Life Cycle Assessment of Interlocking Compressed Earth Brick and Conventional Fired Clay Brick for Residential House

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Abstract. The conventional fired clay brick (FCB) is a significant building material in the construction industry. However, Besides, the construction field nowadays is designed and constructed without the considerations on the environmental impacts. Thus, the interlocking compressed earth brick (ICEB) was introduced replacing the conventional brick where the brick is not fired, thus contribute to carbon emissions reduction and in line with environmental issues regarding air pollution and global warming. In this paper, a comparative study on Life Cycle Assessment (LCA) is carried out for a residential house using conventional FCB and ICEB as the wall system by focussing on the global warming potential (GWP) impact. The adoption of the ICEB in green building construction can lower energy consumption and reduce the overall environmental impact and has the potential in carbon footprint reduction.

1. Introduction
The fired clay bricks (FCB) or burnt clay brick were used in construction industries as a significant building material throughout the world. The FCB is strong, hard, durable, resistive to abrasion and fire, which make it suitable to be used as a structural material, especially in building construction. However, the manufacturing process of the FCB which involving the fuel burning for the firing process cause pollutants and ash emission into the air. Also, the conventional construction method using FCB and reinforced concrete (RC) framing is time-consuming and costly. Thus, ICEB becomes as an alternative to conventional production and system where the brick is fabricated by compressed method (not fired) thus reduce carbon emissions. Furthermore, the interlocking design made the house construction easy to construct with no formwork wastage. The use of ICEB has gained rapid popularity in many foreign countries as an alternative to conventional bricks for sustainable housing.

Nowadays, environmental issues have reached worldwide attention. Quantification analysis using Life Cycle Assessment (LCA) is used to measures the environmental impact in building construction. This paper is focussing on the materials used as a wall system in the residential or building construction. The adoption of the ICEB system in green building construction can lower the energy consumption and reduce the overall environmental impact and has the potential in carbon footprint reduction, in line with Malaysia goals to reduce the carbon emission by the year 2020.

2. Literature Review
Razman, Abdullah, Md Noh, and Abd Wahid [1] summarized that the building envelopes contribute the significant proportion of the materials used in the residential buildings, walls contributing 46% and roofs 16%. In masonry construction, brick is used to make walls, pavements, and other elements. In
general, there are five common types of brick which are conventional brick (FCB), engineering brick (ICEB), sand-lime bricks, concrete brick, and fly ash brick. This paper compares the conventional FCB (used in general work) with the ICEB (excellent load-bearing capacity) by using LCA in term of GWP.

2.1. Fired Clay Brick (FCB) ‘vs’ Interlocking Earth Brick (ICEB)

Conventional fired clay brick (FCB) used as a traditional wall material in the building construction. It is a solid unit of building with standard size and weight. The FCB produced in different colours (dark brown, dull brown, or dark red) depending on the fire temperature during manufacturing process of the bricks which varies from 900°C to 1200°C [2]. In the construction system, the usage of bricks as structural and non-structural elements are unreplaceable, and the conventional brick required burning process during manufacturing. However, this is not in line with environmental issues regarding air pollution and global warming due to increased production of carbon dioxide gas in the conventional combustion bricks process [3].

Recently in Malaysia, ICEB in the building construction receive varied recognition. There is an increasing interest due to its green characteristics and economic factors [1]. Interlocking block or interlocking brick is IBS block type system where the brick are made of soil, cement, and water, which the ideal soil composition for the mixture to produce the bricks is sandy soil with a clay content of 30% and soil content of 70%. However, if the soil contains too high of the clay content, more sand is added to achieve the desired proportions. The mixture is then compressed in a hydraulic press machine, which results in a compacted brick with high density. The ICEB is different from the conventional FCB as no mortar work is required for the masonry work since the brick is interlocked with each other and preventing horizontal movement between them. Due to this characteristic, Asman et al. (2018) and Nasly & Yassin (2010) also mentioned that the walling process of construction could be improved as the process of building walls is faster and requires less skilled labour as the blocks are laid dry and lock into place [4][5]. These bricks can be used for all kinds of structures like load-bearing walls, lintels, sills and wall corners [6]. Interlocking bricks system produced without the burning process, thus contribute to carbon emissions reduction as mentioned by Zultiniar et al. [3] in their study that brick making without combustion process is capable of reducing carbon dioxide emissions. Figure 1 shows the properties comparison of FCB and ICEB.

| Table 1. Properties comparison of FCB and ICEB [1] |
|-----------------------------------------------|
| Properties                               | FCB            | ICEB            |
| Density (kg/m³)                           | 1400-2400      | Dry: 1687.2    |
|                                             |                | Wet: 1898.9    |
| Compressive strength (N/mm²)               | 5-60           | Dry: 14.8      |
|                                             |                | Wet: 12.5      |

2.2. Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a support tool for environmental management, through quantitative analysis the environmental impact in the whole life cycle of product or service [7]. Others study by Biswas [8] define LCA as a support for decision-making process with quantitative data in reviewing alternative management scenarios to improve environmental performances. While Hoon [9] mentioned that LCA is a framework and methodology for the identification of environment-friendly products or processes characterized by the analysis of cumulative environmental impacts over extended system boundaries. The carbon footprint or carbon dioxide emission can be measured by using the LCA approach. The LCA analysis is the dominant method for project carbon footprint evaluation [10]. Figure 1 shows the Life cycle stages of construction works by BS EN 15978: 2011 [11]. In this paper, the LCA boundary is from ‘cradle-to-gate’ which focuses on the construction process stage.
2.2.1 Carbon emission

A recent review of building life cycle assessments demonstrated that embodied carbon could account for anywhere between 2% and 80% of whole-life carbon emissions [12]. A recent study by Abubakar, Mohammed, Abubakar, & Ikara [13] analyzes the Embodied Energy (EE) and Carbon IV Oxide (CO2) emission of Sandcrete Blocks (SCB) and Compressed Earth Bricks (CEB) houses. The comparison revealed that the Compressed Earth Brick house is more sustainable and environmentally friendly in terms of EE and CO2 emission than the Sandcrete Blockhouse.

Studies by Maheshwari & Jain [14] and Vishwavidhyalaya [15] done on carbon dioxide emission per 1000 bricks of bricks manufacturing having conventional fired brick, fly ash brick and autoclaved aerated block with a CO2 emission of 427.99 kgCO2, 1.326 kgCO2 and 99.26 kgCO2, respectively. Technical manual by UNIDO reported that compressed earth brick (CEB) produced 56.79 kgCO2 per m3 wall, 230.06 kgCO2 per m3 wall of kiln-fired brick and 547.30 kgCO2 per m3 wall of country fired brick.

A study by Abd Rashid, Idris, & Yusoff [16] found that the carbon emission of the energy-efficient house using autoclave aerated block reduced the carbon emission compared to a semi-detached house using the conventional clay brick.

3. Methodology

3.1. Case Studies Details

Universiti Malaysia Sabah’s project in Tawau, Sabah using ICEB construction system are selected as a case study. Figure 2 and 3, show the floor plan and the elevation view of model house, respectively. As shown in Figure 4 is Tawau Community Housing using ICEB system having the area 57.14 m2 (615 ft2). The construction stage from life cycle assessment (LCA) method was used to calculate the carbon footprint with boundary limitation of “Cradle to gate” without considering the transportation. In this paper, the amount of carbon emission for each project has been extracted from the Bill of Quantities (BQ) in the contract document.
Figure 2. Floor plan of the model house (sketch-up layout).

Figure 3. Elevation view of the model house (sketch-up).
4. Result and Discussion
From the BQ of Tawau community residential houses project (Table 2), the application of ICEB in building construction eliminates the frame for column and beam (formwork) during construction and reduce the cement intake as no plastering work involved. This can lead to lower energy and reduce the carbon footprint in building construction compared to the conventional construction using the FCB.

Table 2. Quantity of materials for residential houses using FCB and ICEB.

| Element                        | Description                                               | FCB  | ICEB |
|--------------------------------|-----------------------------------------------------------|------|------|
| A - Works below ground floor   | Excavation (Not exceed 1.0m deep)                         | 65 m²| 65 m²|
|                                | Lean Concrete Grade 15 to Ground floor (50mm thk.)         | 3 m³ | 3 m³ |
|                                | Installation of damp proof membrane (0.25 mm thk.)         | 65 m²| 65 m²|
|                                | Installation of BRC A8 (2 layers)                          | 130 m²| 130 m²|
|                                | Concrete Grade 30 to Ground floor (150 mm thk.)           | 9 m³ | 9 m³ |
|                                | Floor Finishing; Cement & Sand rendered (1:3)              | 65 m²| 65 m²|
| B - Frame                      | Column GF-RB                                               |      |      |
| (Column GF-RB)                 | Vibrated reinforced concrete Grade 30                      | 13 m³| -    |
|                                | HT Dia. 12mm                                               | 129 kg| -    |
|                                | MT Dia. 8mm                                                | 106 kg| -    |
|                                | Class F1 Formwork                                          | 35 m²| -    |
|                                | Roof Beam                                                 |      |      |
|                                | Vibrated reinforced concrete Grade 30                      | 3 m³ | -    |
|                                | HT Dia. 12mm                                               | 110 kg| -    |
|                                | MT Dia. 8mm                                                | 53 kg | -    |
|                                | Class F1 Formwork                                          | 33 m²| -    |
| C – Internal and External Wall | FCB                                                       | 230 mm Thick common brick wall jointed in cement mortar (1:3) as specified and reinforced with and including brick reinforcement at every third course and all necessary bonding | 88 m²| -    |
ties
Bituminous felt damp proof course as described laid horizontally under brick wall 300mm wide

Cement and sand (1:3) with an approved plasticiser as specified trowelled smooth to:
Wall, column & roof beam 200 m²
Approved 2 Coats of Nippon Acrylic Coating state finish 200 m²

ICEB
ICEB walling
2 Coats clear paint finish

D - Roofing
Galvanised lightweight truss system 70 m²
Roofing sheet G28 Long run 70 m²
Ridge clapping 9 m²
Long Facia board 34 m²

E - Windows & doors
Natural anodised aluminium with 5mm thk. Tinted glass window 1400mm x 1900mm 8 Nos
Installation of wood single leaf door including ironmongers, accessories and frame 5 Nos

F - Ceiling finishes
Ceiling board 2'x4'9.5mm (Hanging ceiling) 65 m²

5. Conclusion
It can be concluded that ICEB having a less carbon dioxide emission compared to the conventional FCB in building construction. Thus, the ICEB able to reduce the carbon footprint for the global warming potential of the residential building.

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