# Life cycle analysis of three pototypes housing development and its application towards low carbon society

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## Abstract

Living based energy security and fewer emissions compatible with low-carbon society (LCS) in terms of green city are widely concerned issues. Three prototypes of hosing patterns development include Expandable Polystyrene (EPS) house**,** recycled material house, and concrete and mixed natural material house. Considering LCA in pre-production process, recycled material house has less amount of emission (7,249.92 kg$CO_2$eq) than other house types. In production process, the emissions through all types were not quite different and were in the range between 298.91 kg$CO_2$eq - 467.04 kg$CO_2$eq. For the building process and component life Expandable Polystyrene house was found with less emissions of 25,566.92 kg$CO_2$eq. In the process of waste management, concrete and mixed natural material house does not contribute to global warming with zero emission (0.00 kg$CO_2$eq) in comparison with other types. Installation of recycled material house liberated emissions about 629.37 kg$CO_2$eq. Expandable Polystyrene house was higher in emission with 1,856.00 kg$CO_2$eq. Also, Expandable Polystyrene house should be promoted in terms of use of renewable energy in scenario 8 which only liberated $CO_2$ about 8,184.56 kg$CO_2$eq. However, the result of people perception found that concrete and mixed natural material house was the most favorable of the prototypes as using durable materials and easy maintenance.

**Keywords:** *Life cycle analysis, low carbon society, hosing patterns, perception*

## 1. Introduction

Global population rise certainly requires increase in energy supply, foods, houses and many other basic needs, whereas the resources are being a serious issue [1]. This situation directly effects environment especially the amount of $CO_2$ which is increasing continuously. The impacts of environmental changes have stimulated natural phenomenon like floods, droughts, and their frequency of occurrence has been multiplied. In 1960, $CO_2$ emission of the world was approximately 3.1 metric tons and was increased to 4.5 metric tons in 1979. During 2002 – 2008 the amount of $CO_2$ was 4.8 metric tons [2]. Adapting lives to associate with nature and environment in dealing with a demand of consumption in terms of food security and energy resources should be addressed for building an environment to deal with low carbon society perspectives. All sectors must participate to reduce greenhouse gas emission. It might be different and flexible management [3]. Also, reducing greenhouse gas emission related to economic development by efficient energy usage and low carbon technological innovation is essential [4]. And the scope of Low Carbon Society is broadly defined that is not only technology involvement but includes people's perception on clean technology to reduce greenhouse gas emission [5]. Therefore, the housing pattern development of this research is associated with low carbon footprint level, using renewable energy, and reducing $CO_2$ emission concept. This model shall come out to contribute a good housing design environment based on renewable energies to solve global warming issues.

## 2. Life-cycle analysis in housing unit

A life-cycle assessment evaluates the environmental costs associated with a product, process, structure, or activity by identifying energy and materials used and wastes released to the environment. In this context, the term "life cycle" means the assessment considers everything that goes into or is produced as a result of the product or service [6]. The life-cycle assessment can also use the recycled building material to understand environmental footprint with comparative in terms of recyclable and non-recyclable material based on ISO 14040 as shown inFigure 1[7].

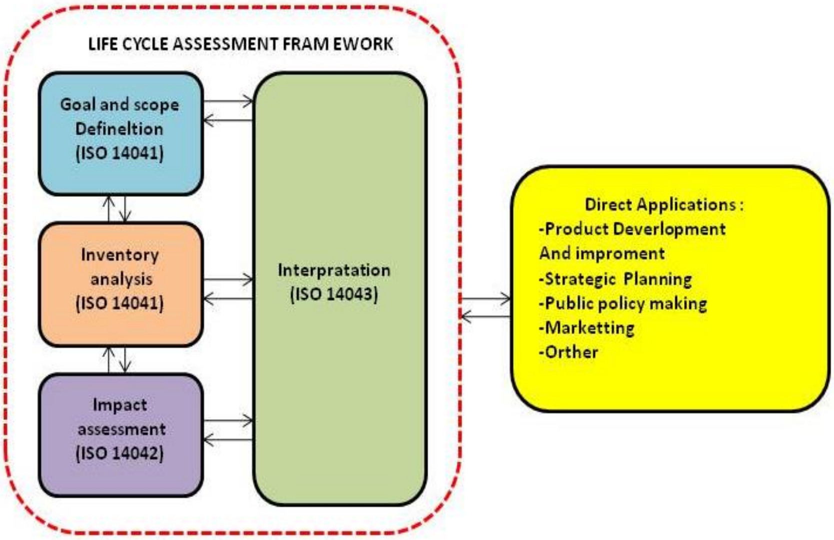


Figure 1. Flow chart life-cycle assessment frameworks

Life Cycle Assessment (LCA) was applied for analyzing $CO_2$ in housing sector of Malaysia [8]. LCA calculation was performed using the equation below:

$$\Delta E = g\,(I-(I-M)\,A)^{-1}\,(I-M)\,\Delta F + \Delta EX \qquad (1)$$

The variables are as follows:

E: Total $CO_2$ emission
ε: Diagonal matrix of directly $CO_2$ emission
I: Identity matrix, M: Coefficient of import
A: Coefficient of supply, F: Final demand,

*For $CO_2$ emission from housing*: by multiplying the material cost by $CO_2$ emission per 1000 RM

$$CO_{2C} = \sum_{i-1} m_i E_i \qquad (2)$$

The variables are as follows:

$CO_{2C}$ : $CO_2$ emission on construction phase (t-$CO_2$),
$m_i$ : cost of the i-th material (‘000RM)

*For $CO_2$ emission from during construction*:

$$CO_{2o} = \sum_{j=1} W_j U_j EI + G \quad (3)$$

The variable are as follows :

$CO_2o$ : $CO_2$ emissions during operation phase (t- $CO_2$),

$W_j$ : electric power (W),

$Uj$ : Usage time (hrs), $EI$ : $CO_2$ emissions per electricity generation (t-$CO_2$/kWh),

G : $CO_2$ emissions by gas usage (t- $CO_2$)

Prior research found that the brick house has a more severe impact on the environment than the wooden house [9]. The main source of brick is clay, which is highly inorganic, non-renewable and also contains highly risking carcinogen. Moreover, the agglomeration process from brick to brick takes lots of energy, which weights the fossil fuel high. On the contrary, wood is a renewable resource and its re-production, with well-developed Code of Forest Management, would be a benefit to human beings.

The studied amount of $CO_2$ pollution from a house construction by brick, precast, and knockdown method with SimaPro 7.1 application in term of cradle-to-gate found that greenhouse gas emission from brick material, precast, and knockdown was 187±28 kg$CO_2$eq./m$^2$, 95±9.5 kg$CO_2$eq./m$^2$ and 25±1.25 kg$CO_2$eq./m$^2$ respectively. For gate-to-gate found that greenhouse gas emission from brick material, precast, and knockdown was 7.44±1.12 kg$CO_2$eq./m$^2$, 0.84±0.08 kg$CO_2$eq./m$^2$ and 6.18±0.31 kg$CO_2$eq./m$^2$ respectively. However, the greenhouse ratio of material and construction process of brick house was 96% and 4%, for precast house was 99% and 1% and for knockdown house was 81% and 19% respectively. Furthermore, an analysis of eco-efficiency of construction method by calculating a profit per greenhouse gas from brick, precast, and knockdown house was 13,681 bath/ kg$CO_2$eq./m$^2$, 14,583 bath / kg$CO_2$eq./m$^2$ and 3,313 bath / kg$CO_2$eq./m$^2$ respectively [10].

Traditionally Thailand constructions were using generally Timber structures, which is an environment friendly option. However, it's expensive both in cost of product and construction process terms. At present, steel structure and concrete structure are involved instead. It was found that steel material gives environment friendly construction by reducing cement, sand, and water about 10% with increased 27% of steel. However, during operation/usage of building, the steel house consumes more energy about 80% of total usage. Therefore, saving energy building concept of steel house should be specifically focusedd in occupancy period [11].

## 3. Methodology

### *3.1 Life-cycle assessment analysis of tree prototypes housing development*

1) Housing pattern development: three types of designing house at Asian Development College for Community Economy and Technology, Chiang Mai Rajabhat University Marim Campus with total area of 10 Rai (16,000 m$^2$).

The prototypes are:

- Expandable Polystyrene (EPS) house
- Recycled material house
- Concrete and mixed natural material house

These houses were selected for analysis and computing amount of carbon by using LCA (Life Cycle Assessment) method. This prototype was classified based on LCA principle as typical elements of house materials, transportation during construction, construction method, and operation phase of occupancy as well as to find out the energy to calculate amount of emission.

2) Environmental aspect: a physical environment especially the landscape surrounding of house by designing a perennial plant and ground cover plant will be used to indicate environmental

conditions as before and after changes.

3) Energy: mainly energy demand for each house type is fossils and DC power grids and also from renewable energy (solar cell). Amount of energy consumption is included as one factor to analyze carbon dioxide emission.

4) Human behavior: all daily routines of people in three houses considering set up for one person who lived in the house with complete electricity in order to assess amount of energy usage and carbon dioxide emission based on a period of time in morning, afternoon, and evening of a day. Also, transportation on daily traveling in averaging within 2 Km was employed for calculation.

Table 1 Elements of three type of housing pattern development

| **Type A** | **Type B** | **Type C** |
|---|---|---|
| Expandable polystyrene house | Recycled material house | Concrete and mixed natural material house |
|  |  |  |
| Area = 30 $m^2$ | Area = 32 $m^2$ | Area = 50 $m^2$ |
| Foam is main material and acts as insulation to protect heat into the house. | The main material of this house was made from pieces of wood and steel. | The main material of this house is concrete by using local material without processing. |
| Heat transfer value was 0.031 w/mk. | Heat transfer value was 0.16 w/mk. Flooring is concrete material. | This type has high heat transfer value of 1.3 w/mk. |
| The area was mostly occupied by Bai Tong Thueng Trees (Dipterocarpus tuberculatus Roxb Tree), the temperature was relatively high,with an average of 34-37 degrees in the daytime. | | |
| Electric power was normally used during Monday - Friday in the morning at 6:00 am.- 8:00 pm. and in the evening at 17:00 pm.- 22.00 pm and on Saturday – Sunday from 07.00 am. - 22.00 pm | | |
| Electrical appliances included TV, refrigerator, microwave, rice cooker, water heater, and air conditioner | | |

From four stages operation as mentioned above, the $CO_2$ emission can be calculated by the following method:

Input/activity level (tons, kWh, km,…,) x (Emissions factor) (kg $CO_2$,) (input/activity) = Greenhouse gas emission ( $CO_2$equivarant of life time or annual)

The general equation for emissions estimation is

$$E = A \times EF \quad (4)$$

where:

E = emissions; A = activity rate; EF = emission factor

*3.2 People perception investigation for adapting tree prototypes housing development*

To fulfill research on the understanding of the public attitudes towards three prototypes of housing pattern, and how it could be practical adaptation, the questionnaire survey was employed to conduct in the study area based on the number of visitors (500 people) as population group at the three housing prototype in 2013. The sample size by using Yamane' at confidence 95% were 227 people. Questionnaire was distributed at the project site to those who came to visit by random method. Content of questionnaire consist; Part 1: Personal information'; Part 2: Living conditions; Part 3: Information and knowledge on low carbon society and behavioral changes for adaptation; Part 4: Considering three housing prototype for adaptation; and Part 5: Suggestions and recommendations. The questionnaire was designed to use both check list and 5-Likert-scale methods. Personal respondent's information was interpreted by descriptive statistic such as number of respondents and percentage on each questionnaire item.

## 4. Results and discussion

### *4.1 Life cycle assessment*

Through Life cycle assessment of three prototypes housing patterns for acquisition of raw materials, production process, transportation &distribution, operation, use of new/ processing, and handling debris after usage, $CO_2$ can be calculated as shown in Table 2.

- **Pre-production**

Table 2 $CO_2$ from preproduction phase by materials

| | item | Amount | Unit | EF | Ref. | kgCO2eq |
|---|---|---|---|---|---|---|
| Expandable Polystyrene: Raw materials | Scrap wood | 800.00 | Kg | 4.3229 | Polyurethane | 3,458.32 |
| | Scrap iron | 300.00 | Kg | 2.4779 | Steel/pipe c | 743.37 |
| | Cement (floor) | 7,680.00 | kg | 0.9440 | CFP | 7,249.92 |
| | Total | | | | | 11,451.61 |
| Recycled material: Raw materials | item | Amount | Unit | EF | Ref. | $kgCO_2eq$ |
| | Scrap wood | 189.00 | Kg | - | | - |
| | Scrap iron | 360.00 | Kg | - | | - |
| | Cement (floor) | 7,680.00 | kg | 0.9440 | CFP | 7,249.92 |
| | Total | | | | | **7,249.92** |
| Concrete: Raw materials | item | Amount | Unit | EF | Ref. | $kgCO_2eq$ |
| | Cement | 25,000.00 | Kg | 0.9440 | CFP | 23,600.00 |
| | Steel | 1,500.00 | Kg | 2.4779 | Steel/pipe c | 3,716.85 |
| | C-pac roof tile | 3,223.00 | kg | 0.9440 | CFP | 3,042.51 |
| | Total | | | | | 30,359.36 |

- **Construction phase**

Table 3 $CO_2$ from construction phase by energy consumption

| | **Area** | **32.00** | **$M^2$** | | | |
|---|---|---|---|---|---|---|
| Expandable Polystyrene: Construction | item | Amount | Unit | EF | Ref. | $kgCO_2eq$ |
| | Diesel (process) | 60.60 | liter | 0.2767 | Diesel | 16.77 |
| | Diesel (burning) | 60.60 | liter | 2.7446 | Gas/Diesel Oil IPCC | 166.32 |
| | Electricity | 159.42 | kWh | 0.6093 | Electricity, grid | 97.13 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | mix | |
| | Total | | | | | 280.22 |
| Recycled material: Construction | **Area** | **30.00** | **$M^2$** | | | |
| | item | Amount | Unit | EF | Ref. | $kgCO_2eq$ |
| | Diesel (process) | 64.64 | liter | 0.2767 | Diesel | 17.88 |
| | Diesel (burning) | 64.64 | liter | 2.7446 | Gas/Diesel Oil IPCC | 177.41 |
| | Electricity | 170.05 | kWh | 0.6093 | Electricity, grid mix | 103.61 |
| | Total | | | | | 289.91 |
| Concrete: Construction | **Area** | **50.00** | **$M^2$** | | | |
| | item | Amount | Unit | EF | Ref. | $kgCO_2eq$ |
| | Diesel (process) | 101.00 | liter | 0.2767 | Diesel | 27.94 |
| | Diesel (burning) | 101.00 | liter | 2.7446 | Gas/Diesel Oil IPCC | 277.30 |
| | Electricity | 265.70 | kWh | 0.6093 | Electricity, grid mix | 161.89 |
| | Total | | | | | 467.04 |

Table 2 shows the life span impact to the environment for three prototypes; the recycled material house has less amount of the pollution/emissions about 7,249.92 $kgCO_2eq$ because the main materials are recycled materials. Use of recycled building materials decreased $CO_2$ from transport as combustion fuel [14]. However, expanded polystyrene and concrete & mixed natural material houses have more amount of the pollution/ emissions about 11,451.61 $kgCO_2eq$ and 30,359.36 $kgCO_2eq$ respectively. In construction phase of energy consumption, the foam prototype generated $CO_2$ of 280.22 $kgCO_2eq$, however, it was not different than the other types because the construction equipments used in the project site area were similar. Therefore, recycled material house type, combined with scrap wood and steel showed significant contribution towards good environment. Also, the studied LCA by analyzing $CO_2$ for housing sector in Malaysia including apartment, detached house, and housing development found that during construction period (building the structure and foundation) of house released higher amounts of $CO_2$ and thus timber house should be promoted [8].

- **Operation phase**

Table 4 $CO_2$ from operation phase by electricity appliances
The result of analysis of electric energy consumption data of three house types for 24 hrs:

| | TYPE | | |
|---|---|---|---|
| | Expandable Polystyrene house | Recycled material house | Concrete and mixed natural material house |
| Total electric energy consumption (Wh)/day | 3832 | 9247 | 13210 |
| Total electric energy consumption (kWh)/day | 3.83 | 9.25 | 13.21 |

The results of $CO_2$ analysis on three house types through 30 years life span:

| | House Life | Days | 30 Years | Total electric energy consumption through 30 years (kWh) | EF | Total $kgCO_2eq$ |
|---|---|---|---|---|---|---|
| Expandable Polystyrene house | 30 | 365 | 10,950 | 41,961 | 0.6093 | 25,566.922 |
| Recycled material house | 30 | 365 | 10,950 | 101,251 | 0.6093 | 61,692.477 |
| Concrete and mixed natural material house | 30 | 365 | 10,950 | 144,645 | 0.6093 | 88,132.11 |

The analysis of total electric energy consumption in each house for 24 hrs revealed that expandable polystyrene house has used less electricity (3.83 (kWh) / day) and released carbon dioxide equivalent to 25,566.922 $kgCO_2eq$ as it contains special additives which reduce the overall thermal conductivity [13]. Concrete and mixed natural material house has used high volume of electricity about 13.21 (kWh) / day, and released carbon dioxide equivalent to 88,132.11 $kgCO_2eq$. Also, the result showed that between 10:00 to 16:00 was peak energy consumption as the temperature outside was very high.

Table 5 $CO_2$ from operation phase by transportation

| | **Items** | | | **Quan.** | **Unit** | **EF** | **Ref** | **Emission Factor ($kgCO_2eq$)** |
|---|---|---|---|---|---|---|---|---|
| **Motorcycle** | traveling | motorcycle | Gasoline<br>Gasoline burned | 581.83<br>581.83 | Liter<br>liter | 0.5090<br>2.2376 | Gasoline<br>Motor<br>Gasoline | 207.29<br>1,301.90 |
| | | | | | | | | 1,509.19 |
| **LPG** | Cooking | Household LPG | LPG<br>LPG burned | 846.01<br>846.01 | Kg<br>Kg | 0.4122<br>3.1133 | Liquefiled Petroleum Gas LPGIPCC Vol.2 | 348.73<br>2,633.88 |
| | | | | | | | | 2,633.88 |
| **BIOGAS** | Cooking | BIOGAS | BIOGAS | 1,992.60 | $M^3$ | - | | |
| | | | BIOGAS burned | 1,992.60 | $M^3$ | 0.0032 | IPCC2006 | 6.46 |
| | | | | | | | | 6.46 |

The carbon dioxide emissions are variable depending on the energy source type. LPG has produced carbon dioxide emissions as producing and burning process with 1,509.19 $kgCO_2eq$, while BIOGAS has produced only 6.45 $kgCO_2eq$. Therefore, use of BIOGAS is recommended as it formed of small organic substances and residues hence there is no carbon dioxide emission on production.

- **Waste management phase**

Table 6 $CO_2$ from operation phase by transportation

| Type | Items | Quant. | Unit | EF | Ref | $KgCO_2eq$ |
|---|---|---|---|---|---|---|
| Expandable Polystyrene House, Landfill | Polyurethane | 800.00 | kg | 2.3200 | Wastes have $CO_2$ | 1,856.00 |
| | Steel L | 300.00 | kg | | Wastes no $CO_2$ | |
| | Cement (flooring) | 7,680.00 | kg | | Wastes no $CO_2$ | |
| | | | | | | 1,856.00 |
| Recycled House, Landfill | Wood scraps | 189.00 | kg | 3.3300 | EF carbon footprint products | 629.37 |
| | Steel scraps | 360.00 | kg | | Wastes no $CO_2$ | |
| | Cement (flooring ) | 7,680.00 | kg | | Wastes no $CO_2$ | |
| | | | | | | 629.37 |
| Concrete House, Landfill | Cement | 25,000.00 | kg | - | Wastes no $CO_2$ | - |
| | Steel | 1,500.00 | kg | - | Wastes no $CO_2$ | - |
| | C-Pac roof tiles | 3,233 | kg | - | Wastes no $CO_2$ | - |
| | | | | | | - |

Building life was expected 30 years, therefore the waste management by landfill showed that concrete and mixed natural material house has not affect on global warming (0.00 $kgCO_2eq$), whereas recycled material house emission about 629.37 $kgCO_2eq$ and Expandable Polystyrene house has higher emission approximately 1,856.00 $kgCO_2eq$.

From above four stages of LCA process of three house types it can be noted that concrete and mixed natural material house produced highest emission about 118,958.50 $kgCO_2eq$. Second, recycled material house produced around 69,870.67 $kgCO_2eq$, and the third ranked is Expandable Polystyrene house has total of 39,154. $kgCO_2eq$ as shown in Figure 2. Thus Expandable Polystyrene house should be promoted as it appears to be more environmental friendly.

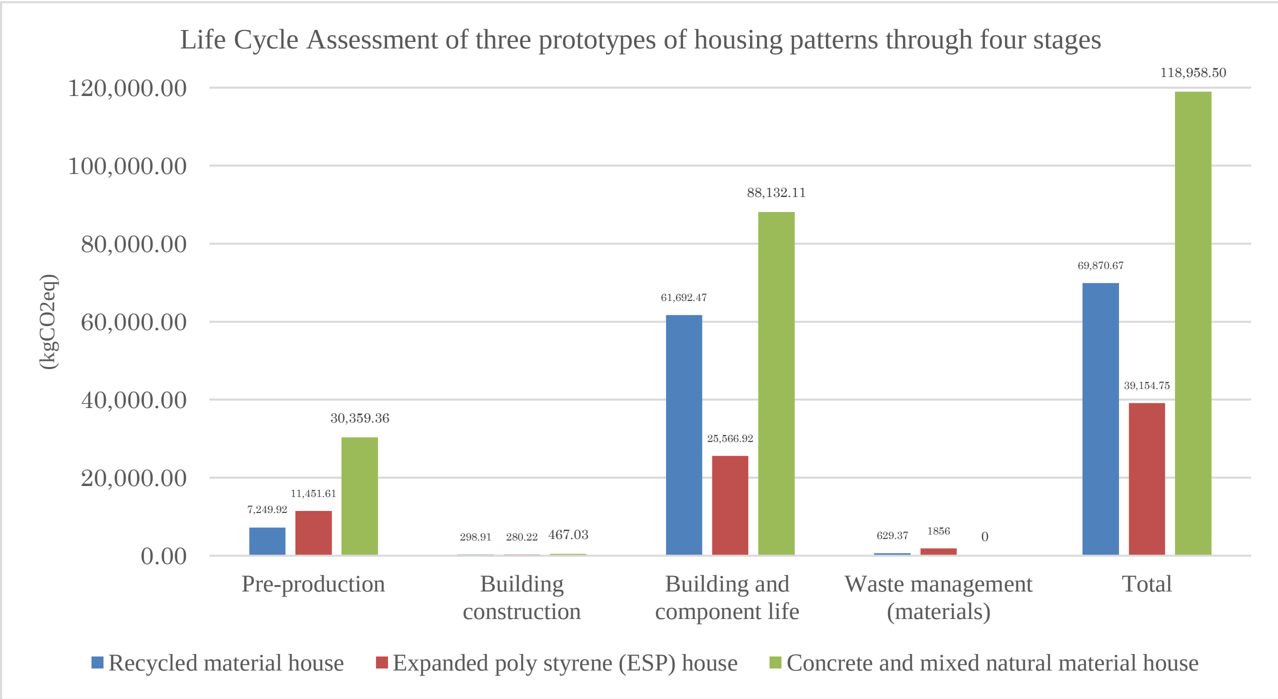


Figure 2. Summarized results of LCA analysis of three house types

Next part of LCA analysis was to provide the analysis upon electricity consumption scenarios from fuel and renewable energy sources for three housing prototypes. This is to evaluate the amount of carbon footprints as well as to find the best alternate solution for global warming problem to achieve low carbon society goals. The result has been shown in Table 7.

Table 7 Alternative energy source from fuel and renewable energy for three house types

| **LCA** | **Conditions** | Expandable Polystyrene house | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 |
| Materials sources | | 11,451.61 | 11,451.61 | 11,451.61 | 11,451.61 | 11,451.61 | 11,451.61 | 11,451.61 | 11,451.61 |
| Operation phase | | 280.22 | 280.22 | 280.22 | 280.22 | 280.22 | 280.22 | 280.22 | 280.22 |
| Usage electricity | Electricity grid mix | 25,566.92 | 25,566.92 | 25,566.92 | 25,566.92 | | | | |
| | Solar cells | | | | | 0.00 | 0.00 | 0.00 | 0.00 |
| Usage energy (occupancy) | Motorcycle | 1,509.19 | 1,509.19 | | | 1,509.19 | 1,509.19 | | |
| | Bicycle | | | 0.00 | 0.00 | | | 0.00 | 0.00 |
| | LPG | 2,982.61 | | 2,982.61 | | 2,982.61 | | 2,982.61 | |
| | BIOGAS | | 6.46 | | 6.46 | | 6.46 | | 6.46 |
| Wastes management | | 1,856.00 | 1,856.00 | 1,856.00 | 1,856.00 | 1,856.00 | 1,856.00 | 1,856.00 | 1,856.00 |
| Landscape change | | 45.00 | 45.00 | 45.00 | 45.00 | 45.00 | 45.00 | 45.00 | 45.00 |
| **Total** | | 43,646.56 | 40,670.40 | 42,137.37 | 39,161.21 | 18,079.63 | 15,103.48 | 16,570.44 | 13,594.29 |
| **Alternative scenario for reducing carbon emission** | | 8 | 6 | 7 | 5 | 4 | 2 | 3 | 1 |

| LCA | Conditions | Recycle material house | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 |
| Materials sources | | 7,249.92 | 7,249.92 | 7,249.92 | 7,249.92 | 7,249.92 | 7,249.92 | 7,249.92 | 7,249.92 |
| Operation phase | | 298.91 | 298.91 | 298.91 | 298.91 | 298.91 | 298.91 | 298.91 | 298.91 |
| Usage electricity | Electricity grid mix | 61,692.48 | 61,692.48 | 61,692.48 | 61,692.48 | | | | |
| | Solar cells | | | | | 0.00 | 0.00 | 0.00 | 0.00 |
| Usage energy (occupancy) | Motorcycle | 1,509.19 | 1,509.19 | | | 1,509.19 | 1,509.19 | | |
| | Bicycle | | | 0.00 | 0.00 | | | 0.00 | 0.00 |
| | LPG | 2,982.61 | | 2,982.61 | | 2,982.61 | | 2,982.61 | |
| | BIOGAS | | 6.46 | | 6.46 | | 6.46 | | 6.46 |
| Wastes management | | 629.37 | 629.37 | 629.37 | 629.37 | 629.37 | 629.37 | 629.37 | 629.37 |
| Landscape change | | 48.00 | 48.00 | 48.00 | 48.00 | 48.00 | 48.00 | 48.00 | 48.00 |
| **Total** | | 74,362.47 | 71,386.32 | 72,853.28 | 69,877.13 | 12,670.00 | 9,693.84 | 11,160.81 | 8,184.56 |
| **Alternative scenario for reducing carbon emission** | | 8 | 6 | 7 | 5 | 4 | 2 | 3 | 1 |

| LCA | Conditions | Concrete and mixed natural material house | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 |
| Materials sources | | 30,359.36 | 30,359.36 | 30,359.36 | 30,359.36 | 30,359.36 | 30,359.36 | 30,359.36 | 30,359.36 |
| Operation phase | | 467.04 | 467.04 | 467.04 | 467.04 | 467.04 | 467.04 | 467.04 | 467.04 |
| Usage electricity | Electricity grid mix | 88,132.11 | 88,132.11 | 88,132.11 | 88,132.11 | | | | |
| | Solar cells | | | | | 0.00 | 0.00 | 0.00 | 0.00 |
| Usage energy (occupancy) | Motorcycle | 1,509.19 | 1,509.19 | | | 1,509.19 | 1,509.19 | | |
| | Bicycle | | | 0.00 | 0.00 | | | 0.00 | 0.00 |
| | LPG | 2,982.61 | | 2,982.61 | | 2,982.61 | | 2,982.61 | |
| | BIOGAS | | 6.46 | | 6.46 | | 6.46 | | 6.46 |
| Wastes management | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Landscape change | | 75.00 | 75.00 | 75.00 | 75.00 | 75.00 | 75.00 | 75.00 | 75.00 |
| **Total** | | 123,450.31 | 120,474.16 | 121,941.12 | 118,964.97 | 35,318.20 | 32,342.05 | 33,809.01 | 30,832.86 |
| **Alternative scenario for reducing carbon emission** | | 8 | 6 | 7 | 5 | 4 | 2 | 3 | 1 |

Comparison of scenario 1 to scenario 8 is clearly indicating that changes of energy resource from electricity grid mix to solar cell has reduced amount of $CO_2$ from three house types. Also, using BIOGAS instead of LPG reduced greenhouse gas emissions [15]. Therefore, renewable energy source is recommended to be integrated with three prototypes housing developments. However, recycled house type in scenario 8 showed the best model of alternative renewable energy sources; its total $CO_2$ emission was only 8,184.36 $kgCO_2eq$. On the other hand, expandable polystyrene house and concrete house were releasing about 13,594.29 $kgCO_2eq$ and 30,332.36 $kgCO_2eq$ respectively.

*4.2 People perception on three prototypes housing development*

Questionnaires had been distributed to visitors at case study site and requested to fill the questionnaire form for the research until the number of respondents reached to 227, as required based on Yamane theory. The gender distribution of total 227 respondents was; male 122 people (53.7%) and female 105people (46.3%). Age of respondents between 18-30 years showed the highest percentage of 37.9%, followed by 31-40 years (29.9%), 41-50 years (18.5%), 51-60 years (10.6%), and over 60 years (3.5%). The questionnaire part of research is to consider the house prototype based on respondent's attitudes. Table 8 showed that most of the total respondents (227 people), 140 people or 61.7% selected the third type for applications. Second and third ranked were type two and type one with 59 people or 26% and 28 people or 12.3% respectively.

Table 8 Consider the house prototype for adaptation

| House prototype | No. of respondents | Percentage |
|---|---|---|
| Expandable Polystyrene | 28 | 12.30 |
| Recycled materials | 59 | 26.00 |
| Concrete | 140 | 61.70 |
| Total | 227 | 100.00 |

Source: Field survey, 2014

The arguments of respondents were:

- **Expandable Polystyrene house**

Foam insulation uses less of air conditioning system as it keeps cooler temperature which is able to save electricity. Foam is permanent material and durable in condition than materials of type two and three, long term energy savings are expected and is a suitable home because the area is not quite large hence uses less energy.

- **Recycled material house**

The reasons for choosing this type were money savings in terms of using recycled materials, appropriate size fit enough for small family, reduces deforestation, value-added house by recycle materials, good ventilation with natural materials that have been used in its construction, it seemed more modern in style and usefulness of construction investment as low cost perspective.

- **Concrete and mixed natural material house**

The house is durable due to use of concrete and steel, offers large area of living, in case of damage can be repaired more easily in terms of materials, its design responses to local climate that creates more efficient ventilation. It was not necessary to have air conditioning. Mix of material provides more strength of structure in a longer period than type two and type one. These opinions of respondents are quite similar with the study of customer preferences in Bangalore City that concrete is waste minimize and gains strength over time especially for ready mixed concrete has higher durability as it better processes [16].

The respondents' were asked whether or not all the prototypes were able to be applied as alternate to their existing house, it was found that 154people or 67.80% thought that all three types of houses could be a model for application, followed by 24 people or 10.6% who thought they were unable to adapt 49 people or 21.60% were not sure about.

Table 9 Application of three prototypes housing development for improvements

| House prototype can be applied for your house improvement | No. of respondents | Percentage |
|---|---|---|
| Yes | 154 | 67.80 |
| No | 24 | 10.60 |
| Not sure | 49 | 21.60 |
| total | 227 | 100.00 |

Source: Field survey, 2014

Improvement program of existing house of respondents was also examined to know probability adaptation of housing development patterns. The Table 10 shows that the respondents who created or modified houses to reduce the amount of carbon and make them energy-efficient were; 46 people or 20.54% use lightweight blocks instead of masonry, 45 people or 20.09% installed exterior shading, 34 people or 15.18% used wall insulation system. Use of prefabricated construction system was minor (7 people or 3.13%) in the group of respondents.

Table 10 List of improvement program of respondents' existing house

| Improvement programs | No. of respondents | Percentage |
|---|---|---|
| Solar system | 19 | 8.48 |
| The roof with good reflective sunlight | 15 | 6.70 |
| Wall insulation system | 34 | 15.18 |
| Use ceiling insulation from heat gain under the roof | 27 | 12.05 |
| Use lightweight blocks instead of masonry | 46 | 20.54 |
| Use synthetic wood | 16 | 7.14 |
| Install exterior shading | 45 | 20.09 |
| Use prefabricated construction system | 7 | 3.13 |
| Use products that received environmental certificate | 12 | 5.36 |
| Other | 3 | 1.34 |
| Total | 224 | 100.00 |

Source: Field survey, 2014

## 5. Conclusion

House directly contributes to global warming as a result of consuming energy. Three prototypes of hosing patterns; expandable polystyrene**,** recycled material house, and concrete and mixed natural material house analyzed by LCA showed clear difference in $CO_2$ emission in terms of main materials of building, size of the building, environments, and occupant's behavior on energy usage from cradle to grave principle. The results of analysis of housing impact on the environment throughout the life span, in terms of highest carbon dioxide emission revealed that concrete and mixed natural material house can be ranked as the highest about 118,958.50 $kgCO_2eq$. Second, recycled material house contributes about 69,870.67 $kgCO_2eq$, and the third ranked is expandable polystyrene house with 39,154. $kgCO_2eq$. The study reveals that in LCA process, the emission of expandable polystyrene house was less than others. Additionally, when changed energy sources from conventional (power grid) to solar cell and biogas through consideration of 8 scenarios it was found that expandable polystyrene can tremendously mitigate GHG at 25,566.922$kgCO_2eq$. Therefore, this prototype could be mentioned as environment friendly product. To achieve low-carbon society, it should be considered at beginning about raw materials accompanied with construction method and/or technique, however 80% of energy consumption is based on resident's activity and household appliances, therefore, the scenario 8 of all types house should be promoted. Further the cost and economic feasibility is recommended to study for large-scale production that people can afford throughout the country or building cost for individual construction purpose. Exploring perceptions towards adapting the three prototypes of housing patterns found that most respondents have selected the concrete and mixed natural material house because of durability, offering large space, easily finding material to fix, its design response to local climate that makes house more efficient in ventilation, and provides more strength of structure over the longer period than expandable polystyrene and recycled material house. Hence, holistic knowledge in housing energy consumption and its impact to environment (from materials) should be provided to people. Also, it is recommended that design of buildings to meet renewable energy applications instead of using fossil fuels based energy should be a priority to be considered in order to combat environmental and energy challenges and enhancing low carbon society in Thailand.

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