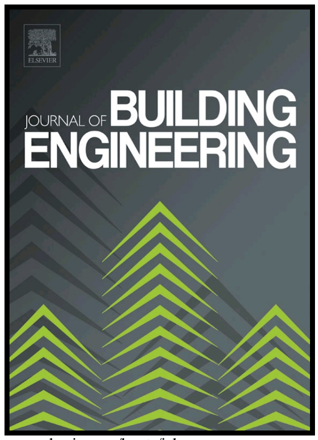
Green Buildings Life Cycle Cost Analysis and Life Cycle Budget Development: Practical Applications

Luay N. Dwaikata, Kherun N. Ali



www.elsevier.com/locate/jobe

PII: S2352-7102(18)30311-5
DOI: https://doi.org/10.1016/j.jobe.2018.03.015
Reference: JOBE437

To appear in: *Journal of Building Engineering*

Received date: 22 April 2016
Revised date: 9 October 2017
Accepted date: 20 March 2018

Cite this article as: Luay N. Dwaikata and Kherun N. Ali, Green Buildings Life Cycle Cost Analysis and Life Cycle Budget Development: Practical Applications, *Journal of Building Engineering,* https://doi.org/10.1016/j.jobe.2018.03.015

Green Buildings Life Cycle Cost Analysis and Life Cycle Budget Development: Practical Applications

Luay N. Dwaikat[1], Kherun N. Ali[2]

Department of Quantity Surveying, Faculty of Built Environment, Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Johor, Malaysia,

luay.dwaikat@gmail.com

b-kherun@utm.my

Abstract

Life cycle costing is gaining considerable attention particularly within the context of sustainable construction. However, the application of life cycle costing in the construction sectors is still limited and facing practical problems. Imperfect understanding of life cycle costing methodology and application is considered one of the key barriers to a widespread application of life cycle costing in the construction industry. This paper presents a study that demonstrates how the life cycle cost analysis was conducted for a green building and shows how the life cycle cost variables were identified and used to develop a life cycle budget for the whole life cycle of a green building which extends for 60 years. It is found in this research that the future costs of the investigated green building are around 3.6 times as high as its initial design and construction costs. Not surprisingly, the energy cost constitutes a weight of 48% of the total life cycle budget for the building, and this ratio goes above 60% when weighted against building operating costs only. It is also found that reduced energy consumption in the green building is the most influential factor to reduce its total life cycle cost.

Keywords: *Construction sector; life cycle costing; life cycle budget; energy cost; green buildings*

1 Introduction

More pressure is being exercised on the construction industry to take into account future running costs associated with a building which are typically assessed using life cycle costing as a cost evaluation technique [1–3]. Within the context of the built environment, life cycle costing is a method used to assess the anticipated economic performance of a building throughout its life cycle which includes: design and construction, operation and maintenance, in addition to disposal [1,4]. Yet, in the construction sector, the application of life cycle costing is still limited and facing practical problems [2,5]. Issues related to poor perception of life cycle cost benefits by building owners, lack of reliable life cycle cost input data, shortage of actual cost and performance information about buildings in use, uncertainty associated with life cycle cost assumptions [1,2,5], in addition to imperfect understanding of life cycle costing methodology and application are considered key barriers to a widespread application of life cycle costing in the construction sector [2,4,6].

The aim of this paper is to improve the understanding of life cycle costing application in the construction industry by providing a detailed description about the process used in developing a life cycle budget for a green building throughout its whole life cycle. The paper also provides a breakdown for the weights of different life

[1] Tel.: +970-598-100395.
[2] Phone: +60-19-7750354.

cycle cost components in reference to buildings life cycle budget. The paper contributes to fill the knowledge gap between theory and practice.

2 Background Information

2.1 Life cycle costing

Life cycle costing is an economic appraisal technique used to evaluate different investment alternatives by taking into account cost and saving associated with each investment alternative along a period of analysis often determined by a period of commercial interest [3,4,6,7]. In the construction sector, it is used to compare different design alternatives for a building, or a system considering the life cycle cost and saving associated with each design option [2,4]. Technically, it is based on the principles of engineering economy to make the costs and benefits comparable by taking into account the time value of money [8]. Life cycle costing is used to develop life cycle budgets and can be conducted at any stage of building life cycle [3,7]. The historical records about life cycle costing origin are vague [3]. However, it is argued that life cycle costing was firstly used by the U.S. Department of Defense, in the mid of 1960s, to assist in the procurement of military equipment [5,9].

The basic function of life cycle costing is to quantify the costs associated with owning a facility along a period of analysis. After introducing the concept of green building in the early nineties [10], there are voices calling for the need to cradle to grave cost assessment rather than limiting the life cycle cost analysis to a period of commercial interest. This approach is considered as an evolution of the classical life cycle costing, and it is known as whole-life cycle costing [1,2]. This evolution was necessary to recognize life cycle costing as a sustainability assessment method to address the economic pillar of sustainable development [11].

2.2 Life cycle cost (LCC)

The life cycle cost, often abbreviated LCC [7], is the total cost associated with building design and construction, building operation and maintenance, in addition to the costs associated with building disposal at the end of its life cycle [2–4]. The International Standard ISO 15686-5:2008 [7] provides a neat cost breakdown structure (CBS) for the components of building life cycle cost includes four major categories which are: (1) design and construction cost, (2) operation cost, (3) maintenance cost, and (4) end of life cost. Under each category, more detailed cost components are proposed to cover all the relevant costs associated with owning a building throughout its whole life cycle. The life cycle of a product or a system can be defined by five major phases: (1) concept and definition, (2) design and development, (3) manufacturing and installation, (4) operation and maintenance, and (5) disposal [6]. Intrinsically, these sequential phases also comprise the whole life cycle of a building [1–3].

3 Case Study Description:

The case study which was analyzed in the research is the Malaysian Real Estate and Housing Developers' Association (REHDA) headquarter in Kuala Lumpur. REHDA headquarter is a three-story green office building certified by the Malaysian Green Building Index (GBI) in 2014 with a gross area of 2,695 m². In line with the concept of the green building, REHDA headquarter was designed to adopt green technologies and eco-friendly features such as double-skin external walls to reduce heat gain, ventilation block walls, water features for cooling, mini rooftop garden, rain water harvesting systems, in addition to a photovoltaic (PV) system with a capacity of 21 kWp. According to the design criteria, the estimated total annual energy demand by the building is around 502,913 kWh/year which is equivalent to 87 kWh/m^2/year. Constructed between the period from 2009 – 2012 and commissioned in 2013, the building is being used as an administrative building.

4 Building Life Cycle Cost Analysis

Although the building was designed as green, life cycle cost analysis was not conducted. However, life cycle costing is not a common practice in the Malaysian construction industry [12]. Furthermore, life cycle costing is not recognized as an evaluation criterion in the Malaysian Green Buildings Index [13]. Nevertheless, the Green Building Index (GBI) Design Reference Guide and Submission Format [13,14], for both residential and non-residential buildings, mandates submitting a three-year sustainable maintenance program and preventative maintenance budget. In estimating the total life cycle cost for the case study, building commissioning year 2013 was used as the base date for life cycle cost data collection and estimate. All of the cost data were available in the local currency in Malaysia (Malaysian Ringgit). The costs were converted from the local currency to the U.S. dollars using the average exchange rate for the year 2012 as reported by the Central Bank of Malaysia [15] which was equal 3.1 RM/USD.

In conducting the analysis, the International Standard ISO 15686-5:2008 [7] was used as a reference to identify the life cycle cost components and elements, in addition to the required data for the analysis which are: (1) building service life, (2) period of analysis, (3) future inflation rate, (4) discount rate, (5) design and construction cost, (6) building operating cost, (7) building maintenance cost, (8) end of life cost.

4.1 Building Service Life

The service life of a building refers to the period of time during which a building or its components satisfy the minimum acceptable level of performance [16]. Fundamentally, determining the service life of the building was essential to identify the time horizon over which the study can be conducted to cover the whole life cycle of the building. However, estimating the service life of a facility is a daunting issue involves several considerations. For example, periodic maintenance and component parts replacements may extend the life span of a facility [2,3]. The International standard ISO 15686-5:2008 recommends that the estimated service life of a building should not be less than its design life. Based on the design specifications of the building, a period of 60 years was estimated as a service life of the case study.

4.2 Period of Analysis

The period of analysis refers to the time horizon over which the life cycle cost is analyzed [2–4,7]. In its origin, life cycle costing does not necessarily cover the whole life cycle of a product, system, or an asset [1,3,7]. Several life cycle costing scholars recommend to limit the analysis to the economic life of a facility which is determined by a period of commercial interest beyond which using the facility is not economically feasible [2,3,6,17]. Kirk and Dell'isola [3] suggest an analysis period ranges from 25 – 40 years for buildings since the present value of future costs that occur beyond a period of 40 years may be insignificant. The international standard ISO 15686-5:2008 [7] recommends not to exceed 100 years for the same reason [7]. However, within the context of sustainable development, it is vigorously argued that life cycle cost analysis should include the whole life cycle of a building, or a product [1,2,18,19]. Since the purpose of the research is to develop a total life cycle cost budget for the case study, the whole building life cycle as determined by the design life is used to determine the time horizon of the analysis, and therefore, the analysis covers a period of 60 years starting from 2009 (Construction start date) to 2068 (expected end of life date) inclusive.

4.3 Inflation Rate

The inflation/deflation refers to the continuous increase/decrease in the general price levels of goods and services [3,16]. In conducting a life cycle cost analysis for economic appraisal purposes, nominal or real costs can be used in the analysis [3,4,7]. The nominal costs refer to the costs which are estimated taking into account the effect of price inflation/deflation; the nominal costs represent the amount of money that will be paid when the costs are due to be paid. The real costs, on the other hand, reflect the current value of goods or services; the effect of inflation/deflation on the costs is disregarded in the real terms [3,4,7]. In using life cycle costing to compare various investment alternatives, it is recommended to estimate the life cycle cost in the real terms to reduce the uncertainty associated with forecasting future inflation/deflation rates [3,4,7,18]. Contrarily, in generating financial budgets in which future money outflow is evaluated, the life cycle cost analysis should be conducted using nominal costs [4,7]. Since it is intended to establish a total life cycle budget for the case study projected over the time horizon, this threshold cannot be violated, and therefore, it was essential to consider future inflation/deflation rates.

Historical information about the past inflation/deflation rates can be obtained from periodic reports frequently issued by department of statistics or other relevant bodies in a country. These reports often contain data about the consumer price index (CPI) for different types of goods and services. The consumer price index (CPI) measures the percentage change through time in the price level of a constant basket of goods and services [20]. For example, the first consumer price index for Malaysia was released in 1987 using 1980 as base year; it was containing nine categories of goods and services [20]. Starting from 2006, eleven categories are being used in reporting the consumer price index, among which housing, water, electricity, gas and other fuels are reported separately [20]. Part of the world development indicators, the World Bank issues annual worldwide reports for inflation rates. The historical inflation rates for Malaysia retrieved from the World Bank database covers a longer period starting from the year 1961 [21]. Figure 1 shows the historical general inflation rates for Malaysia for the period from 1981–2013 obtained from the Malaysia Economic Statistics – Time Series Report issued by the Department of Statistics in 2013 [20], and the historical inflation rate for Malaysia (1961 – 2013) retrieved from the World Bank database [21]. The average inflation rate for Malaysia according to the World Bank data is 3.14% [21], while it is 2.98% according to the Department of Statistics Malaysia [20].

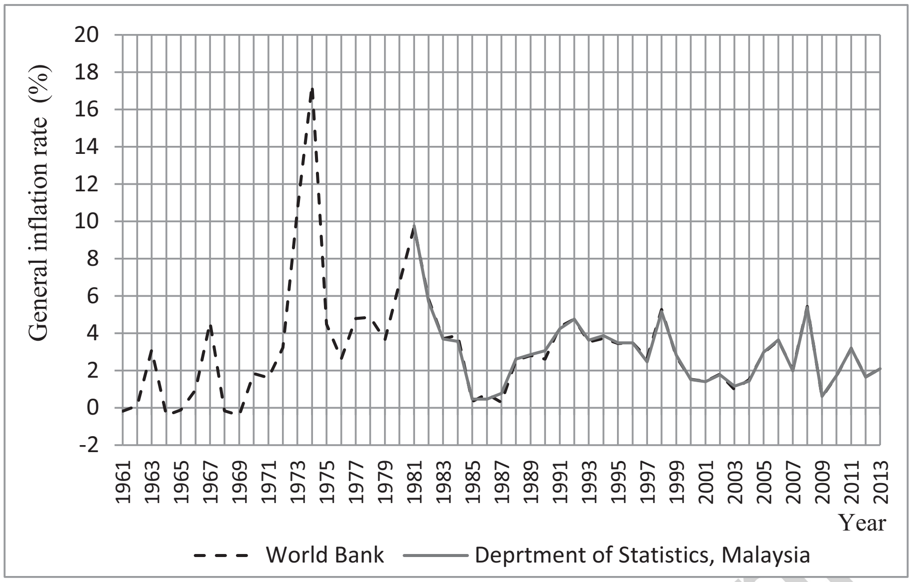


Figure 1: *Historical general inflation rate for Malaysia*

In conducting a life cycle cost analysis, it would be more accurate to consider the energy price escalation separately. This is due to the fact that energy price escalates at different levels than the general price inflation [7]. The energy and water consumer price index in Malaysia is being measured under a separate group in the basket; it occupies a weight of 22.6% which is the second highest weight after the food category. Figure 2 shows the annual percentage increase/decrease in energy, water and other fuel prices in Malaysia for the period from 1981 to 2013. The average energy and water price increase is about 2.4% per year.

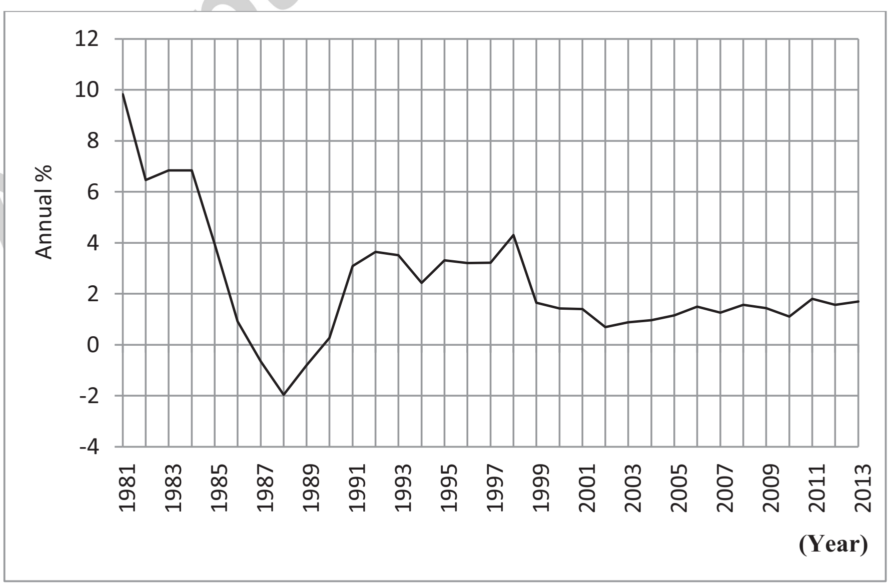


Figure 2: *Historical energy and water escalation rate for Malaysia based on the data obtained from Department of Statistics Malaysia* [20]

There are no official forecasted data for inflation rates in Malaysia for the forthcoming 60 years. However, based on the above descriptive analysis of the inflation rates in Malaysia, and since the World Bank data average covers longer historical period than the Department of Statistics Malaysia (DOSM), the historical average inflation rate for the World Bank data [21], which equals 3.14%, was used in estimating the future life cycle cost for the case study excluding energy and water. The World Bank data do not contain categorized inflation rates for goods and services, therefore, the historical average inflation rate for energy and water obtained from the Department of Statistics Malaysia [20], which equals 2.4 % per year, was used to estimate future energy and water life cycle costs.

The change in the cost (inflation rate) is expressed as a constant compound rate. Once the inflation rate is determined, the change in cost can be calculated using equation 1 [7,8]:

$$\boldsymbol{F = P(1 + e)^n} \quad (1)$$

Where:

F: future value (nominal cost)

P: cost in the base year

e: expected percentage of annual cost increase

n: number of years between the base date and the occurrence of the cost

4.4 Discount rate

Finding the equivalent value now (present worth) of a future amount of money is known as discounting [3,7,8]. The discount rate refers to the rate that reflects the time value of money [4]; it is used to find the current value of future amounts of money . It is also referred to as interest rate if it is used to find the future equivalence for an amount of money now [8]. In conducting a life cycle cost analysis to compare different investment alternatives, it is essential to determine a discount rate to find the equivalent value for each alternative in a common base date [1,3,4].

The International Standard ISO 15686-5:2008 [7] recommends that the determined discount rate, for private sector projects, should cover the opportunity cost of the invested capital which can be: (1) the interest cost of a loan for investment, (2) the interest lost from cash reductions from deposits, (3) the lost return from other possible investment, (4) the actual return from capital investments, or (5) the anticipated rate of return from the new business. For public sector projects, the International Standard recommends to use the discount rate which is determined by the central government.

Since the purpose of the research is to develop a life cycle budget for the building in the nominal terms showing the expected money outflow in the future, the discount rate has no function in the analysis. In other words, discounting the estimated life cycle costs in the nominal terms to find the present worth is not required since it is not intended in the research to conduct economic evaluation for different design alternatives.

4.5 Design and Construction Cost

The design and construction costs constitute a primary cost element of buildings life cycle cost [3,4]. The design and construction works of the building started in 2009 and completed in 2012. The building is under operation since 2013, this implies that the actual design and construction cost is already incurred and known, likewise, the building operating and maintenance costs for the elapsed two years (2013 and 2014). The actual incurred costs are considered as sunk costs and should be ignored if the life cycle cost analysis is conducted for economic appraisal purposes [3,7]. However, since the scope of the analysis is to create a total life cycle cost budget, the design and construction cost for the building is included in the analysis. The estimated design and construction budget for the building by the design team was around 1,361 $\$/m^2$ which corresponds to a total of $3,666,518. This figure is used as the budgeted cost for building design and construction in the total life cycle cost analysis.

4.6 Building Operating Cost

The building operating costs according to the International Standard ISO 15686-5:2008 [7] may include rent, insurance, cyclical regulatory cost, utility cost, taxes, and other operating costs. For the case study, only the utility costs apply as building operating costs which include energy and water consumption bills, in addition to sewerage annual fees. The life cycle costs for energy, water, and sewerage were estimated as follow:

4.6.1 Energy cost:

Two types of data were collected and used to estimate the energy life cycle cost for the case study: total building energy use (kWh/year), and electricity price tariff ($/kWh). According to the design assessment report which was submitted to obtain green certification for the building from the Green Building Index (GBI) Malaysia, the estimated total energy consumption for the case study is around 502,913 kWh/year based on 52 working hours per week.

According to the electric utility company in Kuala Lumpur [22], the electricity price tariffs which were effective in 2013, which is the start of building operating phase, were as follow:

- 0.127 $/kWh for monthly consumption between 0 – 200 kWh
- 0.139 $/kWh for overall monthly consumption more than 200 kWh

Based on the above information, the total annual building energy cost was calculated for the case study starting from the base year 2013. The annual energy cost for the base year was calculated as follow:

$$\begin{aligned} \textit{Total annual energy cost} &= [200\ kWh/month \times 12\ month \times 0.127\ \$/kWh] + \\ &\quad [(502{,}913 - (200\ kWh \times 12\ month)) \times 0.139\ \$/kWh] \\ &= 69{,}876\ \$/year\ (rounded) \end{aligned}$$

According to the Energy Commission [23], fuel prices affect electricity cost in Malaysia. However, the electric utility company, Tenaga Nasional Berhad [24], claims that the electricity prices in Peninsular Malaysia are not directly affected by the oil price movement, factors such as U.S dollar strength against the Malaysian Ringgit (RM) affects the cost of electricity generation. Since, there are no official forecasts for future electricity price in Malaysia, the average historical inflation rate for energy, which equals 2.4% per year, was used in estimating the future energy cost in the building.

By knowing the estimated total annual building energy consumption, the electricity tariffs, in addition to the expected energy price escalation rates, the total life cycle budget for energy was projected over the period of analysis using equation 1starting from 2013 as the base year as shown in Table 1. The total energy life cycle cost for the case study was estimated to be around $8,076,352.

Table 1 *Estimated life cycle energy cost for the case study (2013 as base year)*

Estimated annual energy cost ($/year)							
Year	**Annual energy cost**	**Year**	**Annual energy cost**	**Year**	**Annual energy cost**	**Year**	**Annual energy cost**
2013	69,876	2027	97,392	2041	135,746	2055	189,201
2014	71,553	2028	99,729	2042	139,004	2056	193,742
2015	73,270	2029	102,122	2043	142,340	2057	198,392
2016	75,028	2030	104,573	2044	145,756	2058	203,153
2017	76,829	2031	107,083	2045	149,254	2059	208,029
2018	78,673	2032	109,653	2046	152,836	2060	213,022
2019	80,561	2033	112,285	2047	156,504	2061	218,135
2020	82,494	2034	114,980	2048	160,260	2062	223,370
2021	84,474	2035	117,740	2049	164,106	2063	228,731
2022	86,501	2036	120,566	2050	168,045	2064	234,221
2023	88,577	2037	123,460	2051	172,078	2065	239,842
2024	90,703	2038	126,423	2052	176,208	2066	245,598
2025	92,880	2039	129,457	2053	180,437	2067	251,492
2026	95,109	2040	132,564	2054	184,767	2068	257,528
Total estimated life cycle energy cost							**8,076,352 $**

4.6.2 Water Cost

Similar to energy cost estimate, two types of data were collected and used in estimating the total water life cycle cost for the building: total building water use (m^3/year), and water tariff ($/$m^3$). According to the green certification design assessment report, the estimated total water consumption in the case study is around 1,913 m^3/ year based on 286 working days per year.

According to the water supply company in Kuala Lumpur [25], the water tariff for commercial buildings are as follow:

- 0.67 $/ m^3 for monthly consumption between 0 – 35 m^3.
- 0.74 $/ m^3 for water consumption above 35 m^3.

According to the National Water Service Commission in Malaysia [26], these rates have been effective starting from November 2006. Accordingly, the total annual building water cost was calculated for the base year 2013 as follow:

$$\text{Total annual water cost} = [35\ m^3/\text{month}\ \ X\ 12\ \text{month}\ X\ 0.67\ \$/\ m^3] + [(1,913 - (35\ m^3\ X\ 12\ \text{month}))\ X\ 0.74\ \$/m^3] = 1,386\ \$/\text{year (rounded)}$$

In the consumer price index report issued by the Department of Statistics Malaysia [20], the water falls within the same group of energy, and hence, the same historical escalation rate of energy applies for water. Since there is no official published forecast for water prices in Malaysia, the historical average escalation rate for energy and water which equals 2.4% was applied in estimating water life cycle cost for the case study.

Using the inflation rate, the water total life cycle cost for the case study was projected over the period of analysis using equation 1. Noting that all figures are rounded to the nearest whole number, Table 2 shows the annual estimated water life cycle cost for the case study.

Table 2: *Estimated life cycle water cost for the case study (2013 as base year)*

Estimated annual water cost ($/year)							
Year	**Annual water cost**	**Year**	**Annual water cost**	**Year**	**Annual water cost**	**Year**	**Annual water cost**
2013	1,386	2027	1,930	2041	2,690	2055	3,750
2014	1,419	2028	1,976	2042	2,755	2056	3,840
2015	1,453	2029	2,023	2043	2,821	2057	3,932
2016	1,488	2030	2,072	2044	2,889	2058	4,026
2017	1,524	2031	2,122	2045	2,958	2059	4,123
2018	1,561	2032	2,173	2046	3,029	2060	4,222
2019	1,598	2033	2,225	2047	3,102	2061	4,323
2020	1,636	2034	2,278	2048	3,176	2062	4,427
2021	1,675	2035	2,333	2049	3,252	2063	4,533
2022	1,715	2036	2,389	2050	3,330	2064	4,642
2023	1,756	2037	2,446	2051	3,410	2065	4,753
2024	1,798	2038	2,505	2052	3,492	2066	4,867
2025	1,841	2039	2,565	2053	3,576	2067	4,984
2026	1,885	2040	2,627	2054	3,662	2068	5,104
Total estimated life cycle water cost							**$160,067**

4.6.3 Sewerage Cost

Monthly sewerage services charges are applied for commercial buildings in Malaysia [27], the service charge is calculated as the sum of a basic charge, which is determined based on the annual value of the commercial premises, plus an excess charge determined based on monthly water consumption more than 100 cubic meter [27,28]. According to the Act 171-Local Government Act 1976, published by The Commissioner of Law

Revision, Malaysia, in 2006 [29], the annual value is the estimated gross annual rent which is reasonably accepted by a landlord to pay the expenses of building repair, insurance, maintenance, or other charged public rates and taxes. It is determined by a valuation officer assigned by the relevant authorities. Based on the annual value, the national sewerage company determines the basic charge which is also dependent on whether the property is connected to sewage lines or uses a septic tank. Based on the annual value of the case study, the basic charge which applies for the case study is 112 $/month [28].

In addition to the basic charge, the excess charge also was calculated based on the amount of water consumed in the building. The applied rates to determine the excess sewerage service monthly charge by the national sewerage company are as follow:

- No charge for water consumption up to 100 m^3
- 0.10 $/$m^3$ for water consumption more than 100 m^3 but less than 200 m^3
- 0.15 $/$m^3$ for water consumption more than 200 m^3

The total estimated annual water consumption in the building is around 1,913 m^3, this implies a monthly average consumption around 160 m^3 . By applying the above rates, the monthly excess charge will be 16 $/month (160 m^3 x 0.10 $/$m^3$). The excess charge was added to the basic monthly charge to come up with 128 $/month, or 1,536 $/year as the total sewerage annual cost for the base year 2013. The applied inflation rate for water was used to project the estimated annual sewerage life cycle cost along the period of analysis as shown in Table 3.

Table 3*:* *Estimated life cycle sewerage cost for the case study (2013 as base year)*

Estimated annual sewerage cost ($/year)							
Year	**Annual cost**	**Year**	**Annual cost**	**Year**	**Annual cost**	**Year**	**Annual cost**
2013	1,536	2027	2,145	2041	2,989	2055	4,167
2014	1,573	2028	2,196	2042	3,061	2056	4,267
2015	1,611	2029	2,249	2043	3,134	2057	4,369
2016	1,650	2030	2,303	2044	3,209	2058	4,474
2017	1,690	2031	2,358	2045	3,286	2059	4,581
2018	1,731	2032	2,415	2046	3,365	2060	4,691
2019	1,773	2033	2,473	2047	3,446	2061	4,804
2020	1,816	2034	2,532	2048	3,529	2062	4,919
2021	1,860	2035	2,593	2049	3,614	2063	5,037
2022	1,905	2036	2,655	2050	3,701	2064	5,158
2023	1,951	2037	2,719	2051	3,790	2065	5,282
2024	1,998	2038	2,784	2052	3,881	2066	5,409
2025	2,046	2039	2,851	2053	3,974	2067	5,539
2026	2,095	2040	2,919	2054	4,069	2068	5,672
Total estimated life cycle sewerage cost							**$177,844**

Based on the above analysis of building operating cost components, the total operating life cycle cost for the case study equals $8,414,263. This figure represents the total life cycle budget for energy, water, and sewerage costs which were estimated for the whole building life cycle.

4.7 Building Maintenance Cost

Building maintenance refers to the required actions to keep the building or its components functioning in a manner that meets the minimum performance requirements; it comprises all the required activities to preserve and protect the building structure and components [30]. Maintenance cost is the total incurred labor, material, or any other costs associated with those actions and activities [7]. Building maintenance costs according to the International Standard ISO 15686-5:2008 [7] include:

1. Maintenance management
2. Adaptation or refurbishment of the building
3. Minor repair and replacement cost
4. Major systems or components replacement cost
5. Cleaning
6. Ground maintenance
7. Redecoration tax on maintenance goods and services

Part of the green rating requirements, the Green Building Index (GBI) requires to submit a three-year sustainable maintenance program to ensure that building energy related systems will sustain the anticipated performance beyond the defects and liability period [13]. In response to this requirement, a three-year maintenance program and budget have been prepared for the case study by the design team as shown in Table 4**.**

Table 4: *Estimated building maintenance budget for three years*

No.	Description	Year 1	Year 2	Year 3
1	**Maintenance team cost**			
1.1	Building management team	12,000	12,000	12,000
2	**Maintenance and other services budget**			
2.1	Maintenance service budget cost	11,600	11,600	11,600
2.2	Maintenance of air condition			
2.3	Maintenance of fire fighting			
2.4	Maintenance of lighting			
3	**Other Costs**			
3.1	Security services	3,900	3,900	3,900
3.2	General cleaning	1,900	1,900	1,900
3.3	Landscaping and gardening	1,200	1,200	1,200
3.4	Healthcare and sanitary products	770	770	770
Estimated Total Maintenance cost		**$31,370**	**$31,370**	**$31,370**

Based on building designers' estimate, the annual budgeted maintenance cost was estimated to be around 31,370 $/year. The historical average general inflation rate (3.14% per year) was used to project the estimated maintenance budget over the period of analysis starting from 2013 as the base year. Table 5 shows the projected annual maintenance budget over the period of analysis considering the historical average general inflation rate in Malaysia.

It is worth mentioning that the maintenance cost for the base year 2013 was limited to building management, cleaning, and security costs. The other maintenance costs related to repair and replacement of minor/major building parts are borne by the building contractor as part of the defect liability for the first year of building operation. Although the research in building maintenance seems to be an active topic in Malaysia, building maintenance cost databases and benchmarks are not available to verify the designer's estimated maintenance budget for the case study. All of the studies address the issue of building maintenance from theory perspective [30]; they do not provide much information about the costs associated with building maintenance.

Table 5 *Estimated maintenance life cycle cost for the case study (2013 as base year)*

Estimated annual maintenance cost ($/year)							
Year	**Annual cost**	**Year**	**Annual cost**	**Year**	**Annual cost**	**Year**	**Annual cost**
2013	19,770	2027	48,358	2041	74,546	2055	114,923
2014	32,355	2028	49,876	2042	76,887	2056	118,533
2015	33,372	2029	51,442	2043	79,301	2057	122,254
2026	34,419	2030	53,058	2044	81,792	2058	126,092
2017	35,499	2031	54,724	2045	84,361	2059	130,052
2018	36,614	2032	56,442	2046	87,009	2060	134,135
2019	37,764	2033	58,213	2047	89,741	2061	138,346
2020	38,949	2034	60,041	2048	92,559	2062	142,690
2021	40,172	2035	61,925	2049	95,465	2063	147,170
2022	41,433	2036	63,870	2050	98,464	2064	151,791
2023	42,735	2037	65,875	2051	101,555	2065	156,557
2024	44,076	2038	67,943	2052	104,743	2066	161,474
2025	45,460	2039	70,076	2053	108,032	2067	166,544
2026	46,887	2040	72,277	2054	111,424	2068	171,774
Total estimated maintenance life cycle cost							**$4,397,752**

4.8 End of Life Cost

The end of life cost is an essential cost element of building life cycle cost [1,3,7]. It refers to the cost associated with disposing an asset at the end of its service life including costs of inspections, deconstruction, demolition, disposing of damp material, or any other costs associated with the disposal operations [2,3,7].

Several techniques are commonly used in building demolition including mechanical demolition, deconstruction, and hybrid demolition [31]. The mechanical demolition heavily relies on equipment to demolish a building; it is less time-consuming and less labor-intensive than the other techniques [32]. Deconstruction is a relatively recent environmental friendly practice aligned with the concept of sustainable development [31,32]. Unlike mechanical demolition, deconstruction is more labor-intensive and carefully allows dismantling a building to maximize the recyclable and reusable materials; it significantly decreases the amount of waste placed on the environment by the building disposal operations [32,33]. The hybrid demolition combines both mechanical and deconstruction techniques to expedite the demolition process and to lower the cost [31].

With the increased demand for sustainable practices, particularly, by construction sector [10], it is expected that deconstruction technique will be the most appropriate option to demolish and recycle the building material. Until then, it might be imposed by law and regulations. However, there is no much information about the cost associated with building deconstruction operations, but, it is argued that it is the most economical demolition technique due to the associated income gained from material recycling and reuse [31,32].

The building is expected to generate a waste volume approximately equals 3,416 m^3 calculated by multiplying the building gross area, which equals 2,965 m^2, by a factor of 1.2676 m^3 waste per m^2. This factor was proposed by Solis-Guzman et al. [34] as a factor to estimate the waste generated from building demolition. To clear the site after deconstruction, the total waste will be transferred either to a recycling plant or to landfill sites. The average material transport in Kuala Lumpur is around 8 $/$m^3$ [35]. Accordingly, waste transport cost estimated to be around $27,328 (3,415 m^3 x 8 $/$m^3$). In a paper, Guy [33] estimated around 0.6 hour/m^2 as the require labor effort for building deconstruction. Based on this rate, around 162 labor hours (0.6 hour/m^2 x 2965 m^2) are required for building deconstruction. According to the National Construction Cost Center - Malaysia [36], the average labor rate in Kuala Lumpur in 2013 was around 3.2 $/hour, this yields a total labor cost for building deconstruction equals $518. By adding 10% of the total cost to cover the indirect cost such as supervision and inspections, the total building deconstruction budget will be $30,631 based on 2013 prices as summarized in Table 6.

To find the nominal future value when the deconstruction cost expected to occur, the average general historical inflation rate in Malaysia was used in equation 1 (see section 4.3) to find the future value in 2068 which is the expected end of building life cycle.

Table 6: *Building deconstruction cost estimate.*

No	Description	Area	Unit rate	Quantity	Unit cost	Total cost ($)
1	Site clearing and waste transport	2695 m2	1.2676 m3/m2	3416 m3	8 $/m3	27,328
2	Labor cost	2695 M2	0.06 hour/m2	162 hour	3.2 $/hour	518
3	Indirect cost 10%					2,785
4	Total cost based on 2013 prices					30,631
5	Total cost in 2068					173,014

5 Total Life Cycle Budget

The previous analysis of life cycle cost components and budget can be used as a life cycle cost baseline for the building. The life cycle cost baseline can be defined as a time-phased life cycle budget that includes the life cycle cost elements which apply along the whole building life cycle. The life cycle cost baseline is analogous to the cost performance baseline developed during building construction phase to track the actual construction cost. Therefore, the same principles of creating a cost baseline for building construction phase [37–39] can be applied to create a life cycle cost baseline along the whole building life cycle. First, the life cycle cost components should be identified, estimated, and most importantly projected over the whole building life cycle as discussed in the preceding sections. Second, the annual estimated life cycle cost budget can be tabulated and aggregated to generate the time-phased budget (yearly sums), then, the annual sums are accumulated to determine the rate at which the total life cycle cost is accumulating as shown in Table 7. The design and construction budget can be uniformly distributed over the design and construction duration; this is a recommended practice to develop cost baselines during building construction phase [37,39].

The annual values of life cycle cost can be used as cost control accounts. The cost control account is a management control point at which actual cost performance measurement and analysis takes place [38,39]; it forms a reporting and cost performance measurement checkpoint. Each allocated annual budget constitutes a control account for the corresponding cost element. The aggregated sums are also form control accounts but with higher level of details. The life cycle cost baseline in Table 7 is graphically depicted as a cumulative curve showing the corresponding cumulative life cycle cost value by the end of each year as shown in Figure 3.

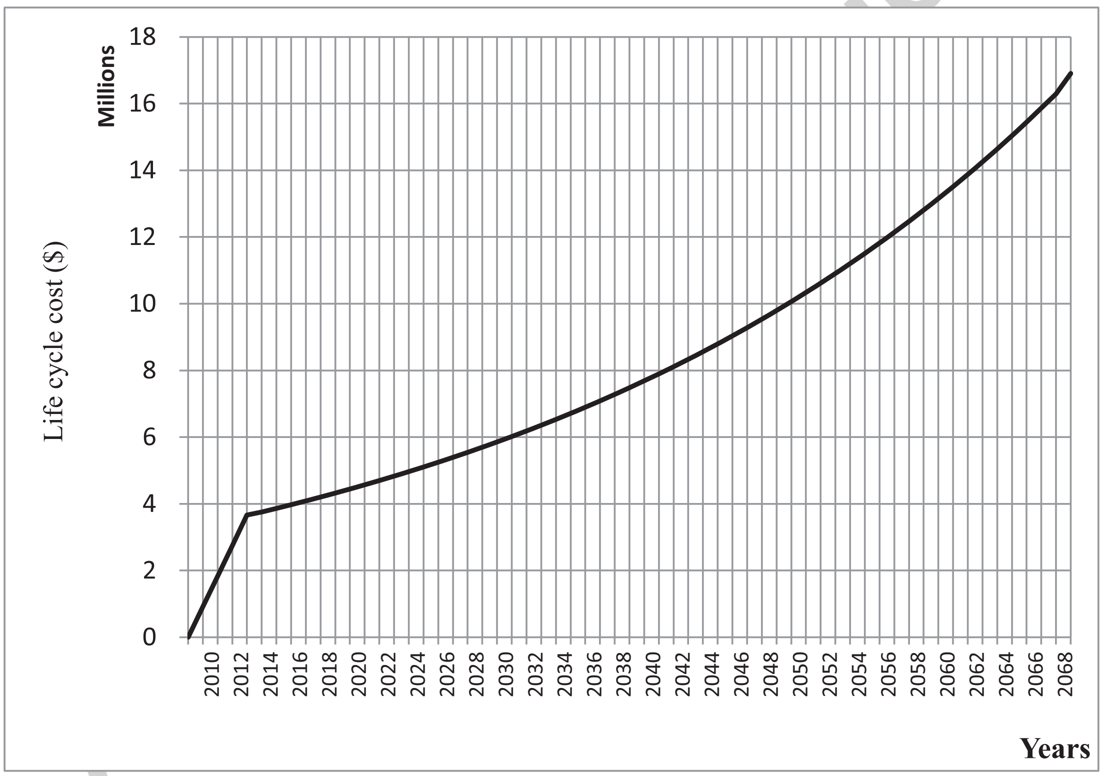


Figure 3: *Life cycle cost baseline*

The shape of the curve is determined by the amount of accumulated cost which affects the slope of the curve at any point in time. It can be noted in Figure 3 that the cost is sharply accelerating from 2009 to 2012. This is, indeed, natural since the sharp portion of the curve is solely determined by the uniformly distributed building design and construction budget. Starting from the year 2013, which is the building occupancy date, the life cycle cost curve accelerates moderately since the life cycle cost accumulates at lower rates than building construction phase. The curvature in the curve is explained by the exponential effect of price inflation on the life cycle cost.

Table 7: *Total estimated life cycle cost for the case study*

	Total life cycle cost ($)											
Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Design and construction cost	916,630	916,630	916,630	916,630								
Building operating cost					72,798	74,545	76,334	78,166	80,043	81,965	83,932	85,946
Maintenance cost					19,770	32,355	33,372	34,419	35,499	36,614	37,764	38,949
Total annual life cycle cost	916,630	916,630	916,630	916,630	92,568	106,900	109,706	112,585	115,542	118,579	121,696	124,895
Cumulative life cycle cost	916,630	1,833,259	2,749,889	3,666,518	3,759,086	3,865,986	3,975,692	4,088,277	4,203,819	4,322,398	4,444,094	4,568,989
Year	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Building operating cost	88,009	90,121	92,284	94,499	96,767	99,089	101,467	103,901	106,394	108,948	111,563	114,241
Maintenance cost	40,172	41,433	42,735	44,076	45,460	46,887	48,358	49,876	51,442	53,058	54,724	56,442
Total annual life cycle cost	128,181	131,554	135,019	138,575	142,227	145,976	149,825	153,777	157,836	162,006	166,287	170,683
Cumulative life cycle cost	4,697,170	4,828,724	4,963,743	5,102,318	5,244,545	5,390,521	5,540,346	5,694,123	5,851,959	6,013,965	6,180,252	6,350,935
Year	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**
Building operating cost	116,983	119,790	122,666	125,610	128,625	131,712	134,873	138,110	141,425	144,820	148,295	151,854
Maintenance cost	58,213	60,041	61,925	63,870	65,875	67,943	70,076	72,277	74,546	76,887	79,301	81,792
Total annual life cycle cost	175,196	179,831	184,591	189,480	194,500	199,655	204,949	210,387	215,971	221,707	227,596	233,646
Cumulative life cycle cost	6,526,131	6,705,962	6,890,553	7,080,033	7,274,533	7,474,188	7,679,137	7,889,524	8,105,495	8,327,202	8,554,798	8,788,444
Year	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**
Building operating cost	155,498	159,230	163,052	166,965	170,972	175,076	179,278	183,581	187,987	192,498	197,118	201,849
Maintenance cost	84,361	87,009	89,741	92,559	95,465	98,464	101,555	104,743	108,032	111,424	114,923	118,533
Total annual life cycle cost	239,859	246,239	252,793	259,524	266,437	273,540	280,833	288,324	296,019	303,922	312,041	320,382
Cumulative life cycle cost	9,028,303	9,274,542	9,527,335	9,786,859	10,053,296	10,326,836	10,607,669	10,895,993	11,192,012	11,495,934	11,807,975	12,128,357
Year	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**
Building operating cost	206,693	211,653	216,733	221,935	227,262	232,716	238,301	244,021	249,877	255,874	262,015	268,304
Maintenance cost	122,254	126,092	130,052	134,135	138,346	142,690	147,170	151,791	156,557	161,474	166,544	171,774
End of life cost												173,014
Total annual life cycle cost	328,947	337,745	346,785	356,070	365,608	375,406	385,471	395,812	406,434	417,348	428,559	613,092
Cumulative life cycle cost	12,457,304	12,795,049	13,141,834	13,497,904	13,863,512	14,238,918	14,624,389	15,020,201	15,426,635	15,843,983	16,272,542	16,885,634

6 Results and Discussion

The total estimated building life cycle cost in the nominal terms equals $16,885,634. This yields an average total life cycle cost of 6,266 $/m^2 ($16,885,634 / 2,695 m^2). This figure covers a period of 60 years and represents the total life cycle cost required for design and construction, building operating and maintenance, in addition to building deconstruction. Table 8 contains a summary breakdown of the estimated total life cycle costs and weights. The energy cost constitutes 48% of the total life cycle budget and this weight goes above 60% when the design and construction cost was excluded from the life cycle budget. This ranks the energy cost as the highest weight among the other life cycle cost components; it is more than double the estimated design and construction cost. The building maintenance cost forms 27% of the total life cycle budget which is also higher than the design and construction cost. Totally, the future cost of the building is around 3.6 times higher than its initial design and construction cost.

Table 8: *Total life cycle budget summary for the case study*

No	Description	Total life cycle cost ($)	Weight
1	Design and construction cost	3,666,518	22%
2	Building energy cost	8,076,352	48%
3	Building water and sewerage cost	337,911	2%
4	Building maintenance cost	4,631,839	27%
5	End of life cost	173,014	1%
6	**Total life cycle cost**	**16,885,634**	100%

The equivalent value of the total estimated life cycle cost can be found in the current time by discounting all future life cycle costs to a base date, 2016 for example, and by finding the equivalence of the formerly estimated design and construction cost in the same base year. Finding the equivalence is necessary to conduct economic analysis for different investment alternatives [3,4,8,16]. However, since the building is already under operation, this falls beyond the scope of this research.

As the largest single component in the estimated life cycle budget, the same analysis was repeated, but taking into account the past building performance to assess how much the energy saving constitutes from the total life cycle budget for the building. The average actual monthly energy consumption in 2014 was 10,955 kWh/month which yields an annual energy consumption equals to 131,460 kWh, which constitutes around 26.1% of the predicted annual energy consumption based on design simulations which equals 502,913 kWh/year. The corresponding actual energy cost for the same year was $20,410 as billed by the utility service provider, and hence, recalculating the life cycle cost of energy based on the actual energy performance, and using the same inflation rate, leads to a total life cycle cost of energy equals to $2,283,803. This figure represents the total life cycle cost of energy based on the recorded actual energy consumption and cost in 2014, and it constitutes 28.3% of the life cycle cost of energy which was calculated based on design predictions (see Table 1). This yields a life cycle cost saving of $5,792,549 which is the difference between the calculated life cycle cost of energy based on design simulations and the calculated life cycle cost based on actual energy consumption. This saving in energy cost alone reduces the total life cycle cost from $16,885,634 to $11,093,084, which corresponds to 34.3%.

Recalculating the life cycle cost based on the actual water and sewerage cost is not feasible since they constitute only 2% of the total life cycle budget. This is also the case for recalculating the life cycle cost considering the actual design and construction cost, because the difference between the actual and the estimation was insignificant from life cycle perspective. For building maintenance cost, it would be inaccurate to estimate the life cycle cost for building maintenance based on the actual performance for the first years of building operation. This is because that the maintenance cost in the first years is minimal and does not reflect the budget requirements for the subsequent years.

7 Conclusion

Life cycle costing is a powerful tool that allows cost quantification for relatively long period of time considering price changes. The technique has been theoretically explained in the literature; however, its implementation in reality is associated with some difficulties in obtaining the required cost variables, particularly, if the analysis is conducted to develop life cycle budgets in the nominal terms, in which future inflation/deflation rates for the different cost elements cannot be disregarded.

This research explains a theory in practice and demonstrates how the life cycle cost of a green building was analyzed and estimated for a period of 60 years. It is found that the future costs associated with building operation and maintenance, in addition to deconstruction are around 3.6 times higher than the design and construction cost of the building. Not surprisingly, the energy cost constitutes 48% of the total life cycle cost of the building, which is more than double the weight of the design and construction cost. Therefore, reducing energy consumption was found to be the most influential factor to reduce the total life cycle cost of the investigated green building.

The accuracy of the results is a function of the accuracy of the used life cycle cost variables. However, with more accurate information about the actual building performance become available with the course of time, or due to changing requirements and conditions, the estimated life cycle budget can be updated accordingly. The developed life cycle budget can be used as a life cycle cost performance baseline against which the actual life cycle cost spending can be tracked and compared.

Acknowledgment: The authors wish to thank the the Malaysian Real Estate and Housing Developers' Association (REHDA) for their collaboration in providing the required data. The authors also acknowledge the financial support provided by the Malaysian Ministry of Higher Education.

References:

[1] A. Boussabaine, R. Kirkham, Whole life-cycle costing: risk and risk responses, Blackwell Publishing Ltd, Oxford, UK, 2004.

[2] R. Flanagan, C. Jewell, G. Norman, Whole Life Appraisal for Construction, Blackwell Publishing Ltd, Oxford, UK, 2005.

[3] S.J. Kirk, A.J. Dell'isola, Life Cycle Costing for Design Professionals, 2nd ed., McGraw-Hill, Inc, United States of America, 1995.

[4] J.W. Bull, Life Cycle Costing for Construction, Taylor & Francis, London, United Kingdom, 2003. doi:10.4324/9780203487723.

[5] R.J. Cole, E. Sterner, Reconciling theory and practice of life-cycle costing, Build. Res. Inf. 28 (2000) 368–375. doi:10.1080/096132100418519.

[6] G. Norman, Life cycle costing, Prop. Manag. 8 (1990) 344–356. doi:10.1108/EUM0000000003380.

[7] ISO, Buildings and constructed assets - Service-life planning - Part 5: Life-cycle costing (ISO 15686-5:2008), 1st ed., International Organization for Standardization, Geneva, Switzerland, 2008.

[8] L. Blank, A. Tarquin, Engineering Economy, 7th ed., McGraw-Hill, Inc, New York, NY, 2012.

[9] Y. Asiedu, P. Gu, Product life cycle cost analysis: State of the art review, Int. J. Prod. Res. 36 (1998) 883–908. doi:10.1080/002075498193444.

[10] C. j Kibert, Sustainable Construction: Green Building Design and Delivery, 3rd ed., John Wiley & Sons Inc, Hoboken, New Jersey, USA, 2012.

[11] UNEP, Towards a Life Cycle Sustainability Assessment: Making informed choices on products, United Nations Environment Programme (UNEP), 2011. http://www.unep.org/pdf/UNEP_LifecycleInit_Dec_FINAL.pdf (accessed April 20, 2014).

[12] N.A.M. Rum, Z.A. Akasah, Implementing Life Cycle Costing in Malaysian Construction Industry: A Review, J. Civ. Eng. Archit. 6 (2012) 1202–1209.

[13] GBI, Non-Residential New Construction (NRNC): Design Reference Guide and Submission Format, Version 1.05, Green Building Index, Kuala Lumpur, Malaysia, 2011. http://www.greenbuildingindex.org/Resources/GBI Tools/GBI Design Reference Guide - Non-Residential New Construction (NRNC) V1.05.pdf (accessed May 12, 2014).

[14] GBI, Residential New Construction (NRNC): Design Reference Guide and Submission Format, Version 3.1, Green Building Index, Kuala Lumpur, Malaysia, 2014. http://www.greenbuildingindex.org/Resources/GBI Tools/RNC Reference Guide V3.1.pdf (accessed June 21, 2014).

[15] Central Bank of Malaysia, Rates and Statistics, Hist. Exch. Rate. (2016). http://www.bnm.gov.my/index.php?ch=statistic&pg=stats_exchangerates (accessed May 26, 2015).

[16] ISO, Buildings and constructed assets - Service life planning - Part 1: General principles/Framework (ISO 15686-1:2008), Vesion 2.2, International Organization of Standardization, Geneva, Switzerland, 2008.

[17] S.K. Fuller, S.R. Petersen, Life-cycle costing manual for the federal energy management program, U.S Government Printing Office, Washington, DC, 1996.

[18] M. Kishk, A. Al-Hajj, R. Pollock, G. Aouad, N. Bakis, M. Sun, Whole life costing in construction-A state of the art review, RICS Found. Res. Pap. 4 (2003) 1–39.

[19] T.E. Swarr, D. Hunkeler, W. Klöpffer, H.-L. Pesonen, A. Ciroth, A.C. Brent, et al., Environmental life-cycle costing: a code of practice, Int. J. Life Cycle Assess. 16 (2011) 389–391. doi:10.1007/s11367-011-0287-5.

[20] DOSM, Malaysia Economic Statistics - Time Series Report 2015, Department of Statistics Malaysia, 2015. https://www.statistics.gov.my/dosm/uploads/files/3_Time Series/Malaysia Time Series 2013/Penerbitan_Time_Series_2013.pdf (accessed May 15, 2015).

[21] World Bank, World Development Indicators, Inflation, Consum. Prices (Annual %). (2015). http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG/countries/MY?display=graph (accessed April 27, 2015).

[22] TNB, Pricing & Tariff, Electr. Pricing Tarif. (2015). http://www.tnb.com.my/tnb/business/for-commercial/pricing-tariff.html (accessed April 12, 2015).

[23] Energy Commission, Peninsular Malaysia Electricity Supply Industry Outlook 2014, Energy Commission, Putrajaya, Malaysia, 2014.

[24] TNB, Oil Price Movement and Its Impact on Electricity Tariff, Tenaga Nasional Berhad, Kuala Lumpur, 2014. http://www.tnb.com.my/tnb/application/uploads/energywatch/4282936d25e0a50168c8c5d64bfbdde2.pdf (accessed May 19, 2015).

[25] SYABAS, Water Tariff, (2015). http://www.syabas.com.my/consumer/water-bill-water-tariff (accessed April 20, 2015).

[26] SPAN, Water Prices and Rates, Water Rates 2011. (2014).

http://www.span.gov.my/index.php/en/statistic/water-statistic/water-rates (accessed May 20, 2015).

[27] National Water Commission, Sewerage Charge, Seweragre Stat. 2013. (2015). http://www.span.gov.my/ (accessed June 3, 2015).

[28] National Sewerage Company, Sewerage charge, (2015). http://www.iwk.com.my/v/customer/commercial (accessed June 3, 2015).

[29] Malaysia, Laws of Malaysia - Local Government Act 1976 (Reprint), The Commissioner of Law Revision, 2006. http://www.agc.gov.my/Akta/Vol. 4/Act 171.pdf (accessed July 3, 2015).

[30] A.L. Olanrewaju, A.-R. Abdul-Aziz, Building Maintenance Processes and Practices: The case of a Fast Developing Country, 1st ed., Springer-Verlag, Singapore, 2015. doi:DOI 10.1007/978-981-287-263-0.

[31] S.K. Pun, C. Liu, C. Langston, Case Study of Demolition Costs of Residential Buildings, Constr. Manag. Econ. 24 (2006) 967–976. doi:10.1080/01446190500512024.

[32] C.J. Kibert, J.L. Languell, Implementing Deconstruction in Florida: Materials Reuse Issues, Disassembly Techniques, Economics and Policy, 2000. http://www.cce.ufl.edu/projects/deconstruction/implementing-deconstruction-in-florida/final-report/#deconCosts (accessed August 21, 2015).

[33] B. Guy, The Optimization of Building Deconstruction for Department of Defense Facilities: Ft. McClellan Deconstruction Project, J. Green Build. 1 (2006) 102–122. doi:10.3992/jgb.1.1.102.

[34] J. Solís-Guzmán, M. Marrero, M.V. Montes-Delgado, A. Ramírez-de-Arellano, A Spanish Model for Quantification and Management of Construction Waste, Waste Manag. 29 (2009) 2542–2548. doi:10.1016/j.wasman.2009.05.009.

[35] Langdon and Seah, Spon's Asia Pacific Construction Costs Handbook, 5th ed., CRC Press LLC, 2015.

[36] CIDB, Construction Cost, Labor Wage Rate. (2014). http://www.cidb.gov.my/cidbv4/index.php?option=com_content&view=article&id=153&Itemid=421&lang=en (accessed May 15, 2015).

[37] S. Mubarak, Construction Project Scheduling and Control, 2nd ed., John Wiley & Sons, Inc, Hoboken, New Jersey, 2010.

[38] J.W. Hinze, Construction Planning and Scheduling, 4th ed., Pearson Prentice Hall, New Jersy, USA, 2011.

[39] Q.W. Fleming, J.M. Koppelman, Earned Value Project Management, 2nd editio, Project Management Institute, Inc, Pennsylvania, USA, 2000.

Highlights

- Our research demonstrates how to conduct a life cycle cost analysis for a green building.
- We estimated the total life cycle budget for a green building as a case study.
- The energy cost constitutes a weight of 48% of the total life cycle budget of the green building.
- The future costs are 3.6 times as high as building initial design and construction costs.