LIFE CYCLE ASSESSEMENT OF AN INTERLOCKING COMPRESSED EARTH BRICK SYSTEM FOR GREEN BUILDING CONSTRUCTION

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ABSTRACT

Building construction significantly contributes to the carbon growth due to the high carbon emissions produced by buildings and their effects on climate change. Sustainable building products, materials, and construction techniques, namely green building materials selection is crucial to achieve sustainable construction. The type of building materials influences the carbon emissions of a construction project. Then contribute to the problem of pollution, where carbon dioxide is the primary pollutant that contributes to global warming's negative effects. Brick is a significant building material in the construction industry. Interlocking Compressed Earth Bricks (ICEB) has been introduced as an alternative low carbon building material replacing the conventional brick. The objective of this study is to determine the environmental impact of ICEB production using Life Cycle Assessment (LCA). Then to evaluate the environmental impacts and carbon footprint reduction of ICEB system with the conventional construction. This study also analyzes the hotspot of the energy used and CO_2 emission on material stages of residential building in Sabah. Finally, to develop a carbon calculator for ICEB manufacturing. In this study, quantification analysis using LCA is used to measure the environmental impact. The scope of this study cover cradle-to-gate system boundaries with 1 kg of functional unit and was conducted at the Interlocking Brick Teaching Factory located at the Faculty of Engineering, Universiti Malaysia Sabah. The embodied carbon was analyzed using the GaBi software. Meanwhile, the study of residential buildings involved the selected community housing project in Sabah evaluates using LCA for cradle-to-gate with $1m^2$ of built-up area. The result shows that the embodied carbon of ICEB production is 0.202 $kgCO_2eq$ and result on sensitivity analyses found that the GWP reduced (27%-51%) with the cement content (10% and 15%). The implementation of ICEB in building construction contributes to carbon footprint reduction 34% from the conventional construction. ICEB is suitable to be used as a low carbon footprint building material where the conventional concrete and brickwork contribute to 75% (embodied energy) and 77% (embodied carbon) from the construction process. During hotspot identification for the material stage of building life cycle, concrete, brick, and steel are the major materials contributed to environmental impact of building construction. The adoption of the ICEB system in green building construction can lower the energy consumption (2.75 GJ/m^2 of conventional, to a 1.3 GJ/m^2), reduce the overall environmental impact (to 184 $kgCO_2/m^2$). This study develops a carbon footprint calculator which can evaluate the environmental impact of brick manufacturing in Sabah, Malaysia for product development. Sustainable materials (such as quarry dust) are calculated using the carbon calculator with various percentage of Portland cement replacement in ICEB mix design. The incorporation of the green materials improved the environmental impact. In general, implementation of sustainable materials in ICEB design mix production and construction can potentially reduce the greenhouse gases emission and hence maximize the carbon footprint reduction.

ABSTRAK

PENILAIAN KITAR HAYAT BAGI SISTEM BATA TANAH MAMPAT BERKUNCI UNTUK PEMBINAAN BANGUNAN HIJAU

Pembinaan bangunan menyumbang kepada pertumbuhan karbon disebabkan oleh pelepasan karbon yang tinggi terhasil oleh bangunan dan kesannya terhadap perubahan iklim. Produk binaan mampan, bahan dan teknik pembinaan, iaitu pemilihan bahan binaan hijau adalah penting untuk mencapai pembinaan mampan. Jenis bahan binaan mempengaruhi pelepasan karbon projek pembinaan. Kemudian menyumbang kepada masalah pencemaran, di mana karbon dioksida adalah bahan pencemar utama yang menyumbang kepada kesan negatif pemanasan global. Bata adalah bahan binaan yang penting dalam industri pembinaan. Batu Tanah mampat Berkunci (ICEB) telah diperkenalkan sebagai alternatif kepada bahan binaan rendah karbon menggantikan bata konvensional. Objektif kajian ini adalah untuk menentukan kesan alam sekitar pengeluaran ICEB menggunakan Penilaian Kitaran Hayat (LCA). Kemudian untuk menilai kesan alam sekitar dan pengurangan jejak karbon sistem ICEB dengan pembinaan konvensional. Kajian ini juga menganalisis titik panas tenaga yang digunakan dan pelepasan CO_2 pada peringkat bahan bangunan kediaman di Sabah. Akhir sekali, untuk membangunkan kalkulator karbon untuk pembuatan ICEB. Dalam kajian ini, analisis kuantifikasi menggunakan LCA digunakan untuk mengukur kesan alam sekitar. Skop kajian ini meliputi sempadan sistem cradle-to-gate dengan 1 kg unit berfungsi dan telah dijalankan di Kilang Pengajaran Interlocking Brick yang terletak di Fakulti Kejuruteraan, Universiti Malaysia Sabah. Karbon yang terkandung telah dianalisis menggunakan perisian GaBi. Sementara itu, kajian bangunan kediaman melibatkan projek perumahan komuniti yang terpilih di Sabah dinilai menggunakan LCA untuk cradle-to-gate dengan 1m^2 kawasan binaan. Keputusan menunjukkan bahawa jumlah karbon bagi pengeluaran ICEB ialah 0.202 kgCO_2eq dan hasil analisis kepekaan mendapati GWP berkurangan (27%-51%) dengan kandungan simen (10% dan 15%). Pelaksanaan ICEB dalam pembinaan bangunan menyumbang kepada pengurangan jejak karbon sebanyak 34% daripada pembinaan konvensional. ICEB sesuai digunakan sebagai bahan binaan jejak karbon rendah di mana konkrit konvensional dan kerja bata menyumbang kepada 75% (tenaga terwujud) dan 77% (karbon terwujud) daripada proses pembinaan. Semasa pengenalpastian titik panas untuk peringkat bahan kitaran hayat bangunan, konkrit, bata dan keluli adalah bahan utama yang menyumbang kepada kesan alam sekitar pembinaan bangunan. Penggunaan sistem ICEB dalam pembinaan bangunan hijau boleh mengurangkan penggunaan tenaga (2.75 GJ/m^2 konvensional, kepada 1.3 GJ/m^2), mengurangkan kesan keseluruhan alam sekitar (kepada 184 kgCO_2/m^2). Kajian ini membangunkan kalkulator jejak karbon yang boleh menilai kesan alam sekitar pembuatan bata di Sabah, Malaysia untuk pembangunan produk. Bahan mampan (seperti habuk kuari) dikira menggunakan kalkulator karbon dengan pelbagai peratusan penggantian simen dalam reka bentuk campuran ICEB. Penggabungan bahan hijau meningkatkan kesan alam sekitar. Secara amnya, pelaksanaan bahan mampan dalam pengeluaran dan pembinaan campuran reka bentuk ICEB berpotensi mengurangkan pelepasan gas rumah hijau dan seterusnya memaksimumkan pengurangan jejak karbon.

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LIST OF ABBREVIATIONS

BQ	-	Bill of Quantities
BEES	-	The Building for Environmental and Economic Sustainability
BS	-	British Standard
CE	-	Carbon Emission
EOL	-	End-of-life
EC	-	Embodied Carbon
EC	-	Embodied Carbon Factor
EE	-	Embodied Energy
EEF	-	Embodied Carbon Factor
FCB	-	Fired Clay Brick
FKJ	-	Faculty of Engineering
FU	-	Functional Unit
ICE	-	Inventory of Carbon and Energy
IBS	-	Industrialized Building System
GBI	-	Green Building Index
GDP	-	Gross Domestic Product
GHG	-	Greenhouse Gas
GWP	-	Global Warming Potential
IBS	-	Industrialized Building System
ICEB	-	Interlocking Compressed Earth Brick
ICEBS	-	Interlocking Compressed Earth Brick System
ISO	-	International Organization for Standardization
JKR	-	Jabatan Kerja Raya (Public Works Department)
KASA	-	Kementerian Alam Sekitar dan Air (Ministry of Environment and Water)
LCA	-	Life Cycle Assessment
LCI	-	Life Cycle Inventories
LCIA	-	Life Cycle Impact Assessment
MGTC	-	Malaysian Green Technology and Climate Change Centre

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OPC	-	Ordinary Portland Cement
PC	-	Portland Cement
QD	-	Quarry Dust
RB	-	Residential Building
RC	-	Reinforced Concrete
SB	-	System Boundary
UMS	-	Universiti Malaysia Sabah

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LIST OF SYMBOLS

%	-	Percentage
α^{i}_{j}	-	Material Emission factor for material j
β	-	Electricity Emission Factor
γ	-	Transportation Emission Factor
ρ	-	Density
CO_2	-	Carbon Dioxide
d	-	Distance for transportation from raw material extraction to brick manufacturing
EE	-	Total embodied energy of building (MJ)
GJ	-	GigaJoule
h	-	Hour
kg	-	Kilogram
kg/m^3	-	Kilogram of carbon dioxide equivalent per metre square
$kgCO_2/m^2$	-	Kilogram of carbon dioxide equivalent per metre square
$kgCO_2$ **eq**	-	Kilogram Carbon Dioxide Equivalent
kt	-	Kiloton
kWh	-	kilowatt hour
kt	-	Kilotonne
M	-	Material quantity
m^2	-	Meter Square
m^{i}_{j}	-	Mass of raw material j
$M_{PR}{}^{i}_{j}$	-	Machinery Power rate for machine j
MJ	-	MegaJoule

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min	-	Minutes
N/mm^2	-	Newton per square milimeter
T	-	Transportation of one tonne of materials over one Kilometer distance
t^i_j	-	Machinery usage time duration for machine j
tkm	-	Tonne-kilometre
V	-	Volume
Q_{mat}	-	Carbon emission of raw materials
Q_{machi}	-	Carbon emission of machinery used during production
Q_{trans}	-	Carbon emission from transportation
Q_T	-	Total carbon emission of ICEB production
V	-	Material Volume (m^3)

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