Carbon Footprint Assessment of Hostel Building Construction Using the Industrialized Building System In Pauh Putra, Perlis

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Abstract
This study performs a carbon footprint (CF) assessment in carbon dioxide equivalent tons (tCO₂eq) for hostel building construction in Perlis, Malaysia, through a case study by using the Industrialized Building System construction method. Life cycle assessment from cradle-to-gate is conducted to calculate the CF produced by manufacturing prefabricated sandwich panels (Prefab-SP) for machinery operation and their actual site installation stages. Results show that the actual site installation of Prefab-SP component requires the extensive use of an excavator leaves a significantly high CF of 81.59 tCO₂eq (34.00%), especially during the completion of floor construction. Building work contributes a notable CF of 159.32 tCO₂eq (63.87%), followed by preliminary work, foundation, and earthwork with 35.08 (14.06%), 34.30 (13.75%), and 20.76 (14.06%) tCO₂eq, respectively. The shortcrete mixture used for plastering works releases a high CF of 360.04 tCO₂eq (73.11%) due to its high cement consumption and high embodied energy factor of extraction and production. Given the magnitude of the CF spike from the construction phase, its implications are expected to elicit the attention of policymakers in setting sustainability reduction targets for construction phases.

Keywords: Carbon footprint, Industrialized building system, Sustainability building construction, Carbon emission

1. Introduction
Anthropic acts on the environment are gaining attention from the global community and require the establishment of effective strategies to manage their effects, such as global warming, and creation of alternative approaches for climate change mitigation. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2013 stated that climate warming via the atmosphere and oceans is indisputable; it results in reductions in snow and ice, increments in sea levels, and increased accumulation of greenhouse gases (GHGs). Nearly the entire planet has experienced surface warming according to the observed surface temperature change from 1901 to 2012 [1]. The GHG emissions between 2000 and 2010 increased on the average by 1.0 GtCO₂eq (2.2%) compared with 0.4 GtCO₂eq (1.3%) between 1970 and 2000.
Malaysia, as a participant in the United Nations’ Framework Convention on Climate Change, has voluntarily committed to reduce its emission intensity per unit of gross domestic product (GDP) by 40% in 2020 in comparison with its emissions in 2002 [2]. In the 21st Conference of the Parties in Paris, the country revealed its intent to reduce its GHG emission intensity by 45% per unit of GDP in 2030 relative to its emission intensity in 2005, following the Intended Nationally Determined Contribution. Malaysia is in the process of endorsing the Paris Agreement, which will soon replace the Kyoto Protocol that expires in 2020; this would allow the country to participate strongly in the reduction of global carbon emissions. Malaysia has presented its GHG inventory for 2011 that includes sectoral sources of GHG emissions [3]. The inventory shows that the energy sector is the primary source of GHG emissions, followed by waste, industrial process, and agricultural sectors. Out of the 80% energy sector emissions, the largest GHG emissions are from energy industries, transport and manufacturing, and construction sectors.

Malaysia’s construction sector foresees the rapid growth of the construction industry. The sector’s contribution to GDP was 5.9% in 2017, and the total industry growth for the year was 6.7%. Despite the revision of mega projects by the government and the slowdown in the global construction sector, Malaysia’s domestic construction industry recorded MYR 35.4 million’s worth of construction work for the first half of 2018 [4]. Many benefits, such as healthy economic growth, increased job opportunities, and improved social infrastructures are brought about by the construction industry [5] but this industry causes alarming environmental issues, including depletion of natural resources due to raw material extraction for building materials and emission of GHGs to the environment. Sustainability in the construction industry relies on the creation and responsible maintenance of a healthy, well-built environment with regard to ecological principles and efficient use of resources (should provide first-rate responses to current environmental and socio-economic issues, [6]. In 1964, the Malaysian government introduced the Industrial Building System (IBS) for which utility components are built offsite to promote sustainable construction deliverables. Offering sustainability performance criteria, this system is superior because of its production environment, minimal construction waste, low energy consumption of building materials, short construction period, and good working conditions [7, 8].

Policies have been enforced through the Treasury Circular Letter (referred to as Surat Pekeliling Perbendaharaan Bil 7/2008) by the Malaysian government to encourage IBS adoption. The circular states that public projects worth more than MYR 10 million must incorporate 70% of IBS components as part of the contract document for tender [9]. However, after more than 50 years, this industry still has a low adoption rate of modern IBS technology in favor of the conventional construction method. Approximately 42% and 70% of government and private projects, respectively, use IBS technology. Serious challenges in IBS implementation continue to change the industry’s perception of this modern construction method. Traditional construction players are already familiar with the conventional method of building. As such, they are unwilling to make the transition to IBS despite its numerous benefits.

This study applies half life cycle assessment (LCA) to identify the CF in tons of carbon dioxide equivalent (tCO$_2$eq) during the manufacturing and installation of prefabricated sandwich panels (Prefab-SP) in student hostel buildings in Pauh Putra, Perlis, Malaysia. The specific objective is to calculate CF, which are the cause of the high GHG emissions from machine and building materials throughout construction work. Subsequently, environmental management improvements can be made.

1.1 LCA Tools Associated with Carbon Emission and the Construction Industry

The internationally standardized LCA method is beneficial to decision making because it can be used to review sustainability initiatives during the entire life cycle of buildings, which includes design, detailing, delivery, and deconstruction phase. Malaysian Palm Oil Board used full LCA or cradle-to-grave analysis to assess the sustainability of palm oil production, particularly its potential environmental implications [10]. Afterward, full LCA was applied to other industries, such as electronics, consumer goods, electricity generation, waste management, and buildings [11-15]. SIRIM Berhad in Malaysia has been tasked to build a national life cycle inventory to expedite efforts by these industries to use LCA.

In building construction, the use of LCA has focused on the impact assessment of different building materials. Marsono and Balasbaneh, (2015) found that the new building scheme that combines timber with
Precast concrete can improve the structural stability of timber, thereby endowing this material an increased life span and reduced CO$_2$ emission. Rashid et al., (2017) reported that residential buildings in Malaysia have a high global warming potential because the use of primary raw materials, such as concrete, in the pre-use phase of substructures contributes a high carbon emission of $3.65 \times 10^2$ kg-CO$_{2}$eq. Shafiq et al., (2018) used LCA to assess factual recurrent impacts of CF on conventional housing in tropical regions; they justified the importance of including CF impacts in pre-emptive mitigation toward sustainability at the initial stage of housing projects. The primary CO$_2$ contributors are ceramic tiles, false ceilings, plaster, and roof tiles, which are also prevailing top materials. Traditional diesel releases high carbon emission, which is roughly 86 wt.%. It is a remarkable source of global GHGs, which implies a practicability for this substance to produce high carbon emissions for a similar quantity of other burned fuels. Hulail et al., (2016) studied the CF of road pavement rehabilitation. They suggested that deliberate equipment selection can decrease the environmental release up to 10% for foundation piling work. High engine capacities and prolonged use of equipment, such as milling machines onsite result in the release of high CO$_2$ emission to the environment.

IBS is a term conceived by the industry and government in Malaysia to present the adoption of sustainability construction industrialization and use of prefabrication of components in building construction. These components are manufactured in a controlled environment and are transported, and assembled into structures that provide high performance, quality, and sustainability in construction [20]. They reduce actual site activities and risks related to occupational safety and health and alleviate the dependency on unskilled foreign labourers [21]. The implementation of IBS in the Malaysian construction industry is evolving and currently consists of a modern precast component system, fabricated steel structures, a mould system, a modular block system, and prefabricated timber.

2. Research Methods

LCA

LCA was conducted in this current study at four levels of (a) goal and scope outlining, (b) inventory evaluation, (c) impact assessment, and (d) final interpretation as depicted in the Result and Discussion section.

Goal and Scope Definition

The current study aims to assess CF emission produced by primary machinery during the manufacturing of Prefab-SP and their actual site installation in five-story hostel buildings. The scope covers a built-up area of approximately 538.8 m$^2$ with a total area of 24,124.6 m$^2$ located at Universiti Malaysia Perlis. The inventory analysis includes the life cycle of energy consumption for machinery operation and materials for Prefab-SP installation in accordance with the construction stages. The inventory transportation data of the IBS component from a factory in Perak about 300 km, to the construction site were disregarded, which means that the environmental performance interpretation of materials is not directly related to localization. The embodied energy (EE) generated by Prefab-SP made of lightweight polystyrene beads (PBs) was also disregarded due to insufficient information.

System Boundaries

To determine the boundaries of the study, LCA was divided into the following stages: material acquisition, construction, operation and maintenance, and disposal (Figure 1).
The assessment subjects included machinery and materials that cover the Prefab-SP manufacturing processes, type of machinery, onsite materials, engine capacity (EC), duration of operation, and electricity and diesel consumption. The data were collected and verified by experienced respondents, such as managers, engineers, and Universiti Malaysia Perlis Project Management Office’s personnel. The bill of quantities and architectural and engineering (AE) drawing specification were used as the source to compute the amount of materials and actual site work. The amounts of fuel and electricity consumed during the manufacturing and construction stages were calculated by analysing data from standard Malaysian estimates and the site office.

**Inventory Analysis**

The life cycle inventory (LCI) phase of LCA considers the amount of each input and output for processes that occur during the life cycle of a product or system. Data inventory is an interactive process where data are constantly being updated as this technology is considered new in Malaysia.

**Inventory of Machinery Operation of Prefab-SP Manufacturing**

The inventory data of the manufacturing processes covers, type of machinery and EC used including boiler of 1047 kW/h EC, pre-expander of 5.5 kW/h EC, block moulder, 2D-computer numerical control (CNC) cutter, straightener/cutter, stitcher, and bender of 384 kW/h EC for each machine for operation period of 8 hour per day. For each series of expended polystyrene (EPS) block production, a steam boiler was used to initiate six to eight bars of steam and obtain the processing temperatures required in the semi-automated plant. The raw PB were weighed and screened to obtain the refined formation of 80% by weight. They were combined with 20% recycled EPS in the silos. Then, the PBs were heated via a series of physical–chemical pre-expansion processes.

Next, the bead mixture was steamed at a temperature of 90 °C and later shifted to a particular silo for air drying during maturation. A block moulder was used to weld, compress, and dry the dilated PB blocks. As a result, they become swollen due to water vapour. Thus, the completely adjoining interstices between the PBs developed a homogeneous block of foam following the welding process. After cooling, an automated 2D-CNC hot-wire high-precision pantograph cutter was used for the final cutting of dried SP into specific sizes and shapes. A straightener and cutter were used for unwinding, straightening, and cutting longitudinal wires of 20 loading coils to make galvanized flat steel meshes with automated cross wires welded at a variable pitch. The stitching procedure produced SP with two or four flat straight welded wire meshes and one or two panel blocks according to the client order. Afterward, bending machines were used to assemble the accessories, such as angle mesh, and flat mesh onto the SP.
Inventory of Machinery Operation and Construction Stages

For machinery inventory, diesel was used as the main source of energy (Table 1). The total 10,920 litre fuels with a density of 0.850 kg/l transported from main supply in Pulau Pinang to the construction site every week was considered the fuel transportation inventory value.

Inventory of Construction Materials for Prefab-Installation

Table 2 summarizes the quantity and density of materials and their EE factors. Table 3 shows the total quantity of Prefab-SP for a typical four-rooms hostel house estimated for all hallway floor panels, staircases, and landings estimated in accordance with given AE design drawings. Every item was calculated discretely and categorized in accordance with its base material, such as concrete, and fine aggregate. In the case of insufficient data, standard material specifications were inferred after consulting with the project architect. Table 3 summarizes the quantity and density of materials and their EE factors.

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**Table 1**: Machinery operation for construction work breakdowns

| Stages          | Work breakdowns | Machinery       | EC (kW/h) | Duration (hour) | Fuel usage (litre) |
|-----------------|-----------------|-----------------|-----------|-----------------|-------------------|
| Preliminary     | Site clearing   | Excavator       | 110       | 160             | 4224              |
|                 |                 | Back pusher     | 59        | 54              | 764.6             |
|                 |                 | Backhoe         | 69        | 34              | 563               |
|                 | Unloading       | Excavator       | *         | 80              | 2112              |
|                 | materials       |                 |           |                 |                   |
|                 | Repair access   | Excavator       | *         | 80              | 2112              |
|                 | road            | Roller compactor| 21        | 24              | 121               |
| Earthwork       | Cutting and filling | Excavator     | *         | 96              | 2534.4            |
|                 |                 | Bulldozer       | 96        | 48              | 1105.9            |
|                 | Levelling       | Excavator       | *         | 64              | 1689.6            |
|                 |                 | Backhoe         | *         | 32              | 529.9             |
| Foundation      | Unloading tower | Mobile crane    | 200       | 56              | 2688              |
|                 | crane parts     |                 |           |                 |                   |
|                 | Unloading       | Excavator       | *         | 32              | 844.8             |
|                 | materials       | Mobile crane    | *         | 40              | 1920              |
|                 | Raft foundation | Excavator       | *         | 160             | 4224              |
| Building        | Unloading       | Mobile crane    | *         | 80              | 3840              |
|                 | materials       | Truck           | 262.5     | 90              | 5670              |
|                 | Wall construction| Generator set  | 200       | 160             | 7680              |
|                 | Concreting      | Generator set   | *         | 160             | 7680              |
|                 |                 | Concrete truck mixer | 247.5 | 120            | 7128              |
|                 | Floor construction| Excavator     | *         | 200             | 5280              |
|                 |                 | Crawler crane   | 200       | 160             | 7680              |

*The value of EC for similar machine is same as throughout the work breakdowns
Table 2: Materials quantity and EE factor

| Materials          | Quantity (tons) | Density (kg per m$^3$) | EE factor (kgCO$_2$eq/kg, 23) |
|-------------------|-----------------|------------------------|---------------------------------|
| Prefab-SP         | 157.12          | 150                    | 3.29                            |
| Shotcrete mixture | 3.14            | 3                      | 0.74                            |
| Fine aggregates   | 94.27           | 90                     | 0.0052                          |
| Steel wire meshes | 83.80           | 80                     | 0.269                           |
| Steel bars        | 31.42           | 30                     | 1.40                            |

Table 3: Inventory of Prefab-SP quantity

| Sections/Panels          | Type/Thickness (mm) | Area (m$^2$) |
|--------------------------|---------------------|--------------|
| Floor                    | 25                  | 7.82         |
|                          | 30                  | 5.04         |
|                          | 35                  | 15.6         |
| Wall                     | 40                  | 6.9          |
|                          | 60                  | 19.5         |
|                          | 10                  | 24.6         |
| Hallways and Roofs       | Ground floor        | 15           | 172.85 |
|                          | 25                  | 204          |
| 1$^{st}$, 2$^{nd}$, 3$^{rd}$, and 4$^{th}$ Floor | 25 | 827.4 |
| Roof                     | 35                  | 827.4        |
| Stair case and landing   | Staircases          | 30           | 10.62  |
|                          | Landing             | Type I       | 4.05   |
|                          |                     | Type II      | 8.1    |

Impact Assessment

Impact Assessment of Machinery Operation for Prefab-SP manufacturing

Estimating the embodied carbon emissions ($E_i$) in tCO$_2$eq arising from electricity consumption from machinery in the factory. The recorded quantity of purchased electricity ($E_q$) in kWh from the power company with an embodied emission factor ($f_i$) of 0.54 kg-CO$_2$eq/kWh [24] that was divided by 1,000 (Eq.1).

$$E_i = \frac{E_q \times f_i}{1000} \quad \text{(Eq.1)}$$

For the production of Prefab-SP in the factory, the fuel mass consumption ($F_c$) of machinery in litres was estimated by multiplying the usage hour ($t$), the engine capacity ($R_e$) in kW, and the fuel mass consumption rate of 0.24 kg/kWh ($R_c$) as shown in Eq. 2 [25].

$$F_c = t \times R_e \times R_c \quad \text{(Eq. 2)}$$

Impact Assessment of Machinery and Materials at Construction Stages
The fuel mass consumptions of machinery usage were calculated using Eq. 3. The CF of machinery EE ($CF_{EE}$) in tCO$_{2eq}$ was estimated by multiplying the fuel mass consumption ($F_c$) in litres with the diesel factor of 0.003176 ($CO_{2DF}$).

$$CF_{EE} = F_c \times CO_{2DF}$$  \hspace{1cm} (Eq. 3)

The total amount of CF for material EE ($CF_{EEM}$) was denoted in tCO$_{2eq}$ and estimated by the multiplication of material quantity ($M_q$) in tons with the embodied emission factor ($f_e$) in kg-CO$_{2eq}$/kg (Table 2). Hence, its embodied CF emission is summarized as Eq. 4

$$CF_{EEM} = M_q \times f_e$$  \hspace{1cm} (Eq. 4)

The overall total CF was assessed from the summation of embodied carbon emission ($E_i$) and CF resulting from machinery fuel consumption ($CF_{EE}$) and materials ($CF_{EEM}$, Eq. 5).

$$CF = E_i + CF_{EE} + CF_{EEM}$$  \hspace{1cm} (Eq. 5)

3. Results and Discussion

CF for Prefab-SP Manufacturing

The manufacturing prefab-SP with an eight-hour duration per day generates total CF of 14.50 tCO$_{2eq}$. Evidently, due to the high EC of 1047 kW/h, a heating steam boiler contributes the highest CF of 4.52 tCO$_{2eq}$ which account for 31.17%. Other machines, such as the mixer, block moulders, and 2D-CNC pantograph cutter, straightener generates 1.66 tCO$_{2eq}$ through various processes such as pre-expensioning, sintering and moulding, pantographing, unwinding and straightening, stitching, and accessories installation. The boiler operates for eight hours a day and is one of the most crucial components of a plant because it maintains the desired processing temperature of the entire plant’s operation. The steam heating process requires a substantial amount of energy, which is commonly nonrenewable, thereby generating remarkable CO$_2$ emission. To overcome this manufacturing issue, the rule provided by IPPC 2006 can be considered in utilizing a residual biomass boiler furnace, which releases zero-net CO$_2$ emission, for steam generation. This scenario is attractive for the mass production of Prefab-SP with a compatible process of environmental practices, thereby reducing the IBS components’ prices and promoting high value of the technology to serve clients’ best interests.

CF of Machinery Operation and Construction Stage

The results showed that building work contributes high amounts of CF at 159.32 tCO$_{2eq}$ (63.87%), followed by preliminary work of 35.08 tCO$_{2eq}$, foundation work of 34.3 tCO$_{2eq}$ and earthwork of 20.76 tCO$_{2eq}$. During actual site construction, the excavator was used for all types of work. Hence, it released the highest CF of 81.59 tCO$_{2eq}$ (34.0%). Particularly, with its 110 kW/h EC, it has a high energy consumption of 20908.8 liters of diesel in an eight-hour duration per day; in addition, the extensive use of the excavator for floor construction released CF of 18.71 tCO$_{2eq}$. The second and third highest CF contributors were the generator set and crawler crane with 22.69% and 11.34% (54.44 and 27.21 tCO$_{2eq}$), respectively, mostly during building work for concreting and floor construction. These machines were used to power equipment that is essential onsite and to mobilize and uplift the Prefab-SP and other construction materials. Predictably, an increase of 31.53% in CF occurred when heavy machinery, such as 100-ton crawler crane, was used during floor installation.
CF of construction materials for Prefab-SP installation

High CF characteristics were expected for the machinery used in the construction stage. However, the amount of CF was relatively low compared with the preceding material consumption and its CF release of 506.43 tCO$_{2eq}$ (66.56%). The shotcrete cement blend with 25 MPa strength used to attach and plaster the Prefab-SP released the highest CF of approximately 73.11% (369.04 tCO$_{2eq}$) due to its high cement consumption of 388.46 tons and its high EE of 0.74 kg-CO$_2$/kg. Raw natural fine aggregates released a fairly low CF of 1.21 tCO$_{2eq}$ due to the superior IBS implementation. The assessment of the total CF for constructing a hostel building was 760.89 tCO$_{2eq}$. Cement content can have excessive extraction and production of carbon emissions, thereby significantly intensifying carbon emission in addition to its CO$_2$ generation of chemical reaction processes, such as limestone calcination creation. The total CF proportion linked with cement production was determined by the principal material and manufacturing energy starting point consumption. Conventional manufacturing of cement from crude limestone, clay, sand, and slag substances released roughly 5%-7% of worldwide anthropogenic carbon emission. This technology of Prefab-SP permits low usage of fine aggregates during its installation and is suitable for quality control procedures. This current analysis indicated that these lightweight Prefab-SP needed for an entire hostel block is 157.12 tons and produce a low CF of 25.56 tCO$_{2eq}$ (5.05%), which accounts for 3.29 kg-CO$_2$/kg of the EE factor.

The alternative, in-situ casting using IBS technology, influences the CF assessment to some degree. Massive quantities of reinforced steel bars and wire meshes are needed, indicating that the wall loading protocol has a high load-bearing characteristic; thus, they release a high CF of 89.73 (17.72%) and 20.89 (4.12%), tCO$_{2eq}$, respectively. Furthermore, reinforcing bars are a major construction material when considering LCA, LCI, and life cycle cost on the basis of the life cycle of CO$_2$. They are major CO$_2$ emitters in construction industries. Therefore, the present study suggests that the principal method to decrease the carbon emissions of semi-prefabrication construction is the cutback of steel usage via design enhancement of reinforced joint bracket systems.

4. Conclusions

The overall CF for four-rooms hostel buildings constructed using prefabricated SP was 4,565.34 tCO$_{2eq}$, for machinery operation and materials in accordance with the construction work. Lightweight IBS component structures require less substructure bases than traditional in-situ casting. The uncertainties in the assessment method, data quality, different construction technologies, and different geographic locations influence the final interpretation. CF reduction measures in the construction life cycle should start from the initiation phase because the project owner has prominent authority in determining the series of construction work. By revealing the sustainability of low-carbon materials in the initiation phase, low-carbon design and low-carbon construction technology can be achieved.

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