A CASE STUDY OF CARBON REDUCTION BEST PRACTICES AND BENCHMARKING IN THE MALAYSIAN CONSTRUCTION INDUSTRY

By

Fatin Nornabilah binti Idris

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Mohd Faris Khamidi)

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TRONOH, PERAK

May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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FATIN NORNABILAH BINTI IDRIS

ABSTRACT

Building construction is the largest source of carbon emission which has the enormous impact on environment. The green building materials selection is crucial to achieve sustainable construction. The type of building materials affects the amount of carbon emission of a construction project. The aim of this study is to determine the carbon reduction best practice based on the benchmark level of building materials from a case study in the Malaysian construction industry. The objectives of this study are (1) to determine the amount of carbon emission for various types of building materials based on a case study of a construction project; and (2) to conduct carbon emissions modeling of building materials from the benchmark level for the Malaysian construction industry. The study extracts the building materials from the bill of quantity and converts in term of carbon emission. Using the Inventory of Carbon and Energy (ICE) by Hammond & Jones, the embodied carbon impact for each material was identified using boundaries defined by a 'Cradle-to-Gate' in building life cycle. The carbon calculator is used to estimate the amount of carbon emission for every model of building materials. Furthermore, fly ash used as the alternative materials of concrete in Model 1 while steel materials are replace by the recycled steel for Model 2 and secondary glass used in Model 3 instead of primary glass. The overall alternative from previous model used in Model 4. The consumption of timber is fixed in this study due to the natural and low embodied carbon. The result of this study shows the steel has the highest contribution of carbon emission. As the result of the models comparison, Model 4 is selected as a carbon reduction best practice with the carbon reduction of 15.2% by consumption of overall alternative materials. This reduction of carbon followed by Model 2 with 8.6%, Model 1 with reduction of 6.0% and Model 3 with the reduction of 0.6% carbon emission. From the research, the average carbon reduction of 7.6% based on the benchmark level of case study is achievable to be a helpful reference for the construction professionals in selecting green construction material.

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ABBREVIATIONS

BedZED – Beddington Zero Energy Development

BEI – Building Energy Index

CH_4 – Methane

CIDB – Construction Industry Development Board

CO_2 – Carbon dioxide

CO_2-eqv – Carbon dioxide equivalent

CRC – Cooperative Research Centres

EIT – European Institute of Innovation and Technology

EPA – Environmental Protection Agency

GDP – Gross Domestic Product

GGBS - Ground Granulated Blastfurnace Slag

GHGs – Greenhouse Gases

GWP – Global Warming Potential

HFCs – Hydrofluorocarbons

ICE – Inventory Carbon & Energy

IPCC – Intergovernmental Panel on Climate Change

KLCC – Kuala Lumpur City Centre

KLIA – Kuala Lumpur International Airport

N_2O – Nitrous oxide

NRC – National Research Council

OECD – Organization for Economic Co-operation and Development

PFCs – Perfluorocarbons

SBCI – Sustainable Buildings and Climate Initiative

SF_4 – Sulphur hexafluoride

UNEP – United Nations Environment Programme

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, Malaysia has become one of the rapidly growing developing countries. Indeed, there are many creative designs of buildings that were constructed in the country such as KLCC, Menara Kuala Lumpur and KLIA. Furthermore, the construction in Malaysia obtained recognition from the world regarding one of the high-rise building constructions which is KLCC with a great structure and intelligent interior design.

The construction industry is one of Malaysia's important economic sectors which play primary role contributed vastly in developing the country. Also, the construction industry encompasses the development of housing, commercial, and infrastructure. Moreover, they consist of multifarious fields involving architecture, civil engineering, mechanical engineering, electrical engineering, quantity surveying, land surveying, building contracting, and landscaping among others. The high level growth of Malaysian economic and aspiration of becoming a developed country has created the environment for growth, and stimulated changes in construction industry. Besides, the construction industries enclose 3.0 percent of the total Gross Domestic Product (GDP) in the country in 2010 based on the records by Department of Statistics Malaysia (2010).

However, every creation in the world has their negative impact as well as building constructions which have negative side regarding environmental issues. The increase of the earth temperature leads to the global warming and global climate change. The effect of the global warming is due to the excessive of the greenhouse gas (GHG) emissions. The emissions of GHGs from various sources influence the environmental condition and human health. The increase of carbon dioxide (CO_2) emission as one of the GHGs has effect in global warming and lead to environmental impact such as floods, storms and droughts. The human activities are one of the sources of impact of global warming with evident of almost 30 billion tones of CO_2 produced from human activities (NRC, 2010).

The construction industry promote up to 40% of GHG emissions during the life time of the buildings due to the energy use (Levine et al, 2007). Therefore, the GHG emissions from the building life cycle has become a great issue as one of the impact due to global climate change which become the priority to the world in identifying opportunities to reduce these emissions. Moreover, the existent of industrialization process since over the past decades contribute to the GHG emissions which through natural or human activities. In the past decade, human gone through the industrial process and depend on energy to operate vehicles, heat homes, and operate industries. Thus, developed countries tend to induce more emissions than developing countries. In addition, the developing countries have no requirement to regularly report their GHG emissions based on current international rules. However, there is believed that some developing countries have surpassed developed countries in GHG emissions (Burnett, 2006).

Building materials selection is important in order to achieve the sustainable building construction and reduce the carbon emissions that affect the environmental condition. The type of building materials plays an important in changing the value of carbon emission from the building construction. Building life cycle of 'cradle to gate' boundary condition consist of the building materials selection which is crucial in designing the green building. The alternative materials should be use in the building materials selection to achieve carbon reduction best practices. Furthermore, the reduction of carbon emissions needs to be achieved in order to accomplish the sustainable development of the country.

1.2 Problem Statement

Construction industry has become the major sources of environmental problem and health impact even though they provide countless benefits to the nation economic and society. The contribution of this industry is undeniable to bring the country toward the huge development. However, the increase of earth temperature brought to the development of global warming and climate change which result in adverse impact to the economic and society. One of the sources of the impact is the contribution of GHG emission from the human activities such as in construction industry. The contribution of CO_2 which is the primary GHG emissions during the life cycle of the building construction affects the earth surface temperature and global climate.

Furthermore, the selection of building materials during the building life cycle which is from the ‘cradle to gate’ boundary has the significant impact to the carbon emissions in building construction. The embodied carbon for each of the materials plays an important role in order to achieve the sustainable building construction. The higher embodied carbon result in greater carbon emission of the building. Carbon emissions from the construction industry tend to be increase in line with modernity and affect the economy and society. Furthermore, the Malaysian construction industry not yet establish the any benchmark level of carbon emission for the building construction in order to provide the reference of carbon emission level in Malaysia in term of building materials to the engineers and architects in designing the buildings.

The country with the largest carbon emission in the world is United States with a total emission of 5,762,050 metric tonnes. Malaysia is the ranked 30^{th} in the world for countries that has the largest amount of carbon emission (CO_2) with 123,603 metric tonnes. The construction industry in Malaysia contributed 24% of the total carbon emissions which at the crucial level to take action on the increasing of this pollution (Nation Master, 2013). The problem emphasized by the fact that it is important to identify selection of the building materials in order to achieve the green building and reduce the impact of GHG emission to the human life and environment.

1.3 Objective of the Study

The aim of this study is to determine the carbon reduction best practices and benchmarking for building materials in the Malaysian construction industry. In order to achieve this aim, the following objectives are identified:

i. To determine the amount of carbon emission for various types of building materials based on a case study of a construction project.
ii. To conduct carbon emissions modeling of building materials from the benchmark level for the Malaysian construction industry.

1.4 Scope of Study

New buildings are being constructed in every year with new construction materials are being introduced on the name of modernity and to achieve the development of sustainability. However, carbon emission from the building materials in construction has become the major issues in degradation of environment. The building materials such as steel are higher in carbon emissions that lead to the global warming and climate change.

Basically, the scope of this study is to identify the carbon emissions from construction industry and its materials generated from a office building as a case study in the boundary of 'cradle to gate' condition and to develop carbon reduction best practices by using Inventory of Carbon and Energy (ICE) database calculator within the Malaysian construction industry. The selected case study has been chosen based on its properties. The calculations of carbon emission for every material are determined by using carbon calculator in order to identify the amount of the carbon emit to the atmosphere and to develop the alternative materials that have the smaller amount of carbon emission for the Malaysian construction industry. These alternative materials can reduce the impact of global warming and environmental condition.

This research is focus on the calculation of the case study building materials and the simulation of the four models of building materials based on the case study in order to select the building materials that have the carbon reduction best practices. The carbon emission of the case study is selected as a benchmark level for the models simulation. The models were consuming the alternative materials to achieve the potential carbon reduction for the Malaysian construction industry based on the case study. The main materials were selected from the case study as the input of the models. Furthermore, the quantity and total area of the case study is similar with the models.

It is crucial to understand the relationship and steps involved in the building construction as well as the selection of the building materials that need to be extracted from the bill of quantity of the chosen project in order to carry out the calculation of carbon emission of the building. Therefore, the comparison between the four models is carried out to determine the most sustainable building materials within the Malaysian construction industry. This project is feasible and completed within the allocated time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 Construction Industry

Construction industry is one of the profitable industries that continuously contribute to the economy. This industry takes place as the primary sector that contributes to the Malaysian economy as a catalyst of improvement to the other sectors. It is provide job opportunities for 800,000 people which show 8% of total workforce and responsible as the influential sector for the advancement of the infrastructure, transportation facilities and accommodation for residents and also has predicted by many as the catalyst of economic recovery as well as a driver for the modernization of Malaysia (CIDB, 2006).

According to CIDB (2011), that has been proving in 2009, the construction industry growth at 0.6% and contributed 3.0% total Gross Domestic Product (GDP) of Malaysia. Therefore, in order to improve the sustainable development, the industry has come out with some of the initiatives which builds of housing, office buildings, public buildings and services, communication energy, water and sanitary infrastructures, and provides the context for social interactions (CIDB, 2011). In addition, the construction of the buildings develops undeniable social and economic benefits to society.

However, the construction industries also have the bad impact to the environmental quality such as energy use, waste generation, construction materials transportation, and consumption of hazardous materials (Akadiri, 2011). The rapid growth of the industrialization results in increase of carbon emissions which contribute to the adverse impact to the environment. This is evident that the present of carbon emissions in the construction sector contribute to the global warming and degradation of economic status.

2.2 Climate Change and Global Warming

The world has experienced extremely destructive natural disasters in the past few decades. The global climate change is one of the source of these strong phenomena that leading to global warming. The recent and continuous increase in earth temperature brought to the global warming. The reason of this happened due to rise in concentration of GHG emissions that change the global climate patterns.

IPCC (2007) determined the temperature of the surface earth is expected to increase from 1.1 to 2.9 °C (2 to 5.2 °F) for the lowest emission scenario and to 6.4 °C (4.3 to 11.5 °F) for the highest during the 21st century. Thus, the temperature may possibly continuous for many years in the future if there are no actions regarding the recovery of this problem. Small differences surface earth temperature can lead to greater and potentially dangerous shifts in climate and weather (IPCC, 2007). According to Safaai et al., (2010), during 20th century, the global sea level has rise by 10-20 cm. The natural disaster such as tsunami, floods, and severe heat waves were the effect of climate change (EPA, 2013). This is proven of climate change consequences due to disturbance of natural environment by emission of GHGs. As these climate changes become more pronounced in the coming decades, they will affect our environment and society.

Generally, the global warming has a primary impact toward the society and surface of the atmosphere. IPCC (2007) described the human activities such as the deforestation and burning fossil fuels contributed into increasing concentrations of GHGs that affect the warming of climate change. In accordance with Glasby (2002), the contributing of global warming into the atmospheric surface brought to significant increase in the frequency and severity of heat waves and associate impact on human health. Furthermore, the report in 1990 also indicates that human activities cause the harmful impact in the increase atmospheric concentration of CO_2 and greenhouse effect (Kininmonth, 2003). This is the evidence that global warming is a problem cause by human influence. Therefore, the adverse human activities on the nature brought the impact to themselves.

The GHGs are one of the sources that brought to the harmful climate change in the future claimed by IPCC in 1995 and 2001 (Kininmonth, 2003). Thus, over emitted of GHGs can change the climate and effect to human health and ecosystems. Loaiciga (2009) stated the global warming has the same properties as climate change because of the excessive emission of GHGs into surface earth caused rising in average temperature that impact the climate on earth. They also claimed the temperature of the surface earth has increased between 0.3°C and 0.6°C during the previous 150 years according to the IPCC in 2007 (Loaiciga, 2009).The climate change has the strong relationship with the global warming in degradation of environment through rising of temperature. This is proven the increasing of the concentration of carbon dioxide and other GHGs in the surface earth effect the climate change.

2.2.1 The Effects of Greenhouse Gases (GHGs)

Table 1: The global warming potential of the Kyoto gases. Source: (Burnett, 2006)

KYOTO GAS	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)	23
Nitrous oxide (N_2O)	296
Sulphur hexafluoride (SF_6)	22200
Perfluorocarbons (PFCs)	4800-9200
Hydrofluorocarbons (HFCs)	12-12000

The GHGs consist of six gases as the potential global warming gases contribute to the climate change and global warming covered by the Kyoto Protocol (Burnett, 2006). CO_2 is the important anthropogenic of GHGs which contribute to the increase of global warming because of human activities and it has the highest contribution (70%) to the greenhouse effect followed by CH_4 with 24%, N_2O about

6% (Safaai et al., 2010). According to table 1, the CO_2-eqv in GHGs act as the GWP and a relatively small emission can have a considerable impact toward the high GWP.

The greenhouse effect is one of the major contributions of the climate change into the atmospheric pressure. The absorption and emission of radiation of infrared by gases in the atmosphere surface is defined as the greenhouse effect. IPCC 2007 claimed the strong evidence regarding the rising concentration of greenhouse gas in the surface atmosphere by changing the global climate system can cause the harmful impact in ecosystem, socio-economic and technological systems (Burnett, 2006). They also discussed regarding the studies of the global climate system and anthropogenic interference with the global climate system. Furthermore, they claimed the environmental pollution including heat waves, drought, flooding, a rise in sea level, coastal erosion and the failure of food production systems as the major effect of the temperature on atmosphere surface (Burnett, 2006).

CO_2 of GHG emission is considering releasing from eight major sectors which is power station (21.3%), industrial processing (16.8%), transportation fuels (14.0%), agricultural by-products (12.5%), fossil fuel retrieval processing & distribution (11.3%), commercial & other sectors (10.3%), land use & biomass burning (10.0%) and waste disposal & treatment (3.4%) and affects the global warming (Sagheb, 2011). Figure 1 shows the energy flows in the atmosphere and the earth's surface. They described how the energy flows trap the heat on the surface atmosphere and form the greenhouse effect. Furthermore, CO_2 is the main anthropogenic GHGs and contribute to the climate change through burning fossil fuel which increases the CO_2 concentration. Goodal reported that every year CO_2 contribute approximately 30 billion tonnes to the atmosphere through the result of human activities (Safaai et al., 2010).

In addition, the fossil fuel that effect the GHGs emission are being burned for transportation, electricity production, domestic and industrial uses and some of these fossil fuels are being consumed in the forest industry, as a result of logging, transportation and processing operation. The greenhouse effect is an essential piece of Earth's climate. Under stable situation, the energy penetrate the atmosphere from solar radiation will balance the amount being radiated into space and a constant average temperature over time could be achieved. The greater evaporation and reduction of water availability become the result of greenhouse effect as well as increasing temperatures. Thus, GHGs emission brought major impact to the nature (IPCC, 2007).

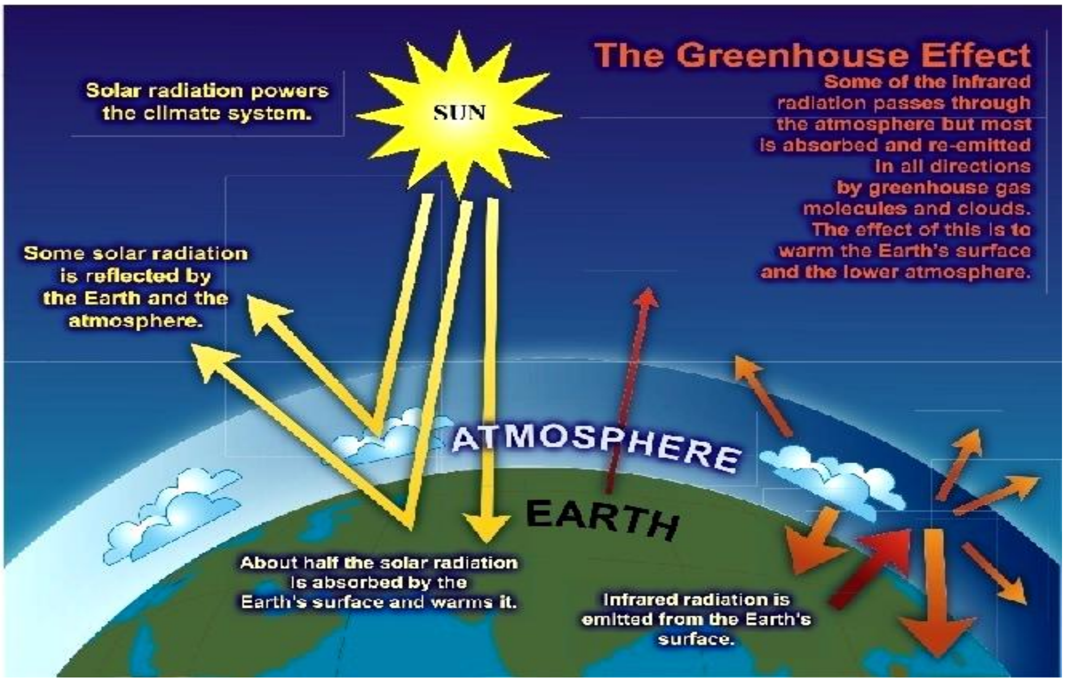


Figure 1: The GHG effect Source: IPCC (2007).

Since the industry revolution, the increase concentration of the GHGs in the atmosphere surface effect by human activities and also contributed to increase radioactive from CO_2 (70%), CH_4 (24%), and N_2O about 6% (Safaai et. al, 2010). In accordance with United Nation (2011), the rising of the temperature of the surface earth, length of seasons variation, melting of the ice-caps and rise in sea level were the major impact of global climate change. The emission of CO_2 has increase by 30% with the earth temperature risen by 0.3-0.6^{o}C (Safaai et. al, 2010). In addition, the combustion of fossil fuels includes petroleum, diesel and biomass consume from trees and solid wastes contribute the rising of carbon content which produce GHGs as well as the depletion of the stratospheric ozone layer.

The other sources that lead to the impact of the properties of the earth surface as well as global climate is land use change which are include urbanization, forestry and agricultural activities. The changes in regional precipitation, earlier break-up of ice on rivers, long period of growing seasons, replace in plant and animal ranges, and too soon flowering of trees were the impact of the higher temperature of atmosphere (United Nation, 2011). Furthermore, the global climate change has the greater impact to the human being and environment since the climatic events such as hurricanes, droughts, wildfires and other natural disasters, resulting in damages to human lives, property and the nation's economy (IPCC, 2007).

2.2.2 Building Construction and Carbon Emission

The estimation of building-related GHGs emissions likely between 8.6 million metric tons CO_2-eqv in 2004 claimed by Fourth Assessment Report of the IPCC (Levine et al, 2007). Building and GHG emissions are inextricably linked. Thus, the building construction operations are contributed to the environmental pollution. In between 1971 and 2004, the estimation of CO_2 emissions include the usage of electricity in buildings have grown at a rate of 2.5% per year for commercial buildings and at 1.7% per year for residential buildings (Levine et al, 2007). In the United Kingdom, the concentration of carbon emission is almost 14% from the building industry (Stern Review, 2006). Therefore, the GHG is one of the major effects of the building construction activities which give rise to global warming.

The environmental impact such as acid rain, flooding, safety and health problem due to harmful environment related to the process of building construction. Currently, the world is in danger due to the increasing of global warming and climate change. According to IPCC (2007), the rate of decadence of external shells of building structures is related on climate, depending on the materials used and buildings are affected by water-logging related to the precipitation patterns. In 2004, the impact of natural disaster has effect the 131 million people in Asia and 97% were affected by weather related disasters (IPCC, 2007). Therefore, the weather-related and climate are the major concern due to the environmental impact.

Global Carbon Project stated the record estimation of the GHG emissions increase by 2.6% with 35.6 billion tonnes at the end of 2012 when compared to previous year (IPCC, 2007). In addition, the burning of fossil fuels and the manufacture of cement as the major contributor to the CO_2 emissions and include during consumption of solid, liquid and gas. According to IPCC (2007), the increase of global temperature during hot spells is one of the effects of building construction. Furthermore, the GHGs emitted from building construction consist of CO_2 from energy use and non energy uses of fossil fuels as well as non CO_2 gases. In addition, according to Price et al. (2006), the construction industry contributes more than 90% of CO_2-eqv GHG emissions in most countries. This is proven the CO_2 emissions as the major adverse impact to the environmental condition.

The emissions of CO_2 to the atmosphere surface is depend on three sources which are from the use of fossil fuels for energy directly by industry for heat and power generation or indirectly in the generation of purchased electricity and steam, use of fossil fuels for non energy in chemical processing and metal smelting and cement and lime manufacture as the non fossil fuel sources. Therefore, among the carbon emissions contribute to the construction industry, the CO_2 has the most important role in the manufacture of building materials (Buchanan, 1994). The building industry plays the important role in the development of a sustainable built environment by controlling and reducing GHG emissions. Furthermore, figure 2 indicated the buildings as the major economic mitigation potential expected to be available in 2030. Building industry has the biggest potential for reducing GHG emissions instead of the other the other industries.

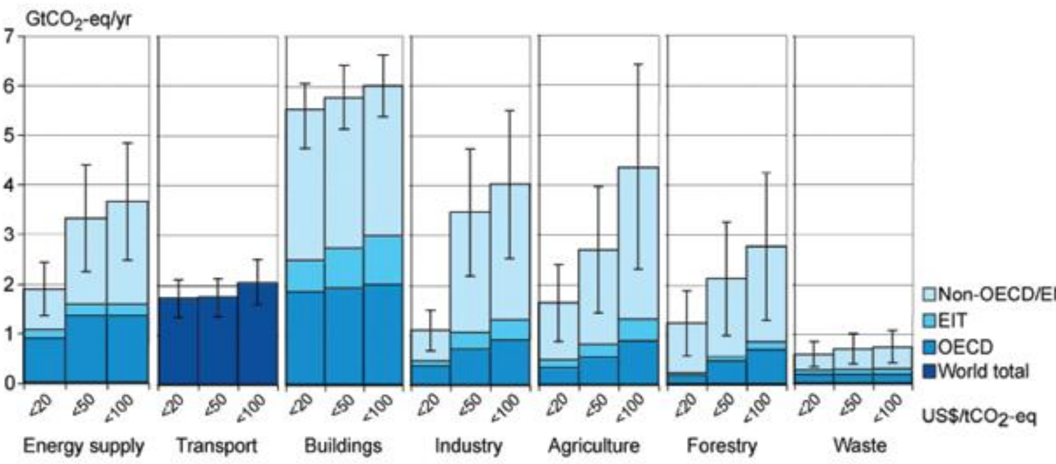


Figure 2: Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. Source: IPCC, 2007.

2.3 Life Cycle of Building Construction

In construction project, there are emissions before use (embodied emissions), during use (from use of building services and appliances, and maintenance and refurbishment) and after use (UNEP SBCI 2010). Furthermore, European Union analyze that the life cycle of the building construction consist of construction, operation and demolition which consume the high amount of energy and contribute to CO_2 emissions release to the atmosphere (European Commission, 2007). In the building construction, the consumption of raw materials consist of extracted, processed and manufacture, transported, added in the construction phase and finally disposed.

Jones (1998) stated there are five phases of energy consumption in buildings which first is the manufacturing of building materials and components (embodied energy). The second and third phases consist of grey energy (the energy for transportation of materials from producing plant to project site while third phase is induced energy (energy consumption during construction). The operation energy is the fourth phase of the energy consumption in buildings which consumed at the operation phase. Then, demolition and recycling energy are the final stage in energy consumption which is energy use up in the demolition and recycling process.

Embodied energy refers to the total energy needed for construction final product (material) which are include extracting of raw materials, process and manufacture as well as assembling transporting to site (Slesser M., 1988). The system boundary defined which unit processes need be included within a whole life cycle of building products. The selected system boundary has to be clearly defined since it influences the final embodied carbon value. According to Hammond and Jones (2008), the embodied energy or carbon has common referring to ‘Cradle to Gate’ which is the beginning of raw material extraction until the transportation to construction site which more specified as compare to boundary condition of ‘Cradle to Grave’ which refer as the beginning of raw material extraction until finish and lack of specified boundary conditions (figure 3). In this study, the stages of construction until demolition and recycling are not considered. The focus system boundary for this study is limited to ‘cradle-to-gate’ for these building materials.

During the life cycle of a building which includes raw materials extraction, transportation, construction and operation & maintenance, refurbishment and end-of life contain the GHG emissions from the embodied carbon. The harmful pollutants related with energy such as CO_2 emissions which impact the global warming and climate change could be viewed over their lifecycle. Since the building construction consumed major raw materials, the high embodied energy content such as aluminum, cement and steel resulting in CO_2 emissions due to fossil fuels usage. The environmental effect always consider in the life cycle of building constructions which from extraction of raw materials, processing and manufacture, consideration of fuels, electricity, and heat during life cycle as well as transportation. This study is focus on quantitative study of the system boundaries consist of raw materials extraction, manufacturing and intermediary transportation effects associated with cradle-to-construction site gate life cycle stages (Hammond and Jones, 2008).

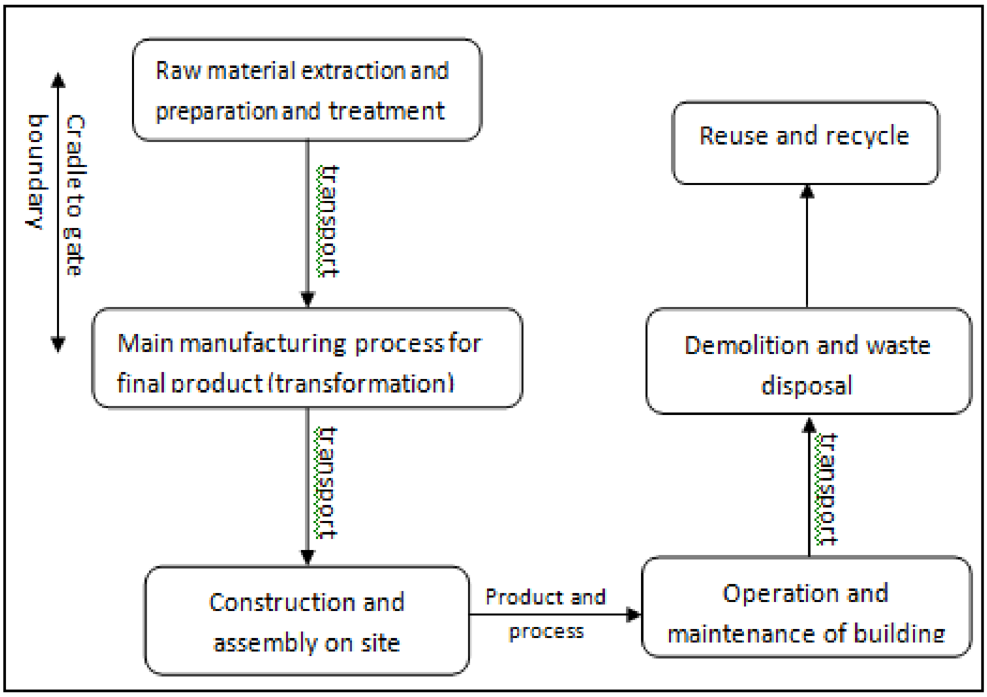


Figure 3: Life Cycle of Building. Source: Hammond and Jones (2008).

2.3.1 Building Materials

In building construction, the materials used have broadly varying amounts of GHGs linked with their extraction, refining, manufacture or processing and delivery. According to (Burnett, 2006), concrete, cement and steel have high embodied carbon. The materials consumption in construction industry have various amounts of GHGs such as cement and steel which has over 10% of GHG emissions (Burnett, 2006). In order to develop new buildings with better reduction of carbon emissions, the emissions combine with materials make up a larger proportion of their total climate change impact. Therefore, the awareness of climate change impact is experience among planners, developers, architects and builders including consideration for their selection of materials in building constructions (Burnett, 2006). Lane (2007) states the steel and concrete are the major sources of embodied carbon in building constructions with associated impact of 35% and 18%. This indicate that the production of steel and concrete as building materials might increase the carbon emissions and resulting in impact of safety and environment.

Concrete

The mixing of cementing material, coarse aggregate, fine aggregate and water due to chemical reaction of the cement and water produced concrete material which also known as artificial material (Gielen D.J, 1997). The combination of steel reinforcement commonly produces the increasing of the flexural strength increase the CO_2 emissions per ton of concrete and the usage of cement consists of calcium carbonate as a raw material in concrete production generated greater CO_2 emissions (Gielen D.J, 1997). The cement is widely utilized in concrete production. According to Green Ration Book (2010), 0.9 pounds of CO_2 is produced from the manufacture of cement and production of 3900 lbs concrete emits around 400lbs of carbon emission. The embodied carbon for general concrete is 0.130 $kgCO_2$ / kg (Hammond and Jones, 2008). Each type of concrete has its specialty according to the concrete quality, strength and heat conductivity. The production process can be classified into on site cast concrete and precast shapes as well as based on the content of steel reinforcements (Gielen D.J, 1997).

Steel

Steel is used as construction elements such as for concrete reinforcements and as cladding materials. This material is essential for building construction in the modern world. According to Worldsteel (2013), steel consumed for every year with more than 1.4 billion tonnes. Currently, China is the main region that produced and consumes the steel materials which is 45% (Worldsteel, 2013). There are several benefits using the steel in building constructions such as multicycling, reusable, safe, and zero waste (Gielen D.J, 1997). Steel is the building materials that capable to be reuse repeatedly with maintaining their quality and standard. Connection of steel using bolted connection allows steel removed from the main structure easily and efficiently (Gielen D.J, 1997). This is prove that steel can be reusable for many times without reducing their quality and never sent to landfill as well as made it zero waste of building materials. The International Energy Agency in 2010 reported the steel industry has contributed almost 6.7% of the CO_2 emissions (Worldsteel, 2013). The embodied carbon for general steel use in building constructions is 1.77 $kgCO_2$ / kg which are higher among the other materials (Hammond and Jones, 2008). This is show that steel has higher impact of carbon emissions than other products.

Timber

Timber which also known as wood is widely used in building constructions because of its properties which is applicable to oppose breaking with it strength. According to Gielen D.J. (1997), wood has advantage compare to the other building materials with rational price, ease of working, attractive look and adequate life if secured from moisture and insects. CRC (2013), point out the production of timber in building constructions can save more than 25 tones of CO_2 to build a single storey house compared with using the other alternative materials. Timber also required energy for 8 times less compare to steel and it takes 46 times less energy than aluminum (CRC, 2013). Furthermore, the carbon release by the wood only when it is burnt or when it decays. According to Australian Timber Database (2013), the carbon footprint for timber is less than the other building materials as shown in figure 4. Timber has less energy required compare to concrete, steel, ceramic, brick and aluminum which result in lower carbon emission (Gielen D.J, 1997).

Fly Ash

Nowadays, fly ash is a popular alternative material that replaces the cement in production of concrete. General cement has high amount of embodied carbon compare to fly ash. The production of fly ash is through combustion of pulverized coal in electric power generating plants. In the process of fly ash, the coal's mineral impurities such as clay and shale during combustion are carried away by the exhaust gases from the combustion chamber. These mineral impurities also fuse in suspension. Then, this fused material is being cools and solidified into fly ash which also known as spherical glass particle. The collection of fly ash from the exhaust gases during combustion is using the electrostatic precipitators. The carbon emission of building life cycle is decrease by using fly ash as the alternative materials in production of concrete. The consumption of fly ash generates the durable finished concrete and increase the strength of the concrete in building construction. Besides, this alternative material contributes to the aesthetic appearance creative design of the concrete. Concrete has the flexibility in production of curve structures. Furthermore, it is generate the smooth flow of the building construction and reduce the time constrain for particular building.

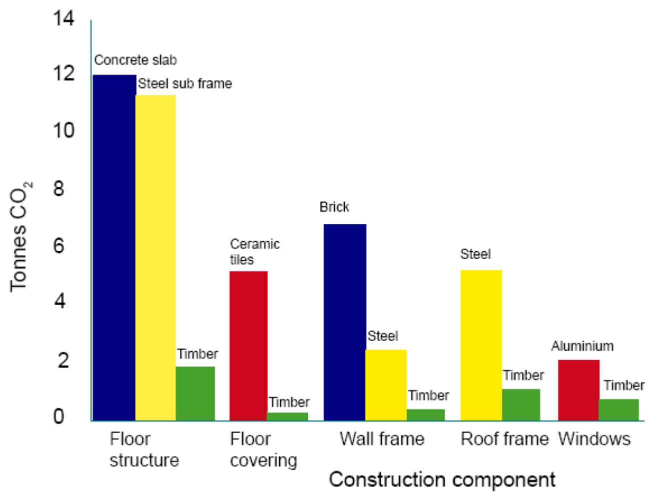


Figure 4: Greenhouse gas emissions from the manufacture of different building components in a family home (Source: CRC, 2013)

2.3.2 ICE Database

Emissions factors for the life cycle of building materials for this project were taken from standard data provided by Inventory Carbon and Energy (ICE) (Hammond and Jones, 2008) due to the absence of carbon conversion rates of construction materials used in Malaysia. ICE is the conversion rate for embodied energy and embodied carbon of building materials develop by University of Bath. Hammond G.P. and Jones C.I. stated that this database is popularly used in United

Kingdom and several of countries in the world. The goal of ICE is to create a database of the emissions factor for energy and carbon emitted from building materials (Hammond and Jones, 2008). The specified boundaries condition to create ICE database for building materials usually from cradle to gate. Table 2 below shows the criteria for ceramics, clay and concrete. The embodied carbon for these materials is present in functional unit of $kgCO_2/Kg$. These materials have their own specification of data for the embodied carbon in order to calculating the carbon footprint of the materials.

TABLE 2: Inventory of carbon and energy (ICE) Source: Hammond and Jones (2008).

Materials	Embodied Energy & Carbon Data	
	EE - MJ/kg	EC - kgCO2/Kg
Ceramics		
General	10.00	0.65
Fittings	20.00	1.05
Refractory products	5.50	0.51
Sanitary Products	29.00	1.48
Tile	9.00	0.59
Clay		
General (Simple Baked Products)	3.00	0.22
Tile	6.50	0.46
Vitrified clay pipe DN 100 & DN 150	6.19	0.45
Vitrified clay pipe DN 200 & DN 300	7.03	0.49
Vitrified clay pipe DN 500	7.86	0.53
Concrete		
General	0.95	0.130
NOMINAL PROPORTIONS METHOD (Volume), Proportion from BS 8500:2006 (ICE C		
1:1:2 Cement:Sand:Aggregate	1.39	0.209
1:1.5:3	1.11	0.159
1:2:4	0.95	0.129
1:2.5:5	0.84	0.109
1:3:6	0.77	0.096
1:4:8	0.69	0.080

2.3.3 Case Study 1

A case study conduct by Gustavsson L, and Sathre R. (2006) shows the comparison between production of wood materials and concrete materials in constructed a 4-story apartment due to CO_2 emissions. The CO_2 balances of the reference case production of materials for similar sizes and designed of buildings. The figure 5 shows the production of CO_2 balances (tC) of the wood-frame and concrete-frame in building construction.

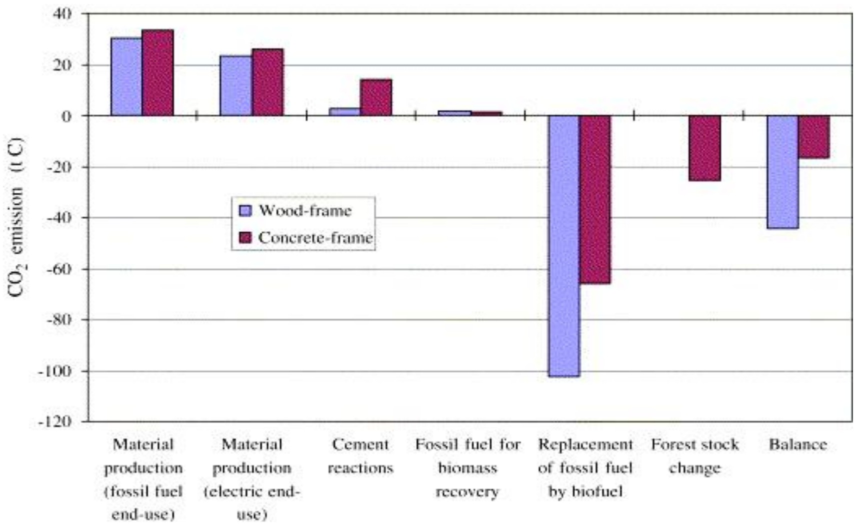


Figure 5: Contributions to CO_2 balances (tC) of the reference case production of materials for the wood and concrete-frame buildings. Source: Gustavsson L, Sathre R. (2006)

The greater end-use fossil fuel and electricity use in the concrete-frame building have higher CO_2 emission. The concrete-frame also has higher CO_2 emissions due to chemical process reactions during cement manufacture. The larger quantity of biofuels produced as residues from the production and utilized of wood-based materials for the wood-framed generated the greater negative emission due to replacement of fossil fuels by biofuel. The extra forest in the concrete case, due to the need for less wood-based building materials, is assumed to increase in biomass resulting in a negative emission. Therefore, it can be conclude that the wood base material is more efficient in reduction of CO_2 emissions compare to concrete.

Case study 2

A case study conducts by Burnett (2006) show comparison carbon benefits of timber in construction of three buildings. The aim of this study is to compare the GHG emissions increase from the embodied energy of various building materials as well as to quantify the ability of GHG benefits of increasing the timber content of the 3 types of accommodation. The study show that the increasing of timber content in building constructions will result lower GHG emissions associated with the embodied energy of construction materials.

Table 3: Building materials carbon footprint comparison. Source: Burnett (2006)

Type of building	Typical practice Scotland footprint (tCO_2)	Increased timber content footprint (tCO_2)	Difference (tCO_2)	Percentage saving (%)
2 bed semidetached	12.2	3.1	9.2	75%
3 bed detached	16.8	2.4	14.4	86%
4 storey block of flats	128.3	21.8	16.5	83%
Average	52.4	9.1	13.4	81%

Case Study 3

Lazarus (2002) state the Beddington Zero Energy Development which known as BedZED is the project of houses with environmental friendly development which located at Wallington, England. The development of these houses includes the sustainable selection of the building materials and components with less GHG. The low carbon emissions find in this project is regarding the type of materials selected for window frames that resulting in reduction of embodied carbon for between 790 and 840 tonnes CO_2-eqv (Lazarus, 2002). The selection of hardwood compare to softwood indicated the lower maintaining required. Reduction of approximately 50% can be achieved from the resident at BedZED life style. Therefore, the development of BedZED is as a model to the construction industry in order to improve the sustainability in this industry.

2.4 High-rise Building

High-rise building is the tall building that also called multi-story building which is the structure whose architectural height is between 35 and 100 meters. There are several definitions of high-rise building. According to Emporis Standards (2012), high-rise is a multi-story structure between 35-100 metres tall as well as a building of unknown height from 12-39 floors. Besides that, the building code of Hyderabad, India state a high-rise building describe as a building with four floors or more (Narayan, 1996). A building is automatically determined as a high-rise when it has a minimum of 12 floors whether or not the height is known (Emporis Standard, 2012). These types of buildings tower are requiring the application of a system of mechanical vertical transportation such as elevators.

The office building is the popular example of high-rise building in Malaysia. It is also known as an office block or business centre that form of commercial building which contains spaces mainly designed to be used for offices. The first high-rise buildings were constructed in the United States in the 1880s and created a demand for buildings that raised vertically than spread horizontally which occupying less precious land area (Britanica, 2013). These kinds of buildings are expected to be trend of future dwelling as well as office development in Malaysia. The reinforced concrete and steel are the building materials that usually used for the structural system of high-rise buildings. The office building was found to be the most significant building type, responsible for an estimated 27% of total sector emissions in 1990 (Bush, Shane et al 1997). According to EMET Consultants and Solarch Group (1999), office building has the highest amount of GHGs as shown in figure 6. Abdul Karim J. (2010), the statistic of BEI in Malaysia show office building consumed 200-300 kWh/m^2 per year. This is proven that the energy consumption and GHGs are highest in office building.

2.5 Building Construction and the Environment

The construction industry is a dominant sector contributes to the global warming and climate change. Even though this sector plays important roles toward the development of the country, it has adverse impact regarding the environment issues. Concern is growing toward required actions needed in prevent environmental pollutions due to achieved sustainable in development of construction (Abidin, 2010). Thus, the construction industry and environmental concern has a unique relationship toward the human health and country development.

Abidin, (2010) stated the environment deterioration due to the construction industry development. Indeed, the environment is the major implication due to the construction activities during the off-site, on-site and operational activities, which alter ecological integrity (Ding, 2008). Moreover, in Malaysia itself the environmental pollution has become the great issues. According to Yussof (2007), in Klang Valley, more than six million tonnes of remnant produced which quarter in construction of buildings. The natural resources such as forest for timber, housing and industry become the victim to the environmental pollution due to improper prevention of natural resources.

Furthermore, the inadequacy of environmental concern in the exploitation, development and management of resources can present the environmental issues. The dream toward sustainable building constructions will become harder to achieve since the efficient strategic and mind set to prevent the environmental pollution is not evolve strongly. In Malaysia, the environmental issues still enshroud the image of great building construction in this country in many sources such as waste management, rainwater harvesting and reduction of carbon footprint as compared to the developed nations.

According to Azqueta (1992), in the past 1960s and early 1970s shows the ecosystem performance becomes the big issues due to the environmental problems in order to support the economic activities. The energy consume during building constructions include extraction of raw materials, processing and transportation has the major contribution toward the pollution as the construction industry need to take action toward these issues.

Therefore, nowadays the materials using in the construction such as aluminum, cement, concrete and steel that content large carbon emissions need to comply with new directives to prevent pollution problems. Moreover, the world today stands with the three bases toward development of sustainable constructions which are include environmental, social and economic. Thus, it is proven that the strong relationship between construction and sustainable development that brought to the social and economy impact.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The main target of this project is to determine the carbon reduction best practices for building materials and benchmarking in the Malaysian construction industry. In order to complete the research study, the objectives of the research in the chapter 1 is required to be achieve. This study involves the quantitative data and in the boundary of 'cradle to gate' of life cycle building. There are three stages engaged in this research methodology to obtain the accurate and sufficient results.

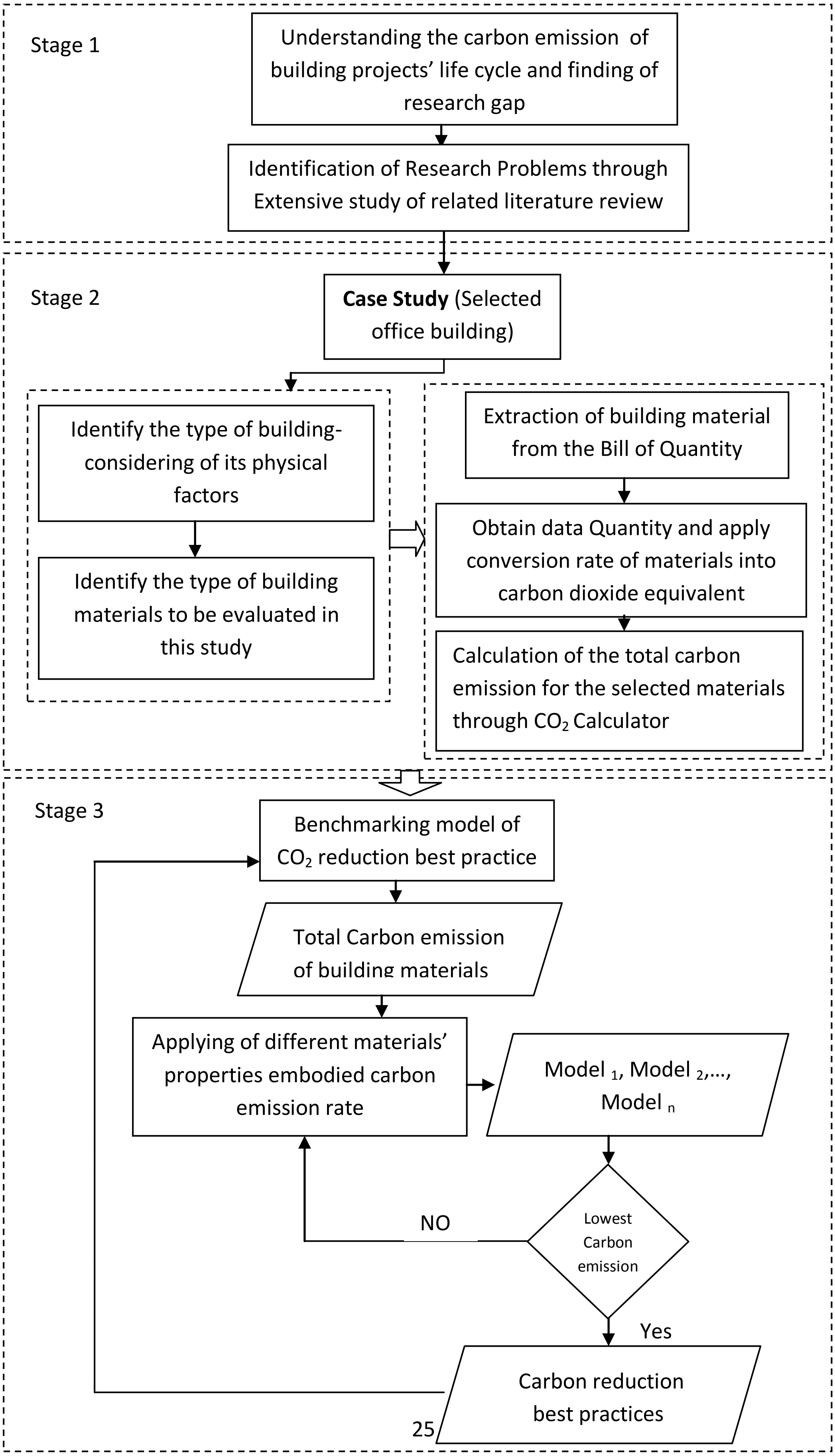
The first stage of the methodology consists of the understanding requirement involve of the carbon emission of building projects' life cycle and finding of research gap. The relationship between carbon emissions with building materials is studied and the research problem is identified through the extensive study of related literature review. Furthermore, a literature review involved a thorough review of current practices and previous research in the area of carbon emission impacts on the building materials and effect of environmental to the construction industry. The literature review also explored the life cycle of the building construction in Malaysia. In addition, the environmental fields also contribute the implication of carbon emissions.

Second stage involves the case study for this research which is an office building. The selected office building is chosen by considering its physical factors such as gross floor area. The type of the building materials for this case study is identified in order to be evaluated in the analysis part in chapter 4. Lot 4C11 office building in Putrajaya was chosen as the case study for this research. In this stage, the materials involve is extracted from the bill of quantity of the project. Bill of quantity is a document used in tendering for the construction industry in which materials, parts and labors (including costs) are itemized. The quantity data obtained from the bill of quantity then convert into the carbon dioxide equivalent by applying the conversion rate of the materials using Inventory Carbon and Energy (ICE) database from Hammond and Jones (2008). ICE contains the embodied carbon as the tool to obtain the result in term of carbon emission. Furthermore, the total carbon emission for the selected materials is evaluated through carbon calculator by considering its weight and conversion rate factor.

Next stage involves conducting carbon emissions modeling of building materials from the benchmark level to achieve the carbon reduction best practices in the Malaysian construction industry. Lot 4C11 office building was chosen as a benchmark level of carbon emission to achieve the carbon reduction best practice for building materials. The green building materials of this structure make it a sustainable building. However, the potential reduction of carbon emission can still be improved by the alternative low carbon replacement that used in this research study.

The main building materials were selected based on the benchmark building which are concrete, steel, glass and timber. However, regarding the assessment for carbon emissions modeling of building materials, four building materials models were developed in order to determine the carbon reduction for the materials. For Model 1, carbon emission for the concrete material is reduced by replacement of fly ash as the alternative low carbon. Model 2 has replaced the steel material with the recycled steel while the primary glass material is replaced by the secondary glass in the Model 3. Therefore, the overall replacement in the three models is applied in the Model 4. Timber material is not replaced because it is already a green natural material that has low carbon emission that widely used in the construction industry nowadays. Furthermore, the lowest carbon emission from the models of building materials is choose as the carbon reduction best practice in the Malaysian construction industry. However, this analysis of carbon reduction best practice is only applicable for the particular building related to the case study building.

3.2 Research Methodology Flowchart



CHAPTER 4

RESULTS & DISCUSSION

4.1 Introduction

The methodology of this research will be elaborated in detail in this chapter. An office building has been selected as a case study for this research. The data and information of the office building have been obtained from the selected site. In order to determine the sustainability of the office building, the type of building materials were selected due to their range of carbon emissions. Furthermore, the selected materials are used as the tool to the selection of sustainable or conventional building. The building materials used for this project was obtained from the bill of quantity of the respective types of structure provided by the developer. Therefore, the conversion rate of materials into carbon dioxide equivalent is used to obtain the result in term of carbon emission.

Furthermore, the carbon emission modeling of building materials is conduct in order to determine the carbon reduction best practices based on the case study as a benchmark in this research study. Every model of building materials in this research has different amount of carbon emission even though they used the similar main materials based on the benchmark building. It is due to the replacement of the building materials for every model by the alternative low carbon materials in the building life cycle in ‘cradle to gate’ boundary. The lowest carbon emission resulting from the models is chosen as the carbon reduction best practice in the Malaysian construction industry and reference of green building construction.

4.1.2 Case Study Background

Nowadays, the office buildings around the world getting its popularity among the construction sector as its play an important role in the development of the economic and industry toward Malaysia vision 2020. Indeed, the Malaysian construction sector and building construction has the major impact toward the environment and great issues have been raised recently such as global warming and GHGs. The impact of global warming and GHGs are primary resulting from the construction industry and it is necessary to investigate the sources of GHGs of the building constructions and establish a method to mitigate and reduce the impact of this building which located in the area of Putrajaya, Selangor. An office building is selected due to its type of building materials associated with embodied carbon.

In order to initiate the analysis of this project, it is important to study and understand the nature of the selected office building in details. The properties of the selected office building can be described as the following:

- the office building under the category of high rise building
- the height of the buildings is about 18-50 floors

In order to achieve the aim of this research, the assessment is required to select and proven the type of office building. The office building is required as a benchmark level of carbon emission in order to determine the carbon reduction best practices by simulation of the models of building materials. The Lot 4C11 office building is selected as a case study because of its properties which have larger area in sizes and many floors. This type of building is widely developed and continuous developing in almost all the countries in the world because of the economic developing and required the space as well as place to the workers to achieve better economical aspect. The demand for office building is gradually increasing due to the rising in nation economic sector and to achieve a sustainable development. In addition, as the new Federal Government Administrative Centre of Malaysia, Putrajaya has the future strategy regarding becoming the green city in reducing the carbon emission by sustainable development. Therefore, the construction of green building is widely developed in this city to achieve the objective of its development.

Lot 4C11 is one of the green buildings in Putrajaya that chosen as a case study for this research.

4.2 Findings

4.2.1 Carbon Emission Conversion Factor

In order to obtain the building materials data in term of carbon dioxide equivalent (CO_2-eqv), a conversion factor is required to standardize the units of measurement of various types of materials in this case study. This conversion factor will allow the conversion of building materials into kilograms of carbon dioxide equivalent (CO2-eqv). The carbon emission conversion factor includes the various classifications for different types of materials in order to determine the carbon emission for specified materials. The embodied carbon acted as the factor of conversion in term of $kgCO_2$ /kg.

The database from Inventory of Carbon & Energy (ICE) by Prof. Geoff Hammond (Hammond G.) and Craig Jones (Jones C.) is applied due to the absence of carbon conversion rates of construction materials used in Malaysia. Hammond G.P. and Jones C.I. (2008) stated that this database is popularly used in United Kingdom and several of countries in the world.

Figure below is the example of the conversion factor database from Inventory of Carbon & Energy (ICE) by Prof. Geoff Hammond (Hammond G.) and Craig Jones (Jones C.). This figure shows the materials and their classification as well as the embodied carbon as the conversion factor. For example, concrete is divided into several types for higher accuracy in calculating the carbon emission. The embodied carbon is established for every type of the materials. According to ICE, the change of the classification of the main materials will not affect the strength of the building materials.

Materials	Embodied Energy & Carbon Data	
	EE – MJ/ kg	**EC – $kgCO_2/kg$**
Concrete		
General	0.95	0.130
1:1:2 Cement:Sand:Aggregate	1.39	0.209
1:1:5:3	1.11	0.159
1:2:4	0.95	0.129
1:2:5:5	0.84	0.109
1:3:6	0.77	0.096
1:4:8	0.69	0.080
Steel		
General (average of all steels)	24.40	1.77
Virgin	35.30	2.75
Recycled	9.50	0.43
Bar & rod	24.60	1.71
Virgin	36.40	2.68
Recycled	8.80	0.42

Figure 6: Embodied Carbon for Specific Building Materials

The specific quantity of the building materials can be obtained from the bill of quantity in the particular project. The majority of the inventory database of the carbon conversion rate express the carbon emission of the building materials in term of unit mass (in kilogram), then it is necessary to convert the quantity of the building materials into their respective masses in order to calculate their carbon emissions. Therefore, the quantity of materials is converted into unit of kilogram weight in order to make the further calculation easier and more efficient by standardize the unit for carbon conversion.

Then, the application of ICE database by Hammond and Jones is used in this project by converting the quantity of the materials in unit of weight into the providing unit of CO_2 equivalent. The quantity of CO_2 emitted from individual building materials was calculated by multiplying the quantity of materials (in kilogram) with the corresponding embodied carbon factor. The conversion rate factor for every building materials involved in this project is crucial in order to standardize the unit used in ICE database which is in $kgCO_2/kg$. The table below summarized the value of embodied carbon for every selected type of materials for this research and its density.

Table 4: ICE Database Conversion Factor manual

Materials	Type	Embodied carbon ($kgCO_2/kg$)	Density (kg/m^3)
CONCRETE	General	0.130	2400
	1:1:2	0.209	2410
	1:1:5:3	0.159	2400
	1:2:4	0.129	2430
	1:3:6	0.096	2400
STEEL	General	1.77	8000
	Bar & Rod	1.71	7900
	Section	1.76	6700
	Stainless	6.15	2700
GLASS	General Glass	0.8	2450
	Toughened Glass	1.27	2600
TIMBER	General	0.46	480
	Hardboard	0.86	700
	MDF	0.59	70
	Plywood	0.81	540
	Sawn Hardwood	0.47	880

4.2.2 Building Selection

An office building selected as a case study and benchmark level for carbon emission in order to determine the carbon reduction best practice of the building materials in the Malaysian construction industry. Below shows the detail regarding the selected office building:

Figure 7: Selected case study- Lot 4C11, Precint 4, Putrajaya

Lot 4C11, Putrajaya

Building Details:

Name of building: Lot 4C11

Location: Precint 4, Putrajaya.

Total No. of Floors: 10 storeys

Gross Floor Area: 77600 sqm.

4.3 Results and Discussion

4.3.1 Lot 4C11 Office Building (Benchmark Level)

This section presents the building materials data for Lot 4C11 office building operating the carbon emission assessment. The building materials data analysis from the bill of quantity is described below.

Table 5: Quantification and CO_2 conversion of building materials extracted from Bill of Quantity for Lot 4C11 Putrajaya

MATERIALS	QUANTITY	WEIGHT (kg)	CARBON EMISSION ($kgCO_2$)
CONCRETE	43,527 m^3	104,605,480	16,290,153
STEEL	7,313,603 kg	7,313,603	19,999,495
GLASS	465 m^3	1,164,600	1,181,710
TIMBER	4,793 m^3	2,461,460	1,174,441
TOTAL			38,645,800

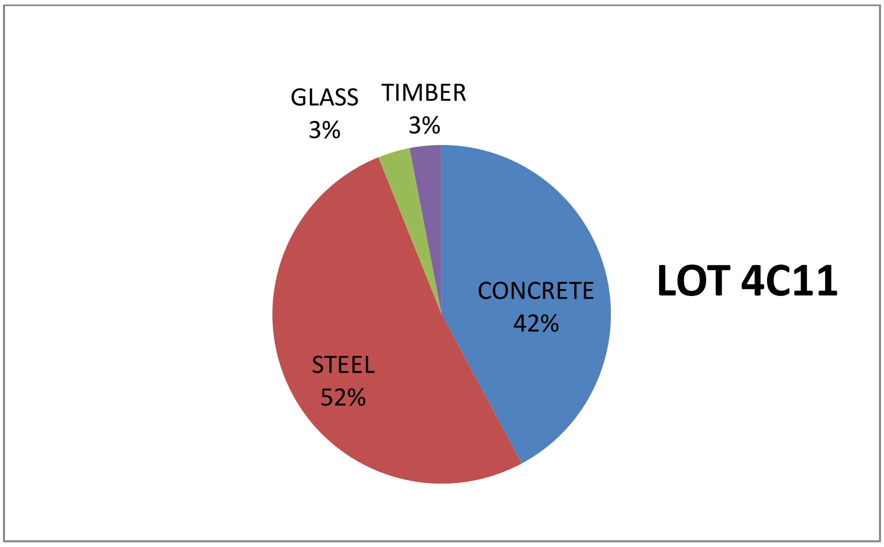


Figure 8a: General breakdown of Carbon Dioxide Equivalent of building material for Lot 4C11, Putrajaya.

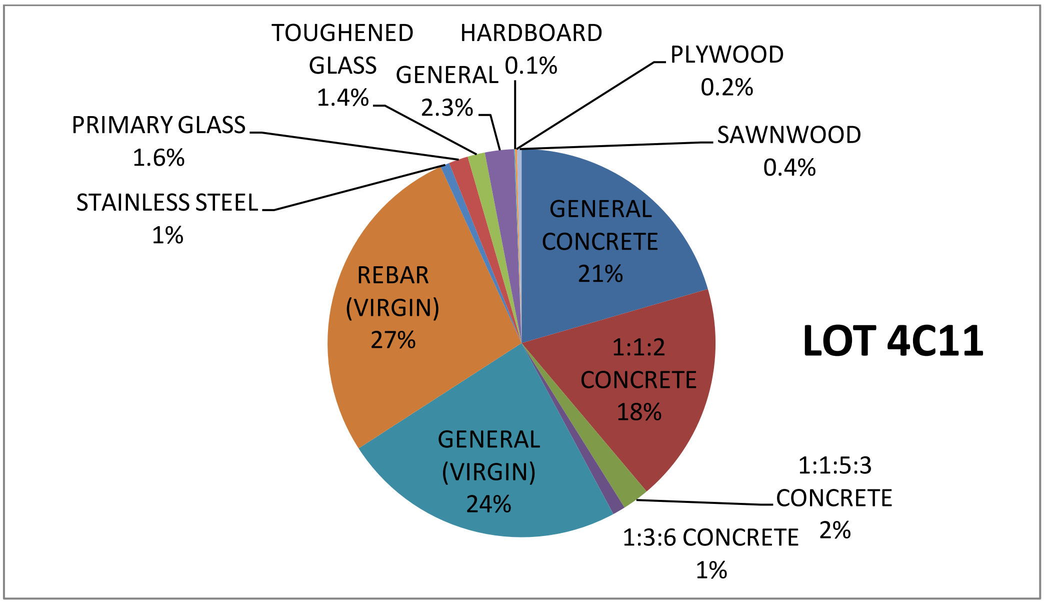


Figure 8b: Further Breakdown of Carbon Dioxide Equivalent of building material for Lot 4C11, Putrajaya.

Table 6: Carbon Emission Equivalent of Building per Square Meter

Project	**CO_2 emission (CO_2e) (kg)**	**Gross Floor Area (m^2)**	**CO_2 per sqm ($kgCO_2/m^2$)**
Lot 4C11	38,645,800	77600	498.01

Table 5 shows the amount of carbon emissions for the selected materials in Lot 4C11 office building. There are four types of main materials used in this research study which are concrete, steel, glass and timber as the factor to assess the sustainability of the building construction. The materials are compared in terms of their embodied carbon and quantity (in kilogram) of the materials.

From the Figure 8a, it is obvious that steel has the highest percentage of building materials contribute to the carbon emission for the Lot 4C11 office building (52%). This is highly related to the high amount of embodied carbon factor for steel materials. It is followed by concrete with 42% of carbon emissions which is higher than other materials. Despite percentage of concrete is larger, notice that the quantity of the concrete is higher than steel even though it's embodied carbon is lower. The amount of concrete used for this structure is more than steel. The carbon emission percentages for the timber and glass were the same with 3% which is their quantity is lower than concrete and steel.

Furthermore, Figure 8b shows the details classifications for every type of main materials contribute in this building construction. For concrete material; general concrete, mixture of 1:1:2 concrete ratio, 1:1:5:3 concrete ratio and 1:3:6 concrete ratio were used for the structure. The mixtures of concrete ratio consist of cement, sand and aggregate to produce various range of strength and function in construction sector. Moreover, general steel, rebar and stainless steel were the steel materials used for this building which is the stainless steel has the higher embodied carbon among the steel materials. Despite the embodied carbon for stainless steel is high, the value usage for this structure is low with only 1% of the carbon emission from it. Thus, its consumption is not really affect the values of carbon emit throughout the building life cycle.

Besides, the primary glass and toughened glass are the type of glass materials consumed which is lower in carbon emission due to the amount usage of glass (in kilogram). For timber material; general timber, hardboard, plywood and sawnwood is used as the materials for this structure. Timber is the natural material which is not toxic, does not leak chemical vapour into the building and is safe to handle and touch. It is produce the low carbon emission to the atmosphere. Based on the total area of the Lot 4C11 in table 6, the amount of the carbon emission equivalent of building per square meter is 498.01kgCO_2/m^2.

4.3.2 Model Simulation

The model simulation of building materials applying the Lot 4C11 office building as a reference in order to obtain the result of carbon reduction best practices in the Malaysian construction industry. Lot 4C11 office building was selected as the benchmark for carbon emission due to the lower amount of carbon emit from the building. Therefore, the building materials data of Lot 4C11 office building is used in the model analysis. The properties of the materials such as the quantity and type of the materials are the same with the reference building.

The simulation of carbon reduction best practice for building materials consist of four types of models which are Model 1, Model 2, Model 3 and Model 4. For Model 1 and 2, the alternative low carbon material is used for 20% of the selected materials. Nowadays, scientists have conducted the experiment regarding the purpose of the 20-80 rule of quality in engineering product. It states that, from many events, roughly 80% of the effects come from 20% of the causes. For this case, 20% of the alternative low carbon materials used in the building materials affect the amount of the carbon emit from the structure. Besides, the glass materials replacement in the Model 3 consume 100% of the low carbon material due to the small amount of glass used in this building construction and it does not affect the strength and other properties of the building materials. Therefore, we use fully low carbon materials to determine the performance of the green building materials in this research study.

4.3.3 Model 1

The analysis data of carbon emission for model 1 is given in table below. Model 1 has changed the concrete materials to achieve low carbon emission. Fly ash is used as the alternative low carbon for the concrete materials which is 20% is replace from the quantity of cement in the concrete materials without changing the amount of sand and aggregate of the concrete ratio. The other materials are similar with the benchmark building. The carbon emission of concrete is lower than steel even though it has the highest quantity due to the lower in embodied carbon by using fly ash as the alternative low carbon material.

From the Table 7, steel has the highest amount of carbon emission with the value of 19,999,495 $kgCO_2$. Concrete materials followed by 13,979,932$kgCO_2$. The value of carbon emission for the concrete is reduce from the original value based on the Lot 4C11 building materials due to the consumption of fly ash. The total amount of the carbon emission for model 1 is 36,335,579$kgCO_2$.

Fly ash is the most commonly used in the construction industry in order to reduce the impact of carbon emission to the environmental condition. Engineers, architects and contractors widely using fly ash as the alternative materials in building construction to improve the quality of their project and to increase their cost effectiveness. Besides, the additions of fly ash in the building materials will give higher strength in concrete.

Table 7: Quantification and CO_2 conversion of building materials extracted from Bill of Quantity for Model 1

MATERIALS	QUANTITY	WEIGHT (kg)	CARBON EMISSION ($kgCO_2$)
CONCRETE	43527m^3	91,171,028	13,979,932
STEEL	7,313,603kg	7,313,603	19,999,495
GLASS	465m^3	1,164,600	1,181,710
TIMBER	4,793m^3	2,461,460	1,174,441.6
TOTAL			36,335,579

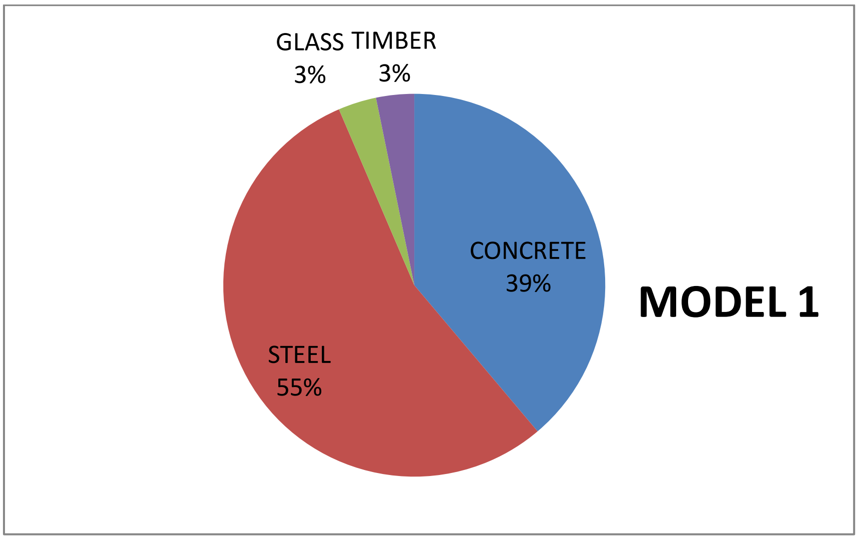


Figure 9a: General breakdown of Carbon Dioxide Equivalent of building material for Model 1.

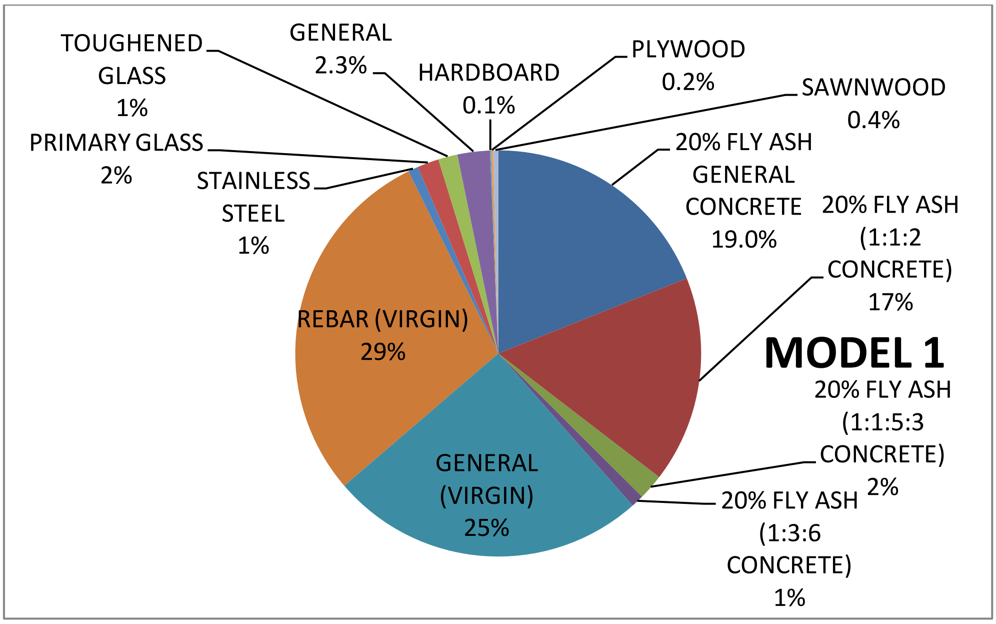


Figure 9b: Further Breakdown of Carbon Dioxide Equivalent of building material for Model 1.

4.3.4 Model 2

Furthermore, the simulation of Model 2 consume the recycle steel as the alternative low carbon material which is the replacement 20% of recycle of general steel from the virgin general steel and similar with the rebar steel. The usage of higher recycle content materials for this model brought the reduction of the carbon intensities. Therefore, the other building materials are remains the same with the benchmark building. From table 8, steel has 16,675,316kgCO_2 which is slightly high than concrete materials for this model. This is because the recycled steel in this model has less carbon emission compare to the virgin steel based on the building materials of Lot 4C11.

Based on the Figure 10b, the usage of recycle steel for general and rebar steel reduce the carbon emission compare to the virgin steel used in the Lot 4C11 office building. Therefore, the recycle material has the lower embodied carbon than the virgin material and does not affect the strength of the steel materials in the building construction. The stainless steel is not replaced by the low carbon materials because of the lower usage and it does not affect the increment of carbon emission for this model.

Table 8: Quantification and CO_2 conversion of building materials extracted from Bill of Quantity for Model 2

MATERIALS	QUANTITY	WEIGHT (kg)	CARBON EMISSION (kgCO_2)
CONCRETE	43,527 m^3	104,605,480	16,290,153
STEEL	7,313,603kg	7,313,603	16,675,316
GLASS	465 m^3	1,164,600	1,181,710
TIMBER	4,793 m^3	2,461,460	1,174,441
TOTAL			35,321,621

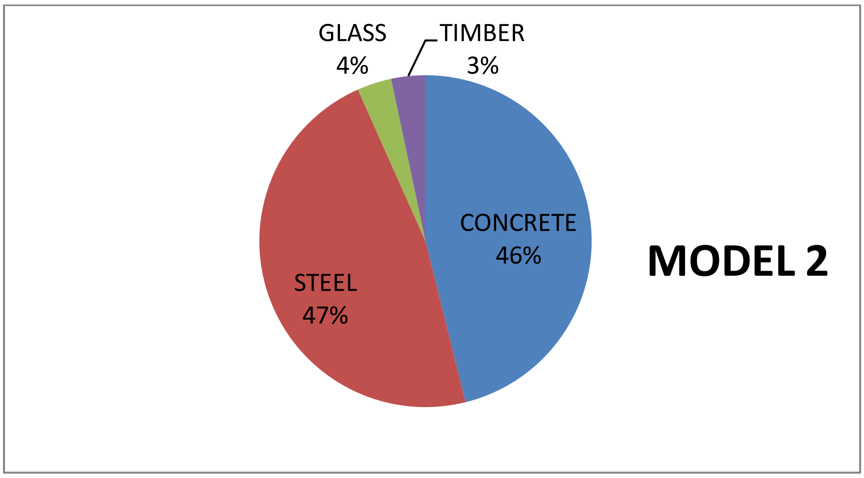


Figure 10a: General breakdown of Carbon Dioxide Equivalent of building material for Model 2.

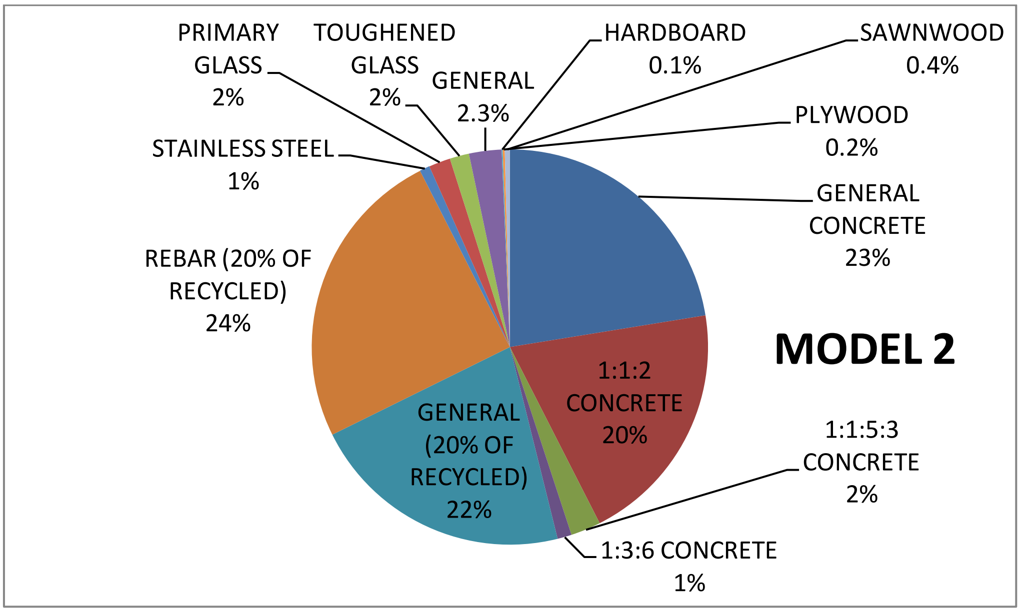


Figure 10b: Further Breakdown of Carbon Dioxide Equivalent of building material for Model 2.

4.3.5 Model 3

Table 9 shows the amount of glass material is the lowest among the materials used in the Model 3. The total amount of carbon emissions for this model is 38,412,848kgCO_2. Glass materials use the alternative low carbon material which is the secondary glass with the value of 948,758kgCO_2 which is smaller than primary glass. The secondary glass is use for 100% to replace the primary glass in order to achieve the lower embodied carbon. The selection of the secondary glass as the alternative low carbon materials is based on the ICE guidelines for building materials. The guideline indicates the secondary glass has the lower embodied carbon.

Despite the glass materials is replaced by the alternative low carbon material, it is not really affect the change in amount of carbon emission for this model due to the lower quantity of the glass material. Thus, we replace the materials with 100% of the secondary glass to look at its performance regarding the value of carbon emission. In the Figure 11b, the toughened glass is one of the glass materials used in this model beside primary glass that replaced by the secondary glass. The performance of toughened glass is required in building construction in order to strengthen the safety of the building. This type of material is safety glass that has increased strength and will usually shatter in small, square pieces when broken. Thus, the toughened glass is fixed in this model analysis.

Table 9: Quantification and CO_2 conversion of building materials extracted from Bill of Quantity for Model 3.

MATERIALS	QUANTITY	WEIGHT (kg)	CARBON EMISSION ($kgCO_2$)
CONCRETE	43,527 m^3	104,605,480	16,290,153
STEEL	7,313,603kg	7,313,603	19,999,495
GLASS	465 m^3	1,149,800	948,758
TIMBER	4,793 m^3	2,461,460	1,174,441
TOTAL			38,412,848

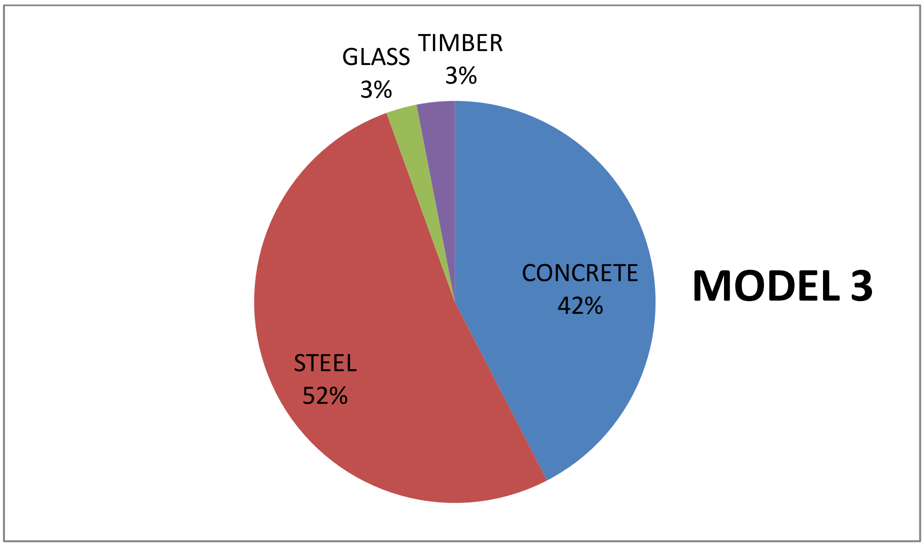


Figure 11a: General breakdown of Carbon Dioxide Equivalent of building material for Model 3.

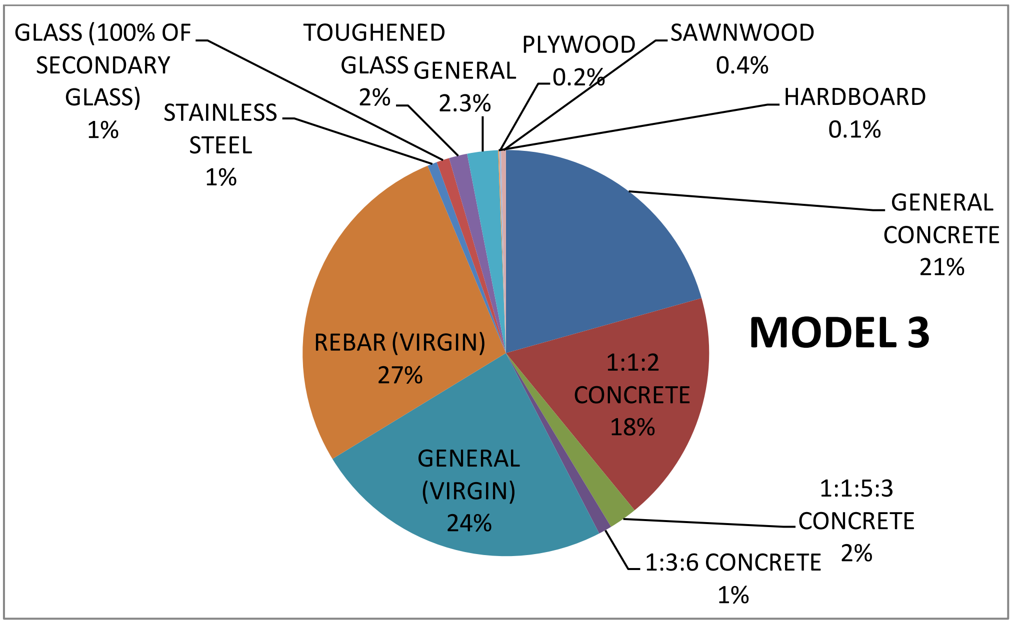


Figure 11b: Further Breakdown of Carbon Dioxide Equivalent of building material for Model 3.

4.3.6 Model 4

The overall replacement by the alternative low carbon materials in the previous models is conducted in the Model 4. Concrete, steel and glass materials are replaced by the alternative low carbon materials such as fly ash, recycled steel and secondary glass. This model has much reduction of carbon emission because of many alternative low carbon materials consumption. The total value of carbon emission for this model is 32,778,447kgCO_2. According to table 10, steel has the highest carbon emission due to the greater in its embodied carbon. Furthermore, timber material is not consider replacement of the low carbon materials because of their amount of carbon emission which is not really impact the overall of carbon emitted from the building model. Other than that, timber is a highly organic material which has relatively low embodied carbon. The lowest embodied carbon of the timber materials are already used in the models and the case study.

Table 10: Quantification and CO_2 conversion of building materials extracted from Bill of Quantity for Model 4.

MATERIALS	QUANTITY	WEIGHT (kg)	CARBON EMISSION ($kgCO_2$)
CONCRETE	43,527 m^3	91,171,028	13,979,932
STEEL	7,313,603kg	7,313,603	16,675,316
GLASS	465 m^3	1,149,800	948,758
TIMBER	4,793 m^3	2,461,460	1,174,441
TOTAL			32,778,447

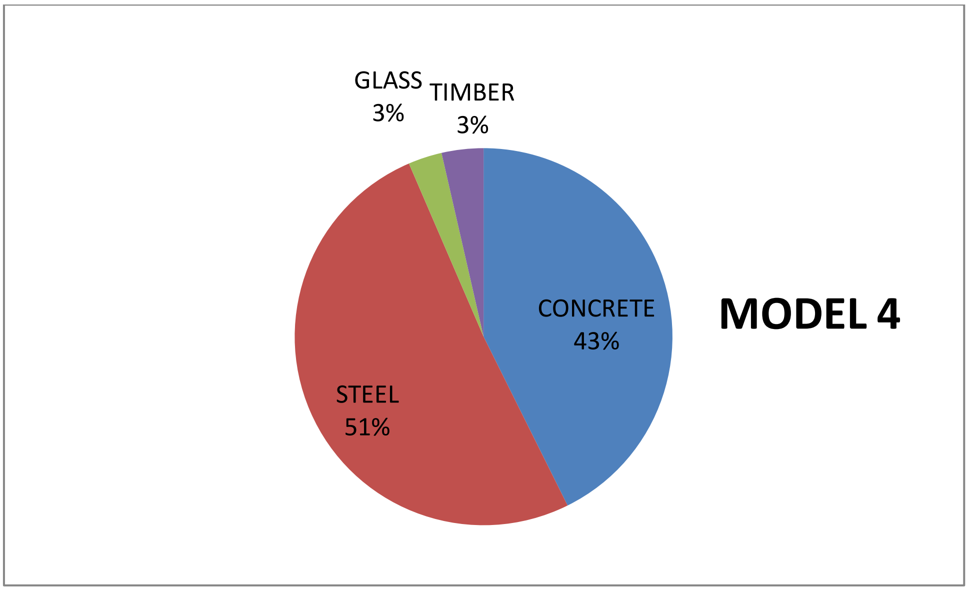


Figure 12a: General breakdown of Carbon Dioxide Equivalent of building material for Model 4.

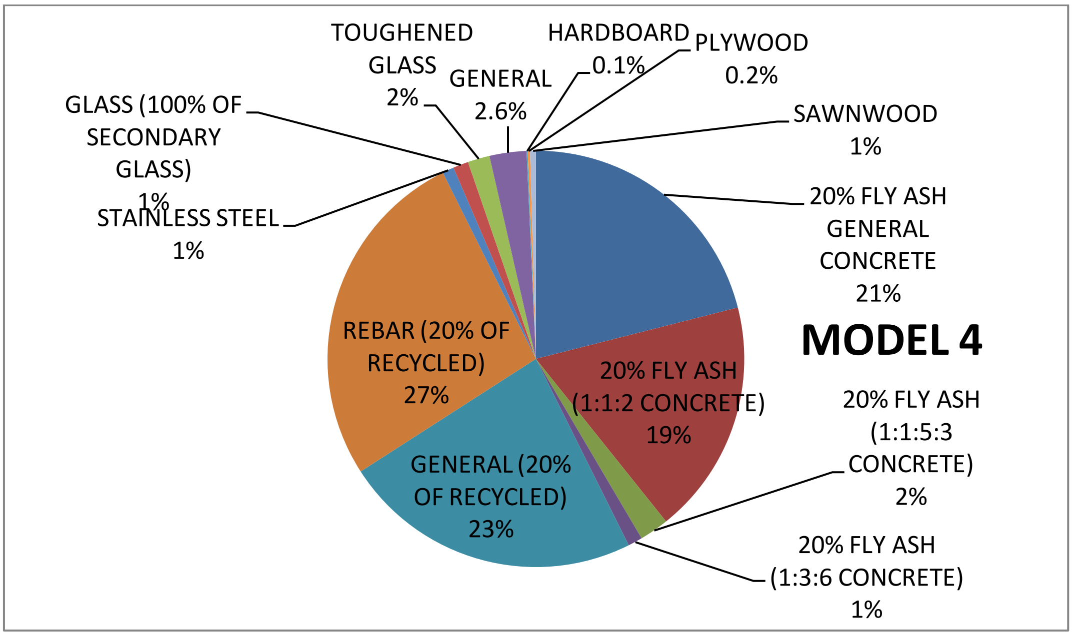


Figure 12b: Further Breakdown of Carbon Dioxide Equivalent of building material for Model 4.

4.3.7 Analysis and Discussion

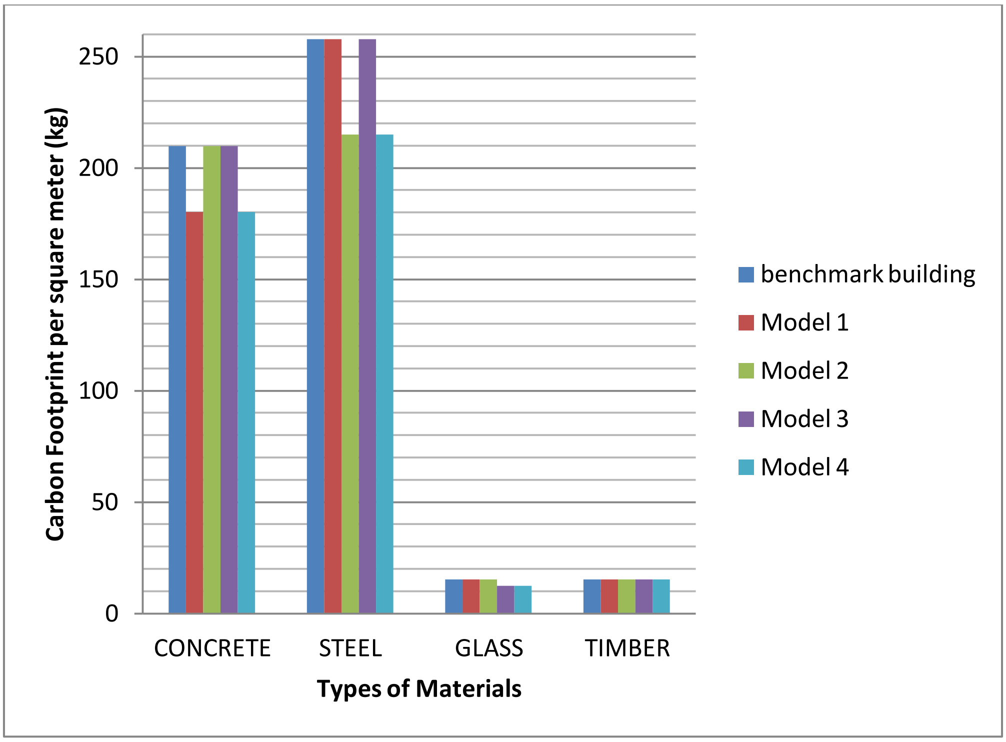


Figure 13: Comparison of carbon footprint of building materials (kg) per square meter.

Based on the graph comparison of building materials, steel has the highest amount of carbon emission compare to the other materials followed by concrete materials. Glass and timber are the least materials according to the Figure 13 which has the similar amount of carbon emission.

By comparing the building materials for benchmark building, Model 1, Model 2, Model 3 and Model 4 as shown in Figure 13, the concrete materials for Model 1 and Model 4 have the lower carbon emission compare with the benchmark building, Model 2 and Model 3. It is because the concrete is replaced by the alternative low carbon material which is fly ash. The replacement of concrete materials in the Model 1 brought to the reduction of carbon emission into the atmosphere. In Model 1, the replacement is only occurring to the concrete while the other building materials used in the model are fixed based on the Lot 4C11 building materials. For Model 2, the low carbon materials of recycled steels are used to replace the virgin steels and let the other materials in their original state. Besides, Model 3 uses the secondary glass to reduce the carbon emission of the primary glass material with 100% of replacement. The secondary glass was selected as the alternative material based on the ICE guideline. Model 4 is a combination of the alternative low carbon materials from Model 1, 2 and 3. The low carbon materials from concrete, steel and glass contribute to the reduction of the carbon emit to the atmosphere.

The mix design of concrete have different ratio of cement, sand and aggregate that result in the various strength of concrete. Concrete mix 1:1:2 (embodied carbon: 0.209) would eventually produce a higher carbon emission because of its higher embodied carbon factor in its own main material category. It is followed by concrete mix 1:1:5:3, general concrete and concrete mix 1:3:6. These concrete materials are replaced by 20% of fly ash as the low carbon material in order to reduce the carbon emission of the building materials. Fly ash is a popular alternative of the concrete with the production of high strength concrete that accommodates the design of thinner sections. Mixtures that contain fly ash can be slower to cure, are stronger and smoother, denser, more workable and less permeable.

Furthermore, the 20% of the recycle steel for replacement of general steel and rebar steel is contribute to the greener steel materials. This type of alternative material is capable to reduce the carbon emission which is known as recyclable materials. The glass materials used in this research study include general glass and toughened glass which can be replaced by the alternative low carbon materials in order to achieve the sustainable materials in the building construction. The secondary glass (embodied carbon: 0.55) is the alternative material for the glass which has high carbon emission. It is used only to replace the general glass (embodied carbon: 0.86) because the toughened glass is required in the building construction to ensure the safety and strengthen of the structure.

On the other hand, the use of hardboard (embodied carbon: 0.86) and plywood (embodied carbon: 0.81) in the building construction result in the higher emission of CO_2. General timber and sawnwood can be the alternative low carbon materials because of their lower embodied carbon. Selection of the materials is absolutely crucial as it is affect the whole building life cycle and as the most significant factors of carbon emission. Therefore, the types of building materials need to be chosen in the design phase of the building construction in order to avoid the contribution toward the emission of CO_2.

Therefore, steel has contributed the highest amount of CO_2 per area of the building. It is followed by concrete as the second highest of carbon emission. In this case, the contribution of CO_2 through concrete related to the quantity of the materials. Nowadays, the usage of steel and concrete are higher in building construction industry due to their good properties. However, steel has the higher embodied carbon as a factor to contribute the larger amount of CO_2. On the other hand, the emission of carbon for timber and glass are lower than the previous materials. It is due to their embodied carbon and quantity usage in the building construction. Based on the analysis, Lot 4C11 office building as a benchmark building emit larger amount of CO_2 per area of building and followed by Model 3. Besides, Model 4 has the lowest amount of carbon emission according to the overall materials compare to the other models due to the consumption the alternative low carbon materials for concrete, steel and glass.

Table 11: Carbon Emission Equivalent of Building Per Square Meter And Percentage Reduction Of The Models.

PROJECT	CO_2 EMISSION (KG)	GROSS FLOOR AREA	CO_2 PER SQM	Reduction	Reduction %
LOT 4C11	38,645,800	77600	498.01		
Model 1	36,335,579	77600	468.24	2,310,222	6.0
Model 2	35,321,621	77600	455.18	3,324,179	8.6
Model 3	38,412,848	77600	495.01	232,952	0.6
Model 4	32,778,447	77600	422.40	5,867,353	15.2

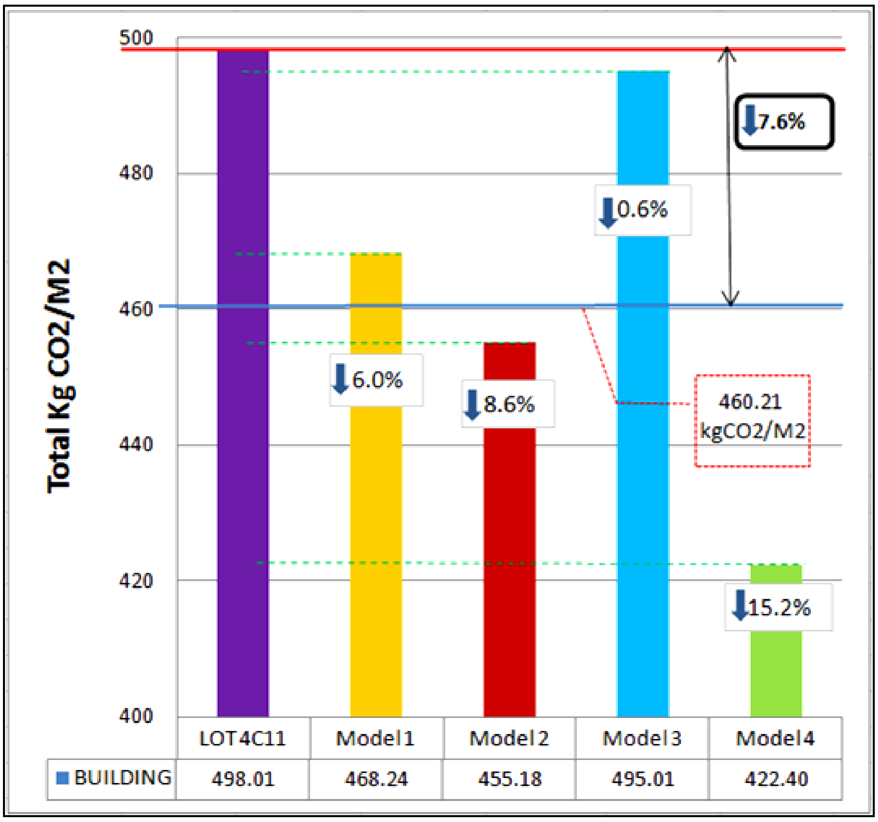


Figure 14: Benchmark for the carbon reduction best practice in Malaysia construction industry.

Four models of building materials carry out the result of the simulation which leads to the carbon reduction best practices in the Malaysian construction industry based on the benchmark level of carbon emission from Lot 4C11 office building. Based on the table11, the carbon emission for model 4 is selected as the lowest emitted carbon in the building construction with the value of 422.40kgCO_2/m^2 followed by model 2 and model 1; 455.18kgCO_2/m^2 and 468.24kgCO_2/m^2 respectively. Model 3 has the highest carbon emission among the models based on the benchmark of green building with the value of 495.01kgCO_2/m^3.

From the models simulation, technically Model 4 emits less carbon compare to other models and Lot 4C11. This is due to the efficiency in using building materials in construction activities for these green building projects. In order to find the result of carbon reduction best practice in the Malaysian construction industry, the reduction percentage of the models and Lot 4C11 is estimated to give the clear picture of the comparison between the models with Lot 4C11 as the benchmark of green building. Thus, the percentage can be calculated as;

Carbon emission Reduction percentage:

- Reduction percentage for Model 1:

$$\frac{38{,}645{,}800 - 36{,}335{,}579}{38{,}645{,}800} \times 100\% = 6.0\%$$

- Reduction percentage for Model 2:

$$\frac{38{,}645{,}800 - 35{,}321{,}621}{38{,}645{,}800} \times 100\% = 8.6\%$$

- Reduction percentage for Model 3:

$$\frac{38{,}645{,}800 - 38{,}412{,}848}{38{,}645{,}800} \times 100\% = 0.6\%$$

- Reduction percentage for Model 4:

$$\frac{38{,}645{,}800 - 32{,}778{,}447}{38{,}645{,}800} \times 100\% = 15.2\%$$

From the calculation shown above, it is determined from the study that generally Model 4 has the lowest carbon emission among the other models with Lot 4C11 as the benchmark building. Based on the percentage of building materials reduction, Model 4 is chosen as the carbon reduction best practice in the Malaysian construction industry with 15.2% of carbon reduction. It is followed by Model 2 with the8.6% of carbon reduction. Model 1 and Model 3 have the percentage of carbon reduction of 6.0% and 0.6% respectively.

From the case study, the main structural materials used for the models are basically the same. However, there are differences in selecting the alternative low carbon materials for each of the model in this research study, in which it affects the values obtained for carbon emission per square meter for every model.

The average carbon emission per square meter for four models estimated with the value of 460.21kgCO_2/m^2 which is represented by the blue line as shown in Figure 12. It can be concluded that for further building construction practice in terms of building materials, the amount of carbon emission is recommended to be below the blue line which is the average values of the four models evaluated in this particular study. Furthermore, in term of average building materials, potential reduction of carbon emission for this study has the value of 7.6% from the benchmark level of the Lot 4C11 building. This value can be a reference to the engineers in constructs the green building in the future.

The process to obtain the value of carbon emission for all models is done through basic software developed using Microsoft Excel. The carbon calculator is develop in order to simplify the process to obtain the amount of carbon emission building materials and assist the user in estimate the amount of the carbon emission of the building materials during its life cycle boundary condition which is from ‘cradle to gate’ boundary. There are various types of main material and sub-materials state in the carbon calculator database which will result in accurate and precise calculating of the carbon emission for particular building.

The Figure in appendix shows the calculation of the total amount of carbon dioxide per square meter emitted from Model 1 by using carbon calculator and the graphical chart is provided in order to help the user to determine the quantifying of the structure materials.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In the previous chapter, the findings of the research have been presented and discussed thoroughly. This final chapter will conclude the research findings in relation to the aims and objectives of the study. Finally, the recommendation is provided in order to strengthen this research.

5.1 Review of Study Objectives

The aim of this study is to determine the carbon reduction best practices and benchmarking for building materials in the Malaysian construction industry. In order to achieve this aim, the following objectives are identified:

i. To determine the amount of carbon emission for various types of building materials based on a case study of a construction project.
ii. To conduct carbon emissions modeling of building materials from the benchmark level for the Malaysian construction industry.

5.2 Research Conclusion

The building constructions industries is considered as a major contributor to the sustainable country at a positive side and also act as catalyst to the environmental problems resulting in negative impact. The GHG emissions from the building materials during buildings life cycle have harmful impact to the human life and nature.

At the end of this study, the result of carbon emissions modeling of building materials based on the case study is obtained. Model 4 is selected as the carbon reduction best practice for building materials by the value of 422.40CO_2/m_2 with the consumption of all the alternative low carbon materials in this research study. It is followed by Model 2 and Model 1, 455.18kgCO_2/m_2 and 468.24kgCO_2/m_2 respectively. Model2 consume recycled materials to obtain the lower carbon in building construction while Model 1 using fly ash in replacement of cement in the concrete mix ratio as the alternative reduction carbon. Model 3 with the value of 495.01kgCO_2/m_2 has the highest amount of carbon emission based on the benchmark level with the consumption of secondary glass as low carbon material. Carbon emission of Lot 4C11 office building is choosing as a benchmark level for the models in this study with the value of 498.01kgCO_2/m_2. Therefore, many alternative low carbon materials applied in the building construction brought to the larger potential reduction of CO_2.

The simulations of four models of building materials in this study apply basically the similar main materials with the case study. However, it is differ in consumption of alternative low carbon materials for every model in order to determine the lowest carbon emission for building materials. In addition, the quantity of materials and gross floor area of the building models is based on the Lot 4C11 as a benchmark building. Therefore, the average value of the carbon emission for the models is 460.21kgCO_2/m_2 which shown in the blue line in the Figure 14. This base line of the carbon emission can be as a reference to the engineers and architects of the building construction in order to considering the selection of the green building materials in the design phase of the construction.

The building materials selection is crucial in order to achieved sustainable in building construction. The three selected type of building materials; concrete, steel and glass were analyzed to find the alternative low carbon materials of each of the selected materials. The analysis is considering the embodied carbon factor of the building materials. In this research study, concrete consume fly ash as the alternative low carbon material which has the lower embodied carbon factor. The consumption of fly ash contributes to the higher strength of the concrete materials. The recycle general steel and recycle rebar steel are selected as the low carbon materials for the steel materials. The recycle materials have the lower embodied carbon compare to the virgin materials. Besides, the secondary glass selected as the alternative material for the glass based on the ICE guideline.

From the Figure 13, concrete consume the alternative material of fly ash for Model 1 and Model 4 with the value of 182.96kgCO_2/m^3 of carbon emission compare to the original consumption of concrete in the structure with the value of 209.93kgCO_2/m^3. The consumption of the alternative material result in lower emits of carbon to the atmosphere and avoids the harmful environment. The recycle steel is used in the Model 2 and Model 4 for the reduction of the carbon emission of the structure with the value of 43.54kgCO_2 which is lower than steel in the Model 1 and Model 3 based on the benchmark green building (257.73kgCO_2). Besides, the alternative material for glass which is secondary glass has the lower amount of carbon emission with the value of 12.23kgCO_2 compare to the primary glass material of 15.23kgCO_2 carbon emission.

Timber is not replace to the alternative materials because it is already has the lower embodied carbon for its sub-material. Timber also has the smaller amount of carbon emission which is not affect the change in the carbon reduction of the building materials. Furthermore, in order to calculate the carbon emission, the carbon calculator is established and used to assist calculation in proper and precise methods. This application is expected to be used wisely especially in the Malaysian construction industry.

Based on the average building materials used in this research study, in term of practice, the potential reduction of 7.6% from the benchmark level is achieved. This value is achievable for the engineers and architects to take as a reference in selection of the sustainable building materials. Therefore, steel is the major contributor to the carbon emission in construction industry. Engineers need to take action regarding the carbon emission reduction of steel without affect its strength. This study is emphasize that even though Lot 4C11 office building is a green building, we can improve the sustainability of the building by consume the alternative low carbon materials in this study. The development of carbon reduction models for building materials will help the local civil engineers to assess and compare the environmental impact of building projects in different locations of Malaysia and also help to identify sustainable building material for Malaysia.

5.3 Recommendation

The carbon reduction best practices should be developed in the Malaysian construction industry in order to achieve the green building construction that brought to the sustainable development in Malaysia. The life cycle boundary of 'cradle to gate' of the building consists of the raw materials consumption which produced large amount of carbon emission. In order to improve the sustainability of the building construction industry in Malaysia, some recommendation is provided. Selecting the type of materials use in the building life cycle is important in order to prevent the increasing of carbon emissions and resulting in sustainable building materials. The building materials that have higher embodied carbon can lead to unfriendly nature environment and affect the global temperature and climate patterns.

Steel and concrete as the major contributor to the carbon emission can be reduced by applying alternative low carbon materials. Consumption of ground granulated blastfurnace slag (ggbs) or fly ash as the alternative of the cement replacement in concrete product can significantly reduce the overall carbon emissions. In addition, salvaged and reusable building materials can be the alternative materials beside the recycled steel. The larger reduction can be achieved when the material is reused without reprocessing.

Furthermore, the improvement of building materials design will result in reduction of use of the building materials for example use of gas concrete rather than common concrete block. This option can contribute to the significant saving and reduction of environmental impact. In addition, the low carbon emission in building construction can be achieved by reducing the amount or quantity of the materials. The quantity of the building materials is considered as the factor of significant greenhouse emissions. The higher amount of materials leads to greater contribution of CO_2 associate with embodied carbon factor for particular materials. Thus, the light weight materials such as light weight concrete can contribute to the sustainable building materials by reduce the loading carried by structural elements such as main beams and columns. With much lower load, the emission impact will be reduced significantly.

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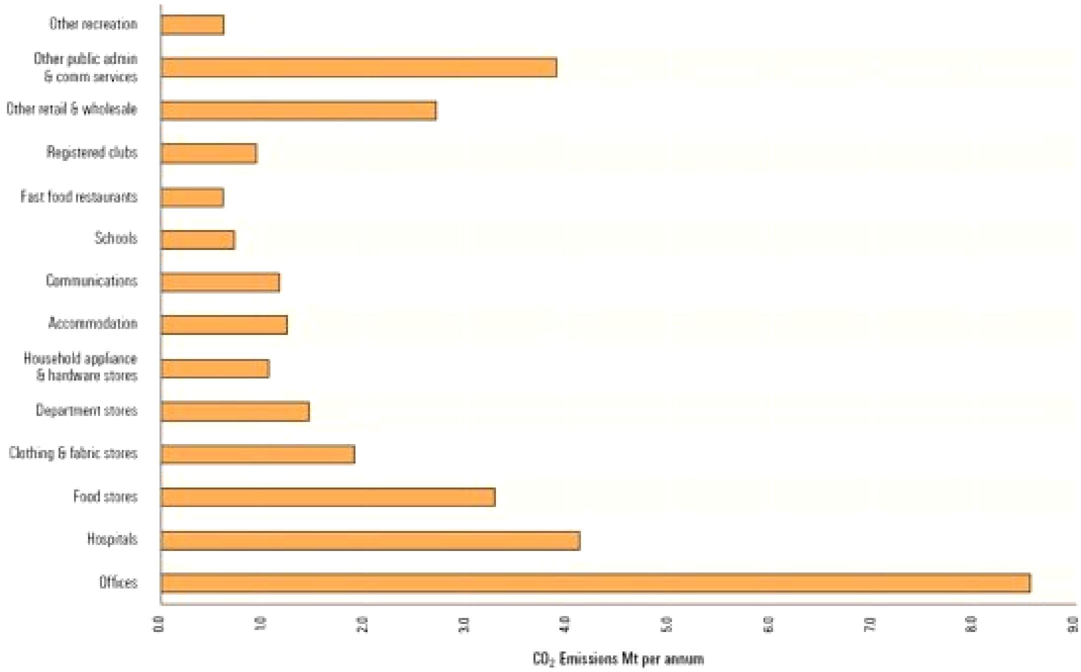
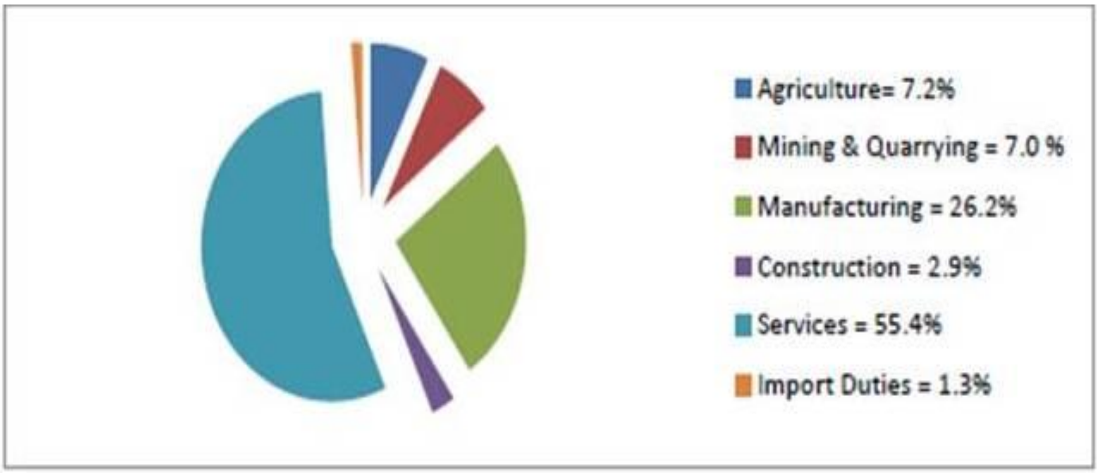
APPENDICES



Commercial building greenhouse gas emissions by key building types 1990 Source: EMET Consultants and Solarch Group (1999).



Percentage Distribution of GDP Based on Economic Activity for the Year 2010

Type	Quantity (m3)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
General	25407	2400	60976800	0.13	7926984
1:1:2	14068	2410	33903880	0.209	7085910.92
1:1:5:3	2273	2400	5455200	0.159	867376.8
1:3:6	1779	2400	4269600	0.096	409881.6
Nil	0	0	0	0	0
				TOTAL	16290153.32

Type	Quantity (kg)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
General	3334068	8000	3334068	2.75	9168687
Bar & Rod	3931796	7900	3931796	2.68	10537213.28
Stainless	47739	2700	47739	6.15	293594.85
Nil	0	0	0	0	0
				TOTAL	19999495.13

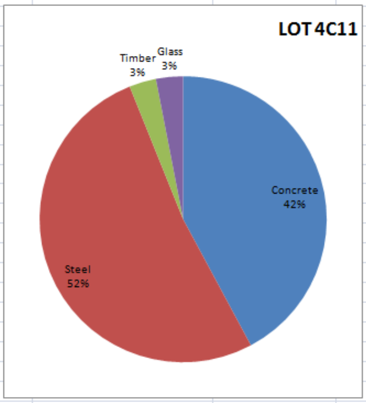
Nil
General
Bar & Rod
Section
Stainless

	antity (m2)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
General	4255	480	2042400	0.46	939504
Hardboard	49	700	34300	0.86	29498
Plywood	134	540	72360	0.81	58611.6
Sawn Hardwood	355	880	312400	0.47	146828
Nil	0	0	0	0	0
Nil	0	0	0	0	0
				TOTAL	1174441.6

Type	Quantity (m3)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
Asphalt	0	700	0	0.45	0
Bricks	0	2400	0	0.22	0
				TOTAL	0

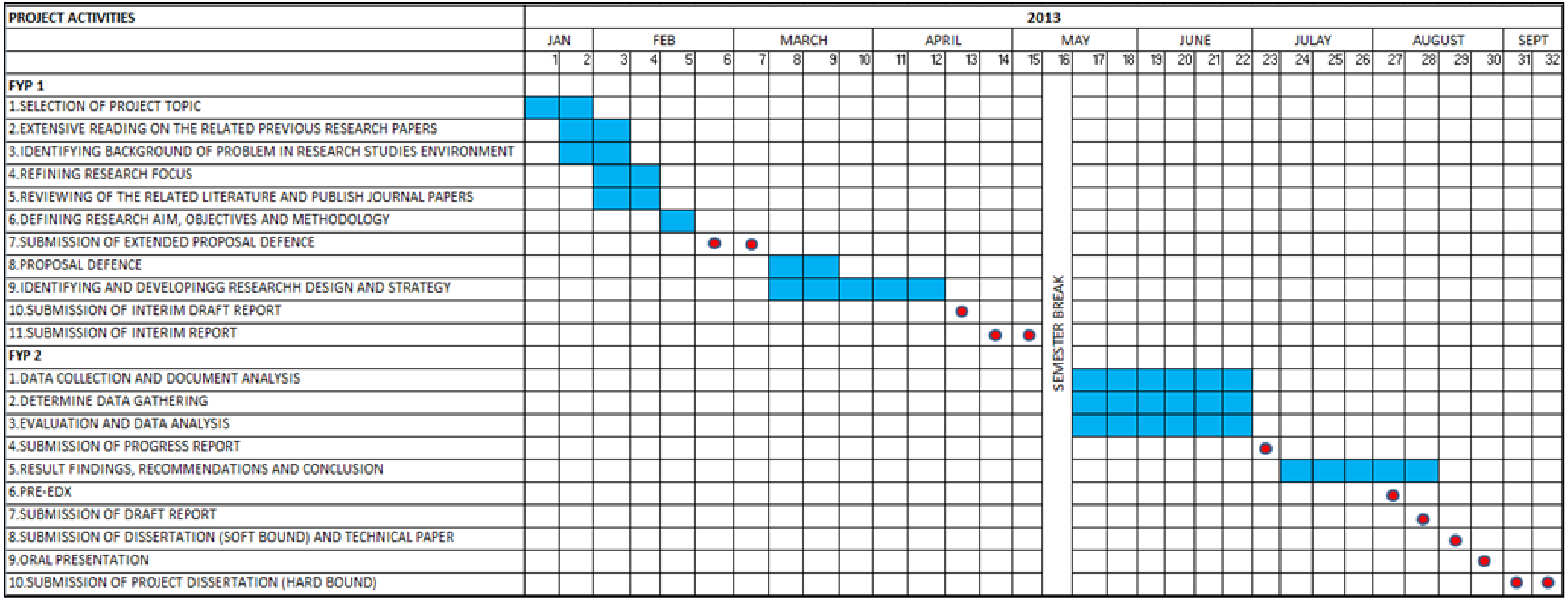
Type	Quantity (m2)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
General Glass	296	2450	725200	0.86	623672
Toughened Glass	169	2600	439400	1.27	558038

Name of Building	LOT 4C11
Gross Floor Area (m2)	77600
Total Carbon Emission (kg)	38645800.05
Carbon footprint kg/m2	498.0128872



Carbon calculator

Gantt Chart



Milestone

Process