GLOBAL WARMING POTENTIAL OF A RESIDENTIAL BUILDING CONSTRUCTION IN MALAYSIA USING THE LIFE CYCLE ASSESSMENT (LCA) APPROACH

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Abstract
Building industry consumes substantial natural resources and produces considerable greenhouse gas emission. This paper presents a life cycle assessment approach to assess Global Warming Potential (GWP) of a residential building in Malaysia. The results show that building element that uses a cement-based material such as concrete contributed the highest GWP in comparison to other materials. In the construction phase, temporary timber formwork has the highest GWP. The results also show that the semi-detached house has higher GWP per m^2 compared to flats. The findings from this research can serve as the benchmark for LCA for buildings in Malaysia.

INTRODUCTION

Climate change and sustainable development are among major issues being discussed these days all over the world thoroughly. These issues demand improvement in government policies and industry standard. Building industry contributed considerably to the economy and social development but also responsible for excessive natural resource consumption and emission released (Arena and de Rosa, 2003). Recent research estimated that buildings responsible for 50% of Greenhouse Gas (GHG) emission and consume 40% of all primary energy globally (Asif et al., 2007).

Due to the increasing awareness of environmental issues, numerous studies have been conducted to reduce buildings' environmental impact including the implementation of Life Cycle Assessment (LCA) (Singh et al., 2011). Currently, LCA method is one of the assessment tools that being applied to assess the environmental impact thoroughly. LCA is globally accepted as a tool to improve the environmental impact of manufacturing processes and services in various industries and recently has been introduced to the building industry (Fava et al., 2009; Ortiz et al., 2009). LCA is a systematic analysis for quantifying industrial process and products by itemizing flows of energy and material use, wastes released to the environment and evaluating alternatives for environmental improvements (Fay et al., 2000; Guinée, 2012).

In Malaysia, the palm oil industry is the first sector to apply LCA as it was part of the requirement to export biodiesel to European countries (Ismail and Chen, 2010). Research on LCA has evolved to various industries in Malaysia since, ranging from electronics (Syafa et al., 2008), potable water production (Sharaai et al., 2009a, 2009b), electricity generation (Shafie et al., 2012), waste management (Onn and Yusoff, 2012) and buildings (Bin Marsono and Balasbaneh, 2015; Omar et al., 2014; Wan Omar et al., 2014; Wen et al., 2014).

The research on buildings primarily focused on the impact assessment of different materials and to highlight the benefit of integration of Industrialised Building System (IBS) in comparison to conventional construction system.

RESEARCH METHOD

This study follows the LCA method standardised by the ISO 14040 series. The ISO 14040 series describes the principal and framework for LCA which includes four stages namely goal and scope definition, Life Cycle Inventory (LCI), life-cycle impact assessment (LCIA) and interpretation (ISO, 2006a, 2006b).

Goal and scope definition

In this stage, it is important to select a suitable functional unit for the LCA study for validation in the interpretation stage. The functional unit selected in this study was 1 m^2 of Gross Floor Area (GFA), and the building lifespan was assumed to be 50 years as suggested by previous research (Abd Rashid and Yusoff, 2015). The case study is a semi-detached residential building, located in the district of Kuala Selangor, about 70 km from Kuala Lumpur. This building has an area of 218 m^2 with five bedrooms, two living rooms, a dining room, a kitchen, utility room and three bathrooms. It is two-storey high, and the primary structure is reinforced concrete with clay bricks as the building envelope as shown in Figure. 1.

The building life cycle was evaluated from cradle-to-gate within specific system boundaries outlined in Figure. 2. The site clearance works, external works and infrastructure works that cover the overall development were excluded.

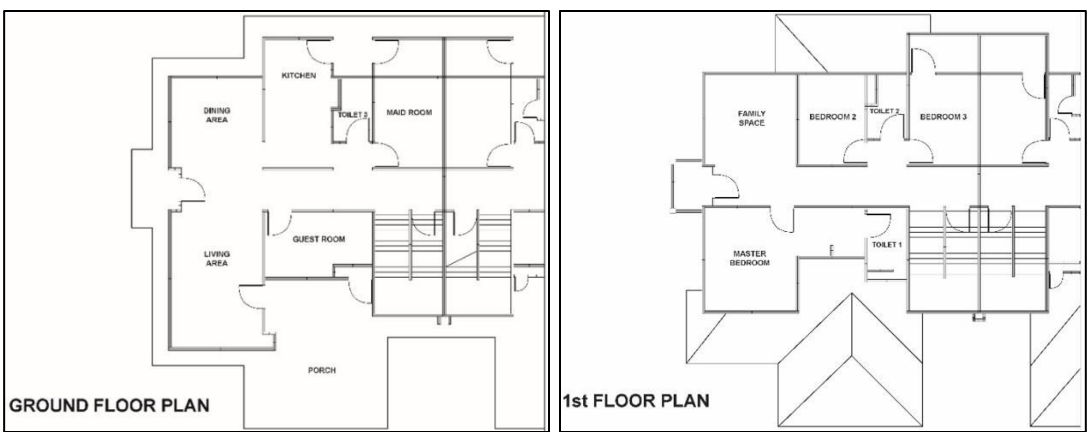

Figure 1. The building layout

The LCA modelling has been carried out in SimaPro V7.3.3 (PRé, 2015). Malaysia Life Cycle Inventory Database (MYLCID) was used in the LCI especially on raw materials such as cement and diesel to produce significant results for Malaysian scenario (MY-LCID, 2013). The Ecoinvent database was used due to limitation in the MYLCID. The database was adapted to Malaysian conditions by replacing the local electricity mix data set as suggested by Horváth and Szalay (2012).

Life Cycle Inventory

Pre-use phase

The data for LCI for the pre-use phase is obtained from the bill of quantities. The quantities are then divided into GFA of the building as shown in Table 1. Few assumptions have been considered due to the limitation of the databases as follows:

- An additional of 5% of material waste during construction was added as suggested by previous studies (Buchan et al., 2003; Rossi et al., 2012)
- The types and materials are limited to process data equipped in the MYLCID and Ecoinvent databases.
- Acrylic emulsion paint was substituted with alkyd paint due to the limitation in the databases.
- The transportation distances from the manufacturer to the construction site were assumed to be 300 km for all materials meanwhile, the distance is 50 km for ready-mix concrete, as suggested by (Wittstock et al., 2012).
- A 16-ton lorry was used to transport materials from manufacturers to site whereas a 24-ton ready-mix lorry was used to transport concretes.

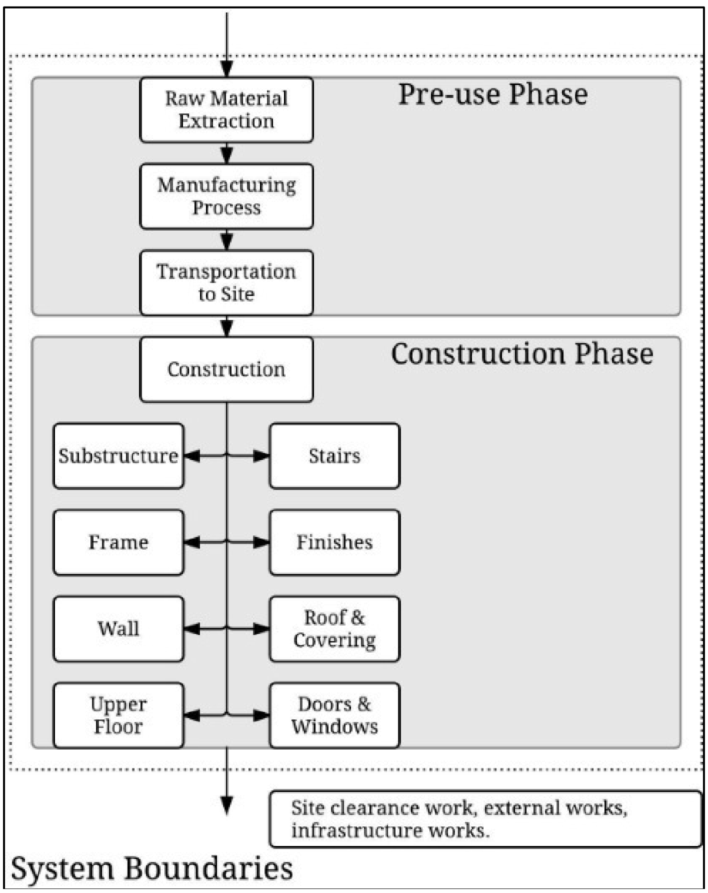

Figure 2. System boundaries of the life cycle model

Table 1. Quantity of materials used in the construction of the building

Item	Materials	Quantity	Quantity/m^2 GFA	Unit
A	*Substructure*			
	Excavation	153.50	0.70	m^3
	Hardcore	18.75	0.09	m^3
	Concrete Grade 7	8.50	0.04	m^3
	Concrete Grade 30	38.00	0.17	m^3
	Concrete Grade 35	18.50	0.08	m^3
	Reinforcement	6524.83	29.93	kg
	Formwork	5.91	0.03	m^3
B	*Frame*			
	Concrete Grade 30	31.95	0.15	m^3
	Reinforcement	4980.54	22.85	kg
	Formwork	7.46	0.03	m^3
C	*Upper Floor*			
	Concrete Grade 30	15.59	0.07	m^3
	Reinforcement	1222.54	5.61	kg
	Formwork	1.60	0.01	m^3
D	*Stairs*			
	Concrete Grade 30	4.50	0.02	m^3
	Reinforcement	375.00	1.72	kg
	Formwork	0.50	0.00	m^3
E	*Brick wall*			
	Clay brick			
	Half brick thick	474.00	2.17	m^2
	One brick thick	36.50	0.17	m^2
	Concrete block	0.02	0.00	m^2
F	*Roof and covering*			
	Concrete Grade 30	2.00	0.01	m^3
	Reinforcement	175.18	0.80	kg
	Formwork	0.26	0.00	m^3
	Wall plate	0.00	0.00	m^3
	Fascia board	0.00	0.00	m^3
	Painting wood	23.00	0.11	m^2
	Steel Roof Trusses	6812.50	31.25	kg
	Concrete roof coverings	272.50	1.25	m^2
G	*Finishes*			
	Cement screed	6.98	0.03	m^3
	Ceramic tiles	303.30	1.39	m^2
	Timber strip	53.70	0.25	m^2
	Plasterwork	29.20	0.13	m^3
	Painting	1635.80	7.50	m^2
	Ceiling	170.00	0.78	m^2

Construction phase

During construction, only three processes were taken into consideration specifically excavation works, transportation of the excavator to the construction site and temporary timber formwork. An excavator was assumed to be used during excavation works whereas, other installation works to be completed by manual labours. The transportation of the excavator was considered to be 50 km distance from the construction site by using a 40-ton low-loader. The formwork was expected to be used multiple times before disposal as suggested by Abdullah (2005).

Life cycle impact assessment (LCIA)

Blengini and Di Carlo (2010) suggested that the selection of indicators in the LCIA stage must be consistent with the ISO recommendations. Basically, there are two methods use in conducting LCIA, which is problem-oriented (midpoints) and damage-oriented methods (endpoint) (Abd Rashid and Yusoff, 2015). Midpoints are considered to be a point in the cause-effect chain of a particular impact category after the LCI before the endpoint (Bare et al., 2000). The midpoint assessment approach developed by Centre of Environmental Science (CML), Leiden University was used (Heijungs et al., 2009). Generally, common impact categories from CML 2001 were applied namely, global warming potential (GWP), acidification, ozone depletion (ODP) and eutrophication as suggested by Khasreen et al. (2009) although, for this research, only GWP will be assessed.

Interpretation

The final step in LCA is the interpretation of results. The results from the LCIA will be examined for robustness and sensitivity to inputs (Ochsendorf et al., 2011) and conclusions are drawn with reference to the goals and objectives of the LCA (ASTM Standards E1991-05, 2005). Subsequently, data validation will be conducted by comparing the results to other published research (Ochsendorf et al., 2011).

RESULTS AND DISCUSSION

The LCIA of materials used in the building was evaluated from cradle-to-gate i.e. from raw material extraction, manufacturing process and transportation to the site. Each building elements later converted to the functional unit of 1 m^2 of GFA. Figure 3 shows the LCIA of every element in the building.

Substructure elements have the highest impact for GWP (1.57E+02 kg CO2 eq) whilst the door is the lowest on all impact categories. Cement contributed the highest environmental impact due to high usage of concrete-based building elements such as in substructure, frame, stairs and finishes. Ceramic tiles for finishes and clay bricks for walls have also indicated high environmental impact compare to other elements. The construction process contributed only 4.70E+00 kg CO2 eq which largely contributed by the temporary formwork (3.74E+00 kg CO2 eq) as shown in Figure 4.

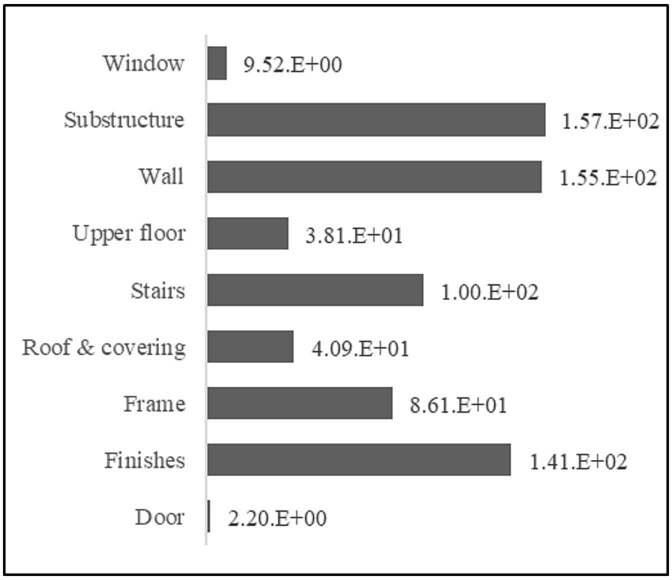

Figure 3. LCIA of the building using CML 2001 by building elements in pre-use phase

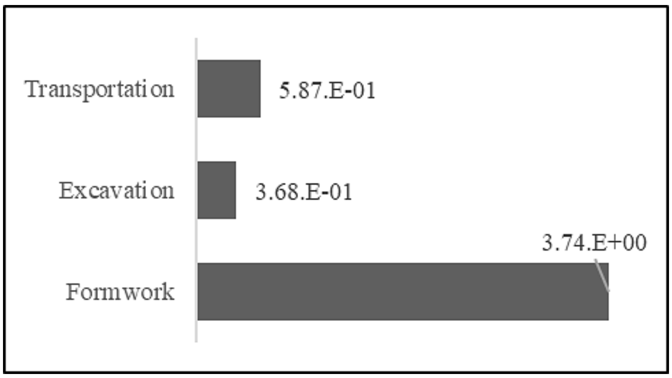

Figure 4. LCIA of the building using CML 2001 in the construction phase

Comparison with other studies

To complete the LCA process, the findings from this study will be compared to other published data for validation as shown in Table 2. For this purpose, only one research was used (Wen et al., 2014) as it is the only comparable data available in Malaysia with similar LCA method and functional unit. The GWP of the flats is much lower in comparison to this study by 3.91E+02 and 4.37E+02 kg CO2 eq.

Table 2. Comparison of GWP of the building with other research

Building	GWP (kg CO2 eq)	Gross Floor Area (m^2)	References
Flat (cast in situ)	3.44E+02	110.69	(Wen et al., 2014)
Flat (IBS)	2.98E+02	111.45	(Wen et al., 2014)
Semi-detached house	7.35E+02	218.00	This study

The lower impact from the flat due to the lower quantities per m^2 as most of the building elements such as substructure, walls, ceilings, floors, and roof were shared with multiples units. The specification for the flats was also not clearly defined explicitly. The different type of bricks, for example, may produce different results overall.

CONCLUSION

The results show that in general, the building elements related to the usage of concrete such as substructure, upper floor, stairs and frame have the highest impact per m^2 in comparison to other materials. Subsequently, clay bricks and ceramic tiles indicated high GWP while door and window have the lowest GWP. The construction has much lower GWP in comparison to the pre-use phase and most of the impact is contributed by temporary timber formwork. The results also show that the semi-detached house has a higher GWP per m^2 in comparison to flats due to most of the building elements are shared with multiple units. The findings from this study can serve as a benchmark for future LCA studies related to buildings in Malaysia.

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