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Carbon footprint of construction using industrialised building system

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Abstract. Industrialised Building System (IBS) is more sustainable to the environment as compared to the conventional construction methods. However, the construction industry in Malaysia has low acceptance towards IBS due to the resistance to change and also lack of awareness towards sustainability development. Therefore, it is important to study the amount carbon footprint produced by IBS during its manufacturing and construction stage, and also the amount of carbon footprint produced by one meter square of gross floor area of IBS construction using Life Cycle Assessment (LCA) to ease future research through the comparison of the carbon footprint of IBS with the conventional building system. As a result, a case study on a residential type of construction in the vicinity of Johor Bahru, Malaysia was carried out to obtain the necessary data and result. From the data analysis, the amount of greenhouse gases (GHG) for a residential type IBS construction based on the raw materials and resources involved to manufacture and construct IBS components is 0.127 tonnes fossil CO₂Eq per meter square. Raw material that contributed to the most amount of carbon footprint is Ordinary Portland Cement (OPC), followed by steel bars, autoclaved aerated blocks and diesel. The LCA data acquired will be very useful in implementing IBS in the residential type construction. As a result, the awareness towards sustainable construction using IBS can be improved.

1. Introduction

As a developing country, construction sector represents a significant percentage of Gross Domestic Product (GDP) per annum in Malaysia. Despite all the advantages brought by the construction industry to the country in terms of healthy economic growth and job opportunities, the industry also causes alarming environmental issues such as construction waste, depletion of natural resources due to raw material extraction for building materials, emission of greenhouse gases (GHG) to the atmosphere during the manufacturing of building materials and the construction stage and etc [1]. Even though Industrialised Building System (IBS) is more sustainable to the environment as compared to the conventional construction methods, the construction industry in Malaysia has low acceptance towards IBS due to the resistance to change and also lack of awareness towards sustainability development in this area [2]. Moreover, Malaysia still does not have reliable statistics to showcase the amount carbon footprint in IBS determined via LCA to further convince the decision making in adopting this system. Majority of the IBS product in Malaysia are originated from the United States, Germany and Australia with market share of 25%, 17% and 17% respectively. Malaysian's produced systems only account for



12% [3]. This indicates that there is a considerable room for improvement in the area of research and development of IBS in Malaysia. Most of the industries still holds preference towards conventional building system even though IBS was introduced for more than 50 years in Malaysia [4].

As a result, it is important to study the amount GHG produced by IBS during its manufacturing and construction stage using Life Cycle Assessment (LCA) to ease future research through the comparison of carbon footprint in IBS construction and the conventional building system. LCA is the most adopted framework in the world to evaluate the environmental load of processes and products during their life cycle from cradle to grave [5]. A case study on a residential type of construction in the vicinity of Johor Bahru, Malaysia was carried out to obtain the necessary data and result.

2. Literature review

2.1. IBS in Malaysia

Early 1960s marks the beginning of IBS in Malaysia when the Ministry of Housing and Local Government visited several European countries and evaluate their housing development program [6]. After their successful visit in the year 1964, the Government had launched pilot project on IBS to speed up the delivery time, built affordable and quality houses. This was important as there were no short in the increasing demand for construction due to the increase of population and improvement in the quality of life. For instance, the demand for residential buildings alone in Malaysia between the years 1995 and 2020 has been projected to be around 8,850,554 units, which includes 4,964,560 units of new housing units [7].

According to a research done by Abdul Kadir in year 2006 [3], 55 projects out of 100 residential projects used conventional building system as the main structural system. This is followed by various types of IBS including cast in-situ table form system with 16 projects and precast concrete wall and precast half slab system with 15 projects [4]. The frequency distribution on the type of structural building systems is shown in table 1. Table 1 also shows the type of project of the 100 residential projects. Ibrahim *et al.* [8] added, IBS system such as precast concrete hollow core slabs with concrete topping may come in different joint. This may reduce the life cycle for one product. Conventional account for the most maybe due to the flexibility of conventional construction methods which can suit all types of construction work. Cast in-situ table and tunnel form systems were only used for apartment (21 projects) and condominium (four projects) because the steel moulds are costly, and are only suitable to construct large number of houses. Apartments were the major share for full precast concrete systems with 11 projects [4]. Nowadays the number of IBS project has obviously increased in Malaysia construction industry, opening a demand for whole new sets of data up-to-date.

Table 1. Distribution on the type of residential project and structural building systems [4].

Type of residential project	Conventional	Cast in-situ table form	Cast in-situ tunnel form	Full precast concrete	IBS Composite	Block	Timber	Total
Apartment	21	13	8	11	1	Nil	Nil	54
Condominium	5	3	1	1	Nil	Nil	Nil	10
Terrace house	19	Nil	Nil	2	2	1	1	25
Bungalow	4	Nil	Nil	1	Nil	Nil	Nil	5
Semi-detached	6	Nil	Nil	Nil	Nil	Nil	Nil	6
Total	55	16	9	15	3	1	1	100

Today, the use of IBS as a method of construction in the Malaysian construction industry is evolving. The obligation to implement IBS serves both to improve performance and quality in

construction, as well as to minimize dependency on unskilled foreign labour in the construction market [2]. Previously in 2002, it was reported that at least 21 suppliers and manufacturers are actively involved in the dissemination of IBS in Malaysia [3]. As of December 2013, it was reported that there are 171 suppliers and manufacturers actively involved in the dissemination of IBS, of which only 5 of them are bumiputera. Selangor contributed the most with total of 67 suppliers and manufacturers [9]. Although members of the industry are open to the idea of IBS, a major portion of the industry stakeholders are indifferent, perhaps due to resistance towards change, insufficient information and lack of technology transfer method to support feasibility of change to IBS [10]. In this case, it has been proven that it is difficult to introduce new method and technologies in the construction sector. Construction sector is known as a traditional sector that can be characterised as reluctant and even resistant to change [11].

2.2. LCA tools related to construction industry

There are many types of tools that can be used for environmental assessment. As summarised by Ortiz *et al.* [5], these tools have been classified according to three levels. Level 3 is called “Whole building assessment framework or systems” and consists of tools such as BREEAM, LEED, GBI and MyCREST. Level 2 is titled “Whole building design decision or decision support tools” and uses tools such as LISA, Ecoquantum, Envest, ATHENA and BEE. Finally level 1 is for product comparison tools and includes Gabi, SimaPro, TEAM and LCAiT. Some databases used for environmental evaluation are CML, DEAM TM, Ecoinvent Data, GaBi 4 Professional, IO-database for Denmark 1999, Simapro database, the Boustead Model 5.0 and US Life cycle inventory database [5]. Instead of analysing an environmental assessment tools, this study will focus on Life Cycle Assessment (LCA), a much more detailed process compared to rating tools. LCA is a tool to investigate environmental burdens of a product or process, considering the whole life cycle, from cradle to grave [12]. All aspects considering natural environment, human health and resource depletion are taken into account and together with the life cycle perspective, LCA avoids problem-shifting between different life cycle stages, between regions and between environmental problems [13]. Previous tools and databases vary according to users, application, data, geographical location and scope [5]. The data represents conditions in industrialized countries. Data from developing and emerging countries, however, is still lacking [14]. For example the use of European and American database may not lead to correct decisions in developing countries [5].

2.3. LCA studies of building materials

An LCA study done in Spain by Cuchi (2007), shows the amount of energy invested in manufacturing some specific materials for one square metre (considering the gross floor area) in a standard building equals the amount of energy produced from the combustion of more than 150 L of petrol. Figure 1 and figure 2 show the relative contribution of the main building materials to the primary energy demand and CO₂ emissions associated with a square metre in a Spanish standard block of flats. The high impact of commonly used materials such as steel, cement and ceramics is notable [15].

Another LCA study did by Bribian *et al.* [16] which to evaluate certain energy and environmental specifications of different building materials, analysing their possibilities for improvement and providing guidelines for materials selection. In this study, one kg of material is the selected functional unit and the stages considered are the material manufacturing, the transportation from production plant to building site, the construction and demolition of the building, and the final disposal of the product. The study was carried out according to a static focus, so the life cycle inventories include intermediate values of the current processes within the system analysed, without analysing their variation over time. The software tool used in the study is SimaPro v7.1.8. In the manufacture stage, the supply of starting materials, the associated transport needs and the factory manufacturing processes of the different construction materials analysed are considered. Regarding transport from the production plant to the building site, a 20 to 28-tonne lorry covering an average distance of 100 km has been considered. A sensitivity assessment for other means of transport has also been developed [17].

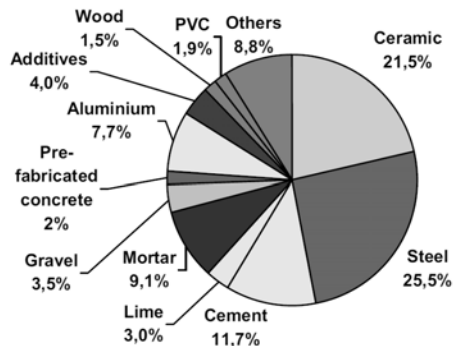


Figure 1. Contribution of energy demand for the manufacturing of construction materials per square meter of floor [14].

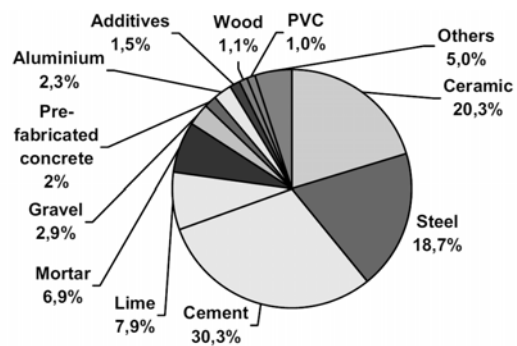


Figure 2. Contribution of carbon dioxide emissions for the manufacturing of construction materials per square meter of floor [14].

Table 2. Impact calculation coefficients for transport stage from production plant to building site of 1 tonne [16].

Impact Category	Lorry, Road (m1)	Freight Rail (m2)	Transoceanic Freight Ship (m3)
Primary Energy Demand (MJ-Eq/km)	3.266	0.751	0.170
Global Warming Potential (kg CO ₂ -Eq/km)	0.193	0.039	0.011
Water Demand (l/km)	1.466	1.115	0.097

Table 3. LCA results for cement and concrete [16].

Building Product	Density (kg/m ³)	Thermal Conductivity (W/mK)	Primary Energy Demand (MJ-Eq/kg)	Global Warming Potential (kg CO ₂ -Eq/kg)	Water Demand (l/kg)
Cement	3150	1.4	4.235	0.819	3.937
Cement Mortar	1525	0.7	2.171	0.241	3.329
Reinforced Concrete	2546	2.3	1.802	0.179	2.768
Concrete	2380	1.65	1.105	0.137	2.045

3. Methodology

The information gathered for this study were obtained through site visits and through interviews with people who are related to the study such as the site engineer, senior site supervisor, casting plant production manager and etc. The interviewees have at least 5 years of experience in a similar nature of construction works from the selected site. During site visits, observation was done thoroughly to identify the type of IBS components utilised in the structure, the manufacturing process of the IBS components and also the construction process of the structure. These data leads to the amount of carbon footprint released by the IBS components of the structure. The site was selected based on several criteria, which are:

- i. More than 80% of the structure was constructed using IBS system.

- ii. The developer follows the IBS criteria set by CIDB strictly, proven by the accreditation obtained from various local and international accreditation bodies.
- iii. The site is located in Johor Bahru vicinity and the permission to enter the site was granted by the developer.
- iv. The type of project was residential type.
- v. The construction stage and duration reached the practical completion of at least 90% during the research period.

After obtaining the data and information, the “Carbon Calculator” produced by Environmental Agency, UK was used to analyze the amount of carbon footprint, also known as the carbon dioxide equivalency (CO₂Eq) emitted during the manufacturing and construction of housing using IBS. CO₂Eq is calculated through the multiplication of materials (plus unit of distance travelled) by the emission factor associate with that material. Estimates of mobile plant fuel mass consumption is derived by multiplying the hours of operation by the kW rating of the engine and by the appropriate fuel mass consumption rates.

4. Result and discussion

The selected residential type construction project is situated at Taman Skudai Indah 2, about 4.8 km from Universiti Teknologi Malaysia. The project consists of sixty (60) units of 3-storey cluster residential house. The total built up area of one (1) triple-storey cluster residential house is 315 meter squares. Data was taken up to 90% of completion. The IBS construction site is named as Site-A. The manufacturing processes of precast concrete components used in Site-A was observed in Site-B, an IBS components casting plant situated at Lima Kedai, Skudai, Johor, which is about 6.0 km away from Site-A.

4.1. Types of IBS component at Site-A

Types of IBS component which were identified in Site-A were precast concrete beams, precast concrete wall panels, precast concrete slabs, in-situ steel formwork shear wall, and lightweight concrete blocks wall. The structure has more than 80% of its components constructed using IBS system.

Precast concrete beams, precast concrete suspended slabs and precast wall panels were produced in the casting plant owned by the developer, which is named as Site-B. The components were transported to Site-A based on the construction timeline to avoid overcrowding at Site-A. The 13 meter long shear wall was constructed via reusable steel formwork instead of being precast at Site-B because it is not practical to transport such a large panel from the casting plant to the construction site. Lightweight concrete blocks which replaced the usage of bricks in conventional construction were not produced in Site-B. The blocks were purchased from other manufacturers and transported to the site.

Figure 3 shows that precast concrete slabs have the highest percentage by volume, which is 36.6% among all other IBS components, equivalent to 29.21 m³. This is because the entire first floor and second floor of the structure was constructed using precast concrete slabs which consist of a large area of 162.3 m².

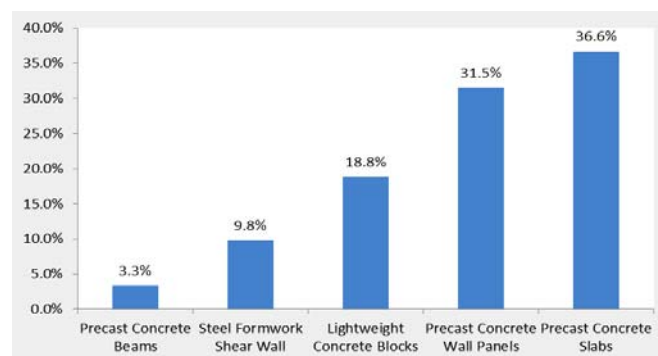


Figure 3. The composition of IBS components by percentage of volume.

4.2. Manufacturing and construction processes of IBS

The manufacturing processes began with the weighing of the raw materials, namely Ordinary Portland Cement, fine aggregates, coarse aggregates and water for the precast concrete components. The raw materials were mixed in the batching plant and poured into the concrete truck mixer to be transported to a location where steel moulds customised to produce the precast concrete components were located. The concrete mix was poured into the steel moulds where steel bars and wire mesh were fixed prior to concrete pouring. After the concrete hardened, the steel moulds were removed and the concrete components were cured. Prior to delivery to Site-A, the concrete components are refined to ensure that they adhere to the quality measurements. From the manufacturing processes, elements that could contribute to carbon footprint were raw materials used to produce precast concrete components, diesel and electricity used to operate batching plant and diesel to operate concrete truck mixer.

In the construction stage, the concrete mix was transported to Site-A to construct in-situ steel formwork shear wall. The lightweight concrete blocks were bonded using rendering mortar to form wall panels. Precast concrete components were transported to the site using trucks and were located into place using a crane. Elements that contributed to carbon footprint during the construction stage were raw materials to construct steel formwork shear wall, lightweight concrete blocks, rendering mortar for lightweight concrete blocks, diesel used to transport concrete mix and precast concrete components from Site-B to Site-A and diesel used to operate heavy cranes.

4.3. Carbon footprint analysis

The quantifying of carbon footprint was done by the method discussed in the previous section. In table 4, it is obvious that Ordinary Portland Cement (OPC) has the highest amount of carbon footprint among all other raw materials, which is 23.965 tonnes of fossil CO₂Eq even though its quantity is lower than the quantity of 20mm aggregates and fine aggregates. This is highly related to the high amount of embodied carbon in the manufacturing process of cement that requires heating up to 1400 degree Celsius. Steel bar has the second highest amount of carbon footprint, which is 7.254 tonnes of fossil CO₂Eq. Despite having a relatively small quantity, which is about 3.1% out of the total tonnage of raw materials, steel bars contributed to 17.72% of the total carbon footprint in the IBS manufacturing and construction processes. This phenomenon is related to the hot-rolled process in steel bar manufacturing process, normally with coal, which is a considerable CO₂ source. Autoclaved aerated blocks, which are cured using steams, produced a carbon footprint of 3.686 tonnes fossil CO₂Eq, is ranked the third in table 4. Therefore, we can observe that raw materials that require complex manufacturing processes, such as OPC, steel bars and autoclaved aerated blocks produce more carbon footprint compared natural materials such as coarse and fine aggregates.

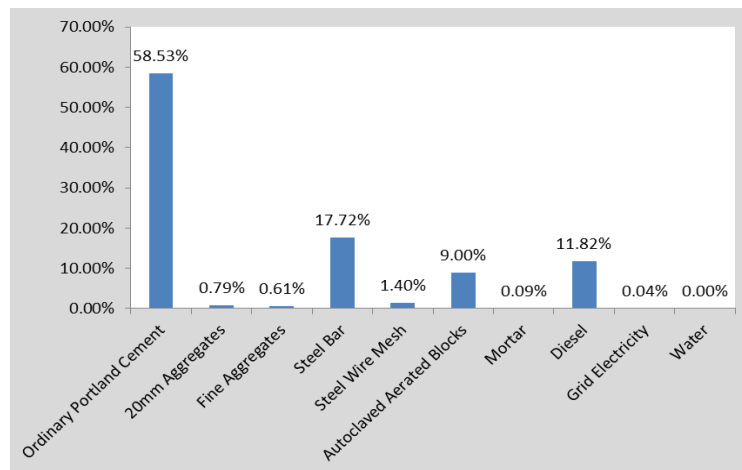
From table 5, diesel produced the highest amount of carbon footprint in the plant and equipment category, which is 4.841 tonnes fossil CO₂Eq. Diesel, in this study, is consumed to operate batching plant, concrete truck mixer, crawler crane and trucks. In the table, we can observe that water has no carbon footprint due to its low embodied energy. According to figure 4 when the carbon footprint in raw materials category and emissions from plant and equipment category is compared, OPC has the highest percentage of carbon footprint, which is 58.53%. This is followed by steel bar (17.72%), diesel (11.82%) and autoclaved aerated blocks (9.0%) respectively.

Table 4. Carbon footprint in IBS raw materials.

Raw Material	Embodied tCO ₂ Eq Per Tonne of Material	Quantity (Tonnes)	Carbon Footprint (Tonnes Fossil CO ₂ Eq)
Ordinary Portland Cement	0.74	32.3850	23.965
20 mm Aggregates	0.005	64.7052	0.324
Fine Aggregates	0.005	48.5775	0.248
Steel Bars	1.40	5.1816	7.254
Steel Wire Mesh	0.269	1.9431	0.575
Autoclaved Aerated Blocks	0.31	11.988	3.686
Mortar (1:1:6 cement: lime: sand mix)	0.17	0.200	0.035
Total			36.087

Table 5. Carbon footprint from the emissions from plant and equipment.

Emissions	Embodied tCO ₂ Eq Per Unit of Material	Quantity (Unit)	Carbon Footprint (Tonnes Fossil CO ₂ Eq)
Diesel (litres)	0.0031761	1524.15	4.841
Grid Electricity (kWh)	0.0005937	30	0.018
Water (litres)	0.00000034	200	0
Total			4.859

**Figure 4.** Tonnes fossil CO₂Eq classified according to raw material and plant and equipment.

4.4. Amount of carbon footprint by 1 meter square of gross floor area

The total amount of carbon footprint for the structure is 41 tonnes fossil CO₂Eq. Divided by its total build up area, which is equivalent to 315 m², we can obtain the amount of carbon footprint per meter square equals to 0.127 tonnes fossil CO₂Eq.

5. Conclusion

From this study, it can be concluded that OPC, steel bar, diesel and autoclaved aerated blocks contributed to the most significant amount of carbon footprint. The amount of carbon footprint can be minimized by replacing the raw materials used partly or entirely with materials with lower embodied energy. For example, the amount of OPC can be reduced by replacing it with a portion of ground granulated furnace slag or fly ash which has lower embodied carbon content. The estimated amount of carbon footprint generated per floor area for the IBS structure in this study is 0.127 tonnes fossil CO₂Eq per square meter. This data is useful to estimate the amount of carbon footprint for other IBS structures with similar properties by multiplying the total build up area with the factor of 0.127 tonnes fossil CO₂Eq.

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