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Embodied Carbon Footprint of Existing Malaysian Green Homes

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***Abstract*—**Part and parcel of building green homes (GHs) with favorable thermal comfort (TC) is to design and build with reduced carbon footprint (CF) from embodied energy in the building envelope and reduced operational CF overall. Together, the environmental impact of GHs can be reduced significantly. Nevertheless, there is still a need to identify the base CF value for Malaysian GHs and this can be done by assessing existing ones which can then be compared to conventional and vernacular houses which are built differently with different building materials. This paper underlines the research design and introduces the case studies. For now, the operational CF of the case studies is beyond the scope of this study. Findings from this research could identify the best building material and construction technique combination to build GHs depending on the available skills, financial constraints and the condition of the immediate environment.

***Keywords*—**Embodied carbon footprint, Malaysian green homes.

I. Introduction

BASED on previous studies by other researchers, there has never been a study on the extent of carbon footprint (CF) of existing green homes (GH) or any other types of houses in Malaysia. The unavailability of the CF data of these houses are significant so as to prove that there is a difference between conventionally constructed houses as compared to GHs in the Malaysian tropical climate in terms of the net energy and water consumption during construction and net embodied energy in the building materials. It also remains to be seen that the existing Malaysian GHs do indeed have lower embodied CF as compared to conventionally constructed houses. Therefore, this study will consolidate the association between reduced CF of Malaysian GHs due to the construction method and building materials of the houses.

II. Background of Study

A. Justification for the Research

To live sustainably, typical households have to limit their daily CF by reducing their resource consumptions [1]. This can be done by making adjustments to their daily routines by using public transport rather than private vehicles, switching off unused electrical appliances, taking shorter showers, using recycled water for washing and so on. However, each household already has a CF deficit due to used building material manufacturing methods, architectural designs of their houses and the construction methods used which must be mitigated [1]-[3] to reduce associated greenhouse gas (GHG) emissions.

Newton and Tucker [4] pointed out that a combination of energy efficiency (building envelope, built-in appliances and plug-in appliances) and access to a low or zero GHG emission energy supply (expressed as CO_2 equivalent) emitted per dwelling is needed to reduce the amount of GHGs emitted from the housing sector. They argued that information pertaining to energy sources, building materials, building designs and the climate are important unlike behavioral issues in creating roadmaps to deliver net zero energy, CO_2 neutral or zero CO_2 housing [4]. However, there are still a number of studies which focused on the behavioral issues relating to energy use and GHG emissions. For instance, [5], [6] investigated the energy use patterns of house occupants in three Japanese cities with three distinct climates. They found that energy use fluctuates between different groups of people according to gender, age and employment among others [5], [6]. In addition to these studies, [7] studied the energy consumption patterns of hotel patrons in New Zealand. Earlier, [8] also studied energy use patterns to decide on energy conservation and retrofitting potential in Hellenic hotels. Besides them, [9] looked at the effects on carbon emissions due to household energy use in China when the type energy source is changed. In all, these studies focused on the amount of energy use and consumption patterns of building occupants or the human aspect of buildings.

Nonetheless, for architects, information that will lead to the reduction of carbon emissions due to building material and construction technique choices is more valuable and practical. This is because behavioral patterns such as energy usage patterns cannot be easily mitigated as it is totally dependent upon the needs and desires of house occupants. Hence, rather than a comprehensive investigation into the whole Life Cycle Analysis (LCA) of a house which includes all stages of life of the house, a truncated LCA of the design and construction stages of a house is favored. This has led to the advent of the GH rating schemes that utilize part LCA examinations of building materials and construction techniques such as in Comprehensive Assessment System for Building Environmental Efficiency for Home (Detached House) or CASBEE-H (DH) [10]. The approach used in this rating scheme prescribed three types of building construction techniques including timber-framed, steel-framed and reinforced concrete or RC-framed houses and a number of building materials for the walls, roofs and floors of assessed houses and the relative carbon emission is based on the ‘box

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house model' created by IBEC, different Japanese climate zones and carbon emission coefficients [10].

B. Definition of Carbon Footprint

Carbon footprint (CF) is a popular buzzword that has received widespread acceptance and recognition among governments, organizations and businesses [11]. Currently there is a common understanding that CF can be used to indicate the tonnage or weight of carbons emitted due to various activities associated with the manufacturing and use of products and services [11]-[13]. Despite this, there has not been a definitive definition for CF and interested parties have defined CF according to their needs [11]. Through the study of CF definitions by various researches, [13] defined CF as "*...a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity over the life stages of a product.*"

They explained further that the estimations of CFs for products (goods and services) have to include all direct and indirect activities of individuals, populations, government, companies, organizations, processes, industry sectors among others [13]. Although there are other GHGs that have global warming potential (GWP) such as methane, only carbon dioxide (CO_2) can be included in CF estimations due to data availability [13], [14]. Wiedmann and Minx [13] argued that if all GHGs are included in the calculations, then CF should instead by termed 'climate footprint.'

Kitzes and Wackernagel [15] clarified further that CF forms part of a full Ecological Footprint (EF) analysis and in a full EF calculation is expressed as area in global hectares required to absorb these carbon emissions. They argued that when CO_2 emissions are expressed in global hectares the biological capacity of the planet can be highlighted when considering various types of energy use [15]. Nevertheless, they conceded that CF can assist people who are unfamiliar with climate sciences [15]. Proponents of LCA on the other hand dismissed CF as meaningless due to accuracy issues caused by the use of the mean CF value expressed as tonnage of CO_2 equivalents [11], [16]. Moreover, they argued that CF savings for products become meaningless as the associated activities including vehicular travels by consumers to use the product among others are not considered in the estimation of CFs [11], [16]. Hence, suggestion by [12] that boundaries to CF estimations are clarified to either 'cradle to gate' or 'cradle to grave' footprints depending on the life cycle stages included. Steps required to conduct CF estimation include the:

- Analysis of materials and supply chain processes
- Building of a supply chain map for the product
- Definition of assessment boundaries
- Collection of data
- Calculation of emissions using appropriate emission factors

C. Research Hypothesis

"The embodied carbon footprints of existing green homes in Malaysia are less than the carbon footprints of conventional houses of similar typology and the Malay house."

D. Research Aim

This study aims at evaluating and distinguishing the operational and embodied CF of an existing GH, an existing conventional bungalow and an existing vernacular Malay house then compare the results to identify the best combination of building material and construction technique to design and build houses with reduced CF.

E. Research Objectives

In order to do so, a set of research objectives (with a set of research questions) has to be followed and they are:

1. To establish differences between conventional, green and sustainable homes.
- *What differentiate GHs from conventional and sustainable homes?*
2. To establish an understanding about the environmental pressures associated with the building of landed (houses with individual land lots) houses in Malaysia.
- *What is the environmental impact of landed houses on the Malaysian environment?*
3. To comprehend the concept of carbon footprint (CF).
- *What is CF and why it is important?*
4. To explore the technique to estimate the operational and embodied CF of a house.
- *How can CF be calculated?*
5. To evaluate the operational and embodied CF of an existing Malaysian GH, an existing conventional bungalow and an existing Malay house.
- *What is the CF of selected house in Malaysia?*
6. To isolate the building material and construction technique with the largest CF.
- *What is the CF of main building materials and corresponding construction technique?*
7. To compare the total CF of existing Malaysian GH with the conventional bungalow and Malay house to validate any improvements.
- *Is it superior to the CFs of the conventional bungalow and Malay house? and*
- *How do different building materials and construction techniques influence the amount of CF?*

F. Research Methods and Limitations

Fig. 1 shows the flow of research activities that will take place during this study. The case studies are selected based on a comparable building typology (bungalow). Each case study will either be a GH, a conventional house or a vernacular house. This is to highlight differences in CF between different types of construction techniques and building materials.

Besides the truncated LCA method used in CASBEE-H (DH), the CF of a product can be estimated using two other methods. The first method is a 'bottom up' approach called 'process analysis' (PA) and the second is a 'top down' approach called the 'input-output analysis' (IO) [14]. The PA is more accurate for small entities but not effective for large entities such as households, companies and organizations in complete reverse to the IO [14]. Therefore, Wiedmann and Minx [13] proposed that a hybrid PA-IO is used instead with

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elements of PA used to estimate the CF of smaller items of a product and the IO for larger associated items with the product. However, this hybrid method still requires boundaries.

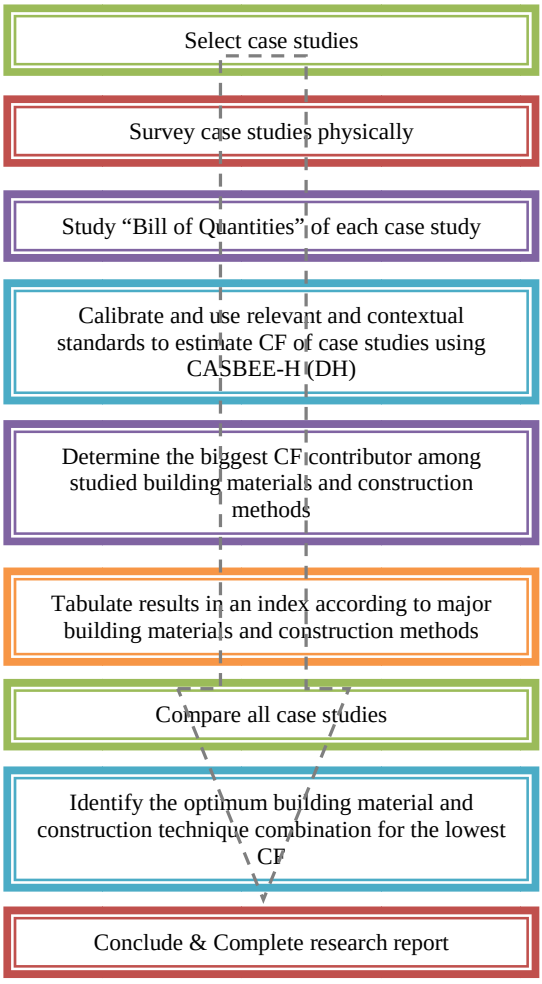


Fig. 1 Flow chart of research activities

III. Preliminary Findings

A. CETDEM's DCEE House

CETDEM is the acronym for Centre of Environment, Technology and Development, Malaysia. It has been actively involved in research and education to improve the quality of the environment [17]. In doing so, they have modified the late 1970's home of its founder in bustling SS2 urban centre in Petaling Jaya into a demonstration house for public awareness. This was achieved with funds from the Danish International Development Assistance (DANIDA). Construction work took 60 days to complete at a cost of MYR 100,000 [18]. The renovation involved retrofitting the existing roof with reflective aluminum foil to reflect heat from the sun and 'Rockwool' insulation. New counter-battens were laid beneath the reused clay tiles to allow hot air trapped underneath to move freely out of the roof. New aluminum louvers are also fitted to shield all windows from morning and afternoon sun.



Fig. 2 CETDEM's DCEE House

Combined with night ventilation, the house was a thermally comfortable home at a minimum of 27˚C or an average of 3˚C lower than outside temperature [18], [19]. Even though the average yearly relative humidity (RH) remains high at 80% internally due to unsealed doors and windows [20], [21], the occupants were well adapted to this condition, thus air-conditioning (a/c) was not needed. Due to the deep and obstructed internal planning of the house and the layout of the surrounding area, cross ventilation was not possible. Moreover, depending on location in Malaysia, the wind speed was less than 0.3 m/s or calm for 30% to 50% of the year which was insufficient for this purpose [21].

A grid-connected 0.9 kWp photovoltaic (PV) system was also installed during the renovation to offset the 270 kWh average monthly electricity consumption of the occupants by about 1/5[7], [18].

B. Smart and Cool Home (SCH)

This two storey bungalow is situated in the rural township of Beranang in the state of Selangor, Malaysia. This house was built using the Smart and Cool Home (SCH) technology whereby old car tires were reused as foundation material to replace the majority of concrete that otherwise would be needed to build conventional raft foundation [22]. Part of the SCH system was the use of arched and corrugated steel sheets for suspended floor slab reinforcement to reduce the use of concrete. All walls including internal and external infill panels were made of autoclaved aerated concrete (AAC) blocks which have a very small U-value of 1.091 W/m^2K as investigated by [23] and small carbon footprint compared to clay bricks which were the building material of choice in Malaysia. As a result of the construction technique, the overall thermal transfer value (OTTV) of the building envelope was only 16.05W/m² [24] which was significantly lower than the baseline standard of 50 W/m^2 as stipulated by the Green Building Index Malaysia or GBI [25].

Rather than being a massive heat sink that stores irradiated heat from the blazing sun and conducted heat from the ground,

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the foundation, external water tank, driveway and fence absorb heat from other parts of the house and occupants and dissipate it quickly. In order to complement the construction system, night ventilation was also practiced at this house. No a/cwas installed at the house. The interior of the Semenyih house has been recorded to be at least 7˚C lower than outside temperatures [23] which needed only the ceiling fans to increase air speed within the house to achieve thermal comfort.



Fig. 3 Smart and Cool Home

As with the DCEE house, SCH house was also susceptible to warm and humid air leaking through the gaps in the door and window frames which were not properly sealed. An additional advantage to the SCH system was that it required less workers and time to construct the house because the recycled tire cassettes were modularized and the AAC blocks were significantly lighter to carry than clay bricks and can be easily cut to suit edges and angles, increasing construction accuracy and reducing building material wastage. The ground floor slab also did not require any toxic chemical treatment to prevent termite infestations, hence, better for the environment and health of occupants [22].

With funds from the national photovoltaic project called the SURIA 1000 project which was run by the Energy Commission, this house was fitted with a 5.25 kWp photovoltaic system that could generate at an average of 340 kWh of electricity per month [26] that could offset about 92% of the average monthly usage of up to 370kWh.

C. CoolTek House

Similar to Semenyih house, this private bungalow was built away from any neighbors at the edge of a golf and country club in Melaka and surrounded by heavily wooded area. This house was called the CoolTek house for its unique cooling system that helps to significantly reduce energy demand for cooling. Reimann et al. [27] highlighted that it took only 8 kWh per day to run the a/c to cool the 200 m^2 house for 24 hours. This was attributed to the orientation of the house, building materials, construction technique and a tight overall seal around the house.

Unlike the previous two case studies, the Melaka house was air-conditioned but set to a bare minimum because the well-insulated envelope of the house alone kept the heat out while rubber seals around window and door edges kept the air-conditioned coolness from escaping [27]-[29]. The house was designed to have an internal temperature of 18˚C to 24˚C with a relative humidity of 40% to 70%. The a/cwas also intended to keep the humidity down to that level to achieve thermal comfort [30].

The house was planned properly with only small walls and windows facing East and West (morning and afternoon sun) and larger fenestrations were orientated to the North and South to receive diffused daylight. The East and West walls were also shaded away from the sun by vegetation. All fenestrations were set deep into the external walls and were sheltered by deep overhangs that stretched around the house. The foundation of the Melaka house was a conventional concrete trench to carry the load bearing walls which effectively reduced the amount of concrete and steel reinforcements needed to build the house. The load bearing walls were made of 250mm thick AAC blocks and painted white to mitigate heat and sound transmissions while the windows were all double glazed with a low emissivity coating to stop heat radiating through [30], [31].



Fig. 4 CoolTek House

Fresh and filtered 26˚C air was constantly supplied via an underground cooling chamber buried within the wooded area of the site. Stale and warm air was then expelled through a solar chimney conveniently located above the refrigerator in the kitchen with the assistance of a small extractor fan placed strategically at the outlet. In order to allow air movement within the house, each internal door that separate rooms inside the house were made of a single piece of armor-plated glass and attached directly to the AAC block walls without any frames. The cooling system installed at this house was far superior to the vast majority of houses in Malaysia which were not sealed and inadequately insulated. The Uniform Building By-laws of Malaysia did not even have a provision for insulation for private homes [32].

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D.CASBEE-DH

According to the Institute for Building Environment and Energy Conservation (IBEC), CASBEE-H (DH) is a voluntary GHRM aimed at increasing the stock of superior housing that provide good living environment which can be used for a long time and designed to save energy and resources to reduce the environmental load and improve the quality of living in Japan [10]. There are two dimensions to CASBEE-H (DH)'s evaluation of the environmental performance of detached houses which are the "Building Environmental Quality" (Q) of the house and the "Building Environmental Load" (L) on the external environment caused by the house [10]. Both Q and L have three assessment categories each containing specific assessment items or indicators (please refer to Table I for details). In the case of L, the evaluation is based on the load reduction (LR) that can be achieved. An "H" is affixed to Q, L and LR to differentiate CASBEE-H (DH) assessment from other CASBEE rating schemes [10]. According to IBEC [10], higher scores are given to detached houses with balanced qualities in all relevant environmental fields.

TABLE I
ASSESSMENT CATEGORIES IN CASBEE-H (DH)

Building Environmental Quality (Q_H)	Building Environmental Load (L_H)
Q_H1 = Comfortable, healthy and safe indoor environment	LR_H1 = Conserving energy and water
Q_H2 = Ensuring a long service life	LR_H2 = Using resources sparingly and reducing waste
Q_H3 = Creating a richer townscape and ecosystem	LR_H3 = Consideration of the global, local and surrounding environment

Similar to LEED-H, CASBEE-H (DH) can "...evaluate a house based on assumed conditions even though the house is at a stage in which not all of the assessment conditions have been established, such as at the initial design stage" [10]. IBEC implies that the end result of such rating condition is tentative.

All six Q and L assessment categories are classified as "major item" and each of them are further divided into one to three stages from "medium level item" to "minor item" or "detailed item" [10]. These assessment items (indicators) are ordered and weighted according to a hierarchy. Detailed items are valued as percentages (or points as used in CASBEE-H (DH)) of minor items which are themselves percentages of medium level items adding to the total percentage of each Q and L assessment categories. There is a total of 54 assessment items in CASBEE-H (DH) from medium level to detailed items and each are allocated a maximum of five points which is equivalent to Level 5 [10]. Then sum of each assessment item levels is then calculated and displayed using bar charts and radar charts to show building achievements.

$$BEE = \frac{Q}{L} \quad (1)$$

whereby, BEE = Building Environmental Efficiency; Q = Building Environmental Quality; L = Building Environmental Load.

TABLE II
RANKING BASED ON THE BEE VALUE

Rank	Assessment	BEE value	Star ranking
S	Excellent	BEE = 3.0 or higher	5
A	Very good	BEE = 1.5 or higher but less than 3.0	4
B+	Good	BEE = 1.0 or higher but less than 1.5	3
B-	Fairly poor	BEE = 0.5 or higher but less than 1.0	2
C	Poor	BEE = less than 0.5	1

In order to ensure that the level of human comfort is not reduced greatly in order to reduce the environmental load, the overall score from a CASBEE-H (DH) assessment is calculated from the mathematical proportion of Q over L, described as the "Building Environmental Efficiency" (BEE) value as in (1) [10]. The BEE value is displayed as a straight line passing the reference point in a coordinate axis with a slope of QH / LH when plotted on vertical and horizontal axes [10] as in Fig. 5. Other detailed medium level scores are also included in CASBEE-H (DH) report sheet to show achievements for specific assessment categories to guide house designers or owners to make necessary improvements either by improving a specific Q or by reducing specific environmental load (LR).

In some instances, specific assessment items can be discarded from the evaluation process and their allocated weights are distributed equally among the remaining assessment items albeit detailed items or minor items [10]. This is to maintain the overall calculation of BEE, scoring points and star chart.

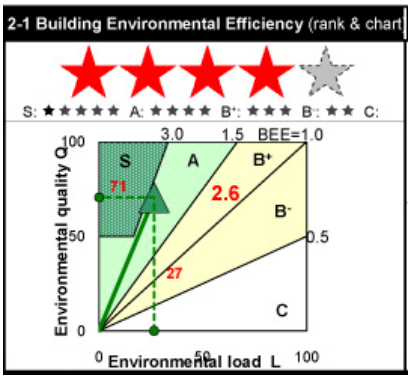


Fig. 5 A BEE plot in a CASBEE-H (DH) report sheet

E. Preliminary Estimation of CF Using CASBEE-DH

Through the researcher's observation and survey of the case studies, a sizeable amount of GH features have been identified and they could potentially lead to low CF estimations as compared to a selected conventional bungalow and a vernacular house. Such GH features were lightweight building materials, non-usage of a/c, installation of photovoltaic systems for electricity generation, installation of solar hot water system, installation of rainwater harvesting systems and so on [33]. Consequently there were two types of CF reduction strategies employed at all of the case studies, firstly, the reduction of embodied energy that can be quantified using an

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LCA and secondly, reduction of usage of non-renewable resources which can be calculated by estimating the amount of CO_2 emitted due to resource use. Embodied energy quantity of each house is static unless the building occupants and owners alter their shape and design in the future or the house gets demolished [34].

In a study by Ismail and Prasad, two of the three houses were rated against the CASBEE-H(DH) [35] and they found that the embodied energy of both DCEE House and SCH was 13.4kgCO_2/year m^2. In addition, the operational carbon footprint of the DCEE House and SCH were 17.82kgCO_2/year m^2 and 2.35kgCO_2/year m^2 respectively.

IV. Conclusion

This paper introduced three case studies to determine the base embodied CF value of existing Malaysian GHs which will be compared to a conventional bungalow and a vernacular house. Each house has been chosen due to the differences in terms of used construction methods and building materials. This is against a background of prevailing reinforced concrete frame construction with block work infill panels in Malaysia. The amount of CF difference between these GHs, conventional and vernacular construction methods and building materials combinations is yet to be determined. Nevertheless, findings from this next phase of the study could help to educate building designers and builders to employ a construction method and building material combination that is less damaging to the environment.

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