Quantifying the Sustainable Building Criteria Based on Case Studies from Malaysia

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Abstract—In order to encourage the construction of green homes (GH) in Malaysia, a simple and attainable framework for designing and building GHs is needed. This can be achieved by aligning GH principles against Cole's 'Sustainable Building Criteria' (SBC). This set of considerations was used to categorize the GH features of three case studies from Malaysia. Although the categorization of building features is useful at exploring the presence of sustainability inclinations of each house, the overall impact of building features in each of the five SBCs are unknown. Therefore, this paper explored the possibility of quantifying the impact of building features categorized in SBC1 – "Buildings will have to adapt to the new environment and restore damaged ecology while mitigating resource use" based on existing GH assessment tools and methods and other literature. This process as reported in this paper could lead to a new dimension in green home rating and assessment methods.

Keywords—Green homes, Malaysia, Sustainable Building Criteria, Sustainable homes

I. INTRODUCTION

IN a previous research by the authors, three Malaysian case studies were evaluated against Cole's five "Sustainable Building Criteria" (SBC) through the classification all of their green home (GH) features [1]. The case studies were GHs of varying styles and impacts. These GHs were CETDEM's Demonstration, Cool and Energy Efficient (DCEE) House, the Smart and Cool Home (SCH), and the CoolTek House. It was found that both SCH and CoolTek House aggregated the most amounts of GH features, hence deemed the most "Sustainable" [1]. However, the methodology of classification of GH features against the five SBCs needed to be developed further in order to ascertain the actual impact needed to qualify these houses as "Sustainable." Thus, a series of indicators and ensuing metrics were needed to quantify the impact of each GH features which have been outlined in this paper.

II. BACKGROUND OF STUDY

A. *Sustainable Building Criteria*

The green building (GB) and GH industry in Malaysia is

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still in its infancy with only a handful of certified buildings and houses. So far, only the Zero Energy Office (ZEO) building of Malaysian Green Technology Corporation has been certified by the Green Building Index (GBI) assessment suite since its release in 2009, only one completed building certified by Green Mark evaluation method from Singapore with a few others in design and construction stages and two buildings in design and construction by the Leadership in Energy and Environmental Design (LEED) assessment system from the USA. The size of the GB industry stakeholders are steadily increasing with an estimation of 379 building practitioners, building academicians and government officers who are known to be associated with the GB movement in Malaysia [2]. However, there is a need to further educate the stakeholders and the public in general in order to increase the number of GBs and GHs. Since GH rating in Malaysia is voluntary and most developers are still not receptive to the financial legibility of GHs and the difficulties in changing their design and construction culture, a simple and attainable framework for designing and building GHs is needed to encourage them to design and build GHs. This is where the SBCs could play a guiding role.

According to Cole [3], compliance with all five SBCs would result in Sustainable Buildings (SB). SBs other than houses could be designed to encompass all SBCs and become sustainable as their scales are larger. Houses however, could not sustain themselves unless they were designed as autonomous houses or they were designed as part of a wider sustainable and autonomous housing community with adequate infrastructures [3]. Unfortunately, this is rarely feasible since much of existing infrastructures in Malaysia are centralized. There is also very little government policy support for decentralized infrastructures except for remote communities. In effect, only new or retrofitted GHs can be developed around existing and expanding electricity supply network, water and sewerage networks, waste disposal system, telecommunication networks and so on. Although the introduction of the SBC was part of dismissing the incremental improvements by the building industry to address environmental issues as slow [3], Cole did eventually concede that there is no such thing as sustainable homes [4]. Moreover, this ad-hoc method of making houses green does not fit with Yeang's ethos for ecological architecture [5] but it could still be effective at spreading the core ideas of GHs. Cole's [3] five SBCs are as the following:

- Buildings will have to adapt to the new environment and restore damaged ecology while mitigating resource use.

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- Buildings need to have a wider positive influence on the surrounding area and buildings rather than serving itself.
- Building features should be contextually suitable and sensitive to local cultural conditions.
- Buildings should be valued in terms of its significance to the society and environment, beyond its financial worth.
- Buildings should also continually perform for a very long time rather than only achieve short-term benefits.

Out of all five SBCs, only SBC1 is readily quantifiable. Other SBCs can only be associated with subjective GH features or criteria. Only the presence of such feature or criteria can be counted but the actual impact cannot be objectively quantified and compared with other houses. For instance, for SBC3, the architectural styles of the assessed GHs [1] can only be subjectively evaluated whether or not they fit into the existing context. For SBC4, all case studies were used as educational tool to spread the knowledge of GHs to the general public [1] and only the presence of such programs can be counted but their effectiveness are open for debate. Moreover, most of the GH features were grouped under SBC1 as shown in Table I. Hence, in the context of this paper, indicators and their implicating metrics for only SBC1 were laid out and discussed.

B. 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 [6]. 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 [7]. 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.

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 [7, 8]. Even though the average yearly relative humidity (RH) remains high at 80% internally due to unsealed doors and windows [9, 10], 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 [10].

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] .

C. 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 [11]. 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/m2K as investigated by Sh. Ahmad et al. [12] 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 16.05 W/m² [13] which was significantly lower than the baseline standard of 50 W/m2 as stipulated by the Green Building Index Malaysia or GBI [14].

Rather than being a massive heat sink that stores irradiated heat from the blazing sun and conducted heat from the ground, 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/c was installed at the house. The interior of the Semenyih house has been recorded to be at least 7°C lower than outside temperatures [12] which needed only the ceiling fans to increase air speed within the house to achieve thermal comfort.

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 [11].

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 [16] that could offset about 92% of the average monthly usage of up to 370kWh.

D. 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

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house was called the Cooltek house for its unique cooling system that helps to significantly reduce energy demand for cooling. Reimann et al. [17] highlighted that it took only 8 kWh per day to run the a/c to cool the 200 m2 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 [17-19]. 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/c was also intended to keep the humidity down to that level to achieve thermal comfort [20].

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 250 mm 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 [20, 21].

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 [22].

III. FINDINGS FROM PREVIOUS RESEARCH

The features of all case studies were grouped against Cole's SBC to determine whether or not these houses were indeed sustainable.

TABLE I
NUMBER OF GH FEATURES OF EACH CASE STUDY ACCORDING TO SBCs

	SBC1	SBC2	SBC3	SBC4	SBC5	Total
DCEE House	14	0	1	3	1	19
SCH	21	0	1	3	1	26
CoolTek House	22	0	1	4	1	28

From Table I it is clear that most of the GH features were in accordance with SBC1. In comparison with other SBCs, GH features from each case study that belong to SBC1 form a total of 78.1% of all features from all case studies. However, the actual impact of each GH feature under SBC1 is unknown unless they are reclassified into known types of design strategies that are quantifiable. From careful consideration and thorough coding of each GH feature, it was found that all of them can be reclassified as either attributable to achieve thermal comfort or to reduce carbon footprint or to increase the gross vegetated area. All three classifications fit the requirements of SBC1 which states that "Building will have to adapt to the new environment and restore damaged ecology while mitigating resource use."

IV. QUANTIFICATION OF SBC ONE

A. Thermal Comfort

GH features such as orientation of the house, depths of eaves, insulation of building envelope, double glazing windows and so on [1] were in fact directly attributable to the achievement of thermal comfort for the occupant. Without these GH features, thermal comfort could only be achieved mechanically by means of a/c that requires precious amount of energy to operate. There are three main parameters to thermal comfort which are indoor air temperature, relative humidity (RH) and air speed [12, 23]. All of which can be validated against the Predicted Mean Vote (PMV) index that highlights occupants' level of thermal comfort due to acclimatization [24]. In the case of the DCEE house, the indoor air temperature hovered around 27°C during the day with RH of up to 80% because the house was unsealed [1]. Similarly, the indoor air temperature of SCH was between 26.5°C to 30.3°C throughout a 24 hour cycle [12] with RH of up to 80% [10], again due to the lack of sealed building envelope. The indoor air temperature of the CoolTek House was more constant as the occupants utilize a/c to keep it between 18°C and 24°C with RH of 40% to 70% depending on outside conditions [20]. The house was totally sealed and fitted with an underground fresh air supply system.

TABLE II
THE TYPE OF GH FEATURES OF EACH CASE STUDY ACCORDING TO SBC1

	Thermal Comfort	Carbon Footprint	Gross Vegetated Area	Total
DCEE House	7 (50.0%)	5 (35.7%)	2 (14.3%)	14 (100.0%)
SCH	11 (52.4%)	9 (42.9%)	1 (4.7%)	21 (100.0%)
CoolTek House	14 (63.6%)	5 (22.7%)	3 (13.7%)	22 (100.0%)

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A. Carbon Footprint

A sizeable amount of GH features listed under SBC1 were closely related to the reduction of carbon footprint. 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 [1].

Consequently there were two types of carbon footprint reduction strategies employed at all of the case studies, firstly, the reduction of embodied energy that can be quantified using a lifecycle analysis (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 [3]. Meanwhile, the amount of CO_2 emission is dependent upon the needs and lifestyles of the occupants and can be mitigated by utilizing more resource efficient appliances and fixtures or by more education and knowledge of handling the GH.

In another study, two of the three houses were rated against the Comprehensive Assessment System for Building Environmental Efficiency for Detached House (CASBEE-H(DH)) [25]. It was found that the embodied energy of both DCEE House and SCH was $13.4 kgCO_2/year\ m^2$ [25]. Furthermore, the operational carbon footprint of the DCEE House and SCH were $17.82 kgCO_2/year\ m^2$ and $2.35 kgCO_2/year\ m^2$ respectively.

B. Gross Vegetated Area

All landed properties are built on what used to be vegetated land of various degrees. In order to at least restore the amount of lost vegetation and the immediate ecology due to the building of houses, ample area for vegetation to grow is needed. Instead of only recognizing the gross vegetation area on a horizontal plain as per 10% of development area in the GBI [14], types of plants in LEED-H [26], vegetation on any plain must be counted as in CASBEE-H(DH) [27]. All three case studies have different amounts of vegetation on site. For instance, DCEE House has vertical trellises for creepers to grow, thus allowing more growing space for its small front garden. Similarly, SCH cleverly incorporated earth pockets in the boundary fence for small plants and creepers to thrive. The boundary fence was constructed using the same recycled tires as in the foundation of the house, stacked and rigidly fastened to the foundation of the fence [11]. Meanwhile, at CoolTek House, an adjacent vacant lot of land which was heavily vegetated with matured trees was purchased and conserved instead [21] and plants around the house were conservatively planted on the ground or in pots. Nevertheless, it is still possible to calculate the gross vegetated area in and around the houses in order to partly restore and replenish the immediate ecology.

V. CONCLUSION

This study argued that SBC1 can be used to encourage

developers to build more GHs by showing that the core strategies to build GHs were only thermal comfort for the occupants, reduction in carbon footprint by using renewable resources and alternate building materials and an increase in the gross vegetated area to replenish the immediate ecology. It is up to the creativity and ability of the developers and designers to achieve the three strategies. Quantification of other SBCs however, is more problematic since the GH features which were classified in them were subjective and could only be counted in terms of their presence, not actual impact as per GH features in SBC1.

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