A Survey of Housing Features and Thermal Comfort of Medium and Low Income Earners in Thailand

Research Programme on Reducing Energy Consumption Cost and GHG Emission for Tropical Low-income Housing: Thailand Contribution

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CHAPTER 1
BACKGROUND

1.1 Background and significance of the surveys

1.1.1 National census information

Thailand population has reached 65.5 million people with a growth rate of 0.72 percent (Figure 1.1) as reported in Bureau of Statistical Forecasting [1] from The results of population and housing census conducted in 2010. The population was increased around 5 million people for every 10 years since 1990 while the growth rate is reduced from 3.15 to 0.72 percent during 1960 to 2010, population growth of Thailand is now near saturation.

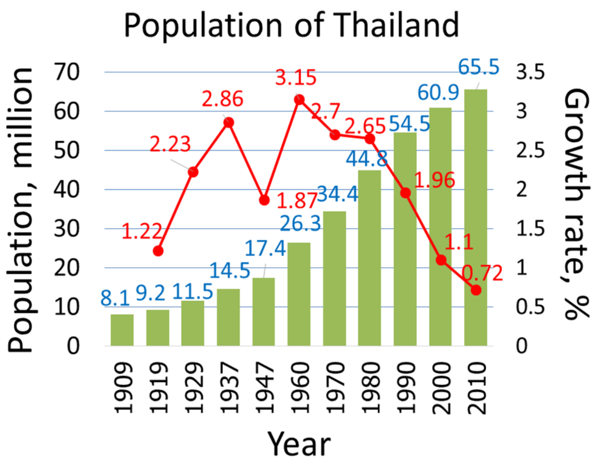


Figure 1.1 Population and growth rate of Thailand.

Growth rates of Bangkok, central, and southern region are higher than the others but the real meaning is not higher growth rate but from migration of people to the central region for better job and life (Table 1.1). Migration of the southern Thailand is lower due to many jobs in their local area; tourism, agriculture, small industry, and fishery while in the north and northeastern region are less local career.

Table 1.1 Population and growth rate of each region.

		2004	2007	2010	2013
Bangkok	**Population, million**	5.6	5.7	5.7	5.7
	Growth rate*, %	2.6			
Central	**Population, million**	15.0	15.3	15.7	16.2
	Growth rate*, %	2.4			
Northern	**Population, million**	11.8	11.9	11.8	11.8
	Growth rate*, %	0.0			
North-eastern	**Population, million**	21.3	21.4	21.6	21.8
	Growth rate*, %	-1.0			
Southern	**Population, million**	8.4	8.7	8.9	9.1
	Growth rate*, %	0.9			

* Growth rate is averaged during year 2000-2010

Number of households has reached 20.3 million families in 2010 and were increased around 5 million families during the year 2000 to 2010 (Figure 2.1) while population was increased only 5 million people as shown in the figure 1.1. The reason of increasing of family size is mostly from smaller family size rather than the increasing of population.

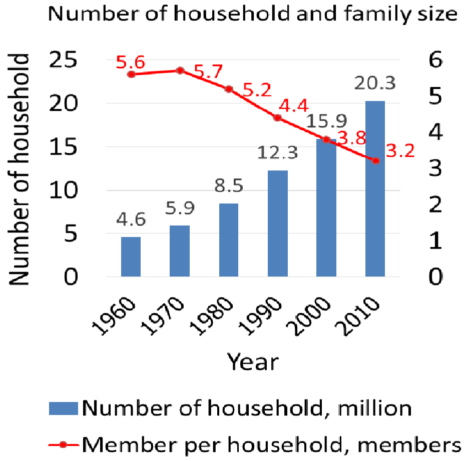


Figure 1.2 Number of households and family sizes during year 1960-2010.

Table 1.2 shows that the reducing of family size occur in all regions of Thailand. This leads to increase house constructions and energy use although the population is not increased.

Table 1.2 Average family size of each region.

Region	Member per household	
	Year 2000	Year 2010
Nation	3.8	3.2
Bangkok	3.6	2.9
Central	3.6	3.0
North	3.5	3.1
Northeast	4.1	3.5
South	4.0	3.5

From the 2010 national census, the Bureau of Statistical Forecasting reports that 77% of families in the whole kingdom and 90% of families in northern and northeastern region live in detached houses as shown in Table 1.3. The same census also records that almost all dwellings are constructed with concrete block and cement only (54%), wood only (23%), and a combination of concrete block and cement and wood (22%). The houses constructed by concrete block and cement and a combination of concrete block and cement and wood were increased around 151% and 40% during year 2000 to 2010 (Table 1.4).

Table 1.3 Types of dwellings of Thailand

	Region					
Type of dwellings	**National**	**Bangkok**	**C**	**N**	**NE**	**S**
Detached houses	77.3	45.7	64.0	90.2	92.4	76.3
Twin houses / townhouses	7.3	25.3	12.9	1.5	1.1	4.3
Shop houses/ row houses	12.9	25.6	19.5	6.3	4.6	17.4
Condominium/flat	1.8	2.8	2.8	1.3	1.0	1.1
Others	0.7	0.6	0.8	0.7	0.9	0.9

Table 1.4 Types of construction materials of dwellings of Thailand

Construction materials	Year 2000	Year 2010	percent of changing
Cement or brick	4,371,495	10,976,748	151
Wood/Permanent materials	6,710,727	4,631,836	-31
Wood and cement or brick	3,119,850	4,382,377	40
Others	1,169,085	192,658	-84
Total	15,371,157	20,183,619	31

1.1.2 Changes in social and housing features

Thai vernacular house designs are influenced by local cultures, living styles, climates and local climatological events such as storms and floods. Ramasoot and Nimsamer [2] studied vernacular house designs of riparian community of central region of Thailand. A part of the report shows that house designs of the community which annually encounter flooding, always comprise 2 stories, and the structure constructed with durable- simple to repair materials such as wood (old houses) or concrete walls (new houses). Chirarattananon, Hien and Tummu [3] also studied on thermal performance of light and massive walls of commercial and residential buildings enclosing spaces used under different functions. The results show that light wall is proper for Thai houses because absorption of solar radiation during daytime is lower, the heat release into the spaces during night time is also lower. The results also show that interior surface temperatures on light walls at night are also lower resulting in lower thermal radiation from them during night time. It is surmised that these must have contributed to influencing adoption of low mass materials such as wood in traditional houses in Thailand. For roofs, it is a high pitch roof (Fig. 1.3 (a)) so as to be able to drain rain water faster. In the past, basements was raised around 1 m for keeping their agricultural tools and to avoid inundated water in the rainy season. For Thai modern house Figure 1.3 (b), configurations of houses and materials of walls are changed because of differences of living styles and local construction materials in local area. The uses of wooden materials for Thai house construction seem to be very difficult for low and middle income earners because of high prices and legal requirements not to cut them while the concrete materials are cheaper and easier for finding in the local areas. Apart from that, occupations of the people is also changed from agricultural base to be employees due to depressed market of agricultural products, This makes no longer required to have a basement except for areas that are flooded.

In the past when there were no factories, children who finished education would work in the field nearby their house farming, growing vegetables or sugar cane, or selling things. Now that agriculture is declining and being replaced by factories, people are unlikely to live in their hometown. Today the young generation is less likely to stay home because no work is available and land is limited so only their parents can work. Most of them find more comfortable jobs elsewhere and earn more. Parents want their children to work elsewhere for their own future and better life. Children are likely to scatter from parents. They leave grandchildren with grandparents while they go to work elsewhere. House style in present reflect living style because this change. The most of present house in northern has only a single storey because the house is renovated for older people, who always live at first floor. This situation is reported in Knodel [4].

Carbon embedded in construction materials is one of the significant sources related to carbon footprint of residential houses. Our previous studies focused on the estimation of greenhouse gas (GHG) emission from conventional houses and modern houses with different construction materials such as precast concrete, light-weight concrete and brick. It was reported that 98% of GHG emissions were from construction materials. Cement and steel were major sources of GHG emission, Aneksaen [5]. However, GHG emissions from low income houses have not been investigated. This study aims to evaluate GHG emissions from construction materials of low income houses in Thailand. The activity data of constructing materials were extracted from house plans and Bill of Quantities (BOQ) of low income houses in Thailand. The GHG emissions in the unit of kgCO2 e/m2 were calculated in the scope of cradle to gate following the Thai national guideline for carbon footprint of product, Thailand Greenhouse Gas Management Organization [6].

a) Traditional

b) Modern

Figure 1.3 Traditional and modern housing features

1.2 The purpose of the surveys

The surveys aim to study on design features, living styles, material uses, lighting conditions, energy uses, interior thermal environment, and GHG emission due to the use and construction of houses of low and middle income earners in Thailand. Preliminary results of the surveys are reported in this study. Results will be used to define a base line of housing feature, energy use, living style and GHG emission of vernacular houses of each region. The results will lead to examination for appropriate Thai house designs and construction for low energy and low greenhouse gas emissions in the near future.

1.3 Scope of study

The surveys were conducted to collect data to establish baseline of energy uses and features of Thai houses for low and middle income earners. The questionnaire and equipment were prepared to collect data as follows.

- Electric appliance and energy uses
- Housing layout, features, and materials used
- Geography
- Economic
- Community environment, social, and culture
- Thermal environment
- Thermal and visual comfort condition

Before conducting the surveys, questionnaire and measuring instruments were prepared and tested in KMUTT campus, a sample detached house of an ELITH Thailand member, and Rama II - NHA community houses (near the KMUTT campus) to evaluate and improve methods of collecting survey data.

The survey sites are in 4 main regions of Thailand and for each region, survey sites are distinguish into 2 groups as follows

- NHA houses: Residential buildings built under the projects of NHA,
- selected detached houses.

Selected detached houses are the typical houses of each region which are similar features, sizes, and use the same materials.

Meetings were conducted with samples of NHA to consult about survey requests and NHA members also participated in the surveys. 12 NHA and 12 selected detached houses were survey in each region.

1.4 Methodology

A field surveys were conducted in 4 main regions of Thailand (Fig. 1.4). Chiang mai (Yellow highlight), Phra Nakhon Si Ayutthaya (Red highlight), Ubon Ratchathani (Green highlight), and Phuket (Blue highlight) were selected to be a sample of northern, central, north-eastern and southern Thailand.

Figure 1.4 Survey sites of each region

Survey sites of this study are as in Table 1.5. The duration of the surveys are 2 days for each region, the surveys were conducted and finished in September 2014.

Table 1.5 Target building of the survey.

Area	**Project developer/Owner**	**Province**	**Survey date**
Central	NHA houses	Phra Nakhon Si Ayutthaya	September 4, 2014
	Other detached houses	Pathum Thani	September 5, 2014
Northern	NHA houses	Chiang Mai	September 11, 2014
	Other detached houses	Chiang Mai	September 12, 2014
North-eastern	NHA houses	Ubon Ratchathani	September 18, 2014
	Other detached houses	Ubon Ratchathani	September 19, 2014
Southern	NHA houses	Phuket	September 25, 2014
	Other detached houses	Phang Nga	September 26, 2014

Remarks:

NHA houses: Residential buildings built under the projects of National Housing Authority (NHA),

selected detached houses: Other houses apart from NHA houses.

A questionnaire and measuring instruments were prepared to collect design features, living styles, material uses, lighting conditions, energy uses, and interior thermal environment of houses of low and middle income earners in Thailand. Table 1.6 shows lists of the required data of the surveys. Parameters required for thermal comfort assessment were also measured during interviewing; DB temp, Globe temp, Wind velocity, %RH, Light illuminance.

Table 1.6 Details of the required information in the questionnaire.

Required data	Details
General information	Information of residents and houses (Income, Education, age, family size, Etc.)
Data of energy uses	History of energy uses and energy uses for lighting, cooking, entertainment, convenience, and transportation category
Changing trends in energy use	Opinion of the house owners on changing type of energy use of cooking or transportation and the reason of changing
House configuration	Configurations, size and material of roof, wall, glazing and interior walls including reason behind those designs
Material types and quantities	Types and quantities of construction material quantities.
Thermal and lighting indoor environment	Conditions of lighting, temperature, wind speed, relative humidity, radiant temperature, and CO_2 in houses

CHAPTER 2
SURVEY RESULTS OF NORTHERN THAILAND

2.1 Introduction

Area of this region is 93,690.85 sq. km and this region is divided into 17 provinces i.e. Chiang Rai, Mae Hong Son, Chiang Mai, Phayao, Lamphun, Lampang, Phrae, Nan, Uttaradit, Phitsanulok, Sukhothai, Tak, Phichit, Kamphaeng Phet, Nakhon Sawan, Uthai Thani and Phetchabun. Most areas of the region are hilly and mountainous which is the source of several important rivers. These north-south oriented hill ridges are parallel from west to east and intersected by a number of major valleys, particularly those near Chiang Mai, Chiang Rai, Lampang and Nan provinces (Fig. 2.1). The highest mountain, about 2,595 meters high above mean sea level, is Doi Inthanon in Chiang Mai. Along the eastern border with the Northeastern Part is mountainous called central highlands. The area in the southern portion between the western mountains and the central highlands is a central valley.

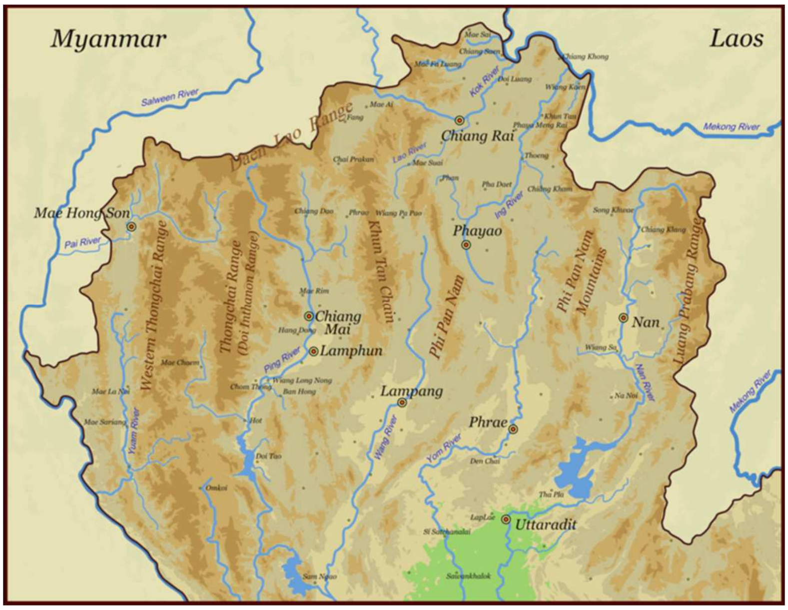


Figure 2.1 The northern Thailand geography
(Source: http://en.wikipedia.org/wiki/Thai_highlands)

The annual average temperature is 26.5 C, with the average highest temperature being 28.8 C, and the average lowest temperature being 23.6 C. The highest temperature ever recorded in the North was 44.5 C (Uttaradit Province, 1960) and the lowest until recent times was 2.0 C (Chiang Rai Province).

The rain in the North is usually provided by the southwest monsoon winds and depression storms. On average the annual rainfall in the North is 1200 mm. The province with the most annual rainfall (recorded between 1937 and 1955) is Chiang Rai province (1744 mm.), the least is Lampun province (1045.9 mm.)

Population of the northern region has not changed significantly from year 2004 to year 2010; around 11.8 million people (Table 2.1) which male and female are almost equal to about 6 million people, Bureau of Statistical Forecasting [7]. Migration of people from non-municipal area to municipal area had increased every year during year 2004 to 2013 and dramatically increased during the year 2007 to 2010. Another point of interest is while number of population of Thailand had been increasing from 60,124,743 to 63,723,702 people during year 2000-2010, but the population of the northern people is likely to be saturated. The reason of this situation is migration of people to other provinces to find a better job such as Bangkok which population had increased rapidly from 6,241,033 to 7,778,353 during these years.

Table 2.1 Population of northern Thailand

Gender and area	2004	2007	2010	2013
Total	**11,842,299**	**11,871,934**	**11,788,411**	**11,825,955**
Male	5,861,484	5,869,022	5,812,340	5,820,466
Female	5,980,815	6,002,912	5,976,071	6,005,489
Municipal area	**2,301,993**	**2,420,944**	**3,135,586**	**3,145,643**
Male	1,106,698	1,162,435	1,508,180	1,509,741
Female	1,195,295	1,258,509	1,627,406	1,635,902
Non-municipal area	**9,540,306**	**9,450,990**	**8,652,825**	**8,680,312**
Male	4,754,786	4,706,587	4,304,160	4,310,725
Female	4,785,520	4,744,403	4,348,665	4,369,587

2.2 Survey results

The purpose of this section is to examine design features, living styles, material uses, lighting conditions, energy uses, and interior thermal environment of houses of low and middle income earners in Thailand comparing to the literature review and establish the baseline for this region.

2.2.1 Living styles

Family sizes of the sample households are in a range of 1-6 members as shown in Table 2.2. The average family size is 3.3 members per family. This situation comply with a report of National Statistical Office of Thailand, Bureau of Statistical Forecasting [1], family size is reduced from 3.5 to 3.0 members from year 2000 to year 2010 for the Northern Thailand while number of family is increased from 3,194,220 to 3,771,529 family. Age of most people of the Northern Thailand is between 45-60 years old (Table 2.3). The reason of this situation is as reported in the Chapter 1, most working-age people left their hometown to work elsewhere for higher income and better life quality. Therefore most people in the birthplace are older people and children.

Table 2.2 Family size distribution of the samples of northern Thailand

Family size, persons	Number of households
1	2
2	4
5	1
6	3

Table 2.3 Age distribution of the samples of northern Thailand

Age, year	Persons
<15	5
16-30	4
31-45	9
45-60	10
>60	5

Family income of 90% of the samples is below 15,000 Baht per month (Table 2.4). The reason is 55% of them are unemployed (Retired persons and students), only 26% are employees near their local area and 7% are farmers which earn relatively low wages (Table 2.5). This status cause moving of working-age to other areas especially to the other regions especially the central region.

Table 2.4 Family income distribution of the samples of northern Thailand

Family Income	Number of households
Less than 5,000	4
5001-15000	5
15000-30000	0
More than 30,000	1

Table 2.5 Occupation distribution of the samples of northern Thailand

Occupation	Number of persons
Unemployed (retired)	8
Farmers	2
Students	9
Government employees	2
Small commercial	2
Employees (private)	8

2.2.2 Housing features

Northern style houses are wooden houses raised on stilts (Fig. 2.2). Traditional Lanna houses can be divided as follows:

1. "Toob" or ruen krueng pook. This style of house is made mainly of bamboo. The walls are made of woven bamboo strands. The house frames are held in place by locking or tying different pieces together. Roofing materials come from dried grass leaves. This is a temporary house erected in gardens or rice fields by poor people or small families just starting out. It lasts between 2-4 years.

2. Wooden house or ruen krueng sup. It is made of a combination of soft and hard wood which was abundant in the North. All the frames and major structure-of the house are made of hardwood while soft wood was used for minor parts. This type of house can last 30-50 years. In general, the houses face the south to catch the summer wind. The kitchen faces the west to protect the bedroom from the afternoon sun. The housing compound consists of at least a living quarter and a kitchen connected by walkways and terraces. The largest terrace is for drying

clothing, fruits and vegetables. Potted plants such as flowering plants, parsely, shallot and pepper chilli etc. are also kept in this part of the house.

3. Ruen Galae. This type of house belongs to the rich, the community leaders and the elite. Galae refers to the roof beams at the front and the rear of the house extended beyond the ridgepole to form a V-shaped design. The prominent feature of this style of house is the elaboratedly-carved sections of the Galae. The houses are built with the best materials and craftsmanship.

Figure 2.2 typical house in the north.
(**Source:** http://www.thailandlife.com/thai-culture/thai-house-in-the-north.html)

Table 2.6-2.8 show that, all houses of the samples of the northern region are 1-storey house and 60% of them are new houses which is not over 10 years old and built of concrete wall (Figure 2.3). This character is to adapt to current lifestyle as mentioned in the Chapter 1. And apart from that concrete wall is easy to buy in local area and cheaper than wood this leads to increase a number of the use of concrete walls in the near future.

Table 2.6 House feature distribution of the samples of northern Thailand

Single story	10
2-story	0

Table 2.7 Housing material distribution of the samples of northern Thailand

Wall materials	Households
Wood	2
Concrete	6
Wood + Concrete	2

Table 2.8 Age of house distribution of the samples of northern Thailand

Age of houses	Households
<5 Years	3
6-10 Years	3
11-15 Years	1
>20 Years	3

Figure 2.3 Concrete typical house in Northern Thailand

For the older houses which is over 10 years when wooden materials is still available for new house of that period and some wooden houses is a legacy from their ancestor. These houses used to be a 2-storey wooden houses with opened spaces of a first floor. Nowadays those houses are now renovated to be a 1-story wooden houses (Fig.2.4) while some house uses a combination of wood and concrete for walls (Fig.2.5).

Figure 2.4 Wooden typical house in Northern Thailand

Figure 2.5 Combination of concrete and wooden typical house in Northern Thailand

Common features of 3 types of houses of northern Thailand (Fig. 2.3-2.5) is near the same; 1-storey houses, pitched roof with asbestos tiles, collocations of rooms inside houses, and size of houses. By the concept of establishing a baseline of typical houses of northern region for further improvements of better designs and materials. And to meet with the changing trends in the use of materials in the future, the concrete wall houses as in Figure 2.3 is selected to be a sample houses of this region.

2.2.3 Energy consumption and GHG emission from electricity use

Figure 2.6 shows the electricity consumption distributions of the samples by varying floor area, family size, and family income. It indicates that electricity consumption is influenced by family size and family income, higher family size and higher family income are likely to be higher electricity consumption in houses.

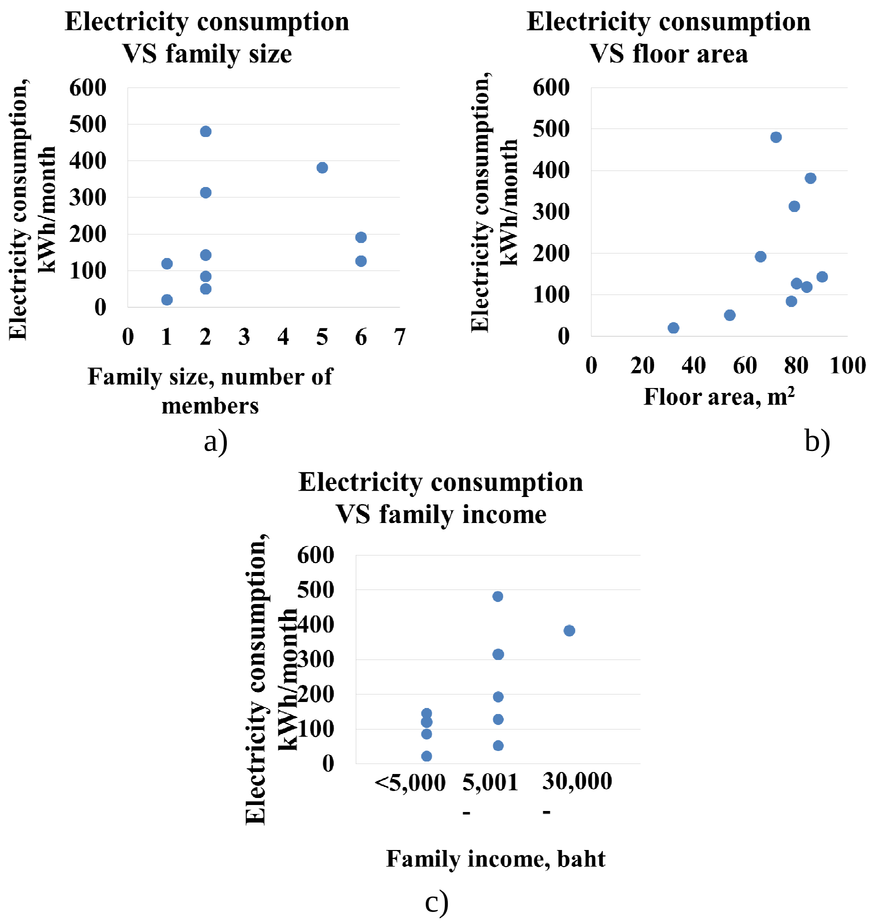


Figure 2.6 Electricity consumption distribution of the Northern Thailand

The use of air-conditioner and water heater is 30% and 40% of the samples respectively (Table 2.9-2.10).

Table 2.9 Air conditioner use distribution of the samples of northern Thailand

Use of air-conditioner use	Household
Use-air con	3
Not use-air con	7

Table 2.10 Water heater use distribution of the samples of northern Thailand

Use of water heater	Household
Use-water heater	4
Not use-water heater	6

Table 2.11 shows electricity consumption of electricity appliances of the sample houses of northern Thailand. The appliances are distinguished into 4 categories; lighting, entertainment, convenience, and cooking. The results show that, the convenient category consume the highest electricity of 72.8%. Main appliances which consume high power of this category are air conditioner, refrigerator, fan, and water heater which consume 20.69%, 16.98%, 15.07% and 10.54% respectively. While cooking, lighting and entertainment categories consume 17.4%, 11% and 9.8%. Appliances that consume the most power each category are kettle (9.85%), lamp (11%), and TV (9.8%) for cooking, lighting and entertainment categories respectively.

Table 2.11 Electricity consumption of each appliance and category of the Northern Thailand

Category	Appliance	Electricity consumption, kWh/month	% 0f appliance	% of category
Lighting	Lamp	190.1	11.01%	11.0%
Entertainment	DVD player	0.6	0.04%	9.8%
	TV	168.7	9.77%	
	CD player	0.2	0.01%	
Convenience	PC	46.8	2.71%	72.8%
	Washing machine	44.9	2.60%	
	Vacuum cleaner	22.4	1.30%	
	Water heater	182.0	10.54%	
	air conditioner	357.3	20.69%	
	Refrigerator	293.2	16.98%	
	Iron	48.0	2.78%	
	Printer	2.4	0.14%	
	Fan	260.2	15.07%	
Cooking	Toaster	20.3	1.18%	17.4%
	Electric stove	28.0	1.62%	
	Microwave	35.7	2.07%	
	Rice Cooker	45.8	2.65%	
	Kettle	170.1	9.85%	

Average floor area of the houses is 72 m^2 and around 34.3 m^2 per person while average electricity consumption is 191.7 kWh per month (Table 2.12). The electricity consumption of the surveyed households per month is 191.7 kWh or 2,300 kWh per household per year. The Thailand Greenhouse Gas Management Organization, Commitee Report [8], uses an emission factor of 0.6093 kg/kWh for the present mix of fuels used in electric power generation. Total emission for the model house throughout its life is then

= 35.02 ton, if the life of the house is 25 years, or

= 70.07 ton, if the life of the house is 50 years.

However, it is more likely that the low-income earners would become middle income earners and consume electricity at a rate that is more than twice the figure used here, as they will have air-conditioning and use electric hot water heating.

Table 2.12 Average floor area, average floor area per person, electricity consumption and cost of the Northern Thailand

Average floor area	72
Average floor area per person (m^2/person)	34.4
Average electricity consumption (kWh/Month)	191.7
Average electricity cost (Baht/Month)	460

2.2.4 Thermal environment and thermal comfort assessment

Most sample houses were designed to enhance the uses of daylighting and natural ventilation with the use of ceiling under roof (Fig.2.7). The houses were designed to be stayed during daytime also therefore the houses were enclosed by many windows on walls while shading from roof wings is reasonably well to prevent direct solar radiation fall into the houses.

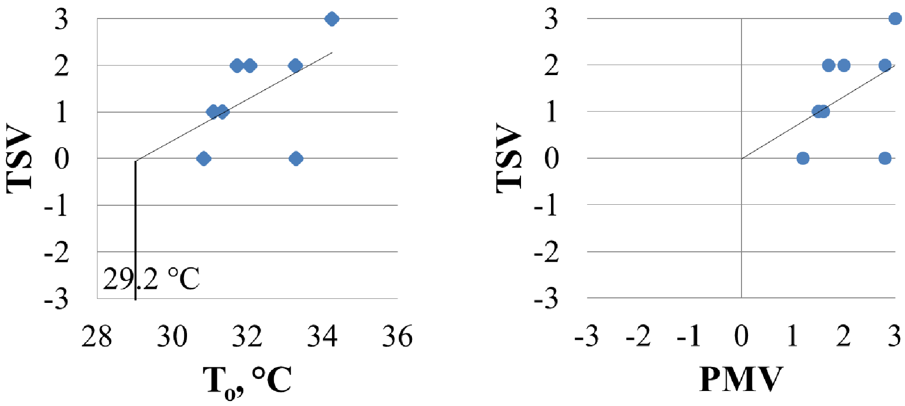
Figure 2.7 Interior house designs and roof wing features of the northern region.

Table 2.13 shows thermal environments in the sample houses, the parameters were also used in thermal comfort assessment calculations. The measurements were conducted during the daytime when solar radiation is available. Due to the housing designs lead low direct solar radiation into the houses and low thermal radiation through roof from using ceiling under roof, air temperature and mean radiant temperature in the houses are also low. While the circulation of air from the outside through the windows lead to be a comfortable condition easily and provide low CO_2 level in houses.

Table 2.13 Interior thermal environment in the sample houses of the northern region.

	Air temp. (°C)	Mean radiant temp. (°C)	Air speed (m/s)	Relative humidity (%)	CO2 (ppm)
Max	34.1	34.5	0.8	70.3	537.0
Min	30.6	31.1	0.2	58.9	460.0
Ave	32.4	32.6	0.6	65.1	493.8

For thermal comfort assessment, thermal sensation of house owners was interviewed by using the ASHRAE thermal sensation scale (7 scales) and the parameter from interviewing is called "Thermal sensation value" (TSV) while the thermal environment parameters were measuring at the same time. The Operative temperature (T_o) and predicted mean vote (PMV) was also calculated by using Fanger's equation, the measured thermal environment parameters was used in the calculations. Figure 2.8 a) shows relationship of TSV and T_o, and the results show that thermal sensations of most sample persons are in the neutral to warm zone of the thermal sensation scale (PMV is in the range of 0-2) because of the surveys was conducted during the daytime and no air-conditioners were used in the sample houses during the surveys. Neutral operative temperature of sample people of this region is 29.15°C. Relationship of TSV and PMV is shown in Figure 2.8 b), the PMV values from calculations are almost larger than the TSV values. It indicates that PMV values are not appropriate to evaluate or predict thermal sensation of Thai people but the relationship of TSV and PMV can be used for other purposes such as to predict TSV value after obtaining PMV value from computer simulations or measurements.



a) b)

Figure 2.8 Thermal comfort assessment of the Northern Thailand

2.2.5 Lighting condition in houses

The light illuminances were measured in the sample houses on the work plain level. Targets of the measurements are all rooms in those houses but in fact, the measurements are not possible in some area due to inconveniences of the owners. Table 2.14 shows lighting condition of the sample houses, light illuminances of most houses are likely to be according to Thai law; above 100 lux for residential rooms. Only 2 samples are below the standard. Causes of the issues are the windows were opened a little due to the need of a rest of the house owners (Patients were revived). Only preliminary results are shown in this report, for deeply analysis and improvements will be reported in the next phase.

Table 2.14 Values of illuminance at work plane level, lux.

Space	House number										Average
	1	2	3	4	5	6	7	8	9	10	
Living quarter	-	225	200	740	-	-	42	70	250	424	278
Bedroom	-	-	-	-	-	-	-	-	-	265	165

2.3 Greenhouse Gas Emissions of Low Income Houses in Northern Region

In northern region, the house designs are commonly affected by living lifestyle, income and environment. According to the field survey, people living in the north are mostly farmers. Their average incomes are in a range of 1,500 to 15,000 baht per month, considered as low income. The common houses are one storey houses with large space in the center of the houses. People use this space as a living room. Only bedrooms, bathroom and kitchen are separated out from the space with the partitions. The example of house design in the north is presented in Figure 2.9.

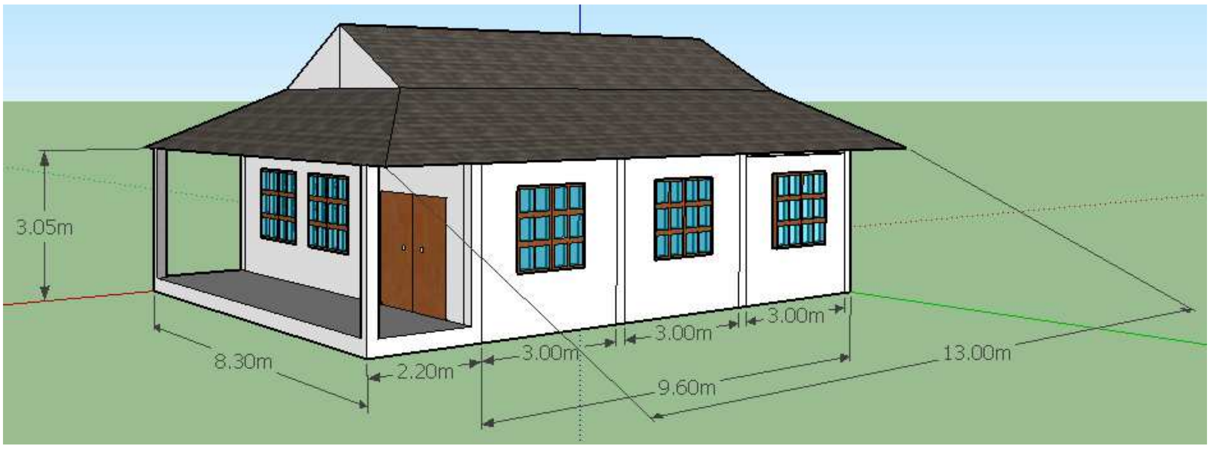


Figure 2.9 Floor plans of the detached house in northern region.

Figure 2.9 exhibits the floor plan of the detached house in northern region sketched from survey data. The plot area of the house is 11.80 x 8.30 m. The height of the floor is 3.05 m. The ground floor comprises multi-function room, restroom and there are two or three bedrooms. Kitchen, cloth washing area and bathroom are at the backside of the house. They use common, affordable and durable materials for their houses. Roofing materials are roof tile. Ceilings are made from fiber cement panels. Walls are constructed from concrete block. The lists of construction materials and the quantity of each material were shown in Table 2.15.

Table 2.15 Input data of construction materials of the detached house in Northern region.

Materials	Quantities	Unit
Sand	7,472.00	kg
Concrete	41,1345.51	kg
Cement	6,431.87	kg
Steel	967.66	kg
Roof Tiles	2,181.90	kg
Fiber cement panels	736.28	kg
Lime	532.43	kg
Glass	881.28	kg

- **Methodology**

The activity data of construction materials were extracted from house plans and Bill of Quantities (BOQ) of low income houses. The GHG emission was calculated in the unit of $kgCO_2e/m^2$ by the following equation.

$$\text{GHG emission } (kgCO_2e/m^2) = \sum [\text{Activity data (unit) x Emission factor } (kgCO_2e/\text{unit})] / \text{area}$$

Emission factors used in this study were referred from Thai national database (Thailand Greenhouse Gas Management Organization [6]), Simapro and the study from University of Bath (University of Bath [9]) as presented in Table 2.16. The GHG emissions from different building styles were then compared and the emission hotspots were pointed out.

Table 2.16 Emission factors used in this study.

Items	Unit	Emission factor ($kgCO_2e$/unit)	References
Cement	kg	0.490	TGO (2011)
Concrete	kg	**0.130**	University of Bath (2008)
Glass	kg	**1.130**	SimaPro 7.1
Fiber cement panels	kg	**1.09**	University of Bath (2008)
Lime	kg	**0.740**	University of Bath (2008)
Roof Tiles	kg	**0.353**	SimaPro 7.1
Sand	kg	**0.0037**	TGO (2011)
Steel	kg	**1.25**	SimaPro 7.1

- **Results and discussion**

The GHG emissions from construction materials of the detached house in northern region were shown in Table 2.17. The share of GHG emissions from each materials was presented in Figure 2.10. Major GHG emission hotspots came from concrete (44.91 $kgCO_2e/m^2$), cement (32.16 $kgCO_2e/m^2$) and steel (12.34 $kgCO_2e/m^2$), respectively. This is because major construction materials like concrete, cement and steel have high carbon footprints. The results are consistent with our previous study. It was reported that the major GHG contribution came from concrete, steel and cement (Aransiri [10]).

Table 2.17 GHG emissions from construction materials of the detached house in Northern region

Materials	GHG Emission($kgCO_2 e/m^2$)
Sand	0.28
Concrete	44.91
Cement	32.16
Steel	12.34
Roof Tiles	7.79
Fiber cement panels	8.19
Lime	4.24
Glass	10.16
Total	**120.70**

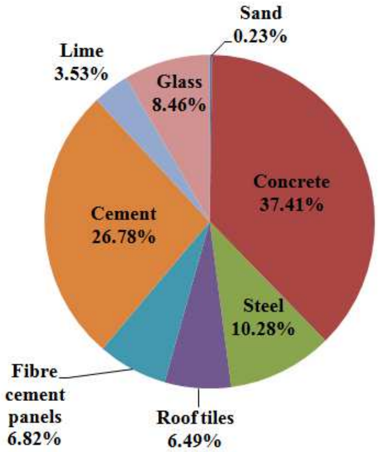


Figure 2.10 Percentage of GHG emissions from construction process of detached house in northern region

CHAPTER 3
SURVEY RESULTS OF NORTHERN-EASTERN THAILAND

3.1 Introduction

Northeast region of Thailand as known as Isan covers an area of 170,226 sq km or one third of the country. This part is divided into 19 provinces i.e. Nong Khai, Loei, Udon Thani, Nong Bua Lam Phu, Nakhon Phanom, Sakon Nakhon, Mukdahan, Khon Kaen, Kalasin, Maha Sarakham, Roi Et, Chaiyaphum, Yasothon, Amnat Charoen, Ubon Ratchathani, Sri Sa Ket, Nakhon Ratchasima, Buri Ram and Surin. The region sits on Korat plateau which distinctly raises from the Central region. The plateau tilts from Phetchabun mountain range in the west of the region down towards Mekong River (Fig. 3.1). It has high mountain range of around 500 - 1,000 metres above sea level in the west and the south and are the watersheds of 5 rivers. The San Kamphaeng mountain range and Phanom Dong Rak mountain range border Thailand with Cambodia and Laos. The highest peak is Phu Luang at 1,571 metres and Phu Kradueng at 1,325 metres. Both are popular tourist destinations. The north and the east of the region border Laos divided by Mekong River from Loei to Ubon Ratchathani. The south of the region borders Cambodia. The region has 641 km Mun River originated in Nakhon Ratchasima running through Burirum, Surin, Roi Et and Si Sa Ket. It joins Chi River and Mekong River in Ubon Ratchathani. Chi River originating in Chaiyaphum flows through Kkon Kaen, Maha Sarakham, Kalasin, Roi Et, Yasothon and joins Mun River in Ubon Ratchathani. The river is 765 km long. Songkram River originates in Sakon Nakhon and runs through Udon Thani, Sakon Nakhon, Nong Khai and moves down to Mekong River in Nakhon Phanom. The river is 420 km long.

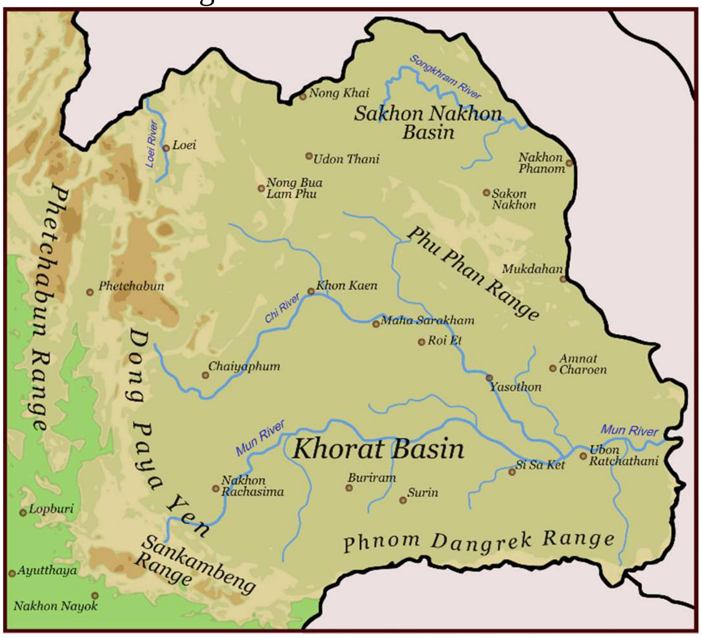


Figure 3.1 Geography of north-eastern Thailand
(**Source:** http://en.academic.ru/dic.nsf/enwiki/133143)

The average temperature range is from 30.2 °C to 19.6 °C. The highest temperature recorded was 43.9 °C in Udon Thani, the lowest -1.4 °C at Sakhon Nakhon Agro Station. Rainfall is unpredictable, but is concentrated in the rainy season from May to October. Average annual precipitation varies from 2000 mm in some areas to 1270 mm in the southwestern provinces of Nakhon Ratchasima, Buriram, Maha Sarakham, Khon Kaen and Chaiyaphum. The rainy season begins with occasional short but heavy showers, eventually raining very heavily for longer periods almost every day, usually in the late afternoon or at night, until it ends abruptly at the onset of the cool season. The other seasons are the cool season from

October to February, when the people sit outside around fires in the evenings, and the hot season from February to May with its sudden peak of high temperatures in April.

Population in this region is the highest in Thailand. Table 3.1 shows that population of the north-eastern Thailand has slightly changed from 21.2 to 21.7 million people in year 2004 to 2013 while male and female are almost equal of 10.5 million people. Number of people in municipal area is increased from 3.2 to 4.4 million people during these year while population is decreased in non-municipal area from 18 to 17.3 million people. The situation of migration of this region is similar to the northern region because of similar living styles, cultures, and occupations.

Table 3.1 Population of north-eastern Thailand

Gender and area	2004	2007	2010	2013
Total	**21,267,426**	**21,385,647**	**21,573,318**	**21,775,407**
Male	10,618,616	10,675,024	10,766,709	10,856,675
Female	10,648,810	10,710,623	10,806,609	10,918,732
Municipal area	**3,247,541**	**3,452,582**	**4,294,486**	**4,397,520**
Male	1,593,027	1,692,736	2,109,086	2,153,327
Female	1,654,514	1,759,846	2,185,400	2,244,193
Non-municipal area	**18,019,885**	**17,933,065**	**17,278,832**	**17,377,887**
Male	9,025,589	8,982,288	8,657,623	8,703,348
Female	8,994,296	8,950,777	8,621,209	8,674,539

3.2 Survey results

The purpose of this section is to examine design features, living styles, material uses, lighting conditions, energy uses, and interior thermal environment of houses of low and middle income earners in Thailand comparing to the literature review and establish the baseline for this region.

3.2.1 Living styles

Living styles of low income people in this region are similar to people of the northern Thailand. Most working-age people moved to work in municipal areas or other regions such as metropolitan areas for higher income and better life quality. In some families of the samples who live in the local area, only elderly people and children lived alone in the houses as reported in Knodel [4] which family size is between 2-4 members (Table 3.2). For the larger family size, there was another family of their descendants who also live in the houses and age distributions of the people are as in Table 3.3.

Table 3.2 Family size distribution of the samples of north-eastern Thailand

Family size	Households
2 person	2
3 persons	1
4 persons	1
5 persons	4
6 persons	4

Table 3.3 Age distribution of the samples of north-eastern Thailand

Age, year	Persons
<15	9
16-30	4
31-45	20
45-60	9
>60	17

Occupations of most sample people are farmers (Table 3.4) which monthly family incomes are below 15,000 Baht (Table 3.5). For the higher income family, most of them are officers and employees and their work places are near their houses.

Table 3.4 Occupation distribution of the samples of north-eastern Thailand

Occupation	Persons
Not working (Retired)	6
Farmer	36
Student	9
Officer	5
Business	0
Employee	3

Table 3.5 Family income distribution of the samples of north-eastern Thailand

Family Income	Households
<5000	4
5001-15000	3
15000-30000	3
>30000	2

During the daytime, only elderly people live in the houses (Figure 3.2) while other members (If available) go to schools or works.

Figure 3.2 Living styles of people in the north-eastern Thailand

3.2.2 Housing features

Traditional houses of north-eastern region were 2-storey wooden houses with opened ground floor (Fig. 3.3). The housing features and materials were almost near the same as in the northern Thailand because of similar living styles and occupations (farmer) but still a bit difference due to their cultures and local materials, the most different point was no “Ruen Galae (See Fig.2.2)” constructed on their roof. The ground floor was also designed for keeping agricultural tools and avoid water flows in the rainy season.

Figure 3.3 Traditional houses in the north-eastern Thailand
(**Source:** www.virtualtourist.com/Asia/Thailand/Northeastern_Thailand)

Most houses of the samples are 2-storey houses (Table 3.6) while wall materials can be categorized into 3 types (Table 3.7); wooden houses, concrete houses and the houses which are combinations of wood and concrete as shown in Figure 3.4, 3.5, and 3.6 respectively. Reasons behind the housing features and materials are as mentioned in Chapter 1.

Table 3.6 House feature distribution of the samples of north-eastern Thailand

House configurations	Households
Single story	1
2-story	11

Table 3.7 Housing material distribution of the samples of north-eastern Thailand

Wall materials	Households
Wood	1
Concrete	1
Wood + Concrete	10

Figure 3.4 Wooden house in north-eastern Thailand

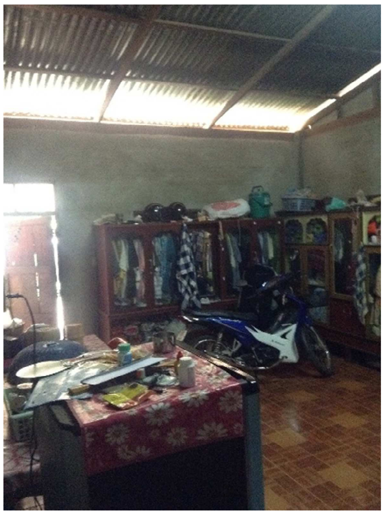


Figure 3.5 concrete house in north-eastern Thailand

Figure 3.6 Wood + Concrete typical house in north-eastern Thailand

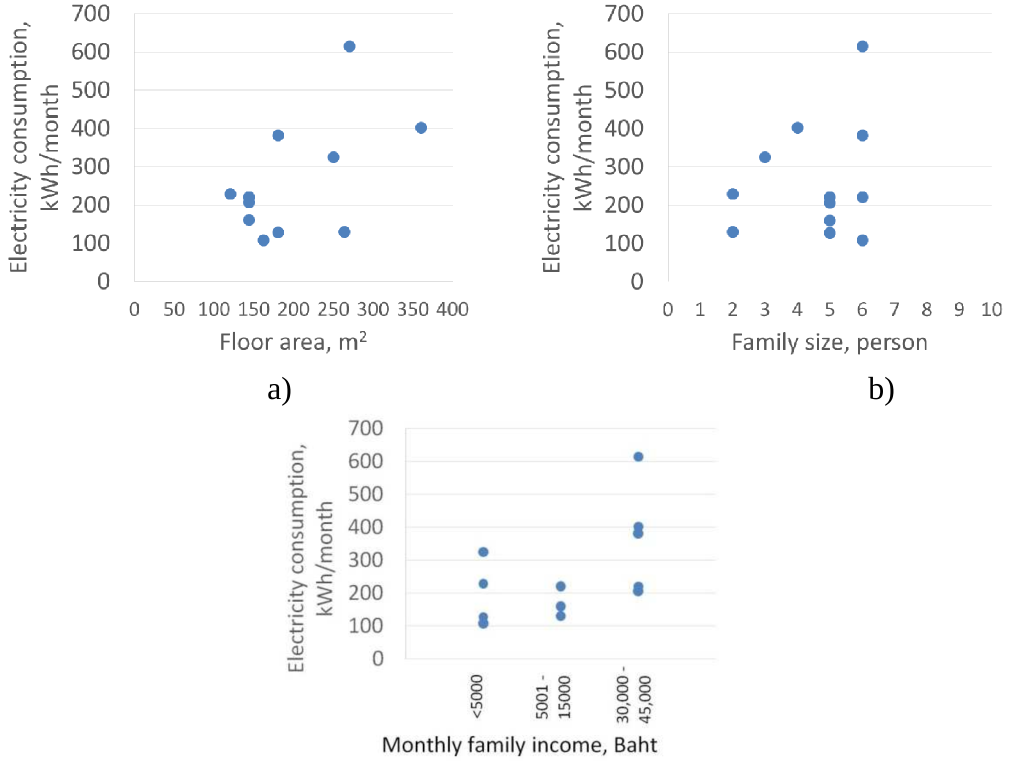
All houses of the samples are over 20 years old (Table 3.8) and most of them are Inheritances from their ancestor, this is why main wall materials are still wood although currently it is very expensive. The original housing features are as in the Figure 3.4 but after changing of living styles such as migrations of people to municipal areas cause smaller family sizes and leaving the elderly alone with children, the housing features were renovated by adding concrete walls of the downstairs as in Figure 3.6 to be easier for the elderly who is difficult to climb up and down the houses. For new houses, a single storey houses with concrete walls as in Figure 3.5 is possible to be increased as same as in the northern region due to cheaper and faster constructions.

Table 3.8 Age of house distribution of the samples of north-eastern Thailand

Age of houses	Households
<5 Years	0
6-10 Years	0
11-15 Years	0
>20 Years	12

3.2.3 Energy consumption and GHG emission from electricity use

Energy consumptions in houses of this region are likely to be influenced by family incomes and family sizes as shown in Figure 3.7. Higher monthly family income and larger family sizes lead to be higher electricity consumptions.



a) b)

c)

Figure 3.7 Electricity consumption distribution of the north-eastern Thailand

The uses of air conditioner (Table 3.9) and water heater (Table 3.10) are around 8-16% of the samples and currently only the higher income families use such appliances. But in the near future when family incomes of the others are getting higher, it is possible to increase the number of the use of these appliances.

Table 3.9 Air conditioner use distribution of the samples of north-eastern Thailand

Use of air-conditioner use	Household
Use-air con	2
Not use-air con	10

Table 3.10 Water heater use distribution of the samples of north-eastern Thailand

Use of water heater	Household
Use-water heater	1
Not use-water heater	11

Main electricity consumptions of the samples are in convenience category as same as in the northern region. It consumes around 65% while other categories consume around 12% of the total as shown in Table 3.11. Refrigerators and fans consume highest electricity in the convenience category while in the lighting, entertainment, and cooking category, the most electricity consumptions are from lamps, TV, and kettles respectively.

Table 3.11 Electricity consumption of each appliance and category of the north-eastern Thailand

Category	Appliance	Number of appliances	Electricity consumption	% of appliance	% of category
Lighting	Lamp	12	388.9	11.61%	11.6%
Entertainment	Radio	1	4.5	0.13%	11.6%
	TV	12	353.3	10.55%	
	Audio	2	30.6	0.91%	
Convenience	PC	3	80.6	2.41%	64.3%
	Washing machine	5	93.8	2.80%	
	Vacuum cleaner	1	72.0	2.15%	
	Water heater	1	84.0	2.51%	
	air conditioner	2	325.4	9.71%	
	Refrigerator	11	768.8	22.95%	
	Iron	5	194.0	5.79%	
	Hair Dryer	1	78.1	2.33%	
	Fan	12	457.5	13.66%	
Cooking	Microwave	3	91.2	2.72%	12.5%
	Rice Cooker	7	121.4	3.62%	
	Kettle	8	206.0	6.15%	

Average floor area of the houses is 197 m^2 and around 51 m^2 per person, larger than in the northern Thailand (Table 3.12) because of most houses are 2-storey. Average electricity consumption is also higher because family income of the samples of this region is higher. Average electricity consumption is 279.2 kWh per month or 3,360 kWh per household per year. The Thailand Greenhouse Gas Management Organization, Commitee Report [8], uses an emission factor of 0.6093 kg/kWh for the present mix of fuels used in electric power generation. Total emission for the model house throughout its life is then

= 51 ton, if the life of the house is 25 years, or
= 102 ton, if the life of the house is 50 years.

However, it is more likely that the low-income earners would become middle income earners and consume electricity at a rate that is more than twice the figure used here, as they will have air-conditioning and use electric hot water heating.

Table 3.12 Average floor area, average floor area per person, electricity consumption and cost of the north-eastern Thailand

Average floor area	197
Average floor area per person (m^2/person)	51
Average electricity consumption (kWh/Month)	279.2
Average electricity cost (Baht/Month)	615

3.2.4 Thermal environment and thermal comfort assessment

Thermal environment measurements and thermal comfort interviews were almost conducted in the downstairs of 2-storey houses (Figure 3.8), therefore the average value of thermal environments were not too inferior as shown in Table 3.13. But actually, thermal environment of the second floor was very torrid and high thermal radiation due to no ceiling or any thermal radiation bariers were used as in Figure 3.2 and 3.5. Thermal environments of the upstairs were measure in some house and the results are shown as the maximum values of thermal environment conditions in Table 3.13.

Figure 3.8 Interior house designs and roof wing features of the north-eastern region.

Table 3.13 Interior thermal environment in the sample houses of the north-eastern region.

	Air temp. (°C)	Mean radiant temp. (°C)	Air speed (m/s)	Relative humidity (%)	CO2 (ppm)
Max	36.2	38.2	3.8	68.9	564.0
Min	31.5	31.7	0.0	51.0	451.0
Ave	33.1	33.3	1.2	63.1	497.7

Thermal comfort interviews was also conducted in the same position which measured the thermal environments by using ASHRAE thermal sensation 7 scales to obtain thermal sensation value (TSV). Operative temperature (T_o) and predicted mean vote (PMV) values were also calculated. Relationship of TSV and T_o are shown in Figure 3.9 (a) and indicates that neutral temperature of the sample people is 30.16°C which is higher than ASHRAE standard and sample people in the northern region. Relationship of TSV and PMV is shown in Figure 3.9 b), it indicates that the PMV cannot be used to predict thermal comfort conditions of people in this region accurately due to familiarity of the people is different from European or north America people.

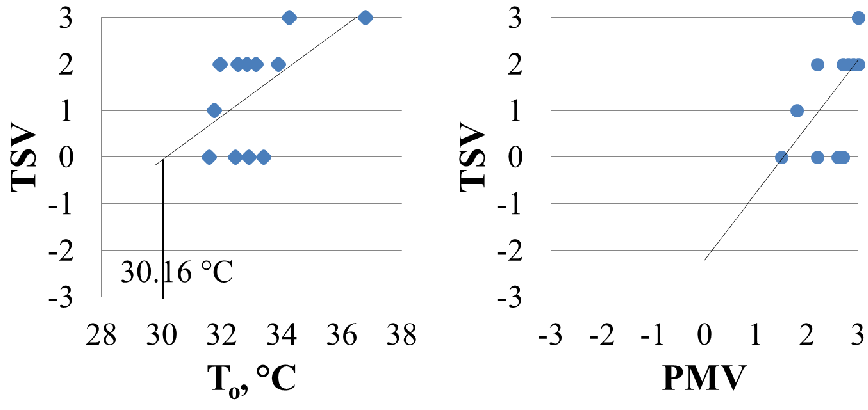


Figure 3.9 Thermal comfort assessment of the north-eastern Thailand

3.2.5 Lighting condition in houses

Lighting condition of living room and bedroom of the samples seem to be lower than standard (100 lux) in some house although many windows on walls (Table 3.14) due to the use of curtains on windows or opaque windows to prevent glare and excess daylighting through windows as shown in Figure 3.10. But for toilets and kitchens, most lighting conditions are likely to be above the standard due to the use of translucent roofs or walls as in Figure 3.11.

Table 3.14 Lighting condition in the sample houses of the north-eastern region.

House number	Illuminances (lux)			
	Living room	Bedroom	Toilet	Kitchen
1	96	45	530	
2	80			
3	200	25	660	46
4	42		9	290
5				
6	200			
7				
8				
9	110		1235	1224
10	80	78	3130	
11	12		1189	28
12	81			
Average	100.1	49.3	1125.5	397.0

Figure 3.10 The use of curtains on windows

Figure 3.11 The use of translucent roofs

3.3 Greenhouse Gas Emissions of Low Income Houses in Northeastern Region

The survey results indicated that the age of the low income houses in northeastern regions houses is approximately 10-30 years old. The houses are typically 2-storey detached house built from wood and concrete as seen in Figure 3.12. The ground floor is built from concrete block or brick while the second floor is built from hardwood. The ground floor has large open space with the stair located at the middle of the house. The open space is usually modified for a bedroom for old people. While the space in the second floor is still opened for multi-purposes. The pillars are made from reinforced concrete or hardwood. The galvanized steel sheets are used for rooftop.

Figure 3.12 Floor plans of the detached house in northeastern region of Thailand.

Figure 3.12 exhibits the draft floor plan of the 2-storey detached house with the total area of 149.82 m^2. The dimension of the first floor is 13.1 x 6.6 m and that of the second floor is 9.6 x 6.6 m. The floor-to-floor height of the first floor and the second floor are 3.05 m. and 2.75 m, respectively. The first floor comprises multi-function room and rest room and there is an opened space on the second floor. Kitchen, cloth washing area and toilet are provided at the backside of the house. The lists of construction materials and the quantity of each material are shown in Table 3.15.

Table 3.15 Input data of construction materials of the detached house in Northeastern region.

Materials	Quantities	Unit
Sand	4,400.00	kg
Concrete	33,109.58	kg
Cement	3,442.67	kg
Steel	158.41	kg
Galvanized steel sheet	1,104.00	kg
Hardwood	226.66	ft^3
Lime	284.99	kg
Glass	1,142.13	kg

- **Methodology**

The activity data of construction materials were extracted from house plans and Bill of Quantities (BOQ) of low income houses in northeastern region. The GHG emission was calculated in the unit of $kgCO_2e/m^2$ by the following equation.

$$\text{GHG emission } (kgCO_2e/m^2) = \sum [\text{Activity data (unit) x Emission factor } (kgCO_2e/\text{unit})] /\text{area}$$

Emission factors used in this study were referred from Thai national database (Thailand Greenhouse Gas Management Organization [6]), Simapro 7.1 and the study from University of Bath (University of Bath [9])as presented in Table 3.16. The GHG emission hotspots were pointed out.

Table 3.16 Emission factors used in this study.

Items	Unit	Emission factor ($kgCO_2e$/unit)	References
Cement	kg	0.490	TGO (2011)
Concrete	kg	0.130	University of Bath (2008)
Glass	kg	1.130	SimaPro 7.1
Hardwood	Ft^3	-33.00	SimaPro 7.1
Lime	kg	0.740	University of Bath (2008)
Galvanized steel sheet	kg	2.7073	TGO (2011)
Sand	kg	0.0037	TGO (2011)
Steel	kg	1.25	SimaPro 7.1

- **Results and discussion**

The GHG emissions from construction materials of the house in northeastern region were shown in Table 3.17. Major GHG emission hotspots came from concrete (23.64 $kgCO_2e/m^2$), followed by galvanized steel sheet (19.95 $kgCO_2e/m^2$) and cement (11.26 $kgCO_2e/m^2$), respectively. Due to their energy intensive productions, the carbon footprints of these materials are very high. Aside from cement and concrete, hardwood is commonly used to build low income houses in northeastern region. This causes the advantage in carbon offset. The carbon dioxide removal from hardwood was 49.93 $kgCO_2e/m^2$, accounted for 75% of GHG emissions (Figure 3.13). As a result, the net GHG emission of northeastern low income houses was only 16.44 $kgCO_2e/m^2$ which is the lowest compared to that of other low income houses in other regions in Thailand. The results are in agreement with in Aneksaen [5]. They reported the GHG emission from half wood half concrete houses located in Bangkok as 2.47 $kgCO_2e/m^2$. The GHG emission reduced by wooden materials was accounted for 49%.

Table 3.17 GHG emissions from construction materials of the detached house in northeastern region

Materials	GHG Emission($kgCO_2$ e/m^2)
Sand	0.11
Concrete	23.64
Cement	11.26
Steel	1.32
Galvanized steel sheet	19.95
Hardwood	-49.93
Lime	1.48
Glass	8.61
Total	**16.44**

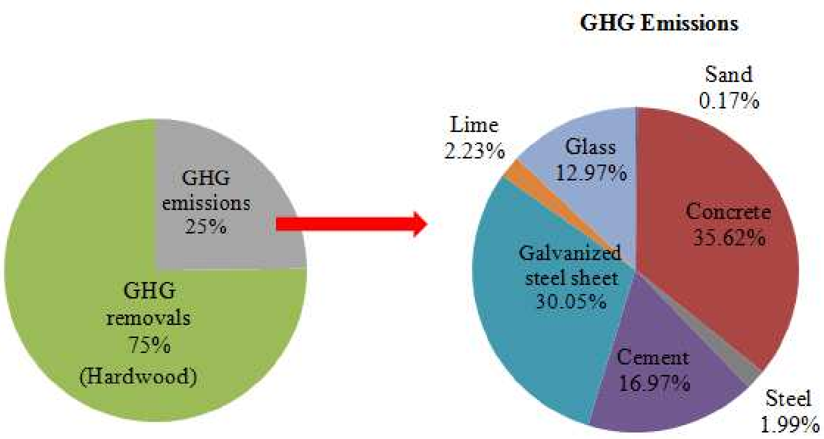


Figure 3.13 percentage of GHG emissions from construction process of house in northeastern region in Thailand

CHAPTER 4
SURVEY RESULTS OF SOUTHERN THAILAND

4.1 Introduction

Southern Thailand is on the Malay Peninsula, the shape of southern region is long and narrow and the area of this region stretches from north to south which is approximately 750 km (Figure 4.1). This region covers an area of 70,700 km^2, which is equivalent to 13.3 % of the total land area of the country (the smallest area in Thailand). It consists of 14 provinces which (1) Chumphon, (2) Ranong, (3) Surat Thani, (4) Phang-nga, (5) Phuket, (6) Krabi, (7) Nakhon Si Thammarat, (8) Trang, (9) Phatthalung, (10) Songkhla, (11) Satun, (12) Pattani, (13) Yala, and (14) Narathiwat. In the region, there are various zones which can be geographically divided into the following three areas: (1) The upper south covers Chumporn and Ranong, which are adjacent to the southern part of Prachuab Khiri Khan. This provincial area is the major industrial iron base of the country. Ranong is also a gateway for investment to neighboring countries, such as Myanmar, Bangladesh and the eastern part of India. (2) The central south covers Surat Thani, Nakhorn si Thammarat, Phuket, Phangnga, Krabi, Trang and Phattalung provinces. In this area, Phuket, Phangnga, Krabi and Samui Island are known worldwide as attractive maritime tourist destinations, while the economies of Surat Thani, Nakorn si Thammarat, Trang and Phattalung are based on the agriculture and agri-processing industries. (3) The border provinces of the Lower South are Satun, Songkhla, Yala, Pattani and Narathiwat. These provinces are important strategic areas for economic and social development as well as for the national security of southern Thailand. Different from the other southern provinces in respect to region and culture, the southern-most provinces are closely linked to Malaysia both economically and socially.

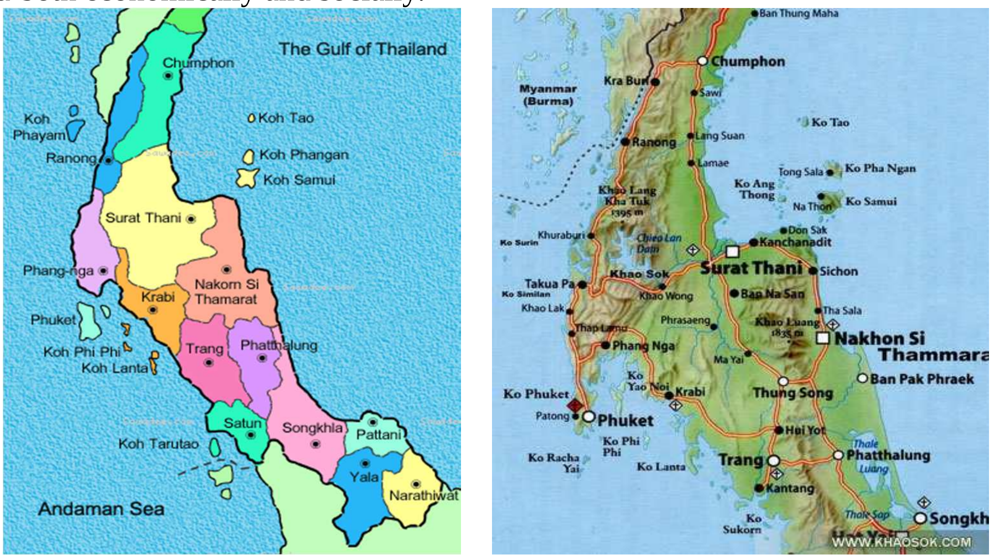


Figure 4.1 Geography of southern Thailand
(**Source :** http://thailand.sawadee.com/south_of_thailand/)

The southern part of Thailand is very different from other parts of the country. It has two seasons which are rainy and summer season. People in the southern provinces have to face heavy rain and scattered thunder showers several times a year. And when the hot or summer season comes, it's not as sultry as the other parts of the country since there are mild winds from the northwest and southeast. The winds also bring rain during the summer, so people living in the south have to bear with rain for nearly the whole year, which has also influenced their way of building houses.

Table 4.1 shows that population of the southern region increases around 200,000 people every 3 years and increase from 8.5 to 9.1 million people during year 2004 to 2013. This situation is different from the north and north-eastern Thailand which population is not changed but seems to be migration to work in other region. But in the southern region, most people seems to work in their region because of having variety of works in the region such as tourism, industry, fishery, agriculture, and Etc. The change of the population is most likely to be in urban areas while slightly changed in rural areas.

Table 4.1 Population of southern Thailand

Sex and area	(2004)	(2007)	(2010)	(2013)
Total	**8,432,696**	**8,654,831**	**8,893,050**	**9,131,425**
Male	4,179,417	4,283,002	4,392,580	4,502,795
Female	4,253,279	4,371,829	4,500,470	4,628,630
Municipal area	**1,993,201**	**2,169,813**	**2,511,226**	**2,585,068**
Male	968,322	1,049,272	1,211,823	1,246,787
Female	1,024,879	1,120,541	1,299,403	1,338,281
Non-municipal area	**6,439,495**	**6,485,018**	**6,381,824**	**6,546,357**
Male	3,211,095	3,233,730	3,180,757	3,256,008
Female	3,228,400	3,251,288	3,201,067	3,290,349

4.2 Survey results

The purpose of this section is to examine design features, living styles, material uses, lighting conditions, energy uses, and interior thermal environment of houses of low and middle income earners in Thailand comparing to the literature review and establish the baseline for this region.

4.2.1 Living styles

Family size of people in this region vary from 1-7 members (Table 4.2) while a number of elderly people is less than the north and north eastern regions (Table 4.3). For the smallest family (1 member), most of them are elderly people who have a small commercial in their houses (Figure 4.2) while their children move to work in the rural areas. For the bigger family (3-7 members), most of them also work in the local area as a small commercials in houses and employees, the rest of them are mostly students (Table 4.4).

Table 4.2 Family size distribution of the samples of southern Thailand

Family size, person	Number of households
1 person	4
3 persons	1
4 persons	3
5 persons	1
7 persons	1

Table 4.3 Age distribution of the samples of southern Thailand

Age, year	Persons
Less than 15	6
16-30	8
31-45	7
45-60	8
More than 60	2

Figure 4.2 Living styles of people in the southern Thailand

Table 4.4 Occupation distribution of the samples of southern Thailand

Occupation	Persons
Unemployed (retired)	2
Farmers	0
Students	8
Government employees	0
Small commercial	10
Employees (private)	11

For most small family size, family income is in the range of 5,000 to 15,000 Baht per month which is sufficient for elderly people who live alone in rural areas (Table 4.5). While larger family earns higher family incomes.

Table 4.5 Family income distribution of the samples of southern Thailand

Family Income	Number of households
Less than 5000	1
5001-15000	5
15000-30000	2
More than 30000	2

4.2.2 Housing features

Basements are built for most traditional Thai house in Thailand, but for the southern region, its basements are built to be higher than other regions in Thailand (Figure 4.3). The objective of having basements is doing activities, relax, storage and supplementary occupations. For example, raise animals which can easily take care of their animals. The most different point of the southern regional houses is the "Teen Sao", the pillars of the house are made of hardwood and have cement bases to prevent rotting in the humid weather. This is because the southern region of Thailand has the highest rainfall in the country and easily gets flooding.

Figure 4.3 Traditional houses of southern Thailand
(**Source:** http://hgq2.weebly.com/southern-region.html)

Most houses of the samples are single storey house (Table 4.6) which are constructed by concrete walls (Table 4.7). Due to humid weather and highest rainfall of Thailand including cost and availability of construction materials in local area, most people prefer constructing their houses by using concrete walls and single storey to prevent climatological events such as storms (Figure 4.4). These house configurations are mostly less than 20 years old (Table 4.8).

Table 4.6 House feature distribution of the samples of southern Thailand

House configurations	Number of households
Single story	9
2-story	1

Table 4.7 Housing material distribution of the samples of southern Thailand

Wall materials	Number of households
Wood	0
Concrete	9
Wood + Concrete	1

Figure 4.4 concrete house in southern Thailand

A combination of wooden and concrete wall houses is also available in the samples (Figure 4.5) for the houses which are mostly over 20 years old. But in the near future when the house is going to be renovated, the walls is very possible to be replaced by concrete walls only.

Figure 4.5 Wood + Concrete typical house in southern Thailand

Table 4.8 Age of house distribution of the samples of southern Thailand

Age of houses	Number of households
Less than 5 Years	1
6-10 Years	2
11-15 Years	2
16-20 Years	1
More than 20 Years	3

4.2.3 Energy consumption and GHG emission from electricity use

As mentioned before, most low income people in this region always have small commercial in their houses which mostly are small stores. Electric appliances in houses are not for lighting, entertainment, amenity, and cooking only but also for their small commercial in the houses. Therefore electricity consumption is not directly related to floor area of houses, family size, and family income as in the north and north-eastern regions (Figure 4.6). But relationship of energy consumption is still slightly available for of family sizes, and family incomes.

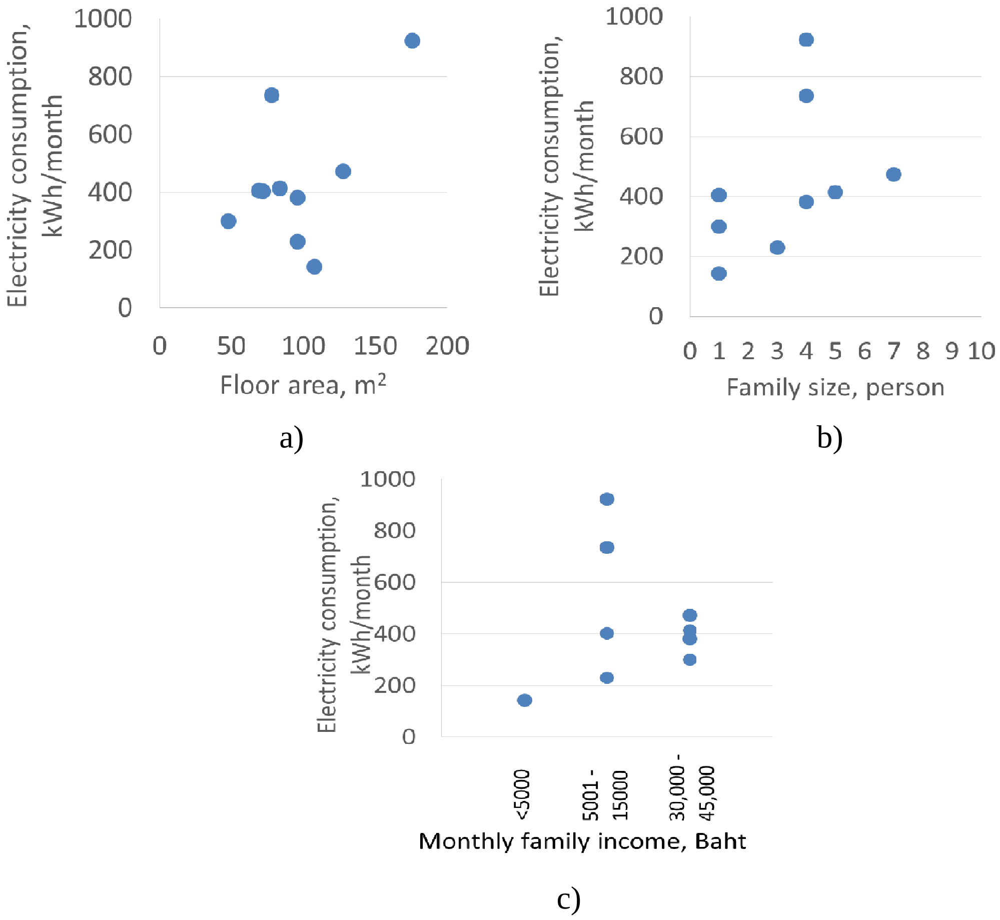


Figure 4.6 Electricity consumption distribution of the southern Thailand

The uses of air-conditioner are only for higher income earners (around 20%) of the sample (Table 4.7) while the uses of water heaters are absent (Table 4.8) because of no winter season in this region. The use of air-conditioner tends to be larger as same as other regions when their incomes are higher.

Table 4.7 Air conditioner use distribution of the samples of southern Thailand

The use of air-conditioners	Number of households
Use	2
Not use	8

Table 4.8 Water heater use distribution of the samples of southern Thailand

The use of water heaters	Number of households
Use	0
Not use	10

Most electricity consumption in houses of the samples is from amenity category (as same as other regions) which is mainly consumed by refrigerators and fans. For other categories; lighting, entertainment, cooking, and small business are mainly consumed by lamps, TV, kettles, and freezers respectively (Table 4.9). Small commercial category is added in the table for this region to point out clearly for Influences of electric power increased from doing business at home.

Table 4.9 Electricity consumption of each appliance and category of the southern Thailand

End-use Category	Appliance	Number of appliance	Electricity consumption, kWh/month	Percentage of total	Percentage for each category
Lighting	Lamp	10	312.0	7.3	7.3
Entertainment	TV	10	483.6	11.3	11.8
	LCD monitor	1	20.2	0.5	
Amenity	CCTV camera	1	110.9	2.6	42.5
	PC	1	39.2	0.9	
	Washing machine	7	88.0	2.1	
	Vacuum cleaner	1	5.6	0.1	
	air conditioner	2	292.9	6.9	
	Hair Dryer	1	128.8	3.0	
	Refrigerator	6	661.9	15.5	
	Iron	5	121.6	2.9	
	Electric hair clamp	1	5.6	0.1	
	Electric candle	1	1.1	0.0	
	Fan	10	353.5	8.3	
Cooking	Kettle	7	394.8	9.3	18.8
	Rice Cooker	10	342.4	8.0	
	Electric stove	1	63.0	1.5	
Small commercial	Water Cooler	1	174.7	4.1	19.6
	Freezer	3	661.9	15.5	

Average floor area and average floor area per person of this region are 95.5 m^2 and 45.2 m^2/person respectively, lower than other region but electricity consumption is higher than other regions at around 426.2 kWh per month or 5,114 kWh per household per year (Table 4.10) because of small commercial in houses as mentioned before. The Thailand Greenhouse Gas

Management Organization, Commitee Report [8], uses an emission factor of 0.6093 kg/kWh for the present mix of fuels used in electric power generation. Total emission for the model house throughout its life is then

= 78 ton, if the life of the house is 25 years, or

= 156 ton, if the life of the house is 50 years.

However, it is more likely that the low-income earners would become middle income earners and consume electricity at a rate that is more than twice the figure used here, as they will have air-conditioning and use electric hot water heating.

Table 4.10 Average floor area, average floor area per person, electricity consumption and cost of the southern Thailand

Average floor area	95.5
Average floor area per person (m^2/person)	45.2
Average electricity consumption (kWh/Month)	426.2
Average electricity cost (Baht/Month)	962.7

4.2.4 Thermal environment and thermal comfort assessment

Table 4.11 shows that mean radiant temperature of most houses are higher than ambient temperature because of no ceilings are used in most houses as shown in Figure 4.7. Ceiling under roofs are also used for higher income housing of the samples (Figure 4.8). Wind speed in houses are mostly zero, fan is needed to provide air movement as shown in the table while CO_2 level in all houses is in the normal level because there are many opening on walls although it is relatively small when comparing to other regions (Figure 4.9).

Table 4.11 Interior thermal environment in the sample houses of southern Thailand

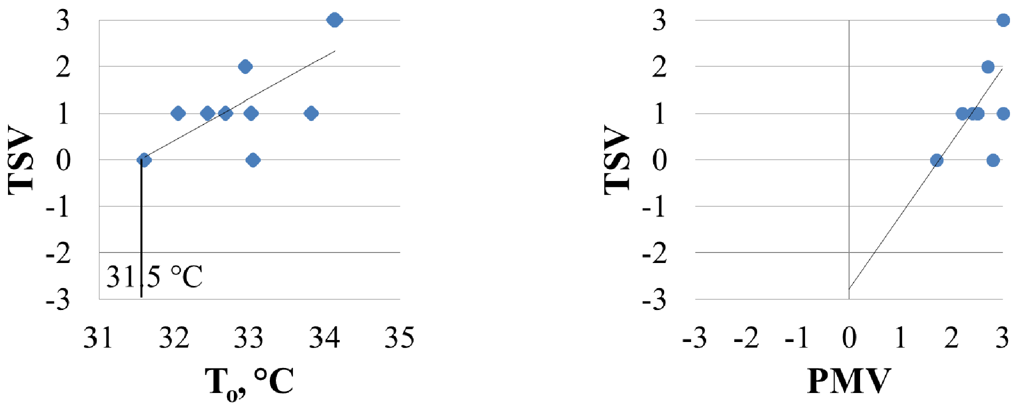
	Air temp. (°C)	Mean radiant temp. (°C)	Air speed (m/s)	Relative humidity (%)	CO2 (ppm)
Max	34.0	34.7	4.1	65.4	615.0
Min	31.6	31.6	0.0	56.9	407.0
Ave	32.9	33.1	1.1	59.7	477.6

Figure 4.7 Interior house designs of southern Thailand

Figure 4.8 The uses of ceiling of houses of southern Thailand

Figure 4.9 Openings of houses of southern Thailand

Figure 4.10 shows relationship of thermal sensation value (TSV), Operative temperature (To), and predicted mean vote (PMV) of the sample people from interviewing and calculations from the measured data. The results show that neutral temperature of the sample people is 31.54°C which is higher than other regions, it means that people of this region is possible to feel comfort with higher temperature than other regions due to their familiarity of no winter season (Only rainy and summer season) of this region.



a) b)

Figure 4.10 Thermal comfort assessment of southern Thailand

4.2.5 Lighting condition in houses

Table 4.12 shows lighting levels of each room of the sample houses. The results show that most low income housings are insufficient light due to poor designs of daylighting usage (small opening on walls) as shown in Figure 4.11, lamps are sometimes needed for visual comfort. For higher income housing, designs for daylighting usage seem to be better as shown in Figure 4.12.

Table 4.12 Lighting condition in the sample houses of southern Thailand

Space	House number										Average
	1	2	3	4	5	6	7	8	9	10	
Living quarter	65	100	30	373	41	300	66	100	550	59	168
Bedroom 1	60			140	58	225	88	80	178		118
Bedroom 2				150	340	253	40	40	147		162
Toilet			147	247	8	171	228	45			141
Kitchen				3880	144	2400	770	3020			2043

Figure 4.11 Interior lighting of low income housing in southern region

Figure 4.12 Interior lighting of higher income housing in southern region

The use of daylighting in toilets and kitchens of most houses are mostly sufficient due to the uses of translucent walls and roofs (Figure 4.13) especially for low income earners.

Figure 4.13 Lighting condition of toilets in houses of southern region

4.3 Greenhouse Gas Emissions of Low Income Houses in Southern Region

The climate in southern Thailand is quite different from other regions due to hot and humid weather. Moreover, monsoons and storms are typically found in this region, which strongly influence the house construction styles (Figure 4.14**)**. The survey results found that one-storey house is the most popular house style in the region. The house structure needs to be strong and withstand the weather. Most houses are built from concrete block, cement and steel. Windows and doors are made from hardwood. The low slope roofing with steel structure, generally made from roof tiles, is designed to reduce the storm impacts. Due to hot and humid weather, the house has no ceiling because the people needs more space for good ventilation. The partitions are used to separate a bed room out from multipurpose area. During day time, the terrace is also utilized as a living space because the outside temperature is much lower than the temperature inside the house.

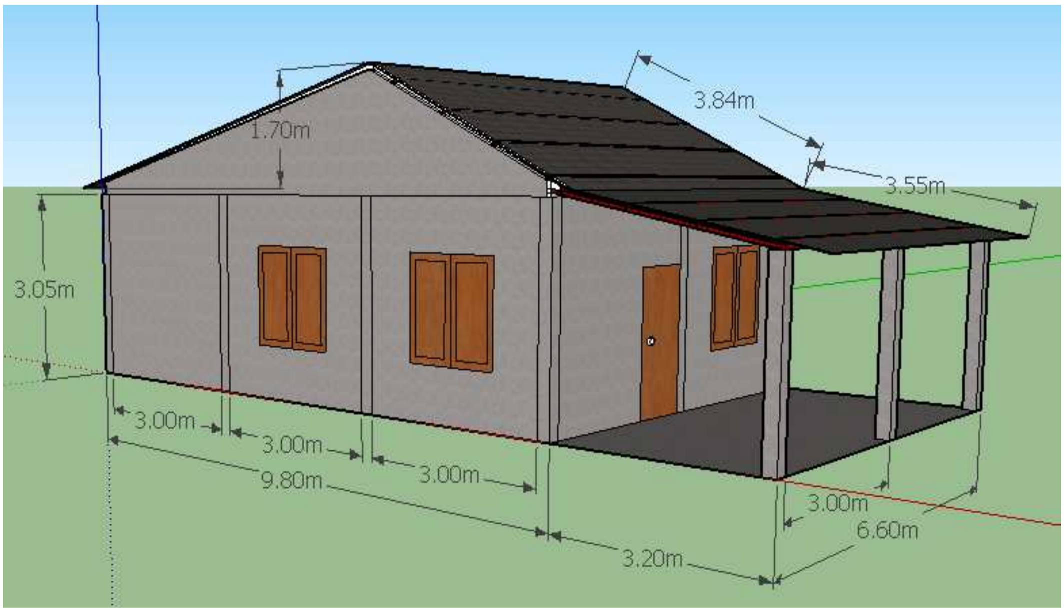


Figure 4.14 Floor plans of the detached house in southern region.

Figure 4.14 exhibits the sketched floor plan of the detached house in southern region. The house area is 13.0 x 6.60 m. The height of the floor is 3.05 m. The ground floor comprises multi-function room, and one bedroom. Kitchen, cloth washing area and restroom are at the backside of the house. The lists of construction materials and the quantity of each material are shown in Table 4.13.

Table 4.13 Input data of construction materials of the detached house in Southern region.

Materials	Quantities	Unit
Sand	6,336.00	kg
Concrete	33,610.09	kg
Cement	5,386.54	kg
Steel	761.06	kg
Roof Tiles	1,414.35	kg
Lime	445.90	kg
Hardwood	30.56	ft^3

- **Methodology**

The activity data of construction materials were extracted from house plans and Bill of Quantities (BOQ) of low income houses in southern region. The GHG emission was calculated in the unit of $kgCO_2e/m^2$ by the following equation.

$$\text{GHG emission } (kgCO_2e/m^2) = \sum [\text{Activity data (unit) x Emission factor } (kgCO_2e/\text{unit})] /\text{area}$$

Emission factors used in this study were referred from Thai national database (Thailand Greenhouse Gas Management Organization [6]), Simapro 7.1 and the study from University of Bath (University of Bath [9]) as presented in Table 4.14. The GHG emissions from different building styles were then compared and the emission hotspots were pointed out.

Table 4.14 Emission factors used in this study.

Items	Unit	Emission factor ($kgCO_2e$/unit)	References
Cement	kg	0.490	TGO (2011)
Concrete	kg	0.130	University of Bath (2008)
Lime	kg	0.740	University of Bath (2008)
Roof Tiles	kg	0.353	SimaPro 7.1
Sand	kg	0.0037	TGO (2011)
Steel	kg	1.25	SimaPro 7.1
Hardwood	ft^3	-33.00	SimaPro 7.1

- **Results and discussion**

The GHG emissions from construction materials of the detached house in southern region were shown in Table 4.15. The share of GHG emissions from each material was presented in Figure 4.15. Major GHG emission hotspots came from concrete (41.91 $kgCO_2e/m^2$), cement (30.76 $kgCO_2e/m^2$) and steel (11.09 $kgCO_2e/m^2$), respectively. This is because the concrete, cement and steel are major construction materials for detached house construction and their carbon footprints are also very high. However the carbon dioxide removal from hardwood was 11.75 $kgCO_2e/m^2$, accounted for 13% of GHG emissions (Figure 4.15). As a result, the net GHG emission of southern low income houses was 82.15 $kgCO_2e/m^2$.

Table 4.15 GHG emissions from construction materials of the detached house in southern region

Materials	**GHG Emission($kgCO_2$ e/m^2)**
Sand	0.27
Concrete	41.91
Cement	30.76
Steel	11.09
Roof Tiles	5.82
Lime	4.05
Hardwood	-11.75
Total	**82.15**

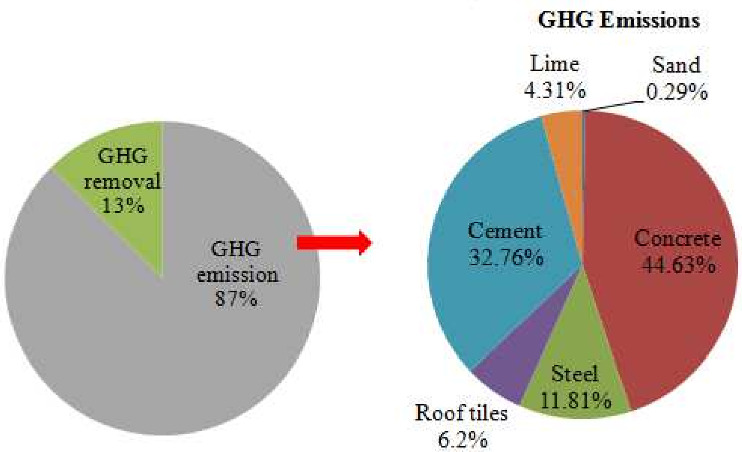


Figure 4.15 Percentage of GHG emissions from construction process of detached house in southern region

CHAPTER 5
SURVEY RESULTS OF CENTRAL THAILAND

5.1 Introduction

Fig. 5.1 shows the central Thailand geography. This region is divided into 18 provinces i.e. Bangkok, Pathumthani, Nonthaburi, Samutprakarn, Kanchanaburi, Nakhonsawan, Suphanburi, Chainat, Uthaithani, Ayuthaya, Samutsongkhram, Samutsakorn, Ratchaburi, Nakhonpathom, Saraburi, Lopburi, Singburi and Angthong. It is covered the broad alluvial plain of the Chao Phraya River. It is separated from northeast Thailand (Isan) by the Phetchabun mountain range. The Tenasserim Hills separate it from Myanmar to the west. In the north it is bounded by the Phi Pan Nam Range, one of the hilly systems of northern Thailand. The area was the heartland of the Ayutthaya Kingdom, and is still the dominant area of Thailand. Central Thailand contains the Thai capital of Bangkok and it is the most populated region in the country.

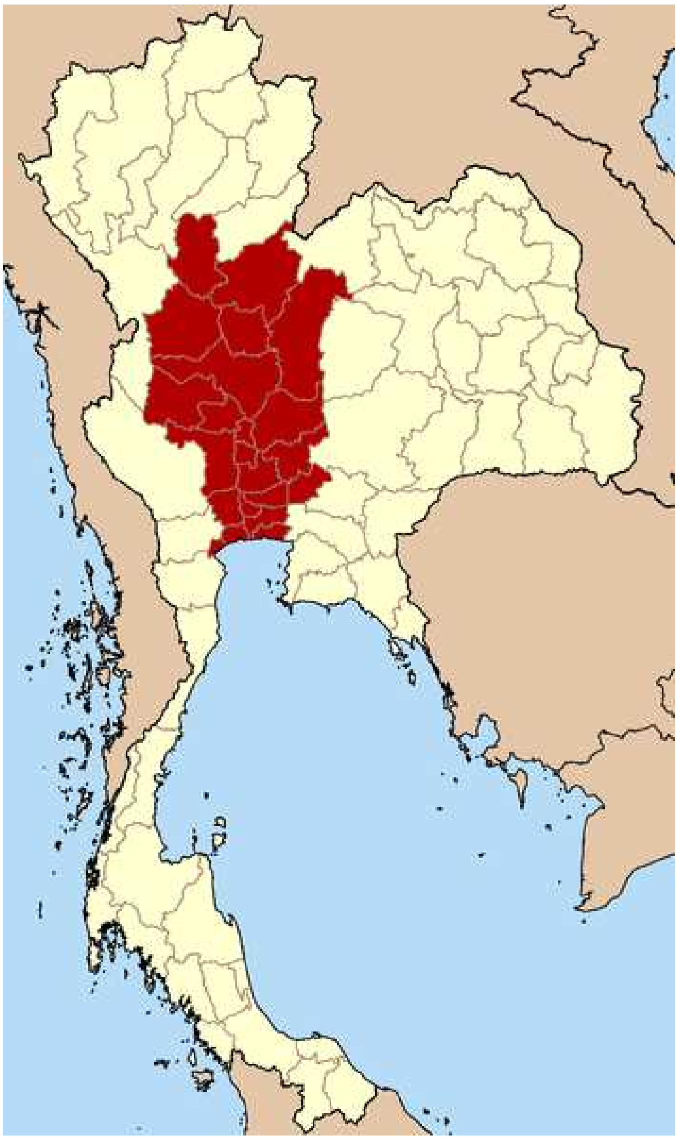


Figure 5.1 The central Thailand geography
(**Source:** http://en.wikipedia.org/wiki/File:Central_Thailand_six_regions.png)

Central Thailand is a natural self-contained basin often termed "the rice bowl of Asia." The complex irrigation system developed for wet-rice agriculture in this region provided the necessary economic support to sustain the development of the Thai state from the 13th century Sukhothai kingdom to contemporary Bangkok. Here the rather flat unchanging landscape facilitated inland water and road transport. The fertile area was able to sustain a dense population, 422 people per square kilometer in 1987, compared with an average of 98 for the country as a whole. The terrain of the region is dominated by the Chao Phraya and its tributaries and by the cultivated paddy fields.

Population of the central region has reached 16.2 million in 2012. Male are about 7.9 million people while about 8.3 million people is female. It has changed significantly from year 2003 to year 2012 as shown in Table 5.1. The main reason of the changes may be from migration of people from other provinces to Bangkok to find a better jobs and life quality. Moreover, migration of people from non-municipal area to municipal is increased every year during year 2003 to 2012.

Table 5.1 Population of central Thailand

Gender and area	2003	2006	2009	2012
Total	**14,987,041**	**15,264,732**	**15,742,529**	**16,222,892**
Male	7,387,811	7,479,818	7,687,262	7,905,485
Female	7,599,230	7,784,914	8,055,267	8,317,407
Municipal area	**4,771,186**	**4,996,723**	**5,805,650**	**6,145,897**
Male	2,326,012	2,419,307	2,799,835	2,962,633
Female	2,445,174	2,577,416	3,005,815	3,183,264
Non-municipal area	**10,215,855**	**10,268,009**	**9,936,879**	**10,076,995**
Male	5,061,799	5,060,511	4,887,427	4,942,852
Female	5,154,056	5,207,498	5,049,452	5,134,143

5.2 Survey results

The purpose of this section is to examine design features, living styles, material uses, lighting conditions, energy uses, and interior thermal environment of houses of low and middle income earners in Thailand comparing to the literature review and establish the baseline for this region. Target groups of the surveys are distinguish into 2 groups; rural group (Uthai thani and Supan buri province) and suburban group (Pathumthani province). The results of the surveys are shown as follows.

5.2.1 Living styles

- **Rural group**

Living styles of the samples of this group are near the same as in northern and northeastern Thailand, most people who live in houses during daytime are elderly (Figure 5.2). They always live in the first floor of houses which are opened spaces but for the cases that no opened spaces of the houses, a small hut are constructed outside near their houses. Family sizes of the sample households are in a range of 2-6 members as shown in Table 5.2. 45% of the samples are 2 members per family and average family size is 3.3 members per family. Age of people are diversity (Table 3.3) but most working-age move to work in other areas.

Figure 5.2 Living style of people in central Thailand (rural area)

Table 5.2 Family size distribution of the samples of central Thailand (rural area)

Family size	Households
2 person	8
3 persons	3
4 persons	2
5 persons	3
6 persons	2

Table 5.3 Age distribution of the samples of central Thailand (rural area)

Age, year	Persons
<15	12
16-30	12
31-45	9
45-60	13
>60	14

Family income of all samples is below 15,000 Baht per month (Table 5.4). The reason is 35% of them are not working (Retired persons and students), about 42% and 23% are farmers and employees respectively which earn relatively low wages (Table 5.5).

Table 5.4 Family income distribution of the samples of central Thailand (rural area)

Family Income, Baht	Households
<5000	4
5001-15000	14
15000-30000	0
>30000	0

Table 5.5 Occupation distribution of the samples of central Thailand (rural area)

Occupation	Persons
Unemployed (retired)	8
Farmers	25
Students	13
Government employees	0
Small commercial	0
Employees (private)	14

- **Suburban group**

Living styles of the samples in this group are totally different from the rural group because this group is near greater Bangkok area which many jobs in factories and companies re available. Apart from that household area of the samples are rented from the temple, they do not have their own land (Figure 5.3) and family size of the samples is very scattered (Table 5.6).

Figure 5.3 Living style of people in central Thailand (suburban area)

Table 5.6 Family size distribution of the samples of central Thailand (suburban area)

Family size	Households
2 person	2
3 persons	2
4 persons	2
5 persons	2
6 persons	1
7 persons	1
8 persons	1

Most people in this group are below 15 years old (Table 5.7) and they are students (Table 5.8). Occupations of most working-age are employees while some of them are unemployed (retired or housewifely). Family income are also various but average family income is much higher than the rural group (Table 5.9).

Table 5.7 Age distribution of the samples of central Thailand (suburban area)

Age, year	**Persons**
<15	18
16-30	6
31-45	9
46-60	9
>60	9

Table 5.8 Occupation distribution of the samples of central Thailand (suburban area)

Occupation	**Persons**
Unemployed (retired)	12
Farmers	0
Students	23
Government employees	0
Small commercial	3
Employees (private)	14

Table 5.9 Family income distribution of the samples of central Thailand (suburban area)

Family Income, Baht	**Households**
<5000	3
5001-15000	4
15000-30000	5

5.2.2 Housing features

Traditional houses of central region are wooden structure raised on posts (Figure 5.4). The structure of the stilt house in the central region is the most common and of very simple style. The high gable roof which in its center has a shape like the halo of the sun is the most outstanding structure, where there is a space for cooking smoke to flow out .The long overhanging eaves can protect from sun or rain. The wide terrace outside the house is suitable for summer use. In addition, a more important structure is the high open space under the house which is supported by many poles. This space is the area for storage of tools or agricultural equipment, parking, eating meals and other activities.

Figure 5.4 typical house in the central.
(**Source:** http://www.thaiworldview.com/centre/centre3.htm)

- **Rural group**

Table 5.10-5.12 show that housing features of the samples of this group are similar to northern and northeastern region (because of similar occupations and living styles); old houses (over 20 years old) (figure 5.5) are wooden 2-storey houses (some of them are constructed concrete walls on the first floor) and new houses are 1-storey houses constructed with concrete and some of them constructed by other materials such as zinc sheet (Figure 5.6).

Figure 5.5 Housing features of old houses of central region (rural group).

Figure 5.6 Housing features of new houses of central region (rural group).

Table 5.10 House feature distribution of the samples of central Thailand (rural group).

House configurations	Number of houses
Single story	9
2-story	9

Table 5.11 Housing material distribution of the samples of central Thailand (rural group).

Wall materials	Households
Wood	4
Concrete	5
Wood + Concrete	6
Others	3

Table 5.12 Age of house distribution of the samples of central Thailand (rural group).

Age of houses	Households
<5 Years	4
6-10 Years	2
11-15 Years	2
16-20 Years	1
>20 Years	9

- **Suburban group**

Table 5.13-5.14 show that the sample houses are classified into 3 groups; (1) old houses which homeowners have their own land (Figure 5.7), (2) old houses of central region which homeowners do not have their own land (Figure 5.8), and (3) new houses of central region which homeowners have their own land (Figure 5.9).

Figure 5.7 Housing features of old houses of central region which homeowners have their own land (suburban group).

Figure 5.8 Housing features of old houses of central region which homeowners do not have their own land (suburban group).

Figure 5.9 Housing features of new houses of central region which homeowners do not have their own land (suburban group).

All houses of the samples are 2-storey houses (Table 5.13) because the houses of this group are located near the Chao Phraya River which always face flood situations and most houses are over 15 years. Construction materials of 3 groups of houses are also different. Houses of the first group are mainly constructed by wood even most of them are added with concrete wall on the first floor (Figure 5.7). Most houses of the second group are constructed by temporary materials such as flat tiles (some of them are also woods) because their land are rental area as mentioned before. For the third group, housing materials and features are similar to the second group but the material types are more diverse due to advancing the development of new materials, synthetic woods and concrete were used.

Table 5.13 House feature distribution of the samples of central Thailand (rural group).

House configurations	Number of houses
Single story	0
2-story	12

Table 5.14 Housing material distribution of the samples of central Thailand (rural group).

Wall materials	Households
Wood	3
Concrete	1
Wood + Concrete	4
Others	5

Table 5.15 Age of house distribution of the samples of central Thailand (rural group).

Age of houses	Households
<5 Years	1
6-10 Years	0
11-15 Years	1
16-20 Years	5
>20 Years	5

5.2.3 Energy consumption and GHG emission from electricity use

- **Rural group**

Figure 5.10 shows the electricity consumption distributions against floor area, family size, and family income. The results indicate that electricity consumption is influenced by family size and family income, higher family size and higher family income are likely to be higher electricity consumption in houses. The use of air conditioner in this group is only 12 percent of total (Table 5.16) due to their average family income is still low.

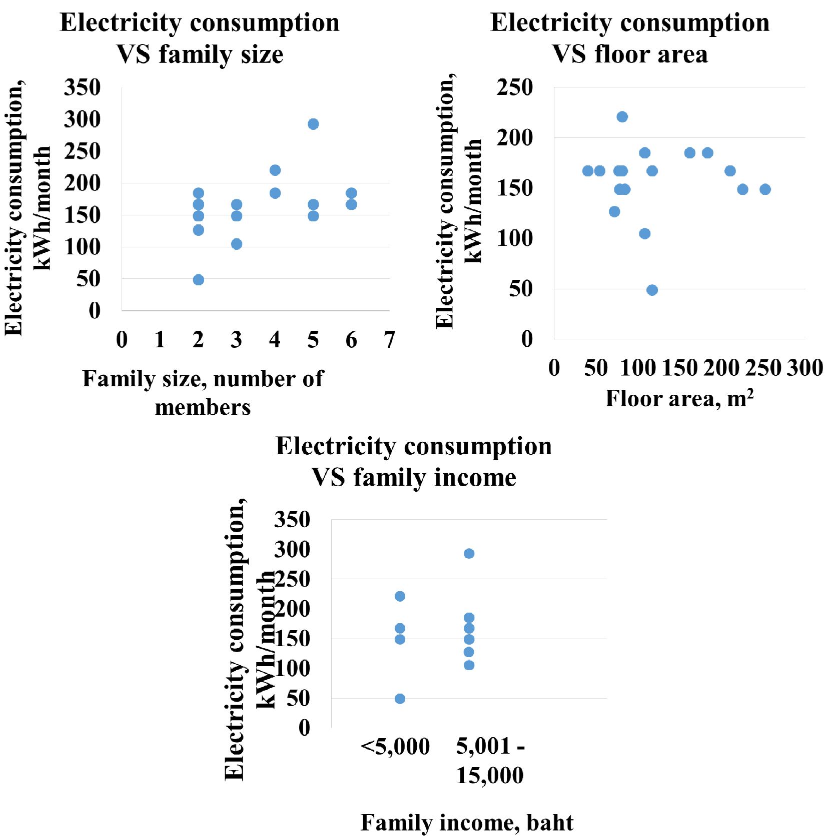


Figure 5.10 Electricity consumption distribution of the central Thailand (rural group).

Table 5.16 Air conditioner use distribution of the samples of central Thailand (rural group).

Use of air-conditioner use	Household
Use-air con	2
Not use-air con	16

Electricity consumption of electricity appliances of the sample houses of central Thailand (rural group) is shown in Table 5.17. There are 5 categories of the appliances are distinguished; lighting, entertainment, convenience, cooking, and small commercial in houses.

The results show that, the convenient category consume the highest electricity of 59%. Main appliances which consume high power of this category are refrigerator, fan, and iron which consume 32.3%, 12.0% and 9.6% respectively. While cooking, lighting and entertainment categories consume 22%, 8% and 9% respectively. Appliances that consume the most power each category are rice cooker (17.1%), lamp (8.3%), TV (8.9%), and refrigerator (32.27%) for cooking, lighting, entertainment and convenient categories respectively. Small commercial in houses category consumes only 1% of totally.

Table 5.17 Electricity consumption of each appliance and category of the Central Thailand (rural group).

End-use Category	Appliance	Number of appliance	Electricity consumption, kWh/month	Percentage of total	Percentage for each category
Lighting	Lamp	18	217	8.3%	8%
Entertainment	TV	18	232	8.9%	9%
	Radio	2	5	0.2%	
Amenity	PC	1	10	0.4%	59%
	Washing machine	5	27	1.0%	
	Hair dryer	1	10	0.4%	
	Refrigerator	17	842	32.3%	
	Iron	9	252	9.6%	
	Water pump	1	3	0.1%	
	Fan	17	314	12.0%	
	Air conditioner	2	89	3.4%	
Cooking	Hot pot	5	132	5.1%	22%
	Toaster	1	3	0.1%	
	Rice cooker	13	445	17.1%	
Small commercial	Coconut Machine	1	11	0.4%	1%
	Power saws	1	13	0.5%	
	Drill	1	6	0.2%	

Average floor area and average floor area per person of this region are 134 m^2 and 42 m^2/person respectively. Electricity consumption is around 145 kWh per month or 1,740 kWh per household per year (Table 5.18). The Thailand Greenhouse Gas Management Organization, Commitee Report [8], uses an emission factor of 0.6093 kg/kWh for the present mix of fuels used in electric power generation. Total emission for the model house throughout its life is then

= 26 ton, if the life of the house is 25 years, or

= 53 ton, if the life of the house is 50 years.

However, it is more likely that the low-income earners would become middle income earners and consume electricity at a rate that is more than twice the figure used here, as they will have air-conditioning and use electric hot water heating.

Table 5.18 Average floor area, average floor area per person, electricity consumption and cost of the central Thailand (rural group).

Average floor area	134
Average floor area per person (m^2/person)	42
Average electricity consumption (kWh/Month)	145
Average electricity cost (Baht/Month)	362

- **Suburban group**

Figure 5.11 shows the electricity consumption distributions against floor area, family size, and family income. The results indicate that electricity consumption is influenced by family size and floor area. The results are different from in rural area because many houses in this group have problem about electricity leakage causes abnormal electricity consumption in some houses even their family incomes are low. But after eliminating the abnormal data, electricity consumption seems to be influenced by family size and family income as same as in rural area group. Percentage of air conditioner use of this group is around 42% (Table 5.19), higher than in rural area due to higher average family income.

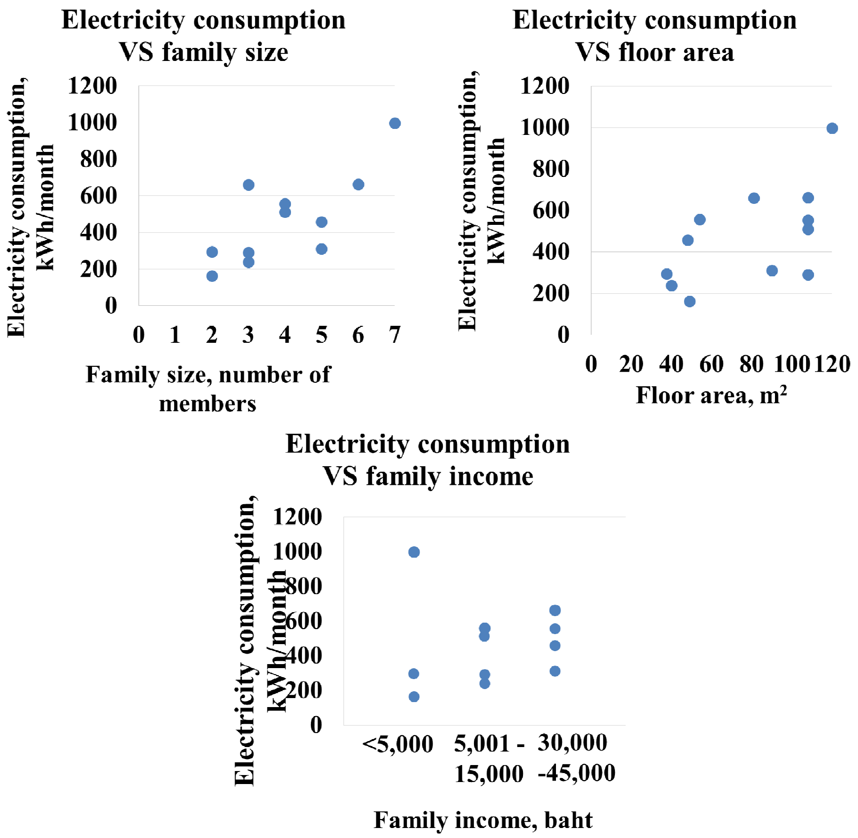


Figure 5.11 Electricity consumption distribution of the central Thailand (suburban group).

Table 5.19 Air conditioner use distribution of the samples of central Thailand (suburban group).

Use of air-conditioner use	Household
Use-air con	5
Not use-air con	7

Table 5.20 shows that most electricity consumption in this group is in amenity category (57.5%) which the highest electricity consumption is from air conditioner (23.4%) and refrigerator (13.5%). For other categories, most electricity consumptions are from lamp (5.8%), TV (11.6%), and kettle (18.5%) for lighting, entertainment, and cooking category respectively.

Table 5.20 Electricity consumption of each appliance and category of the central Thailand (suburban group).

Category	Appliance	Electricity consumption	% 0f appliance	% of category
Lighting	Lamp	334	5.82	5.82
Entertainment	TV	664	11.58	12.29
	CD player	34	0.59	
	Game player	6	0.10	
	Radio	1	0.02	
Amenity	PC	10	0.18	57.5
	Washing machine	59	1.03	
	Water heater	294	5.13	
	air conditioner	1,343	23.41	
	Refrigerator	773	13.48	
	Iron	292	5.09	
	Fan	497	8.67	
	Ventilators	2	0.04	
	Charger	27	0.47	
Cooking	Kettle	1,062	18.51	24.4
	Electric stove	1	0.02	
	Electric pot	2	0.04	
	Rice cooker	334	5.83	

Average floor area and average floor area per person of this region are 79 m^2 and 20 m^2/person respectively. Electricity consumption is around 478 kWh per month or 5,736 kWh per household per year (Table 5.21). The Thailand Greenhouse Gas Management Organization, Commitee Report [8], uses an emission factor of 0.6093 kg/kWh for the present mix of fuels used in electric power generation. Total emission for the model house throughout its life is then

= 87 ton, if the life of the house is 25 years, or

= 175 ton, if the life of the house is 50 years.

Electricity consumption and GHG emission of this group is around 3 times of rural group however it is more likely that the low-income earners would become middle income earners and consume electricity at a rate that is more than twice the figure used here, as they will have air-conditioning and use electric hot water heating.

Table 5.21 Average floor area, average floor area per person, electricity consumption and cost of the central Thailand (suburban group).

Average floor area	79
Average floor area per person (m^2/person)	20
Average electricity consumption (kWh/Month)	478
Average electricity cost (Baht/Month)	1308

5.2.4 Thermal environment and thermal comfort assessment

- **Rural group**

Table 5.22 shows that thermal environment of most of is poor due to high solar radiation through roofs (no ceiling was use) and low natural ventilation (small opening on walls) as shown in Figure 5.12. In some house which thermal condition in houses is extremely bad, most of them construct a small shelter as shown in Figure 5.13 for rest during daytime.

Figure 5.12 Interior of the sample houses of central Thailand (rural group).

Table 5.22 Thermal environment of the sample houses of central Thailand (rural group).

	DB	%RH	Globe Temp	Wind speed, m/s	CO_2
Max	37.9	47.1	37.5	1.2	650.0
Min	28.6	33.9	28.6	0.0	393.0
Ave	32.7	39.8	33.3	0.2	468.6

Figure 5.13 The cottages which are used for rest during daytime

- **Suburban group**

Table 5.23 shows that thermal environment of the samples of this group is also poor for the houses which do not use ceiling under roof (high radiant temperature from roof). For other houses which have ceiling under roof, opening in some house is also relatively small (cause low natural ventilation), thermal condition is also poor as shown in Figure 5.14.

Figure 5.14 Interior of the sample houses of central Thailand (suburban group).

Table 5.23 Thermal environment of the sample houses of central Thailand (suburban group).

	Air temp. (°C)	**Mean radiant temp. (°C)**	**Air speed (m/s)**	**Relative humidity (%)**	**CO2 (ppm)**
Max	33.5	34.1	1.7	67.7	619.0
Min	30.6	30.6	0.0	58.0	424.0
Ave	31.8	32.3	0.6	62.5	497.3

Figure 5.15 shows relationship of thermal sensation value (TSV), Operative temperature (To), and predicted mean vote (PMV) of the sample people from interviewing and calculations from the measured data. The results show that neutral temperature of the sample people is 29.01°C.

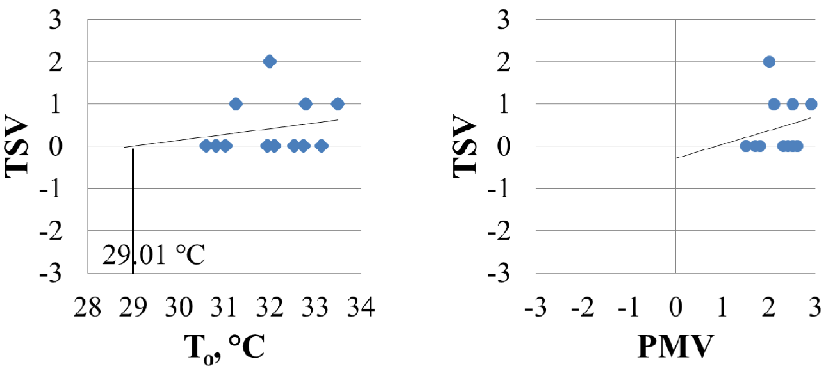


Figure 5.15 Thermal comfort assessment of the samples of central Thailand (suburban group).

5.2.5 Lighting condition in houses

- **Rural group**

Table 5.24 shows that lighting conditions of most houses are sufficient. Only some house which does not open windows (because they do not live in the houses during daytime) possess poor lighting condition as shown in Figure 5.16.

Figure 5.16 Interior lighting condition of the samples of central Thailand (rural group).

Table 5.24 Lighting condition of the samples of central Thailand (rural group)

House number	**Illuminances (lux)**			
	Living room	**Bedroom**	**Kitchen**	**Toilet**
1	1100	3	76	34
2	309	680	30	309
3	12	12	21	6
4	171	700	5	20
5	1200	80	30	20
6	102	102	130	61
7	47	87	93	26
8	74	658	110	20
9	389	49	14	71
10	17	3	27	5
11	106	18	7	120
12	12	0	83	0
13	24	13	24	13
14	180	100	1200	930
15	1800	9	10	10
16	400	30	20	20
17	342	0	27	12
18	3	0	21	200
Average	349.3	141.3	107.1	104.3

- **Suburban group**

Table 5.25 shows that lighting conditions of most houses are insufficient due to small opening on walls and does not open windows (because they do not live in the houses during daytime) therefore lighting conditions are poor as shown in Figure 5.17.

Figure 5.17 Interior lighting condition of the samples of central Thailand (suburban group).

Table 5.25 Lighting condition of the samples of central Thailand (suburban group)

House number	Illuminances (lux)			
	Living room	Bedroom	Kitchen	Toilet
1	140	48		
2	45			164
3	160	6	420	
4	90			
5	60			
6	190	70		
7	250		160	0
8	30			
9	70			
10	220	300	60	70
11	0			
12	400	40		
Average	165	464	640	234

5.3 Greenhouse Gas Emissions of Low Income Houses in Central Region

Central region in Thailand is located in a river basin area. In the past, most people lived nearby riversides. Agriculture was major economic sector in this region. Nowadays the population density in central area has been increasing due to the urbanization. The inland communities have been populated and industry has become more important economic sector than agriculture. This life style has an effect on their house designs. Most low-income houses along the riverside are two-storey detached houses, which the design is adapted to the intertidal environment and flooding. While the inland houses are one-storey detached houses. The details of each house are explained as follows.

1) Low income house in central region model 1 (Suburban group)

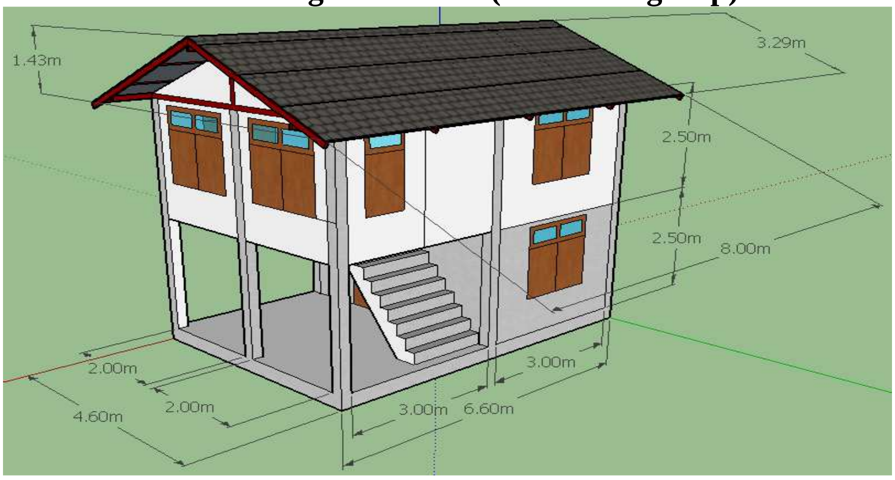


Figure 5.18 Floor plans of the detached house model 1 in Central region of Thailand.

The floor plan of the first and second stories of the detached house (model 1) in central region sketched from survey data is shown in Figure 5.18. The 2-storey detached house consists of high basement, which is designed to prevent flooding. The plot area of the first floor is 4.6 x 6.6 m and that of the second floor is 4.6 x 6.6 m. The floor-to-floor heights of the first floor and the second floor are 2.5 m and 2.5 m, respectively. The first floor comprises multi-function room and there are one or two bedrooms on the second floor. Kitchen, cloth washing area and toilet are provided on the first floor of the house. The wall of first floor is made from concrete block. While the wall of the second floor is made from fiber cement panels. Roof tile is the most popular roofing material. The upper floor, doors and windows are made from hardwood. The lists of construction materials and the quantity of each material are shown in Table 5.26.

Table 5.26 Input data of construction materials of the detached house (model 1) in Central region (area size 60.72 m^2)

Materials	Quantities	Unit
Sand	2,112.00	kg
Concrete	13,433.00	kg
Cement	1,273.00	kg
Steel	761.00	kg
Fiber cement panels	251.00	kg
Roof tiles	772.00	kg
Hardwood	80.52	ft^3
Lime	105.38	kg
Glass	171.36	kg

- **Methodology**

The activity data of construction materials were extracted from house plans and Bill of Quantities (BOQ) of low income houses in northeastern region. The GHG emission was calculated in the unit of $kgCO_2e/m^2$ by the following equation.

$$\text{GHG emission } (kgCO_2e/m^2) = \sum [\text{Activity data (unit) x Emission factor } (kgCO_2e/\text{unit})] /\text{area}$$

Emission factors used in this study were referred from Thai national database (Thailand Greenhouse Gas Management Organization [6]), Simapro 7.1 and the study from University of Bath (University of Bath [9]) as presented in Table 5.27. The GHG emission hotspots were pointed out.

Table 5.27 Emission factors used in this study.

Items	Unit	Emission factor ($kgCO_2e$/unit)	References
Cement	kg	0.49	TGO (2011)
Concrete	kg	0.13	University of Bath (2008)
Fiber cement panels	kg	1.09	University of Bath (2008)
Glass	kg	1.13	SimaPro 7.1
Lime	kg	0.74	University of Bath (2008)
Roof Tiles	kg	0.353	SimaPro 7.1
Sand	kg	0.0037	TGO (2011)
Steel	kg	1.25	SimaPro 7.1
Hardwood	ft^3	-33.00	SimaPro 7.1

- **Results and discussion**

The GHG emissions from construction materials of the low income house (model 1) in central region were shown in Table 5.28. Major GHG emission hotspots came from concrete (23.67 $kgCO_2e/m^2$), followed by steel (15.67 $kgCO_2e/m^2$) and cement (10.27 $kgCO_2e/m^2$), respectively. Aside from cement and concrete, hardwood is commonly used to build low income houses in central region. This causes the advantage in carbon offset. The carbon dioxide removal from hardwood was 43.76$kgCO_2e/m^2$, accounted for 69% of GHG emissions (Figure 5.19). As a result, the net GHG emission of central region low income houses (model 1) was only 19.51 $kgCO_2e/m^2$.

Table 5.28 GHG emissions from construction materials ofthe detached house (model 1) in Central Region.

Materials	**GHG Emission(kgCO_2 e/m^2)**
Sand	0.13
Concrete	23.67
Cement	10.27
Steel	15.67
Roof tiles	4.49
Fiber cement panels	4.50
Hardwood	-43.76
Lime	1.35
Glass	3.19
Total	**19.51**

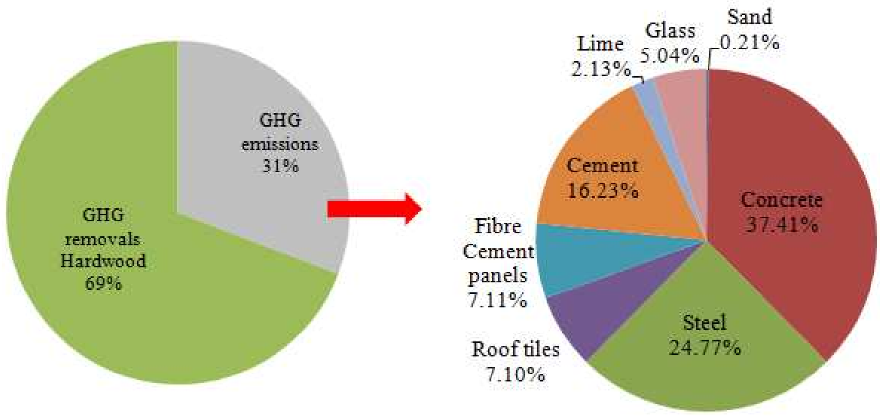


Figure 5.19 Percentage of GHG emissions from construction process of the detached house (Model 1) in Central Region.

2) Low income house in central region model 2 (Rural group)

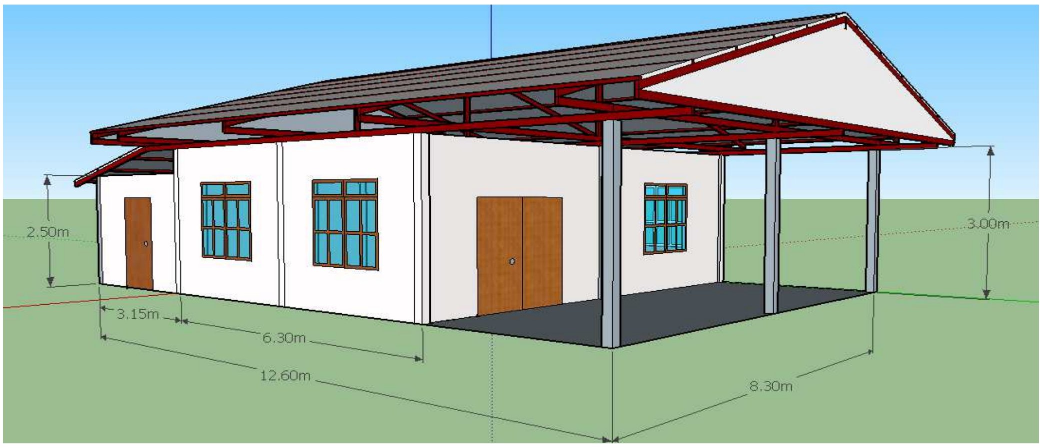


Figure 5.20 Floor plans of the detached house model 2 in Central region of Thailand.

The recent low income house style is shown in Figure 5.20. The modern house consisted of one storey. The plot area of the house is 12.6 x 8.3 m. The height of the floor is 3.0 m. The ground floor comprises multi-function room, restroom and there are one bedrooms. Kitchen, cloth washing area and bathroom are at the backside of the house. Roofing materials are roof tile and steel. Ceilings are made by fiber cement panels. Walls are constructed from concrete block. Windows are made from glass and doors are made from hardwood. Reinforced concrete is used for floor. The lists of construction materials and the quantity of each material are shown in Table 5.29.

Table 5.29 Input data of construction materials of the detached house (model 2) in Central region (area size 104.58 m^2).

Materials	**Quantities**	**Unit**
Sand	5,408.00	kg
Concrete	39,311.25	kg
Cement	4,418.00	kg
Steel	1,275.61	kg
Fiber cement panels	153.29	kg
Roof tiles	2,175.00	kg
Hardwood	12.72	ft^3
Lime	365.72	kg
Glass	757.52	kg

- **Results and discussion**

The GHG emissions from construction materials of the low income house (model 2) in central region were shown in Table 5.30. Major GHG emission hotspots came from concrete (40.22 $kgCO_2e/m^2$), followed by cement (20.70 $kgCO_2e/m^2$) and steel (15.25 $kgCO_2e/m^2$), respectively. The carbon dioxide removal from hardwood was only 4.01 $kgCO_2e/m^2$, accounted for 4% of GHG emissions (Figure 5.21). As a result, the net GHG emission of central region low income houses (model 2) was 92.21kgCO_2e/m^2.

Table 5.30 GHG emissions from construction materials of the detached house (model 2) in Central Region.

Materials	GHG Emission(kgCO_2 e/m^2)
Sand	0.19
Concrete	40.22
Cement	20.70
Steel	15.25
Roof tiles	7.34
Fiber cement panels	1.60
Hardwood	-4.01
Lime	2.73
Glass	8.19
Total	**92.21**

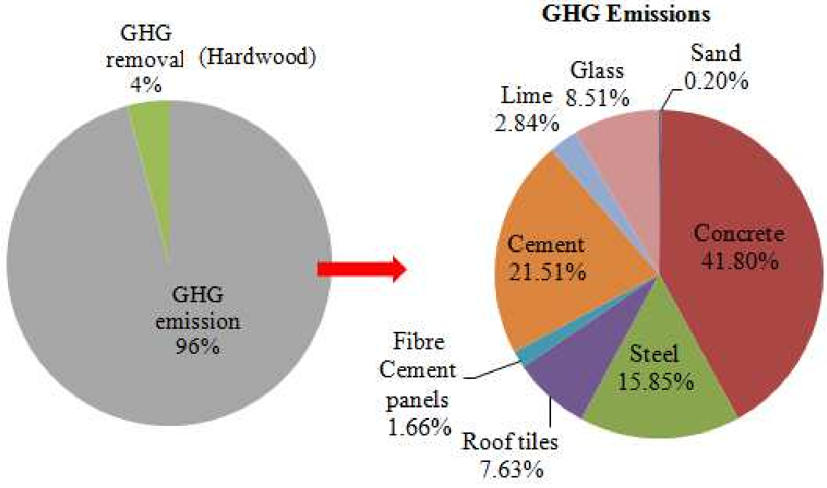


Figure 5.21 Percentage of GHG emissions from construction process ofthe detached house (Model 2) in Central Region.

CHAPTER 6
SURVEY RESULTS OF NHA HOUSES

6.1 Introduction

After the Second World War, there was a period of high population growth. The government at the time invested heavily to improve utilities, sanitation, and infrastructures in cities, especially in Bangkok. The policies created economic opportunities that attracted rural people to Bangkok and that started informal settlement into vacant land plots, often near job sites in cities. In 1972, the National Housing Authority (NHA) was created to solve housing shortage by providing welfare housing to low-income people. A number of schemes were operated including some heavily subsidized housing projects, site and services scheme (where the NHA provided prepared site completed with access road, electricity, water supply, drainage, and sanitation services and clients design and construct their own houses), and semi-commercial scheme. In 2002, the government mandated NHA to provide 600,000 units of 'Ban Eau Arthorn (BEA)'. These are constructed with the same designs for 4 types of housing, which are detached houses (Figure 6.1 a)), twin houses(Figure 6.1 b)), shop houses(Figure 6.1 c)), and flats (4-storeyed multiple unit) (Figure 6.1 d)). The sites are chosen from different locations in the country, but more than half of them in Bangkok. The government subsidized about a quarter of the cost of each unit of about THB 400,000 and size of 30 m^2. Eligible Thai nationals are those that do not own land, having lived near the area where the site is located, and earning less than THB 15,000 per month (This was later increased to 30,000.). Eventually 270,466 units were built, some are still unoccupied, Usavagovitwong [11].

a) b)

c) d)

Figure 6.1 Configurations of NHA houses

6.2 Survey results

There are 3 groups of NHA houses which were surveyed; (1) the houses which are over 20 years old (Figure 6.2), (2) the houses which are between 5-10 years old (Figure 6.3), and new houses which are less than 5 years old (Figure 6.4). The first group of houses had been renovated or reconstructed from the original NHA designs already, these houses are not considered in this reported.

Figure 6.2 NHA houses which are over 20 years old

Figure 6.3 NHA houses which are between 5-10 years old

Figure 6.4 NHA houses which are less than 5 years old

6.2.1 Living styles

Family size and age of people of the samples in NHA houses are various, most of them are in working-age (Table 6.1). And according to NHA houses are in urban or suburban area therefore most of residents are employees or have their own small commercial in houses, no residents who are famers such as in rural area while the rest of them are retired people and students. Average family income is also higher than in rural area due to many employee works are available in urban area.

Table 6.1 Household data of NHA houses

		Detached house	Twin house	Townhouse	Condominium
Family size, households	1	0	0	5	3
	2	1	1	2	6
	3	3	2	3	2
	4	0	2	0	1
	5	1	0	3	2
	6	2	0	0	1
	7	0	0	0	0
	Average	4.0	3.2	2.5	2.7
Age, persons	Less than 15	6	3	7	8
	16-30	10	3	6	6
	31-45	6	4	7	17
	45-60	2	4	8	9
	More than 60	4	2	5	1
Occupation, households	Unemployed (retired)	11	3	12	8
	Farmers	0	0	0	0
	Students	4	3	8	12
	Government employees	8	4	5	9
	Small commercial	2	6	5	4
	Employees (private)	3	0	3	8
Family income, households	<5000	0	1	1	0
	5001-15000	0	2	4	7
	15000-30000	3	1	3	5
	>30000	4	1	5	3

6.2.2 Housing features

There are various configurations of NHA houses but main features and construction materials are near the same. Most houses which are used for consideration in this report are the houses under "Ban Eau Arthorn (BEA)" project which most of them are new houses and still in the original design. Housing features, material uses, and dimension are in the previous report (in the 2nd and 3rd report of ELITH-Thailand). Average floor area and floor area per person of those houses are shown in Table 6.2.

Table 6.2 Average floor area and floor area per person of NHA houses

	Detached house	Twin house	Townhouse	Condominium
Ave. floor area , m^2	40.6	45.9	47.6	31.2
Ave. floor area person, m^2/person	11.8	15.3	27.8	15.6

6.2.3 Energy consumption and GHG emission from electricity use

Figure 6.5-6.8 show relationship of electricity consumption distribution of each NHA houses against family size and floor area. The electricity consumption distributions seem to be scattered. But in twin houses, townhouses, and condominium, the electricity consumptions are likely to be increased while family sizes and floor areas are larger although the relationships are not clear-cut.

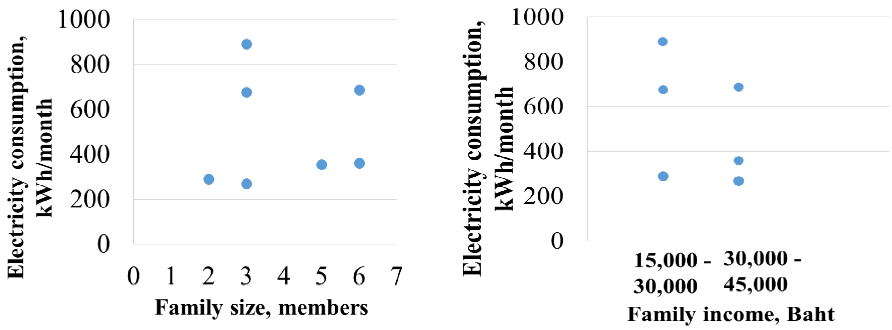


Figure 6.5 Energy consumption distribution of single detached houses

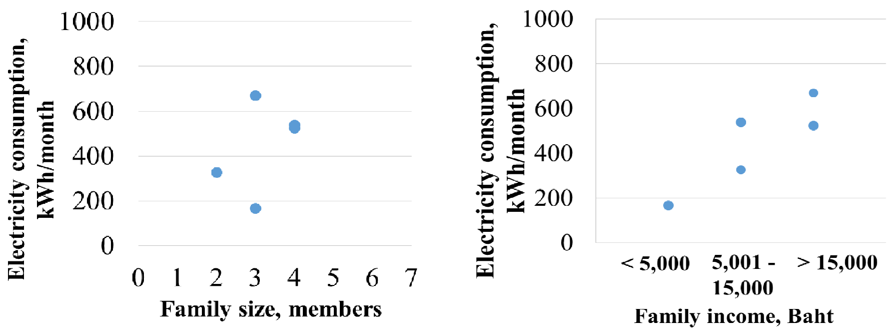


Figure 6.6 Energy consumption distribution of twin houses

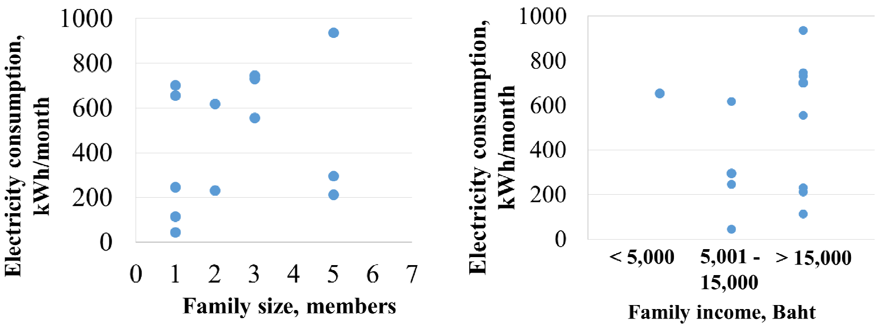


Figure 6.7 Energy consumption distribution of town houses

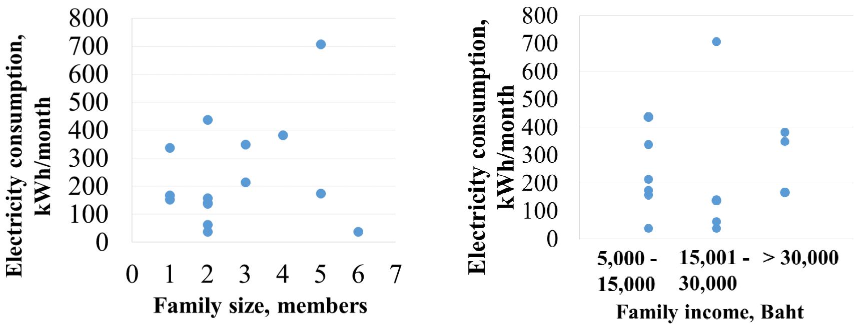


Figure 6.8 Energy consumption distribution of condominium

Table 6.3 shows electricity consumption of appliances of each type of NHA houses. The appliances which consume the highest electricity are lamp, TV, air conditioner, kettle, and freezer for lighting, entertainment, amenity, cooking, and small commercial category respectively. Percentage of air conditioner usage and types of appliances of NHA houses are higher than other detached houses which may be the results of higher average family income.

Table 6.3 Electricity use of appliances of NHA house samples.

End-use Category	Appliance	Detached house		Twin house		Townhouse		Condominium	
		Number of possession	Elec. Cons, kWh/month	Number of possession	Elec. Cons, kWh/month	Number of possession	Elec. Cons, kWh/month	Number of possession	Elec. Cons, kWh/month
Lighting	Lamp	7	142	5	136	13	352	15	264
Entertainment	TV	7	241	0	0	12	389	14	303
	DVD player	0	0	0	0	1	2	0	0
	Radio	1	14	0	0	1	3	0	0
	Audio	2	2	0	0	0	0	0	0
	Aquarium	0	0	0	0	0	0	1	22
Amenity	PC	2	36	2	23	4	61	6	214
	Washing machine	5	186	4	69	7	372	7	70
	Water heater	2	134	1	101	2	332	2	268
	Air conditioner	4	981	3	879	4	782	4	684
	Hair dryer	0	0	0	0	1	20	1	21
	Refrigerator	0	0	5	385	10	1017	12	756
	Iron	3	76	3	66	2	83	6	238
	Fan	7	206	5	187	13	373	16	284
	Microwave	2	46	0	0	1	5	2	55
	Printer	0	0	0	0	0	0	1	0
Cooking	Hot pot	0	0	3	112	11	418	5	90
	Coffee maker	0	0	0	0	1	8	0	0
	Microwave	2	46	0	0	1	5	2	55
	Rice cooker	7	110	1	29	8	306	9	223
	Kettle	4	508	0	0	0	0	0	0
	Electric pan	1	28	0	0	0	0	0	0
	Steam oven	0	0	0	0	0	0	1	20
Small commercial	Water dispenser for sale	0	0	0	0	1	67	0	0
	Freezer	1	336	0	0	3	1056	0	0
	Ice cream freezer	0	0	0	0	2	454	0	0

Table 6.4 shows average monthly average electricity consumption and GHG emission from energy use. Average electricity consumption of townhouse is highest due to the houses also have small commercial such as retail stores while condominium consumes the lowest electricity consumption. This could be the results of lower family income and unable to conduct small commercial in houses. And because the highest energy use, the townhouse also emit the highest GHG around 86 and 172 ton GHG per year for life of houses of 25 and 50 years respectively.

Table 6.4 Average electricity consumption and GHG emission of NHA houses.

	Life of house	Detached house	Twin house	Townhouse	Condominium
Ave. Electricity use, kWh/month		442	397	470	238
GHG emission from electricity use, ton	**25 years**	81	73	86	43
	50 years	162	145	172	87

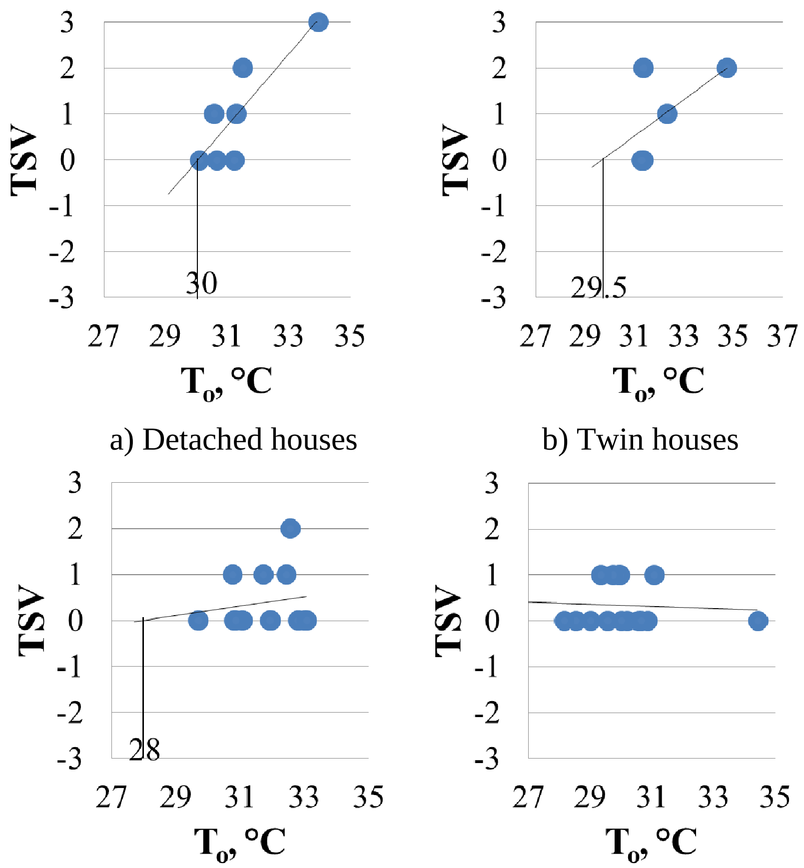
6.2.4 Thermal environment and thermal comfort assessment

Thermal environment measuring were conducted in the living room of condominium and on the first floor of detached houses, twin houses, and townhouses (Table 6.5). Therefore the thermal environments seem to be in the normal condition while the conditions of the upper floor are rather warmer and inconvenience to stay during the daytime.

Table 6.5 Thermal environments of each NHA house.

House types	Air temp. (°C)			Mean radiant temp. (°C)			Air speed (m/s)			Relative humidity (%)			CO2 (ppm)		
	Max	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**
Detached houses	33.4	30.1	31.2	34.8	30.1	31.6	0.8	0.0	0.3	75.2	53.0	67.0	871	465	620
Twin houses	34.7	30.9	32.2	34.8	31.1	32.2	1.8	0.0	0.4	66.7	53.1	62.1	868	467	586
Townhouses	32.9	29.4	31.6	34.2	30.4	32.0	2.6	0.0	0.9	76.7	59.0	64.8	850	416	582
Condominium	32.8	28.1	30.0	38.2	28.3	30.3	3.4	0.0	1.1	77.6	59.5	68.4	747	443	551

The thermal comfort assessment were conducted under non-air conditioner condition. Neutral operative temperatures of the samples of NHA houses are varied between 28-30^{o}C as shown in Figure 6.9, the results are near the same as in the other detached house surveys as mentioned before.



a) Detached houses b) Twin houses

c) Townhouses d) Condominium

Figure 6.9 Thermal comfort assessment of the samples of NHA houses.

6.2.5 Lighting condition

Table 6.6 shows average lighting condition of each NHA house types by measuring illuminances on the work plan at many points. Level of The interior daylight is low by closing windows for privacy of the residents. The open space where daylight is introduced through the windows were covered later with large roof to increase the utilization space.

Table 6.6 Lighting condition of each NHA house type.

Type	Detach		Twin		Townhouse		Condo	
Lighting cons.	142 kWh (4%)		136 kWh (7%)		352 kWh (6%)		264 kWh (8%)	
	Daylight illuminance (lux)							
	Range	Average	Range	Average	Range	Average	Range	Average
Living	17-170	81	40-83	56	5-160	67	7-170	69
Bed	12-113	63	30-170	78	12-113	65	5-80	70
Toilet	2-4	3	4	4	2-4	3	18-20	19
Kitchen	6-380	147	114-200	152	6-143	75	96-140	122

6.3 Greenhouse Gas Emissions of Low Income Houses

Carbon embedded in construction materials is one of the significant sources related to carbon footprint of residential houses. Our previous studies focused on the estimation of greenhouse gas (GHG) emission from conventional houses and modern houses with different construction materials such as precast concrete, light-weight concrete and brick. It was reported that 98% of GHG emissions were from construction materials. Cement and steel were major sources of GHG emission (Aneksaen [5]). However, GHG emissions from low income houses have not been investigated.

Baan Eua-Arthorn Project is the government housing project for low income people in Thailand. The project was established in 2003 by National Housing Authority (NHA) with the 4 low income houses styles such as detached house (61.97 m^2), twin house (109.67 m^2), townhouse (552.20 m^2), and condominium (2,121.15 m^2) with the total units of 281,550.

This study aims to evaluate GHG emissions from construction materials of low income houses under Baan Eua-Arthorn Project. The activity data of constructing materials were extracted from house plans and Bill of Quantities (BOQ) of low income houses in each region. The GHG emissions in the unit of $kgCO_2$ e/m^2 were calculated in the scope of cradle to gate following the Thai national guideline for carbon footprint of product (Thailand Greenhouse Gas Management Organization [6]).

- **Methodology**

The activity data of construction materials were extracted from house plans and Bill of Quantities (BOQ) of low income houses. The GHG emission was calculated in the unit of $kgCO_2e/m^2$ by the following equation.

$$\text{GHG emission } (kgCO_2e/m^2) = \sum [\text{Activity data (unit) x Emission factor } (kgCO_2e/\text{unit})] / \text{area}$$

Emission factors used in this study were referred from Thai national database (Thailand Greenhouse Gas Management Organization [6]), SimaPro 7.1 and the study from University of Bath (University of Bath [9]) as presented in Table 6.7. The GHG emissions from different building styles were then compared and the emission hotspots were pointed out.

Table 6.7 Emission factors used in this study.

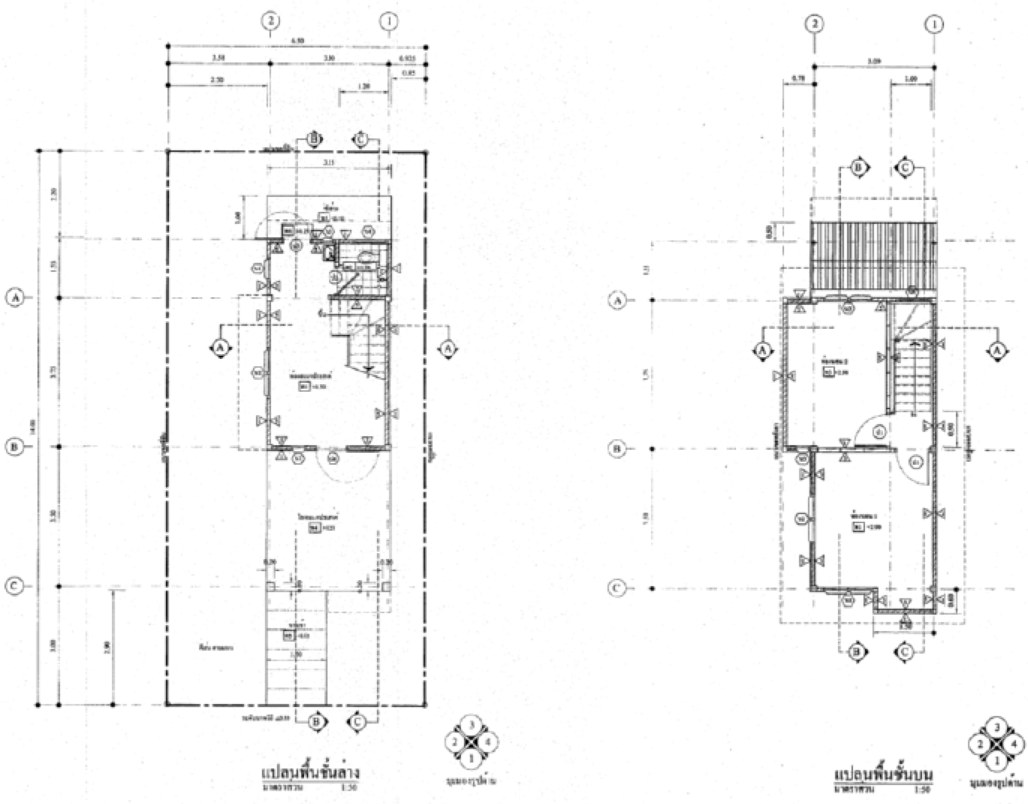
Items	**Unit**	**Emission factor ($kgCO_2e$/unit)**	**References**
Brick	kg	0.218	TGO (2011)
Cement	kg	0.490	TGO (2011)
Concrete	kg	0.130	University of Bath (2008)
Glass	kg	1.130	SimaPro 7.1
Gypsum Ceiling	kg	0.346	SimaPro 7.1
Hardwood	Ft^3	-33.00	SimaPro 7.1
Lightweight Concrete	kg	0.220	SimaPro 7.1
Lime	kg	0.740	University of Bath (2008)
Roof Tiles	kg	0.353	SimaPro 7.1
Sand	kg	0.0037	TGO (2011)
Steel	kg	1.25	SimaPro 7.1

- **Results and discussion**

The details of floor plan, the list of B.O.Q. and the GHG emissions of each NHA houses under Baan Eua-Arthorn Project were presented as follows.

a) Detached house

Figure 6.10-6.11 exhibits the floor plan of the first and second stories of the detached house developed by NHA. The plot area of the house is 7.25 x 3 m. The floor-to-floor height of the first floor and the second floor are 2.6 m. and 2.75 m., respectively. The lists of construction materials and the quantity of each material were shown in Table 6.8.



(a) First floor (b) Second floor

Figure 6.10 Floor plans of the NHA detached house, (a) first floor and (b) second floor.

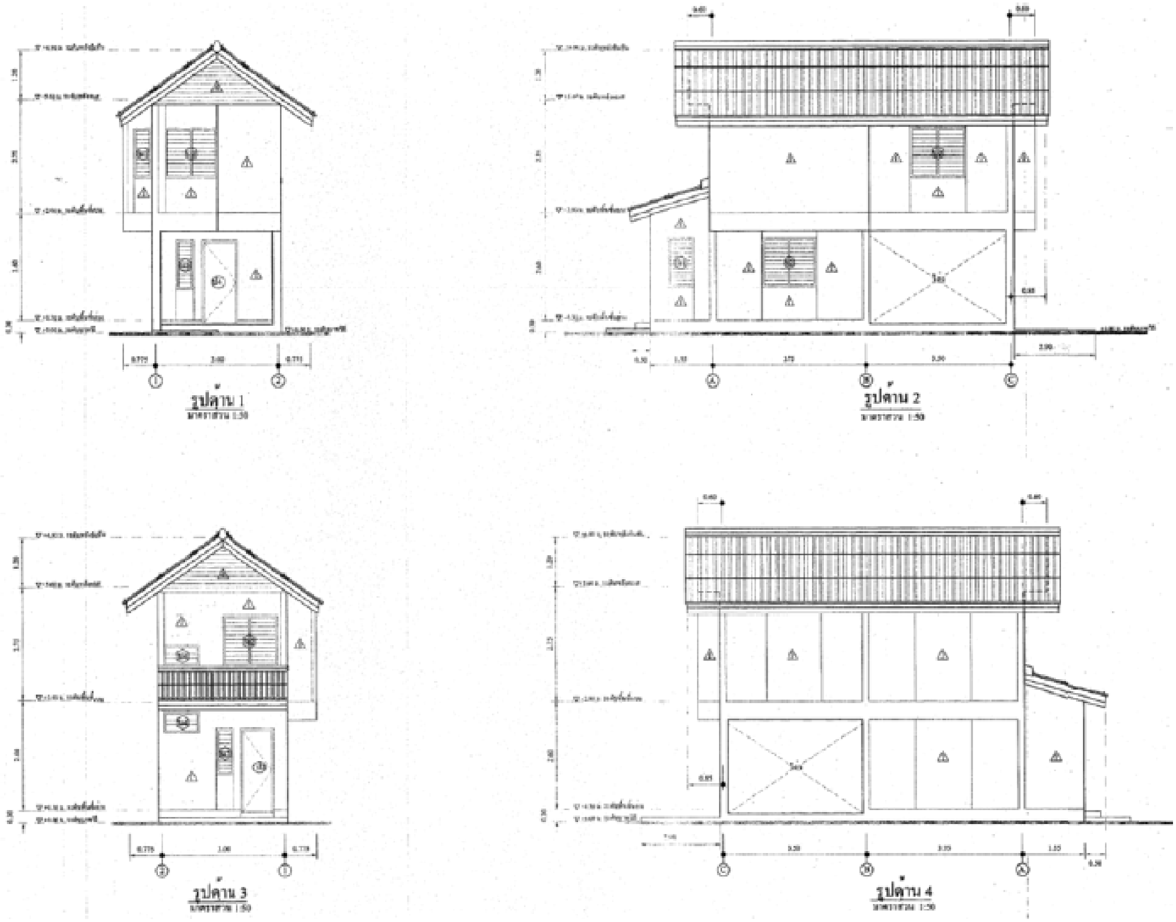


Figure 6.11 Side plans of the NHA detached house.

Table 6.8 Input data of construction materials of the NHA detached house.

Materials	Quantities	Unit
Sand	6,144.00	kg
Concrete	26,796.00	kg
Cement	2,711.50	kg
Steel	723.30	kg
Roof Tiles	568.80	kg
Gypsum Ceiling	216.00	kg
Lime	379.26	kg
Glass	74.26	kg

The GHG emissions from construction materials of the NHA detached house were shown in Table 6.9. Major GHG emission hotspots came from concrete (46.27 $kgCO_2e/m^2$), cement (21.44 $kgCO_2e/m^2$) and steel (14.59 $kgCO_2e/m^2$), respectively. This is because the concrete, cement and steel are major construction materials for detached house construction and their carbon footprints are also very high. Percentage of GHG emissions of each materials is shown in Figure 6.12**.**

Table 6.9 GHG emissions from construction materials of the NHA detached house.

Materials	GHG Emission(kgCO_2 e/m^2)
Sand	0.37
Concrete	46.27
Cement	21.44
Steel	14.59
Roof Tiles	3.21
Gypsum Ceiling	1.21
Lime	4.77
Glass	1.35
Total	**93.21**

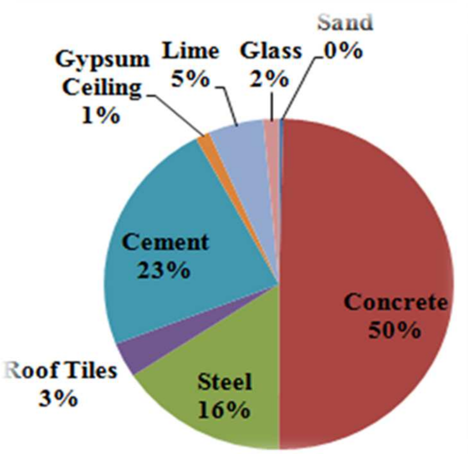
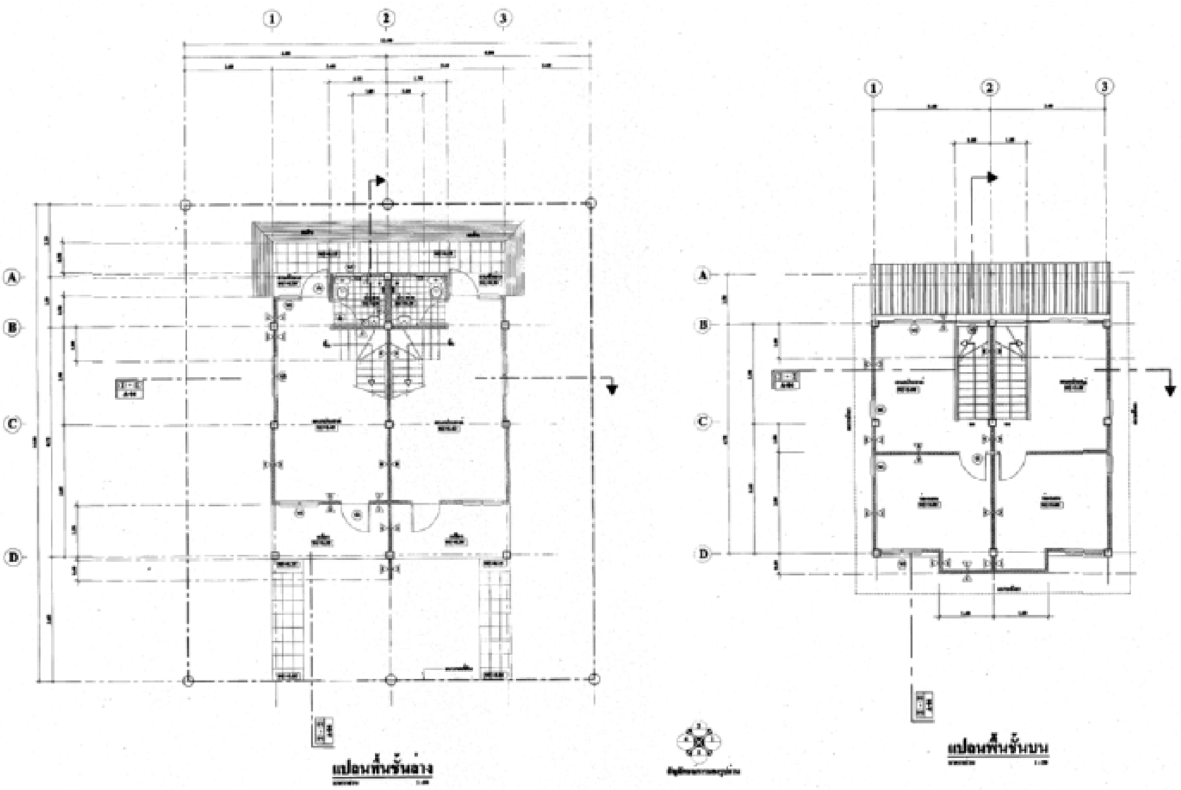


Figure 6.12 Percentage of GHG emissions from construction process of detached house

b) Twin house

Twin house is a residential buildings that two house are constructed and separated with a common wall. Each house has its own open spaces at the front and back of the house and at the opposite side of the common wall. Each house has its own entrance and exit door. The twin house has its plot area of 6.75 x 3.4 m. The height of the first floor is 2.6 m. the second floor height is 2.6 m. The level from ceiling to the apex of the gable roof is 1.95 m. The first floor comprises multi-function room and rest room. Cloth washing area is provided at the backside of the house. On the second floor there are two bedrooms. The floor plans and side plans of the NHA twin house were shown in Figure 6.13 and Figure 6.14, respectively. The lists of construction materials and the quantity of each material were shown in Table 6.10**.**



(a) First floor (b) Second floor

Figure 6.13 Floor plans of the NHA twin house, (a) first floor and (b) second floor.

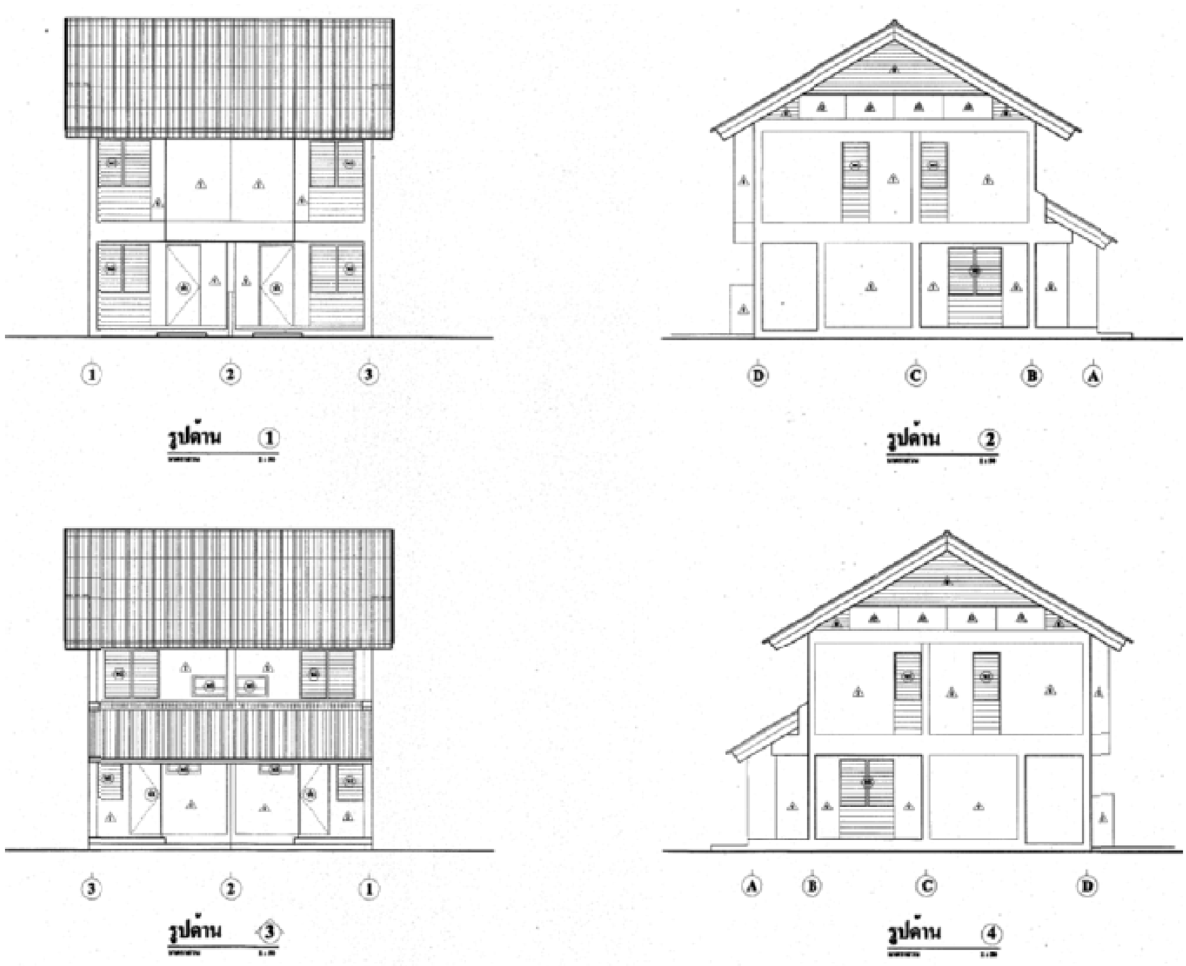


Figure 6.14 Side plans of the NHA twin house.

Table 6.10 Input data of construction materials of twin house.

Materials	Quantities	Unit
Brick	1,327.56	kg
Sand	13,104.00	kg
Concrete	52,582.90	kg
Cement	5,843.65	kg
Steel	1,368.60	kg
Roof Tiles	1,234.00	kg
Gypsum Ceiling	405.00	kg
Lime	688.41	kg
Glass	125.66	kg

The GHG emissions from construction materials of the NHA twin house were shown in Table 6.11. Major GHG emission hotspots came from concrete (51.30 $kgCO_2e/m^2$), cement (26.11 $kgCO_2e/m^2$) and steel (15.60 $kgCO_2e/m^2$), respectively. Percentage of GHG emissions of each materials is shown in Figure 6.15**.**

Table 6.11 Greenhouse Gas Emissions from construction process of twin house.

Materials	GHG Emission(kgCO2 e/m^2)
Brick	2.64
Sand	0.44
Concrete	51.30
Cement	26.11
Steel	15.60
Roof Tiles	3.97
Gypsum Ceiling	1.28
Lime	4.89
Glass	1.29
Total	**107.53**

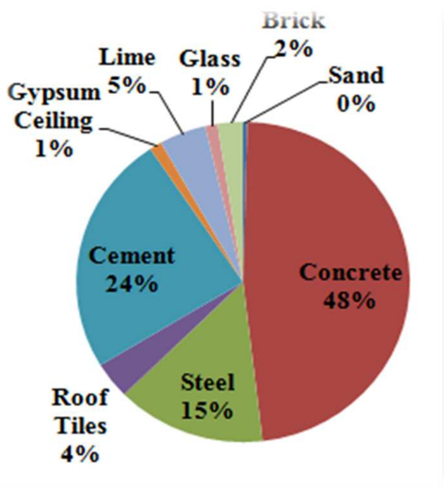


Figure 6.15 Percentage of GHG emissions from construction process of twin house

c) Townhouse

Townhouse is a residential building comprising a series of each separated house which share together common side walls. Figure 6.16 and Figure 6.17 shows the floor plans and side plans of the townhouse for low and medium income earners developed by NHA. The house has its plot area of 7.7 x 4.0 m. The first floor height is 2.65 m. The second floor height is 2.6 m. The level from ceiling to the apex of the gable roof is 1.86 m. The building height is 7.11 m. The first story comprises multi-function room and rest room and toilet room. Cloth washing area is provided at the back of the house. On the first floor, there are two bedrooms. The lists of construction materials and the quantity of each material were shown in Table 6.12.

Figure 6.16 Floor plans of the NHA townhouse: first floor and second floor.

Figure 6.17 Side plans of the NHA townhouse.

Table 6.12 Input data of construction materials of townhouse.

Materials	Quantities	Unit
Brick	17,940.00	kg
Sand	13,104.00	kg
Concrete	242,291.50	kg
Cement	41,522.25	kg
Steel	6,985.30	kg
Roof Tiles	6,011.80	kg
Gypsum Ceiling	2,085.00	kg
Lime	3,920.39	kg
Glass	445.54	kg
Hardwood	3.30	ft^3

The GHG emissions from construction materials of the NHA townhouse were shown in Table 6.13. Major GHG emission hotspots came from concrete (46.95 $kgCO_2e/m^2$), cement (36.84 $kgCO_2e/m^2$) and steel (15.81 $kgCO_2e/m^2$), respectively. Percentage of GHG emissions of each materials is shown in Figure 6.18**.**

Table 6.13 Greenhouse Gas Emissions from construction process of townhouse.

Materials	**GHG Emission(kgCO_2 e/m^2)**
Brick	7.08
Sand	0.63
Concrete	46.95
Cement	36.84
Steel	15.81
Roof Tiles	3.84
Gypsum Ceiling	1.31
Lime	5.53
Glass	0.91
Hardwood	-0.20
Total	**118.73**

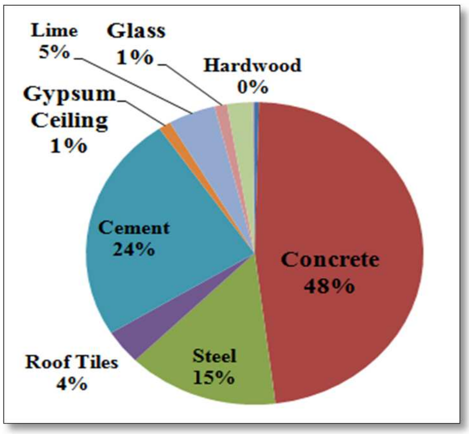


Figure 6.18 Percentage of GHG emissions from construction process of townhouse

d) Condominium

Condominium or apartment is a self-contained housing unit (a type of residential real estate) that occupies only part of a building. The condominium developed by NHA has five stories with the total building height of 18 m. The plot area of the apartment is 32.2 x 12.3 m. with floor-to-floor height of 2.8 m. The vertical distance from the ceiling level to the roof apex is 3.53 m. Each room unit has the dimension of 6 x 5.2 m, consisting of bedroom, living room, dining room, kitchen, toilet and terrace. Figure 6.19 shows the floor plans of the NHA condominium for low and medium income earners but only the first floor level and the fifth floor level. Figure 6.20 shows the side plans of the NHA condominium. The lists of construction materials and the quantity of each material were shown in Table 6.14.

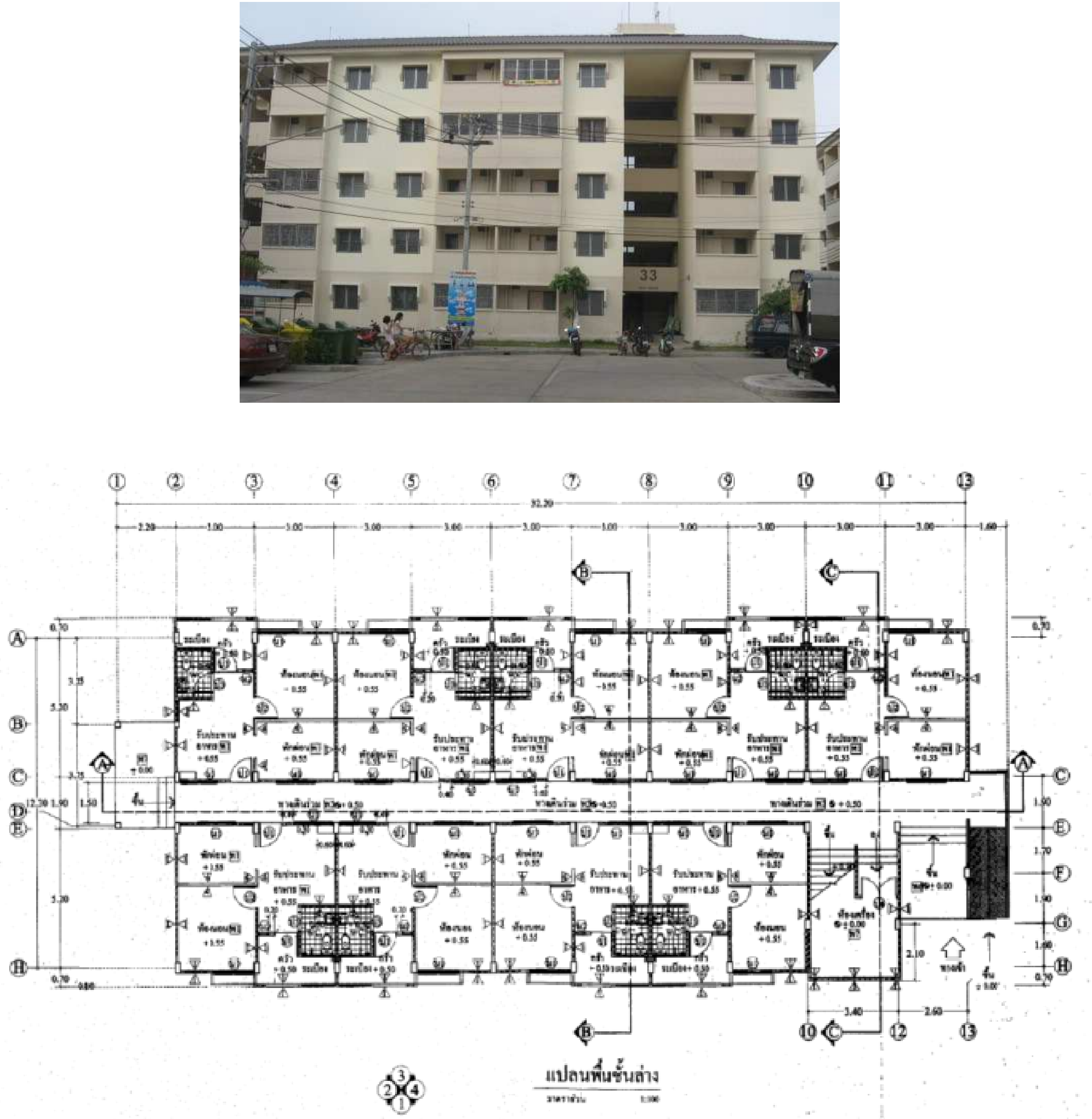


Figure 6.19 Floor plans of the NHA condominium.

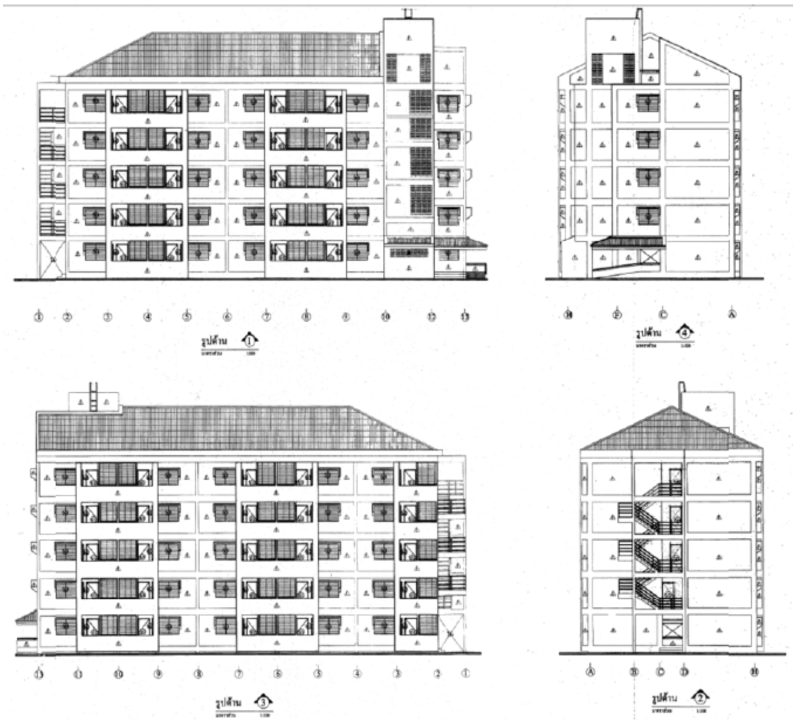


Figure 6.20 Side plans of the NHA condominium.

Table 6.14 Input data of construction materials of condominium.

Materials	Quantities	Unit
Brick	442,350.00	kg
Sand	228,416.00	kg
Concrete	983,114.00	kg
Cement	193,259.00	kg
Steel	47,011.00	kg
Roof Tiles	5,872.80	kg
Lime	25,340.01	kg
Glass	1,799.28	kg

The GHG emissions from construction materials of the NHA condominium were shown in Table 6.15. Major GHG emission hotspots came from concrete (49.59 $kgCO_2e/m^2$), brick (45.47 $kgCO_2e/m^2$) and cement (44.65 $kgCO_2e/m^2$), respectively. Percentage of GHG emissions of each materials is shown in Figure 6.21**.**

Table 6.15 Greenhouse Gas Emissions from construction process of condominium.

Materials	**GHG Emission(kgCO_2 e/m^2)**
Brick	45.47
Sand	0.40
Concrete	49.59
Cement	44.65
Steel	27.70
Roof Tiles	0.98
Lime	9.32
Glass	0.96
Total	**179.06**

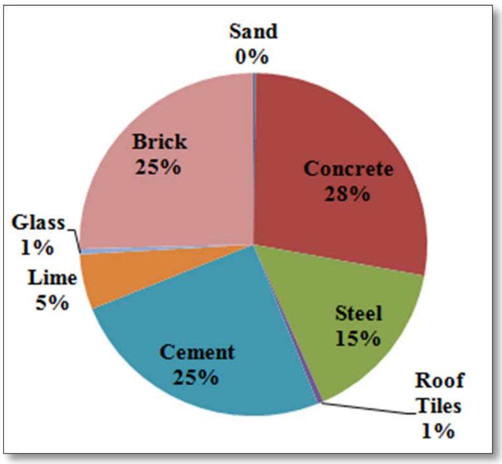


Figure 6.21 Percentage of GHG emissions from construction process of condominium

The comparison of GHG emissions per square meter for all types of the NHA houses under Baan Eua-Arthorn Project was exhibited in Figure 6.22. Condominium contributed the highest GHG emissions (179.06 kgCO_2 e/m^2), followed by townhouse (118.73 kgCO_2e/m^2), twin house (107.53 kgCO_2e/m^2), and detached house (93.21 kgCO_2e/m^2), respectively. Major GHG emission hotspots came from concrete, cement and steel due to their high consumption and their high carbon footprints.

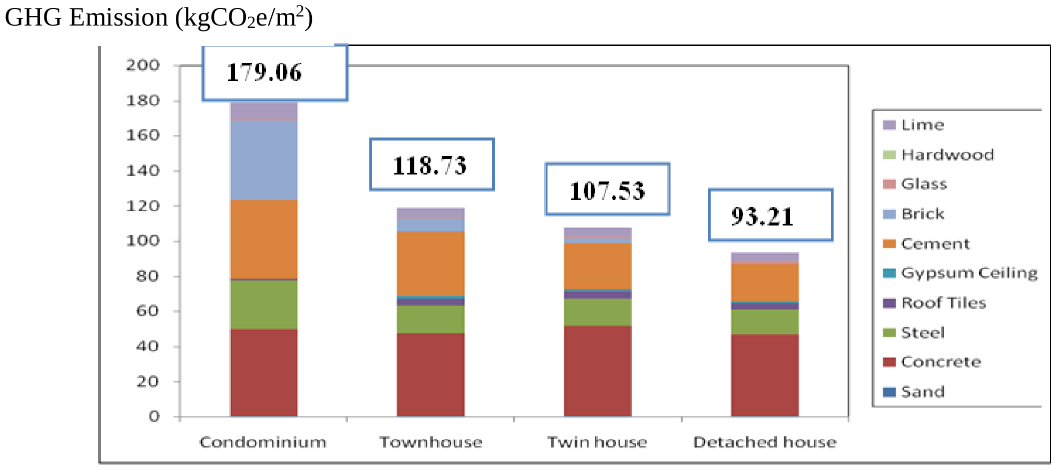


Figure 6.22 GHG emissions ($kgCO_2e/m^2$) of all HA houses under Baan Eua-Arthorn Project.

Among all types of the NHA houses under Baan Eua-Arthorn Project, the highest GHG emission from construction materials belongs to condominium (179.06 $kgCO_2 e/m^2$), followed by townhouse (118.73 $kgCO_2e/m^2$), twin house (107.53 $kgCO_2e/m^2$), and detached house (93.21 $kgCO_2e/m^2$), respectively. Concrete, cement and steel are the main hotspots of GHG emissions due to their high consumption per unit area and their GHG emission during material manufacturing.

CHAPTER 7
CONCLUSION

The survey conducted meets the set objective. The socio-economic conditions of the surveyed houses match with those from national census, so that a model house with detailed features and construction could be formed to represent houses of low income earners of Thailand. From the surveyed results on electricity consumption and construction materials identified, carbon dioxide emission from construction materials used ('embedded carbon dioxide') and from occupants' daily activities while occupying the house have been quantified. The investigation on thermal comfort illustrates that rural houses are reasonably comfortable with natural ventilation, at least during the duration of the survey. Present house design and features also allow natural daylight into the interior sufficiently during daytime without the need for electric lighting.

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Thailand Contribution

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