by building materials, when hypothetically replaced with building materials that has sustainable features. An eighteen story residential tower, built in the emirate of Abu Dhabi using

[2] Embodied Energy accounts for all energy expended for production and transportation plus inherent energy at a specific point of the life cycle of a product. (Mendler et al, 2006).

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 CO_2 emissions and have the highest content of energy in comparison with other types of buildings.

1.2 Research Line and Methodology

- Describe the case study building including the area break down, main building elements and materials used.
- Estimate the total weight of the main building materials in Kilograms.
- Estimate the CO_2 emissions and the embodied energy produced by the building materials used.
- Assess the strategies used to reduce the weight of the building.
- Assess the strategies used to reduce CO_2 emissions and the embodied energy in building materials.
- Estimate the percentage of weight reduction when using building materials with sustainable features.
- Estimate the percentage of reduction in the CO_2 emissions and the embodied energy of the building materials when using building materials with sustainable features.

1.3 Dissertation Structure

The structure of this dissertation is divided into five chapters as followed:

Chapter 1

This chapter begins with an introduction that gives a general idea about the reasons of selecting this topic and the UAE in particular, as the country of data. The research aim is stated clearly and the methodology used is based on a case study.

Chapter 2

This chapter gives a more detailed picture about the UAE, discussing the location climate, pre and post oil discovery in the UAE with all the facts, dates, numbers and figures.

Chapter 3

This chapter is a literature review of the key building materials and the construction development in the UAE. It defines sustainable design, goals, benefits, and features of sustainable building materials. In addition, it presents the life cycle phases of building materials and analyzes two case studies of good practice examples.

Chapter 4

This chapter is the main scope of the dissertation, where it presents the research line and the methodology in full details; to fulfill the aim of this research.

Chapter 5

It includes the conclusions, findings and the recommendations obtained through the process of this study.

2.0 Brief

2.1 Location

The United Arab Emirates (UAE) is a federation of seven Emirates – Abu Dhabi, Dubai, Sharjah, Umm Al-Quwain, Ajman, Ras Al Khaimah and Fujairah. The UAE is situated in Southwest Asia between latitudes 22.0° and 26.5°N and between 51° and 56.5°E longitude. The UAE shares borders with Qatar to the west, Saudi Arabia to the south and west, and the Sultanate of Oman to the east and south.

It occupies an area roughly the size of Portugal. UAE spans approximately 83,600 square kilometers and has approximately 1318 kilo-meters of coastline, with sandy beaches scattered along it (Initial national communications, 2006).

Figure 2-1: The UAE in regional context

The UAE can be divided into three major ecological areas: coastal areas, mountainous areas, and desert areas. Over four-fifths of the UAE is classified as desert, especially in the western parts of the country, however there are oasis's such as Liwa and Al Ain.

Along the Arabian Gulf coast there are numerous offshore islands, salt marshes, and coral reefs. For the most part seawater depth here is less than 10 meters, with an average overall depth of 31 meters and a very narrow tidal range. Along the Gulf of Oman, there are fertile plains and the Hajar Mountain range, which reach an altitude of over 1,300 meters and extend along the northeast border to Oman. The UAE has a diverse and contrasting environment, (UAE Interact, 2007).

2.2 Climate

The United Arab Emirates has a hot arid climate and two main seasons; winter and summer. Although, it is generally warm and dry in the winter, coastal weather brings in humidity along with very high temperatures during the summer months. Winter lasts from November through March, a period when temperatures seldom drop below 6 degrees Centigrade. Summers are very dry, stretching from April through the month of October, with temperatures rising to about 48 degrees Centigrade in coastal cities – and in the southern desert regions, temperatures can climb to 50 degrees Centigrade, (Initial national communications, 2006). Winter daytime temperatures average a very pleasant 26 degrees Centigrade, although nights can be relatively cool, between 12 to 15 degrees Centigrade on the coast. In the depths of the desert or high in the mountains temperature can reach less than 5 degrees Centigrade. In winter, desert areas exhibit large temperature fluctuations during the course of the day and minimum temperatures can approach zero. Humidity in coastal areas averages between 50 and 60 percent, touching over 90 percent in summer and autumn. Inland humidity declines sharply where its annual average reaches 45 percent. Evaporation rates are typically very high, averaging about 8 mm per day. Local north-westerly winds (*shamal*) frequently develop during the winter, bringing cooler windy conditions. Most of the country is subject to violent dust storms with rainfall being infrequent and irregular. UAE is subject to ocean effects due to its proximity to the Arabian Gulf and the Gulf of Oman. A combination of atmospheric depressions and northwesterly winds from the Mediterranean results in much of the rainfall occurs in the winter months, with February and March being the wettest months of the year, (UAE Interact, 2007).

Table 2-1: Mean monthly maximum temperature (Bateen airport, Abu Dhabi) and national mean monthly rainfall.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Temp. in °C	24	25	29	33	38	39	40	40	39	35	30	26
Rainfall in mm	11	38	34	10	3	1	2	3	1	2	4	10

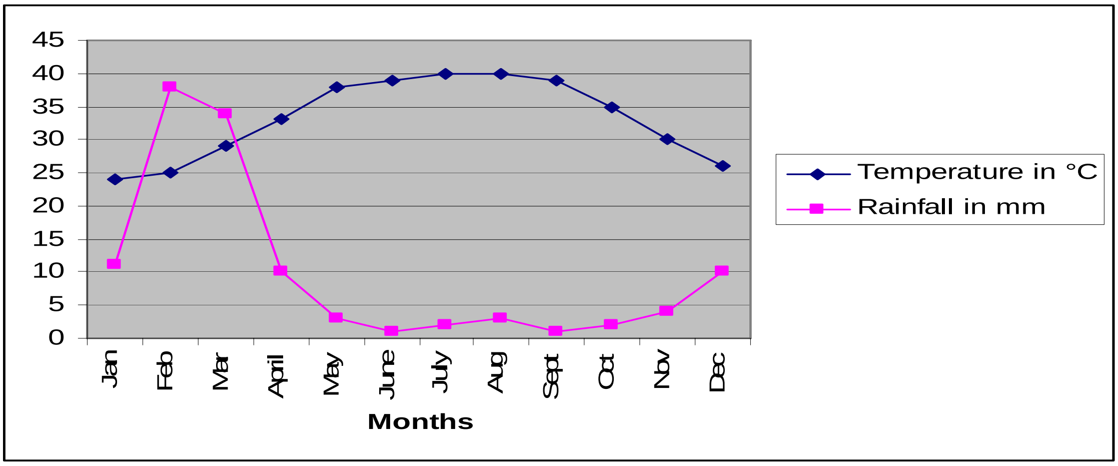


Figure 2-2: Mean monthly maximum temperature (Bateen airport, Abu Dhabi) and national mean monthly rainfall.

2.3 Pre Oil Discovery

The UAE has a history dating back to over 100,000 years ago. Stone tools from the Early Stone Age have been found along the edge of the Hajar Mountains. Archaeological evidence suggests that the earliest human occupation dated from the Neolithic period, 5500 BC or 7500 years ago. Back then, the climate of the UAE was significantly different, it was wetter and food resources were abundant. Before the discovery oil, during the nineteenth and early twentieth centuries, UAE's economy depended on the pearling industry, fishing and herding. Many of the inhabitants were semi-nomadic, pearling in the summer months and tending to their date gardens in the winter. The First World War, world economic depression of the late 1920s and early 1930s, and the Japanese invention of the cultured pearl destroyed this economy. The pearl fishery industry eventually faded away just after the Second World War and the population faced considerable hardship with little opportunity for education and no roads or hospitals. However the discovery of oil in the early 1950's soon changed all those circumstances and the first cargo of crude was exported from Abu Dhabi in 1962. Following the British withdrawal from the Gulf, a federation of initially six and later seven emirates, to be known as the United Arab Emirates (UAE), was formally established on 2 December 1971 with Sheikh Zayed, who had been instrumental in its formation, as its first President and Sheikh Rashid as Vice-President, (UAE Interact, 2007).

Table 2-2: Important Dates for the UAE

Event	Date
Evidence of extensive human occupation in UAE	c.5500 BC
Survey of the Gulf resulting in the publication of the first accurate charts and maps of the area.	1820–1864
Collapse of the natural pearl market; first agreements signed by rulers of Dubai	1930's
Oil discovery	1950's
First export of oil from Abu Dhabi	1962
The Formation of the United Arab Emirates	1971

However what is important to note is that before the discovery of oil, the people of the UAE were simple people that had little possessions that could all be carried on a single camel. Also many of UAE's inhabitants practiced the semi-nomadic lifestyle and depended on the camel for their livelihood. The camel is uniquely adapted to the desert and long periods were spent wandering great distances in search of winter grazing provided by dormant vegetation brought to life by intermittent rainfall. Once the arid summer approached, almost all the tribes, returned to a home in one of the oasis settlements, many to tend and harvest their date gardens. The camel was not just a useful mount and means of transporting possessions and goods on long treks across inhospitable terrain; it also provided food, clothing, household items, recreation, and at the end of the day was a primary source of wealth. In many cases camel milk and the products derived from it were the only protein available to *bedu* families for months on end. The camels were capable of surviving for long periods without water, but it was camels' milk that quenched the herders' thirst. Young male camels were slaughtered on special occasions to provide meat for feasts and informal camel races were held during the festivities. Camel hide was used to make bags and other useful utensils, while tents, rugs and items such as fine cloaks (*bisht*) were woven from camel hair, (UAE interact, 2007). Our ancestors made use of all their resources and nothing went to waste unlike our present generation where the UAE has the largest ecological footprint measured as 11.9 global hectares per person, compared to 9.6 hectares per person for the United States and a global average of 2.2 hectares a person, (USA Today, 2007).

2.4 Population Growth

The current UAE population according to the recent census is 4,104,695 and is the second most populated country among the other five Gulf Cooperation Council (GCC) countries. Since the formation of the UAE the population has increased by 15 times compared to the population in 1971, when it was numbered under 287,000. However, the UAE had over a 70% increase in population in the past decade since 1980 to 2005. This rapid population boom is attributed to the high birth rate among nationals, steady decreases in the infant mortality rate, improvements in life expectancy, and the massive influx of expatriates and foreign labor. The average growth rate stood at around 6.4

percent between 1980 and 1985 after which it peaked up to 7.7 percent from 1986 to 1995 and 8.8 percent from 1996 to 2003. The UAE has one of the highest growth rates in the world (UAE Interact, 2007).

Table 2-3: UAE population

Population Increase					
Year	1970	1980	1995	2000	2005
Population	248,000	1,042,099	2,411,041	3,247,000	4,104,695
Population Breakdown					
Male	Females	Nationals	Non - Nationals	National Males	National Females
67.6%	32.4%	21.9%	78.1%	50.7%	49.3%

The three most populous Emirates – Abu Dhabi, Dubai, and Sharjah - account for roughly 85% percent of total population. The remaining 15% live in Umm Al Quwain, Ajman, Ras al Khaimah and Fujairah. The overwhelming majority of the population lives in urban areas in coastal zones.

Table 2-4: Population by Emirate

Emirate	**1975**	**1980**	**1985**	**1995**	**2003**
Abu Dhabi	211,812	451,848	566,036	942,463	1,591,000
Dubai	183,187	276,301	370,788	689,420	1,204,000
Sharjah	78,790	159,317	228,317	402,792	636,000
Ajman	16,690	36,100	54,546	121,491	235,000
Umm Al-Quwain	6,908	12,426	19,285	35,361	62,000
Ras Al-Khaimah	43,845	73,918	96,578	143,334	195,000
Fujairah	16,655	32,189	43,753	76,180	118,000
Total	557,887	1,042,099	1,379,303	2,411,041	4,041,000

This sharp increase was coupled with high growth in its economy and income.

2.5 Economy Growth

UAE after the discovery of oil has not only undergone a population boom but one can also say that it is experiencing an urban boom. Real Estate and property development is a rapidly growing business in the UAE and the sector is expected to see the total value of developments rise to more than US$50 billion by the year 2010. Some of the biggest operators are AlDar in Abu Dhabi (a Mubadala company) and Nakheel and EMAAR, both based in Dubai. The UAE has been described as the world's most buoyant property market.

In 2005 it dominated the Gulf construction sector with DH130.6 billion (US$35.42 billion) worth of projects under construction, accounting for 63.7% of the total value of projects under construction in the GCC states. Much of the success of the real estate sector is attributable to new property laws that regularize the purchase of land and property for nationals and grant varying degrees of property rights to non-nationals (UAE Interact, 2007).

Table 2-5: GDP at constant prices for 2003–2005 (in million dirham)

Year	2003	2004	2005
Real Estate	23,272	27,046	30,832

According to the year 2005 census, there are 336,815 buildings in the country and 34.9% (117,469) of them are in the Emirate of Abu Dhabi. The total number of housing units in the country is 863,860, of which 60.8% are in the emirates of Abu Dhabi and Dubai. The total number of establishments in the country is 192,247, of which 38.1% (73,294) are in the Emirate of Dubai (UAE Interact, 2007).

2.6 Energy Production in the UAE

In the UAE, the primary sources of energy are fossil fuels whereas; energy supply is dependence on oil and natural gas. Biomass accounts for less than 0.1% of energy supply. GHGs emitted from the energy sector are mainly CO_2, CH_4, and NOx. 85% of Crude oil production and Natural gas production are consumed within the UAE and the balance exported. 30% of the Total energy consumption is consumed in the form of gasoline, diesel, LPG, kerosene, residual oil, and other refined oil products. About 70% is consumed as natural gas, and less than 0.1% is consumed in the form of charcoal. The transport sector is entirely dependent on petroleum, accounting for about 50% of Greenhouse Gas emissions. The electricity sector relies on natural gas for over 96% of its fuel supply, with the balance provided by diesel (3%), residual oil and crude oil (both less than 0.5%). The manufacturing and construction industries also rely heavily on natural gas, with about 85% of total energy consumed coming from this energy source, with the balance provided mostly by residual fuel oil (Initial National Communications, 2006).

2.7 CO2 Emissions in the UAE

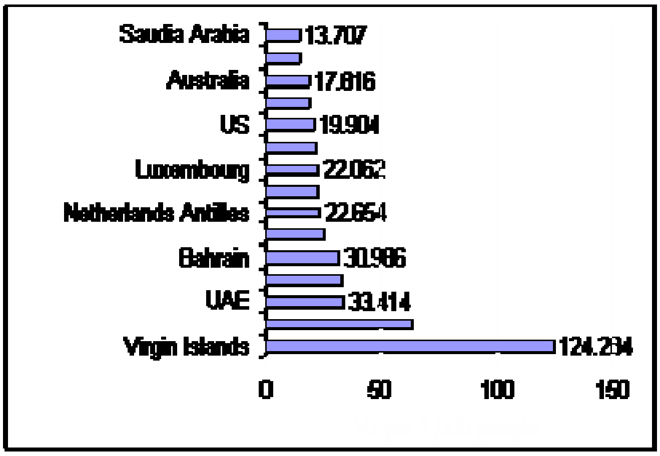


Figure 2-3: CO2 Emissions (per capita).

As a result of this economical and population growth, industrial process and real estate boom. The UAE is considered the third country after Kuwait and Virgin Islands in CO_2 emissions per capita as shown in table 2-6, with annual emissions of 33,414 kilograms of CO_2 per 1000 people. If the total population for the year 2003 is 4,041,000 then the total emissions will be 135,025,974 kilograms of CO_2 (Nation Master Facts and Statistics, 2008). Annual energy-related CO_2 emissions from fossil fuel production and combustion are 60,246 billion grams; about 95% of the total CO_2 emitted. Also, Industrial processes account for about 4% of CO_2-

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.

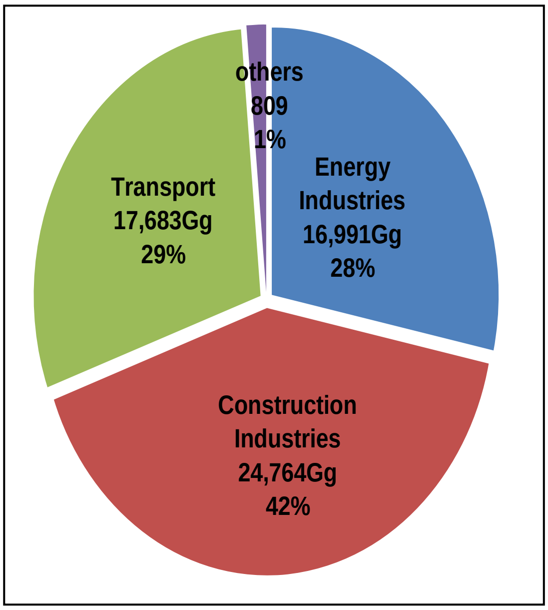


Figure 2-4: CO2 emissions in the UAE by sector

Manufacturing and construction industries emits 24,764 billion grams of CO2 to the atmosphere; which is about 42% 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).

3.0 Sustainable Design

3.1 Background

Sustainable practices have become of a great importance within the last ten years due to the negative impact of the construction developments on the environment. In Europe, 50% of the material resources are used in the construction sector and result in 50% of national waste production and 40% of the energy consumption (AboulNaga et al, 2001). In the UAE, these figures are higher, whereas the building industry, particularly in Abu Dhabi and Dubai; is forming a large portion of the economy; critical attention should be directed for practitioners to create a healthy, sustainable built environment and awareness for the public.

3.2 Building Construction in the UAE

The UAE is considered one of the top countries in the construction industry as, billions of dollars are spent yearly to improve the infrastructure and provide new facilities within the country. Nowadays, the UAE has a vast network of roads that interlinks the whole country as well as links it to the neighboring countries. Also, a number of modern ports and airports connect the country to the outside world.

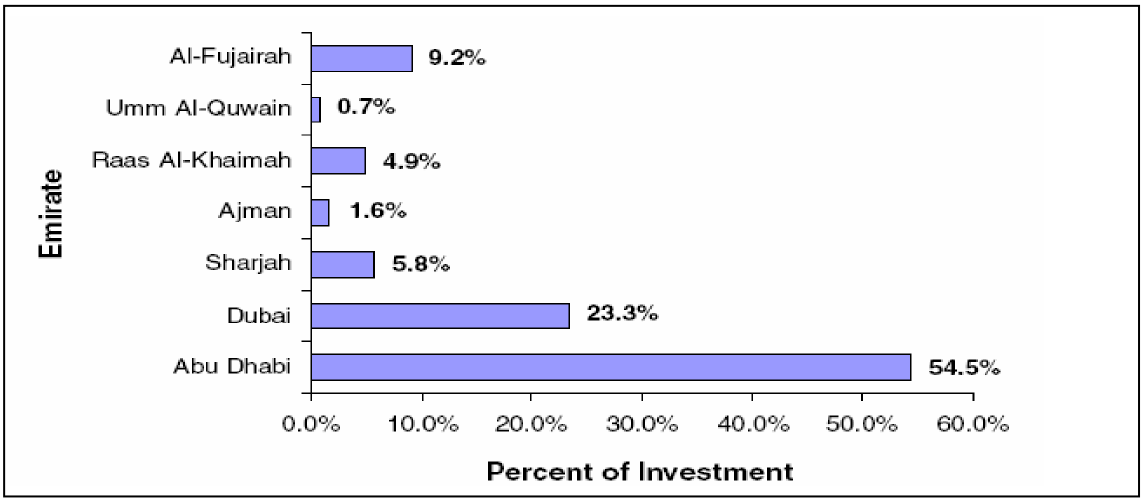


Figure 3-1: the percentage of construction investment in the UAE

Majority of the constructed projects that took place in a very short period are mostly in the emirates of Abu Dhabi and Dubai such as housing compounds, schools, hospitals, shopping malls, telecommunications, electricity and water, luxury hotels, and recreational facilities, as shown in Figure 3-1 (Zaneldin, 2006).

As a result of the high electricity demand of these new facilities specially residential and commercial buildings, the construction sector is responsible for about 28% of all energy related greenhouse gas emissions in the UAE, and about 25% of all carbon dioxide emitted, (Initial National Communication, 2006).

3.3 Key Building Material

In order to understand the process of the release of CO2 emissions to the atmosphere through the manufacture phase of a building material. A short description of the chemical compounds, uses, and means of extraction and production process of the key building materials is included in table 3-1 (Kim et al, 1998b).

Table 3-1: Key building materials

Building Material	Uses	Production Process	Environmental Impact
Limestone (calcium carbonate)	▪ A cladding material. ▪ Production of a wide range of building products such as: concrete and plaster.	Mining Drilling Exploding Cutting Crushing Burning Heating	▪ Acid rain ▪ CO2 release ▪ Damage to topsoil, vegetation and large rocks.
Aluminum (bauxite ore)	▪ A cladding material. ▪ Different applications in construction.	Mining Drilling Smelting	▪ Rainforest damage ▪ Electricity consumer ▪ Hazardous waste production. ▪ CO2 release ▪ High embodied energy
Steel (iron ore, limestone, magnesium and coal)	▪ Structural building elements. ▪ Different applications in construction.	Mining Refining Smelting Molding Milling	▪ Use of rare resources. ▪ CO2 release.
Wood	▪ Structural building	Farming Harvesting	▪ CO2 release ▪ Natural biological diversity

	elements. ▪ Different applications in construction. ▪ Production of a wide range of building products such as: plywood and particle wood.	Cutting	damage.
Petro-chemicals	▪ Used in building related products such as; plastics, plywood adhesives, insulation and paint.	Drilling Burning Heating	▪ Groundwater and soil contamination. ▪ CO2 release. ▪ Oil and natural gas consumption. ▪ Hazardous waste.
Brick and Tiles (clay and adobe soil)	▪ Used in covering floors, and walls and paving, etc. ▪ Different applications in construction.	Mining Firing Heating Melting Glazing	▪ Energy consumer ▪ CO2 release. ▪ High embodied energy
Concrete (53% gravel, 26% sand, 14% cement and 7% water)	▪ Structural building elements. ▪ Different applications in construction.	Extraction of raw materials. Mining Drilling Exploding Cutting Crushing Burning Heating	▪ Acid rain ▪ CO2 release ▪ Damage to topsoil, vegetation and large rocks. ▪ Water and energy consumer.
Glass (60% silver sand, 20% sodium carbonate, 20% sulphates)	▪ Recyclable as low grade glass. ▪ Different applications in construction.	Mining Heating Melting Hardening	▪ CO2 release. ▪ SO2 fluoride release. ▪ High energy consumer.

3.4 Environmental Impacts of Buildings and Construction

Buildings are major contributors in generating waste, pollution and consuming energy especially when manufacturing building materials. Also, vast open spaces are consumed to provide buildings and infrastructure to support the need of people and economy, where natural life is destroyed.

"According to the world watch institute, buildings in the United States use 17% of the total fresh water flows and 25% of the harvested wood; they are responsible for 50% of chlorofluorocarbon (CFC) production, use 40% of the total energy flows, generate 33% of CO2 and generate 40% of landfill material as a result of construction waste" (Sandra et al, 2006). This means that the environmental impacts of buildings are eroding our quality life as shown in figure 3-2

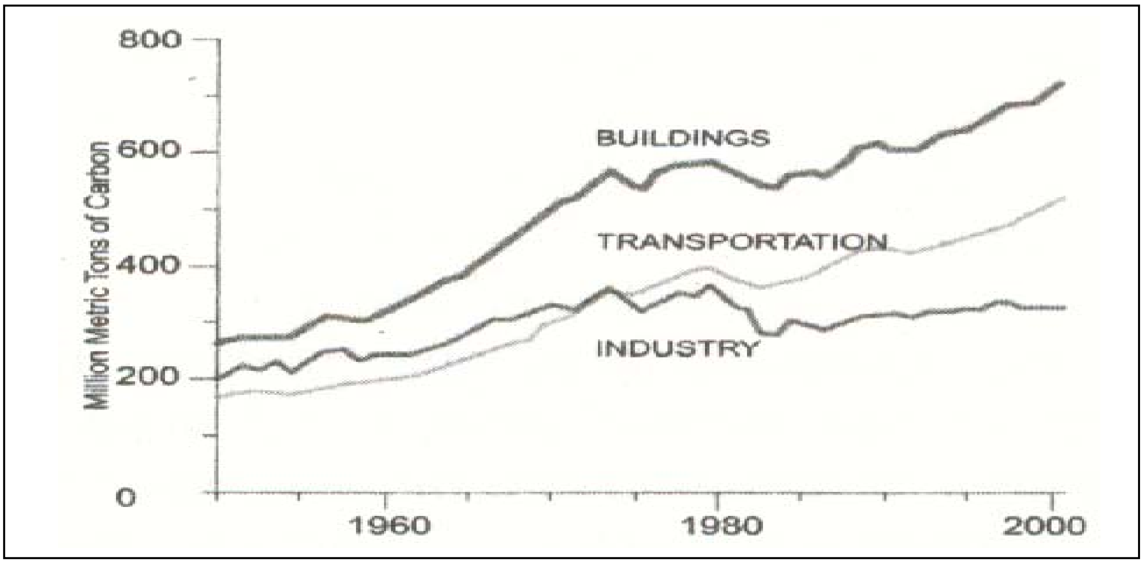


Figure 3-2: US CO2 emissions by sector

According to the U.S Environmental Protection Agency (EPA), one third of all buildings suffer from "sick building syndrome[3]". Also, the American Institute of Architects (AIA) reported that buildings accounts for half of all green house gas

[3] Sick building syndrome is an illness affecting workers in office buildings, characterized by skin irritations, headache, and respiratory problems, and thought to be caused by indoor pollutants, microorganisms, or inadequate ventilation (Answers, 2007).

emissions where buildings have a life span that lasts for 50 to 100 years throughout which they consume energy and produce emissions. The building sector as the major U.S. and global green house gas emitting sector is poised to fuel the world's rush towards climate change. The U.S. alone is projected to need 1,300 to 1,900 new power plants over the next 20 years about one power plant per week). Most of this energy will be needed to operate buildings, (Williams, 2007).

3.5 Materials and Embodied Energy[4]

Domestic household energy consumption accounts for 29% of the UK's CO2 emissions. By comparison, the materials used in a house's construction account for just 2-3%. Consequently long term efficiency in the construction performance is the primary driver of design. It is then implemented by measures that aim to minimize the impact of construction materials employed. This impact is however not negligible: the embodied energy of a building over its life is affected by the embodied energy of the constituent materials and their replacements. Over an estimated 60 years life, about one fourth (26%) of the energy is directly linked to the materials used. As about 40% of the embodied energy is linked to replacement and maintenance (recurring embodied energy), the durability of materials is another key issue in achieving a sustainable development.

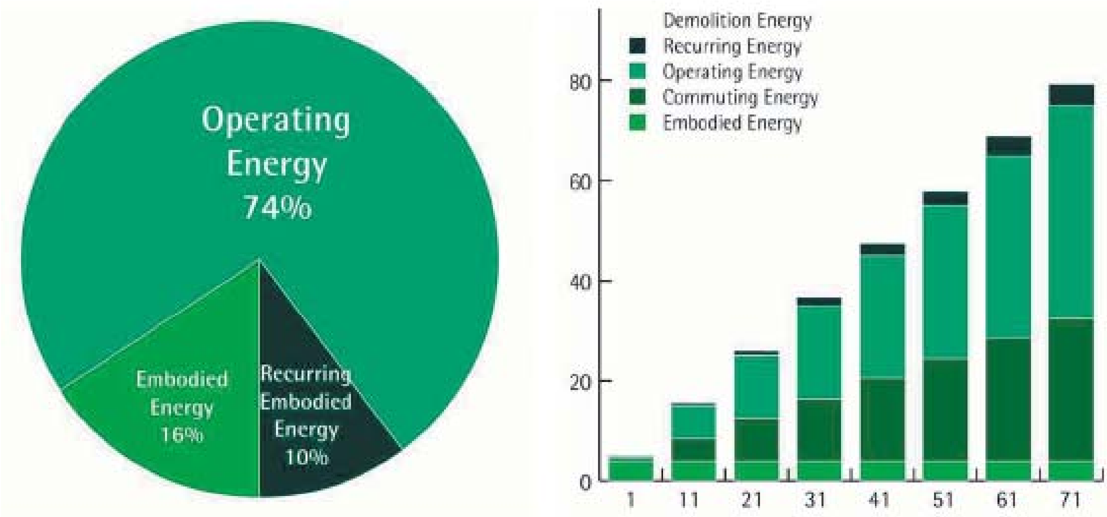


Figure 3-3: Embodied energy in materials through the life cycle.

4 The information is based on best practice examples of Foster+Partners consultants in the UK and a specific study conducted for Abu Dhabi city by them about sustainable design, 2008.

3.5.1 Direct impact of materials

The impact of materials is both direct and indirect. The direct ones are those that are usually considered in a Life Cycle Assessment (LCA). LCA is a method of evaluating the environmental impact of a system taking into account its full life cycle, from the cradle to the grave. This means taking in consideration all the impacts associated with the production and use of a system, from the first time that man has an impact on the environment till the last. This means including a number of different steps in the life of the material such as:

- Production;
- Transportation;
- Assembly;
- Maintenance;
- Disposal/ recycle.

3.5.2 Indirect impacts of materials

Physical properties of materials also impact the energy balance of buildings and cities during their operational life. In a complete assessment of the environmental impact of the buildings also those elements should be factored in as over an estimated 60 years life expectancy the smallest operational energy saving can multiply its effect.

3.6 Materials Recycling

An ongoing debate is developing about the merits of recycling and how recycling may not always represent best environmental practice, especially where high-value and polluting energy sources are consumed to recycle low-value material. To asses whether recycling is an appropriate choice or not the following criteria should be taken in account:

- The percentage of recycled material contained within a product;
- The percentage capable of being recycled;
- The percentage savings embodied energy if the specification used recycled material rather than virgin.

3.7 Materials Transportation[5]

Transportation accounts for about 10-15% of total embodied carbon of materials. A maximum carbon allowance is set usually based on the estimated carbon emission per tonne/kilometre (t/km) of a Light Good Vehicle on an 80km (50 miles) distance. This value defines what is considered as "local". The assessment of CO2 emission per t/km for different transportation modes offers a factual basis to challenge the conventional notion of 'locally sourced materials'. This allows as well for a wider range of materials to be used and to control the total transport related emissions which help to;

- Reduce the embodied energy of construction.
- Reduce packaging.
- Reduce freight transport has wide benefits; less pollution, road damage, noise etc.
- Allow the widest possible collection area for materials while minimizing impact.

Table 3-2: Transportation Mode and CO2 emissions

Mode of Transportation		CO2 estimated emissions (g/ton-kilometere)	Equivalent emission/ton estimated radii (Km)
Road	Light Good Vehicles (LGVs)	360	80
	Heavy Good Vehicles (HGVs)	138	200
Rail	Diesel	30	960
	Electrical	14	2050
Waterborne	Inland waterways	35	820
	Coastal shipping (medium-small carrier)	30	960
	International shipping (Large bulk carrier)	7	4100
Airborne	Air cargo	800	35

[5] The information is based on best practice examples of Foster+Partners consultants in the UK and a specific study conducted for Abu Dhabi city by them about sustainable design, 2008.

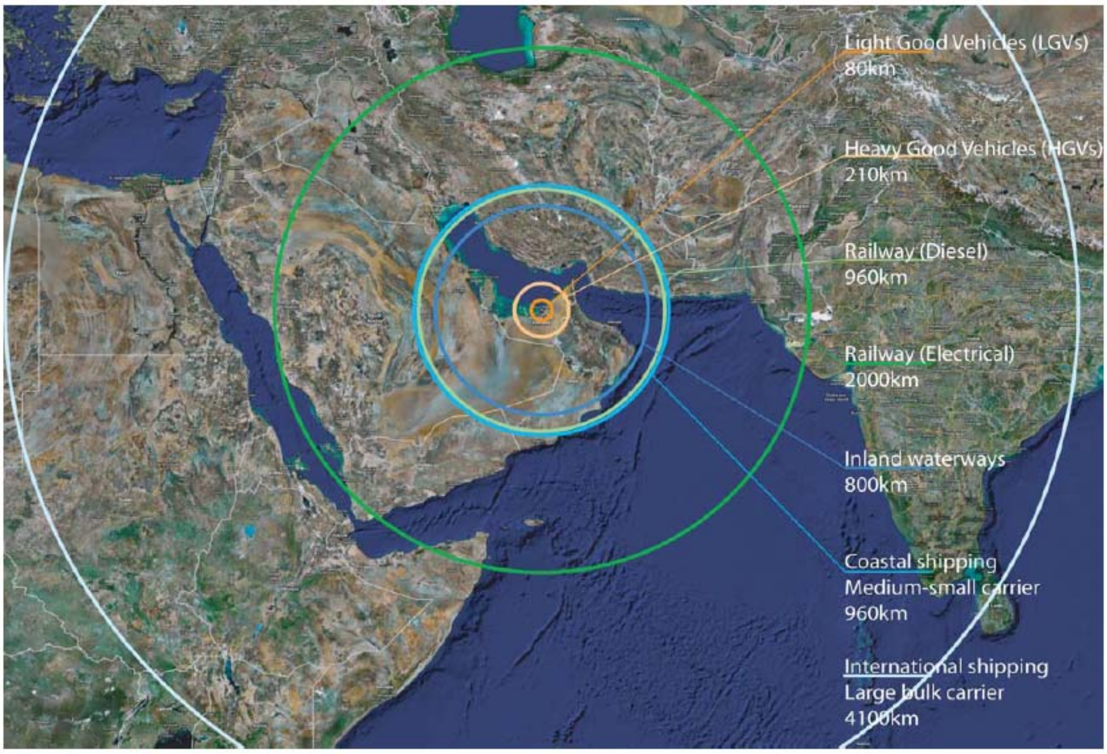


Figure 3-4: Theoretical CO2 emissions equivalent radii (g/tones-km)

Figure 3-5: Potential sources of material from neighboring countries

3.8 What is Sustainable Design?

Follow the sun,

Observe the wind,

Watch the flow of water,

Use simple materials,

Touch the earth lightly.

Glen Murcutt, Architect, (Williams, 2007).

“Sustainability has been defined by the Brundtland Commission[6] 1987, as “meeting the needs of the present generation without compromising the ability of the future generations to meet their own” (Williams, 2007). Also, William D. Ruckelshaus[7], first administrator of the Environmental Protection Agency, 1989 defined sustainability as” sustainability is the [emerging] doctrine that economic growth and development must take place, and be maintained over time, within the limits set by ecology in the broadest sense by the interrelations of human beings and their works, and the biosphere...it follows that environmental protection and economic development are complementary rather than antagonistic processes” (Williams, 2007).

Sustainability is becoming the answer toward the increase in world population and pollution and the heavy demand on natural resources. Where as, sustainable design moves away from extractive and disposable systems that are

[6] The Brundtland Commission, formally the World Commission on Environment and Development (WCED), known by the name of its Chair Gro Harlem Brundtland, was convened by the United Nations in 1983. The commission was created to address growing concern "about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development." In establishing the commission, the UN General Assembly recognized that environmental problems were global in nature and determined that it was in the common interest of all nations to establish policies for sustainable development (Wikipedia, 2008).

[7] William Ruckelshaus**,** born in 1932, American lawyer, businessman, and two-time head of the Environmental Protection Agency (EPA). Ruckelshaus played a significant role in the Watergate affair that eventually led to the resignation of President Richard M. Nixon (1969-1974). As deputy attorney general of the United States, Ruckelshaus resigned rather than carry out Nixon's order to fire Watergate Special Prosecutor Archibald Cox (Encarta, 2008).

energy intensive, resource inefficient, and toxic, toward cyclical, closed loop systems that are restorative, dynamic, and flexible, (Mendler et al, 2006).

3.9 Sustainable Design Goals

Sustainable design seeks to control the following:

- The use of natural energy and its biological process.
- Eliminate reliance on fossil fuels and toxic materials.
- Improve resource efficiency.
- Reduce construction and building operations waste.
- Design for flexibility and durability.
- Encourage resource reuse.
- Avoid use of scarce materials.
- Fit form to function.
- Use renewable energy and material resources.
- Use material and resources available locally.
- Reduce reliance on mechanical systems.
- Provide daylight and direct connections to nature.

In the short run, the impact of these changes will be to reduce the environmental impact of the designs. In the long run, the goal is to create buildings that are not harmful but actually part of the natural systems and restorative of those systems. It is concerned with the quality of the environment as a whole system and to create buildings and communities that are part of the natural world, (Mendler et al, 2006).

3.10 Economic Benefits

Sustainable design can lead to a variety of economic benefits when integrated into design. These include economic benefits of energy, water, and materials savings, as well as reduced maintenance and other operational costs. Numerous studies highlighted the connection between sustainable buildings and increased productivity, with sustainable buildings human productivity increases from two to fifteen percent, provide personal control, personal expression, improve social equity and encourage positive public relations (Mendler et al, 2006).

3.11 Life Cycle

Conceptually, the life cycle of building materials can be categorized into five phases: Extraction, production, building, occupational and demolition. Understanding the life cycle helps to improve the quality of the design and the selection of building materials through the different phases, this will contribute positively to the sustainable built environment, (Anink et al, 1996).

3.11.1 Extraction Phase

The selection of materials is important at this stage: the impact of materials processing can be global and have long-term consequences. The extraction of raw material has economic, technical and environmental impacts. Some materials will be worn-out, if the scale of the present extraction continues. In addition, the extraction of raw materials often results in damage to the nature, in release of harmful emissions or in the risk of environmental disaster such as the extraction and transportation of oil and chlorine (Anink et al, 1996). In order to reduce that, the following should be considered in the pre-building phase or when selecting building materials in the first stages of design:

- **Use renewable resources materials**

Materials from renewable resources reduce the need for nonrenewable materials such as petroleum and metals. Whereas, they are produced in a rate that can cover the human needs (Kim et al, 1998a).

- **Use materials extracted with low ecological damage**

Materials extraction is usually associated with exploding, mining and drilling operations which cause high ecological damage to the local and the global environment (Kim et al, 1998a).

- **Use recycled materials**

Recycled materials reduce the use of virgin materials which in return reduces the energy used to manufacture these materials and therefore reduces the embodied energy. Also, it reduces waste and landfill areas (Kim et al, 1998a).

- **Use durable materials**

Durable materials reduce waste because they do not need to be replaced, reduce landfill and the use of toxic cleansers which helps to create a healthier environment for occupants (Kim et al, 1998a).

3.11.2 Production Phase

During this phase, the raw materials extracted are manufactured, resulting in a material or product. There are several problems that occur during this phase such as: harmful emissions, waste and high energy consumption (Anink et al, 1996).

3.11.3 Building Phase

During this phase, high attention should be given to the various building elements where building influences its life span as well as the overall structure. Noise, vibration, dust, pollution, waste and energy consumption are the most important problems in this phase (Anink et al, 1996). In order to reduce that consider;

- **Minimizing site impact**

Site planning is very important to reduce the impact of excavation, drilling and construction activities. Whereas design, built structures and vehicles access should respect any existing vegetation, wildlife and site typology (Kim et al, 1998a).

3.11.4 Occupational Phase

This phase is a result of the choices made in the previous phases, where materials are already selected, erected and building is occupied. Environmental damage is mainly to the health of the occupants in the form of emission of noxious substances from different building materials (Anink et al, 1996). So, the following should be considered:

- **Employ nontoxic materials**

Usually building materials are maintained and cleaned using toxic materials. So, it is essential to use nontoxic cleansers to reduce the outgases released into air which stays for a period of time in the ventilation system and cause serious health issues for the occupants (Kim et al, 1998a).

3.11.5 Demolition Phase

During this phase, an overall assessment should take place to examine the environmental use of the demolished structure. There are several choices that can be invested such as: reuse, recycling of components and disposal (Kim et al, 1998a).

3.12 Features of Sustainable Building Materials

Five groups of criteria were identified previously, based on the material life cycle that can be used in evaluating the environmental sustainability of building materials. The presence of one or more of these features in building materials make it environmentally sustainable as shown in table 3-3 (Kim et al, 1998b).

Table 3-3: Features of sustainable building materials

Pollution Prevention + Waste Reduction	
Advantages	Examples
▪ Reducing amount of scrap materials. ▪ Efficient production process. ▪ Reduce packaging and shipping effect. ▪ Reduce the use of water. ▪ Reduce defective or damaged products. ▪ Use waste products.	▪ Concrete incorporate fly ash from smelting operations. ▪ Water reused from equipment cooling.
Recycled Content	
Advantages	Examples

▪ Use post industrial/consumer waste. ▪ Preserve embodied energy[8]. ▪ Use less energy.	▪ Recycled aluminum uses 95% less processing energy. ▪ Crushed concrete can be used in new masonry. ▪ Reform glass, plastics and metals through heat.
Natural Materials	
Advantages	Examples
▪ Less embodied energy. ▪ Less toxicity. ▪ Less processing. ▪ Less damage.	▪ Wood is more sustainable than non-renewable material.
Minimal Construction Waste	
Advantages	Examples
▪ Reduce landfill need. ▪ Cost savings.	▪ Concrete mixed on site is better than pre-mixed and delivered to site.
Locally Produced	
Advantages	Examples
▪ Shortens transport distances. ▪ Reduce air pollution. ▪ Better suited to climate conditions. ▪ Support local economy.	▪ Marble quarried from far distance countries is not justifiable.
Energy Efficiency	
Advantages	Examples
▪ Reduce generated energy. ▪ Reduce long-term running cost. ▪ Availability of quantative measurements such as: R-Value[9], shading coefficient[10], system efficiency, etc.	▪ Regular maintenance, keeps equipment operating at peak efficiency. ▪ Shading devices blocks solar heat gain at certain times. ▪ Certain glass or applied films allow selective transmission of the visible radiation (light) while preventing or reducing the transmission of infrared radiation (heat).
Water Treatment	
Advantages	Examples
▪ Reduce the use of water.	▪ Gray water from cooking or hand

[8] The embodied energy of a material refers to the total energy required to produce that material, including the collection of raw materials. This includes the energy of the fuel used to power the harvesting or mining equipment, the processing equipment, and the transportation devices that move raw material to a processing facility (Kim et al, 1998b).

[9] R-Value: Building envelopes are generally rated by their insulating value, known as the R-value (Kim et al, 1998b).

[10] The shading coefficient (SC) is a ratio of the solar heat gain of a building's particular fenestration to that of a standard sheet of double-strength glass of the same area.(Kim et al, 1998b).

▪ Less chemicals use. ▪ Less energy costs. ▪ Recycle water.	washing may be channeled to flush toilets.
Non/Less Toxic	
Advantages	Examples
▪ Less hazardous to building occupants. ▪ Enhance indoor air quality.	▪ Adhesives emit dangerous fumes for only a short time during and after installation. ▪ Volatile organic compounds (VOCs) can continue to be emitted into the air long after the materials containing them are installed.
Durable	
Advantages	Examples
▪ Less often replaced. ▪ Reduce use of natural resources. ▪ Cost saving. ▪ Less waste and landfill.	▪ The selection of initially expensive materials like slate or tile can be justified by their longer life spans.
Low Maintenance	
Advantages	Examples
▪ Reduce construction costs. ▪ Reduce exposure to toxic chemicals. ▪ Enhance indoor air quality.	▪ Less frequent cleaning of materials reduces the exposure of the building occupants and janitorial staff to cleaning chemicals.
Reusable	
Advantages	Examples
▪ Useful uses in building decommissioning. ▪ Easy to reuse and reinstall.	▪ Windows and doors, plumbing fixtures, and brick can be successfully reused.
Recyclable	
Advantages	Examples
▪ Creation of new materials. ▪ Reduce waste.	▪ Steel is a commonly recycled building material, because it can be easily separated from construction debris by magnets.
Biodegradable[11]	
Advantages	Examples
▪ Reduce waste. ▪ Less hazardous.	▪ Organic materials return to earth rapidly, while others, like steel, take a long time.

[11] The biodegradability of a material refers to its potential to naturally decompose when discarded, (Kim et al, 1998b).

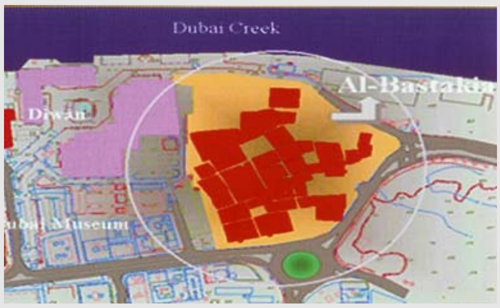
3.13 Sustainable Practice in the UAE

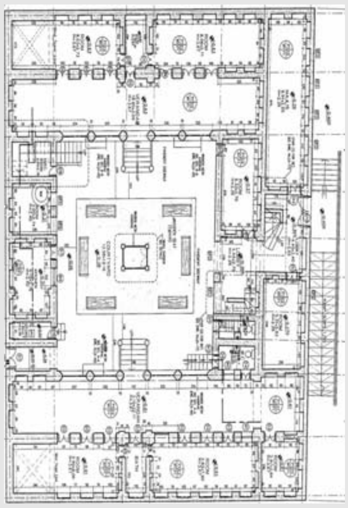
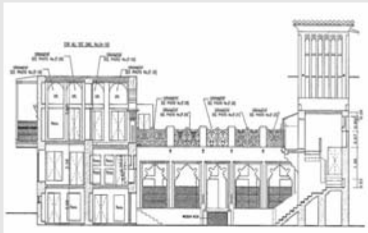
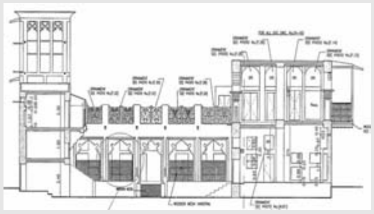
Strategies to reduce CO_2 emissions and energy use in buildings are not given a high priority in the UAE. However, most of the existing buildings lack the attractive features of sustainability. On the other hand, traditional architecture in the UAE shows some examples of environmental friendly buildings where they illustrate good selection of building materials and special techniques in climate and comfort such as: Al Bastakia Houses.

3.13.1 Al Bastakia Traditional Houses

The Bastakia quarter, located on the south bank of Dubai Creek, is one of the last few fragments of Dubai's architectural heritage. It's an urban cape of an earth-plastered thick buildings, shaded courtyards, silent spaces and wind towers. The area got its name from the Bastaki people, emigrants from Bastak, a town in southern Iran who fled their hometown to settle in Dubai in 1800's. Bastakia was an ideal site for the merchant community, being close to the creek, where the dhows unloaded, and the market, where business was conducted. The style of architecture was transplanted directly from Iran. Bastakia's twisting alley ways provided shelter from the harsh sunlight and desert winds, while the wind towers (or barajeels) would funnel the cool sea breeze into the interior of the house. More details are shown in table 3-4 (Elements of traditional architecture in Dubai, 2005).

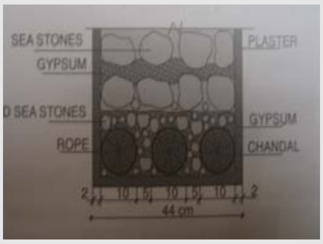
Table 3-4: Bastakia traditional houses overview

Overview		
Location	Dubai, UAE	
Site value	Historical	
Site location	Western side of the Arabian Gulf	
Features	58 Traditional courtyard houses with 25 wind towers	
Design Goals		
• Adoption to hot humid climate • Use locally available construction materials • Respect people tradition and religious aspects		

Plan	Section	Elevation
	 	 

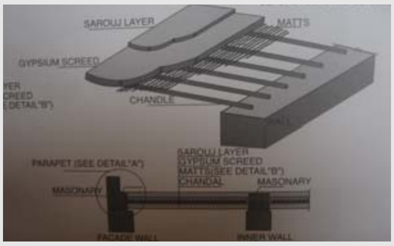
Main Structural Concept

- Beams were made of (Chandal) wood (Palm tree trunk) with rope tied around it and gaps were filled with crushed sea stones and gypsum.
- Slaps were constructed by laying a number of (Chandal) wood with palm leaves matt on top and then a thick layer of gypsum screed and a sarouj layer as the last layer.



Beam

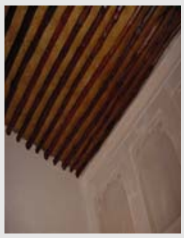
Chandal wood

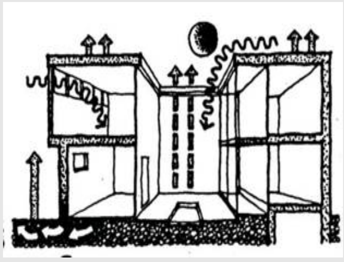
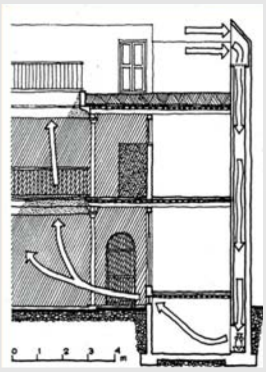
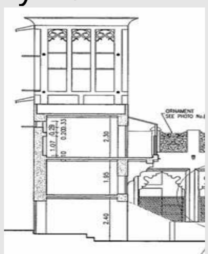


Slap

Building Materials

Type	Location/ Uses	Country of Origin
Slate	Exterior walls cover Flooring	Dibbah - UAE
Gypsum	Decorative arches and panels	
Salvaged wood	Kitchen cabinets Furniture Flooring Doors windows	Sharjah - UAE
Clay (Saroj)	Plaster	UAE
Sea shell	Exterior walls construction	UAE
Coral stone	Exterior walls construction	UAE
Chandales (wood)	Roof construction	East Africa and India



<table>
<tr><td>Palm trunk</td><td>Foundations</td><td>UAE</td><td rowspan="2"></td></tr>
<tr><td>Palm leaves</td><td>Joists</td><td>UAE</td></tr>
<tr><td colspan="4">Courtyard</td></tr>
<tr><td colspan="4">
• Constant air circulation
• Shade (Double Height)
• Minimize the solar radiation impact on the exterior Walls
• Extension to the surroundings
• Focal point
• Privacy (rooms looks inward)
• Better living atmosphere
 
</td></tr>
<tr><td colspan="4">Urban Tissue</td></tr>
<tr><td colspan="2">
• Creation of shady narrow streets (sikkas).
• Permitting prevailing North wind.
• Increase wind velocity.
• Create a comfortable area for users.
</td><td colspan="2">  </td></tr>
<tr><td colspan="2">Air Pullers</td><td colspan="2">Wind Tower</td></tr>
<tr><td colspan="2">Air striking the exterior wall is directed through the void between the two parallel walls to circulate to the different rooms for ventilation.
  
</td><td colspan="2">
▪ Rise to about fifteen meters above ground level.
▪ The upper part consists of four concave inner walls with pillars, arches.
▪ Catches wind channeled through a chimney down to a common room.
▪ Confirm old city skyline.
 
</td></tr>
</table>

Al Bastakia shows that some local materials are available in the UAE, and they are useable and durable. The only limitation to the use of these materials such as the coral stones is that; it can not be used in high rise buildings but it can be used in multi storey buildings which are dominant in the UAE, integrated with the effective design strategies and smart energy efficiency technologies it will provide the needed functions, provide a healthy atmosphere for the occupants and reduce the impact on the environment.

3.14 Good Practice Examples

There are many good practice examples around the world that shows sustainable design in different climatic zones using different techniques. Where as, this research is interested in building materials with sustainable features; the selection of the case study is based on highlighting the criteria of selecting these materials and summarizing the rest of the techniques used to save energy. Based on that, this section will illustrate two case studies of good practice examples which are the Government of Canada building and Santa Clarita Transit Maintenance Facility (Mendler et al, 2006).

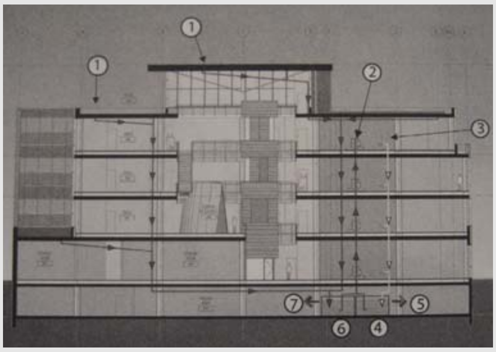
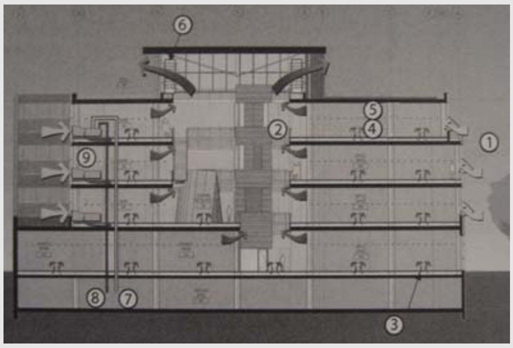
3.14.1 Government of Canada building

Table 3-5: Government of Canada building design overview

Overview	
Building size 17,300 m2	
Location Charlottetown, Prince Edward Island, Canada	
Construction cost $27 million	
Sustainable Design goals	
• Public showcase for sustainable building technologies for the federal government's new national initiative. • Blend sustainable design features with the city's historical architecture. Creating a landmark and a model for urban revitalization. • The facility is a model for cost-effective sustainable design. • Promote planning and construction efficiencies.	
Design Overview	
• The building consists of two wings with, • Deep loft space of large areas of open offices. • A main spine carries the support elements and service spaces. • An atrium of three stories is the central focus and orientation point.	
Materials and Resources	
Material selection was based on the following criteria: ▪ Performance ▪ Durability ▪ Low maintenance ▪ Free of harmful chemical emissions ▪ Resource efficiency	

▪ Renewable materials ▪ Recycled content ▪ Sustainable source			
Exterior materials	**Use**	**Source**	**Value**
Wallace sandstone	Render the wall	Local	Widely used
Red brick	One of the building's wings	Local	Historical value
Interior materials	**Use**	**Source**	**Value**
Drywalls	Walls	Local	High recycled content.
Acoustic ceiling tiles	False ceiling	Local	80% of recycled content.
Carpet	Flooring	Local	Recyclable
Resilient	Flooring		Durable and low maintenance material made of renewable linseed oil and wood floor.
ceramic	Flooring	Local	Durable
Millwork		Local	Made out of soy-based boards.
Wood			Certified sustainable wood finished with water based, low VOC[12] content adhesives.
Recycled or reused materials			
• The structural concrete used has 25 to 40% of fly ash content. • Salvaged materials are used for flooring and paving.			
Future recycling			
• Millwork and woodwork is mounted with mechanical means so it can be removed when necessary.			

[12] VOC refers to volatile organic compound, chemicals that contain carbon molecules and have high enough vapor pressure to vaporize from material surfaces into indoor air at normal room temperatures (Mendler et al, 2006).

Energy and Atmosphere	
 1. Rain water harvesting on roof 2. Grey water supply to janitor and water closets. 3. Gray water harvesting from sinks and showers. 4. Grey water cistern 5. Overflow to sanitary sewer 6. Rainwater cistern 7. Overflow to storm sewer.	 1. Operable windows for natural ventilation. 2. Atrium collects and removes exhaust air. 3. Under floor air distribution. 4. Occupied zone. 5. Stratified zone. 6. Heat recovery from exhaust air. 7. Chiller. 8. District heat. 9. Air handlers with 100% fresh air supply.

3.14.2 Santa Clarita Transit Maintenance Facility

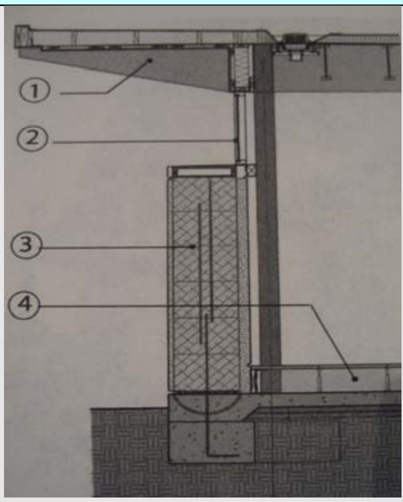
Table 3-6: Santa Clarita Transit Maintenance Facility overview

<table>
<tr><th colspan="4">Overview</th></tr>
<tr><td colspan="2">Building size
4,366 m2</td><td colspan="2" rowspan="4"></td></tr>
<tr><td colspan="2">Location
Santa Clarita, California, US</td></tr>
<tr><td colspan="2">Construction cost
$15.6 million</td></tr>
<tr><td colspan="2">Climate
Hot, dry desert environment</td></tr>
<tr><th colspan="4">Sustainable Design goals</th></tr>
<tr><td colspan="4">▪ Reach to the highest LEED[13] possible rating within the budget.
▪ Promote green building practices in the community.
▪ Promote sustainable design and energy efficient buildings.</td></tr>
<tr><th colspan="4">Design Overview</th></tr>
<tr><td colspan="4">▪ The facility consists of an office building, a bus maintenance garage, parking areas for 150 buses and 250 cars, a bus yard and 3 fueling stations.
▪ Site located northwest of downtown.
▪ Narrow floor plates based on a solar access analysis was planned to promote day lighting strategy.
▪ Office building equipped with a super insulated envelope with under floor air distribution.
▪ Building envelope was constructed of straw bales with a lime plaster layer.</td></tr>
<tr><th colspan="4">Materials and Resources</th></tr>
<tr><td colspan="4">▪ The building was designed to be durable and low maintenance.
▪ A resource efficiency strategy was used.
▪ Low-VOC, bio based finish were used.
▪ Very little carpeting and suspended ceiling in few rooms.</td></tr>
<tr><th>Exterior materials</th><th>Use</th><th>Source</th><th>Value</th></tr>
<tr><td>Heavy timber</td><td>Main building structure</td><td>Local</td><td>High recycled content – engineered limber[14].</td></tr>
<tr><td>Lime plaster</td><td>Exterior finish</td><td>Local</td><td>Porous
Allow moister to move through straw bale</td></tr>
<tr><td>Metal shingles</td><td>Cover exterior</td><td>Local</td><td>High recycled copper</td></tr>
</table>

[13] The Leadership in Energy and Environmental Design (LEED) Green Building Rating System encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally understood and accepted tools and performance criteria (USGBC, 2007).

[14] Engineered limber is wood made from relatively young trees that are from managed forests (Mendler et al, 2006).

	wall surface (not straw)		
Interior materials	**Use**	**Source**	**Value**
Straw bale (waste product of the grain farming industry)	Walls	Local	Extreme durable long Fire resistance Cheap Very high insulation Pest infestation[15] Contain no VOC
Energy and Atmosphere			



Straw bale wall section
1. Wood Structure
2. Clerestory windows
3. Straw bale walls
4. Raised floor plenum.

- Straw bale construction requires wider walls and larger foundations.
- Setting the glazing in the deep openings creates shadows and contrast on the exterior façade.
- Design strategy was to combine straw bale wall construction with high performance glazing and a well “cool” roof to create a super insulated envelope.
- Under floor air, system reduces loads by allowing conditional air to be delivered at a higher temperature.
- The mechanical system is a series of water source heat pumps.

From presenting these good practice examples, it can be concluded that buildings that achieve a high level of sustainable design, will serve for many decades while minimizing the cost of operations or change overtime. Also, it will reduce the impact of the construction industry on the environment and people’s life. Save the scarce resources and reduce GHG emissions associated with this industry especially from transportation and materials manufacturing.

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[15] A system of controlling plant pests and diseases without the use of chemicals, by employing predators and parasites that feed upon them. For example, populations of ladybugs can be introduced into the garden to consume aphids (Answers, 2007).

4.0 Methodology

4.1 Introduction

The research presented here has been carried out on a real case study of a high-rise residential building in the UAE constructed in a conventional way and with no specific selection of materials, comparing it with a hypothetically created building with similar characteristics but using building materials with sustainable features.

4.2 Physical Range and Technical Data

The physical range is clearly determined: residential cubic tower in the urban range of a small size city, of extreme hot arid climate, for an average social class, within a conventional family, built by private developers and performed with an average construction technology. All these characteristics make the results obtained applicable to a large and a general field and therefore of great effect.

The country of the study is the UAE, but because of the absence of quality UAE data sources, it was not possible to ignore foreign data especially UK sources because all the material documentation and specifications used and implemented in the UAE are mostly to UK standards. Therefore, the embodied energy and embodied carbon values used in this case study are based to UK electricity generation and fuel mixes. On the other hand, all the information about the case study building including: specifications, bill of quantities, documentations and drawings are provided from a well-known local consultant “Architectural Consultancy Group – ACG” which has more than 25 years of experience in the filed of architecture in the UAE, won several competitions and designed hundreds of existing projects.

Therefore, the case study building is interesting since the data obtained can be applied to the most common type of buildings in the UAE: the residential towers. In addition, the reason of choosing this particular building is the availability of full information, access to the building site and the corporation of the designer and the developer.

4.3 Research Line and Methodology

The development of this research work has followed the stated methodology:

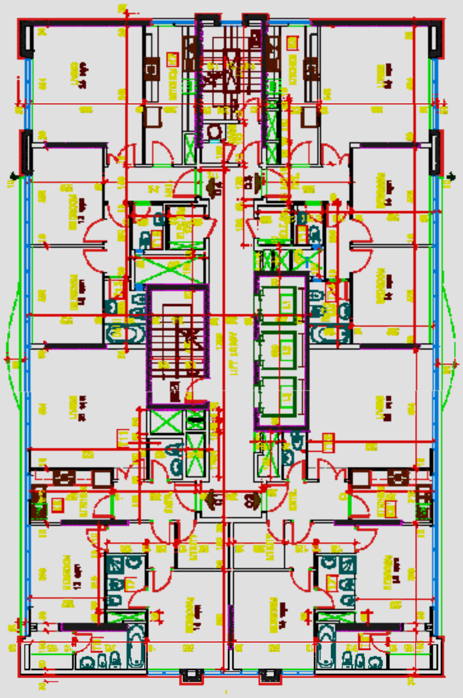
4.3.1 Description of the case study building

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 40 years 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 (Maklouf, 2000). The building is similar to most buildings in the UAE where the elevations are fully glazed with aluminum 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, aluminum 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 4-1 below.

Table 4-1: Case study building details

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	(60 nos.) 2 Bedroom apartments	5,220
	Building Services	2,025

(15 nos.)	Sub Total	7,245
Roof level	Building Services	365
	Grand Total:	*14,332m2*

Main Building Components

- Site work and substructure
- Concrete works – super structure
- Block work
- Carpentry, joinery and ironmongery
- Roofing and waterproofing
- Equipments and fixtures
- Metal works
- Aluminum and glazing
- Floor and wall finishes
- Painting
- Sanitary ware
- Conveying system
- Air conditioning and ventilation installation
- Plumping and drainage installation
- Fire fighting installation
- LPG installation
- Electrical installation

Main Building Materials

1.	Reinforced concrete ▪ Concrete grade 40N/mm2. ▪ Reinforcing steel of 460N/mm2
2.	Concrete floor finishing • Cement: Ordinary Portland Cement • Sand: Natural sharp angular, washed free of chlorides and free of sulphate. • Water: Clean, fresh, potable, and free of sulphate and chlorides.
3.	Concrete Block • Solid blocks having a compressive strength of 12.5 N/mm^2, 20% moisture • Insulation between Tops of Concrete Block Partitions and Underside of Structure: Mineral wool or fibrous glass. • Horizontal Reinforcing Galvanized Steel Mesh: galvanized mild steel rods.
4.	Wood • Plywood • Kiln dry wood • Medium Density Fiberboard (MDF) • Mahogany wood (all doors) • Meranti wood • Spano board (fire resistance) • Chipboard

6.	Waterproofing ▪ Bitumen membrane ▪ Polystyrene thermal insulation board ▪ Synthetic geotextile slip sheet ▪ Foam concrete ▪ Concrete roofing tiles
7.	Aluminum Cladding ▪ Composite aluminum cladding of 0.5mm aluminum sheets on both sides and 5mm Polyethylene core in between. ▪ Insulation of 50m thick semi rigid rock wool slab (to be fixed on concrete) having 50 Kg/m^3 density backed with aluminum foil.
8.	Glass ▪ 24mm hermetically sealed Structural Silicone Double Glazed units.
9.	Paint ▪ Epoxy – Polyurethane Paint (Textured finish) ▪ Emulsion Paint ▪ Alkyd Enamel Paint ▪ Epoxy – Polyurethane Paint (Smooth finish): Over Concrete, GRC
10.	Thermal Insulation ▪ Insulation board: 50mm minimum thick rigid board, 35 kg/m3 density, extruded polystyrene for roof.
11.	Floor finish ▪ 20mm thick marble. ▪ Ceramic tiles.
12.	Suspended ceiling ▪ Aluminum plain tiles -Clip in system ▪ Gypsum board ceiling ▪ Acoustic Treatment

4.3.2 Estimate the weight of the main building materials

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 as shown in table 4-2.

Table 4-2: Weight in kilograms of conventional construction materials in the case study building.

Structural Building Elements	Volume in m3	Density Kg/m3	Steel Weight in Kgs	Concrete in Kgs	Total Weight in Kgs
raft foundation	2,240	2500	1,582,560	4,586,400	6,168,960
staircase steps & landing	22	2500	8,635	47,025	55,660
column	56	2500	21,980	119,700	141,680
column, circular or curved on plan	43	2500	16,878	91,913	108,790
perimeter wall	466	2500	182,905	996,075	1,178,980
walls	166	2500	65,155	354,825	419,980
wall, curved on plan	84	2500	32,970	179,550	212,520
suspended slab, 300 mm thick	390	2500	153,075	833,625	986,700
ditto...sloping, to ramps	242		94,985	517,275	612,260
columns	17	2500	11,781	30,940	42,721
circular columns	10	2500	6,930	18,200	25,130
walls	1,073	2500	743,589	1,952,860	2,696,449
beams, up stands, down stands	108	2500	74,844	196,560	271,404
parapets	66	2500	45,738	120,120	165,858
staircases - steps & landings	118	2500	81,774	214,760	296,534
suspended slab, 200 mm thick	18	2500	12,474	32,760	45,234
ditto...220 mm thick	1,506	2500	1,043,658	2,740,920	3,784,578
ditto...300 mm thick	45	2500	31,185	81,900	113,085
ditto...350 mm thick	108	2500	74,844	196,560	271,404
ditto...400 mm thick	107	2500	74,151	194,740	268,891
ditto...500 mm thick	9	2500	6,237	16,380	22,617
Steel Weight 4,366,348 and Concrete Weight 13,523,088					

Block Works	Quantity	Volume	Density	Weight
200 mm thick	1,845	-	263	485,235
150 mm thick	163	-	218	35,534
100 mm thick	260	-	188	48,880
200 mm thick	3,824	-	263	1,005,712
150 mm thick	545	-	218	118,810
100 mm thick	7,024	-	188	1,320,512
for 200 mm thick block walls	-	0.1	2500	250.00
for 150 mm thick block walls	-	0.075	2500	187.50
for 100 mm thick block walls	-	0.05	2500	125.00
			Block work weight	**3,015,246**

Wood Work	Quantity	Density Kg/m3	Volume (m3)	Weight (Kgs)
48 mm thick door shutter with solid Mahogany wood lipping, Mahogany veneer skin on plywood decking, 38 mm thick 2 hour fire-rated spano board core on Meranti wood structural frame, and solid Mahogany door frame				
D-1, overall size 1100 x 2200 mm	72	500	0.13	4,680.00
D-1a, overall size 1200 x 2200, double leaf	3	500	0.15	225.00
D-4a, overall size 1400 x 2200, double leaf	1	500	0.16	80.00
D-4b, overall size 1000 x 2200 mm	2	500	0.12	120.00
48 mm thick door shutter with solid Mahogany wood lipping, beads, Mahogany veneer skin on plywood decking, 38 mm thick tubular chipboard core on Meranti wood structural frame, vision panel, and solid Mahogany door frame.				
D-8, overall size 800 x 2200 mm	77	500	0.08	3,080.00
D-8a, overall size 750 x 2200 mm	69	500	0.08	2,760.00
46 mm thick door shutter with solid Mahogany wood lipping, beads, Mahogany veneer skin on plywood decking, 38 mm thick tubular chipboard core on Meranti wood structural frame, vision panel, and solid Mahogany door frame.				
D-2, overall size 1200 x 2200 mm, double leaf	63	500	0.3	9,450.00
48 mm thick door shutter with solid Mahogany wood lipping, beads, Mahogany veneer skin on plywood decking, 38 mm thick 2 hour fire-rated spano board core on Meranti wood structural frame and solid Mahogany door frame.				
D-3a, overall size 700 x 2200 mm	4	500	0.25	500.00
D-5, overall size 900 x 2200 mm	78	500	0.28	10,920.00
D-6, overall size 900 x 2200 mm	67	500	0.28	9,380.00
D-7, overall size 800 x 2200 mm	39	500	0.28	5,460.00
D-7a, overall size 700 x 2200 mm	20	500	0.28	2,800.00
D-8, overall size 1400 x 2200 mm, double leaf	2	500	0.35	350.00
48 mm thick door shutter with solid Mahogany wood lipping, Mahogany veneer skin on plywood decking, 38 mm thick 2 hour fire-rated spano board core on Meranti wood structural frame, and solid Mahogany door frame.				
D-9a, overall size 1100 x 2200 mm	2	500	0.3	300.00
D-11, 700 x 2200 mm	1	500	0.28	140.00
D-11a, 800 x 2200 mm	30	500	0.28	4,200.00
D-12, 1600 x 2200 mm, double leaf	6	500	0.38	1,140.00

48 mm thick door shutter with solid Mahogany wood lipping, beads, Mahogany veneer skin on plywood decking, 38 mm thick tubular chipboard core on Meranti wood structural frame and solid Mahogany door frame.				
D-4, overall size 900 x 2200 mm	223	500	0.28	31,220.00
Wooden closet comprising of 18 mm thick white melamine faced MDF with PVC lipping.				
CB-1, 2400 mm high x 2140 mm long	6	400	0.25	600.00
CB-2, 2400 mm high x 3010 mm long	15	400	0.35	2,100.00
CB-3, 2400 mm high x 1000 mm long	15	400	0.12	720.00
CB-4, 2400 mm high x 2700 mm long	1	400	0.28	112.00
CB-5, 2400 mm high x 2300 mm long	1	400	0.26	104.00
Reception Counter, 1100 mm high x 600 mr wide x 1600 mm long	1	400	0.15	60.00
Vanity Counter, 600 mm wide x 1700 mm long	1	400	0.2	80.00
600 mm wide x 1880 mm long	1	400	0.22	88.00
Kitchen cabinets including shelves, drawers, shutters, frames, plinths, glazing, 30 mm thick x 600 mm wide granite work top, 20 mm thick x 60 mm high splash back.				
Lower cabinet - 600 mm wide x 900 mm hig x 2840 mm long	169	400	0.15	10,140.00
Upper cabinet - 330 mm wide x 700 mm hig x 1800 mm long	78	400	0.12	3,744.00
600 mm wide x 2500 mm long counter	1	400	0.1	40.00
				Wood Weight 209,346.00

Roofing and Waterproofing	**Quantity**	**Density Kg/m3**	**Weight (Kgs)**
Concrete roofing tiles laid on polypropylene spacers 500 x 500 x 50 mm thick	416	125	52,000
Foam concrete in varied thickness (50 mm minimum thick) and minimum density of 700 kg/m3 to slope	416	700	291,200
One slip sheet non woven synthetic geotextile 100 g/m2, loose laid	416	100	41,600
One layer 4 mm thick SBS elastomeric bitumen membrane with 180 g/m2 stable non-woven polyester reinforcement, loose laid with side and end laps torched and seamed	416	180	74,880
100 g/m2 geotextile separation layer	416	100	41,600
50 mm thick extruded polystyrene thermal insulation board, 35 kg/m3	416	35	14,560
135 g/m2 geotextile separation layer	416	135	56,160
3 mm thick SBS elastomeric bitumen corner reinforcement strip, 200 mm wide & fully torched at angle including cement-sand fillet	314	85	16
One layer 3.7 mm thick SBS elastomeric bitumen flashing membrane with 85 g/m2 glass grid underfaced with torch off film and self protected with aluminum foil	314	85	20
50 mm thick, semi rigid rock wool slabs insulation 50 kg/m3, to external concrete/block walls, behind aluminum cladding.	4,088	50	10,220
behind granite cladding	320	50	800
behind spandrel type curtain walls	825	50	2,063

Roofing and Waterproofing Weight 585,118					
Aluminum Curtain Walls	**Quantity**	**Thickness**	**Volume (m3)**	**Density Kg/m3**	**Weight (kgs)**
CW1, 9100 mm wide x 6200 mm max. high	1	4mm	0.23	2700	621
CW2, 3620 mm wide x 5700 mm high	1	4mm	0.08	2700	216
CW3, 3200 mm wide x 6200 mm max. high	1	4mm	0.08	2700	216
CW4, 3700 mm wide x 3800 mm high	2	4mm	0.12	2700	324
CW5, 9240 mm wide x 3800 mm high	1	4mm	0.14	2700	378
CW5a, 5590 mm wide x 6200 mm max. high	1	4mm	0.14	2700	378
CW6, 1900 mm wide x 5700 mm high	1	4mm	0.04	2700	108
CW7, 8690 mm wide x 6200 mm max. high	1	4mm	0.22	2700	594
CW8, 7000 mm wide x 2350 mm high	1	4mm	0.66	2700	1782
CW9, 2840 mm wide x 66900 mm high	2	4mm	1.52	2700	4104
CW10, 6800 mm wide x 32300 mm high	2	4mm	1.76	2700	4752
CW11, 7500 mm wide x 5100 mm high	1	4mm	0.15	2700	405
CW12, 7000 mm wide x 5100 mm high	1	4mm	0.14	2700	378
CW13, 2500 mm wide x 58000 mm high	1	4mm	0.58	2700	1566
CW14, 1000 mm wide x 58000 mm high	1	4mm	0.23	2700	621
CW15, 17580 mm wide x 4250 mm high	1	4mm	0.3	2700	810
CW16, 1280 mm wide x 4250 mm high	4	4mm	0.08	2700	216
CW17, 9210 mm wide x 4250 mm high	2	4mm	0.32	2700	864
Aluminum curtain walls weight 18333					
Aluminum Doors	**Quantity**	**Thickness**	**Volume (m3)**	**Density Kg/m3**	**Weight (kgs)**
sandwich panel door to CW2, 1200 mm width x 2400 mm height	1	4mm	0.01	2700	27
AD-6, 1000 mm wide x 2400 mm high	1	4mm	0.01	2700	27
AD-7, 1000 mm wide x 2000 mm high	3	4mm	0.03	2700	81
ditto... 2400 mm width x 2840 mm high	1	4mm	0.03	2700	81
AD-1, 1200 mm wide x 2400 mm high	3	4mm	0.03	2700	81
AD-2, 2400 mm wide x 2400 mm high	1	4mm	0.02	2700	54
AD-4, 1000 mm wide x 2400 mm high	1	4mm	0.01	2700	27
Aluminum Doors weight 378					
Aluminum External Cladding	**Quantity**	**Thickness**	**Volume (m3)**	**Density Kg/m3**	**Weight (kgs)**

aluminum cladding (Finish E1)	2,120	0.004	8.48	2700	22896
aluminum cladding (Finish E2)	1,362	0.004	5.448	2700	14709.6
ditto...fixed to soffits	190	0.004	0.76	2700	2052
circular columns 900 mm diameter x 5900 mm high	2	4mm	0.04	2700	108
ditto...to semi-circular columns 850 mm girth x 5900 mm high	2	4mm	0.04	2700	108
polished aluminum fins, 100 x 100 mm	118	4mm	0.005	2700	13.5
External Aluminum cladding weight 39887.1					

Glass Windows	Quantity	Thickness	Volume (m3)	Density Kg/m3	Weight (kgs)
AD-3, 2400 mm wide x 2400 mm high	3	13.14mm	0.23	2579	593.17
AD-5, 1000 mm wide x 2400 mm high	2	13.14mm	0.64	2579	1650.56
AW-1, 11440 mm wide x 2650 mm high	14	13.14mm	5.58	2579	14390.82
AW-1', 11440 mm wide x 2650 mm max. high	2	13.14mm	0.8	2579	2063.2
AW-2, 6970 mm wide x 2650 mm high	5	13.14mm	1.2	2579	3094.8
AW-2', 6970 mm wide x 1700 mm high	1	13.14mm	0.16	2579	412.64
AW3, 2050 mm wide x 1700 mm high	34	13.14mm	1.56	2579	4023.24
AW-4, 18240 mm wide x 2650 mm high	8	13.14mm	5.08	2579	13101.32
AW-5, 19540 mm wide x 2650 mm high	3	13.14mm	2.72	2579	7014.88
AW-6, 16780 mm wide x 2650 mm high	2	13.14mm	1.17	2579	3017.43
AW-7, 15480 mm wide x 2650 mm high	2	13.14mm	1.08	2579	2785.32
AW-9, 1000 mm wide x 1900 mm high	1	13.14mm	0.02	2579	51.58
AW-10, 1500 mm wide x 1900 mm high	2	13.14mm	0.07	2579	180.53
AW-11, 2500 mm wide x 1900 mm high	1	13.14mm	0.06	2579	154.74
AW-8, 400 mm wide x 800 mm high	120	13.14mm	0.5	2579	1289.5
Glass windows weight 53823.73					

Marble	Quantity	Thickness	Volume (m3)	Density Kg/m3	Weight (kgs)
400 x 400 mm & cut to size x 20 mm thick	42	0.02	0.84	2563	2152.92
cut to size x 20 mm thick marble tiles to floors & landings	30	0.02	0.6	2563	1537.8
30 mm thick tread x 300 mm wide, with rounded nosing including anti-slip strip	88	0.03	0.792	2563	2029.896
20 mm thick x 160 mm x 600mm average high risers	88	0.02	0.169	2563	433.0445

100 mm high x 600 mm x 20 mm thick stair & landing skirting (S1)	84	0.02	0.1008	2563	258.3504
30 mm thick x 100 mm wide x 600mm	197	0.03	0.3546	2563	908.8398
30 mm thick x 200 mm wide x 600mm	190	0.03	0.342	2563	876.546
20 mm thick x cut to size marble (marble type M3) cladding to GF Main Entrance	101	0.02	2.02	2563	5177.26
30 mm thick x cut to size polished granite external cladding (Finish type E8)	320	0.03	9.6	2563	24604.8
30 mm thick x 600mm x 300 mm wide marble coping around building perimeter (below curtain walls)	29	0.03	0.1566	2563	401.3658
20 mm thick x 600mm x 160 mm approx. high marble skirting around building perimeter	55	0.02	0.1056	2563	270.6528
					Marble weight 38651.48
Ceramic Tiles	**Quantity**	**Thickness**	**Volume (m3)**	**Density Kg/m3**	**Weight (kgs)**
300 x 300 mm glazed porcelain tiles to Basement & Typical Lift Lobbies	655	0.005	3.275	2403	7869.825
400 x 400 mm tiles (F4), to shops & offices	277	0.005	1.385	2403	3328.155
200 x 200 mm tiles (F5), to garbage & pump room	42	0.005	0.21	2403	504.63
200 x 200 mm tiles (F5), to toilets & pantries	174	0.005	0.87	2403	2090.61
450 x 450 mm tiles including decorative border (F6), to ent. lobby, living & dining	2,109	0.005	10.545	2403	25339.64
245 x 120 x 10.2 mm klinker tiles	57	0.005	0.285	2403	684.855
200 x 200 mm tiles (F12), to bathrooms	245	0.005	1.225	2403	2943.675
200 x 200 mm tiles (F13), to kitchens	724	0.005	3.62	2403	8698.86
300 x 600 mm glazed porcelain tiles to Basement & Typical Lift Lobbies	1,289	0.005	6.445	2403	15487.34
200 x 200 mm tiles (W5), to garbage& pump room	299	0.005	1.495	2403	3592.485
200 x 250 mm tiles including border (W5), to toilets & pantries	1,071	0.005	5.355	2403	12868.07
200 x 250 mm tiles including border (W9), to bathrooms	1,476	0.005	7.38	2403	17734.14
200 x 250 mm tiles including border (W10), to kitchens	2,281	0.005	11.405	2403	27406.22
					Ceramic tiles weight 128548.5

As a result, of all the previous calculations, the weight of concrete, steel, block work, wood, waterproofing, aluminum, glazing, marble and ceramic tiles were obtained as shown is table 4-3. 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 in order to calculate the weight.

Table 4-3: Weights and percentages of building materials in the case study building.

Building Material		Weight (Kgs)	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.	Aluminum 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

Table 4-3 and figure 4-1 show 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 have similar contribution in comparison with their actual used quantity in the building. Finally, the total building weight is approximately 22,000,000 kilograms.

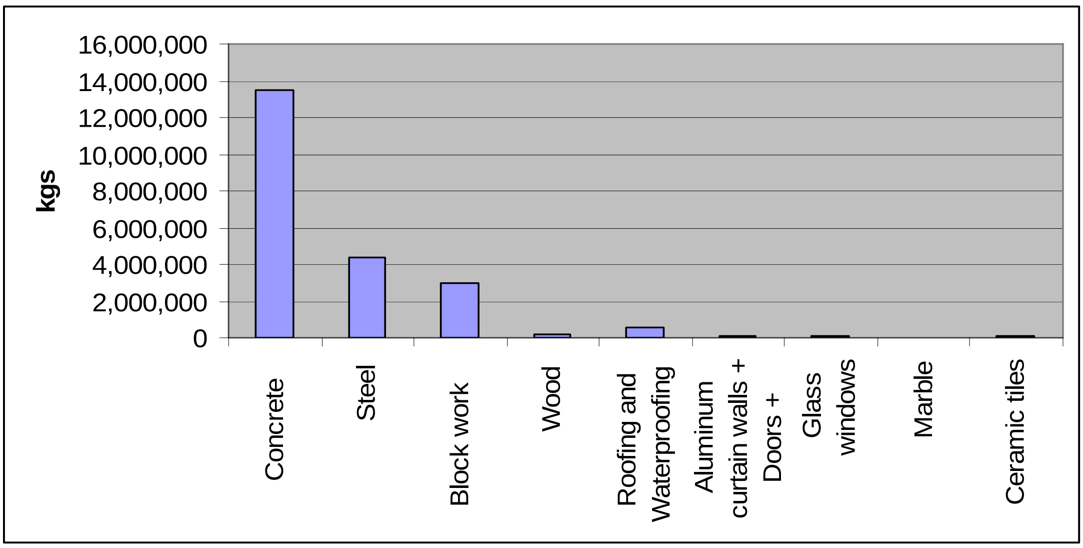


Figure 4-1: Comparison of Weights of building materials in the case study building.

4.3.3 Estimate the CO2 emissions and the embodied energy

In order to estimate the CO2 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: aluminum 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. Results are shown in table 4-4.

Table 4-4: 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
Aluminum	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*[16]. Whereas, after a through search in literature, books, electronic documents and internet. Several consultants like W.S.Atkins[17] in Dubai and Dcarbon8[18] (carbon & sustainability consultants in

[16] For more information, please visit <URL: http://people.bath.ac.uk/cj219/>.
[17] For more information on W.S.Atkins consultants in Dubai, please visit <URL: http://www. atkins-me.com/>.

the UK) recommended and advised the use of this inventory were it is the only inventory that has the complete list of building materials with the embodied energy and CO2 factors and it is the most updated one.

The results as concluded in table 4-4 are:

- The total weight of the main elements in the building is 21,017,104 Kg.
- The total embodied energy of this building is 127,433,013 MJ.
- The embodied energy of one square meter of this building is 8892 MJ/m2.
- The total CO2 emission of this building is 12,853,824 Kg of CO2.
- The CO2 emission of one square meter of this building is 897 KgCO2/m2.

Figure 4-2: Comparison of embodied energy in the case study building materials.

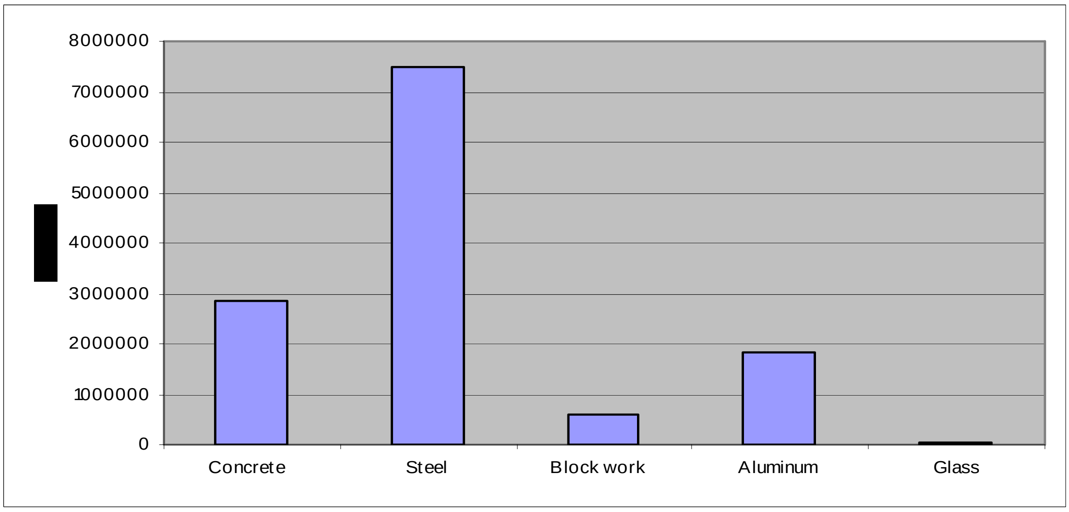


Figure 4-3: Comparison of CO2 emissions in the case study building materials.

[18] For more information about dcarbon8 consultants in UK, please visit <URL: http://www. dcarbon8.com/>.

4.4 Analysis and Results

4.4.1 CO2 Emissions and Embodied Energy Reduction Strategy

Based on the results in tables 4-4, and figures 4-2 and 4-3, it is clear that steel and concrete are the main producers of CO2 emissions, and they have the highest embodied energy values, in comparison to the quantity used in the building. On the other hand, other materials such as aluminium should be considered although its contribution to the total weight of the building is 60,000 kilograms, which is small, compared to concrete weight, which is 13,000,000 kilograms, because aluminium has the highest embodied energy and embodied carbon factors compared to the other building materials. Therefore, the strategy used in this study is considering two main scenarios:

Scenario one:

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.

Scenario Two:

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

These scenarios will be translated to different options of alternative building materials with sustainable features for the main building materials of the case study building, listing the advantages and the disadvantages of each and considering the embodied energy and the embodied carbon as the main scope as shown in table 4-5 and 4-6 and figures 4-4 and 4-5 below.

Table 4-5: Building materials with sustainable features for the case study building.

Building Element / Material **(All the EE & CO2 factors are derived from Hammond G. et al, 2006) for more details refer to page 52.**	
Concrete	
Option 1	High performance concrete with high volume fly ash replacing 15%-50% of the ordinary Portland cement (OPC), (Mehta, 2003).
Advantages	• Limit the use of natural resources. • Reduce energy use. • Improves workability and durability. • Minimize thermal cracking and drying shrinkage. • Reduce environmental impact of cement industries. • Fly ash is a more efficient void-filler than OPC (Mehta, 2003). • Cement volumes replaced with fly ash has a very low embodied energy and low CO2 emissions including the transportation process from China or India. (Information based on a technical meeting with W.S. Atkins Consultants in Dubai, 2008).
Disadvantages	• High cost.
Breakdown of Concrete (1 Cement: 1 Sand: 2 Gravel) (no fly ash & no steel)	- 25% cement (@ EE 4.8 & CO2 0.82) => EE 1.2 & CO2 0.205 - 25% sand (@ EE 0.1 & CO2 0.0053) => EE 0.025 & CO2 0.0013 - 50% virgin gravel (@ EE 0.15 & CO2 0.008) => EE 0.075 & CO2 0.004 - Water & mixing (as balance of EE 1.43 & CO2 0.211) => EE 0.13 & CO2 0.001 Total values => EE 1.43 & CO2 0.211
Breakdown of Concrete - (No fly ash + 9% steel)	- Concrete (1 Cement: 1 Sand: 2 Gravel); No steel => EE 1.43 & CO2 0.211 - 3% steel in concrete (a balance of EE 2.88 & CO2 0.306) => EE 1.45 & CO2 0.095 - In the case study there is 9% steel => EE 4.35 & CO2 0.285 - New values => EE 5.78 & CO2 0.496

Breakdown of Concrete with 50% cement replaced by fly ash (No Steel)	- 12.5% cement (@ EE 4.8 & CO2 0.82) => EE 0.6 & CO2 0.1025 - 12.5% fly ash (@ EE 0.09 & CO2 0.0053) => EE 0.011 & CO2 0.00066 - 25% sand (@ EE 0.1 & CO2 0.0053) => EE 0.025 & CO2 0.0013 - 50% virgin gravel (@ EE 0.15 & CO2 0.008) => EE 0.075 & CO2 0.004 - Water & mixing (as balance of EE 1.43 & CO2 0.211) => EE 0.13 & CO2 0.001 - New values => EE 0.841 & CO2 0.109 - The reduction in EE (1.43-0.841)/1.48 = 39.8% - The reduction in CO2 (0.211-0.0109)/0.211= 94.8%
Breakdown of Concrete (fly ash + 9% steel of which 20% is recycled steel)	- Concrete with fly ash => EE 0.841 & CO2 0.109 - 9% steel => EE 4.35 & CO2 0.285 (see steel section below for calculations details) Thus the reduction when using 9% steel of which 20% is recycled steel is; - The reduction in EE= 14% - The reduction in CO2= 14% - 9% steel with 20% recycled steel => EE3.741& CO2 0.245 - New values => EE 4.582 & CO2 0.354 - In comparison with Concrete - (No fly ash + 9% steel) with EE 5.78 & CO2 0.496 The reduction in EE is ((5.78-4.582)/5.78)*100= 21% - The reduction in CO2 is ((0.496-0.354)/0.496)) *100= 29%
Option 2	Concrete with 20% of reclaimed aggregates (Anink et al, 1996). (contains crushed concrete, brick, masonry waste and crushed glass) (Green Building Design, 2007)
Advantages	• Minimize demolition waste. • Limit the quantity of new gravel required.
Disadvantages	• The availability of suppliers for reclaimed aggregate is still limited. • Very low increase in EE up to 0.7% with no change to CO2.
Breakdown of Concrete with 20% of virgin gravel replaced by recycled gravel	- 25% cement (@ EE 4.8 & CO2 0.82) => EE1.2 & CO2 0.205 - 25% sand (@ EE 0.1 & CO2 0.0053) => EE 0.025 & CO2 0.0013 - 40% virgin gravel (@ EE 0.15 & CO2 0.008) => EE 0.06 & CO2 0.0032 - 10% recycled gravel (@ EE 0.25 & CO2 0.008) => EE 0.025 & CO2 0.0008 - Water & mixing (as balance of EE 1.43 & CO2 0.211) => EE 0.13 & CO2 0.001 - New values => EE 1.44 & CO2 0.211

	- The increase in EE (1.44-1.43)/1.43 = 0.7% - No change in CO2 (there were no values for CO2 for recycled gravel thus the same values of virgin gravel is used. Which results in no change in CO2)
Steel	
Option 1	Recycled steel (steel manufactured with 20% recycled content, 14% is post-consumer) (Woolley et al, 2000)
Advantages	• Minimize demolition waste. • Limit the use of resources. • Ease of reclamation of steel, which is removed from the waste stream magnetically and can be recycled into high quality products (Woolley et al, 2000). • 60-70% is the estimated recovery rate of steel. • Recycled steel consumes 30% of primary energy production.
Disadvantages	• Recycling steel with plastic coatings releases dioxin emissions -hormone disrupters- (but there are no reliable figures).
Breakdown of Steel bar & rod with 20% recycled steel	- Virgin steel bar & rod => EE 19.7 & CO2 1.72 Steel with 20% recycled steel (recycled steel consumes 30% less energy of virgin steel) - EE: 0.8 * 19.7 + 0.2 * (0.3 * 19.7) = 16.94 - CO2: 0.8 * 1.72+ 0.2 * (0.3 * 1.72) = 1.479 - New values => EE 16.94 & CO2 1.479 - The reduction in EE is (19.7-16.94)/19.7= 14% - The reduction in CO2 is (1.72-1.479)/1.72= 14%
Slabs	
Option 1	Pre cast hollow core slabs. • The case study buildings consist of 24 slabs with an area of 500m2 each + thickness of 0.25m. It leads to a total volume of concrete in slabs equal to 3,125m3 with 2500Kg/m3 density. So, the total concrete weight of the 24 slabs is 7,812,500Kgs. • The steel in slabs is equal to 2,978,184 Kgs which is up to 68% of the total steel used in the building.
Advantages	• Uses less material and less energy than solid concrete slabs. • Saves 50% on the use of steel reinforcement (Anink et al, 1996).
Disadvantages	• Construction joints are visible in ceilings. However, can be covered with gypsum boards or false ceilings.
Breakdown of Hollow core slabs- (no fly ash & no steel)	- Concrete (1 Cement: 1 Sand: 2 Gravel); No steel => EE 1.43 & CO2 0.211
Breakdown of Hollow core	- Concrete (1 Cement: 1 Sand: 2 Gravel); No steel => EE 1.43 & CO2 0.211

slabs- (no fly ash + 3% steel)	- 3% steel in concrete (a balance of EE 2.88 & CO2 0.306) => EE 1.45 & CO2 0.095 - New values for steel (0.5 saving in 3% steel) - (0.5*1.45),(0.5*0.095) => EE 0.725 & CO2 0.0475 - New values for Hollow core slabs => EE 2.155 & CO2 0.2585
Breakdown of Hollow core slabs (fly ash + 3% steel of which 20% is recycled steel)	- Values for concrete in hollow core slabs (no fly ash) => EE 1.05 & CO2 0.155 - Values for concrete in hollow core slabs (with 50% cement replaced by fly ash) - The reduction in EE = 39.8% - The reduction in CO2= 94.8% - New values for concrete => EE 0.6321 & CO2 0.0081 - Values for 3% steel in hollow core slabs => EE 1.45 & CO2 0.095 - Values for steel in hollow core slabs with steel of which 20% is recycled steel - The reduction in EE= 14% - The reduction in CO2= 14% - New values for steel => EE 1.247 & CO2 0.0817 - New values for both=> EE 1.879 & CO2 0.0898 - In comparison with Concrete slabs - (No fly ash + 9% steel) with EE 5.78 & CO2 0.496 - The reduction in EE is ((5.78-1.879)/5.78)*100= 67% - The reduction in CO2 is ((0.496-0.0898)/0.496)) *100= 82%
Block Work	
Option 1	Autoclaved Aerated Concrete-A.A.C (Delmon AAC Factory, 2007) has different applications; • External Walls • Lightweight Partition Walls • *Hourdi* (filler)Blocks • Fire Protection for Steel Structure • Roof Thermal Insulation Tiles • Smooth Face Walls • Floor Blocks • Load Bearing Walls
Advantages	• Reduces load on the concrete structure. • Reduces 33% of the dead load when using A.A.C for the *hourdi* slabs and walls. Reduction in weight means using fewer materials whereas; energy is used to produce a smaller amount of materials. This in return reduces EE energy + CO2 emissions. • Fire resistance. • Sound insulator. • High thermal insulation.

	• Reduces electricity consumption in buildings up to 50-70%. • Reduces construction waste, where it can be sawed, nailed and drilled easier than wood, by suitable tools available for this purpose (Delmon AAC Factory, 2007).
Disadvantages	• Higher cost of the standard blocks.
Breakdown of General brick replaced by AAC	- General brick=> EE 3.00 & CO2 0.2 - AAC blocks => EE 3.5 & CO2 0.32 - AAC weighs 33% less than standard brick, its EE & CO2 values must be multiplied by 0.67. - New values=> EE 2.345 & CO2 0.22 - Reduction in EE (3-2.345)/3= 22% - Increase in CO2 (0.22-0.2)/0.2= 10%
Aluminium /claddings	
Option 1	Recycled Aluminium
Advantages	• Saves 80-95% of production energy. • Reduces EE up to 93%[19] • Reduces CO2 up to 80%[20]
Disadvantages	• Powder coated aluminium is not recyclable.
Option 2	Sustainable durable wood (wood panels)
Advantages	• Less environment damage. • Uses less energy.
Disadvantages	• Needs continuous maintenance. • Needs to be protected by a boiled paint application.
Breakdown of Aluminum with 50% recycled aluminum	- Virgin Aluminum=> EE 210 & CO2 31.5 - Recycled Aluminum=> EE 14 & CO2 6.4 - (210-[(210*0.5) + (14*0.5)]/210)*100 = 47%reduction in EE - (210-[(31.5*0.5) + (6.4*0.5)]/31.5)*100 = 40% reduction in CO2 - New values => EE 111 & CO2 19
Glazing	
Option 1	Glass with aluminium-clad timber frames (Menzies et al, 2005).
Advantages	• High insulation properties than other frame types. • Using aluminium-clad timber frames reduces EE to 69%[21]
Disadvantages	• 25%-35% higher in cost than double glazing. However, it

[19] EE of conventional aluminium is about 180-240MJ/kg compared with the recycled aluminium with an EE of 10-18MJ/kg (Woolley et al, 2000), if we take the average of each of the previous values, a reduction in EE is reached up to 93%.

[20] One ton of conventional aluminium produces 26-37 tons of CO2 compared with recycled aluminium (Woolley et al, 2000) where one ton produces 6.4tons of CO2, which leads to a reduction in CO2 up to 80%.

[21] Timber and aluminum-clad timber frames have significantly lower embodied energy than conventional frames such as: uPVC or metal-based frames (738 MJ and 899 MJ compared to 2657 MJ or higher) (Menzies et al, 2005). This means that using this type leads to a reduction in EE up to 69%.

	is repaid by the energy saved within its lifetime.
Option 2	Glass with 50% recycled glass
Advantages	• Less use of energy and cheaper
Disadvantages	• Low grade glass quality.
Breakdown of Glass with 50% recycled glass	- General Glass=> EE 13.5 & CO_2 0.77 - Glass with 50% recycled glass => EE 7 & CO_2 0.77 - New values => EE 6.48 & CO_2 0.77 - (13.5-7)/13.5=48% => 52% reduction in EE - No change in CO_2 (there were no values for CO_2 for recycled glass thus the same values of virgin glass is used. Which results in no change in CO_2)
Insulation	
Option 1	Cork, cellulose (is a by-product of waste paper) for Wall insulation (Anink et al, 1996)
Advantages	- Raw materials are renewable. - Degradable waste. - It has lower EE & CO_2 per Kg and a higher density. Where volume is important in insulations.
Disadvantages	- Can be used in enclosed construction only. - Cannot be used in cavities.

Insulation material	Density (kg/m3)	EE (MJ/kg)	EE* (MJ/m3)	CO_2 ($kgCO_2$/kg)	CO_2* ($kgCO_2$/m3)
Cork	120	4	480	0.19	22.8
Fiberglass	105	28	2940	1.35	141.75
Polystyrene	55	86.4	4752	2.7	148.5
* EE & CO_2 is multiplied by the density (Incropera F. et al, 2007)					

The end result from table 4-5 is shown as a comparison between embodied energy and CO_2 emissions factors in conventional building materials and in building materials with sustainable features; showing the reduction percentages in EE, CO_2 and weight as shown in table 4-6.

Table 4-6: comparison between the embodied energy and the CO2 emissions factors in conventional building materials and in building materials with sustainable features. (All the EE & CO2 factors are derived from Hammond G. et al, 2006) for more details refer to page 52-59.

Conventional Materials	**EE**	**CO2**
Concrete (1 Cement: 1 Sand: 2 Gravel) (no fly ash & no steel)	1.43	0.21
Concrete (1 Cement: 1 Sand: 2 Gravel) (no fly ash + 9% steel)	5.78	0.5
Hollow core slabs (no fly ash & no steel)	1.43	0.21
Hollow core slabs (no fly ash + 3% steel)	2.16	0.258
General blocks	3	0.2
Steel bar & rod	19.7	1.72
Aluminum	210	31.5
Glass	13.5	0.77
Building materials with sustainable features	**EE**	**CO2**
Concrete with 20% reclaimed aggregates (no steel)	1.44	0.21
Concrete with 50% cement replaced by fly ash (no Steel)	0.84	0.11
Concrete with 50% cement replaced by fly ash + 9% steel of which 20% is recycled	4.58	0.35
Hollow core slabs (with fly ash & no steel)	0.6321	0.0081
Hollow core slabs (with fly ash + 3% steel of which recycled steel)	5.78	0.5
Steel bar & rod with 20% recycled steel	16.9	1.48
AAC-autoclaved aretated blocks	2.35	0.22
Aluminum with 50% recycled aluminum	111	2.19
Glass with 50% recycled glass	6.48	0.77

Conventional building material compared to building materials with sustainable features	**Reduction (-) / increase (+) Percentages**		
	EE	**CO2**	**Weight**
Concrete with virgin aggregates / Concrete with 20% reclaimed aggregates (no steel)	0.70%	No change	No change
Conventional concrete (no steel) / Concrete with 50% cement replaced by fly ash (no Steel)	-39.80%	-94.80%	No change
Conventional concrete (9% steel) / Concrete with 50% cement replaced by fly ash (9% Steel of which 20% is recycled)	-21%	-29%	No change
Conventional concrete slabs (9% steel) / Hollow core slabs (with 50% cement replaced by fly ash + 3% steel of which recycled steel)	-67%	-82%	-50% in steel weight in slabs.
Virgin steel / steel of which 20% is	-14%	-14%	No change

recycled			
Conventional blocks / AAC-autoclaved aretated blocks	-22%	+10%	-33% in block weight
Conventional aluminum / aluminum with 50% recycled aluminum	-47%	-40%	No change
Conventional glass / glass with 50% recycled glass	-52%	No change	No change

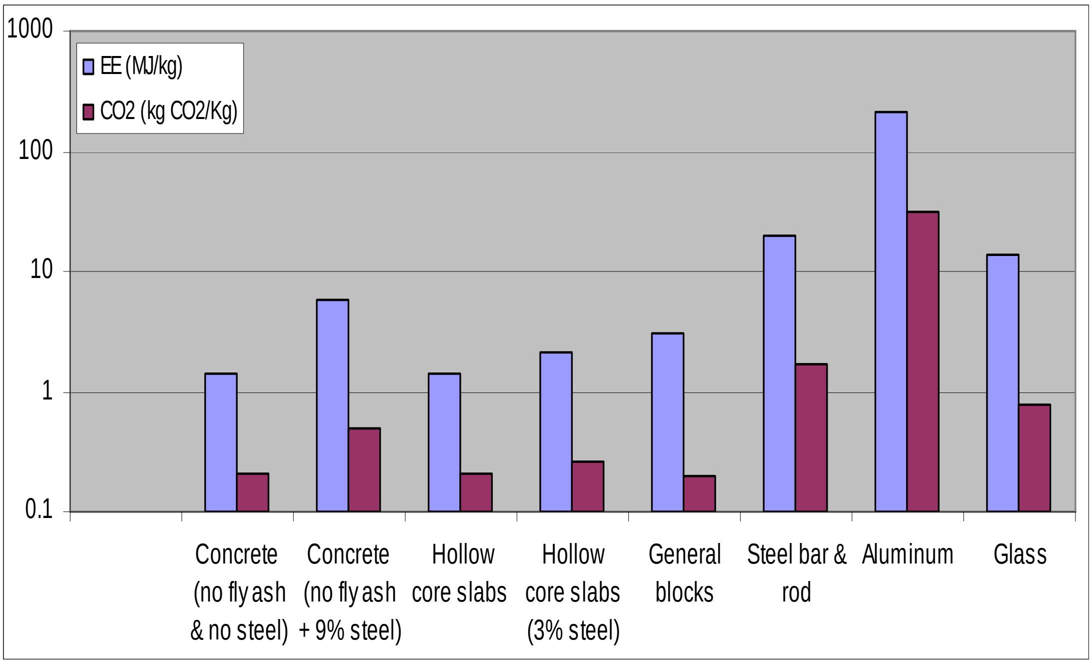


Figure 4-4: comparison between the embodied energy and the CO2 emissions factors in conventional building materials.

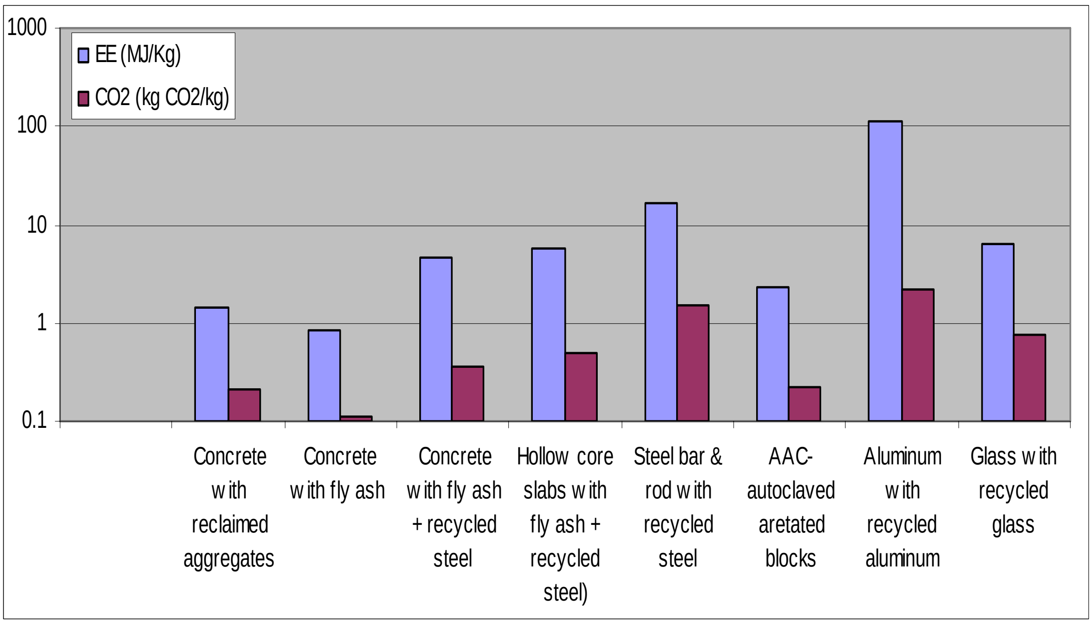


Figure 4-5: comparison between the embodied energy and the CO2 emissions factors in building materials with sustainable features.

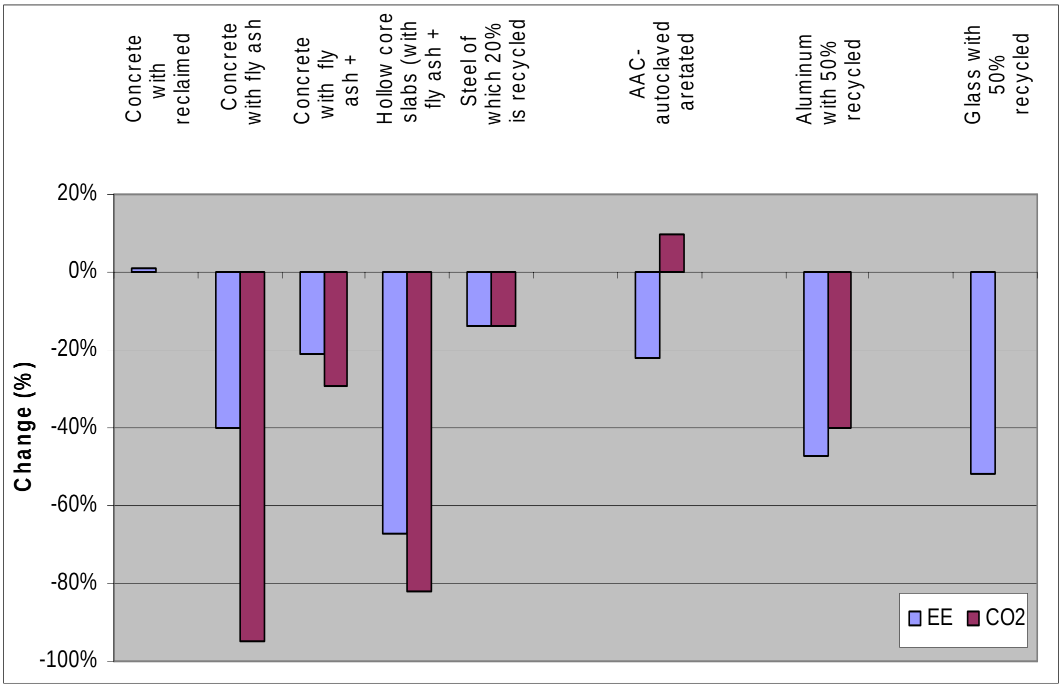


Figure 4-6: reduction and increase percentages in the embodied energy and the CO2 emissions in case of using building materials with sustainable features.

4.4.2 Estimate of CO_2 emissions and embodied energy reduction

As shown in table 4-4, the total embodied energy of the case building is 127,433,013 MJ. Where, the embodied energy of one square meter is 8892 MJ/m2. Also, the total CO_2 emission of this building is 12,853,824 Kg of CO_2. Where, the CO_2 emissions of one square meter of this building are 897 KgCO2/m2. By using tables 4-5 and 4-6 for alternative building materials with sustainability features to hypothetically replace the conventional materials in the case study building; creating a building (with building materials) that has less embodied energy and CO_2 emissions as concluded in table 4-7.

Table 4-7: Embodied energy and CO2 emissions estimate in construction materials of the hypothesis building.

Building materials	**Weight (Kg)**	**EE factor**	**CO2 factor**	**EE (MJ)/Kg**	**CO2 (KgCO2)**
Conventional Concrete replaced with concrete with 50% cement replaced with fly ash (no steel) - all concrete elements with no slabs included.	5,710,588	0.841	0.109	4,802,605	622,454
Conventional slabs replaced with Hollow core slabs (with 50% cement replaced by fly ash + 3% steel of which 20% is recycled)	9,301,592	1.879	0.0898	17,477,691	835,283
Virgin steel replaced with steel with 20% recycled steel - all structural elements with no slabs included.	1,388,164	16.94	1.479	23,515,498	2053095
General blocks replaced by autoclaved aretated blocks	2,020,215	3.5	0.32	7,070,753	646,469
Aluminum replaced with aluminum with 50% recycled aluminum	58,598	111	19	6,504,378	1,113,362
Glass replaced with glass with 50% recycled glass	53,824	6.48	0.77	348,779.5	41,445
Totals	**18,532,981**	**-**	**-**	**59,719,704**	**5,312,107**
Reduction Percentage (in comparison with table 4-4)	**12%**	**-**	**-**	**53%**	**59%**

The results are concluded in the following:

- The total weight of the building is reduced from 21,017,104 kilograms to 18,532,981 kilograms which is up to 12%.
- The embodied energy is reduced from 127,433,014 MJ to 59,719,704 MJ which is up to 53%. This means that the embodied energy of one square meter of the case study building is reduced from 8892 MJ/m2 to 4167 MJ/m2.
- The CO2 emissions are reduced from 12,853,821 KgCO2 to KgCO2, which is 5,312,107 up to 59 %. This means that the CO2 emission of one square meter of the case study building is reduced from 897 KgCO2/m2 to 371 KgCO2/m2.

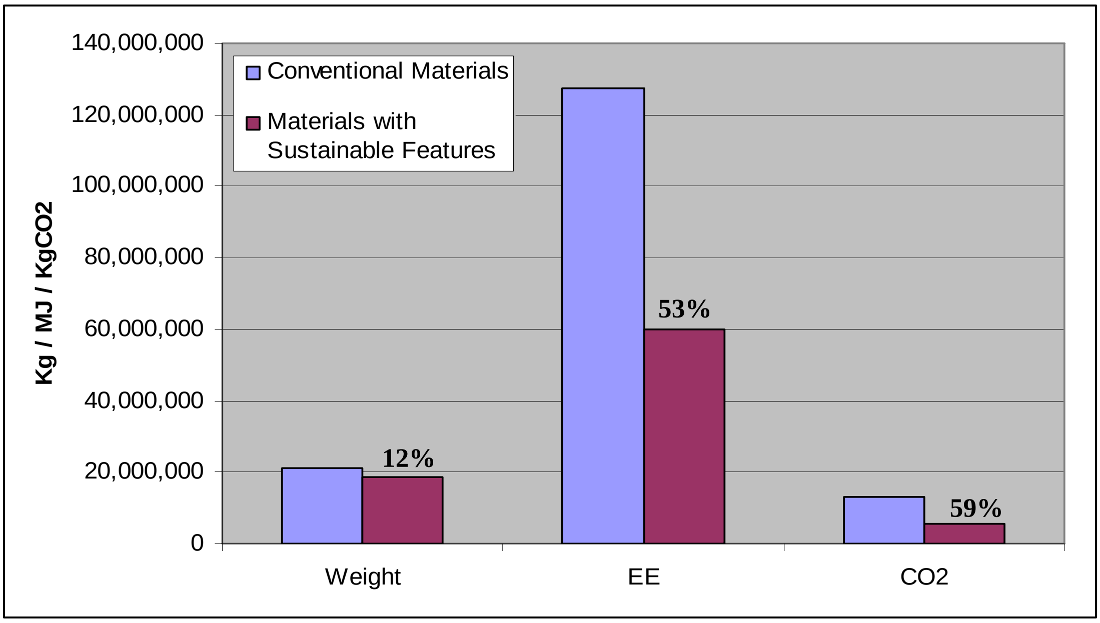


Figure 4-7: Estimate of weight, CO2 emissions and embodied energy reduction when using building materials with sustainable features.

5.0 Findings

5.1 Conclusions

The focus of this study was to examine ways of reducing CO_2 emissions and embodied energy related to building materials during the construction phase through the following strategies:

1. 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 CO_2 emissions such as concrete.
2. Consider building materials with sustainable features as alternatives for materials that have high-embodied energy and embodied carbon factors such as aluminium.

The results show that:

- The total weight of the building is reduced up to 12%.
- The embodied energy is reduced up to 53%
- The CO_2 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 CO_2 emissions and EE associated in the recycling process.

For assessing this study, it is important to know exactly the magnitude of the figures produced. In the case study building analyzed, the CO_2 emission during the construction phase of the building was 12,853,821 $KgCO_2$, which means an impact of 897 Kg of CO_2 emissions per built square meter. For the same case, it was estimated that 7,541,717 Kg of CO_2 and 67,713,327 MJ of embodied energy have been avoided by using the selected materials with sustainable features instead of the conventional ones. The total weight removed from the building is 2,484,123 Kilograms, which is very significant, since it relates to the construction phase only without considering other life cycle phases or the changes that should have be done in the design stage and the building envelope.

As a consequence, regarding the proposed research line in chapter one, and as can be deduced from the figures obtained in chapter four of this study, results are concluded below:

- The CO_2 emission per built square meter is reduced from 897 $KgCO_2/m^2$ to 371 $KgCO_2/m^2$. This means that 526 kilograms of CO_2 are avoided when using building materials with sustainable features.
- The embodied energy per built square meter is reduced from 8,892 MJ to 4,167 MJ. This means that 4,725 MJ are avoided when using building materials with sustainable features.
- The total weight of the building is reduced from 21,017,104 kilograms to 18,532,981 kilograms. This means that 2,484,123 kilograms are avoided when using building materials with sustainable features.

5.2 General Recommendations

To achieve the diminishing of the negative environmental impact caused by the construction industry, the following recommendations are presented:

- In the design stage, all building materials and specifications should consider sustainable materials and main contractors to provide the supply chain information and installation methods of materials to reduce the negative impact and facilitate the assessment of EE and carbon foot print.
- International information exchange on all aspects of construction related to the environment, among architects and contractors, particularly renewable resources.
- Exploration of methods to encourage and facilitate the recycling and reuse of building materials, construction waste, scraps, etc, especially those requiring intensive energy use during manufacturing; and the use of clean technologies.
- Creation of an inventory database for sustainable building materials and the whole supply chain combined with life cycle analysis (LCA) and life cycle cost (LCC) for the UAE.

- Creation of a well designed web-based local information on GHG in the UAE.
- Promote the use of a rating system for buildings, based upon: the environmental quality.

5.3 Future Work

- The reduction in the building weight reported in this study was due to the use of alternative sustainable materials and construction methods without considering how this reduction in weight can affect the foundations and the structure of the building. A lighter building means a smaller concrete foundation, smaller columns with less steel, ect. All of which should further reduce CO2 emissions and embodied energy beyond the percentages mentioned previously. The exact extent of this side-effect benefit can also become a point for future research.
- By engaging potential steel and aluminum manufacturers, structural engineers and concrete contractors, it will be possible to get exact concrete mixes and alternative options for Portland cement, steel and aluminum and estimate the weight, carbon and EE reductions with cost analysis through the life cycle of the building.
- Assess the energy performance impact of using these alternative materials on the environment and running cost.

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