ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to my Final Year Project supervisor, Dr M Faris Khamidi for the continuous support of my FYP research, for his patience, motivation, enthusiasm, thoughtful comments and immense knowledge. His guidance has helped me in making this FYP research and writing of this dissertation possible. I could not have imagined having a better supervisor for my Final Year Project at Universiti Teknologi PETRONAS. Million thanks shall be directed to him for giving valuable advices for me to excel in my Final Year Project & not forgetting his significant guidance for my dissertation preparation.

My sincerest thanks is also directed to Putrajaya Holdings Sdn Bhd, and my internship supervisor, also my ex-coworkers at the Commercial Building Department for offering their confidential data required for this study on their diverse exciting projects such as the construction of the PZ10 hotel and office towers, the Lot 4C11, 2C2 and 3C4 commercial projects, enabling me to further proceed my research result analysis with ease.

Besides that, I would like to thank my friends, for their continuous encouragement, guidance and motivation whenever I needed it. During this time I have numerously been asking for help and guidance from many people for whom I have great regard, and I wish to extend my warmest thanks to all those who have helped me with my research work.

Last but not the least; I would also like to thank my family, my lovely parents especially for all the mental and financial support all these while which had led me towards this stage of my life which I have never imagined possible before.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

1.0 INTRODUCTION

1.1 Background

The building and construction industry encompasses residential, commercial, and infrastructure development in various developing areas of the country. In typical building construction activities, there are a few aspects that are concerned with the environment which may cause unwanted impacts such as excessive emissions into the air, water spills, waste generation, soil pollution, resource consumption, impacts associated with transportation, and also effects on biodiversity in a specific area. Therefore, it is absolutely significant that these factors are taken into consideration in order to maintain the environment from further destruction such as the increasingly dreaded global warming issue.

Constructions in rapidly industrialising countries are the main sources of greenhouse gases emissions which is the main contributing factor in global warming. This climate change (global warming) presents a serious challenge for responsible business leaders in the 21st century. According to a report by the Edinburgh Centre for Carbon Management Ltd,

“ *Most scientists now agree that rising atmospheric concentrations of greenhouse gases (GHGs), particularly carbon dioxide (CO_2), threaten to have severe impacts on food production, natural ecosystems and human health over the next 100 year*s.” [1]

Appendix 1 shows a graph comparing main elements that produces carbon footprint in terms of its total energy use, green house gas index, air pollution index etc. The study was done by Hattie Hartman’s sustainability to measure the emission.

In recent years, many environmentalists have been trying to find ways reduce the carbon footprint emission into the atmosphere. And specifically in this case study, the amount of carbon footprint is to be measured and calculated through a carbon calculator from data gathering of construction activities and building materials.

Based on Wright, Kemp, and Williams, trough their writing in the journal *Carbon Management,*

"A measure of the total amount of carbon dioxide (CO_2) and methane (CH_4) emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as carbon dioxide equivalent (CO_2e) using the relevant 100-year global warming potential (GWP100)." [2]

1.2 Problem Statement

In recent years, there has been growing concern about global warming resulting from increased atmospheric concentrations of the so-called greenhouse gases (GHGs) and the resulting environmental impacts. The country with the largest carbon emission in the world is United States with a total emission of 5,762,050 metric tonnes. Not being too far behind, Malaysia is ranked 30th in the world out of all countries that have largest amount of carbon emission with a total emission of 123,603 metric tonnes of carbon dioxide. In Malaysia, 24% of the total carbon dioxide emission comes from the construction industry in the country itself [3]

The construction industry has a very significant impact towards the environment in terms of emission of carbon dioxide to the atmosphere. Referring to the data taken from the Worldwatch Institute, the construction of buildings annually consumes 40% of stone, sand and gravel, 25% of timber and 16% of water in the world. Manufacturing and transporting of building materials, and installing and constructing of buildings consume great quantities of energy and emit large amounts of greenhouse gases (GHG). In the member states of the European Union, buildings through their life cycle, including construction, operation and demolition, consume approximately 50% of the total energy demand and contribute almost 50% of the CO_2 emissions released to the atmosphere [4]

According to the Environmental Protection Agency (EPA), the construction sector has the third highest CO2 emissions among all industrial sectors. Additionally, a great amount of construction materials are being consumed every day, which produce a magnitude of CO2 emissions due to embodied energy. For example approximately 110 million tons of cement is used every year in the construction industry (Horvath, 2004) [5]

As to reduce the carbon emission into the atmosphere in order to sustain the environment, in this specific study in this paper, a carbon calculator is to be developed through data gathering so that the emission of carbon footprint in construction activities and building materials can be calculated and tracked in order to reduce the energy consumption and greenhouse gases emission associated with the construction industry.

1.3 Objective

The following are the identified objectives that are expected to be achieved upon completing this final year project thesis;

1) Determine the amount of the carbon footprint for various type of building materials in the construction industry.
2) To develop a user friendly carbon calculator software for building materials through qualitative works and data crunching.

1.4 Scope of Work

Building construction is the process of adding structure to a land property using building materials from various resources such as timber and steel that leads to the emission of carbon. Basically, in this entire study, carbon footprint calculation is mainly focused on material used for the construction. Thus, each and every process that is involved in the construction works is extracted as to make a significant calculation of carbon emission of the building materials used.

This calculation is aimed to be done on a commercial type of building in which is considered as a high rise office building. Basically, it is important to understand the steps involved in the building construction and also the type of materials used in order to be able to carry out the calculation of carbon footprint of the building structure.

The calculation of carbon footprint of building materials is considered during its cradle to gate life cycle. Which basically means the carbon emission from moment when the materials are first extracted from its natural resource until it is delivered to the construction site.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Carbon Footprint

In recent years, the term carbon footprint is starting to be widely used throughout the world in relation with climate change. There are several definitions which vary among writers and numerous journal written as stated in the **Table 1** below.

Source	**Definition**
BP (2007)	"The carbon footprint is the amount of carbon dioxide emitted due to your daily activities – from washing a load of laundry to driving a carload of kids to school."
British Sky Broadcasting (Sky) (Patel 2006)	The carbon footprint was calculated by "measuring the CO_2 equivalent emissions from its premises, company-owned vehicles, business travel and waste to landfill." (Patel 2006)
Carbon Trust (2007)	"… a methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions). "… a technique for identifying and measuring the individual greenhouse gas emissions from each activity within a supply chain process step and the framework for attributing these to each output product (we [The Carbon Trust] will refer to this as the product's 'carbon footprint')." (Carbon Trust 2007, p.4)
Energetic (2007)	"… the full extent of direct and indirect CO_2 emissions caused by your business activities."
ETAP (2007)	"…the 'Carbon Footprint' is a measure of the impact human

	activities have on the environment in terms of the amount of greenhouse gases produced, measured in tones of carbon dioxide."
Global Footprint Network (2007)	"The demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion." (GFN 2007; see also text)
Grub & Ellis (2007)	"A carbon footprint is a measure of the amount of carbon dioxide emitted through the combustion of fossil fuels. In the case of a business organization, it is the amount of CO_2 emitted either directly or indirectly as a result of its everyday operations. It also might reflect the fossil energy represented in a product or commodity reaching market."
Paliamentary Office of Science and Technology (POST 2006)	A 'carbon footprint' is the total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product. It is expressed as grams of CO_2 equivalent per kilowatt hour of generation (gCO_2eq/kWh), which accounts for the different global warming effects of other greenhouse gases."

Table 1: Definitions of 'carbon footprint' from literature [6]

According to the journal written by Hassan A.H. (2010), generally in most of the above definition, the term 'carbon footprint' is used as a generic synonym for emissions of carbon dioxide or any other greenhouse gases as a result of any related activities and is expressed in CO_2 equivalents.

2.1.1 Carbon Footprint of a Building

Carbon footprint of a building can be defined as the total amount of carbon dioxide (CO_2) and other greenhouse gases emitted over the life cycle of building. A life cycle of a building is identified as shown in **Figure 1** below.

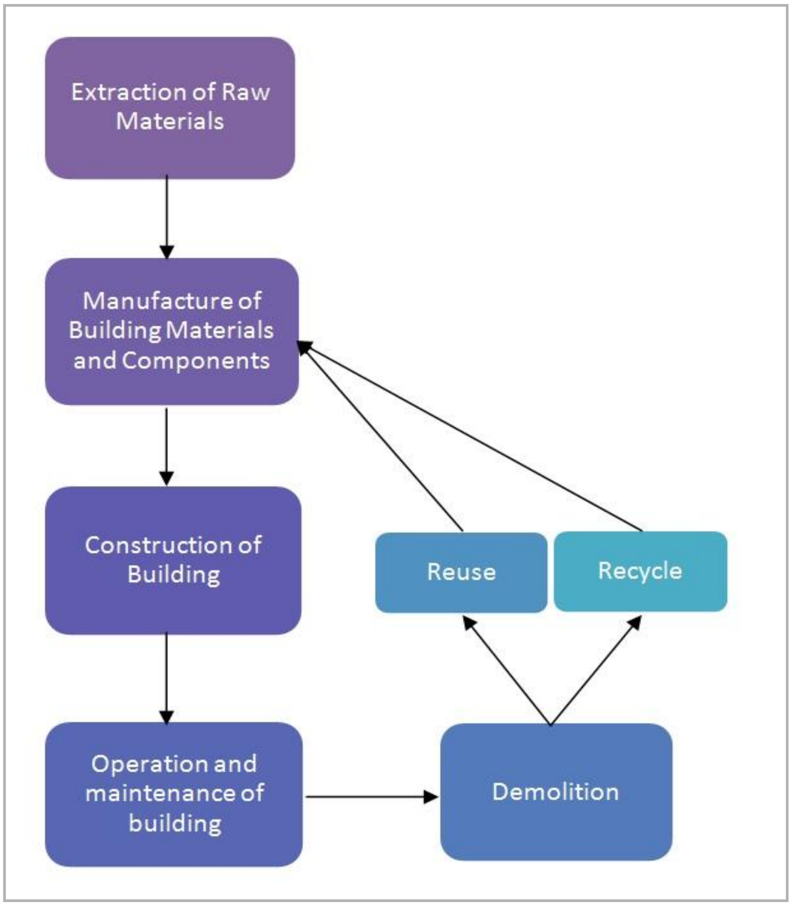


Figure 1 : *Environmental Life Cycle of a Building*

According to Clean Metrics Corp, the evaluation of carbon footprint can be performed through Life Cycle Analysis to access the sustainability of the construction works through consideration of all environmental implications of development, from primary input to disposal of final output and byproduct, including wastes. Furthermore, as stated by Clean Metrics Corp, a carbon footprint which includes all greenhouse gases from the construction of a building, transportation of building materials to the site, operation of the building is calculated throughout the life cycle of the building which is expressed as kilograms of CO2 equivalent. [7]

In addition, the life cycle of the carbon footprint, it is necessary to have a measurement effort of carbon footprint as to monitor carbon dioxide and other greenhouse gases emission. This is because, needed action can be carry out to reduce the emissions of carbon footprint in leading a way to a better environmentally-living manner.

2.1.2 Greenhouse Gasses

Greenhouse gases absorb energy from the sun, trapping it in the atmosphere, as part of the Greenhouse Effect which keeps the Earth warm. However, when the concentration of these gases increases with time within the atmosphere, the temperature is said to be above the normal limits. Most greenhouse gases occur naturally in the atmosphere. However, human activities such as building construction have impacted the concentration of those gases in the atmosphere significantly. [8]

According to the data obtained by National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA). From the data, it is reported that the temperature on Earth's surface has significantly increased by about 1.2 to 1.4ºF in the past 100 years. The eight warmest years that has been recorded (since 1850) have all occurred since 1998, with the warmest year being 2005. It is identified that these phenomenon happened as a result from human activities such as building constructions. [9]

According to the Kyoto Protocol, the greenhouse gases emission include Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N2O), Sulphur Hexaflouride (SF6), Perflourrocarbons (PFCs) and Hydroflourocarbons (HFCc). Carbon dioxide is the usual reference standard for greenhouse gas effects. Other gases is converted into the "CO_2 equivalence effect".

Chemical Species	**Formula**	**GWP**
Carbon dioxide	CO_2	1
Methane	CH_4	23
Nitrous Oxide	N_2O	296
Sulphur Hexaflouride	SF_6	22 200
Perflourocarbons	PFCs	4 800 – 9 200
Hydroflourocarbons	HFCs	12 – 12 000

Table 2 The global warming potential of the Kyoto Gases

*Note: the 'global warming potential' of a gas is its relative potential contribution to climate change over a 100 year period, where CO=1. Source: IPCC (2001).

Generally, greenhouse gases emission in building construction are mainly from six sources, in which are:

1) Manufacture of building materials;

2) Transportation of building materials;

3) Transportation for construction equipment;

4) Energy consumption of construction equipment;

5) Transportation for workers;

6) Disposal of construction waste.[10]

2.2 HIGH RISE OFFICE BUILDING

A high-rise building, also called a multistory building is tall enough to require the use of a system of mechanical vertical transportation such as elevators. The reason for this kind of building is chosen in this project study is mainly because tall buildings such as office towers have become a construction trend in developing countries such as Malaysia. As for this project, the emissions of carbon footprint from high rise office building are to be calculated. And the reason for that is because these kind of tall buildings seem to be the main contributors of energy and greenhouse gas emission in the building sector.

The energy usually is used for space heating, cooling, lighting, water heating as well as operating auxiliary equipment such as computers and motors. Statistics have shown that office buildings in Malaysia have an average Building Energy Index (BEI) of between 200 and 300 kWh/m^2 per year.[11] This is considered high because according to the new Malaysian Standard MS1525:2001 "*Code of Practice on Energy Efficiency and use of Renewable Energy for Non-residential Building*", non residential building must have energy consumption less than 135kWh/m^2 per year. [12]

2.3 SUSTAINABLE BUILDING VS. CONVENTIONAL BUILDING

According to the European Environment Agency (EU), numerous sectors have been recognized in the contribution of greenhouse gases emission as shown in the chart below.

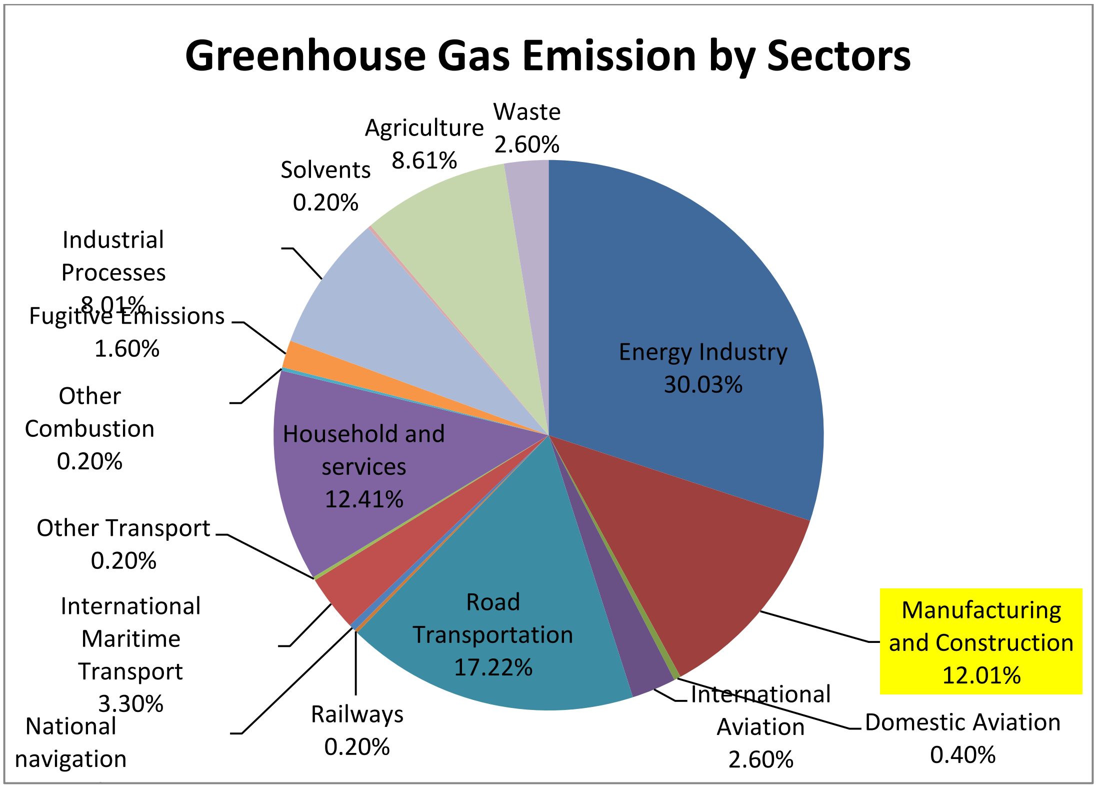


Figure 2: Total Greenhouse gas emissions by sector (%) in EU - 27, 2007

The maroon coloured section as shown in the chart above which accounts for 12.01% of the total greenhouse gas emission represents the manufacturing and construction industry in terms of its contribution of green house gases to the environment. From this statistics, it is clear that the construction industry plays quite an important role in energy and greenhouse gases emission from the building to the environment. In addition, as pointed out by Hassan A.H, one of the main sources for carbon dioxide (CO_2) emissions is from the building materials in construction itself. [13]

A study conducted by Green Ration Book, 2010 shows the amount of common building material of an average house as shown in the Table 3 below. [14]

Building Materials	**Tonnes Per House**
Concrete	508.10
Plaster	198.02
Bricks	558.14
Ceramics	9.57
OtherMineralProducts	3.37
Wood	23.94
Metals(Iron)	30.46
Plastics(PVC)	1.20
Glass	0.27
Paper	0.82
Textiles	0.82
Rubber	0.82
Paints	0.82
Insulation	0.82
Total	**689.61**

Table 3 The average building material content of a house

The conducted study shows that concrete and bricks are the mostly used building materials in a typical house construction in the UK.

Another case study which is conducted by Glover, J n.d 2005, compares the use of several main building materials such as concrete, steel and wood in the construction of similar sizes and designed houses. The information in the following table shows the calculated amount of CO2 emission from the three types of houses. The only difference is that in each house one particular material is being used more than in the rest which eventually compares them between the three. [15] It can be concluded that among these type of houses, the one made out of steel the most has the largest carbon emission to the environment.

	STEEL House	**CONCRETE House**	**WOOD House**
Old Total of CO2	40613	30168	17144
Steel CO2 Component	9578	4908	1403
Wood CO2 Component	377.1	937.2	4890
Concrete CO2 Component (only energy)	6313	9858	2979
Concrete CO2 Component (energy & calcinating)	8545	13206	3971
Adjusted Total of CO2	**42845**	**33516**	**18136**

Table 4: CO2 emissions for different types of houses based on building materials.

2.4 LOW CARBON HOUSING IN BEDZED

The Beddington Zero Energy Development (BedZED) in the United Kingdom is a multi-award winning development that adopted a holistic approach to sustainability. BedZED is not only considered economic, environmental and social aspects of sustainability, but it is aimed to create a zero fossil energy development in a long run.

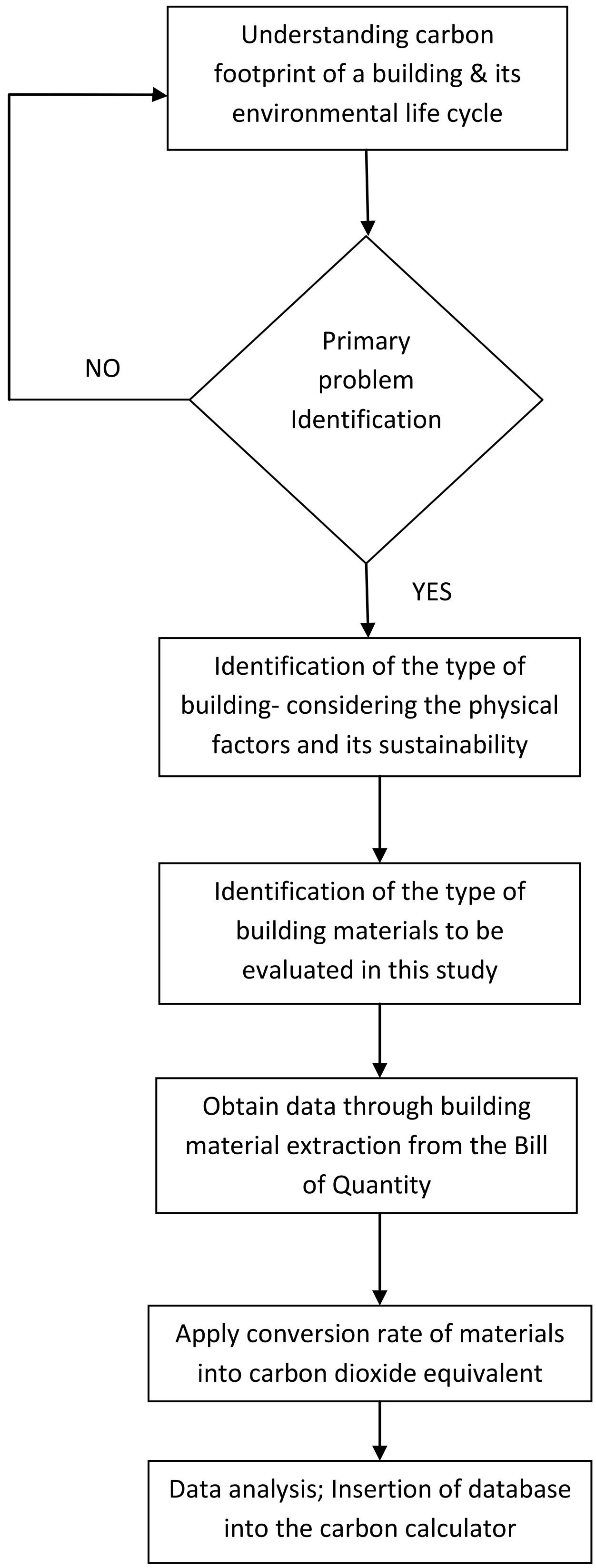
The development of BedZED was done initially to show that in large-scale construction a high level of sustainability can be practical and also cost-effective.

Figure 3 : *The Advanced Green Technologies used in BedZED*

According to the Arup Journal of BedZED, written by Chris Twinn, buildings are key to generating social advancement and prosperity, yet are one of the largest consumers of natural resources and generators of pollution and waste. It is often perceived that about 50% of atmospheric carbon emissions are released from buildings.

In addition, to stabilize the current global increasing atmospheric carbon dioxide levels, it is roughly estimated that around 60% emission reduction is needed by the year 2050. However with the world population which is expected to be two fold (10 billion) within the year 2100 , it is estimated that about 90% of carbon reduction is needed in order to achieve a stable level in terms of atmospheric carbon emission. [16]

3. 0 METHODOLOGY



The method used to approach this study is firstly by understanding the basics of carbon footprint. The literature review done, which included various authors and journals are significant in finding out the basic principles of this study. The method used for carbon calculation is also identified and determined.

Once the fundamental understanding of carbon footprint is captures, the next phase is to categorize type of building to be assessed as well as processes involve in the building construction process. The assessment boundaries are established as to have comprehensible calculation.

The process and materials involve in the construction can be acknowledged by understanding the bill of quantity of the project. Bill of quantity is a document used in tendering in the construction industry in which materials, parts and labors (including costs) are itemized.

Amount of carbon footprint is then calculated by using appropriate conversion factors obtained from Hammond G's study. The result is then been analyzed.

4.0 Results and Discussion

The building materials used for construction are extracted from the bill of quantity of the respective types of buildings for this study (green & conventional high rise office building). This calculation is carried out in order to identify which major construction materials contributes the most in carbon emission to the surrounding.

4.1 Findings

4.1.1 Carbon footprint conversion factor.

In order to compare and contrast different building materials used in constructions, a conversion factor is needed to standardize the units of measurement of different kind of materials in this case study. This conversion factor will enable the conversion of building materials into kilograms of carbon dioxide equivalent (CO_2e).

Due to the absence of carbon conversion rates of construction material used in Malaysia, the Inventory of Carbon & Energy (ICE) by Prof. Geoff Hammond (Hammond G.) and Craig Jones (Jones C.) will be used as carbon footprint conversion factor for this case study. This conversion rate is being used widely in United Kingdom. [17]

An example of the conversion factor developed by Hammond G. and Jones C is shown as below.

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), Proportions 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

Figure 4: Embodied Carbon for Specific Building Materials

Figure 4 above shows the material profile for ceramic, clay and concrete. For example, concrete is divided into several types for higher accuracy in calculating the carbon footprint. For every category, the value of embodied carbon is established.

Through the bill of quantity, the exact quantity of material used in the particular project can be obtained. The quantity of material will then be converted into unit of kilogram weight. This is done in order to ease the calculation by providing similar units for carbon conversion. Next is the conversion of weight to CO_2 equivalent by using Hammond G and Jones C. conversion factor as shown in **Figure 4**. The same procedure also applies to other type of building materials for this project. Most of identified materials in construction can be found in Hammond G and Jones C. Inventory of Carbon Energy Manual.

It is crucial to know the conversion rate for each and every building material involved in the calculation in order to satisfy the unit used in Hammond G. and Jones C. conversion factor which is in $kgCO_2/kg$. Thus, the crucial step that must be taken before calculating the carbon footprint of building materials is the conversion of unit volume (m^3) of materials to unit weight/mass (kg) of materials.

The rate of conversion to unit mass of building materials can be obtained from Hammond G. and Jones C. Conversion Factor manual. The values of embodied carbon of specified materials and its respective density are summarized as in the table below.

Materials	Type	Embodied carbon (kgCO2/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	0.08	2400
STEEL	General	1.77	8000
	Bar & Rod	1.71	7900
	Section	1.76	6700
	Stainless	6.15	2700
TIMBER	General	0.46	480
	Hardboard	0.86	700
	MDF	0.59	70
	Plywood	0.81	540
	Sawn Hardwood	0.47	880
	Sawn Softwoord	0.45	630
MASONRY	Bricks	0.22	2400
	Asphalt	0.45	700
GLASS	General Glass	0.85	2450
	Toughened Glass	1.27	2600

Table 5: Hammond G. and Jones C. Conversion Factor manual

4.1.2 Buildings Evaluated

The four buildings that were studied upon in this research are categorized under 2 types of buildings namely the green building & conventional building.

Figure 5a: Green Building- Lot 4C11, Precint 4, Putrajaya

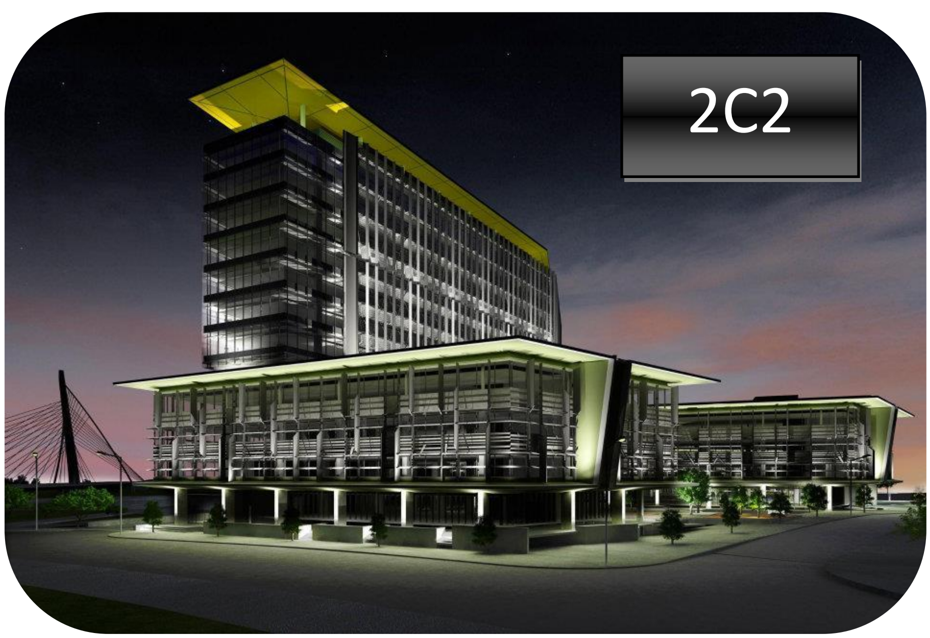


Figure 5b: Green Building- Lot 2C2, Precint 2, Putrajaya

Figure 5c: Conventional Building - Lot 3C4, Precint 3, Putrajaya

Figure 5d: Conventional Building- Plot Z10, Precint 1, Putrajaya

4.2 Results and Discussion

The data analysis done with respect to the bill of quantity is as below.

4.2.1 Green Building

4.2.1.1 Lot 2C2, Putrajaya

Building Details:

Name of building: Lot 2C2

Category: Green Building

Location : Precint 2, Putrajaya.

Total No. of Floors: 12 storeys

Gross Floor Area: 53486 sqm.

Materials	Quantity	Weight (kg)	Carbon Emission (kgCO2)
Concrete	28365.414 m^3	62403910.8	8112508.404
Steel	4680882 kg	4680882	8285161.14
Timber	3739.387 m^3	1869693.5	860059.01
Bricks	2718.5 m^3	6524400	1435368
Glass	695.52 m^3	1808352	1537099.2
		TOTAL	**20230195.75**

Table 6 : *Quantification and CO2 conversion of building materials extracted from Bill of Quantity for Lot 2C2 Putrajaya.*

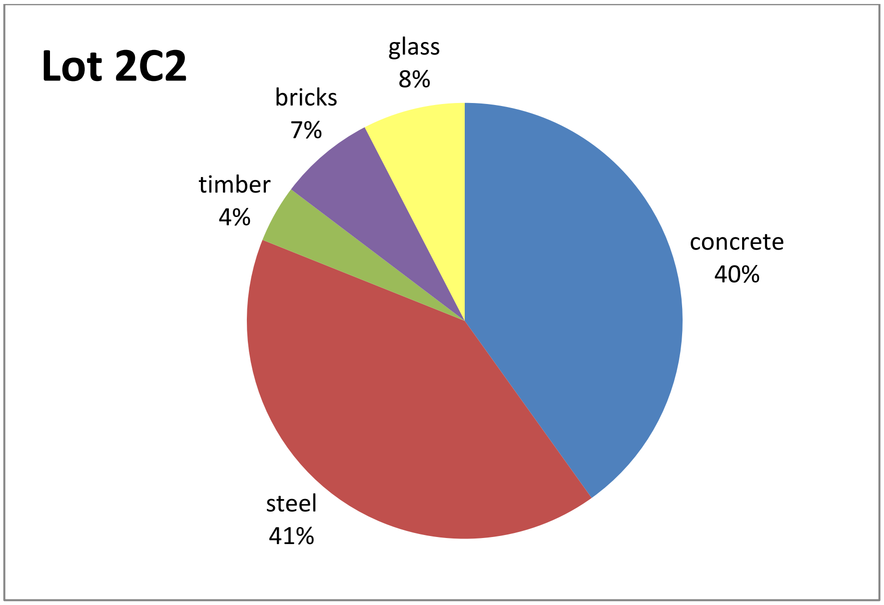


Figure 6a: General Breakdown of *Carbon Dioxide Equivalent of building material for Lot 2C2, Putrajaya.*

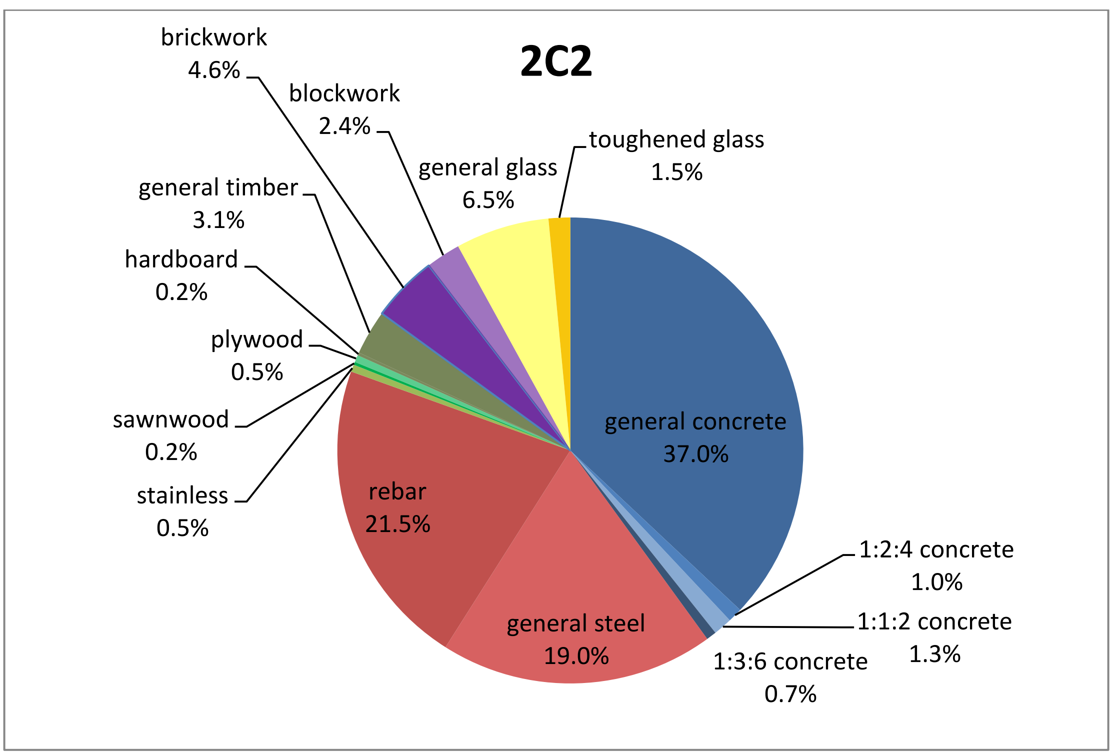


Figure 6b: Further Breakdown of *Carbon Dioxide Equivalent of building material for Lot 2C2, Putrajaya.*

It can be concluded that the usage of the two main building materials-concrete and steel, 40% and 41% respectively contributes most to the carbon emission of the construction. The use of timber contributes the least to the carbon emission followed by brickwork and glass usage of this project.

4.2.1.2 Lot 4C11, Putrajaya

Building Details:

Name of building: Lot 4C11

Category: Green Building

Location : Precint 4, Putrajaya.

Total No. of Floors: 10 storeys

Gross Floor Area: 77600 sqm.

Materials	Quantity	Weight (kg)	Carbon emission (kgCO2)
Concrete	43526.2 m^3	95757640	12448493.2
Steel	7312483 kg	7312483	12943094.91
Timber	4799.07 m^3	2399535	1103786.1
Bricks	3521.5 m^3	8451600	1859352
Glass	304.74 m^3	792324	673475.4
		TOTAL	**29028201.61**

Table 7: *Quantification and CO2 conversion of building materials extracted from Bill of Quantity for Lot 4C11 Putrajaya*

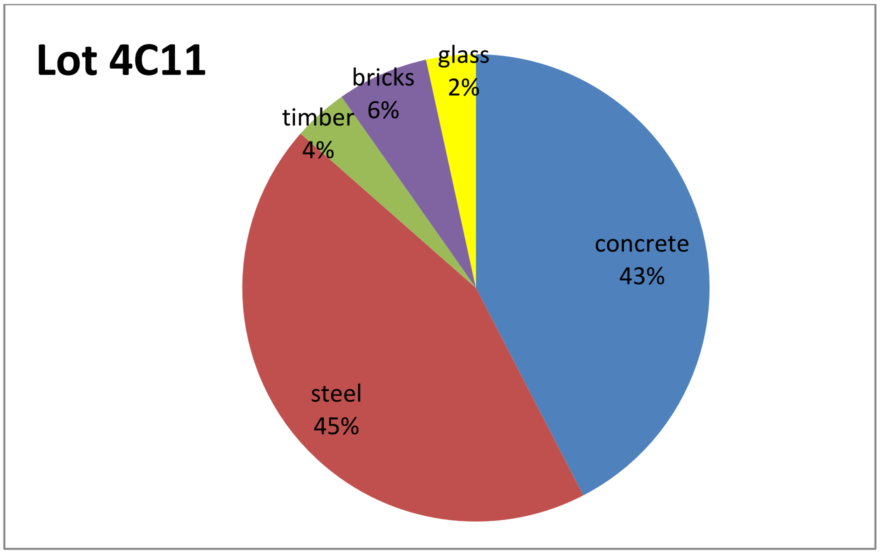


Figure 7a: General breakdown of *Carbon Dioxide Equivalent of building material for Lot 4C11, Putrajaya.*

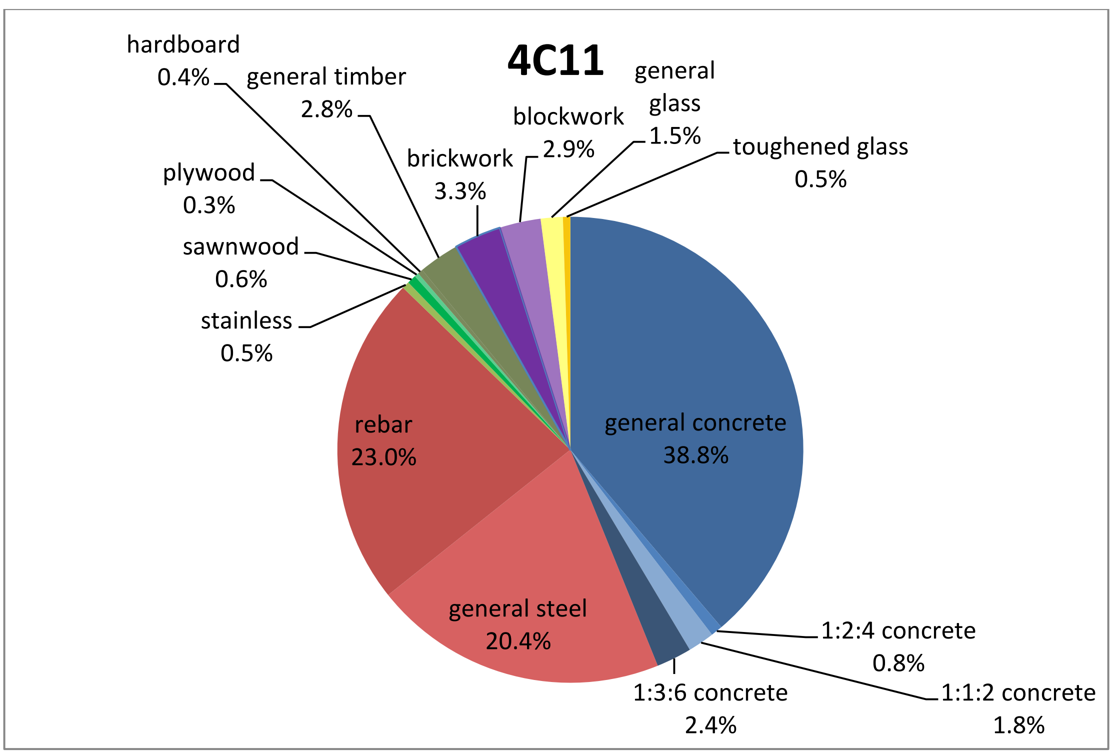


Figure 7b: Further Breakdown of *Carbon Dioxide Equivalent of building material for Lot 4C11, Putrajaya.*

It can be seen that even for this building it shows a similar trend in which concrete and steel has the highest contribution of carbon compared to all other materials. However, notice that the amount or quantity (in kilograms) of concrete used is much higher than steel, yet the emission stays the similar.

4.2.2 Conventional Building

4.2.2.1 Plot Z10 Putrajaya

Building Details:

Name of building: Plot Z10

Category: Conventional Building

Location : Precint 1, Putrajaya.

Total No. of Floors: 10 storeys

Gross Floor Area: 16362 sqm.

Materials	Quantity	Weight (kg)	Carbon emission (kgCO2)
Concrete	10075 m^3	22165000	2881450
Steel	1663578.5 kg	1663578.5	2944533.945
Timber	1571.27 m^3	785635	361392.1
Bricks	1503.15 m^3	3607560	793663.2
Glass	138.78 m^3	360828	306703.8
		TOTAL	**7287743.045**

Table 8: *Quantification and CO2 conversion of building materials extracted from Bill of Quantity for Plot Z10, Putrajaya*

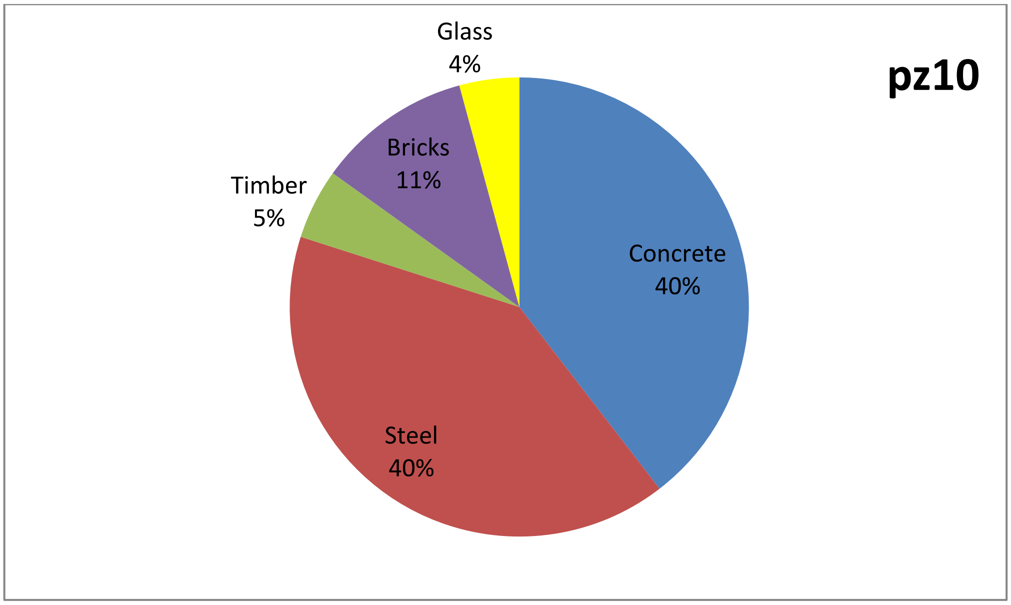


Figure 8a: General breakdown of *Carbon Dioxide Equivalent of building material for Plot Z10, Putrajaya.*

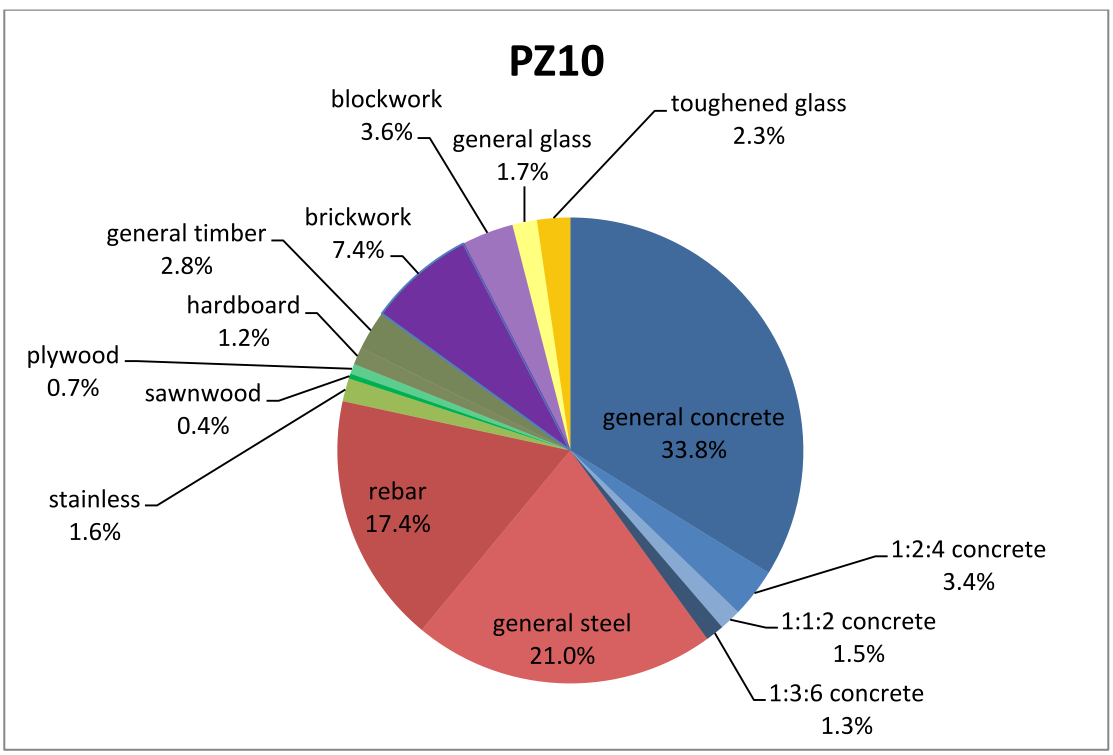


Figure 8b: Further Breakdown of *Carbon Dioxide Equivalent of building material for Plot Z10, Putrajaya.*

However, for this building which is categorized under the conventional building category, it is obvious that the usage of steel surpasses concrete by 7%. The use of bricks seems high in this study, which contributes up to10% of the total carbon emission.

4.2.2.2 Lot 3C4 Putrajaya

Building Details:

Name of building: Lot 3C4

Category: Conventional Building

Location : Precint 3, Putrajaya.

Total No. of Floors: 8 storeys

Gross Floor Area: 29473 sqm.

Materials	Quantity	Weight (kg)	Carbon emission (kgCO2)
Concrete	17583 m^3	38682600	5028738
Steel	2723684 kg	2723684	4820920.68
Timber	2050.27 m^3	1367000	628820
Bricks	2148.2 m^3	5155200	1134144
Glass	287.83 m^3	748332	636082.2
		TOTAL	**12248704.88**

Table 8: *Quantification and CO2 conversion of building materials extracted from Bill of Quantity for Lot 3C4, Putrajaya*

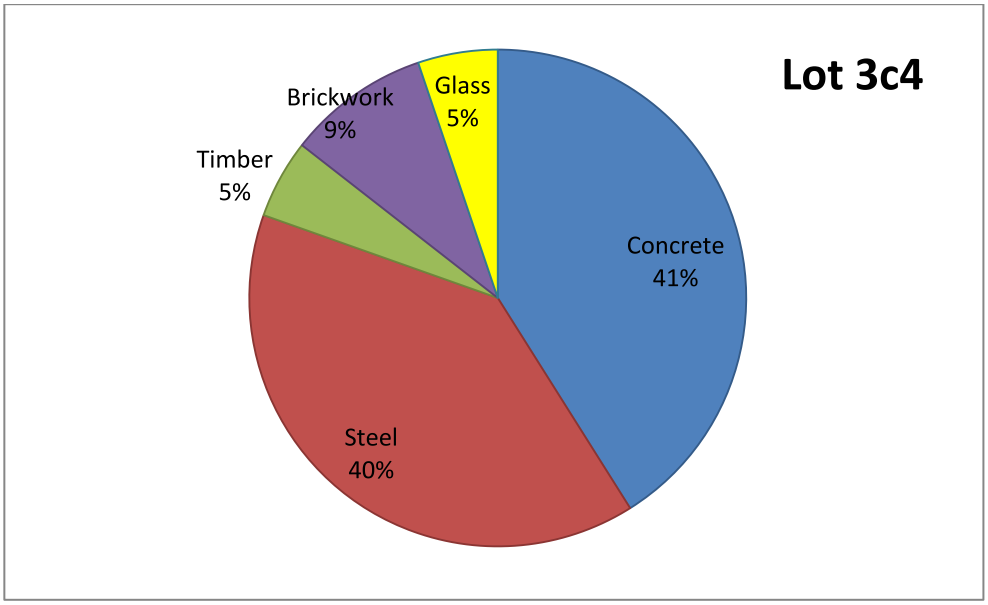


Figure 9a: General breakdown of *Carbon Dioxide Equivalent of building material for Plot Z10, Putrajaya.*

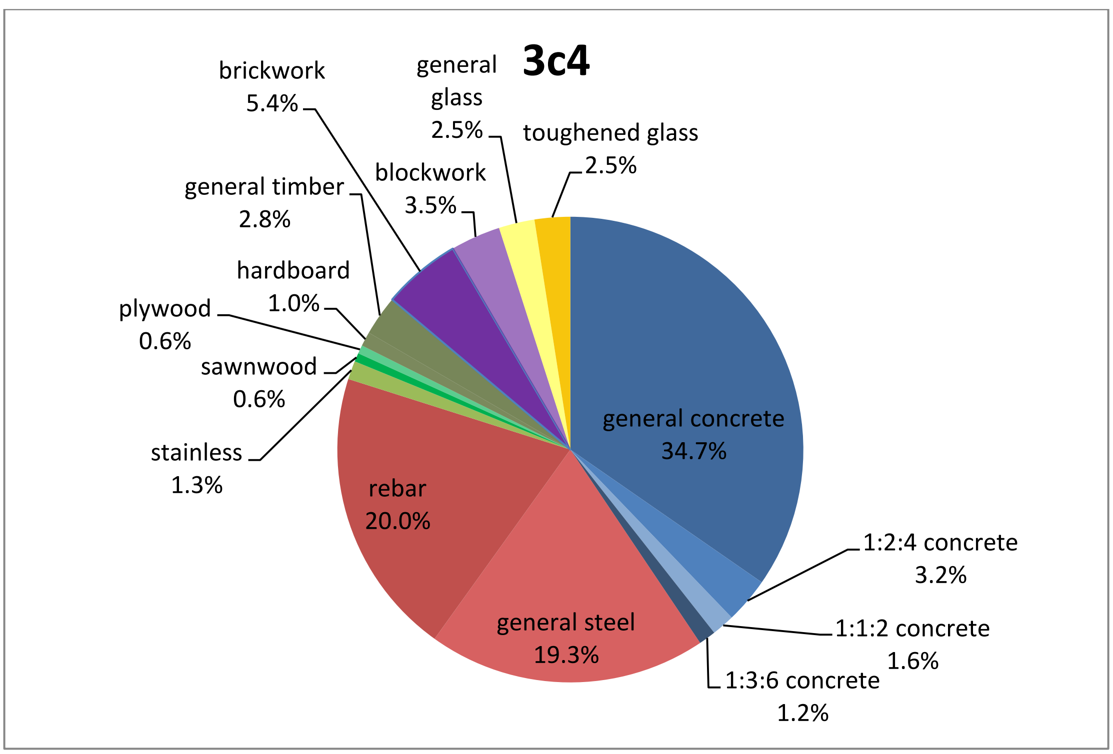


Figure 9b: Breakdown of *Carbon Dioxide Equivalent of building material for Plot Z10, Putrajaya.*

4.2.3 Analysis and Discussion

Project	CO_2 emission (CO_2e) (kg)	Gross floor area (sqm)	CO_2e per sqm. ($kgCO_2/m^2$)
Lot 2C2- Green	20230195.753	53486	**378.233**
Lot 4C11- Green	29359701.612	77600	**378.347**
Plot Z10- Conventional	7287743.372	16362	**445.396**
Loc 3C4 - Conventional	12248705.43	29473	**415.590**

Table 9 : Comparison of carbon emission equivalent of building per meter square.

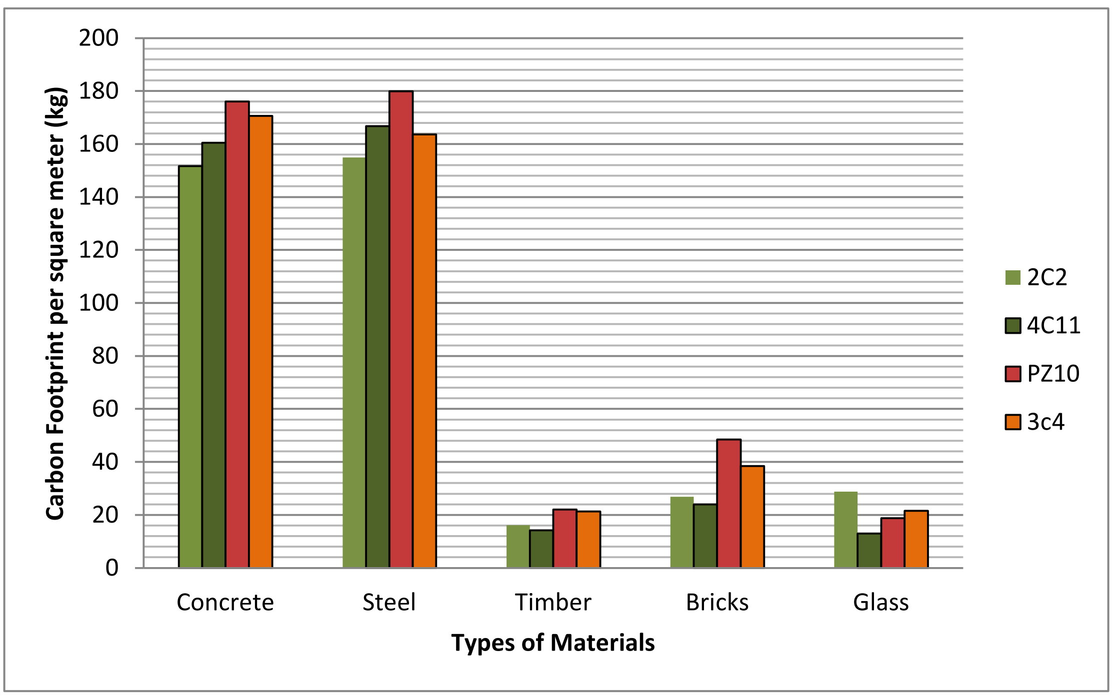


Figure 10: Comparison of carbon footprint of building materials (kg) per square meter.

By comparing the detailed breakdown of building material pie charts as shown in **Figure 6b, & Figure 7b**, it can be said that for the construction of sustainable buildings, the use of general concrete and general glass is relatively higher compared to those used in conventional buildings in **Figure 8b & Figure 9b**. However, the percentage of toughened glass (embodied carbon : 1.27) and also 1:2:2 cement (embodied carbon : 0.209) used in the construction of conventional buildings is much higher compared to sustainable buildings. This type of cement would eventually produce a higher carbon emission because of its higher embodied carbon in its own main material category and it is proven by this study that sustainable building has a smaller ratio in terms of this toughened glass and also the 1:1:2 cement usage.

On the other hand, the use of plywood (embodied carbon: 0.81) and hardboard (0.86) which has a higher embodied carbon compared to other types of timber used in sustainable building construction is slightly lower than its usage in conventional building construction.

In terms of comparing the steel usage in both building, there's only a slight difference in which conventional building uses a higher percentage of general steel (embodied carbon: 1.77) compared to the usage of reinforcement bars (embodied carbon: 1.71). Besides general steel and rebars, the most critical type of steel would be stainless steel because of its highest embodied carbon of 6.15 kgCO2/kg among all other type of steels. The use of stainless steel in both of these two type of constructions differ in which sustainable buildings only comprises of 0.5% total carbon emission whereas its usage in conventional building construction exceeds 1% of carbon emission. The choosing of materials is absolutely crucial as it is one of the most significant factors of carbon emission in terms of type of building material usage.

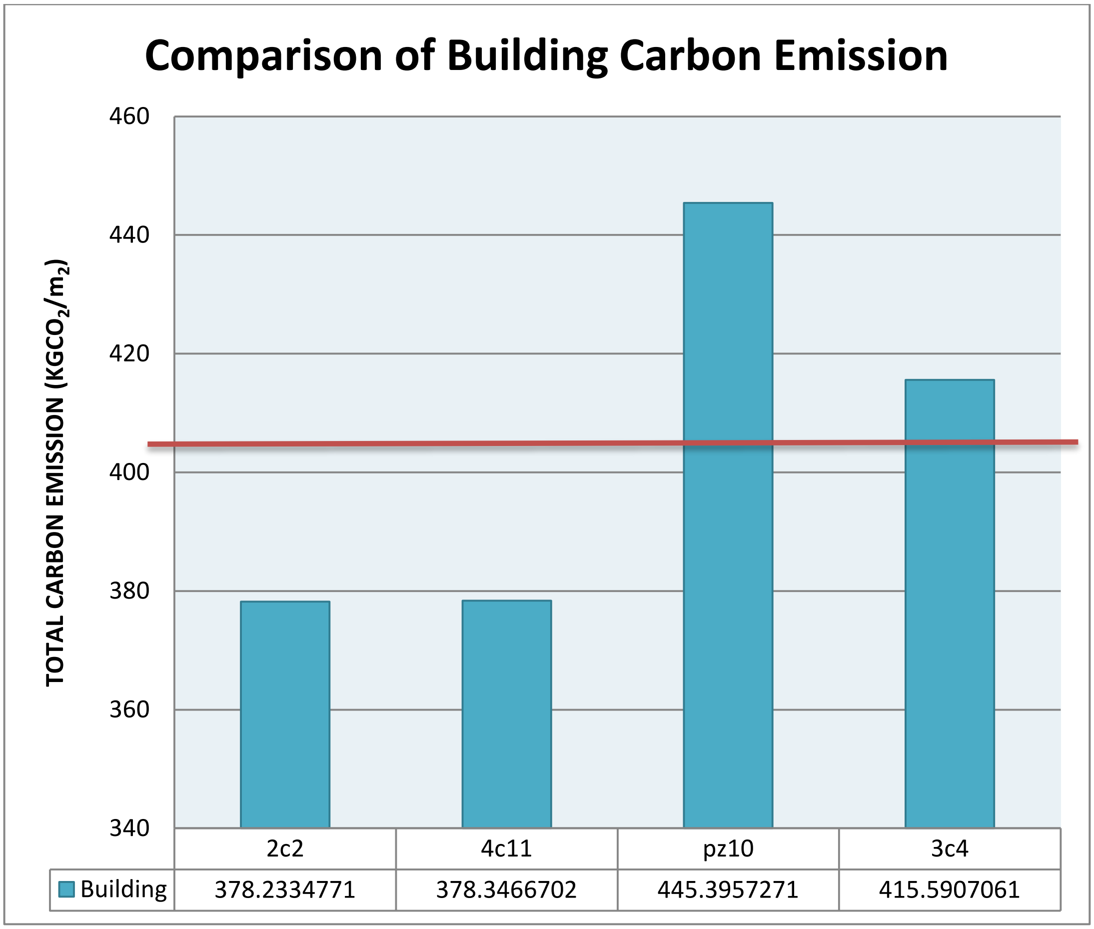


Figure 11 : Total carbon emission per m^2 of building area.

Figure 11 above shows the comparison of carbon emission between two sustainable buildings and two conventional buildings. The carbon emission values obtained for these green buildings through this study is similar which is approximately 378 KgCO2/m2 whereas the values of carbon emission obtained for conventional buildings ranges from 400-450KgCO2/m2.

From the analysis done, technically sustainable buildings emit less carbon footprint than conventional buildings do. This is due to the efficiency in using building materials in construction activities for these green building projects.

In terms of reduction percentage by comparing both sustainable and conventional buildings, the percentage can be calculated as;

- Sustainable building (Lot 2C2 & Lot 4C11) average carbon footprint ($kgCO_2/m^2$)

$$\frac{378.23 + 378.34}{2} = \mathbf{378.285}$$

- Conventional building (Plot Z10 & Lot 3C4) average carbon footprint ($kgCO_2/m^2$)

$$\frac{445.396 + 415.59}{2} = \mathbf{430.493}$$

- Reduction percentage;

$$\frac{430.493 - 378.285}{430.493} \times 100\% = \mathbf{12.13}\%$$

From the calculation shown above, it is found from the study that generally sustainable buildings has a lower carbon footprint than conventional buildings by 12.13%.

From this case study, the main structural materials used for both of these buildings are basically the same. However, for sustainable buildings, the usage of structural material for overall building area is much lower than the conventional buildings as shown in Figure 10 above, in which it affects the values obtained for carbon emission per square meter for every single building.

It can be deduced that the average value of carbon emission of all four buildings conducted for this study is about $404KgCO_2/m_2$ which is represented by the red line as shown in Figure 11. 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 red line which is the average values of the four buildings evaluated in this particular study. Any values obtained above the red line is considered as not being able to adapt the good practice as to conserve the atmospheric carbon level in the environment from further global warming.

The building carbon footprint calculation is done through a simple software developed using Microsoft Excel. The carbon calculator is used mainly to assist stakeholders in calculating the carbon emission of building material during its 'cradle to gate' life cycle (when the material is first extracted from its natural resource until it is used at the construction site).

Various types of main material and sub-materials are included in the calculator database, thus will make the calculation more accurate and precise for calculating the particular building's carbon emission.

The next figure (Figure 12) shows the interfaces and the calculation of the total amount of carbon dioxide per square meter emitted from a sustainable building (4C11, Putrajaya) using the carbon calculator. The calculator also provides a graphical chart to assist the user in determining the quantifying of building materials.

Materials	#	Type	Quantity (m3)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
Concrete (m3)	1	General	39106.2	2400	93854880	0.13	12201134.4
	2	1:1:2	290	2410	698900	0.209	146070.1
	3	1:1:5:3	186	2400	446400	0.159	70977.6
	4	1:3:6	153	2400	367200	0.08	29376
	5	Nil	0	0	0	0	0
						TOTAL	12447558.1
Steel (kg)		Type	Quantity (kg)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
	1	General	7310083	8000	7310083	1.77	12938846.91
	2	Bar & Rod	2365	7900	2365	1.71	4044.15
	3	Nil	0	0	0	0	0
	4	Nil	0	0	0	0	0
						TOTAL	12942891.06
Timber (m2)		Type	Quantity (m2)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
Thickness (m)							
0.03	1	General	164633	480	2370715.2	0.46	1090528.992
0.03	2	Sawn Hardwood	1324	880	34953.6	0.47	16428.192
0.02	3	Sawn Softwoord	1755	630	22113	0.45	9950.85
0	4	Nil	0	0	0	0	0
0	5	Nil General Hardboard MDF Plywood Sawn Hardwood Sawn Softwoord	0	0	0	0	0
0	6		0	0	0	0	0
						TOTAL	1116908.034
Masonry (m3)			antity (m3)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
	1	Asphalt	0	700	0	0.45	0
	2	Bricks	3521	2400	8450400	0.22	1859088
						TOTAL	1859088
Glass (m2)		Type	Quantity (m2)	Density kg/m3	Weight of material	Embodied Carbon	Carbon Emission (kg)
Thickness (m)							
0.03	1	General Glass	5306	2450	389991	0.85	331492.35
0.03	2	Toughened Glass	3472	2600	270816	1.27	343936.32
0	3	Nil	0	0	0	0	0
						TOTAL	675428.67

Name of Building	Lot 4C11
Gross Floor Area (m2)	77600
Total Carbon Emission (kg)	29041873.86
Carbon footprint kg/m2	374.2509519

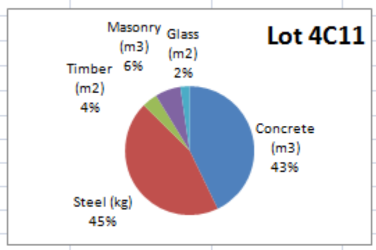


Figure 12 Carbon Calculator

5.0 Conclusion & Recommendation

5.1 Conclusion

At the end of this study, the values obtained for carbon footprint for sustainable buildings and conventional buildings are obtained. On average, for sustainable building, the value obtained is 347kg CO_2 per square meter. The value obtained is less compared to that of conventional building by 430kg CO_2 per square meter which accounts about 12.13% reduction in comparison.

These values differ because the construction of sustainable buildings uses materials more efficiently than conventional buildings do. Therefore for a particular amount of building materials, sustainable building would get a larger area of building compared to construction of a conventional building. It is known that the amount of materials used is one of the factors that cause the carbon emission to be lower in sustainable buildings. Other than that, the type of materials used also contributes to the variation of carbon footprint emissions of building during construction.

On the other hand, the establishment of the carbon footprint calculator is expected to assist calculation of carbon footprint for building materials in construction especially for Malaysian construction industry. Further action and modification shall be made in order to improve the database in order to obtain a better, more precise and accurate result.

It can be concluded that steel gives out the most carbon emission as it has the highest embodied carbon among all other main building materials. The types of building evaluated (sustainable & conventional) also proves that the value of carbon emission varies differently between these two types of buildings. It is proven that sustainable buildings produce less carbon footprint than conventional buildings do and this is essential to prevent further pollution to the environment.

5.1 Recommendation

In order to construct an environmental friendly building which emits less carbon footprint, it is possible to reduce amount of steel and also concrete used to construct the building. This can actually be achieved by using light weight materials such as light weight concrete so that the loading carried by the structural elements such as main beams and columns can be reduced significantly. With a much lighter load, less structural support or reinforcement bars is needed, therefore forms an effective method for buildings to have less carbon emission given off from steel and concrete used during construction.

Choosing the "green" or environmental-friendly materials definitely helps in reducing the carbon footprint of the building. This can be practiced by choosing sustainable building materials such as 'green cement' in which is a combination of cement kiln dust (CKD) and class F Fly Ash instead of the ordinary cement used nowadays.

The selection of building material is one of the most crucial steps in constructing a building which could be rated as a sustainable building or in other words emits less carbon footprint than conventional buildings do. By choosing the right environmental friendly materials, this would absolutely help in minimizing the depletion of natural resources including raw materials such as water, gravel and sand as well as energy (electricity) and water used annually in the manufacturing & construction process.

References

[1] Edinburgh Centre for Carbon Management Ltd. (2006, August). *Edinburgh Centre for Carbon Management.* Retrieved June 21, 2012, from http://www.eccm.uk.com

[2] Wright, K. W. (n.d.). Carbon Footprint. *Carbon Management* .

[3] Nation Master. (2003-2012). *Environment Statistics*. Retrieved June 23, 2012, from CO2 Emissions by country: http://www.nationmaster.com/graph/env_co2_emi-environment-co2-emissions/

[4] Yan H., Shen Q.,Fan L C.H., Wang Y., Zhang L. (2009) Greenhouse Gas Emissions in Building Construction: A Case Study of One Peking in Hong Kong. *Building and Environment.* Elsevier Ltd.

[5] Horvath, A. (2004). Construction materials and the environment. Annual Review of Environment and Resources. *Intergovernmental Panel on Climate Change* , 181-204.

[6] Hassan A.H. (2010). *Quantification of Carbon Footprint in the Malaysian Construction Industry*. (pg 5)

[7] CleanMetrics Corp. (2011). *Building Carbon Footprints*. Retrieved June 23, 2012, from Clean Metrics: http://www.cleanmetrics.com/html/building_carbon_footprints.htm

[8] J, K. (2008). *Meteorology& Climatology*. Retrieved June 24, 2012, from The Importance of Greenhouse Gases: http://suite101.com/article/the-importance-of-greenhouse-gases-a43596

[9] US Environmental Protection Agency (2011). *Climate Change.* Retrieved from http://www.epa.gov/climatechange/basicinfo.html

[10] Yan H., Shen Q.,Fan L C.H., Wang Y., Zhang L. (2009) Greenhouse Gas Emissions in Building Construction: A Case Study of One Peking in Hong Kong. *Building and Environment.* Elsevier Ltd.

[11] Abdul Karim J. (2010,July 31).Building Green for a Better Tomorrow. *The Star Online.* Retrieved from

http://thestar.com.my/columnists/story.asp?file=/2010/7/31/columnists/atyourservice/6667733&sec=At%20Your%20Service

[12] Ministry of Energy, Communication and Multimedia Malaysia. *MECM Low Energy Office Building Putrajaya Malaysia*. Retrieved from http://www.iisbe.org/iisbe/gbpn/non_members_info/malaysia/Malaysia_new_low_e_Ministry_Energy.pdf

[13] Hassan A.H. (2010). *Quantification of Carbon Footprint in the Malaysian Construction Industry*. (pg 5)

[14] Green Ration Book. (2010). *Green Ration Book*. Retrieved Jun 27, 2012, from The Cost of Everyday Living: http://www.greenrationbook.org.uk/category/building/

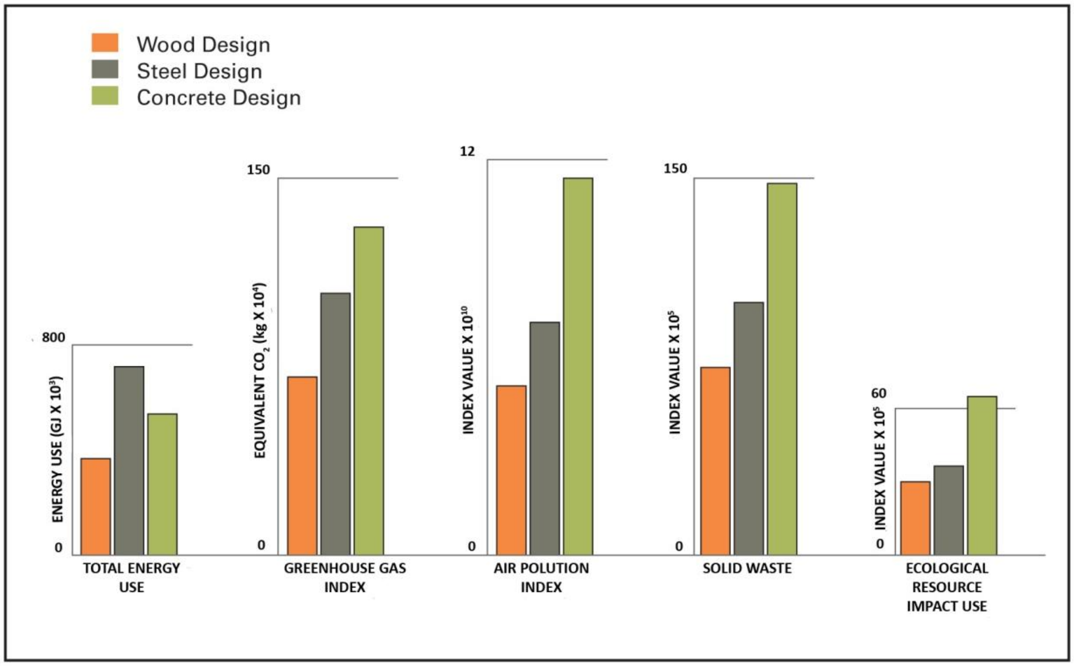
[15] Glover, J n.d, 'Which is Better? Steel, Concrete or Wood', Retrieved: September 14, 2005, from http://www.boralgreen.shares.green.net.au/research3/contents.htm

[16] Twinn, C. (2003). Beddington Zero Energy Development (BedZED). *The Arup Journal*, 16.

[17] Hammond G.P., Jones C.I., (2008) *Embodied Energy and Carbon in Construction Material*. Energy 161 Issue EN2

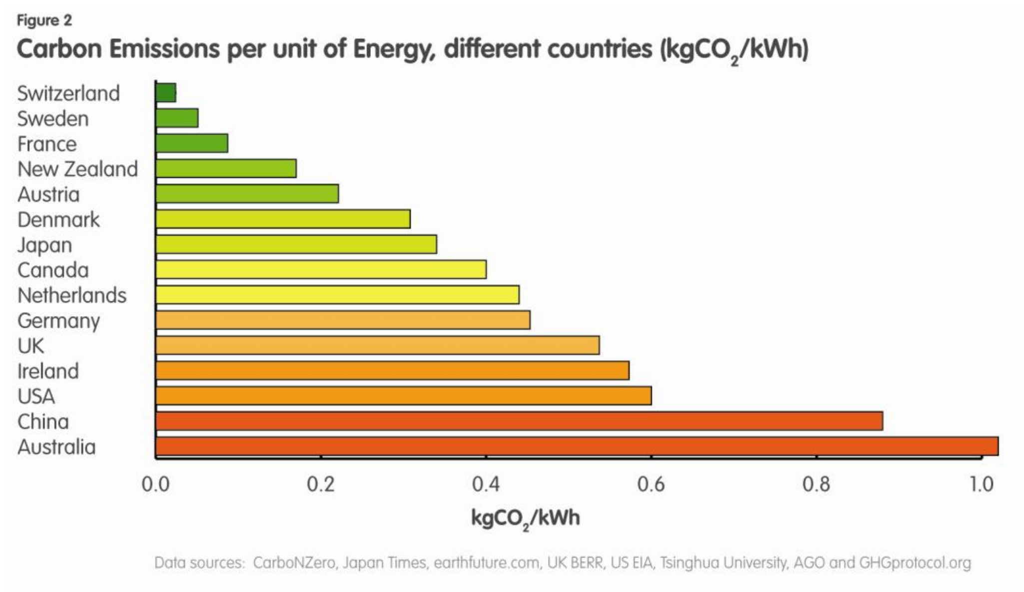
APPENDICES

Appendix 1



Various type of energy usage according to the type of materials used.

Appendix 2



Carbon Emission per unit of Energy for different countries in kgCO2/kWh

Appendix 3: Project Gantt Chart

No	Details/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project														
2	Calculation of construction materials from bill of quantity														
3	Submission of progress report								**X**						
4	Project Work continues														
5	Pre SEDEX											**X**			
6	Draft report													**X**	
7	Oral Presentation														**X**