LIFE CYCLE ASSESSMENT OF ENERGY AND CO_2 EMISSIONS FROM CAST IN-SITU AND INDUSTRIALISED BUILDING SYSTEMS

THONG JIA WEN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Urban and Regional Planning)

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

AUGUST 2019

DEDICATION

This thesis is dedicated to my parents, who taught me that the best kind of knowledge to have is that which is learned for its own sake and the largest task can be accomplished if it is done one step at a time. It is also dedicated to my husband, who gave me support and strength to complete my thesis and not forget to my adorable children, who cheer me up in a very special way.

ACKNOWLEDGEMENT

There are a number of people without whom this thesis might not have been written, and to whom I am greatly indebted.

To my family especially my dearest husband, Chiak Seng who always playing a supportive role for me to finish my thesis and also a very heartfelt appreciation to you for your practical and emotional support as I added the roles of wife and then mother, to the competing demands of work, study and personal development.

To my parents who continue guiding me to learn, grow and develop and who has been a source of encouragement and inspiration to me throughout my life. Both of you have actively supported me in my determination to find and realize my potential, and to make this contribution to our world.

To both of my lovely children, Nikki and Jayden, who always cheers me up when I was emotional in my study, work and life, and giving me encouragement in a very special way.

My sincerest gratitude to my supervisor Prof Dr. Ho Chin Siong and Prof Dr. Zainura Binti Zainon Noor for their continuous guidance and support from the beginning till the completion of the present research. Without their guidance and patience, I may not be able to overcome all the obstacles that I encountered during my journey of study.

ABSTRACT

The conventional cast in-situ (CIS) building construction method is predicted to produce and generate large quantities of waste and carbon emission to the environment. On the contrary, Industrialised Building System (IBS) has shown great potential as a green construction method and in promoting environmental building sustainability. This study evaluated and compared the environmental performance (energy and CO_2 emissions) of residential buildings in Iskandar Malaysia constructed using the CIS and IBS methods via a life cycle assessment (LCA). In addition, the trends in energy consumption and CO_2 emissions during the buildings' operational phase were also identified as this phase had the largest proportion of energy demand and CO_2 emissions. This study also analysed the patterns and hotspots of energy use and CO_2 emissions throughout the building life cycle for both case studies. In the first phase of this study, a functional unit of 1 m^2 of built-up area was identified throughout the building life cycle. The system boundaries were then set from an identified input-output framework from the cradle-to-gate LCA of residential buildings covering the assembly phase, the use phase, and the disassembly phase. The input-output framework of the LCA building processes was identified as an input flowchart for further analysis in GaBi software. The results indicated that IBS residential buildings have a more positive environmental impact than the CIS residential buildings. The CIS building and the IBS building had an 85.17 percent difference in energy consumption and an 87.17 percent difference in CO_2 emissions throughout a building life cycle of over 50 years. The identified hotspots during the material stage provided a better understanding of the contribution of energy and CO_2 emissions, especially by precast concrete, reinforced steel, and concrete. Apart from building performance affecting the building energy and CO_2 emissions during the operational stage, household characteristics, electrical appliances, and resident behaviour are also contributing factors that cannot be neglected. The dramatic reduction in environmental impact during the operational phase of the IBS building is not only interrelated with the application of the building materials used (precast concrete), but also the integration of the LCA methodology into the design phase, such as the orientation of the building facing North-South, further supporting the development of sustainable buildings. This analysis also provides concrete results supporting the adoption of IBS building construction to achieve low-energy and low-carbon residential buildings in Iskandar Malaysia.

ABSTRAK

Kaedah pembinaan konvensional tuangan di-situ (CIS) dijangka menghasilkan sejumlah besar sisa dan pelepasan karbon ke alam sekitar. Sebaliknya, Sistem Bangunan Berindustri (IBS) telah menunjukkan potensi yang baik sebagai kaedah pembinaan hijau dan mempromosikan kemapanan alam sekitar. Dengan itu, kajian ini bertujuan untuk menilai dan membandingkan prestasi alam sekitar (pelepasan tenaga dan CO_2) bangunan kediaman di Iskandar Malaysia yang dibina menggunakan kaedah CIS dan IBS melalui penilaian kitaran hayat (LCA). Di samping itu, penggunaan tenaga dan pelepasan CO_2 semasa fasa operasi bangunan juga dikenal pasti kerana fasa ini mempunyai perkadaran terbesar pelepasan tenaga dan CO_2. Kajian ini juga menganalisis corak dan punca penggunaan tenaga serta pelepasan CO_2 sepanjang kitaran hayat bangunan bagi kedua-dua kajian kes. Dalam langkah pertama kajian ini, unit fungsian sebanyak $1m^2$ kawasan binaan telah dikenal pasti sepanjang kitaran hayat bangunan. Batasan sistem telah ditetapkan daripada satu rangka kerja input-output yang dikenal pasti dari mula ke akhir LCA bangunan kediaman yang meliputi fasa pemasangan, fasa penggunaan, dan fasa pemusnahan. Rangka kerja input-output proses bangunan LCA yang telah dikenal pasti dalam carta aliran input digunakan bagi tujuan analisis dalam perisian GaBi. Hasil kajian menunjukkan bahawa bangunan kediaman IBS mempunyai kesan alam sekitar yang lebih positif daripada bangunan kediaman CIS. Bangunan CIS dan bangunan IBS mempunyai perbezaan sebanyak 85.17 peratus dalam penggunaan tenaga dan perbezaan 87.18 paratus dalam pelepasan CO_2 sepanjang kitaran hayat bangunan lebih daripada 50 tahun. Titik panas yang dikenal pasti semasa peringkat bahan memberi pemahaman yang lebih baik tentang sumbangan tenaga dan pelepasan CO_2, terutamanya konkrit pratuang, keluli bertetulang dan konkrit. Selain daripada prestasi bangunan yang memberi kesan kepada tenaga binaan dan pelepasan CO_2 semasa peringkat operasi, ciri-ciri isi rumah, peralatan elektrik dan kelakuan penduduk juga merupakan faktor yang tidak boleh diabaikan. Pengurangan dramatik alam sekitar semasa fasa operasi bangunan IBS tidak hanya berkaitan dengan penggunaan bahan binaan, tetapi juga integrasi metodologi LCA ke dalam fasa reka bentuk, seperti orientasi pembinaan rumah yang menghadap Utara-Selatan, terus menyokong pembangunan bangunan lestari. Analisis ini juga menunjukkan hasil yang konkrit yang menyokong penggunaan pembinaan bangunan IBS bagi mencapai kediaman lestari di Iskandar Malaysia.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADP	-	Abiotic Depletion
AP	-	Acidification potential
BQ	-	Bill of quantities
CIS	-	Cast In-Situ
CIDB	-	Construction Industry Development Board
EIA	-	Environmental Impact Assessment
EP	-	Eutrophication Potential
EMP	-	Environmental Management Plan
FU	-	Functional Unit
GHG	-	Greenhouse gas
GWP	-	Global Warming Potential
IBS	-	Industrialised Building System
IM	-	Iskandar Malaysia
ISO	-	International Organization for Standardization
IOA	-	Input-Output Analysis
LCA	-	Life Cycle Assessment
LCI	-	Life Cycle Inventory
LCIA	-	Life cycle impact assessment
LPG	-	Landfill gas
MP	-	Malaysia Plan
MSW	-	Municipal solid waste
NGTP	-	National Green Technology Policy
O&M	-	Operations and Maintenance
ODP	-	Ozone Layer Depletion Potential
POPCP	-	Photochemical Ozone Creation Potential
PRISMA	-	Perumahan Rakyat Iskandar Malaysia
SB	-	System Boundary

LIST OF SYMBOLS

M	-	Material quantity per m^2
V	-	Material volume (m^3)
ρ	-	material density (kg/m^3)
M_A	-	Total built-up area (m^2)
E_d	-	Diesel energy density 43MJ/kg
t	-	operating 40hrs/ha
l_{ex}	-	diesel consumption 35l/h
ρ_d	-	density of diesel 0.832kg/l
V_{ex}	-	volume of excavation (ha)
T	-	time used for operation
C_f	-	carbon emission factor 0.074kgCO_2-e/MJ
E	-	Embodied Energy of diesel 0.0009 MJ diesel/kg.km
l_{tr}	-	diesel consumption 5 l/hr
d	-	distance
lp	-	diesel consumption 7.99l/h
lc	-	diesel consumption 13.5 l/h
Et	-	Transportation Energy (MJ)
Ei	-	Energy Intensity (MJ/m^3km)
CO_2	-	Carbon Emission ($kgCO_{2-e}$)
C_{ft}	-	Energy Intensity ($kgCO_{2-e}/m^3km$)
μ	-	Mean
σ	-	Standard Deviation
β	-	*Coefficient*
r		*correlation coefficient*

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Iskandar Malaysia is located at the southern gateway of Peninsular Malaysia. It is one of the largest economic developments in Asia, which has a total of five flagship zones proposed as the key points for those developments. There is also a major urban center for each flagship. Furthermore, the development rate of Iskandar Malaysia has been projected to increase the country's population by 2.2 times, which is from 1,353,202 in 2005 to 3,005,815 in 2025. Besides, it has also been presumed that the average number of occupants of household will increase by 2.4 times to 751,454 in 2025. There will also be an increase in energy consumption in 2025, which is to 1,091 in terms of energy demand and 7,715 $ktCO_2$ in terms of greenhouse gas (GHG) emissions. These amounts are 4.5 times and 5.3 times higher than the amounts of energy demand and greenhouse gas emissions (GHG) back in 2005 respectively (Universiti Teknologi Malaysia *et al.*, 2009).

The rapid increase of population in Iskandar Malaysia has also led to the construction of more high-rise buildings in urban cities, especially Johor Bahru. These will definitely lead to increase of environmental impacts to the environment. The sector of the buildings, which accounted for a large part of the emissions, played an important role in achieving a reduction of CO_2 emissions by 45% or higher. This emission rate was in reference to Malaysia Nationally Determined Contribution, where Malaysia intended to operate 45% reduction of GHG emissions intensity of

GDP by 2030. This amount was in relation to the emission intensity of GDP in 2005 (The Government of Malaysia, 2015). In many ways, the construction sector can influence the quantity of emissions produced from a building throughout its whole lifetime. The World Green Building Council estimates that, globally, up to 30% of worldwide GHG emissions, including carbon, are generated by the built environment (Wang Cai *et al.*, 2017).

There are several significant impacts of the methods used for building construction on energy demand, GHG emissions, and the environment. The application of Industrialised Building System (IBS) in the construction of low and high rise building contributes to several positive effects on the life cycle of buildings. For example, during the production phase, this construction reduces the need for transport of materials. As a result, it prevents unnecessary CO_2 emissions. Meanwhile, during the construction phase, precast concrete limits the amount of CO_2 emissions resulted from heating and cooling processes due to its excellent thermal properties. During the demolition phase, the complete recycling of precast concrete waste results in the minimum rate of CO_2 emissions.

Given that the area focused for this study was located at Iskandar Malaysia, a comparison case study of LCA, which was conducted between residential apartments constructed with IBS and Cast In-Situ (CIS), was to be performed for investigation on the impacts of energy use and CO_2 emission on the environment. The purpose of this was for the stakeholders, such as developers, contractors, government agencies and suppliers, to realize the importance of IBS for a more sustainable environment. However, reducing CO_2 and other greenhouse gases emissions could be considered as challenge for everyone involved in this study.

1.2 Background of Study

The Malaysian Government has committed to reduce the environmental impacts and towards a low carbon country by introducing policies and key practices related to environmental concerns from 6^{th} Malaysia Plan (MP) to 11^{th} Malaysia Plan (MP) which ultimately aims to achieve sustainable development. Referring to Figure 1.0, Malaysian Government has set to use IBS as a cleaner technology towards a greener environment from 9^{th} MP (Mohamad Bohari *et al.*, 2015). The most recent 11^{th} MP, Malaysia Government's committed towards sustainable consumption and production by constructing energy efficient and low carbon buildings in order to reduce the GHG emissions (EPU, 2015).

Policies and key practices related to environmental concerns in Malaysia Plan (MP)

6MP (1991-1995)	7MP (1996-2000)	8MP (2001-2005)	9MP (2006-2010)	10MP (2011-2015)	11MP (2016-2020)
✓ Mandatory legislative requirements for environment protection (EIA, EMP)	✓EMS consistent with ISO 14001	✓Introduction MS 1525:2001 ✓National Strategic Plan for Solid Waste Management ✓ISO 14001:2004 and EMS	✓ Introduction NGTP 2009 (green townships, eco-labelling, green procurement & life cycle costing) ✓ Revised MS 1525:2007 ✓ IBS as a cleaner technology ✓ Introduction of GBI	✓ Introduction ISO 50001:2011 ✓ Introduction of energy and the use of renewable energy for non-residential buildings	✓ Sustainable consumption & production (energy efficient & low carbon building, transport, products & services) ✓ Reduction in GHGs emission intensity of GDP compared to 40% 2005 level by year 2020

Source: Mohamad Bohari *et al.*(2015) & EPU (2015)

Figure 1.1: Policies and key practices related to environmental concerns in Malaysia Plan (MP)

In order to achieve the aims of low carbon building in Malaysia, the efficiency improvements of building should be implemented. According to Asif, Muneer, and Kelley (2007), 30%-40% of primary energy worldwide is used for residential, office, and commercial buildings, which, in turn, produce 40%–50% of greenhouse gas emissions. Based on a life cycle energy analysis of buildings from 13 countries found in the literature, the life-cycle energy use of a building depends on the operational (80%–90%) and embodied (10%–20%) energies of the building (Ramesh et al., 2010). Hence, it is vital to take into consideration these energy consumptions in the building construction process to achieve sustainable development throughout the building life cycle. A life cycle assessment (LCA) is a method broadly used to better understand and focus on the causes and impacts of building construction on the environment in terms of mining, extracting, processing, manufacturing, and transporting materials, as well as for determining the energy required for construction, maintenance, and decommissioning.

LCA could be applied to buildings constructed via the IBS and the CIS method to provide a detailed analysis and interpretation of the overall life cycle of a building from its pre-use, upon use, and end of life cycle. Meanwhile, cast-in-situ is the traditional building construction method. IBS is one of the technologies that have been introduced to reduce the amount of energy emitted to the atmosphere during construction. However, Huberman and Pearlmutter (2008) noted the dramatic increase in the intensity of energy consumption in the pre-use phase (embodiment of energy, EE), the use phase (operational energy, OE), and the end of life phase (demolition or possible recycling and reuse) with industrialisation. Therefore, this study was conducted to compare the CIS method and IBS method during the pre-use stage to the end of life in order to determine the energy consumed for the different methods of building construction and the environmental impacts of each.

Iskandar Malaysia was chosen as a research location because it has plans to achieve a low carbon society. It is also working in line with government policy to promote an Industrialised Building System (IBS) to achieve sustainable development (Universiti Teknologi Malaysia *et al.*, 2009). One of the completed projects constructed by Iskandar Malaysia was Perumahan Rakyat Iskandar Malaysia (PRISMA), residential buildings that have achieved a 97% IBS score, making them low energy and GHG buildings that well suit the comparison purposes of this study. Hence, it is sufficient that only two case studies that is the IBS and conventional cast-in-situ (CIS) construction techniques to be adopted and compared as part of the LCA of residential buildings.

Besides that, it is also important for Iskandar Malaysia to aspire towards becoming a low-carbon society due to its rapid industrialisation process and huge investments in manufacturing and infrastructure development. These are the factors driving the high demand for energy consumption further highlighting the needs for methods to minimise energy consumption and CO_2 emissions. The community, industry, institutions, and government need to put in significant efforts to change their current behaviour towards energy consumption and supply. The benefits of implementing IBS in building construction include reduced amounts of construction work on sites, reduced material wastage in on-site construction, and reduced construction waste at landfill sites; ultimately contributing to the indirect reduction in energy consumption and GHG emissions.

1.3 Problem Statement

The conventional building construction method is predicted to produce and generate large quantities of waste and carbon emissions to the environment. On the contrary, IBS has shown great potential as a green construction method and in promoting environmental building sustainability from its building assembly phase, its building use phase, to its disassembly phase. Based on the findings from Mao et al. (2013) and Pon and Wadel (2011), prefabricated buildings produced approximately 2%–5% lower GHG emissions compared to conventional cast-in-situ buildings. Cao *et al.*, (2015) have conducted research on a comparative study of environmental performance between prefabricated and traditional residential buildings in China which the results showed that prefabricated residential buildings were more energy efficient with 20.49% reduction compared to the conventional type of residential buildings in China. Many studies have focused on the Life Cycle Assessment (LCA) of residential buildings, albeit on selected phases such as embodied energy and greenhouse gas (GHG) emissions from the assembly phase (Nässén *et al.*, 2007a; Pons and Wadel, 2011a; Chang *et al.*, 2012; Mao *et al.*, 2013), whereby some researchers focused on the building use phase (Buyle *et al.*, 2013a; Chastas *et al.*, 2016; Xu *et al.*, 2017), while others compared the modular type of residential building to the conventional type but with wood as the primary structure (Kamali and Hewage, 2016). The scenario in Malaysia, however, is different. The literature reveals that there are still very limited case studies of LCA residential buildings and knowledge about the environmental life cycle performance of modular buildings compared with the residential buildings that are cast in-situ, which is a very common construction type and technique used in Malaysia.

Besides the lack of real-world case studies of LCA residential buildings and limited local research, or the few developers or other government agencies in Malaysia involved from an effectiveness aspect, the waste management and enforcement to reduce carbon footprint in Malaysia's construction industry is still underdeveloped in comparison to the construction industries other developed countries. The primary reasons for this scenario are the challenges associated with applying sustainability initiatives in the commercial development of buildings, especially industry barriers such as technical information and knowledge, capital costs, configuring current operations from CIS to IBS, competitive pressures, industry regulations, and government policy (Mohammad, 2013).

The worldwide issue of global warming and climate change also play a role, especially the impacts and effects caused by construction on the environment. In fact, energy and environmental issues are interrelated with rapid building construction and its methods. For example, the extraction of natural resources results in the consumption of energy by construction materials, environmental degradation, and global warming. Furthermore, the construction industry is a major consumer of non-renewable resources; not only that, but it is also a massive producer of waste and the operations of buildings under this industry account for around half of the overall CO_2 emissions in the world. To illustrate further, construction activities involve the extraction of natural resources such as turning forests into timber, as well as housing and industrial works, where extractions done without proper control could lead to environmental problems (Kamar & Hamid, 2011). Hence, IBS is strongly recommended for building construction in order to reduce the negative environmental impacts that it causes. However, the CIS approach is still used for the construction of most high-rise buildings in Iskandar Malaysia, as private developers prefer the lower labour cost incurred by this construction approach. According to a survey by the Construction Industry Development Board (CIDB), the private sector's adoption of IBS is still low, at around 15%, although the government of Malaysia has enforced a score for contractor-proposed IBS designs of not lower than 70%, as highlighted in the Manual of IBS Content Scoring System published by the Construction Industry Development Board (CIDB, 2010).

Blengini (2009), in his a case study of Turin, Italy, mentioned that the use phase of a conventional building contributed to 90.1% to 95.2% impact on the environment. Meanwhile, the pre-use phase, building materials, and construction operations had 6.2% to 11.5% environmental impact and between 0.2% and 2.6% impact in the end-of-life phase. In this case, the benefits of utilising IBS to reduce environmental impacts must be studied further since IBS could promise sustainability, as it controls the production environment and results in the minimum waste release. This process contributes to minimum energy losses caused by thermal leakages, as well as aids in the reduction of carbon emissions throughout the life cycle of buildings. Other than that, there are many other factors that affect each stage of the building life cycle such as some uncertainties inherent in the building use phase e.g., the occupant behaviour, the building shape, and the building orientation, all of which contribute to uncertainties in electricity usage. Aun (2009) stated that the size, shape, and orientation of a building affect the air conditioning or heating energy requirements. The heating of a building i.e. the heating effect on walls and solar radiation is influenced by two climate factors. The heating effect is also influenced by the facade facing direction, ventilation, and direction of wind associated with the orientation of the building. However, the effectiveness of the IBS performance and the consideration of building façade orientation in reducing energy emissions during each phase of a building's life cycle have yet to be determined.

In order to gain an in-depth understanding of IBS construction methods compared to the conventional method, it is vital to evaluate the sustainability performance of the IBS construction technique throughout the entire life cycle phases of residential buildings. Therefore, assessments of building performance should be extended to include all life cycle stages and should be supported with a Life Cycle Assessment (LCA) methodology that allows the identification of each life cycle hotspot and to assist in the decision-making processes to reduce life cycle environmental impacts.

1.4 Research Questions

Based on the problem statement and background of this study, the following research questions were formulated in order to answer the stated research objectives:-

1. What is the life cycle impact assessment on the life cycle of residential buildings, when the Industrialised Building System (precast concrete system) approach and the cast in-situ building system in Iskandar Malaysia are put in comparison?
2. What is the energy used for construction and carbon emission throughout the life cycle of residential buildings when the Industrialised Building System (precast concrete system) approach and cast in-situ building system in Iskandar Malaysia are put in comparison?

3. What are the primary factors influencing the energy used for construction, carbon emission, and impacts of building construction based on the analysis?
4. How to reduce the impacts posed by the energy used for construction, carbon emission, and the environmental impacts of building construction highlighted in the case studies?

1.5 Objective of Study

The research aims to investigate the environmental impacts of the construction of residential building on IBS and the CIS building system in the aspect of life cycle. The following objectives were formulated in order to achieve the objectives of this study;

1. To evaluate and compare the environmental performance of Industrialised Building System (IBS) and the environmental performance of cast in-situ (CIS) building system in Iskandar Malaysia using Life Cycle Assessment Approach
2. To examine the pattern and hotspot of the energy used for construction and CO_2 emission through comparison between Industrialised Building System (IBS) and cast in-situ (CIS) building system in Iskandar Malaysia using GaBi software
3. To classify the trends on energy consumption during operational phase through comparison between Industrialised Building System (IBS) and cast in-situ (CIS) building system in Iskandar Malaysia using LCA approach

1.6 Scope of Study

The focus of the study is to perform the life cycle assessment of low-rise residential buildings located in Iskandar Malaysia, which was done through comparison between case studies based on the criteria of IBS and CIS building. After identifying the environmental impacts of building construction in the case studies, it would be possible to predict how these impacts would take place in the future, especially the impacts of energy demand and GHG emission in Iskandar Malaysia. This study also aims to achieve 45% of CO_2 intensity reduction rate. According to Knoema (2016), CO_2 emissions for Malaysia growing at an average annual rate of 5.10%

It is also crucial to identify and understand the benefits of implementing the IBS approach for construction in terms of building's life cycle. This approach will be a guideline for stakeholders to develop and implement the IBS approach for their building construction plan. Besides, this approach is suitable for the local planning policy through its improvement to have guard future to justify IBS is better than CIS method.

1.7 Significance of Study

This dissertation can be a supportive improvement for this study's findings and design changes, along with development of new rules and regulations to the stakeholders in Malaysia, especially local authorities and developers for a sustainable and low carbon society. With the results obtained from the case studies, building contractors and Malaysia's government would be able to revise strategies for reduction of energy demand and carbon emission. These reductions can be done by enforcing the implementation of IBS in the construction industry. Based on this study's data analysis, optimization of more environmental-friendly materials and products for building construction, for example solar panels for renewable energy, is necessary.

Other than that, the comparison between case studies (i.e. IBS and CIS) can reveal the patterns of energy consumption and CO_2 emission throughout the life cycle of Iskandar Malaysia in detail. As this study is considered to have made to analyse the patterns for the residential buildings in Iskandar Malaysia, significant insights in the subject particularly the positive impact of IBS construction would be provided.

1.8 Chapter Outline

The structure of this thesis overview, along with contents of individual chapters, is briefly organized. A summary of each chapter is briefly described as follows:

Chapter 1: Introduction

This chapter consists of an introductory review of the problems related to construction methods, background of the problems regarding the energy used for building construction, carbon emissions, and environmental impacts on Iskandar Malaysia. Apart from that, it introduces the scope, objectives, and limitations of research along with research methodologies which were implemented in order to fulfill the research objectives.

Chapter 2: Literature Review

This chapter elaborates on the Life Cycle Assessment (LCA) of construction industry , such as the steps and methods implemented for LCA to take place in every phase of building's life cycle, such as incorporation of materials, construction, operation, maintenance, and demolition. Furthermore, an overview of GaBi Software, which is used to evaluate the life cycle impact assessment of buildings, has also been drawn. In addition, the importance and benefits of Industrialised Building System (IBS) as a construction approach have also been brought into attention in this chapter.

Chapter 3: Research Methodology

This chapter mainly focuses on the measures taken in order to achieve the desired research objectives and results. It provides detailed description on the approaches and methods applied in gathering the information and data required, which are obtained from various resources. This chapter then proceeds to illustrate the overall method frameworks and the procedures required to complete the research.

Chapter 4: Life Cycle Inventories Analysis of Building in the Case Studies in Iskandar Malaysia.

This chapter discusses on the case studies which have been carried out on two different types of residential low-rise buildings which were constructed using two different construction methods, namely IBS and CIS. The data is extracted from the Bill of Quantities (BQ) for material phase, whereas operation data is obtained through household questionnaires. On the other hand, the demolition phase of building will be according to literature review and presumptions. Apart from that, construction materials data is tabulated in an excel spreadsheet. The input-output frameworks of the analysis are created for better understanding regarding the process of LCA on buildings. The profile of survey analysis is also elaborated, and factors affecting energy and carbon emissions are discussed in further details.

Chapter 5: Life Cycle Assessment and Hotspots Comparison in the case studies in Iskandar Malaysia

This chapter primarily discusses on the use of GaBi software in order to obtain the life cycle impact assessment (LCIA) of IBS and CIS for the case study on residential low-rise buildings. This study was specifically focused on the evaluation of IBS and CIS environmental performance and environmental impact, which was based on the determined functional unit. The results of LCIA during each building phase were discussed, particularly on the residential low-rise buildings constructed with IBS and CIS in Iskandar Malaysia. Meanwhile, in this chapter, the factors contributing to high energy demand and climate change, particularly GHG emissions during each life cycle of buildings are discussed further in this chapter. The hotspots of each building life cycle, which contribute to high energy and carbon emissions, are also highlighted here. Moreover, explanation regarding multiple regression analysis attempts in discovering the correlation between the factors contributing to high energy and carbon emissions is provided in this chapter. Additionally, Life Cycle Interpretation, which is focused on sensitive analysis, is included in this chapter's discussion. Besides, ± 20 % of the identified hotspot materials in every phase has been examined, in order to compare the results of energy and carbon emissions which were previously obtained using given assumptions, methods, or data.

Chapter 6: Conclusion and Recommendation

Last but not least, this chapter presents the conclusion of this dissertation in overall, particularly on the building life cycle assessment on IBS and CIS low-rise residential buildings. For future improvement, contribution of knowledge, limitations of research and recommendations for future research and development are also highlighted in this chapter.

REFERENCE

Abd Rashid, A. F. and Yusoff, S. (2015) 'A review of life cycle assessment method for building industry', *Renewable and Sustainable Energy Reviews*. Elsevier, 45, pp. 244–248. doi: 10.1016/j.rser.2015.01.043.

Abdullah, A. (2008) 'A Methodological Analysis of Demolition Work in Malaysia', *Academia*, p. 261. Available at: https://www.academia.edu/396194/A_Methodological_Analysis_of_Demolition_Works_In_Malaysia.

Agriculture, M. (2011) *Life Cycle Assessment : Adopting and adapting overseas LCA data and methodologies for building materials in New Zealand Prepared for the Ministry of Agriculture and Forestry*.

Ahmed, S. I., Johari, A., Hashim, H., Mat, R. and Alkali, H. (2013a) 'Landfill gas and its renewable energy potentials in Johor, Malaysia', *International Journal of Emerging Trends in Engineering and Development*, 1(3), pp. 543–558.

Ahmed, S. I., Johari, A., Hashim, H., Mat, R. and Alkali, H. (2013b) 'Landfill gas and its renewable energy potentials in Johor ', 1(3), pp. 80–90.

Aida Sefic Williams. Life Cycle Analysis: A Step by Step Approach, Illinois Sustainable Technology Center Institute of Natural Resource Sustainability University of Illinois at Urbana-Champaign, December 2009.

Al-Marri, W., Al-Habaibeh, A. and Abdo, H. (2017) 'Exploring the Relationship between Energy Cost and People's Consumption Behaviour', *Energy Procedia*. The Author(s), 105(0), pp. 3464–3470. doi: 10.1016/j.egypro.2017.03.793.

Anand, C. K. and Amor, B. (2017) 'Recent developments, future challenges and new research directions in LCA of buildings: A critical review', *Renewable and Sustainable Energy Reviews*. Elsevier, 67, pp. 408–416. doi: 10.1016/j.rser.2016.09.058.

ASCENT, S. 2007 (2007) 'Precast Concrete Achieves Sustainability Goals'.

Asdrubali, F., Baldassarri, C. and Fthenakis, V. (2013) 'Life cycle analysis in the construction sector: Guiding the optimization of conventional Italian buildings', *Energy and Buildings*. Elsevier B.V., 64, pp. 73–89. doi: 10.1016/j.enbuild.2013.04.018.

Asif, M., Muneer, T. and Kelley, R. (2007) 'Life cycle assessment: A case study of a dwelling home in Scotland', *Building and Environment*, 42(3), pp. 1391–1394. doi: 10.1016/j.buildenv.2005.11.023.

Aun, A. C. S. (2009) 'GREEN BUILDING INDEX – MS1525: Applying MS1525:2007 Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings', *GBI CPD Seminar*, pp. 1–22.

Aye, L., Ngo, T., Crawford, R. H., Gammampila, R. and Mendis, P. (2012) 'Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules', *Energy and Buildings*. Elsevier B.V., 47, pp. 159–168. doi: 10.1016/j.enbuild.2011.11.049.

Basbagill, J., Flager, F., Lepech, M. and Fischer, M. (2013) 'Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts', *Building and Environment*. Elsevier Ltd, 60(February), pp. 81–92. doi: 10.1016/j.buildenv.2012.11.009.

Bastos, J., Batterman, S. A. and Freire, F. (2014) 'Life-cycle energy and greenhouse gas analysis of three building types in a residential area in Lisbon', *Energy and Buildings*. Elsevier B.V., 69, pp. 344–353. doi: 10.1016/j.enbuild.2013.11.010.

Baumann, H. and Tillman, A. (2004) *The Hitch Hiker's Guide to LCA. An orientation in life cycle assessment methodology and application.* : External organization

Bayer, C., Gamble, M., Gentry, R. and Joshi, S. (2010) 'AIA Guide to Building Life Cycle Assessment in Practice', *The American Institute of Architects*.

Bengtsson, J. and Howard, N. (2010) 'A Life Cycle Impact Assessment Part 1: Classification and Characterisation', *BPIC -Building Products Innovation Council*.

Biswas, W. (2008) 'Life cycle assessment of building construction wastes in Western Australia', *EarthCare, Perth*, (October). Available at: https://cleanerproduction.curtin.edu.au/local/docs/publications/2008/lcaofbuilding.pdf.

Blengini, G. A. and Di Carlo, T. (2010) 'The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings', *Energy and Buildings*. Elsevier B.V., 42(6), pp. 869–880. doi: 10.1016/j.enbuild.2009.12.009.

Bokalders V. & Block M. (2010) The whole building handbook: how to design healthy, efficient and sustainable buildings. Published by Earthscan in the UK and USA in 2010

Bras, B. and J. Emblemsvåg (1996). Designing For The Life-Cycle: Activity-Based Costing and Uncertainty. Design for X. G.Q. Huang. London, Chapman & Hall.

Bridge, B. A., Adhikari, D. and Fontenla, M. (2016) 'Electricity, income, and quality of life', *Social Science Journal*. Western Social Science Association, 53(1), pp. 33–39. doi: 10.1016/j.soscij.2014.12.009.

Brien, E. O. (2006) 'Life Cycle Analysis Of The Deconstruction Of Military Barracks: A Case Study At Ft. Mcclellan, Anniston, Alabama', University Of Florida.

British Association of Reinforcement (2013), retrieved from:http://www.uk-bar.org/sustainability.htm

Budavari, Z., Szalay, Z., Brown, N., Malmqvist, T., Peuportier, B., Zabalza, I., Krigsvoll, G., Wetzel, C., Cai, X., Staller, H. and Tritthart, W. (2011) 'LoRe-LCA Low Resource consumption buildings and constructions by use of LCA in Design and Decision Making', pp. 1–46.

Buyle, M., Braet, J. and Audenaert, A. (2013) 'Life cycle assessment in the construction sector: A review', *Renewable and Sustainable Energy Reviews*. Elsevier, 26, pp. 379–388. doi: 10.1016/j.rser.2013.05.001.

Cabeza, L. F., Rinc??n, L., Vilari??o, V., P??rez, G. and Castell, A. (2014) 'Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review', *Renewable and Sustainable Energy Reviews*. Elsevier, 29, pp. 394–416. doi: 10.1016/j.rser.2013.08.037.

Cao, X., Li, X., Zhu, Y. and Zhang, Z. (2015) 'A comparative study of environmental performance between prefabricated and traditional residential buildings in China', *Journal of Cleaner Production*. Elsevier Ltd, 109, pp. 131–143. doi: 10.1016/j.jclepro.2015.04.120.

CDM Executive Board (2012) 'Guidelines for sampling and surveys for CDM project activities and programme of activities', pp. 1–68.

Chang, Y., Ries, R. J. and Lei, S. (2012) 'The embodied energy and emissions of a high-rise education building: A quantification using process-based hybrid life cycle inventory model', *Energy and Buildings*. Elsevier B.V., 55, pp. 790–798. doi: 10.1016/j.enbuild.2012.10.019.

Chastas, P., Theodosiou, T. and Bikas, D. (2016) 'Embodied energy in residential buildings-towards the nearly zero energy building: A literature review', *Building and Environment*. Elsevier Ltd, 105, pp. 267–282. doi: 10.1016/j.buildenv.2016.05.040.

Chau, C. K., Leung, T. M. and Ng, W. Y. (2015) 'A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings', *Applied Energy*, 143(1), pp. 395–413. doi: 10.1016/j.apenergy.2015.01.023.

Chen, J., Wang, X. and Steemers, K. (2013) 'A statistical analysis of a residential energy consumption survey study in Hangzhou, China', *Energy and Buildings*. Elsevier B.V., 66, pp. 193–202. doi: 10.1016/j.enbuild.2013.07.045.

Chen, T.Y.; Burnett, J.; Chau, C.K. Analysis of embodied energy use in the residential building of Hong Kong. Energy 2001, 26.

Choi, I. Y., Cho, S. H. and Kim, J. T. (2012) 'Energy consumption characteristics of high-rise apartment buildings according to building shape and mixed-use development', *Energy and Buildings*. Elsevier B.V., 46, pp. 123–131. doi: 10.1016/j.enbuild.2011.10.038.

CIDB (2016) *Construction Industry Transformation Programme (CITP) 2016-2020, Construction Industry Development Board Malaysia*. doi: 10.11113/jt.v78.4056.

CIRCE (2018) 'LCA and LCC during the design , construction and operation phases', pp. 1–81.

CMRA(2010). Concrete Materials Website, Construction Materials Recycling Association.

Code, P. (2002) 'International Standard', *Shock*, 2006, pp. 1–8. doi: 10.1109/IEEESTD.2007.4288250.

Construction Industry Master Plan (CIMP) Malaysia 2006 – 2015, first printing 2007, ISBN 978-983-2724-44-5, Kuala Lumpur, Malaysia.

Crawford, R. H., Bagley, S. and Crawford, R. H. (2016) 'Using life cycle assessment to reduce the energy use and global warming impacts of a detached house in Melbourne , Australia warming impacts of a detached house in Melbourne , Australia', (July).

Dahlstrøm, O., Sørnes, K., Eriksen, S. T. and Hertwich, E. G. (2012) 'Life cycle assessment of a single-family residence built to either conventional- or passive house standard', *Energy and Buildings*. Elsevier B.V., 54, pp. 470–479. doi: 10.1016/j.enbuild.2012.07.029.

Department of Climate Change and Energy Efficiency. National greenhouse account factors.Australia: Department of Climate Change and Energy Efficiency, 2011.

Dr. Charlene Bayer, Gamble, P. M., Gentry, D. R. and Joshi, S. (2010) 'AIA Guide to Building Life Cycle Assessment in Practice', p. 193.

Ellegård, K. and Palm, J. (2011) 'Visualizing energy consumption activities as a tool for making everyday life more sustainable', *Applied Energy*, 88(5), pp. 1920–1926. doi: 10.1016/j.apenergy.2010.11.019.

ENVIRONMENT, N. C. (2011) 'Environmental Management Tools and Techniques Environmental Management Tools and Techniques'. Available at: http://www.undp.org/content/dam/bhutan/docs/Energy_environment/Env-publications/2011-NEC-Env Mgt Tools.pdf.

Epa (2009) 'Reduce, Reuse, and Recycle Construction and Demolition Materials at Land Revitalization Projects'. Available at: http://epa.gov/brownfields/tools/cdbrochure.pdf.

EPU (2015) 'Pursuing green growth for sustainability and resilience', *Eleventh Malaysia Plan 2016-2020*, pp. 1–31.

European Committee for Standardization (2008) 'CEN/TC 350. Sustainability of construction works – assessment of buildings – part 2: framework for the assessment of environmental performance', (3), pp. 1–35.

Evian Elzinga (2014) 'Strategis To Reduce The Environmental Impact Of A Low-Energy Residential Building', *Master Thesis in Energy-efficient and Environmental Buildings, Faculty of Engineering, Lund University*.

Faridah, A., H., A., Hasmanie, A., H., Hasnain, M., I., A study on construction and demolition waste from buildings in Seberang Perai, Proceeding of 3rd National Conference in Civil Engineering, Copthorne Orchid, Tanjung Bungah, Malaysia, 2004.

Fellows and Liu (2008). Research methods for construction. Blackwell, UK.

FET, D. A. M. (1998) 'ENVIRONMENTAL MANAGEMENT TOOLS AND THEIR APPLICATION – A REVIEW WITH REFERENCES TO CASE STUDIES', pp. 1–14.

Fraunhofer Magazine. (2014). European Diversity. Retrieved from: http://www.fraunhofer.de/en/publications/fraunhofer-magazine/magazine_2014/ Fraunhofermagazine_1-2014/magazine_1-2014_32.html

Frischknecht, R., Jungbluth, N., Althaus, H. J., Doka, G., Dones, R., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G. and Spielmann, M. (2005) 'The ecoinvent database: Overview and methodological framework', *International Journal of Life Cycle Assessment*, 10(1), pp. 3–9. doi: 10.1065/lca2004.10.181.1.

G. Keoleian, S. Blanchard, P. Reppe, Life-cycle energy, costs, and strategies for improving a single-family house, Journal of Industrial Ecology 4 (2) (2001) 135–156.

Gadenne, D., Sharma, B., Kerr, D. and Smith, T. (2011) 'The influence of consumers' environmental beliefs and attitudes on energy saving behaviours', *Energy Policy*. Elsevier, 39(12), pp. 7684–7694. doi: 10.1016/j.enpol.2011.09.002.

Gamle Mursten. The re-brick project, 2012.

Garrison, Noah; Horowitz, Cara; Lunghino, Chris Ann; Devine, Jon; and Beckman, D. S. (2012) 'Looking Up: how Green Roofs and Cool Roofs Can Reduce Energy Use , Address Climate Change , and Protect Water Resources in Southern California', *Nrdc Report*, R:12-06-B(June), pp. 1–33.

George *Tchobanoglous*, Frank *Keith*, Handbook Solid Waste Management, 2002.

Goggins, J., Keane, T., & Kelly, A. The assessment of embodied energy intypical reinforced concrete building structures in Ireland. Energy and Buildings, 2010,42(5), 735–744.

Guin, J. (1999) 'Danish-Dutch workshop on LCA methods , held on 16-17 September 1999 at CML , Leiden (Final report , 26-10- '', *Interpretation A Journal Of Bible And Theology*, (September).

Hammond, G.P & C.I Jones, Embodied Energy and Carbon in Construction Material, 2008

Han, G. and Srebric, J. (2011) 'Life-Cycle Assessment Tools for Building Analysis', *Engr.Psu.Edu*, (Lcc), p. 7.

Hasan, S. A. and Mozumder, P. (2017) 'Income and energy use in Bangladesh: A household level analysis', *Energy Economics*. Elsevier B.V., 65, pp. 115–126. doi: 10.1016/j.eneco.2017.05.006.

http://www.greenspec.co.uk/embodied-energy.php

http://www.nrdc.org/water/pollution/files/greenroofsreport.pdf.

https://knoema.com/atlas/Malaysia/CO2-emissions

Huang, B., Xing, K. and Pullen, S. (2017) 'Energy and carbon performance evaluation for buildings and urban precincts: review and a new modelling concept', *Journal of Cleaner Production*. Elsevier Ltd, 163, pp. 24–35. doi: 10.1016/j.jclepro.2015.12.008.

Huberman, N. and Pearlmutter, D. (2008) 'A life-cycle energy analysis of building materials in the Negev desert', *Energy and Buildings*, 40(5), pp. 837–848. doi: 10.1016/j.enbuild.2007.06.002.

Industrialized Building System (IBS) Roadmap 2003-2010. Construction Industry Development Board (CIDB) Malaysia. 2003.

Inside Iskandar- Quarterly Property Digest for Inskandar Malaysia, Issue:6, 2013.

Islam, H., Jollands, M., Setunge, S., Haque, N. and Bhuiyan, M. A. (2015) 'Life cycle assessment and life cycle cost implications for roofing and floor designs in residential buildings', *Energy and Buildings*. Elsevier B.V., 104, pp. 250–263. doi: 10.1016/j.enbuild.2015.07.017.

ISO 14044:2006(E), Environmental Management- Life Cycle Assessment-Requirement and Guidelines. First Edition 2006-07-01

Jeeninga, H., M. Uyterlinde, and J. Uitzinger, 2001, Energieverbruik van energiezuinige woningen. Effecten van gedrag en besparingsmaatregelen op de spreiding in en de hoogte van het reële energieverbruik, ECN.

Jefferson County and City of Port Townsend, Inventory of Energy Usage and Greenhouse Gas Emissions for Base Year 2005.

Johannsson M., Hietala P., Larsson K., Karlsson H., Hedlund M. & Eriksson L., En handbook – Rivning med Brokk [Electronic] Brokk AB, 2000

Jennifer O'Connor. Survey on actual service lives for North American buildings, October 2004.

Jonsson G. & Wallenius M. (2006) Miljöaspekter vid rivning av betongstation, Examensarbete vid Institionen för samhällsbyggnad avdelningen för geoteknologi, Luleå tekniska universitet

K. Adalberth, A. Almgreen, E.H. Petersen, Life cycle assessment of four multi-family buildings, International Journal of Low Energy and Sustainable Buildings 2 (2001) 1–21.

Kamarul Anuar, M. K., Zuhairi, A. H., Mohd Khairolden, G., Egbu, C. and Arif, M. (2011) 'Collaboration initiative on green construction and sustainability through Industrialized Buildings Systems (IBS) in the Malaysian construction industry', *International Journal of Sustainable Construction Engineering & Technology*, 1(1), pp. 119–127.

Kamali, M. and Hewage, K. (2016) 'Life cycle performance of modular buildings: A critical review', *Renewable and Sustainable Energy Reviews*. Elsevier, 62, pp. 1171–1183. doi: 10.1016/j.rser.2016.05.031.

Kamar, K. A. M. and Hamid, Z. A. (2011) 'Sustainable construction and green building: the case of Malaysia', *WIT Transactions on Ecology and the Environment*, 167, pp. 15–22. doi: 10.2495/ST110021.

Kamarul Anuar Mohamad Kamar, Mustafa Alshawi and Zuhairi Abd Hamid (2009), Barriers to Industrialised Building Systems: The Case of Malaysia, paper proceedings in Bu Hu 9th International Postgraduate Research Conference (IPGRC 2009), The University of Salford, 29– 30th January, 2009, Salford, United Kingdom.

Kamarul Anuar, M. K., Zuhairi, A. H., Mohd Khairolden, G., Egbu, C. and Arif, M. (2011) 'Collaboration initiative on green construction and sustainability through Industrialized Buildings Systems (IBS) in the Malaysian construction industry', *International Journal of Sustainable Construction Engineering & Technology*, 1(1), pp. 119–127.

Karimpour, M., Belusko, M., Xing, K. and Bruno, F. (2014) 'Minimising the life cycle energy of buildings: Review and analysis', *Building and Environment*. Elsevier Ltd, 73, pp. 106–114. doi: 10.1016/j.buildenv.2013.11.019.

Kenanga Research, Property Developers, Johor Study Trip, 29 April 2014.

Keoleian, et. Al. "Life-cycle energy, costs and strategies for improving a single-family house." Journal of Industrial Ecology, 2001, 4 (2): 135-156.

Khasreen, M. M., Banfill, P. F. G. and Menzies, G. F. (2009) 'Life-cycle assessment and the environmental impact of buildings: A review', *Sustainability*, 1(3), pp. 674–701. doi: 10.3390/su1030674.

Koroneos, C., Dompros, A., Roumbas, G. and Moussiopoulos, N. (2004) 'Life cycle assessment of hydrogen fuel production processes', *International Journal of Hydrogen Energy*, 29(14), pp. 1443–1450. doi: 10.1016/j.ijhydene.2004.01.016.

Krigsvoll, G., Wetzel, C., Cai, X., Staller, H. and Tritthart, W. (2011) 'LoRe-LCA Low Resource consumption buildings and constructions by use of LCA in Design and Decision Making', pp. 1–46.

Kuikka, S. (2012) 'LCA of the Demolition of a Building'.

L??pez-Mesa, B., Pitarch, ??ngel, Tom??s, A. and Gallego, T. (2009) 'Comparison of environmental impacts of building structures with in situ cast floors and with precast concrete floors', *Building and Environment*, 44(4), pp. 699–712. doi: 10.1016/j.buildenv.2008.05.017.

Les Strezov and Joe Herbertson. A Life Cycle Perspective on Steel Building Materials. April 2006.

Ling-Chin, J., Heidrich, O. and Roskilly, A. P. (2016) 'Life cycle assessment (LCA) - From analysing methodology development to introducing an LCA framework for marine photovoltaic (PV) systems', *Renewable and Sustainable Energy Reviews*. Elsevier, 59, pp. 352–378. doi: 10.1016/j.rser.2015.12.058.

Lolli, N., Fufa, S. M. and Inman, M. (2017) 'A Parametric Tool for the Assessment of Operational Energy Use, Embodied Energy and Embodied Material Emissions in Building', *Energy Procedia*. The Author(s), 111(1876), pp. 21–30. doi: 10.1016/j.egypro.2017.03.004.

Mao, C., Shen, Q., Shen, L. and Tang, L. (2013) 'Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects', *Energy and Buildings*. Elsevier B.V.,

Marceau, M., Bushi, L., Meil, J. and Bowick, M. (2012) 'Life Cycle Assessment for Sustainable Design of Precast Concrete Commercial Buildings in Canada', *1st International Specialty Conference on Sustaining Public Infrastructure*, (2), p. INF1042-1-12.

Marceau, M. L. and Vangeem, M. G. (2008) 'Comparison of the Life Cycle Assessments of an Insulating Concrete Form House and a Wood Frame House'.

Marceau, M. L., Nisbet, M. A., & VanGeem, M. G. Life cycle inventory of Portland cement concrete. Skokie, IL, USA: Portland Cement Association, 2007.

Mateus, R. and Bragança, L. (2011) 'Life-cycle assessment of residential buildings', *International Conference Sustainability of Constructions - Towards a better built environment*, (FEBRUARY 2011), pp. 255–262.

McGraw-Hill Encyclopedia of Science & Technology, 10th Edition. Copyright 2003 by The McGraw-Hill Companies

Mohamed, A. M. A., Al-Habaibeh, A., Abdo, H. and Elabar, S. (2015) 'Towards exporting renewable energy from MENA region to Europe: An investigation into domestic energy use and householders' energy behaviour in Libya', *Applied Energy*. Elsevier Ltd, 146, pp. 247–262. doi: 10.1016/j.apenergy.2015.02.008.

Mohamad Bohari, A. A., Skitmore, M., Xia, B., Teo, M., Zhang, X. and Adham, K. N. (2015) 'The path towards greening the Malaysian construction industry', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 52(2015), pp. 1742–1748. doi: 10.1016/j.rser.2015.07.148.

Mohamed Nor Azhari Azman, Mohd Sanusi S. Ahmad, Nur Diyana Hilmi. The perspective view of Malaysia Industrialized building system (IBS) under precast manufacturing. The 4th international conference-towards engineering of 21st century. 2012.

Mohammad, M. F. (2013) 'Construction Environment: Adopting IBS Construction Approach Towards Achieving Sustainable Development', *Procedia - Social and Behavioral Sciences*. Elsevier B.V., 85, pp. 8–15. doi: 10.1016/j.sbspro.2013.08.332.

Mohd Idrus Din, Noraini Bahri, Mohd Azmi Dzulkifly, Mohd Rizal Norman, Kamarul Anuar Mohamad Kamar*, and Zuhairi Abd Hamid. The adoption of Industrialised Building System (IBS) construction in Malaysia: The history, policies, experiences and lesson learned. Construction Industry Development Board (CIDB) Malaysia.

Nagapan, S., Rahman, I. A. and Asmi, A. (2012) 'Construction Waste Management: Malaysian Perspective', *The International Conference on Civil and Environmental Engineering Sustainability IConCEES 2012*, 2, pp. 1–11.

Nalanie Mithraratne, Brenda Vale, Life cycle analysis model for New Zealand houses, Building and Environment, Volume 39, Issue 4, April 2004, Pages 483-492, ISSN 0360-1323

Nässén, J., Holmberg, J., Wadeskog, A. and Nyman, M. (2007) 'Direct and indirect energy use and carbon emissions in the production phase of buildings: An input-output analysis', *Energy*, 32(9), pp. 1593–1602. doi: 10.1016/j.energy.2007.01.002.

Ngoc, U. N. and Schnitzer, H. (2009) 'Sustainable solutions for solid waste management in Southeast Asian countries', *Waste Management*. Elsevier Ltd, 29(6), pp. 1982–1995. doi: 10.1016/j.wasman.2008.08.031.

NSWMD, Landfill sites in Johor, National Solid Waste Management Department, Ministry of Housing and Local Government. 2011: Kuala Lumpur, Malaysia.

O'Brien E, Guy B, Lindner AS. Life cycle analysis of the deconstruction of military barracks: Ft. McClellan, Anniston, AL. Journal of Green Building 2006 ; 4:166-83

Of, M. and Science, A. (2005) 'Incorporating Life Cycle Assessment into the LEED Green Building Rating System by'.

Omar, W. M. S. W., Doh, J. H., Panuwatwanich, K. and Miller, D. (2014) 'Assessment of the embodied carbon in precast concrete wall panels using a hybrid life cycle assessment approach in Malaysia', *Sustainable Cities and Society*. Elsevier B.V., 10, pp. 101–111. doi: 10.1016/j.scs.2013.06.002.

Ortiz, O., Castells, F. and Sonnemann, G. (2009) 'Sustainability in the construction industry: A review of recent developments based on LCA', *Construction and Building Materials*. Elsevier Ltd, 23(1), pp. 28–39. doi: 10.1016/j.conbuildmat.2007.11.012.

Padgett J, Biodegradability of wood products under simulated landfill conditions. North Carolina State University MSc Thesis, 2009.

Parent, J., C. Cucuzzella, et al. (2012). "Revisiting the role of LCA and SLCA in the transition towards sustainable production and consumption." The International Journal of Life Cycle Assessment: 1-11, 2012.

Passos Fonseca, T.H. Net energy intensity and greenhouse gas emissions of integrated dairy and bio-fuels systems in Wisconsin. MS thesis. Madison, Wisconsin: University of Wisconsin/Madison, Department of Biological Systems Engineering, 2010.

Pembangunan, L. (2010) 'STANDARD mffi mm', (72).

Peng, C. L., Scorpio, D. E., and Kibert, C. J. (1997). "Strategies for successful construction and demolition waste recycling operations." Construction Management and Economics, 15(1), 49-58.

Piagam Pelanggan dan Norma Pelaksanaan Projek Jabatan Kerja Raya Malaysia (JKR), 2012.

Poon C. S, Wan Yu, A. T, Wong S. W and Cheung E. (2004), 'Management of Construction Waste in Public Housing Projects in Hong Kong', Journal of Construction Management and Economics, Vol. 22, Issue 5, Pp 461-470

Pons, O. and Wadel, G. (2011) 'Environmental impacts of prefabricated school buildings in Catalonia', *Habitat International*. Elsevier Ltd, 35(4), pp. 553–563. doi: 10.1016/j.habitatint.2011.03.005.

Pothitou, M., Hanna, R. F. and Chalvatzis, K. J. (2016) 'Environmental knowledge, pro-environmental behaviour and energy savings in households: An empirical study', *Applied Energy*. Elsevier Ltd, 184, pp. 1217–1229. doi: 10.1016/j.apenergy.2016.06.017.

Quale, J., Eckelman, M. J., Williams, K. W., Sloditskie, G. and Zimmerman, J. B. (2012) 'Construction Matters: Comparing Environmental Impacts of Building Modular and Conventional Homes in the United States', *Journal of Industrial Ecology*, 16(2), pp. 243–253. doi: 10.1111/j.1530-9290.2011.00424.x.

Racoviceanu, A.I., Karney, B.W., Kennedy, C.A., Colombo, A.F.. Life-cycle energy use and greenhouse gas emissions inventory for water treatment systems. Journal of Infrastructure Systems 13, 2007, 261-270.

Ramesh, T., Prakash, R. and Shukla, K. K. (2010) 'Life cycle energy analysis of buildings: An overview', *Energy and Buildings*, 42(10), pp. 1592–1600. doi:

10.1016/j.enbuild.2010.05.007.

Reddy, B. V. V. and Jagadish, K. S. (2003) 'ScienceDirect - Energy and Buildings : Embodied energy of common and alternative building materials and technologies', 35, pp. 129–137.

Reduce, Reuse, and Recycle Construction and Demolition Materials at Land Revitalization Projects, United States Environmental Protection Agencies, EPA-560-F-09-523, October 2009.

Renewable Energy and Energy Efficiency Blueprint for Iskandar Malaysia, Iskandar Regional Development Authority (IRDA), 2011.

Riduan Yunus, Jay Yang, Sustainability Criteria for Industrialised Building Systems (IBS) in Malaysia, Procedia Engineering, Volume 14, 2011, Pages 1590-1598, ISSN 1877-7058

Ronald E. Miller, Peter D. Blair. Input–Output Analysis Foundations and Extensions, Second Edition, 1986.

Salihudin Hassim , Mohd Saleh Jaafar and Saiful Azri Abu Hasan Sazalli Department of Civil Engineering , Faculty of Engineering, U. P. M. (2009) 'The Contractor Perception Towers Industrialised Building System Risk in Construction Projects in Malaysia', 6(5), pp. 937–942.

Sartori, I. and Hestnes, A. G. (2007) 'Energy use in the life cycle of conventional and low-energy buildings: A review article', *Energy and Buildings*, 39(3), pp. 249–257. doi: 10.1016/j.enbuild.2006.07.001.

Sharaai, A. H., Mahmood, N. Z. and Sulaiman, A. H. (2010) 'Life Cycle Impact Assessment (LCIA) Using the Ecological Scarcity (Ecopoints) Method : A Potential Impact Analysis to Potable Water Production', 11(9), pp. 1077–1088.

Soust-Verdaguer, B., Llatas, C. and García-Martínez, A. (2016) 'Simplification in life cycle assessment of single-family houses: A review of recent developments', *Building and Environment*. Elsevier Ltd, 103, pp. 215–227. doi: 10.1016/j.buildenv.2016.04.014.

Stezov, L. and Herbertson, J. (2006) 'A Life Cycle Perspective on Steel Building Materials', (April), pp. 1–21.

The Government of Malaysia (2015) 'Intended Nationally Determined Contribution of the Government of Malaysia', *The United Nations Framework Convention on Climate Change (UNFCCC)*, p. 6. doi: 10.1007/s13398-014-0173-7.2.

Trombley, J. and Halawa, E. (2017) 'Can further energy reductions be achieved through behaviour changes in low income households?', *Energy Procedia*. Elsevier B.V., 121, pp. 230–237. doi: 10.1016/j.egypro.2017.08.022.

Tumminia, G., Guarino, F., Longo, S., Ferraro, M., Cellura, M. and Antonucci, V. (2018) 'Life cycle energy performances and environmental impacts of a prefabricated building module', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 92(September 2017), pp. 272–283. doi: 10.1016/j.rser.2018.04.059.

Universiti Teknologi Malaysia, Kyoto University, Okayama Univeristy and Ritsumeikan University (2009) 'Low Carbon City 2025 - Sustainable Iskandar Malaysia', pp. 1–30.

UTM SAJ Technical Report. SAJ Carbon Footprint Assessment, 2013.

VanGeem, M. (2006) 'Achieving Sustainability with Precast Concrete', *PCI Journal*, (Jan-Feb), pp. 42–61. doi: 10.15554/pcij.01012006.42.61.

Verbeeck, G. and Hens, H. (2010) 'Life cycle inventory of buildings: A calculation method', *Building and Environment*. Elsevier Ltd, 45(4), pp. 1037–1041. doi: 10.1016/j.buildenv.2009.10.012.

Vieira, PMdS (2007) Environmental Assessment of Office Buildings. U.C. Berkeley Doctoral Dissertation in Civil and Environmental Engineering.

Wang Cai, T., Wang, S., Cozzi, L., Motherway, B. and Turk, D. (2017) *Towards a zero-emission, efficient, and resilient buildings and construction sector, Global Status Report 2017*.

Wilburn, D., & Goonan, T. (1998) (no date) 'Aggregates from Natural and Recycled Sources Economic Assessments for Construction Applications — A Materials Flow Analysis', *Geological Survey Circular*.

Williams, A. S. (2009) 'Life Cycle Analysis: A Step by Step Approach', (December), p. 23. doi: http://www.istc.illinois.edu/info/library_docs/tr/tr40.pdf.

Willmott Dixon, Thorpe, D., Enshassi, A., Mohamed, S., Abushaban, S. and Cours, S. (2010) 'The Impacts of Construction and the Built Environment', *Journal of Civil Engineering and Management*, 1(800), pp. 269–280. doi: 10.3846/1392-3730.2009.15.269-280.

Wolsink, M. (2010) 'Contested environmental policy infrastructure : Socio-political acceptance of renewable energy , water , and waste facilities'. doi:

10.1016/j.eiar.2010.01.001.

Wrightson, I., Cooper, S. J., Crookes, M., King, N., Lewis, P., Larner, J., Lohmann, D. H., Maxwell, C., Sanderson, D. M. and Lipworth, S. (2010) 'Environment , Health and Safety Committee Note on : Life Cycle Assessment', *Ehsc*, 3.

Xing, S., Xu, Z. and Jun, G. (2008) 'Inventory analysis of LCA on steel- and concrete-construction office buildings', 40, pp. 1188–1193. doi: 10.1016/j.enbuild.2007.10.016.

Xu, C., Li, Y., Jin, X., Yuan, L. and Cheng, H. (2017) 'A real-time energy consumption simulation and comparison of buildings in different construction years in the Olympic Central Area in Beijing', *Sustainability (Switzerland)*, 9(12). doi: 10.3390/su9122245.

Yue, T., Long, R. and Chen, H. (2013) 'Factors influencing energy-saving behavior of urban households in jiangsu province', *Energy Policy*. Elsevier, 62, pp. 665–675. doi: 10.1016/j.enpol.2013.07.051.

Yunus, R. and Yang, J. (2011) 'Sustainability criteria for Industrialised Building Systems (IBS) in Malaysia', *Procedia Engineering*. Elsevier B.V., 14, pp. 1590–1598. doi: 10.1016/j.proeng.2011.07.200.