Review of Features of and Energy Use in Medium and Low Income Housings in Thailand

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

Submitted to

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By

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CHAPTER 1

INTRODUCTION

1.1 Thailand's Geography

Thailand is situated at the center of the Indochina peninsula in Southeast Asia between latitudes 5° 37′ N to 20° 27′ N and longitudes 97° 22′ E to 105° 37′ E. Thailand covers an area of 513,119 km^2 and is bordered to the north by Burma and Laos, to the east by Laos and Cambodia, to the south by the Gulf of Thailand and Malaysia, and to the west by the Andaman Sea and the southern extremity of Burma. Thailand stretches 1,650 km from north to south, and from east to west 780 km at its widest point with 2,420 km of coast line on the Gulf of Thailand and the Andaman sea. Figure 1.1 illustrates the geography of Thailand.

Figure 1.1 Geography of Thailand (Source: http://www.silkroadpattaya.com/en/images/stories/geography/geography1.jpg)

According to the climate pattern and meteorological conditions, Thailand can be classified into 5 regions i.e. Northern, Northeastern, Central, Eastern and Southern Parts. The topography of each region is different and can be described as follows:

1.1.1 Northern region

This region comprises with 15 provinces and most areas are mountainous. The hill ridges are oriented north-south parallel from west to east and intersected by a number of major valleys, particularly those near Chiang Mai, Chiang Rai, Lampang and Nan provinces. Along the eastern border with the Northeastern region is mountainous called central highlands. The area in the southern part between the western mountains and the central highlands is a central valley.

1.1.2 Northeastern region

This region is naturally a high level plain called Korat plateau. Northwest-southeast oriented Phu Phan ridge in the northeastern portion separates this part into two basins. One is a large high level plain in the west. The other is smaller and slopes towards the east. This region comprises 19 provinces e.g. Udon Thani, Khon Kaen, Roi Et, Ubon Ratchathani, Nakhon Ratchasima, etc.

1.1.3 Central region

Central region comprises 18 provinces including Bangkok Metropolis. This region is a large low level plain where the Ping, Wang, Yom and Nan Rivers flowing from the north join together to form the Chao Phraya River at Nakhon Sawan province. The region is often called the "rice bowl" of Thailand being the most fertile area of the country.

1.1.4 Eastern region

The south and southwest of the part is adjacent to the Gulf of Thailand. Farther in land, most areas are plains and valleys but there are some small hills in the northern, central and eastern portions. This region is divided into 8 provinces i.e. Nakhon Nayok, Prachin Buri, Sra Kaeo, Chachoeng Sao, Chon Buri, Rayong, Chanthaburi and Trat.

1.1.5 Southern region

The topography of this region is the peninsula between the Andaman Sea which is on the western side of the part and the South China Sea which is on the eastern side. The long ridge of western mountains in the Northern and Central parts also extend to this region. Phuket ridge along the west coast and Nakhon Si Thammarat ridge in the central of lower portion forming the backbone of the Southern Part separate this part into two regions, Southern Thailand East Coast and Southern Thailand West Coast. There are sixteen provinces situated in Southern region of Thailand.

1.2 Climate

The climate of Thailand is under the influence of seasonal monsoon winds: southwest monsoon and northeast monsoon. The southwest monsoon starts in May and brings a stream of warm moist air from the Indian Ocean towards Thailand; causing abundant rain over the country, especially the windward side of the mountains. Rainfall during this period is not only caused by the southwest monsoon but also by the Inter Tropical Convergence Zone (ITCZ) and tropical cyclones which produce a large amount of rainfall. May is the period of first arrival of the ITCZ to the Southern region. It moves northwards rapidly and lies across southern China around June to early July that is the reason of dry spell over upper Thailand. The ITCZ then moves southerly direction to lie over the Northern and Northeastern Parts of Thailand in August and later over the central and southern regions in September and October, respectively.

The northeast monsoon starts in October and brings the cold and dry air from the anticyclone in China mainland over major parts of Thailand, especially the Northern and Northeastern Parts which is higher latitude areas. In the Southern Part, this monsoon causes mild weather and abundant rain along the eastern coast of the part. The onset of monsoons varies to some extent. Southwest monsoon usually starts in mid-May and ends in mid-October while northeast monsoon normally starts in mid-October and ends in mid-February.

1.2.1 Season

Due to the influences of the tropical monsoons and the country's topography, Thailand's seasons are generally categorized into hot season, cool season, and rainy season for the landlocked regions of the central, northern, and northeastern Thailand, whereas the southern and coastal regions feature only two.

a) Cool season or northeast monsoon season (November-February)

Between November and February, the weather is rather cool and dry around the northern and northeastern regions of Thailand. The central region also experiences the cool weather but in a shorter period, perhaps only two or three weeks in late December or early January. The southern region of Thailand really has only two seasons – "rainy" and "dry". The dry season begins in late November and continues onto April or May. The region does not technically experience cool weather, but featuring glorious sunshine without unbearable heat.

b) Hot Season or pre-monsoon season (March-June)

The hot season is the transitional period from the northeast to southwest monsoons and lasts from March to June. The temperature of ambient air begins rising in February and April is the hottest month. Occasional rains are the norm around mid-April due to the unrelenting heat. In the inland areas, this often means punishing heat and high humidity.

c) Rainy Season or southwest monsoon season (July-October)

The rainy season lasts from July to October and is dominated by the southwest monsoon, during which time rainfall is abundant in most of Thailand. The wettest period of the year is August to September. Rains during the reason are more likely to consist of flash-flood afternoon downpours than a continual drizzle for days. Typically, the weather in Thailand is still sunny throughout the rainy season, but when the rain comes, it's fast and it's furious. The exception is found in the Southern Thailand East Coast where abundant rain remains until the end of the year that is the beginning period of the northeast monsoon and November is the wettest month.

1.2.2 Temperature

Upper Thailand i.e. the Northern, Northeastern, Central and Eastern Parts usually experiences a long period of warm weather because of its inland nature and tropical latitude zone. March to May is the hottest period of the year and maximum temperatures usually reach near 40°C or more except along coastal areas where sea breezes will moderate afternoon temperatures. The onset of rainy season also significantly reduces the temperatures from mid-May and they are usually lower than 40°C. In winter the outbreaks of cold air from China occasionally reduce temperatures to fairly low values, especially in the Northern and Northeastern regions where temperatures may decrease to near zero. In the Southern region, temperatures are generally mild throughout the year because of the maritime characteristic of this region. The high temperatures common to upper Thailand are seldom occur. The diurnal and seasonal variations of temperatures are significantly less than those in upper Thailand. Following table shows the statistic records of the temperature in the five regions of Thailand.

Table 1.1 Seasonal temperature (°C) in the five regions of Thailand.

Temperature	Region	Winter	Summer	Rainy
Mean	North	23.1	28.0	27.3
	Northeast	23.9	28.5	27.7
	Central	26.1	29.6	28.3
	East	26.4	28.9	28.1
	South			
	- East coast	26.3	28.1	27.7
	- West coast	26.8	28.3	27.4
Mean maximum	North	30.8	35.8	32.2
	Northeast	30.3	35.0	32.3
	Central	31.7	35.5	32.8
	East	31.7	33.9	32.1
	South			
	- East coast	29.9	32.8	32.1
	- West coast	31.9	34.0	31.4
Mean minimum	North	17.1	21.4	23.7
	Northeast	18.3	23.0	24.2
	Central	21.1	24.6	24.8
	East	21.8	25.0	25.0
	South			
	- East coast	22.0	23.2	23.7
	- West coast	22.9	23.7	24.1

Based on 1971-2000 period

1.2.3 Relative humidity

Thailand is covered by warm and moist air in most periods of the year except the areas farther in land the relative humidity may significantly reduce in winter and summer. In the Southern region where is maritime characteristic the humidity is relatively higher. Table 1.2 shows the statistic records of the relative humidity in the five regions of Thailand.

Table 1.2 Seasonal relative humidity (%) in the five regions of Thailand.

Region	Winter	Summer	Rainy	Annual
North	74	64	81	75
Northeast	69	66	80	73
Central	70	69	79	75
East	71	75	81	76
South				
- East coast	80	77	79	79
- West coast	78	76	84	80

Based on 1971-2000 period

1.2.4 Rainfall

Upper Thailand usually experiences dry weather in winter because of the northeast monsoon which is a main factor that controls the climate of this region. Later period, summer, is characterized by gradually increasing rainfall with thunderstorms. The onset of the southwest monsoon leads to intensive rainfall from mid-May until early October. Rainfall peak is in August or September which some areas are probably flooded. However, dry spells are commonly occur for 1 to 2 weeks or more during June to early July due to the northward movement of the ITCZ to southern China. Rainy season in the Southern Part is different from upper Thailand. Abundant rain occurs during both the southwest and northeast monsoon periods. During the southwest monsoon the Southern Thailand West Coast receives much rainfall and reaches its peak in September. On the contrary, much rainfall in the Southern Thailand East Coast which its peak is in November remains until January of the following year which is the beginning of the northeast monsoon.

According to a general annual rainfall pattern, most areas of the country receive 1,200-1,600 mm a year. Some areas on the windward side, particularly Trat province in the Eastern Part and Ranong province in the Southern Thailand West Coast have more than 4,000 mm a year. Annual rainfall less than 1,200 mm occurs in the leeward side areas which are clearly seen in the central valleys and the uppermost portion of the Southern Part. Table 1.3 shows the statistic records of the seasonal rainfall in the five regions of Thailand.

Table 1.3 Seasonal rainfall (mm) in the five regions of Thailand.

Region	Winter	Summer	Rainy	Annual
North	105.5	182.5	952.1	123
Northeast	71.9	214.2	1,085.8	117
Central	124.4	187.1	903.3	113
East	187.9	250.9	1,417.6	131
South				
- East coast	759.3	249.6	707.3	148
- West coast	445.9	383.7	1,895.7	176

Based on 1971-2000 period

1.2.5 Cloudiness

Cloud cover is normally less from November to March. Perfectly clear skies are generally found that is a reason why extreme temperatures usually occur. Most clouds in this period are high clouds but cumulus and cumulonimbus may be seen on some occasions. During the southwest monsoon, most clouds in the sky are convective clouds. Clear skies are seldom occur in this period except during June which have a few days.

1.2.6 Surface wind

The pattern of surface wind directions is characterized by the monsoon system. The prevailing winds during the northeast monsoon season are mostly north and northeast in upper Thailand and east or northeast in the Southern Part while they are south, southwest and west over the country during the southwest monsoon. In summer, prevailing wind are mostly south, especially in upper Thailand.

1.2.7 Thunderstorms

Thunderstorms in upper Thailand often occur in the period from April to October while those in the Southern Part will occur in March to November. The maximum frequency of thunderstorms in upper Thailand is in May. Convection and the confluence of two different air streams, cold and warm, are the main factor of thunderstorms. The afternoon and evening thunderstorms occur from the convection while the other from the confluence of winds of different airstreams.

1.3 Population and Household

From the latest census in 2010 by National Statistical Office, the population in Thailand has around 65.98 million people. From Table 1.4, the population in 2010 increases 21% from that amount in 1990. Based on the total land area of the country and the population, the population density is about 128.37 people per square kilometer. Based on the data source from the Office of the National Economic and Social Development Board, Office of the Prime minister, the Thai population is expected to reach about 70.65 million people by the year 2025 with declining growth rate. After that the death rate will exceed the birth rate as the population is expected to decrease to 70.62 million people in 2030.

Table 1.4 Census records of population and household in Thailand.

Description	1990	2000	2010
Demography			
Population ('000)	54,548.50	60,916.40	65,981.66
Population share in municipal area (%)	29.4	31.1	44.6
Male to female ratio (per 100 female)	98.5	97.1	96.2
Household			
Number of household ('000)	12,317.80	15,877.20	20,364.33
Member per household	4.4	3.8	3.1
Share of single-member family (%)	5.1	9.4	18.3
House constructed using non-permanent materials (%)	9.4	7.1	0.6
House with hygienic toilet facility (%)	86.1	97.8	99.7
Household using LPG and electricity for cooking (%)	38.9	65.6	75.2

In Thailand, urbanization results the share of population in municipal area increases from 29.4 to 44.6 percent during 1990 and 2010. The units of household have risen from 12.3 million to 20.3 million which is the rate greater than the population growth. This would results from the decrease of the number of people per household. The share of single-member family increases from 5.1 to 18.3 during the period. Due to the good economy of the country, the share of houses constructed using non-permanent materials in 2010 is 0.6%, reducing significantly from 9.4 percent in 1990. Almost 100% of the houses have hygienic toilet facility. In energy point of view, LPG and electricity for cooking have been increasing over the two decades.

Table 1.5 summarizes the population and number of households in 2010 with respect to the five regions. Separate data of Bangkok Metropolis is included in the table. For the whole country, about 29.13 million people live in municipal area; this accounts for 44.15% of the total population. The corresponding units of households are 9.69 million, and the number of member per household is 2.9 in average. For non-municipal area, both people and households are in greater number than that of municipal area. The average number of people per household is 3.4 for non-municipal area and equal to 3.1 for the whole country.

Table 1.5 Thai population and number of households in 2010.

Region		Population	Household	People per private household
Whole country	- Total	65,981,659	20,364,334	3.1
	- Municipal	29,133,829	9,685,388	2.9
	- Non municipal	36,847,830	10,678,946	3.4
Bangkok	- Total	8,305,218	2,869,225	2.7
	- Municipal	8,305,218	2,869,225	2.7
	- Non municipal	-	-	-
Central	- Total	18,183,308	5,920,172	2.9
	- Municipal	8,280,992	2,864,829	2.7
	- Non municipal	9,902,316	3,055,343	3.1
Eastern	- Total	4,372,516	1,445,816	2.9
	- Municipal	2,214,743	794,815	2.7
	- Non municipal	2,157,774	651,000	3.2
Northern	- Total	11,656,040	3,741,291	3.0
	- Municipal	4,038,091	1,397,060	2.8
	- Non municipal	7,617,950	2,344,231	3.2
Northeastern	- Total	18,966,090	5,339,779	3.5
	- Municipal	5,539,352	1,651,944	3.3
	- Non municipal	13,426,738	3,687,835	3.6
Southern	- Total	8,871,002	2,493,867	3.4
	- Municipal	2,970,176	902,329	3.1
	- Non municipal	5,900,826	1,591,538	3.6

There are about 8.3 million people living in Bangkok that shares about 12.6% of the total population. The number of household is 2.8 million units. The corresponding number of people per household is 2.7, the smallest figure for the country.

About 18.2 million people live in central region of Thailand. This figure excludes the people in Bangkok. For central region, the number of people in municipal area is smaller but comparable to that of non-municipal area. The number of people per household is 2.7 identical to that of Bangkok.

Eastern region has smallest number of people among other regions. It presents a distinct characteristic from other regions in which the people in municipal area are larger than non-municipal area.

For the remaining three regions of the north, northeast and south, the people are mainly live in non-municipal area. The member per unit of households are larger than 3.0 for all areas, except municipal area of northern region.

National Statistical Office categorizes Thai's dwellings into detached house, town house, condominium and mansion, flat and apartment, and row house or shop house. Other houses include room in house, boat house and un-defined house. Table 1.6 shows the numbers and shares of each house category obtained from the survey in 2010. The data are segregated into municipal and non-municipal areas. It can be observed that up to 72.3% of the dwellings is detached house while row house comes the second with a share of 11.1%. Remaining types of the dwellings share together about 16.6%.

Table 1.6 Type of dwellings in Thailand.

Type of House	Total		Municipal area		Non-municipal area	
	Household	Percent	Household	Percent	Household	Percent
Detached house	14,728,702	72.3	5,137,336	53.0	9,591,366	89.8
Town house	1,297,664	6.4	954,245	9.9	343,419	3.2
Condominium/Mansion	492,368	2.4	437,601	4.5	54,767	0.5
Flat/Apartment/Hostel	1,408,741	6.9	1,225,992	12.7	182,749	1.7
Row house/Shop house	2,256,145	11.1	1,779,643	18.4	476,501	4.5
Others	180,711	0.9	150,567	1.5	30,143	0.3
Total	**20,364,333**	**100.0**	**9,685,386**	**100.0**	**10,678,947**	**100.0**

In Table 1.7, the materials for house construction are presented for each dwelling type. Nowadays, cement and brick are the major construction materials by which 54.4% of the houses in the country are constructed from these two materials. The cement and brick house also possesses the largest share at 67.9% for municipal area and at 42.3% for non-municipal area.

In Thailand, number of wooden houses (constructed from only wood) is currently comparable with that constructed using wood and cement (or brick) together. The share of wooden house is 22.9% while the wooden and cement house is 21.7%. The houses constructed from non-permanent materials share only 0.6% at the present time.

Table 1.7 Construction materials of dwelling units.

Construction materials	Household	Percent	Type of dwelling				
			Detached house	Town house	Condominium/ Mansion	Flat/Apartment/ Hostel	Row house/Shop house
Total	**20,183,620**	**100.0**	**14,728,702**	**1,297,664**	**492,368**	**1,408,741**	**2,256,145**
Cement or brick	10,976,748	54.4	5,945,502	1,297,664	492,368	1,381,524	1,859,690
Wood	4,631,836	22.9	4,414,406	-	-	11,232	206,198
Wood and cement or brick	4,382,377	21.7	4,176,135	-	-	15,985	190,257
Non-permanent materials	120,030	0.6	120,030	-	-	-	-
Reused materials	16,357	0.1	16,357	-	-	-	-
Others	52,002	0.3	52,002	-	-	-	-
Unknown	4,269	a	4,269	-	-	-	-
Municipal	**9,534,818**	**100.0**	**5,137,336**	**954,245**	**437,601**	**1,225,992**	**1,779,643**
Cement or brick	6,477,561	67.9	2,427,008	954,245	437,601	1,203,663	1,455,045
Wood	1,446,147	15.2	1,264,042	-	-	8,396	173,709
Wood and cement or brick	1,560,472	16.4	1,395,648	-	-	13,934	150,890
Non-permanent materials	22,599	0.2	22,599	-	-	-	-
Reused materials	7,206	0.1	7,206	-	-	-	-
Others	17,362	0.2	17,362	-	-	-	-
Unknown	3,472	a	3,472	-	-	-	-
Non-municipal	**10,648,803**	**100.0**	**9,591,366**	**343,419**	**54,767**	**182,749**	**476,501**
Cement or brick	4,499,187	42.3	3,518,494	343,419	54,767	177,861	404,645
Wood	3,185,690	29.9	3,150,364	-	-	2,836	32,489
Wood and cement or brick	2,821,906	26.5	2,780,488	-	-	2,051	39,367
Non-permanent materials	97,432	0.9	97,432	-	-	-	-
Reused materials	9,151	0.1	9,151	-	-	-	-
Others	34,640	0.3	34,640	-	-	-	-
Unknown	798	a	798	-	-	-	-

1.4 Household Socio-Economic Situation

1.4.1 Household Iincome

The result of the 2011 survey showed that household nationwide earned on average 23,544 baht per month. The major source of income (71.9%) was from economically activities such as wages and salaries (38.7%), followed by net profit from non-farm business (20.4%), and net profit from farming (12.8%). Income from economically inactive was mainly from assistance from other persons outside the household or from government (10.7%), followed by income from asset and property rental such as interest receive (1.9%). The other source of earning was from assistance in terms of welfare/goods and services (13.8%).

Concerning household income by region, it was discovered that households in Bangkok Metropolis and the three provinces nearby, which are Nonthaburi, Pathu Thani, and Samut Prakan, earned on average 43,669 baht, which was higher than other region. The following were households in the South (27,720 baht), in the Central (20,445 baht), and in the Northeast (18,159 baht), whereas households in the North earned the lowest of about 17,247 baht.

1.4.2 Household expenditure

During the 2011 survey, household nationwide spent on average 17,861 baht per month. By this amount, 33.8 percent was mainly spent on food and beverages (of which 0.6 percent was paid for alcoholic drinking), followed by expense on housing and household appliances (20.8%), vehicles and transportation (19.1%), personal supplies/clothing/footwear (6.5%), communication (3.1%), recreation and entertainment and education (1.6-2.0%), and activities related to religious (0.9%). In addition, household had non-consumption expenditure such as expenses on taxes, gifts, insurance (non-accumulative), lottery, and interest payment, which was about 11.6 percent.

1.4.3 Expenditure on energy

A survey in 2011 showed that households in the country had the average total expenditure, of about 17,861 baht per month, with this amount it was on energy of about 1,798 baht or 10.3 percent of the total monthly expenditure. The most expenditure on energy (72.3 percent) was on petroleum products, such as gasoline (28.8 percent), diesel (23.7 percent), gasohol (14.0 percent), the LPG and CNG (3.3 percent). The lowest proportion was biodiesel and other renewable energy (0.8 percent). Apart from this, it was the expenditure on other energy (27.7 percent), with the amount; it was the cost of electricity (25.6 percent) and the charcoal and firewood (2.1 percent).

For the total household expenditure on energy in various regions in 2011, it was found that the households in Bangkok and 3 provinces nearby (Nonthaburi, Pathum Thani and Samut Prakan) spent the highest average energy, about 2,763 baht per month which was 2 times higher than those of households in the Northeast which had the least average expenditure on energy of about 1,395 baht per month, followed by households in the South (2,114 baht), in the central region (1,897 baht) and households in the North (1,422 baht), respectively.

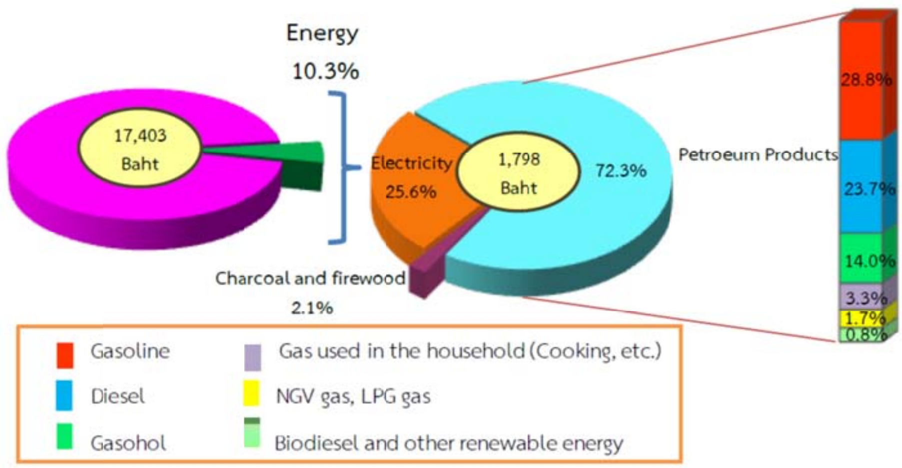


Figure 1.2 Average expenditure of household on energy consumption by type of energy 2011.

Table 1.8 Monthly average of household expenditure on energy in 2011.

Region/items	Whole kingdom	Bangkok and 3 province[1/]	Central	North	Northeast	South
The total expenditure on energy	1,798	2,763	1,897	1,422	1,395	2,114
Gasoline	519	443	536	447	471	792
Diesel	426	424	498	352	366	573
Electricity	460	979	502	328	289	433
Gasohol	252	757	233	167	121	168
NGV,LPG	30	95	38	13	10	23
Gas used in households (Cooking, etc.)	59	49	65	61	53	78
Charcoal and firewood	38	☆[2/]	14	48	76	5
Biodiesel and other alternative energy	14	15	11	6	9	42

1/ Nonthaburi, Pathum Thani and Samut Prakan

2/ negligible amount

When considering the type of energy, it was found that households in Bangkok and 3 provinces (Nonthaburi, Pathum Thani and Samut Prakan) spent on the electricity, gasohol, NGV and LPG higher than households in the other regions. The monthly average cost of electricity, about 979 baht per month, gasohol about 757 baht per month which was 3.4 and 6.3 times of those households in the Northeast, which spent the least on electricity and gasohol (the average monthly expenditure were 289 and 121 baht, respectively)

As for gasoline and diesel, the households in the South had the highest average cost, of about 792 baht and 573 baht per month, respectively, especially fishing and agricultural households, this might be due to the fluctuation of the fuel price. When considering the use of charcoal and firewood, the households in the Northeast had the highest monthly average expenditure, about 76 baht per household, while spending on Biodiesel and other alternative energy had the lowest cost compared to other kinds of energy.

When comparing the cost of energy by households, around the country in 2010 and 2011, it is found that the average monthly cost of energy decreased from 1,818 baht to 1,798 baht or 1.1 percent per year. This might be because of the flood crisis at the end of the year. Especially expenditure on biodiesel and renewable energy decreased by 30.3 percent (from 21 to 14 baht), followed by charcoal and wood decreased by 13.6 percent (from 44 to 38 baht) and electricity decreased by 6.3 percent (from 491 baht to 460 baht). The NGV gas, LPG gas increased by 15.4 percent, which might be caused from the price rise of gas, while gasoline had the least increasing rate, of about 2.8 percent (from 505 to 519 baht).

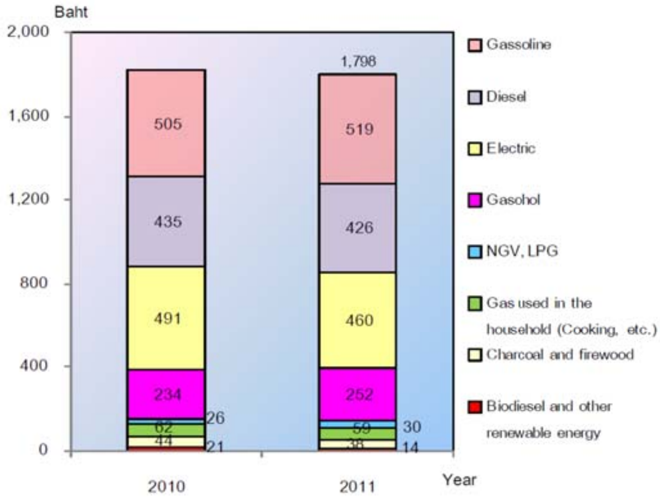


Figure 1.3 Average monthly energy cost of household by energy type between 2010 and 2011.

Comparing, among regions, the cost of energy of household between 2010 and 2011, it was found that households in the South had the increasing rate by 3.0 percent (from 2053 to 2114 baht), followed by those in the Central had the slight increasing rate by 2.0 percent (from 1,894 to 1,897 baht). Households in the North, Bangkok and 3 provinces (Nonthaburi, Pathum Thani and Samut Prakan) had the decreasing rate by 3.0 percent (from 1466 to 1422 baht) by 2.6 percent (from 2,836 to 2,763 baht) and 1.7 percent (from 1419 to 1395 baht), respectively.

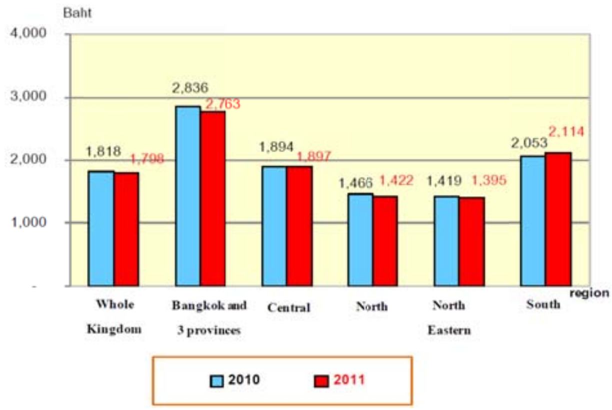


Figure 1.4 Average monthly energy cost of household by region between 2010 and 2011.

When comparing the cost of energy of household by quarter of the year 2010 and 2011, the survey showed that the cost increased from 1st quarter to 2nd quarter. That was the 1st quarter was stepping up from 1,703 baht in 2010 to 1,762 baht in 2011. The 2nd quarter stepped up from 1,768 baht in 2010 to 1,839 baht in 2011, and the cost decreased from the 3rd quarter to the 4th quarter, which was down from 1,921 baht in 2010 to 1,815 baht in 2011. The 4th quarter was dropped from 1,875 baht in 2010 to 1,804 in 2011. This might be caused from the fluctuation of oil price and caused by natural disasters especially at the end of the year 2011. There was severe flood damaging vehicles, although some areas have not flooded, the use of vehicles on the road was still problem. So the cost of energy declined in the 3rd quarter to the 4th quarter.

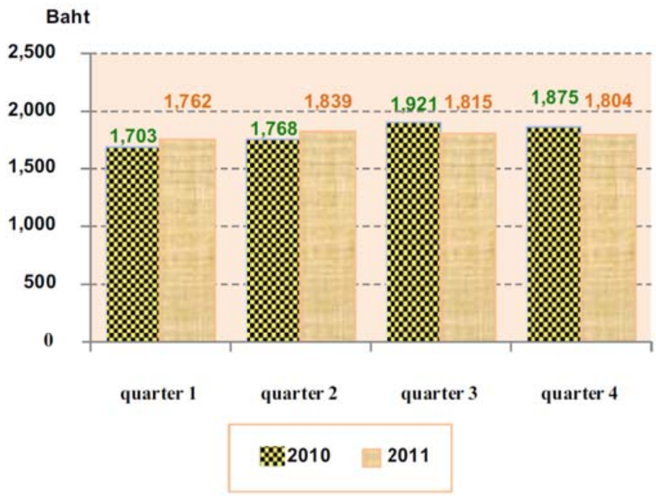


Figure 1.5: Average monthly energy cost of household by quarter of the year 2010 and 2011.

1.5 Scope of Review

In this review, basic informations of Thailand, *i.e.* geography, climate, population, and household socio-economic situation were reviewed above in this chapter for understanding the general background of Thailand. Because low income in each country and report is different, the definition of low income housing in this review was then defined in Chapter 2. In the next Chapters, features of and energy uses in medium and low income housings in Thailand was reviewed.

In Chapter 3, recommended housing designs in each region in Thailand were reviewed. The review was mainly based on the National Housing Authority (NHA), a state enterprise aims to provide housing for low and middle income earners. The rural housings according to NHA in central, north-eastern, northern, and southern regions parts of Thailand were discussed.

In Chapter 4, housing features of each housing design for low and medium income earners, including (1) detached house, (2) town house, (3) row house or shop house, and (4) flat and apartment were reviewed.

In Chapter 5, current energy situation and projection of energy consumption in Thailand were reviewed in the main title of energy uses in residential buildings. In addition, greenhouse gas emission was also included in the review.

In Chapter 6, carbon footprint of housing constructions in Thailand was discussed. Existing ISO standards related to carbon footprint; a publicly available standard (PAS) and greenhouse gas protocol; an assessing greenhouse gas emission at a global level, so called the Intergovernmental Panel on Climate Change (IPCC) guidelines; greenhouse gas accounting tool for construction guideline, and greenhouse gas emission accounting tool for buildings; and emission factor database for calculating carbon footprint of housing, were reviewed. Finally, the literature review on carbon footprint of housing constructions in Thailand was discussed.

References

Bureau of Registration Administration, Department of Local Administration, Ministry of Interior. Population from registration record and dwelling.

Manisarn, V., Lt. Jg. Geography and climatology in every season of various parts in Thailand. Technical No. 551.582-02-1995, ISBN: 974-7567-25-3.

Manisarn, V. Lt. Jg. Statistic of meteorological elements in various parts of Thailand during 30 year period (1961-1990). Technical No. 551.582-03-1995, ISBN: 974- 7567-24-5.

National Statistical Office. Report on the household socio-economic survey 2010 and 2011.

Oldeman L.R. and Frere M. A study of the agroclimatology of the humid tropics of Southeast Asia. FAO/UNESCO/WMO, Inter-Agency on Agroclimatology, Technical Note No. 179, WMO No. 597, Secretariat of the World Meteorological Organization-Geneva-Switzerland, 1982.

Thai Meteorological Department. Climatological data of Thailand for 30 - year period (1961-1990). Meteorological Data Report No. 551.582-02-1994, ISBN: 974-7554-80-1.

CHAPTER 2

DEFINITION OF LOW INCOME HOUSING

2.1 Socio Economy of Thailand

World Bank (2014) has defined the poverty as an income level below some minimum level necessary to meet basic needs. This minimum level is usually called the “poverty line”. The poverty lines vary in time and place, and each country uses lines which are appropriate to its level of development, societal norms and values. In the international standard, the people living on less than $1.25 or 50.98 THB a day are poor (using the international exchange rate in 2005). The World Bank reported the trends of poor people in Thailand as seen in Figure 1 and 2. The numbers of poor people has decreased gradually from 6.5 millions in 1990 to 0.25 millions in 2010. Similarly, the poverty headcount ratio has also decreased from 11.6% in 1990 to 0.4% in 2010. This is an evident that Thai people has better quality of life. In comparison to the poverty of some countries in East Asia and Pacific, the percent population below the international poverty line of Thailand is only 0.4% as shown in Figure 3.

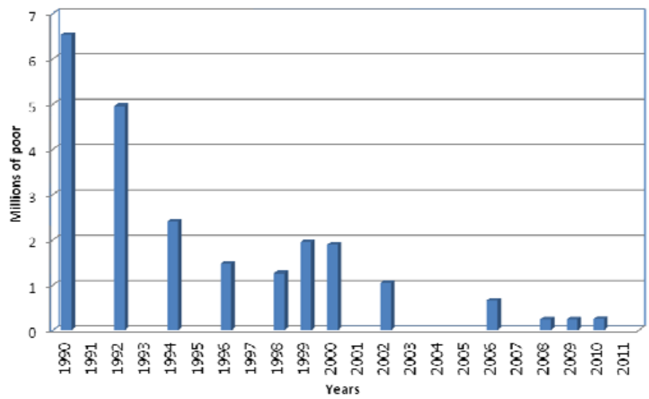


Figure 2.1 The numbers of poor people in Thailand since 1990 (World Bank, 2014).

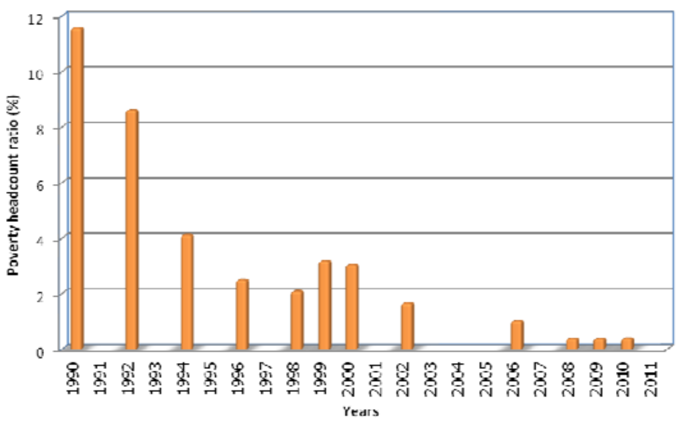


Figure 2.2 The poverty headcount ratio of poor people in Thailand since 1990 (World Bank, 2014).

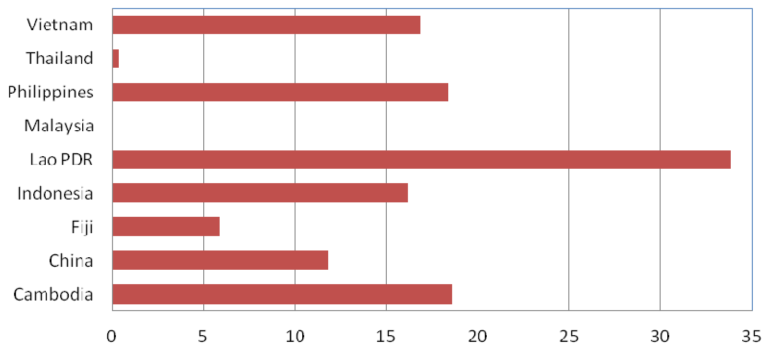


Figure 2.3 Percent population below the poverty line in East Asia and Pacific countries (World Bank, 2014).

In Thailand, the poverty line was obtained from the socio-economic household survey by the Office of the National Economic and Social Development Board as presented in Table 1 (NESDB, 2013). The average Thai poverty line in 2011 was 2,422 THB per capita per month or 2.66 $ per capita per day (30.3 THB = 1$) which was much more than the international poverty line ($ 1.25). The highest poverty line belongs to Bangkok. Among all regions, the central area has the highest poverty line followed by southern, northern and northeastern area. The average percent population below the Thai poverty line (poverty ratio) in 2011 was 13.15% as presented in Table 2. The trends of the poverty ratio decrease approximately 69% from 2000 to 2011. This is a result from the increase of the poverty line as 56% from 2000.

Table 2.1 Thai poverty line by regions from 2000-2011 (NESDB, 2013).

Poverty line (THB/cap/mon)	2000	2002	2004	2006	2007	2008	2009	2010	2011
Bangkok	2,167	2,205	2,315	2,526	2,565	2,677	2,722	2,778	2,910
Central	1,785	1,828	1,955	2,216	2,257	2,395	2,441	2,515	2,617
North	1,381	1,432	1,532	1,736	1,792	1,925	1,974	2,055	2,160
Northeast	1,313	1,346	1,427	1,671	1,741	1,882	1,919	2,020	2,131
South	1,553	1,608	1,737	2,039	2,083	2,226	2,291	2,371	2,500
Average	1,556	1,607	1,721	1,973	2,031	2,170	2,220	2,305	2,422

Table 2.2 Thai poverty ratio by regions from 2000-2011 (NESDB, 2013).

Poverty ratio (%)	2000	2002	2004	2006	2007	2008	2009	2010	2011
Bangkok	5.97	6.49	4.1	3.1	3.55	2.26	2.89	2.43	7.83
Central	29.01	23.55	18.91	14.01	12.92	13.02	12.19	11.26	10.31
North	49.13	41.15	33.36	27.42	26.53	28.68	24.79	22.85	16.04
Northeast	59.54	44.35	39.1	37.4	31.54	31.34	29.29	26.01	18.11
South	42.03	29.43	23.06	21.78	20.72	17.04	18.2	14.77	10.07
Average	42.63	32.64	26.88	23.43	20.94	20.49	19.08	16.91	13.15

The World Bank classifies the country based on the income. The groups are: low income, $1,035 or less; lower middle income, $1,036 - $4,085; upper middle income, $4,086 - $12,615; and high income,$12,616 or more (World Bank, 2014). The average income and average expenditure of Thai people in 2011 are 23,236 and 17,403 THB/ household/ month (Bank of Thailand, 2012). Accordingly, Thailand is classified as upper middle income economy. The income distribution is exhibited in Figure 4. The income is mainly from wage and salary as 72%, followed by services, welfare and property. Figure 5 shows the distribution of Thai expenditure in 2011. The main expenditure of Thai people are 33.6% for food and drinks, 20.4% for housing and 18.9% for transportation.

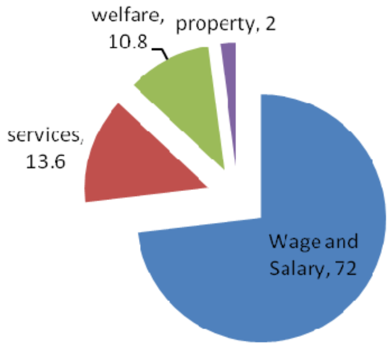


Figure 2.4 The percentages of Thai income distribution in 2011 (Bank of Thailand, 2012).

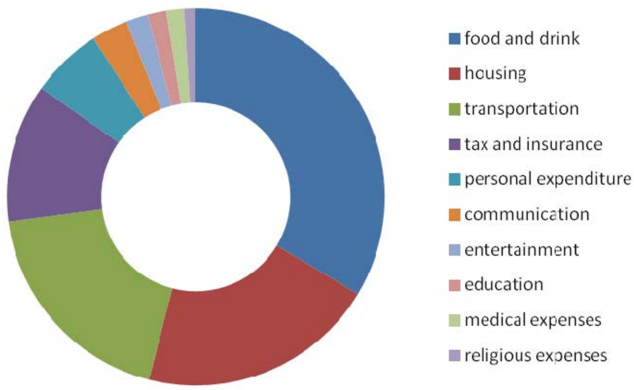


Figure 2.5 The percentages of Thai expenditure distribution in 2011 (Bank of Thailand, 2012).

Different from poverty, the definition of low income in Thailand is quite subjective and ambiguous. The criteria of low income in Thailand are established from different purposes. For example, the Department of Local Administration states that low income people are people who live in urban area and their income are inadequate to afford their needs (DLA, 2006). The occupation defined as low income can be separated in to 2 types: (1) The occupations that generate uncertain income such as labor, temporary worker, freelance *etc.*; and (2) The occupations that generate certain income such as full-time employees, government employees *etc.*

The criteria of low income community provided from the National Housing Authority (NHA) are a community that does not has their own land. The number of households per area is highly populated and their houses look decadent or broken. No basic facilities such as electricity and clean water are provided in the community. And the residents have uncertain occupations such as labor, temporary worker, hawker etc. (UNHabitat, 2008) The low income community was defined when the community meets at least 2 criteria as mentioned above.

2.2 Low Income Housing Provision in Thailand

Low income people in Thailand usually live in apartments, rental-housing compounds, and slums. In 1990, Thailand had a total slum population of 1,763,872, or approximately 3% of the total Thai population. Most of slums were concentrated in Bangkok Metropolitan Region. The remaining 16% were in the other urban centers of the country (UNHabitat, 2008). However, only 18% of slums in Thailand were considered as squatter settlements. Squatters on public lands where are little use and has not been well cared are prevalent. Since 1985, the numbers of slums have decreased gradually by 15% in 2000 due to massive real estate development of formal housing in an open market (UNHabitat, 2008).

The chronological sequence of low-income housing provision has been stared since 1948. After World War II, the government housing bank was established in 1953. During this period, small numbers of national housing units (3,462 units) were built due to high subsidy requirements. In 1996, the first city structural plan for Bangkok proposed the plan for slum clearance, relocation and construction of walk-up department in order to follow the city beautification policy. As a result, 5,120 housing units were built. Nevertheless, the housing applications were as high as 72,192 units, resulting in only 7% of applicants could meet their needs. It was also reported that the government was following the experience of developed countries by building social housing for poor people. This concept was foreign to Thai society at that time. The poor were not familiar with social housing. Additionally, they could not afford the apartment because the apartments were so expensive. Consequently, the housing was over-built and hundred thousand apartment units were unoccupied (UNHabitat, 2008). In late 2002, when the Prime Minister observed the massive construction of social housing in Russian cities, the subsidized housing project called “Ban Uea Athorn” was announced in 2003 . The name “Ban Uea Athorn” means home with care. The aim of this project was to provide affordable homes to low-income people with the target of 600,000 units within 5 years (2003-2007) (UNHabitat, 2008). The 4 different residences were constructed as shown in Figure 6. The first type was condominium. The floor area of the 4th floor and 5th floor condominium was 24 and 33 m^2, respectively. The second type was the 2nd floor detached house with the floor area of 16-24 m^2. The rest are the 2nd floor twin house with the floor area of 16-24 m^2 and the 2nd floor townhouse with the floor area of 16-24 m^2.

Low income people who meet the criteria below can apply for this project.

- Thai nationality and older than 21 years old
- Working or staying in the selected housing area at least 6 months
- No land ownership
- Income less than 30,000 THB/month (for Bangkok, Khon Kaen, Phuket and Udontani province) or income less than 15,000 THB/month for other rural area

Condominium

Twin house

Detached house

Townhouse

Figure 2.6 Types of residences constructed under the Ban Uea Athorn Project (Housing Finance Association, 2005).

According to the report from the Housing Finance Association, 316 subprojects of the Ban Uea Athorn Project were located in Bangkok Metropolitan Area and other cities in rural area as presented in Table 3. The low-income houses were mostly built in Bangkok Metropolitan Area accounting for 64.81%. The total housing units under the Ban Uea Athorn Project were 281,550 units. However, only 96% of total units have been completely constructed and the occupancy rate was 92% (Housing Finance Association, 2005).

Table 2.3 The status of the Ban Uea Athorn Project in 2013 (Monitoring and Evaluation Division, Policy and Planning Department, 2013).

Area	Total			Completed		Under constructed	
	subprojects	units	%	subprojects	units	subprojects	units
Bangkok Metropolitan Area	123	182,481	64.81	118	177,767	5	4,714
Central	16	8,236	2.93	12	6,760	4	1,476
East	49	28,533	10.13	45	27,406	4	1,127
West	13	7,559	2.68	11	6,415	2	1,144
North	38	20,137	7.15	38	20,137	-	-
Northwest	64	25,232	8.96	60	24,427	4	805
South	13	9,372	3.34	9	7,554	4	1,818
Total	316	281,550	100.00	293	270,466	23	11,084

References

Bank of Thailand, 2012, Pra-Siam, online, http://www.bot.or.th/Thai/AboutBOT/Phrasiam/Documents/Phrasiam_4_2555/13.pdf, Feb 11, 2014.

Bank of Thailand, 2013, The quality of growth from dimension of income distribution, online, http://www.bot.or.th/Thai/EconomicConditions/ResearchPublication/symposium/2556/Paper4.pdf, Feb 11, 2014.

Department of Local Administration (DLA), 2006, Standard for housing management for low income people, online, http://www.dla.go.th/work/e_book/eb1/std210550/20/20.htm, Feb 11, 2014.

Housing Finance Association, 2005, Final report of the housing finance funds for low income people: case study "Ban Uea Athorn Project", National Housing Authority.

Monitoring and Evaluation Division, Policy and Planning Department, National Housing Authority, 2013.

National Economic and Social Development Board, 2013, Poverty and Income distribution, online, http://social.nesdb.go.th/social/, Feb 11, 2014.

UNHabitat, 2008, Housing Finance Mechanisms in Thailand, United Nations Human Settlements Program Nairobi.

World Bank, 2014, How we classify country, online, http://data.worldbank.org/about/country- classifications, Feb 10, 2014.

World Bank, 2014, Poverty and Equity, online, http://povertydata.worldbank.org/poverty/region/EAP, Feb 10, 2014.

CHAPTER 3

RECOMMENDED HOUSING DESIGNS IN EACH REGION OF THAILAND

This chapter presents findings obtained from a study under a project of the National Housing Authority (NHA) of Thailand. The NHA, who plays a vital role in improving quality of life and well-being of people, initiated a study on integrated approach rural housing design in response to a continuous and rapid change of rural life-style and socio-economy. The Faculties of Architecture of Khon Kaen University, Rajamangala University of Technology Srivijaya, Silpakorn University, and Rajamangala University of Technology Lanna were assigned to conduct studies aiming at finding suitable housing designs and creating prototypes for rural areas in Thailand. The details shown in this chapter are excerpted from the reports of the studies.

3.1 Rural Housing Design in Central Region

A survey was made during the study in order to understand the ways people are living and working as well as to explore their wisdom and original knowledge. In addition to the findings obtained from the survey, an availability of local construction materials was also set for a condition of a suitable design. The designs can be finalized into 4 patterns as shown in Figure 3.1-3.4. These include Design A, Design A-1, Design A-2 and Design B. Design A shown in Figure 1 is a small residence having a floor area of 79.8 square meters and suitable for 1 – 2 . The construction cost was estimated to be around 490,051 Baht.

Designs A-1 and A-2 are developed from the Design A. Design A-1 has an attachment along its surface adding more space for living area. This design is suitable for upland and plain terrains where is flooded regularly. This pattern takes 173.3 square meters approximately and costs around 896,766 Baht. For Design A-2, the house has an attachment along its vertical to have more space in a basement. This design is suitable for non-flooding plain areas. It takes 108.6 square meters approximately and costs around 870,568 Baht.

Finally, Design B is designed to suite a family with 2 – 6 members. This design takes 129.9 square meters and cost around 721,634 Baht.

Figure 3.1 Perspective of the house type A in central region of Thailand.

Figure 3.2 Perspective of the house type A_1 in central region of Thailand.

Figure 3.3 Perspective of the house type A_2 in central region of Thailand.

Figure 3.4 Perspective of the house type B in central region of Thailand.

3.2 Rural Housing Design in Northeastern Region

In the upper part of north eastern region of Thailand, the so called 'E-San', a pattern of rural housing is transformed throughout its era. Such transformations were gradually developed through social changes and cultural adaptation, which have emerged from the growth and development of infrastructures that have been expanded from city into rural areas. This consequently causes such rapid changes to the Thais who stay in rural area, as well as to their stylistic preference towards rural housing.

As such, the study towards the transformation of rural housing, particularly within the upper part of northeastern, is therefore needed. The study was aimed to develop the rural housing and to design a prototype of rural house which can be retained within today's changing environment. Moreover, it is expected that the outcome will help raise value and enhance socio-cultural environment, which can be further developed towards the local sustainability.

3.2.1 Settlement and context

The geography of Northeastern region is plateau. It is comprised of Korat Basin and Sa-Kon-Nakorn Basin which is considered a dry zone. Each year, this area is lack of water particularly during the summer time. This leads the local community to set up a system for resources management, as well as to specify the area of reserved forest for the community.

The local population is able to live with existing resources within the environment. This becomes a tradition which shows the relationship between nature and rural settlement. However, the settlement in northeastern region is specified according to its context such as: (1) Plateau area is specified as a site for housing; (2) Low land is suitable for rice field; (3) Natural reservoir; and (4) Community reserved forest contains firewood, food, herbs, etc. or is specified as a sacred area (Pa-Pu-Ta) where ancestor shrine (San-Pu-Ta) of the community is located.

3.2.2 Traditional house in northeastern region

The traditional house found in northeastern region can be divided into 3 categories according to its development: (1) Traditional style; (2) Adaptive style; and (3) Present style.

Traditional style

There are evidences confirming that, in the first period of the settlement, the traditional house has a thatch roof and is enclosed with a lattice bamboo wall or banana leaves. The floor is built from a strip bamboo placed on timber structure. This is because these natural materials have light weight, good for natural daylight and ventilation, and can be simply constructed and found nearby the community. Due to the roof drainage, however, the slope of the roof is very steep. The house is normally a single building, without attached shaded-balcony or outdoor terrace. Kitchen area is located within the interior space enclosed with lattice walls. The smoke from the cooker keeps all natural material dry, protects all insects, and can be ventilated through lattice walls.

Adaptive style

When the community is well settled down within its environment, the house is then built into more concrete form. The material is then changed into more solid property such as wooden structure, wooden roof tiles, and so on. By this, the house can be categorized into three types: (1) Terrace house (2) Koei house (House with detached shaded-balcony) (3) Fadd house (Twin gable-roofed house). All mentioned housing styles have detached kitchen area, which completely separates from living or sleeping area. This brings out an importance of service area which is usually located at detached shaded-balcony or shaded-terrace.

Present style

Koei house (House with detached shaded-balcony) becomes the most popular style. After the material is transformed into more solid property, most roofs are then changed to wooden shingle or even new material such as zinc sheets. These new materials affect both appearances and interior spaces of the house. The roof's slope can be less steep and the interior space can be expanded. Also the method of construction becomes easier and faster.

3.2.3 Transformation of traditional house

Community layout and its environment

The community layout is strictly arranged according to tradition and belief of the community. This includes the geography condition, auspicious direction, position of temple, ancestor or sacred area, and community cemetery. However, temple is the most important to be considered because it is a place for gathering community activities. It is usually located at high land or towards the north of the river or the eastern area of the community. Other areas are arranged according to the existing of temple such as cemetery is placed in opposite to the temple and always keep distance with the community.

House layout

While the house and its surrounding are rapidly transformed, there are more functions attached into the spatial layout, such as toilet and bathroom within the house, animal stable is moved out from the ground floor, day-time living area on the ground floor beneath the house. Instead of planning the house's layout or orientation according to the geography or tradition, the layout is arranged according to the road network. There is no homegrown vegetations or fruits, but potted plants for decoration are instead found.

House appearance
Because of the use of new materials, the appearance and proportion of the house is then changed. The uses of concrete stilts lead to higher level of the building, while zinc sheets offer flatter slope for the roof. This includes the use of concrete blocks wall at the ground floor for safety and as an enclosure for storage area.

Activity
Kitchen area is detached from the main building. So the planning of the house is scattered, but still connected each function by using shaded balcony or terrace. This leads to more complex relationship between function and activities. However, the relation between activities and interior spaces are still related to the tradition and belief. Ancestor or sacred area is clearly indicated at the frontal area of the house. At the rear side, the enclosed interior space is usually used as sleeping area for the family. However, the sleeping area of the daughter is separated by using a cupboard or furniture as a wall.

Furthermore, the attached shaded-balcony (Koei or Shia) is built as multi-used space. It is for any activities occurred during day-time. The family rather uses this area which is considered as outdoor space than interior.

Believe and spatial arrangement
The spatial arrangement of the house is firmly related to tradition or belief of the community. The frontal space is indicated as a sacred area or considered as a male space, while the space for female is placed at the rear. Moreover, the sleeping direction is pointed towards ancestor area or Buddha shelf. This includes a position and direction of bedroom or bed area which is arranged according to hierarchy of the family member. For example, the bedroom of the house's owner is placed in the middle, while the male family member's is placed next to the sacred area. The daughter's bed area is located in the proper bedroom, while the female members sleep in front of the daughter's room.

3.2.4 Findings
Settlement and context
Most of the rural communities are expanded family. One whole family setup their houses within the same area, which can be informally linked by small footpath and connected by open spaces. Each household does not clearly define their house area by creating a definite barrier. Instead, the low height-temporal fence is used to define their privacy between each house. This shows such closed social relationship within the community, which is completely different from the city. Within the area of each house, there is a space arranged for storing agriculture tools and equipments, as well as a space for barn and animal stable. The community is normally surrounded by rice field or located next to reservoir or natural water resource.

Built environment and physical condition
Most of the household is expanded family which comprises of 3-5 family members, and can be divided into three generations: (1) Elderly (2) Working age (3) Childhood. Most houses are two-storey with an enclosed ground floor space. However, the house with opened ground floor space or one storey house is also found. Most of the houses are built up to 10-30 years. The oldest and the newest house is 70 and 2 years, respectively. The roof style is mostly gable with a porch. Hip or gable hip is also found. Most houses face its narrow side towards main road (the east or west) and place roof ridge line in parallel to the river.

The estimated construction cost for one house is 100,000 – 400,000 Thai-Baht. This can be obtained from a household income which mostly gained from agriculture work or even from personal loans. Builder is usually the owner, family members, or locals. There is also a house which is hired a non-local contractor or builder who is an outsider. This is because local builder has not got enough skill or the building material cannot be found within the community. However, most of the house can be built by using recycle material such as reused timber from dismantled old house or from their rice field. The period of building one house is around 6-12 months, while some houses take about 2 years to be completed because the owner takes time to collect money.

The traditional house can be divided into 3 styles: (1) Koei (Sleeping house with detached shaded-balcony) (2) House with medium-height stilt (3) Fadd (Twin gable-roofed house). Koei is the most popular style, which has detached kitchen area. Koei and Fadd houses are two-storey house with a set of stilts and an opened ground floor space where most activities take place, whereas house with medium-height stilts is normally retained activities on the upper floor. Most roofs are gable-hip with lean to at attached to the side. The roof direction is mostly place according to both north and south axis, and also east and west axis. Some refers roof ridge according to direction of the river or perpendicular to the river. Moreover, the front of the house is mostly referred to the direction of Buddha shelf or towards north.

Living environment
Today's rural house usually has enclosed living environment, whereas the traditional one would separate service area such as kitchen, toilet, and bathroom from the main building. Even the main staircase of today's rural house is placed within the enclosed ground floor space, while it is attached to outdoor terrace of the traditional one.

Socio-culture within household
According to data collected from a survey, the number of extended family is almost the same number as single family. Most of the extended family is comprised of elders and 1-2 grand children, while single family has 1-3 children. The house for extended family is mostly two storey house with enclosed ground floor space, whereas the single house is generally one storey.

Material and construction
Most of the rural houses is designed and built by local or even the owner. There is no architect or even a construction drawing in the process of building a house. Most houses' structure is post and beam system which is built on-site with a prefabricated construction system. Such prefabricated system can be found in the structure of concrete ground floor and wall within both one and two storey house. The wall is built mostly by using concrete masonry unit or CMU, particularly on the ground floor. While on the upper floor, timber wall is usually applied. Moreover, concrete column is used in most houses, while some timber post with concrete footing is still founded. Most timber structure comes from rice field, dismantled old house, or local construction shop.

Figure 3.5 A small-sized rural house in northeastern region of Thailand.

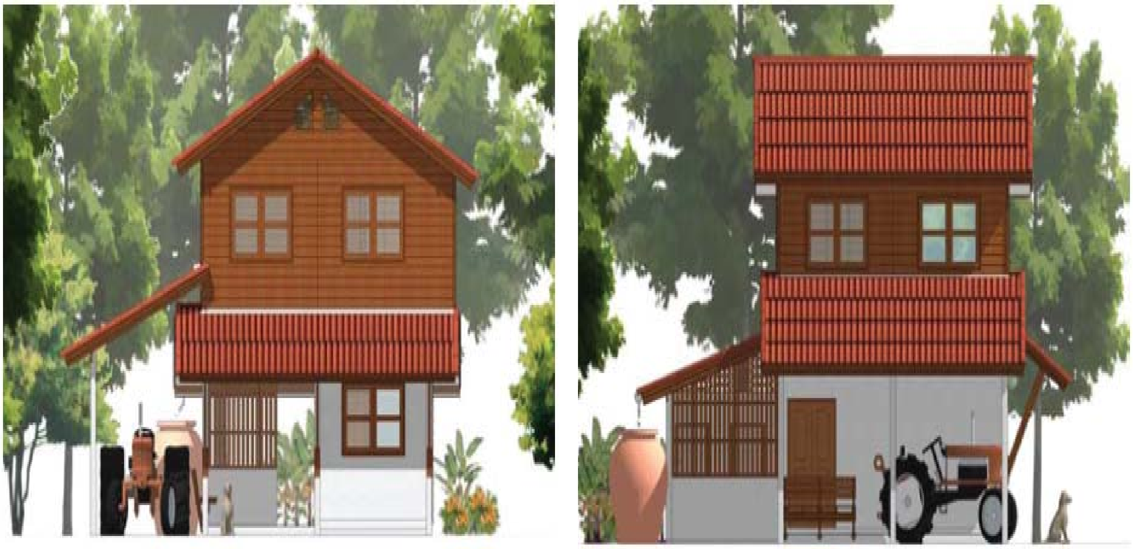


Figure 3.6 A medium-sized rural house northeastern region of Thailand.

3.3 Rural Housing Design of Southern Region

This section review housing design within the area of Songkhla Lake Basin which comprises 3 provinces including Songkhla, Pattalung, and Nakornsrithammarat. The demographic surveys in the Songkhla Lake Basin in 2005 - 2006 showed a total of population in the three provinces of 1,599,986 in which 720,564 are men and 825,319 are women. The densest population is in Hat Yai, Songkhla while the sparsest population is in Krasaesin, Songkhla.

General information about the geography, community, lifestyle, culture and living environment around the Lake Basin are studied. Different housing styles in the past and present are studied as well. The study also focuses on necessary elements, especially building materials and the appropriate technology.

3.3.1 Settlement and habitation

Wooden row houses

Wooden row houses are commonly found along the seashore and canals. Normally, one unit is about 5 meters wide and 20 meters deep but some can be wider or smaller. Most of the wooden row houses share the same roof and wall. In early periods, roofing materials were clay tile transported from Yor Island, galvanized steel and carved tiles. The doorstep, 4 meters wide, is made from dark brown hard wood called "Kheam" and the folding door is locked with a wooden cog.

Wooden single houses

Wooden single houses are found in the old community, especially in the low plain and foothill areas. Houses are usually settled in group and a temple is the center of the community. The pattern of construction is a single house with one gable, two gables, three gables, or no gable. The house is elevated from ground level in order to provide more space to store agricultural equipment or to raise cows which can be commonly found in the area. In addition, in Tha Hin sub district and surrounding areas, houses often have a big courtyard with a water supply tank. Those who make their living from fishery will have houses located near the river bank and have a pier for boarding long-tailed boats.

Concrete and wood house

Concrete and wood house are commonly found along the street. Most of them are approximately 50 years old and the oldest is 110 years old in Yor Island. It has been modified and renovated by using and modern materials.

Modern houses

Modern houses are influenced by original city lifestyles which place importance on convenience and comfortable living. Thus, the styles of house will be various and modern but lack of vernacular identity of Songkhla Lake Basin.

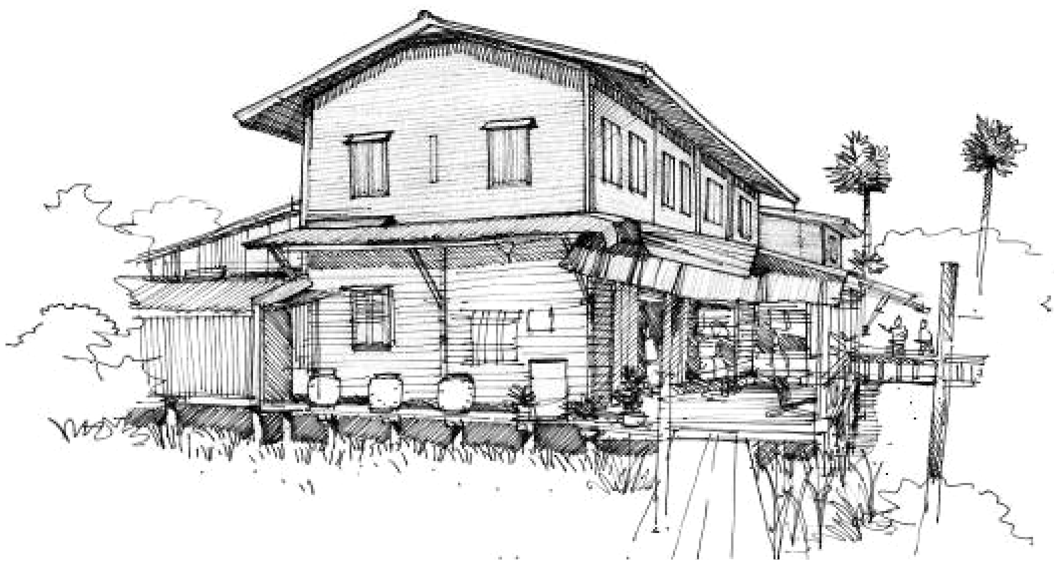


Figure 3.7 A row house on the riverbank in southern region of Thailand.

Figure 3.8 A wooden single house in southern region of Thailand.

Figure 3.9 A concrete and wood house in southern region of Thailand.

Figure 3.10 A modern house in southern region of Thailand.

3.4 Rural Housing Design Northern Region

3.4.1 Identity of vernacular housing in the rural northern

Development of vernacular housing in rural northern house is divided into three generation. Early house over age 50 years, medieval age is 25-50 years, and the present house is less than 20 years. Area-based housing styles in early and medieval houses can be classified in 4 groups.

Group 1: Chiang Rai, Phayao, Nan, Phrae.

This group is commonly found as a single storey wooden house having a high platform and height of about 1.80 m and versatile in use in the daytime. Sometimes, it is used as a store room or bedroom. The roof is mostly a double-gable roof placed in parallel juxtaposition. Roofing materials were found to be wooden or clay shingle and cement tiles. Walls were mostly made of wood.

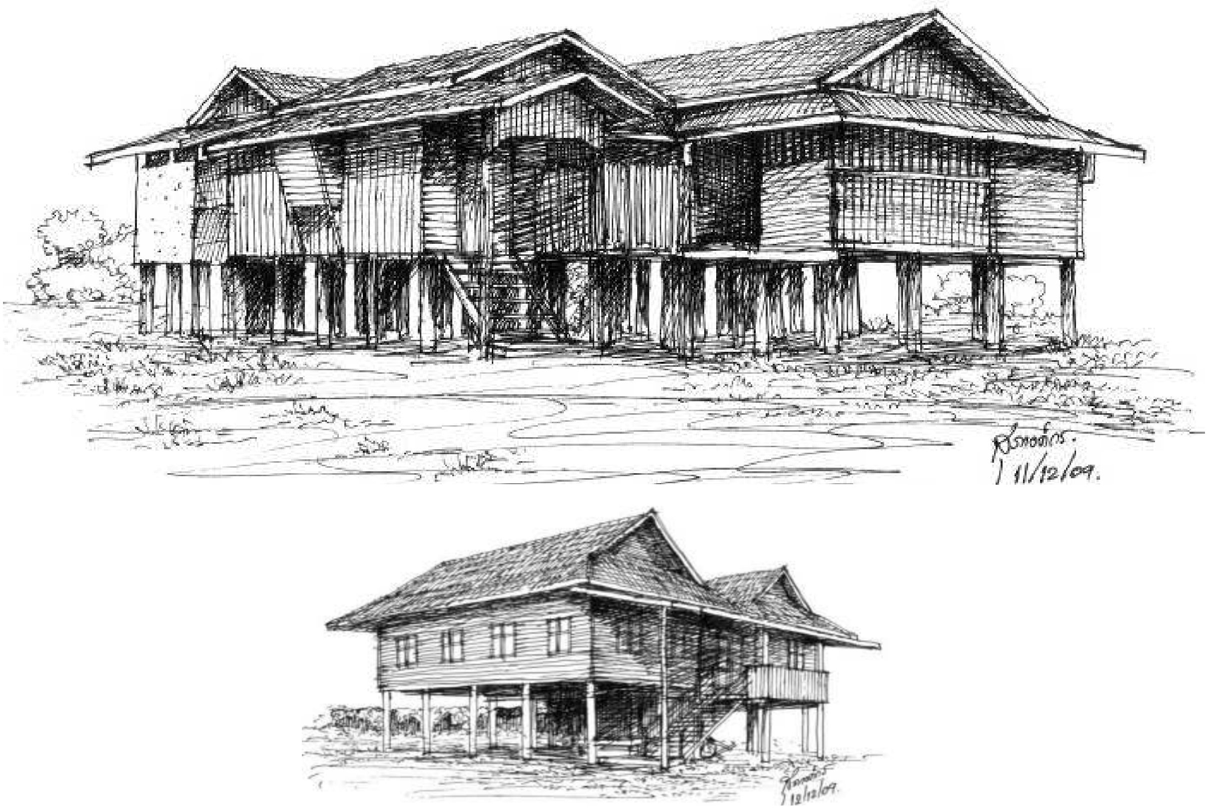


Figure 3.11 Home styles in group 1 in northern region of Thailand.

Group 2: Mae Hong Son, Chiang Mai, Lamphun, and Lampang.

The feature is a single storey wooden raised platform. The roof is gable, hip roof and Manila. Roof is thatched with clay tiles and zinc either with or without ceiling. Some houses are low-raised and some are high A versatile space is used during the day. An open space over a ground level can be ground-filled- compacted and cement surface. Walls are often modern materials such as concrete blocks or bricks. The housing material is often paved with wooden boards aligned. Toilet and kitchen are separated from the house.

Figure 3.12 Home styles in group 2 in northern region of Thailand.

Group 3: Phetchabun, Uttaradit, Phitsanulok, Sukhothai, Tak.
This group is characterized as 2 co-floor house. The windows are small and vents. Area behind the house is rather airy. Roofing material is a tile, cement and zinc sheets. Floors, doors, windows were mostly teak. Space under the house found the raised platforms not very high (approximately 0.90 to 1.20 m). Living space be a storage room, kitchen, bathroom - toilet and versatile space.

Figure 3.13 Home styles in group 3 in northern region of Thailand.

Group 4: Nakhon Sawan, Uthai Thani, Phichit, similarities to the original Thai house.
The hallway is a versatile space including a bedroom and use the stairs outside the house. Found that a bathroom - toilet more and more on housing and found that the kitchen be in the area below.

Figure 3.14 Home styles in group 4 in northern region of Thailand.

3.4.2 Rural house in northern region of Thailand at present
Northern rural lifestyle today affects the architectural style homes. Occupation and income were found most career of locals were the farmers and general contractors. Income ranged from 1,500 to 10,000 baht per month. Thus, the budget for building appropriate rural homes those are in range 200,000-500,000 baht, which are seen that the cost is relatively low due to the low income rural and unpredictable. If dismantled an old house and reconstructed, it may save the material.

Three different patterns of houses are gaining popularity. These are single-story house with floor slab on ground, single story house with raised floor, and 2-story house. The materials and construction methods are modern materials of industrial systems general sales. Due to supply simple, affordable and withstands environment easy to construction such as the roofing materials popularly used roof tiles, Cement paint and zinc. Shell wall of the building one story by many as the pillars finished. All Masonry wall blocks, plastering painted and unpainted depend on the construction budget.

Figure 3.15 A rural house in northern region in present.

Figure 3.16 Space inside the house in northern region of Thailand.

The space inside the house, found the main living area of the house, the house is often a multi-purpose hall, which accounted for most of the total area of the house. It is the center of activities such as watching television and dining, and found that a large central hall is used with the couch because there is good ventilation.

Figure 3.17 A kitchen in northern region of Thailand.

The kitchen is positioned to stay within housing behind for ease of usability. It has a modern house that also not less popular kitchen separate from the house with the reasons of odor and smoke. By housing most 96 percent with the use of gas chambers for convenience, but almost all of them still have charcoal in it but it is unclear how often they are used.

Figure 3.18 A bathroom in northern region of Thailand.

The bathroom is most popular in the house, especially the two-story house. Some may have bathrooms on two floors to ease night-time. The toilet tends to sit flat type, used a water storage system instead of squatting bowl and more. Mostly install for the elderly to use. Found using the showerheads in bath instead of a shower lap more and more often with hot water because cold weather.

Figure 3.19 Convenience and electrical appliances in northern region of Thailand.

For convenience and electrical appliances found that electrical appliances started is a device home. More than 90 percent of homes that are surveyed need to be electricity, washing machines and refrigerators, television sets have almost every house and some have more than one machine. It is interesting locals are still using electricity at a lower rate than people in the city.

References

Faculty of Architecture, Khon Kaen University, 2010, An Integrated Approach on Rural Housing Design in North-eastern of Thailand.

Faculty of Architecture, Rajamangala University of Technology Srivijaya, 2010, An Integrated Approach on Rural Housing Design in Southern Region of Thailand.

Faculty of Architecture, Silpakorn University, 2010, An Integrated Approach on Rural Housing Design in Central Region of Thailand.

Faculty of Art and Architecture, Rajamangala University of Technology Lanna, 2010, An Integrated Approach on Rural Housing Design in Northern Region of Thailand.

CHAPTER 4

HOUSING FEATURES OF EACH HOUSING DESIGN FOR LOW AND MEDIUM INCOME EARNERS

4.1 Current Situation of Thai Population and Housing

Thailand completed the demographic transition from high birth rates and high death rates to low birth rates and low death rates. The transition results in a very low population growth. Population increases in most large cities has been due to migration. More than 36% of Thai peoples live in urban areas. Average household size is 3.5 persons and the average room per household is 2.8 rooms per household.

The typical Thai dwelling is a detached house made of permanent materials supplied with tap water, electricity, and sewage disposal on dweller owned land. About 73% of Thai households own their own dwellings, while approximately 9% live in mortgaged homes and 11% rent. The remaining 5% of households live in rent-free accommodations and 1% pay in-kind for their rental housing. In most cases, Thai people live in detached dwellings (80%). Other types of dwellings include townhouses, apartments and flats, condominiums and row houses. About 94% of dwellings are made of permanent materials; cement or brick 28%, wood and cement or brick 20%, and other hybrid permanent materials 48%. Basic infrastructure is available to more than 95% of households in Thailand. Electricity, water, roads, and septic tanks are widely available in Thailand. The Provincial Electricity Authority provides households with solar electricity until their utilities are constructed.

During the past 10 years or so, most rural districts have been provided potable tap water from wells or other sources. The Thai military and police construction crews provide roadways in remote areas, many of them rolled laterite or asphalt. Concrete materials especially designed for septic tanks are also available nationwide. In many areas, a toilet can be built for about THB 2,000. Local districts often require a proper toilet for house registration. About 97% of households have flush-toilets, squat-toilets or flushing squat-toilets. Water, electricity, and sewage (septic tanks) are installed and used in more than 95% of households. Most households (47%) obtain piped-water from taps. Other households use wells (44%) or rainwater (2%). A small number of households (5%) use other sources like lakes, streams, and waterfalls. Cooking is usually done with gas (57%), or charcoal and wood (33%). Most households (91%) have televisions and 74% of households have refrigerators while 91% have fans. About 16% of households have some type of agricultural equipment and machinery.

Housing stock is difficult to estimate in Thailand. Currently, approximately 18 million dwellings are registered according to the Department of Local Administration records. The number of the households is around 20 million, the housing stock should equal the number of households. Its 63 million people (18 million households) occupy about 20 million dwellings in four major regions. Thus, there is no significant housing backlog and very few street people. Housing sector offers a wide range of types of dwellings in all locations in major urban areas and rural areas throughout the country. Our ecological organization in urban areas is mainly mixed and multi-use urban areas. In terms of providing housing for the lower income households, we may face land shortages due to increased prices of land in urban centers and the need to provide transportation from places of employment to places of residence.

4.2 The NHA and Its Contribution to Low and Medium Income Housing

As reviewed in the previous chapter, established in 1973, the National Housing Authority (NHA) is a state enterprise attached to the Ministry of Social Development and Human Security, Thailand. Under the National Housing Authority Act (B.E. 2537), it currently operates with the objectives to provide housing for low and middle income earners, and to upgrade, demolish or relocate slums in order to assist people in achieving better living, social and economic conditions.

According to the mentioned objectives, NHA have constructed different types of dwellings and improved many slums through a number of projects. Over the past thirty eight years, all construction and improvement activities totaled 685,816 units were completed by September 2011. Three project categories contribute significantly to housing for low and medium income earners that are:

a) Community housing projects
This project category is established on rental and hire-purchased basis for low-income people who want to own a house. These projects are built for home ownership. There are several types of dwelling built including detached, semi-detached, row house, and sites and services with the total of 141,465 units.

b) Projects to solve housing problems for the low-income (Baan Eua-Arthorn Project)
Under this project, NHA developed standardized housing for low-income households, government officials, and junior civil servants at an affordable price. The operational plan targeted urban areas throughout the country and required NHA to build 601,727 units during the five years from 2003 to 2007. This target was in response to housing needs of households with monthly incomes were less than 15,000 Baht per month. At present, households with incomes up to 40,000 Baht per month may purchase a unit. In total, 253,164 units were built.

c) Slum improvement
To improve the quality of life of the low-income households, NHA carried out Improvements on the existing land by improving the physical environment, and providing basic services in existing communities with minimal adjustments to layouts or plot sizes. Resettlement assisted was made for those who were affected by fire, evictions, and land expropriation. Land sharing occurred when NHA was able to negotiate with land-owners so that the community could share a portion of the land. The community's portion of the land is either leased or sold to the community. Some 233,964 households were assisted in this way.

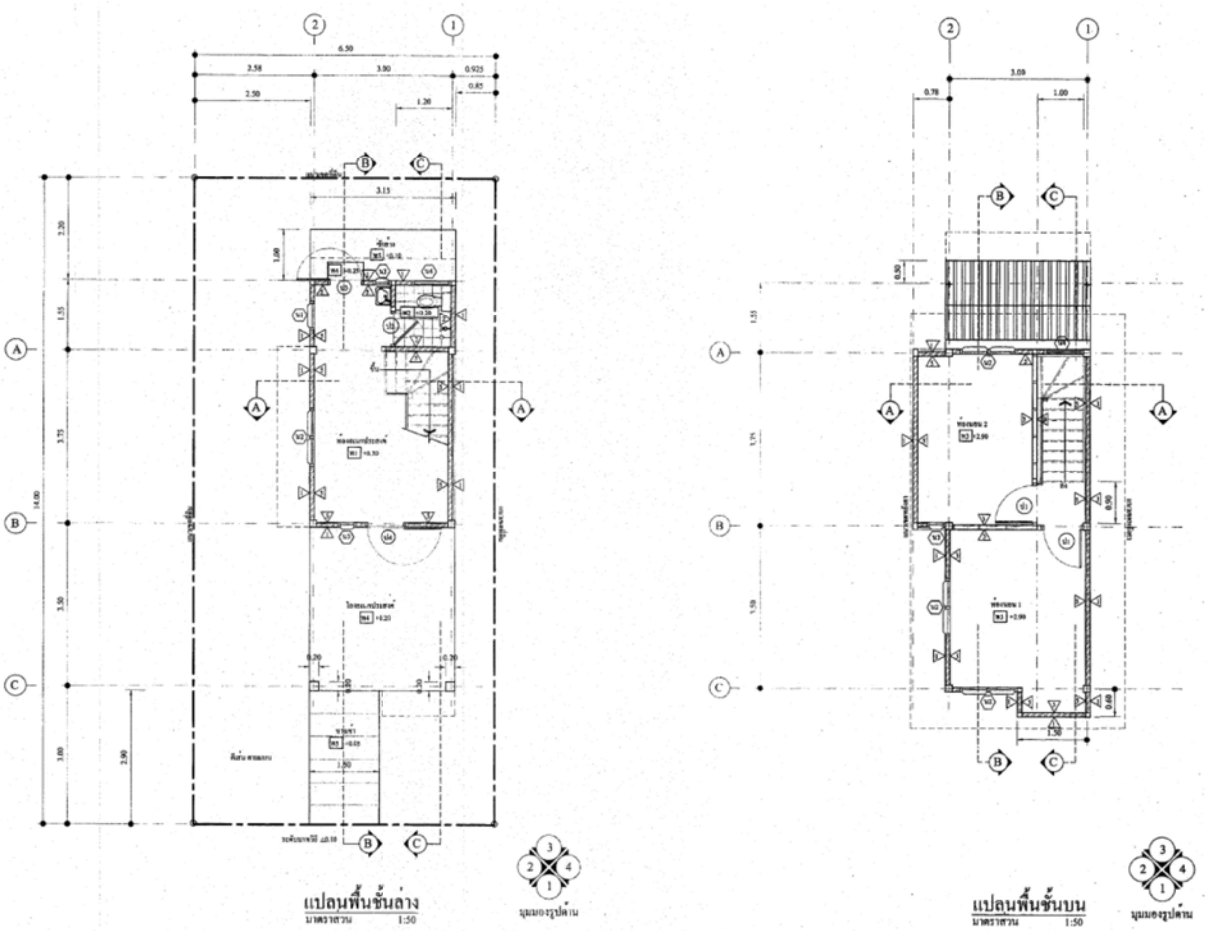
4.3 Standardized Low and Medium Income Houses

Through the project implementations, NHA developed the standardized houses for detached house, town house, row house, and apartment for low and medium income earners. Descriptions of the four houses are provided in this section. Some drawings are also given to illustrate the overall configurations of the houses.

a) Detached house
Figure 4.1 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 ground floor and the first floor are 2.6 m. and 2.75 m., respectively. The height from ceiling

level to the apex of the gable roof is 1.2 m. The ground floor comprises multi-function room and rest room. There are two bedrooms on the first floor. Cloth washing area is provided at the back of the house. Figure 4.2 illustrates the side views of the detached house. The key parameters of the configuration of the detached house can be given as follow:

Utilization area	40.575	m^2
Multiple-purpose room area	13.05	m^2
Bedroom area	25.20	m^2 (2 rooms)
Restroom area	2.325	m^2
Wall area	88.89	m^2
Aperture area	9.60	m^2



(a) First floor (b) Second floor

Figure 4.1 Floor plans of the NHA detached house for low and medium income earners.

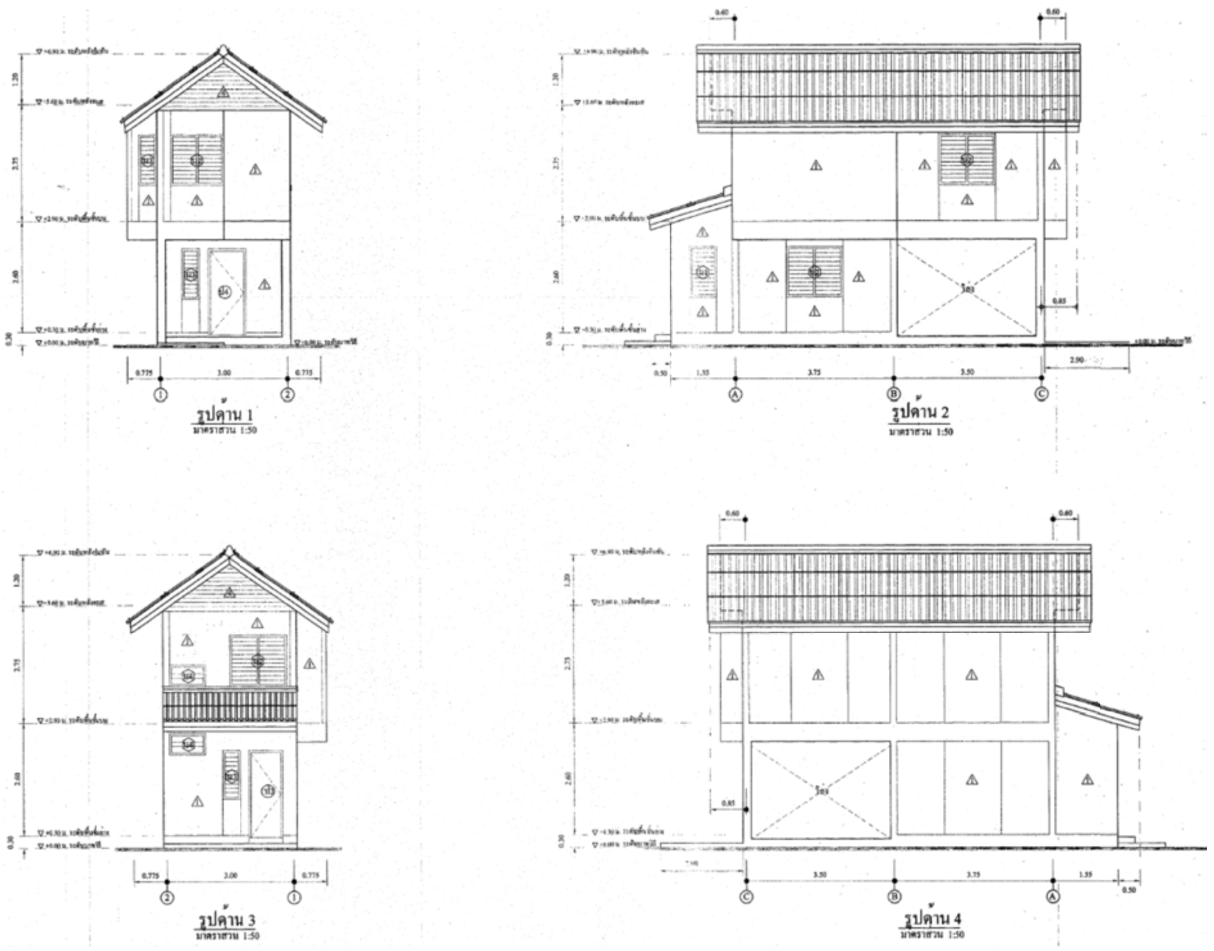


Figure 4.2 Side plans of the NHA detached house for low and medium income earners.

According to the Building Control Act B.E. 2522, a house to be constructed or to be in major renovation are required to make permission with the district office at which the house is located. The drawings of the house have to be submitted for evaluation of its compliance with the code requirements. Table 4.1 summarizes the code requirements for detached house in comparison with the NHA house features.

Table 4.1 Building code requirements for a detached house in comparison with the standard NHA detached house.

Description	**Code requirement**	**NHA house**
Ground floor level	The floor of the first story shall be constructed by using concrete or brick and lifted up at least 0.3 m. from main road level. For a house further away from main road, the floor level shall be at least 0.1 m. above the level of the house base.	The floor level of the first story is 0.3 m. above the outdoor ground.
Utilization area	Utilization area shall be at least 20 m^2.	Utilization area is about 40 m^2.
Bedroom	The width of bedroom shall be exceeding 2.5 m. and the area shall be at least 8 square meters.	There are 2 bedrooms. The main bedroom has dimension of 3.75 x 3.92 m. and the second bedroom has dimension of 3.0 x 3.5 m.
Kitchen	For indoor kitchen that one wall is common with a wall of a rest room, any doors, windows, and apertures are not allowed for that wall. Floor and wall	No indoor kitchen

Description	Code requirement	NHA house
	materials shall be fire-refractory.	
Terrace	The width of terrace shall be at least 1 m. The terrace shall protrude from house not more than 1.2 m. The leading side shall be far from the land border at least 3 m.	No terrace
Corridor	The width of corridor shall be at least 1 m. Daylight shall be provided sufficiently for illumination during daytime.	The width of corridor is 1 m.
Rest room	A house shall have at least 1 rest room and 1 closet. A house with separate rest room and toilet room, each room shall have area at least 0.9 m^2. For rest room with closet, its area shall be at least 1.5 m^2. Floor-to-ceiling height shall be at least 2 m. Aperture with area at least 10% of the floor area shall be provided for ventilation, or a fan shall be provided for sufficient ventilation.	Dimension of the rest room is 1.55 x 1.5 m.
Door, window, clearstory	The areas of doors, windows and apertures altogether shall be more than 10% of the floor area of the room. The door height shall be at least 2 m.	Each door has its dimension of 0.9 m. width and 2 m. height. Dimension of window is 1.5 x 1.5 m. with glazing slats.
Floor-to-floor height	For residential room, the floor-to-floor height shall be at least 2.6 m.	For the first story, the floor-to-floor height is 2.6 m, and that of the upper floors is 2.75 m.
Roof	Roof shall be made using materials enduring with fire. This requirement is except for a house located far away from other houses its roofs made using fire-refractory materials	Roof is constructed with cement roof tile with size 0.54 x 1.2 m. and thick 5 mm. Ceiling is built using 9 mm. thick gypsum board
Construction materials	Decorative materials for exterior walls or materials used as exterior walls shall be held tightly with house structures so that they do not fall and cause any danger or damage. The light reflectance of the exterior wall surfaces shall not be exceeding 30%. Materials for indoor use shall be without any volatile matters danger to health e.g. rock wool, silica, or glass wool except the materials can be protected from spread by protective sheet.	Building walls is brick layer with mortar plastering on both sides. For rest room, the interior wall surfaces are covered with ceramic tile. The gGround floor is polished cement floor. The upper floor is covered with 1.6mm thick PVC-rubber tile.
Ventilation	For a room with natural ventilation, the ventilation shall be provided by which the areas of doors, windows, and apertures altogether must be greater than 10% of the floor area of the room. For mechanical ventilation, the ventilation rate must be complied with the ventilation code.	-
Lighting	Illumination - family room 100 lux - rest room 100 lux - walking area 100 lux - car park 50 lux	-

b) Town house

Town house is the residential buildings that two houses 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 also has its own entrance and exit door.

Figure 4.3 shows the floor plans of the town house for low and medium income earners developed by NHA. The town house has its plot area of 6.75 x 3.4 m. The height of the first story is 2.6 m. The second story height is 2.6 m. The level from ceiling to the apex of the gable roof is 1.95 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 second story, there are two bedrooms. Figure 4.4 shows the side plans of the town house. The key parameters of the configuration of the town house can be given as follow:

Utilization area	45.9	m^2
Multiple-purpose room area	33.585	m^2
Bedroom area	9.69	m^2
Restroom area	2.625	m^2
Wall area	55.61	m^2
Aperture area	11.25	m^2

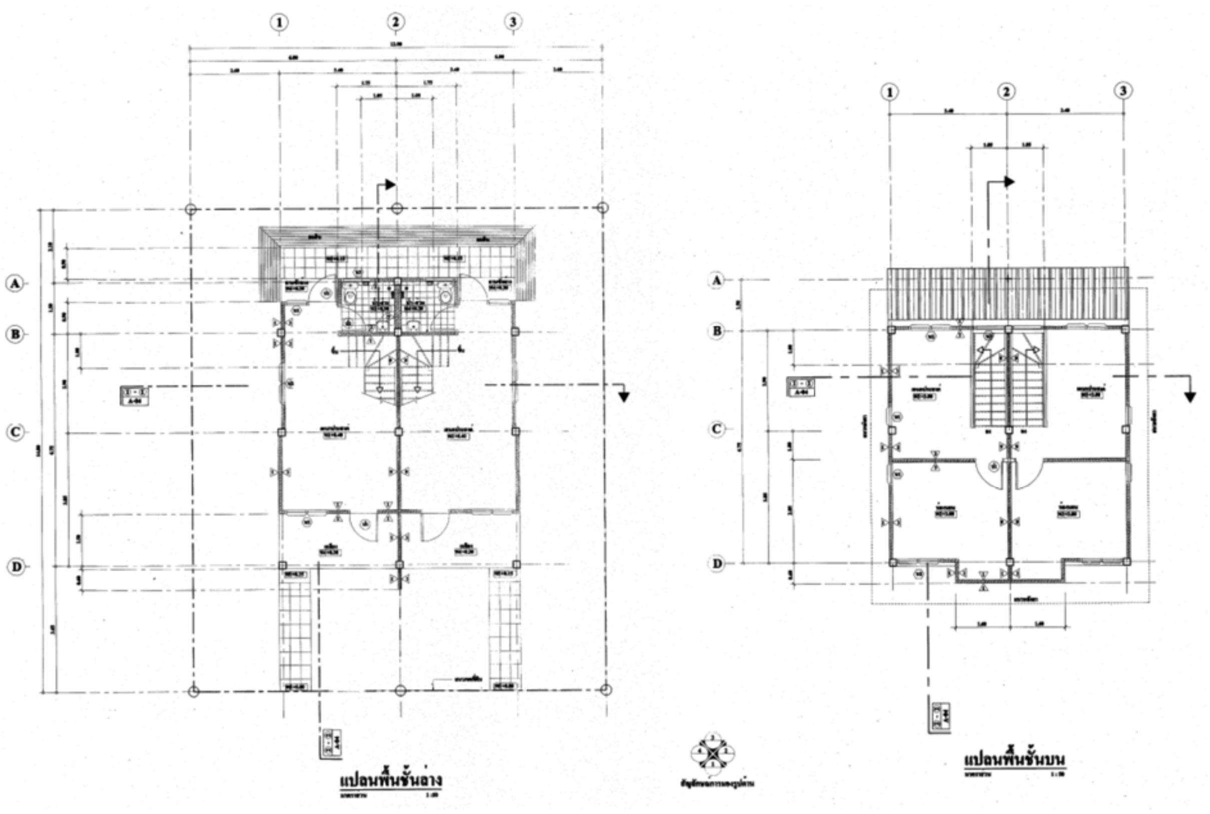


Figure 4.3 Floor plans of the NHA town house for low and medium income earners.

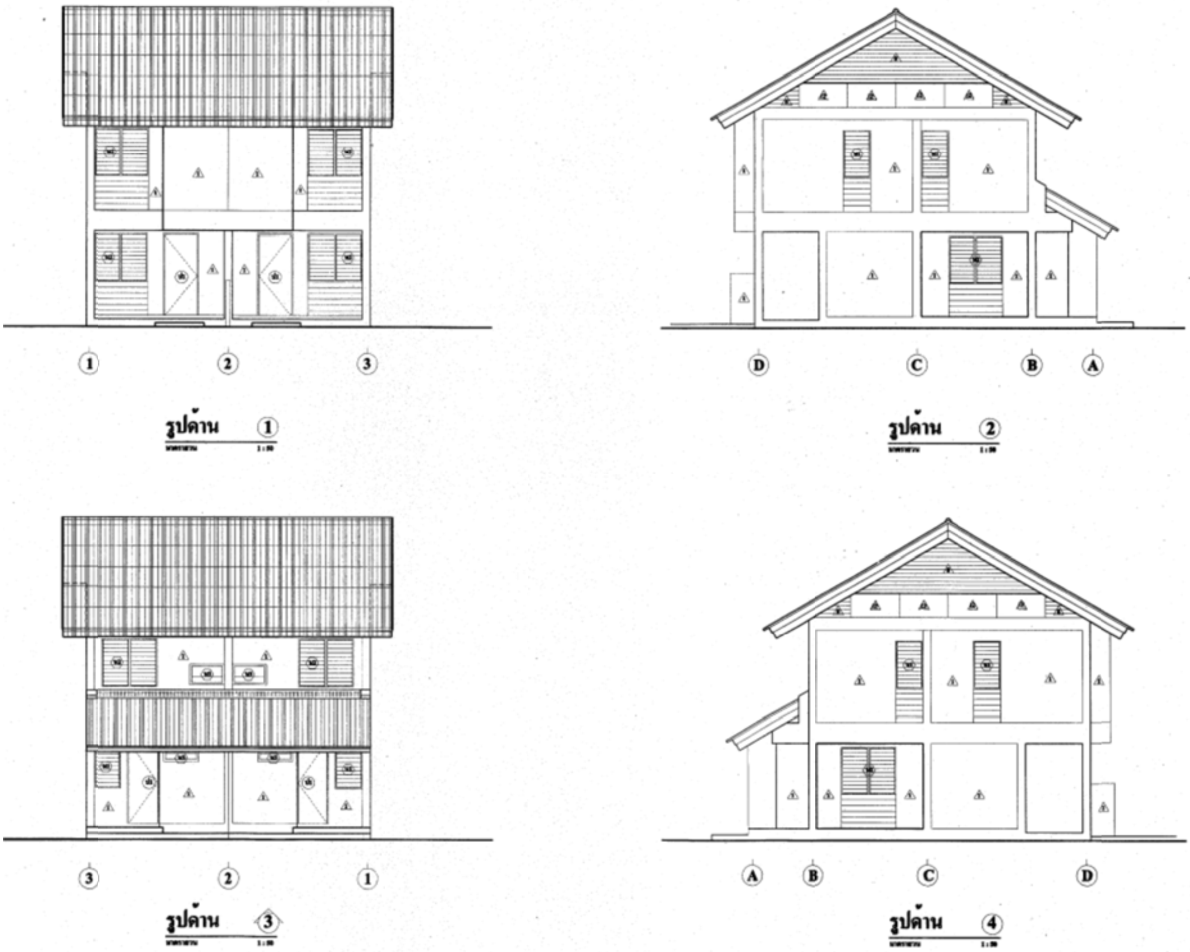


Figure 4.4 Side plans of the NHA town house for low and medium income earners.

Following tables summarized the code requirements for town house in comparison with the town house constructed by the NHA.

Table 4.2 Building code requirements for a town house in comparison with the standard NHA town house.

Description	Code requirement	NHA Town house
Ground floor level	Same as detached house.	The floor level of the first story is 0.4 m. above the building base level.
Utilization area	Each housing units shall have the utilization area at least 20 m^2.	Utilization area is about 45 m^2.
Bed room	Same as detached house.	There is one bedroom with the dimension of 2.85 x 3.4 m.
Kitchen	Same as detached house.	No indoor kitchen
Terrace	Same as detached house.	No terrace
Corridor	Same as detached house.	The width of corridor is 1 m.
Rest room	Same as detached house.	The dimension of the rest room is 1.50 x 1.75 m.
Door, window, clearstory	The areas of doors, windows and apertures altogether shall be more than 10% of the floor area of the room. The door height shall be at least 2 m. For building not higher than 9 m., the building shall be far away from the land border at least 2 m.	Each door has the dimension of 0.9 m. width and 2 m. height. Dimension of window is 1.5 x 1.5 m. with glazing slats.

Description	Code requirement	NHA Town house
	For building higher than 9 m. but lower than 23 m., the building shall be far away from the land border at least 3 m.	
Floor-to-floor height	For residential room, the floor-to-floor height shall be at least 2.6 m.	The floor-to-floor height is 2.6 m.
Roof	Same as detached house.	Roof is constructed with cement roof tile with size 0.54 x 1.2 m. and thick 5 mm. Ceiling is built using 9 mm. thk. gypsum board
Construction materials	Same as detached house.	Building walls is brick layer with mortar plastering on both sides. For restroom, the interior surfaces of the wall are covered with ceramic tile. Ground floor is polished cement floor. The upper floor is covered with 1.6mm thick PVC-rubber tile.
Ventilation	Same as detached house.	-
Lighting	Same as detached house.	-

c) Row house or shop house

Row house is the residential buildings comprising a series of separated house each of which shares together common side walls. The row house can have the maximum 3 stories.

Figure 4.5 shows the floor plans of the row house 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 key parameters of the configuration of the row house can be given as follow:

Utilization area	47.60	m^2
Multiple-purpose room area	28.13	m^2
Bedroom area	17.00	m^2 (2 rooms)
Restroom area	2.48	m^2
Wall area	59.26	m^2
Ventilation area	10.13	m^2

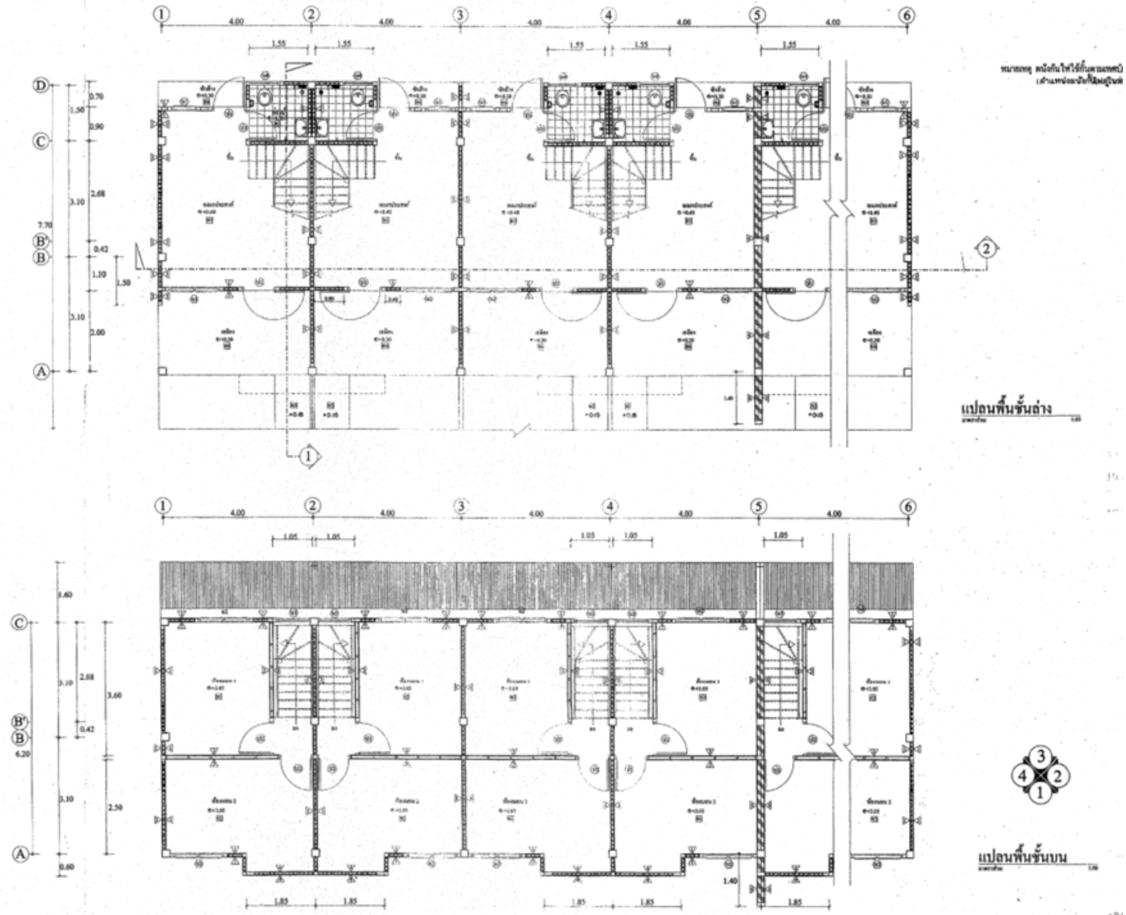


Figure 4.5 Floor plans of the NHA row house for low and medium income earners.

Figure 4.6 Side plans of the NHA row house for low and medium income earners.

Following tables summarized the code requirements for row house in comparison with the row house constructed by the NHA.

Table 4.3 Building code requirements for a row house in comparison with the standard NHA row house.

Description	Code requirement	NHA row house
Building configurations	The building width shall be at least 4.0 m. The building depth shall be at least 4.0 m. but not more than 24.0 m.	The house has its plot area of 7.7 x 4.0 m. The ground floor height is 2.65 m. The first 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 ground floor 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.
Utilization area	The utilization area of each separate house shall be at least 24.0 square meters	Each separate house has 45.0 square meters
Distance between building block	For row house building with less than 10 consecutive houses or the building its length less than 40 m, the building block shall be departed from other building with a distance at least 4.0 m.	-
Ground floor level	The ground floor level shall be at least 0.25 m. above main road level or at least 0.10 m. above pedestrian walkway.	The ground floor level is 0.4 m. above building base level.
Bedroom	Same as detached house.	There are two bedrooms: one with dimension of 3.6 x 3 m. and the other one with dimension of 2.5 x 4 m.
Kitchen	Same as detached house.	No indoor kitchen
Terrace	The width of terrace shall be at least 1 m. The floor-to-ceiling height shall be at least 2.2 m. The terrace shall be far from the land border at least 2 m. for row house with its building height not exceeding 9 m. and at least 3 m. for those with the height exceeding 9 m. but lower than 23 m.	No terrace
Corridor	Same as detached house.	The width of corridor is 1.05 m.
Rest room	Same as detached house.	Dimension of the rest room is 1.55 x 1.60 m.
Wall	Wall shall be constructed with permanent material and can resist fire for at least 8 hours	
Refractory wall	Row house building with more than 5 houses shall provide fire-refractory wall consisted of brick layer at least 0.18 m. or reinforce concrete at least 0.12 m. The refractory wall shall not have any openings through which fire or fire-smoke can pass. The refractory wall shall be constructed from floor level extended through 0.3 m. above roof.	-
Door, window, clearstory	Same as town house.	Each door has its dimension of 0.9 m. Width and 2 m. Height. Dimension of window is 1.5 x 1.5 m. with glazing slats.
Floor-to-floor	The floor-to-floor height of the first story	The floor-to-floor height for every stories

Description	Code requirement	NHA row house
height	shall be at least 3.25 m. The height of the second and third stories shall be at least 3.0 m.	is 2.6 m.
Roof	Same as detached house.	Roof is constructed with cement roof tile with size 0.54 x 1.2 m. and thick 5 mm. Ceiling is built using 9 mm. thick gypsum board
Ventilation	Same as detached house.	-
Lighting	Same as detached house.	-

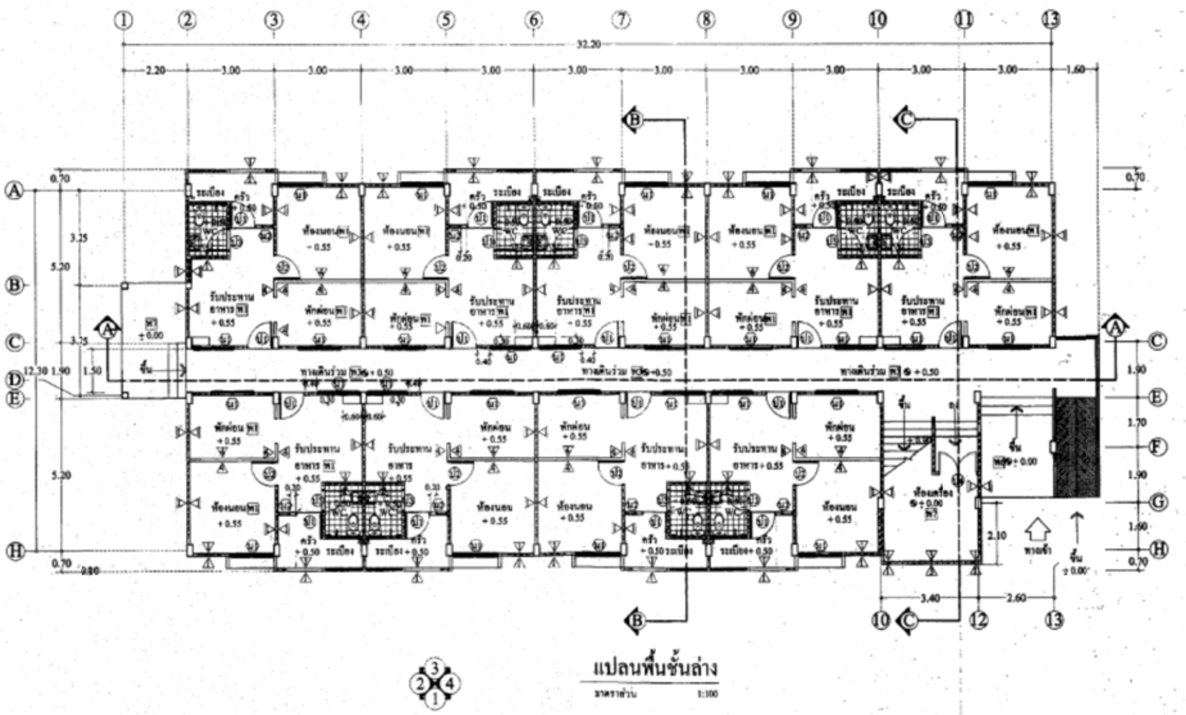
d) Flat and Apartment

Flat and apartment is a self-contained housing unit (a type of residential real estate) that occupies only part of a building. The apartment 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.

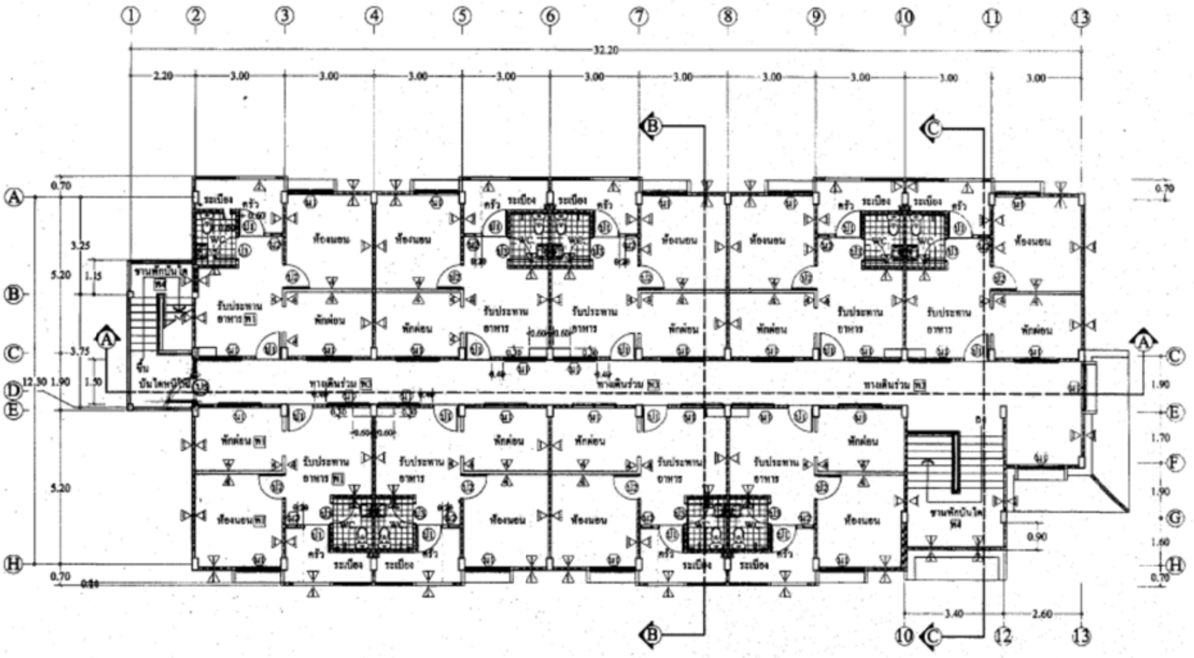
Figure 4.7 shows the floor plans of the NHA apartment for low and medium income earners but only the first floor level and the fifth floor level. Figure 4.8 shows the side plans of the NHA apartment.

The key parameters of the configuration of each room unit in the apartment can be given as follow:

Utilization area	31.20	m^2
Multiple-purpose room area	18.45	m^2
Bedroom area	9.75	m^2
Restroom area	3.00	m^2
Wall area	26.86	m^2
Ventilation area	7.05	m^2



(a) First floor



(b) Fifth floor

Figure 4.7 Floor plans of the NHA apartment for low and medium income earners.

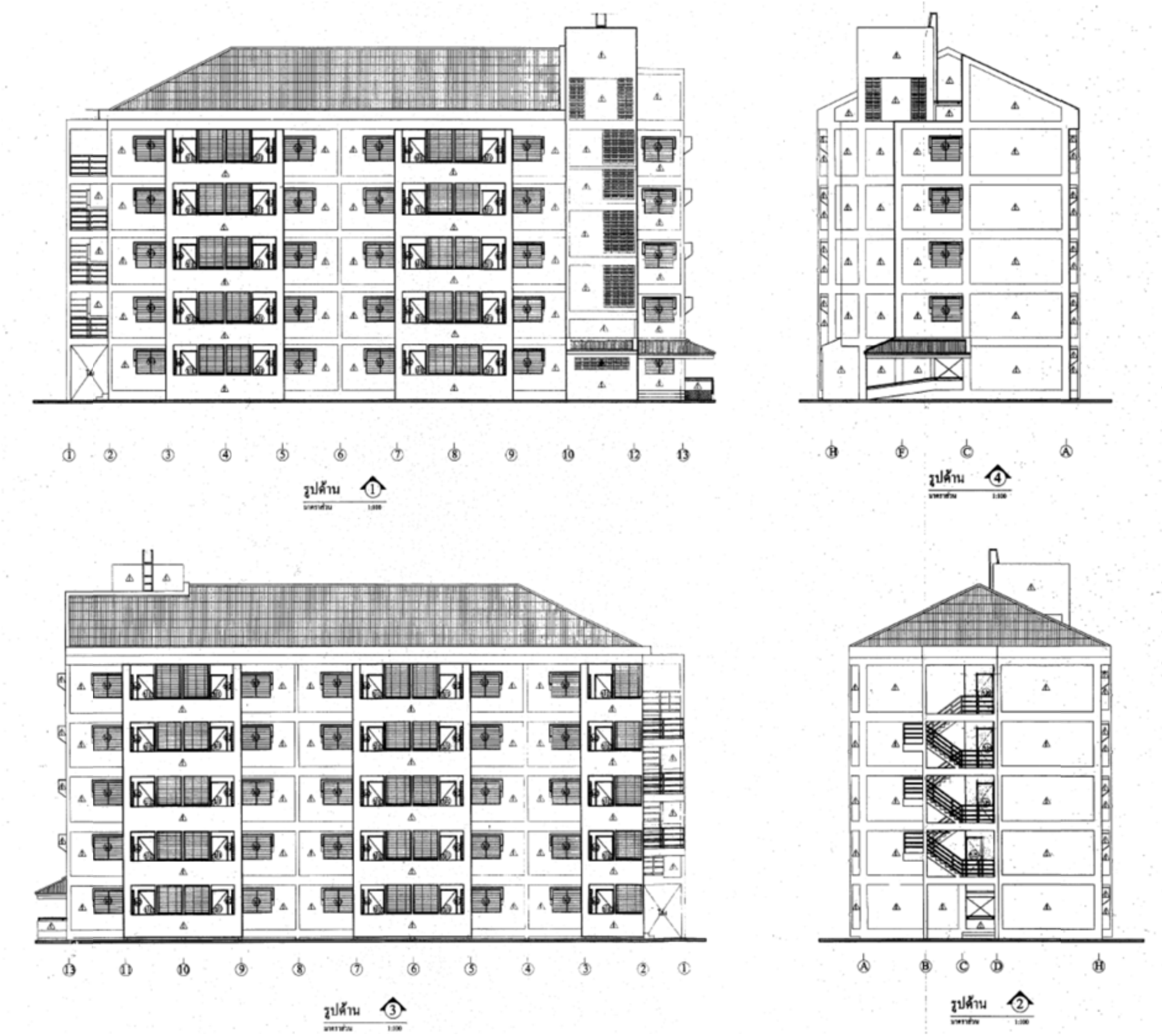


Figure 4.8 Side plans of the NHA apartment for low and medium income earners.

Table 4.4 Building code requirements for an apartment in comparison with the standard NHA apartment.

Description	Code requirement	NHA flat and apartment
Ground floor level	The floor level of the first story shall be at least 0.30 m. above main road level or at least 0.10 m. above pedestrian way.	The ground floor level is 0.5 m. above building base level.
Utilization area	Same as detached house.	The area of each room unit is 31.2 square meters.
Bedroom	Same as detached house.	Dimension of the bedroom is 3.25 m. length by 3 m. width.
Kitchen	Same as detached house.	Dimension of the kitchen is 3.0 m. length by 1.5 m. width.
Terrace	Same as row house.	Terrace protrudes 0.7 m. from the building.
Corridor	Same as detached house.	The width of corridor is 1.5 m.
Toilet room of each unit	Toilet room shall provide at least 1 washbasin, 1 closet. House with separate rest room and toilet room, each room must have the area at least 0.9 square meters. For rest room with closet, its area shall be	The dimension of toilet room is 1.5 x 2 m.

Description	Code requirement	NHA flat and apartment
	at least 1.5 m^2. Floor-to-ceiling height shall be at least 2 m. Aperture with the area at least 10% of the floor area shall be provided for ventilation, or a fan shall be provided for sufficient ventilation. Floor slop of toilet room shall exceed 1:100	
Door, window, clearstory	Same as town house.	Each door has its dimension of 0.9 m. Width and 2 m. Height. Dimension of window is 1.5 x 1.5 m. with glazing slats.
Floor-to-floor height	Floor-to-floor height shall exceed 2.6 m. for all rooms and 2.2 m. for corridor	The ground floor height is 3.3 m. The height of the floors above ground floor is 2.8 m.
Wall	Same as row house.	-
Fire exit door	The fire exit door shall be exceeding 0.8 m. in width and exceeding 1.9 m. in height. The door shall be pushed from inside in order to exit the building.	-
Roof	Same as detached house.	Roof is constructed with cement roof tile with size 0.54 x 1.2 m. and thick 5 mm. Ceiling is built using 9 mm. thick gypsum board
Floor-to-floor height	The height of the first story shall be at least 3.25 m. The height of other stories shall be at least 3.0 m.	The floor-to-floor height is 2.6 m.
Car park	Apartment shall provide 1 parking lot for each room unit with floor area exceeding 60 m^2.	-
Construction materials	Same as detached house.	Building walls is brick layer with mortar plastering on both sides. For restroom, the interior surfaces of the wall are covered with ceramic tile. Ground floor is polished cement floor. The upper floor is covered with 1.6mm thick PVC-rubber tile.
Ventilation	Same as detached house.	-
Lighting	Same as detached house.	-

4.4 Challenges to Low and Medium Income Housing during the Next Decade

According to the present circumstance and its gained experiences, NHA defines the major challenge issues of its operations for low and medium income housing during the next decade as follows:

• *Climate Change: Domestic*

Energy use is a major contributor to GHG emissions. Dramatically improving energy efficiency and increasing the use of carbon neutral energy sources in both new and existing homes is the sector's greatest challenge. NHA is well placed to raise awareness of the issues arising for housing from climate change especially on flooding and good practices in addressing these issues.

• *Corporate Social Responsibility*

Nowadays, consumers expect businesses to go beyond their profit agenda, and be socially responsible. House buyers expect a socially responsible developer to provide more CSR features in their housing projects but CSR add an additional cost to the project. Since CSR is costly so NHA has to balance between the additional cost and the CSR.

- *Rules and Regulations are Obstacles to Congested Community Upgrading*

Rules, regulations, and other requirements are impractical for low-income housing because of increased costs necessary to meet the regulations. For example, the Building Code 1979 establishes minimum requirements for each building's exterior and minimum distances between buildings. In 2011, NHA proposed a revision to the Government through the National Housing Policy Committee and the Government approved a new housing design for the "A House Cluster of 4 Units." It is one house and walls dividing the house into not more than 4 units. This approach allows more open space and setback. This exemption was approved and announced in the Royal Gazette No. 128 January 14 B.E. 2554 (2011 AD). Such rules are needed for low income projects.

References

Ravirungsan, T. 2010. Handbook: Design and Drawing for Buildings in Bangkok. V-Plus Group. ISBN: 978-616-90307-1-3.

National Housing Authority. 2010. Construction drawings for houses in Baan Eua-Arthorn Project.

National Housing Authority. 2011. 2011 Annual report: National Housing Authority of Thailand.

CHAPTER 5

ENERGY USE IN RESIDENTIAL BUILDINGS

5.1 Overview

Residential sector contributes significantly to the national energy demand and production and the greenhouse gas (GHG) emission. In Thailand, residential sector consumed energy at 10,650 thousand tons of crude oil equivalent (ktoe) in 2010; accounting for 15% of the final energy consumption by the whole country. This consumption amount grew 1.50 times that it was in 1990 (EPPO, 2010).

It was anticipated that the final energy consumption in the residential sector would increase to 21,140 ktoe in the next 20 years (year 2030), or about 1.98 times the amount in year 2010. This projection was made under the business-as-usual or BAU scenario that the annual GDP growth (at 1988 constant value) was 4.2%, the population growth was 0.3% per annum, and there was no any special energy conservation measures introduced. It should be noted that under the BAU scheme, the energy consumption would grow at 3.49% each year.

In following sections, the current energy situations in the residential sector are described. Patterns of the energy use are presented for different residential building types. By using the energy use patterns, the end-use model analysis was performed to project the final energy consumptions in the next 20 years. Finally, the GHG emission from this sector was estimated for year 2010 and 2030, respectively.

5.2 Greenhouse Gas Emission

In this section, the GHG emission from fuel use and from electric power generation is presented for Thailand. The emission valves were used as reference for assessing the GHG emission from buildings in the residential sector. According to the report on Greenhouse Gas Inventory in Energy Sector, Thailand (ONEP, 2010), Table 5.1 summarizes the GHG emission values of natural gas, bunker oil, diesel, lignite, coal, LPG, charcoal and wood. These fuels are used commonly in residential buildings. For LPG, the emission values were derived by weighting the emission values of Propane and Butane in a proportion of Propane 70% and Butane 30%.

For power generation, the values of GHG emission were derived based on the electricity generation mix reported in the Thailand Power Development Plan 2010 (PDP) (EGAT, 2010). Table 5.2 estimates the amount of commercial fuels for the power generation in 2010 and in 2030 according to the PDP. In the table, power generation from hydropower, renewable energy, waste, biomass, and nuclear is not included. Table 5.3 summarizes the GHG emissions from each fuel type per Giga Watt-hour (GWh) in 2010 and in 2030, respectively. It should be noted that the amount of electricity generation was determined based on all energy sources, but the amount of the GHG emission was evaluated only from those fuels in Table 5.2.

For Thailand, the GHG emission from power generation is rather low due to that 70% of the electricity come from natural gas. In 2030, the emission will reduce significantly due to introducing nuclear for power generation.

Table 5.1 Reference values of GHG emission from fuel use for Thailand.

Fuel	Unit (Million)	Energy		Emission					
		TOE	TJ	CO_2	CH_4	N_2O	NOX	CO	NMVOC
				Ton, C	kg	kg	kg	kg	kg
Natural gas	cubic feet	24.2	1.0	15.6	1.0	0.102	153.0	20.4	5.1
Bunker oil	Liter	941.2	39.8	839.1	119.3	23.9	7954.0	596.6	198.9
Diesel	Liter	862.0	36.4	735.7	109.3	21.9	7284.0	546.3	182.1
Lignite	kg	247.7	10.5	289.0	10.5	14.7	3141.0	209.4	52.4
Coal	kg	624.2	26.0	696.8	26.0	36.4	7800.0	520.0	130.0
Liquid petroleum gas	kg	1166.9	49.3	789.4	44.4	199.8	3174.1	435.0	117.6
Charcoal	kg	683.6	28.9	745.1	28.9	40.4	8664.0	577.6	144.4
Wood	kg	378.5	16.0	478.1	479.7	64.0	1599.0	15990.0	799.5

Note: The CO_2 emission shown in the table is in unit of tonnage of carbon amount. To determine the amount of CO_2 emission, a factor of 44/12 has to be multiplied with the values in the table. In this report, GHG emission all refers to the carbon amount.

Table 5.2 Commercial fuels for electric power generation in Thailand in 2010 and in 2030.

Fuel	Year 2010			Year 2030		
	Physical unit	ktoe	GWh	Physical unit	ktoe	GWh
Natural gas (Million cubic feet per day)	1,986	17,528	104,217	1,637	14,448	86,158
Bunker oil (Million liter per year)	227	214	910			
Diesel (Million liter per year)	26	22	112	6	5	21
Lignite (Million kilogram per year)	15,940	3,948	16,359	6,920	1,714	8,522
Coal (Million kilogram per year)	3,650	2,278	12,320	26,600	16,603	73,368
Total		23,990	152,954		32,770	347,948
ktoe/GWh		0.15685			0.09418	

Table 5.3 Greenhouse gas emission factor from the electric power generation in Thailand.

Fuel	Emission					
	CO_2	CH_4	N_2O	NOX	CO	NMVOC
	Ton, C	kg	kg	kg	kg	kg
Year 2010						
Natural gas	73.96	4.83	0.48	725.11	96.68	24.17
Bunker oil	1.2454	0.1771	0.0354	11.8046	0.8853	0.2951
Diesel	0.1238	0.0184	0.0037	1.2258	0.0919	0.0306
Lignite	30.12	1.09	1.53	327.34	21.82	5.46
Coal	16.63	0.62	0.87	186.13	12.41	3.10
Total	122.07	6.74	2.92	1251.61	131.89	33.05
Year 2030						
Natural gas	26.80	1.75	0.18	262.74	35.03	8.76
Bunker oil	0.0	0.0	0.0	0.0	0.0	0.0
Diesel	0.0118	0.0018	0.0004	0.1172	0.0088	0.0029
Lignite	7.25	0.47	0.05	71.05	9.47	2.37
Coal	53.27	1.99	2.78	596.30	39.75	9.94
Total	87.33	4.21	3.01	930.20	84.27	21.07

5.3 Current Energy Situation

To assess the energy consumption in the residential sector in Thailand, the numbers of households in year 2010 were estimated using the data from the 2008 annual population statistics report of the Department of Provincial Administration, (DOPA, 2008). Projection of the household numbers was carried out for the next 20 years with an assumption that family members would decrease linearly from 4.0 people per household in 2010 to 3.5 people per household in 2030. The population growth was assumed at a rate of 0.3 percent per annum.

Table 5.4 exhibits the resulting projection where the buildings were categorized to residential houses (RES) and small commercial buildings (SMS) each of which was separated further to those within municipality and outside municipality. It can be observed that even though the Thai population would not much increase during the period of consideration, the total number of household would increase almost 25% in 2030. Due to urbanization, the houses in municipal area increases from 40% of the total in 2010 to about 60% in 2030.

Table 5.4 Number of household in municipal and non-municipal areas.

Million

Year	2010	2011	2012	2013	2014	2015	2020	2025	2030
Residential houses (RES)									
Municipal	5.44	5.60	5.77	5.95	6.13	6.31	7.34	8.55	9.96
Non-municipal	8.05	8.01	7.96	7.91	7.86	7.80	7.43	6.91	6.23
Total	13.49	13.61	13.73	13.86	13.98	14.11	14.77	15.46	16.19
Small commercial buildings (SMC)									
Municipal	1.59	1.64	1.69	1.74	1.80	1.85	2.15	2.51	2.92
Non-municipal	0.94	0.94	0.93	0.93	0.92	0.91	0.87	0.81	0.73
Total	2.54	2.58	2.62	2.67	2.72	2.76	3.02	3.32	3.65
RES&SMC	**16.03**	**16.19**	**16.36**	**16.53**	**16.70**	**16.88**	**17.79**	**18.77**	**19.84**

In Thailand, energy utilized in residential buildings appears in various forms including electricity, liquid petroleum gas (LPG), charcoal, and fuel wood. The last three fuel types have been used commonly for cooking; however, cooking by using electricity is increasing due to changing living style.

Energy consumption in residential buildings varies widely and is influenced by several factors, for instance, household appliances and its use, life style, personal income, etc. From a survey study conducted by Department of Alternative Energy Development and Energy Efficiency (DEDE), Ministry of Energy (MoEn) (DEDE, 2003), Table 5.5 presents patterns of the electricity use in residential buildings. In the table, the electricity use is described in terms of percentage shares of electrical energy consumption by appliances arranged in respect with activities i.e. lighting, cooking, entertainment, amenity and other. Equipment in each activity category can be listed as below:

- lighting category: fluorescent lamp and incandescent lamp,
- cooking category: electric rice cooker, electric stove, LPG stove, electric frying pan, oven, microwave, blender juice, toaster and electric kettle,
- entertainment category: television, stereo, VCD/DVD player, radio and computer,

- amenity category: fan, air-conditioning, vacuum cleaner, washing machine, water heater, electric water pump, iron, refrigerator and freezer.

Table 5.5 The shares of electrical energy uses in four residential building categories.

Activity	Appliance	Share of energy used in residential house		Share of energy used in small commercial building	
		Municipal	Non-municipal	Municipal	Non-municipal
Lighting	Fluorescent lamp	11.93	15.64	11.46	8.73
	Incandescent lamp	0.52	0.86	0.26	0.29
Cooking	Electric rice cooker	4.25	7.31	2.93	3.47
	Electric stove	0.29	0.21	0.33	0.02
	Electric frying pan	1.24	0.99	0.54	0.66
	Microwave	0.97	0.34	0.49	0.1
	Oven	0.28	0.31	0.17	0.03
	Electric kettle	3.69	4.62	2.54	2.55
	Blender juice	0.12	0.19	0.19	0.25
	Toaster	0.26	0.32	0.1	0
Entertainment	TV	8.26	10.67	5.22	5.06
	VDO/VCD player	0.26	0.31	0.19	0.15
	Stereo	5.39	5.27	3.22	3.39
	Radio	0.38	0.58	0.25	0.2
	Computer	2.34	0.94	10.35	1.09
Amenity	Fan	6.09	7.13	3.97	3.66
	Wall fan	1.06	0.97	1.45	1.16
	Floor air-conditioning	12.83	2.9	7.7	2.66
	Wall air-conditioning	10.38	2.88	5.8	0.97
	Vacuum cleaner	0.52	0.2	0.33	0.1
	Washing machine	1.4	1.17	0.91	0.79
	Water heater	7.12	2.42	1.81	1.25
	Iron	5.23	7.16	3.27	3.56
	Electric water pump	1.81	6.06	1.12	2.71
	Refrigerator	9.17	14.9	5.49	6.8
	Freezer	0.61	1.03	21.3	34.33
Other		3.59	4.65	8.62	16.03
Total		100	100	100	100

It can be observed that for all residential building categories, amenity performs the largest electricity-consuming activity that shares 46.8-58.0% of the total electricity consumption. Air-conditioner and refrigerator play the major energy consumers in this activity.

Electricity use for entertainment comes the second with the two main energy consumers of television and stereo. The consumption share in this activity ranges from 9.9% to 19.2%. For lighting, fluorescent lamps are used commonly with a small portion of incandescent lamps. Fluorescent lamps consume energy from 8.7-15.6%.

Table 5.5 presents only the electricity use in the residential buildings. The use of energy in other forms is summarized in Table 5.6; but all for cooking purpose. In the table, the consumptions of LPG, fuel wood, and charcoal are presented in unit of kilogram per household per year, except that of electricity in kilowatt-hour per household per year. In Table 5.6, the data were compiled and analyzed based on documents disseminated by Petroleum Authority of Thailand (PTT), and by Department of Alternative Energy Development and Energy Efficiency (DEDE).

Table 5.6 Annual fuel consumptions for cooking in residential buildings

Energy source	Average annual energy demand for cooking (Unit/household /year)				Unit
	Residential house		Small Commercial building		
	Municipal	Non-municipal	Municipal	Non-municipal	
Electricity	211	354	245	546	kWh
LPG	82	180	103	320	kg
Fuel wood	32	568	6	246	kg
Charcoal	42	649	155	390	kg

Examining Table 5.6, fuel wood and charcoal are used mainly in buildings outside municipal area. In general, small commercial buildings consume more energy for cooking. In Table 5.7, the useful heat from using different fuel types for cooking is presented. Heating value of the fuels and efficiency of using the fuel for cooking are shown in the table, as well. The heating efficiency is based on the present performance of cooking technologies and methods. The useful heat in the table is reported in unit of Mega Joule (MJ). In terms of the useful heat, LPG is the main energy source for cooking in residential houses in Thailand.

Table 5.7 Annual useful energy for cooking each household (MJ/household /year)

Energy source	Heating value	Efficiency (%)	Useful heat			
			Residential house		Small commercial building	
			Municipal	Non-municipal	Municipal	Non-municipal
Electricity	3.6 MJ/kWh	100	761	1,275	884	1,965
LPG	49.3 MJ/kg	49	1,969	4,355	2,480	7,727
Fuel wood	3.6 MJ/kg	15	76	1,362	15	590
Charcoal	3.6 MJ/kg	25	303	4,684	1,119	2,818

It can be observed that in terms of the useful heat, LPG is currently the major fuel type for cooking in Thailand. From the specific energy consumption in each household in Table 6.5-6.6 together with the number of household in Table 5.4, the current energy consumption situation in residential sector in 2010 can be presented as shown in Table 5.8.

From the table, the total electrical energy consumption in residential buildings is 43,006 GWh per year. Amenity activity consumes electrical energy 22,262 GWh per year, equivalent to 52% of the total consumption. Electrical energy for entertainment is the second large consumption at the amount of 7,030 GWh per year, but just one-third of that of amenity activity. Residential houses consume more energy than small commercial buildings due to its larger number of housing units. For Thailand, residential houses and small commercial buildings outside municipal area still consume energy greater than those in municipality.

Table 5.8 Energy consumptions of residential sector in Thailand in 2010.

Activity	Energy	Residential house		Small commercial building		Total (2010)
		Municipal	Non-municipal	Municipal	Non-municipal	
Lighting	Electricity (GWh)	1,288	3,294	638	655	**5,875**
Cooking	Electricity (GWh)	1,149	2,852	391	514	**4,906**
	LPG (1,000 tons)	443	1,452	164	301	**2,360**
	Fuel wood (1,000 tons)	172	4,573	10	231	**4,986**
	Charcoal (1,000 tons)	228	5,224	247	368	**6,067**
Entertainment	Electricity (GWh)	1,719	3,546	1,047	718	**7,030**
Amenity	Electricity (GWh)	5,817	9,346	2,891	4,208	**22,262**
Other	Electricity (GWh)	371	928	470	1,164	**2,933**

Using the GHG emission factors in Table 5.1 and 5.3, the GHG emission from residential sector in 2010 was calculated as shown in Table 5.9. The results show that residential sector emits CO_2 into the atmosphere at 7,133 Ton of carbon. Amenity and cooking are the activities that emit CO_2 at 2,714 and 2,488 Ton of carbon per year, respectively. This amount accounts for 73% of the total CO_2 emission from the sector. Energy for lighting and entertainment shares together the CO_2 emission at 1,575 Ton of carbon per year, or 22% of the total CO_2 emission.

Table 5.9 Greenhouse gas emission from residential sector in Thailand in 2010.

Fuel	Emission					
	CO_2	CH_4	N_2O	NOX	CO	NMVOC
	Ton, C	kg	kg	kg	kg	kg
Year 2010						
Lighting	717	40	17	7,347	774	194
Cooking	2,488	139	486	13,903	1,702	447
Entertainment	858	47	21	8,793	927	232
Amenity	2,714	150	65	27,822	2,932	735
Other	357	20	9	3,660	386	97
Total	**7,133**	**396**	**597**	**61,524**	**6,721**	**1,705**

5.4 Projection of Energy Consumption

A business as usual (BAU) scenario (following PDP) of the energy consumption in residential sector was established from the projected numbers of households and the household energy consumptions described in Section 6.3.1. The detailed description and assumptions are summarized as follow.

a) Influencing factors

- *Change of number of households in municipality area*

Although the energy consumption per unit of household was assumed to be non-change, the overall energy consumption of the whole country would be varied with the change of number of household units within and outside municipality area.

Urbanization due to the immigration of people and the growth of the cities themselves increased the energy demand and consumption of a country. Complexity also increases due to behavioral changes of use of household appliances both within and outside municipality.

- *Saturation of energy used*

Projects of minimum energy performance standard (MEPS) of certain appliances, energy labeling and high energy performance standard (HEPS) which include fluorescent lamp, incandescent lamp, electric stove, oven, microwave, electric kettle, TV, computer, water cool air-conditioning, vacuum cleaner, washing machine, electric water heater, refrigerator and freezer are implemented continuously by DEDE (MU, 2010). Among various appliances, those that could be found in nearly all households mean that the number of equipment per household reaches saturation. For whole energy consumption, although the number of household is increasing, the concentration of saving from the projects and the saturation of equipment per household can be assumed that the energy consumption of activities reach saturation except air-conditioning and electric water heating which has increased each year about 718,980 and 200,000 units (EGAT, 2006), respectively. It is interesting to note that the increasing of air conditioning in Kasikorn Bank Research (KRC, 2010) is around 1,090,000 to 1,150,000 units.

In case of energy for cooking, charcoal substitution by LPG will occur not for economic reasons, but for individuals' desire to improve quality of life, in the context of modernization [Sanga, A.G., 2005]. Although number of household is increasing, the useful heat demand for cooking also reaches saturation but it was obvious that the use of electricity (such as electric stoves and microwave) and LPG (such as LPG stove) for cooking is increasing due to the energy substitution that lead to increase of some energy.

b) Assumptions

Followings are the assumption set for the BAU scenario:

- For residential buildings, the energy consumption for lighting, cooking, entertainment and amenity, except air conditioning and water heating, reach their saturation. In each year, the units of electric water heater will increase 200,000 units (EGAT, 2006). In average, an electric water heater consumes power 4,500 W for 1.5 hours a day and 8 months a year.
- Demand for air conditioning of both residential and small commercial buildings combination will be increasing 718,980 units of air conditioner each year (EGAT, 2006). An air conditioner (EER=10) consumed 596 kWh per year (DEDE, 2003) which now is consume more therefore the energy consumption must be multiplied by 1.5 in order to simulate as close to reality as much as possible since 2010).
- For small commercial buildings, the rate of electricity consumption increases inline with the growth of all activities.
- Number of residential and small commercial buildings within and outside the municipality in each year, as shown in Table 5.4.
- Implementation of the minimum energy performance standard (MEPS), energy labeling and high energy performance standard (HEPS) for household appliances are assumed to be continued.

The total electricity demand is estimated about 47,863 GWh and 98,904 GWh in 2010 and 2030, respectively. In the residential sector, the energy demand in 2030 for within and outside municipal areas is more than 2.2 times and 1.1 times in 2010, respectively. In the small commercial buildings, the energy demand in 2030 is more than 4.9 times and 2.3 times in 2010 for within and outside municipal areas, respectively, as presented in Table 5.10. In this case, the electricity consumption for air conditioning and hot water were separated for clearly shown the growths of the two events were.

Table 5.10 The energy consumption of the residential houses and small commercial buildings in each category in 2010 and 2030

Activity		2010		2030	
		Municipal	Non-municipal	Municipal	Non-municipal
Residential Sector					
Lighting (GWh)		1,288	3,294	2,360	2,548
Cooking	Electricity (GWh)	1,149	2,851	2,106	2,205
	LPG (kton)	443	1,452	812	1,123
	Wood (kton)	172	4,573	315	3,536
	Charcoal (kton)	228	5,224	418	4,040
Entertainment (GWh)		1,719	3,546	3,150	2,742
Amenity (GWh)	Other	2,679	7,080	4,909	5,475
	Air-conditioning	5,138	2,984	13,314	7,732
	Electric hot water	1,375	902	3,994	2,620
Other (GWh)		371	928	680	718
Small Commercial Sector					
Lighting		638	655	3,519	1,524
Cooking	Electricity (GWh)	391	514	2,158	1,196
	LPG (kton)	164	301	903	701
	Wood (kton)	10	231	56	539
	Charcoal (kton)	247	368	1362	855
Entertainment (GWh)		1,047	718	5,770	1,671
Amenity (GWh)	Other	1,995	3,840	10,998	1,206
	Air-conditioning	1,408	465	3,649	8,935
	Electric hot water				
Other (GWh)		470	1,164	2,590	2,708
Total electricity (GWh)		**48,611**		**100,475**	

According to the BAU scenario that no switching energy in the cooking activity and the stove still same efficiency so the percent growth of all energy is the same but difference in each sub sector due to changing of number of houses. In 2030, for residential houses, although the energy demand for cooking within municipal area is expected to increase 83% from 2010 but outside municipal area is expected to decrease only 23%. For small commercial buildings within and outside municipal areas, the energy demand is expected to increase more than five and two times from 2010, respectively. Tables 5.11-5.16 show the prediction of energy consumption by the BAU scenario.

Table 5.11 Prediction of energy consumption in the residential house classified by end use activities (BAU scenario).

Energy	Activities		2010	2011	2012	2013	2014	2015	2020	2025	2030
Electricity (GWh)	**Total electricity**		**35,307**	**36,294**	**37,280**	**38,263**	**39,245**	**40,225**	**45,086**	**49,870**	**54,552**
	Lighting		4,582	4,604	4,625	4,646	4,666	4,686	4,777	4,853	4,907
	Cooking		4,000	4,020	4,039	4,059	4,077	4,096	4,181	4,254	4,310
	Entertainment		5,265	5,299	5,332	5,365	5,398	5,431	5,592	5,747	5,892
	Amenity	Air-conditioning	8,123	8,769	9,415	10,061	10,707	11,354	14,585	17,815	21,046
		Electric hot water	2,277	2,494	2,711	2,927	3,144	3,361	4,445	5,529	6,614
		Other	9,759	9,803	9,845	9,887	9,928	9,968	10,147	10,290	10,384
	Other		1,300	1,306	1,312	1,318	1,324	1,330	1,358	1,381	1,398
LPG (10^3 tons)	Cooking		1,895	1,901	1,906	1,911	1,916	1,921	1,938	1,943	1,935
Fuel wood (10^3 tons)	Cooking		4,745	4,725	4,704	4,681	4,655	4,627	4,449	4,196	3,851
Charcoal (10^3 tons)	Cooking		5,453	5,432	5,408	5,383	5,355	5,324	5,126	4,844	4,458

Table 5.12 Prediction of energy consumption in the small commercial buildings classified by end use activities (BAU scenario).

Energy	Activities		2010	2011	2012	2013	2014	2015	2020	2025	2030
Electricity (GWh)	**Total electricity**		**13,304**	**14,163**	**15,108**	**16,143**	**17,232**	**18,399**	**25,036**	**33,791**	**45,923**
	Lighting		1,293	1,378	1,473	1,580	1,693	1,817	2,544	3,560	5,043
	Cooking		905	963	1,027	1,099	1,175	1,258	1,740	2,403	3,354
	Entertainment		1,764	1,887	2,025	2,179	2,344	2,524	3,602	5,143	7,441
	Amenity	Air-conditioning	1,873	2,023	2,172	2,321	2,470	2,619	3,364	4,109	4,854
		Other	5,835	6,185	6,577	7,013	7,474	7,972	10,822	14,626	19,933
	Other		1,633	1,728	1,834	1,952	2,076	2,209	2,964	3,951	5,298
LPG (10^3 tons)	Cooking		465	493	524	559	597	637	866	1,173	1,604
Fuel wood (10^3 tons)	Cooking		242	253	267	281	296	312	394	488	595
Charcoal (10^3 tons)	Cooking		615	653	696	744	794	849	1,168	1,601	2,218

Table 5.13 Prediction of energy consumption of the within municipal residential sub-sector classified by end use activities (BAU scenario).

Energy	Activities		2010	2011	2012	2013	2014	2015	2020	2025	2030
Electricity (GWh)	**Total electricity**		**13,720**	**14,478**	**15,244**	**16,016**	**16,796**	**17,583**	**21,644**	**25,939**	**30,512**
	Lighting		1,288	1,327	1,367	1,409	1,452	1,496	1,739	2,025	2,360
	Cooking		1,149	1,184	1,220	1,257	1,295	1,335	1,552	1,807	2,106
	Entertainment		1,719	1,771	1,825	1,881	1,938	1,997	2,322	2,703	3,150
	Amenity	Air-conditioning	5,138	5,547	5,956	6,365	6,774	7,182	9,226	11,270	13,314
		Electric hot water	1,375	1,506	1,637	1,768	1,899	2,030	2,684	3,339	3,994
		Other	2,679	2,760	2,844	2,931	3,020	3,112	3,618	4,212	4,909
	Other		371	383	394	406	419	431	502	584	680
LPG (10^3 tons)	Cooking		443	457	470	485	500	515	599	697	812
Fuel wood (10^3 tons)	Cooking		172	177	182	188	194	200	232	270	315
Charcoal (10^3 tons)	Cooking		228	235	242	250	257	265	308	359	418

Table 5.14 Prediction of energy consumption of the outside municipal residential sub-sector classified by end use activities (BAU scenario).

Energy	Activities		2010	2011	2012	2013	2014	2015	2020	2025	2030
Electricity (GWh)	**Total electricity**		**21,586**	**21,815**	**22,036**	**22,247**	**22,449**	**22,642**	**23,442**	**23,930**	**24,040**
	Lighting		3,294	3,277	3,258	3,237	3,214	3,190	3,038	2,828	2,548
	Cooking		2,851	2,836	2,819	2,801	2,782	2,761	2,629	2,448	2,205
	Entertainment		3,546	3,527	3,507	3,484	3,460	3,434	3,270	3,044	2,742
	Amenity	Air-conditioning	2,984	3,222	3,459	3,697	3,934	4,171	5,358	6,545	7,732
		Electric hot water	902	988	1,074	1,160	1,245	1,331	1,761	2,190	2,620
		Other	7,080	7,042	7,001	6,956	6,908	6,856	6,529	6,078	5,475
	Other		928	923	918	912	906	899	856	797	718
LPG (10^3 tons)	Cooking		1,452	1,444	1,436	1,427	1,417	1,406	1,339	1,246	1,123
Fuel wood (10^3 tons)	Cooking		4,573	4,548	4,522	4,493	4,462	4,428	4,217	3,925	3,536
Charcoal (10^3 tons)	Cooking		5,224	5,197	5,166	5,133	5,097	5,059	4,818	4,485	4,040

Table 5.15 Prediction of energy consumption of the within municipal small commercial sub-sector classified by end use activities (BAU scenario).

Energy	Activities		2010	2011	2012	2013	2014	2015	2020	2025	2030
Electricity (GWh)	**Total electricity**		**5,949**	**6,446**	**6,993**	**7,594**	**8,238**	**8,936**	**13,173**	**19,321**	**28,684**
	Lighting		638	692	753	822	897	979	1,496	2,282	3,519
	Cooking		391	425	462	504	550	601	918	1,399	2,158
	Entertainment		1,047	1,135	1,235	1,348	1,471	1,606	2,453	3,741	5,770
	Amenity	Air-conditioning	1,408	1,520	1,632	1,744	1,856	1,968	2,528	3,088	3,649
		Other	1,995	2,164	2,355	2,570	2,803	3,061	4,676	7,131	10,998
	Other		470	510	555	605	660	721	1,101	1,679	2,590
LPG (10^3 tons)	Cooking		164	178	193	211	230	251	384	585	903
Fuel wood (10^3 tons)	Cooking		10	11	12	13	14	16	24	36	56
Charcoal (10^3 tons)	Cooking		247	268	292	318	347	379	579	883	1,362

Table 5.16 Prediction of energy consumption of the outside municipal small commercial sub-sector classified by end use activities (BAU scenario).

Energy	Activities		2010	2011	2012	2013	2014	2015	2020	2025	2030
Electricity (GWh)	**Total electricity**		**7,355**	**7,717**	**8,115**	**8,549**	**8,995**	**9,463**	**11,863**	**14,470**	**17,239**
	Lighting		655	686	720	758	796	837	1,048	1,278	1,524
	Cooking		514	538	565	595	625	657	823	1,003	1,196
	Entertainment		718	752	789	831	873	918	1,149	1,401	1,671
	Amenity	Air-conditioning	465	502	539	576	613	650	835	1,021	1,206
		Other	3,840	4,021	4,222	4,443	4,671	4,911	6,146	7,495	8,935
	Other		1,164	1,218	1,279	1,346	1,415	1,488	1,862	2,271	2,708
LPG (10^3 tons)	Cooking		301	315	331	349	366	385	482	588	701
Fuel wood (10^3 tons)	Cooking		231	242	255	268	282	296	371	452	539
Charcoal (10^3 tons)	Cooking		368	385	404	425	447	470	588	718	855

Table 5.17 and 5.18 exhibit the GHG emission from residential section in 2010 and 2030 based on the BAU scenario.

Table 5.17 Greenhouse gas emission from residential sector in 2010 (BAU case).

Description	CO_2	CH_4	N_2O	NOX	CO	NMVOC
	Ton, C	kg	kg	kg	kg	kg
Lighting	717	40	17	7,347	774	194
Cooking	2,488	139	486	13,903	1,702	447
Entertainment	858	47	21	8,793	927	232
Amenity	2,714	150	65	27,822	2,932	735
Other	357	20	9	3,660	386	97
Total	7,133	396	597	61,524	6,721	1,705

Table 5.18 Greenhouse gas emission from residential sector in 2030 (BAU case).

Description	Unit	BAU	ktoe	CO_2	CH_4	N_2O	NOX	CO	NMVOC
				Ton, C	kg	kg	kg	kg	kg
Lighting	GWh	14,172	1,335	1,238	6	4	5	0	0
Cooking									
Electricity	GWh	11,683	1,100	1,020	5	3	4	0	0
LPG	10^6 kg	5,635	6,576	1,830	120	150	157	27	8
Wood	10^6 kg	11,367	4,302						
Charcoal	10^6 kg	13,838	9,460						
Entertainment	GWh	17,122	1,613	1,495	7	4	6	0	0
Amenity	GWh	40,540	3,818	3,540	16	11	15	1	0
Air-conditioning	GWh	12,106	1,140	1,057	5	3	4	0	0
Electric hot water heating	GWh	2,736	258	239	1	1	1	0	0
Other	GWh	7,829	737	684	3	2	3	0	0
Total	GWh	106,223							
Total			30,339	11,103	162	178	196	29	8

References

Department of Alternative Energy Development and Efficiency (DEDE). 2003. Final report on energy consumption in residential sector. Submitted by King's Mongkut University of Technology Thonburi.

Department of Provincial Administration (DOPA). 2008. Thailand Population Statistics (2008).

Electricity Generating Authority of Thailand (EGAT). 2004. Report on Electric Appliances in Residential Houses (2004).

Electricity Generating Authority of Thailand (EGAT). 2006. A report on an analysis of production and marketing of electrical and appliance labeling and not labeling. Submitted by Kasetsart University.

Electricity Generating Authority of Thailand (EGAT). 2010. Thailand Power Development Plan: 2010-2030.

Energy Policy and Planning Office (EPPO). 2010. The 20-year Energy Efficiency Development Plan (EEDP 2010-2030).

Kasikorn Research Center (KRC). 2010. Air conditioners, 2010: Hot summer boosting sales, promotions abound (Issue No.2208).

Mahidol University (MU). 2010. Project Review on Promoting and Study Plan of Energy Efficiency of High Performance Equipment and Materials for Conservation. On 8th September 2010, at The Twin Tower Hotel, commissioned by Department of Alternative Energy Development and Efficiency (DEDE).

Office of Natural Resources and Environmental Policy and Planning (ONEP). 2010. Greenhouse Gas Inventory in Energy Sector, Thailand.

Sanga, A.G. 2005. Impacts of efficient stoves and cooking fuel substitution in family expenditure of urban households in Dar es Salaam, Tanzania, International Energy Initiative (Latin America Office), Energy Discussion Paper No. 2.59.1/05.

CHAPTER 6

CARBON FOOTPRINT OF HOUSING CONSTRUCTIONS

Greenhouse gas emission from house construction can be evaluated by the concept of carbon footprint. Global Footprint Network (2014) defines carbon footprint as amount of carbon (usually in tonnes) being emitted by an activity or organization throughout the whole life cycle (cradle-to-grave). Generally, carbon footprint is calculated as the carbon dioxide equivalent of the emissions issuing from the extraction of raw materials, transportation and parts for assembly all the way to waste management for end of product life. At present there are several types of carbon footprint such as carbon footprint of product, carbon footprint of organization, carbon footprint of individual, carbon footprint of city etc. Several standards and guidelines on how to perform a carbon footprint are described below (Lundie, *et al.*, 2009).

6.1 Existing ISO Standards Related to Carbon Footprint

Several ISO standards relate to the assessment of a carbon footprint at different levels. The carbon footprint can be quantified either at a product or service level as in life cycle assessment described by ISO standards 14040 and 14044 (2006) or at an organisation or company level as described in ISO standard 14064-1 (2006). The carbon footprint is one indicator of environmental indicators such as resource depletion, ozone depletion, eutrophication, toxicity, energy use etc. Life cycle assessment consists of four steps as described in Figure 6.1.

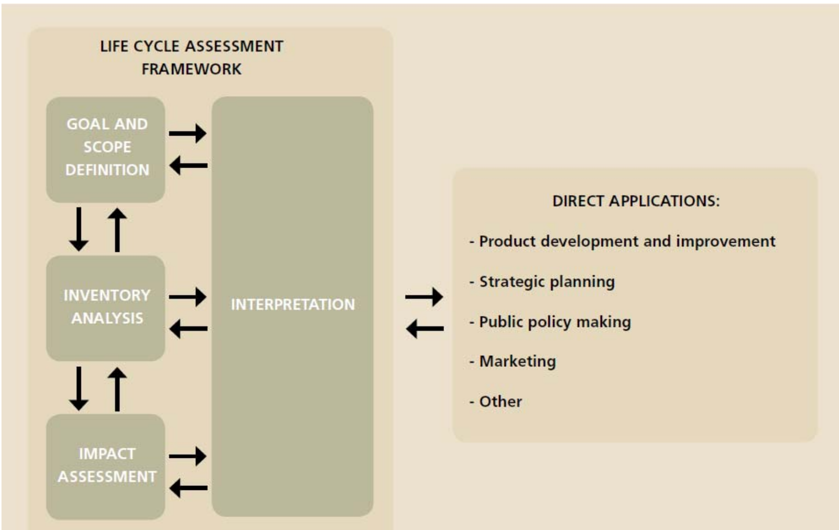


Figure 6.1 Life cycle assessment framework as described in ISO standards 14040 and 14044 (Lundie, *et al.*, 2009).

In the goal and scope phase, the purpose of the study, its scope (geographic, temporal, and technological), the studied function and corresponding system are defined. The level of detail and data quality requirements of a life cycle assessment can vary significantly depending on its particular goal. In the inventory analysis the resources consumed and the emissions to the environment are quantified at all stages of the life cycle such as from the extraction of resources, the production of materials, the use of the product, through the final disposal. For each environmental impact in the life cycle impact assessment stage, a characterisation model is used to convert the inventory data contributing to this impact, into indicator results by multiplying the emissions of each substance by a characterisation factor. For a carbon footprint, amount of greenhouse gas emission is converted to amount of CO_2 equivalent by multiplying with their global warming potentials, following the IPCC guidelines.

6.2 PAS 2050 and Greenhouse Gas Protocol

PAS 2050 is a publicly available specification for assessing product life cycle GHG emissions, prepared by BSI British Standards and co-sponsored by the Carbon Trust and the Department for Environment, Food and Rural Affairs (DEFRA). PAS 2050 is an independent standard, developed with significant input from international stakeholders and experts across academia, business, government and non-governmental organisations (NGOs) through two formal consultations and multiple technical working groups. The assessment method has been tested with companies across a diverse set of product types, covering a wide range of sectors including: Goods and services; Manufacturers, retailers and traders; Business-to-business (B2B) and business-to-consumer (B2C); and UK and international supply chains.

PAS 2050 was introduced in 2008 (revised in 2011) with the aim of providing a consistent internationally applicable method for quantifying product carbon footprints. The GHG Protocol Product Standard was released in 2011. In other words, the GHG Protocol built on the initial PAS 2050 method in development of its International Product Standard called "Product Life Cycle Accounting and Reporting Standard". Currently, GHG Protocol develops several guidelines to quantify greenhouse gas emission from specific activities such as Corporate Accounting and Reporting Standards, Corporate Value Chain (Scope 3) Accounting and Reporting Standard, Project Accounting Protocol and Guidelines etc.

PAS 2050 defines the term 'product carbon footprint' as the GHG emissions of a product across its life cycle, from raw materials through production (or service provision), distribution, consumer use and disposal/ recycling. The recent PAS 2050 considers the emissions from six greenhouse gases which are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), Sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (Carbon Trust, 2008). The boundary of carbon footprint assessment following PAS 2050 is provided in Figure 6.2. Carbon footprint of a given activity is calculated by multiplying activity data with their emission factor (CO_2e per unit). Available relevant emission factors can be searched online from the database of Department for Environment Food & Rural Affairs (DEFRA) at http://www.ukconversionfactorscarbonsmart.co.uk/. The other sources of emission factors can be found online at http://www.ghgprotocol.org/Third-Party-Databases.

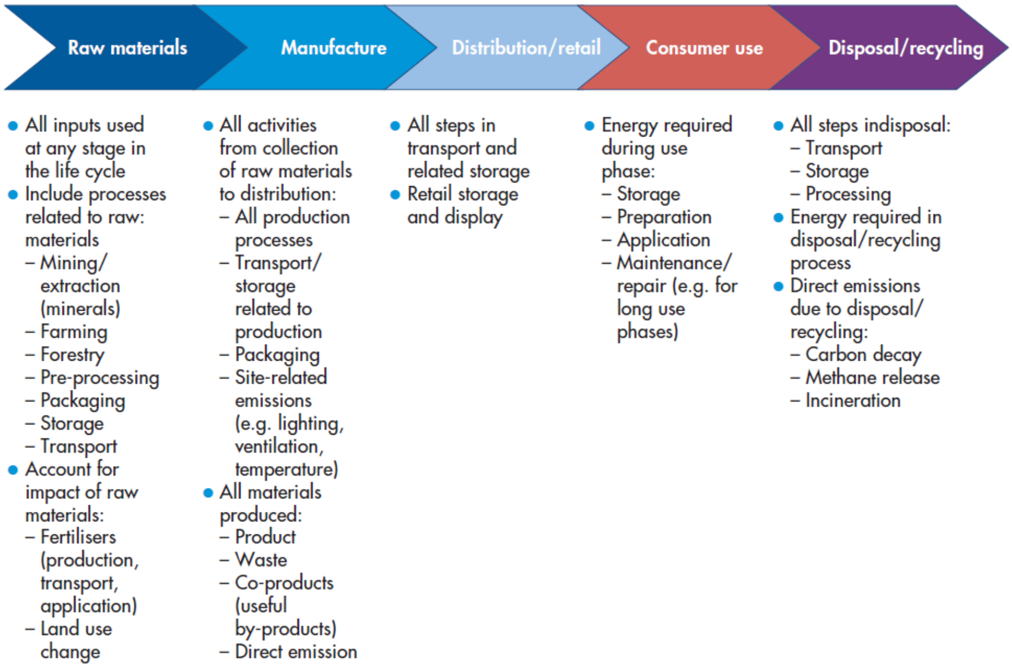


Figure 6.2 Common materials and activities within the boundary of carbon footprint assessment (Carbon Trust, 2008).

6.3 IPCC Guidelines

The Intergovernmental Panel on Climate Change (IPCC) is responsible for assessing greenhouse gas emission at a global level. To avoid the worst impacts from climate change, global CO_2 emissions must be cut by at least 50% by 2050. The IPCC developed the methodology to calculate national greenhouse gas emission by sectors called "IPCC Guidelines for National Greenhouse Gas Inventories". The guidelines were first accepted in 1994 and published in 1995. In 1997, UNFCCC COP3 held in Kyoto reaffirmed that the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories should be used as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" in calculation of legally-binding targets during the first commitment period.

In 2002, the IPCC was invited by the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC to revise the 1996 IPCC Guidelines, taking into consideration the relevant work made under the Convention and the Kyoto Protocol. Finally, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories was launched. These new guidelines cover new sources and gases as well as updates to previously published methods where technical and scientific knowledge have improved. However, the 2006 IPCC Guidelines have not been approved by the Conferences of the Parties (COP) yet. Thus, the preparation of national greenhouse gas inventories has to follow the 1996 IPCC Guidelines (IPCC, 2006). The six Kyoto gases which are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), and hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are taken into account in national greenhouse gas inventory. The most recent IPCC guidelines should be used for determining emissions from: energy (stationary and mobile sources); industrial processes and product use (IPPU); agriculture, forestry and other land use (AFOLU); and waste.

Different from LCA approach, the boundaries of the studied system in those greenhouse gas inventories correspond to the boundaries of the country. The IPCC guidelines generally provide estimation methods at three levels of detail, from tier 1 (the default method) to tier 3 (the most detailed method). The decision tree of each specific emission sources is provided to be a guideline for tier selection. The guideline also gives the advices of mathematical specification of the methods, information on emission factors or other parameters used in each tier equation, and sources of activity data to estimate the overall level of net emissions. Although the purpose and system boundaries of IPCC guidelines are different, these emission factors and methods to estimate greenhouse gas emissions are also relevant for life cycle assessment studies. IPCC guidelines provide default emission factors for greenhouse gas emissions from all sectors, it also encourages the use of country-specific factors if the methods used to calculate them can be defended and withstand international peer-review (Carbon Trust, 2014). Default emission factors are available in IPCC database and can be searched online at http://www.ipcc nggip.iges.or.jp/EFDB/main.php.

6.4 Greenhouse Gas Accounting Tool for Construction Guideline

The Department for Planning, Transport and Infrastructure (DPTI), Government of South Australia developed the Greenhouse Gas Accounting Tool for Construction Guidelines in 2012. DPTI currently undertakes statutory reporting on greenhouse gas emissions from the operation and management of buildings as a requirement of the South Australian Government Energy Efficiency Action Plan. State Government agencies must also contribute to targets and priorities identified in the South Australian Strategic Plan and Tackling Climate Change: South Australia's Greenhouse Strategy 2007-2020. To better understand and quantify these emissions, DPTI has developed the Greenhouse Gas Accounting Tool (GGAT) for construction (DPTI, 2012). The GGAT is to be used on larger transport infrastructure projects where due to size and scope there are opportunities to account for inputs and reduce emissions generated. It is not required for all DPTI projects involving construction. The GGAT has been developed as a Microsoft Excel based software application comprising of a number of worksheets and relevant emission factors. However, the software has not been available online.

6.5 Greenhouse Gas Emission Accounting Tool for Buildings

Civitas Consultants and Center for International Climate and Environmental Research in Norway developed the web based accounting tools for greenhouse gas emission from Norwegian building projects in 2008. The methodology is based on Life Cycle Approach which includes embodied emissions and transport. This tool is beneficial for architects, advisors in construction and urban planners to minimize GHG emissions from buildings. The tool is available online at http://www.klimagassregnskap.no/portal/. Unfortunately, the tool is in Norwegian only (Selvig, 2008).

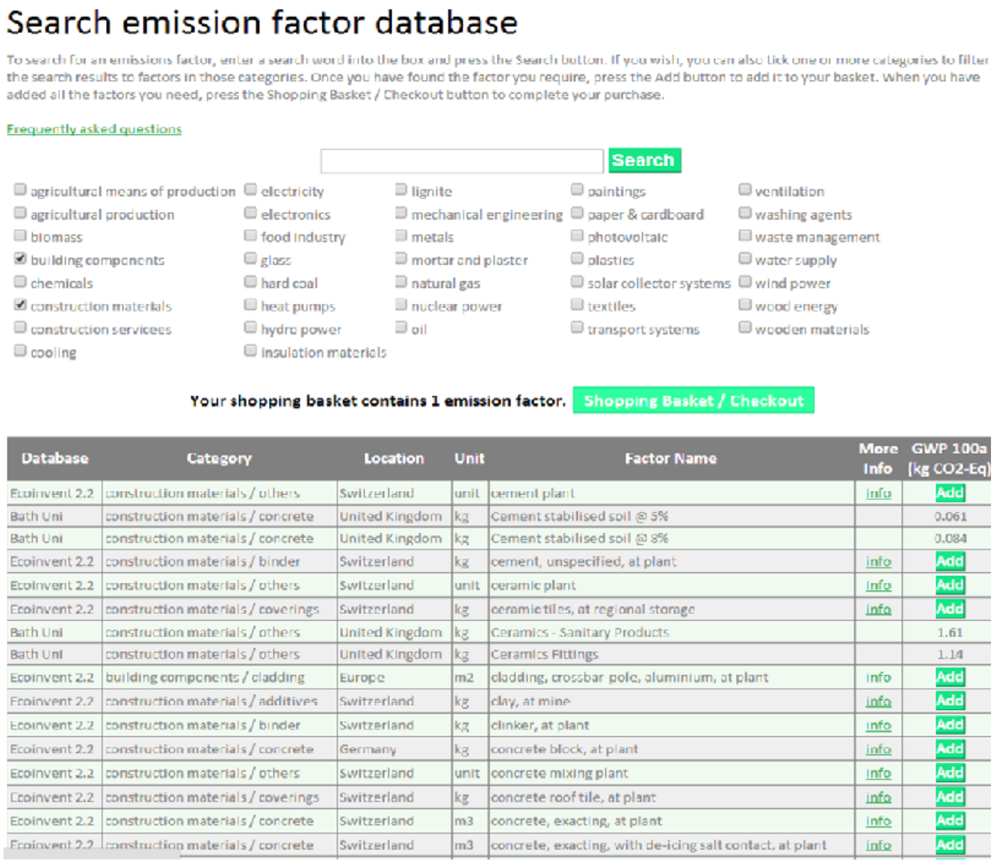
6.6 Emission Factor Database for Calculating Carbon Footprint of Housing

At present, there are several emission factor databases which can be used to calculate greenhouse gas emission as listed below.

Table 6.1 Sources of emission factor databases (WRI/WBCSD, 2014).

Databases	**Sources of databases**
Open Access Process Databases	AMEE, Australian LCA Network, Canadian Raw Materials Database, Earthster, The European Union's European Reference Life Cycle Data System (ELCD), Gemis, LCA Food Database- Denmark, CPM LCA Database (SPINE@CPM), US EPA List of Software and Databases , US Life-Cycle Inventory Database, University of Bath- Inventory of Carbon and Energy
Industry Association Data	World Auto Steel, International Stainless Steel Forum
Process Databases for Purchase	Ecoinvent, World Business Council for
Sustainable Development Umberto	
Input-Output Data	Carnegie Mellon University EIO-LCA, Open IO GHG Database, UK Department for Environment Food and Rural Affairs (DEFRA) Greenhouse Gas Conversion Factors
Additional National LCA/LCI Database Projects	LCA-National Project in Japan and Korea National LCI Database

Among these databases, the emission factors relevant to the assessment of greenhouse gas emission from house construction are mainly found in the databases from University of Bath-Inventory of Carbon and Energy (ICE) and Ecoinvent. The carbonfootprint Ltd. has compiled the available emission factor databases in their website as shown in Figure 6.3 (Carbonfootprint Ltd., 2014). The variety of emission factors are categorized as electricity, food industry, metals, building components, glass, mortar and plaster, construction material, construction services, wooden materials, insulation materials, transport systems etc. The emission factors provided from University of Bath are free of charge; however, those from Ecoinvent cost £11.94 per each emission factor. The Inventory of Carbon and Energy (ICE) studied by Prof. Geoff Hammond & Craig Jones, Department of Mechanical Engineering, University of Bath, UK was launched in 2011 (Hammond and Jones, 2011). This report provides embodied carbon (kgCO2/kg) and energy (MJ/kg) of various materials that are commonly used for building and road construction. The ICE database contains data for over 200 materials, broken down into over 30 main material categories (such as cement, concrete, glass, timber, plastics, steel and etc). The embodied energy data provides the energy consumed to make a building material. This consumption of energy then gives rise to embodied carbon emissions. The ICE database remains a University of Bath resource but the download file is now hosted by Circular Ecology at https://www.circularecology.com/.



Search emission factor database

To search for an emissions factor, enter a search word into the box and press the Search button. If you wish, you can also tick one or more categories to filter the search results to factors in those categories. Once you have found the factor you require, press the Add button to add it to your basket. When you have added all the factors you need, press the Shopping Basket / Checkout button to complete your purchase.

Frequently asked questions

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- [ ] food industry
- [ ] glass
- [ ] hard coal
- [ ] heat pumps
- [ ] hydro power
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- [ ] lignite
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- [ ] metals
- [ ] mortar and plaster
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- [ ] nuclear power
- [ ] oil
- [ ] paintings
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- [ ] water supply
- [ ] wind power
- [ ] wood energy
- [ ] wooden materials

Your shopping basket contains 1 emission factor. Shopping Basket / Checkout

Database	Category	Location	Unit	Factor Name	More Info	GWP 100a (kg CO2-Eq)
Ecoinvent 2.2	construction materials / others	Switzerland	unit	cement plant	info	Add
Bath Uni	construction materials / concrete	United Kingdom	kg	Cement stabilised soil @ 5%		0.061
Bath Uni	construction materials / concrete	United Kingdom	kg	Cement stabilised soil @ 8%		0.084
Ecoinvent 2.2	construction materials / binder	Switzerland	kg	cement, unspecified, at plant	info	Add
Ecoinvent 2.2	construction materials / others	Switzerland	unit	ceramic plant	info	Add
Ecoinvent 2.2	construction materials / coverings	Switzerland	kg	ceramic tiles, at regional storage	info	Add
Bath Uni	construction materials / others	United Kingdom	kg	Ceramics - Sanitary Products		1.61
Bath Uni	construction materials / others	United Kingdom	kg	Ceramics Fittings		1.14
Ecoinvent 2.2	building components / cladding	Europe	m2	cladding, crossbar pole, aluminium, at plant	info	Add
Ecoinvent 2.2	construction materials / additives	Switzerland	kg	clay, at mine	info	Add
Ecoinvent 2.2	construction materials / binder	Switzerland	kg	clinker, at plant	info	Add
Ecoinvent 2.2	construction materials / concrete	Germany	kg	concrete block, at plant	info	Add
Ecoinvent 2.2	construction materials / others	Switzerland	unit	concrete mixing plant	info	Add
Ecoinvent 2.2	construction materials / coverings	Switzerland	kg	concrete roof tile, at plant	info	Add
Ecoinvent 2.2	construction materials / concrete	Switzerland	m3	concrete, exacting, at plant	info	Add
Ecoinvent 2.2	construction materials / concrete	Switzerland	m3	concrete, exacting, with de-icing salt contact, at plant	info	Add

Figure 6.3 The web page of emission factor databases available online at http://www.carbon footprint.com/factors.aspx (Carbonfootprint Ltd., 2014).

By following the concept of LCA, carbon footprint of house construction can be scientifically evaluated. Barrett and Wiedmann (2007) studied a comparative carbon footprint analysis of on-site construction and an off-site manufactured house in UK. This report provides an understanding of the Greenhouse Gas (GHG) emissions from both house building (the production of materials used in construction) and the direct energy requirements of housing. This is calculated for an average house in the UK. The assessment of carbon footprint was based on Economic Input-Output Analysis combined with process life cycle analysis. The list of constructing materials for on-site and off-site house obtained from housing survey was shown in Tables 6.2 and 6.3, respectively.

Table 6.2 Material composition of an on-site construction house (per house) in UK (Wiedmann et al, 2003 cited in Barrett and Wiedmann, 2007).

Materials, Bricks and Mortar	kg		Bricks, Mortar and Frame	kg		Products	kg
Spoil/fill	26,400		Steel	580		Mineral wool insulation	280
Concrete (mass/slab)	28,000		Paint	75		Polyurethene ins. (HCFC)	470
Hardcore	11,600		Glass	720		Aluminium	250
Sand	960		Timber	2,900		Windows/doors uPVC	1,500
Blocks (light)	9,100		Rein. beams/lintels	940		Windows/doors timber	500
Bricks	15,840		Linoleum	2		Plasterboard	1,350
Mortar	9,000		Ceramic tile	210		Plaster	3,000
			Membranes	1,200		Roofing tiles	2,400

Table 6.3 Material composition of an off-site construction house (per house) in UK (John Prewer cited in Barrett and Wiedmann, 2007).

Products	kg		Products	kg
Steel	306		Windows/doors uPVC	100
Paint	4		Windows/doors timber	292
Glass	17		Fermacell	747
Timber	138		Plaster	142
Rein. beams/lintels	45		Ceramic tile	10

The results indicated that the total GHG emissions of all the materials and products for on-site and off-site constructions were 0.66 tonnes and 0.25 tonnes CO_2e per m^2 of floor space. The carbon dioxide emission from indirect energy uses accounted for 70% of total emission. The rest emissions were from constructing material (16%), household maintenance (9%) and transportation (5%).

6.7 Review of Embedded Energy and Carbon in Residential Sector

In Thailand, greenhouse gas emission from house construction was studied by Aransiri (2010) and Aneksaen (2011). Aransiri (2010) studied greenhouse gas emission from various houses construction methods such as using masonry, precast concrete and knockdown methods in Bangkok, Thailand. The data was collected for 3 months from the construction sites. The housing spaces of masonry house, precast house and knockdown house were 155 m^2, 150 m^2 and 30 m^2, respectively. The greenhouse gas emission was calculated from production of construction materials (Cradle-to-Gate$_1$) plus construction process (Gate$_1$-to-Gate$_2$) using SimaPro 7.1 program. The results showed that the greenhouse gas emission from masonry, precast and knockdown construction materials were 187 $kgCO_2eq./m^2$, 110 $kgCO_2eq./m^2$ and 25 $kgCO_2eq./m^2$, respectively. While greenhouse gas emission from masonry, precast and knockdown construction process (Gate$_1$-to-Gate$_2$) were 5.08 $kgCO_2eq./m^2$, 0.65 $kgCO_2eq./m^2$ and 4.19 $kgCO_2eq./m^2$, respectively. The greenhouse gas emitted from the masonry house was 97% from materials and 3% from construction process.

For precast and knockdown houses, 99% and 86% were from materials and the rests were from construction process. Types of envelope materials significantly affect electrical consumption during use phase. The annual electrical consumptions of a house built from masonry, concrete and wood cement board with a certain house plan analysed by VisualDOE 4.0 simulation were 9,438 kWh, 8,234 kWh and 5,494 kWh, respectively.

Aneksaen (2011) investigated energy consumption and greenhouse gas emission from residential construction in Bangkok, Thailand. The activity data were collected from 42 samples which were built by different materials and different styles which are contemporary style, modern style and Thai-modern style. The samples were classified in to three different sizes: small (120-180 m^2), medium (181-350 m^2) and large (351-500 m^2). The greenhouse gas emission in the unit of $kgCO_2e /m^2$ was calculated from three scopes: 1) the acquisition of construction materials (Cradle-to-$Gate_1$) of which the data came from transaction price and quantity of materials (Bill of Quantities), 2) the construction process ($Gate_1$-to-$Gate_2$) and 3) the energy consumption during use phase of the residential houses calculated by the EnergyPlus program. The results indicated that the highest greenhouse gas emissions excluding the greenhouse emission during use phase was belong to the precast house (237.51 ± 40.08 $kgCO_2e /m^2$) followed by the brick house (215.61 ± 36.09 $kgCO_2e /m^2$), lightweight concrete house (194.65 ± 26.56 $kgCO_2e /m^2$) and half wood-half concrete house (4.41 ± 36.91 $kgCO_2e /m^2$), respectively. Considering the size of the house (mixed house models), the large house emitted greenhouse gas less than small and medium-size house. The greenhouse gas emission from large house contributed 82.79 ± 94.14 $kgCO_2e /m^2$, while that from small and medium-sized house contributed 133.24 ± 40.61 $kgCO_2e /m^2$and 120.35 ± 55.15 $kgCO_2e /m^2$. House style also plays an important role in greenhouse gas emission. It was found that the modern house, Thai-modern and contemporary emitted 4.41 ± 36.41 $kgCO_2e /m^2$, 240.65 ± 82.86 $kgCO_2e /m^2$and 253.09 ± 20.63 $kgCO_2e /m^2$, respectively. Interestingly, 98 percentages of greenhouse gas emissions sources came from building materials and only 2 percentages came from construction processes. The differences of wall materials also affected the electricity consumption during use phase of residential houses. The annual electricity consumed for air conditioner of the houses made from lightweight concrete, hardwood, concrete and brick was 18.92 $kWh/m^2/y$, 25.30 $kWh/m^2/y$, 27.23 $kWh/m^2/y$ and 28.89 $kWh/m^2/y$, respectively. Accordingly, the 25-year greenhouse gas emissions during residential phase was emitted from lightweight concrete house (798.45 $kgCO_2e /m^2$), followed by concrete house (813.66 $kgCO_2e /m^2$) and brick house (842.52 $kgCO_2e /m^2$) and Thai-modern house (491.11 $kgCO_2e /m^2$) which is the least emission. This study proposed the alternatives to to reduce energy consumption and greenhouse gas emission from residential houses such as using alternative wall insulation which has low thermal mass and low heat storage, increasing at least 1 ^oC for temperature setting of air conditioner and using alternative glass which has low solar heat gain coefficient. The overall energy reduction and greenhouse gas emission reduction after implementing these options were 995.75 kWh/y and 558.62 $kgCO_2e /y$.

The studies of greenhouse gas emission and energy consumption from house construction were also found in Scotland, the United States, Spain, UK, Hong Kong, China, Korea and Japan. The reviews of these studies are presented as follows.

Upton, *et al*. (2008) estimated the savings of greenhouse gas emissions and energy consumption associated with use of wood-based building materials in residential construction in the United States. The relevant activity data used in this study were developed by the Consortium for Research on Renewable Industrial Materials. Results indicate that houses with wood-based wall systems require 15–16% less total energy for non-heating/cooling purposes than thermally comparable houses employing alternative steel- or concrete-based building systems. Over a 100-year period, net greenhouse gas emissions associated with wood-based houses are 20–50% lower than emissions associated with thermally comparable houses employing steel- or concrete-based building systems. By assuming 1.5 million single-family housing starts per year, the difference between wood and non-wood building systems represents about 9.6 Mt of CO_2 equivalents per year. The corresponding energy benefit associated with wood-based building materials is approximately 132 PJ $year^{-1}$. These estimates represent about 22% of embodied energy and 27% of embodied greenhouse gas emissions in the residential sector of the US economy. However, the conclusion from this study excluded the concern of deforestation effect due to harvesting wood from forest.

In Spain, the total amount of CO_2 emissions in the particular phase of material selection within the life cycle of three dwellings in Valladolid were studied by Gonzalez and Navarro (2006). The compound building is composed of three terraced houses with 125 m^2 of housing surface, 50 m^2 of underground garage and a 119 m^2 garden for each one of them. In total, the research was carried out on a constructed surface of 526 m^2. The research was carried out on a case study of three terraced houses, comparing them with a building with similar characteristics but constructed in a conventional way and with no selection of materials. The embodied energy and carbon were carried out in MJ/kg units and kg CO_2/kg units, respectively. It was found that aluminium has the highest embodied energy and CO_2 emission as 191.00 MJ/kg and 3.0847 kg CO_2/kg, respectively. While wood has the embodied energy of 3.10 MJ/kg and CO_2 emission of 0.0000 kg CO_2/kg. The CO_2 emissions for different types of construction were varied from 250 to 400 kg/m^2. The reduction of CO_2 emission achievable by correct material selection used in construction was 27.28%.

In China, greenhouse gas emissions in the construction stage of house were studied by Mao (2013). This study investigated the differences of greenhouse gas emissions between prefabrication and conventional construction methods. The greenhouse gas was estimated from five emission sources for the semi-prefabricated construction process: embodied emissions of building materials, transportation of building materials, transportation of construction waste and soil, transportation of prefabricated components, operation of equipment, and construction techniques. A quantitative model was then established using a process-based method. A semi-prefabrication project and a conventional construction project in China were employed for preliminary examination of the differences in greenhouse gas emissions. Results show that the semi-prefabrication method produces less greenhouse gas emissions per square meter compared with the conventional construction, with the former producing 336 kg/m^2 and the latter generating 368 kg/m^2. The largest proportion of total greenhouse gas emissions comes from the embodied emissions of building materials, accounting for approximately 85%. Four elements that positively contribute to reduced emissions are the embodied greenhouse gas emissions of building materials, transportation of building materials, resource consumption of equipment and techniques, and transportation of waste and soil, accounting for 86.5%, 18.3%, 10.3%, and 0.2%, respectively, of reduced emissions. A negative effect on reduced emissions is the transportation of prefabricated components, which offsets 15.3% of the total emissions reduction. Thus, adopting prefabricated construction methods contribute to significant environmental benefits on greenhouse gas emissions.

Yan, *et al*. (2010) studied greenhouse gas emissions in building construction in Hong Kong. The emissions from four sources, which are manufacture and transportation of building materials, energy consumption of construction equipment, energy consumption for processing resources, and disposal of construction waste, were calculated by using greenhouse gas calculation model. The results show that 82–87% of the total greenhouse gas emissions are from the embodied greenhouse gas emissions of building materials, 6–8% are from the transportation of building materials, and 6–9% are due to the energy consumption of construction equipment. The results also indicate that embodied greenhouse gas emissions of concrete and reinforced steel account for 94–95% of those of all building materials. Hui suggested that using recycled building materials, especially reinforced steel, would decrease the greenhouse gas emissions by a considerable amount.

In the Republic of Korea, apartment buildings occupy a high portion (86.4%) of total residential buildings. According to Jeong, *et al*. (2012), CO_2 emissions emitted by six different size apartment units due to major construction materials consumed in construction were estimated. The result shows that CO_2 emission of the various construction materials of an apartment unit was estimated to be 569.5 kg-CO_2/m^2. The apartment with the area of 84.9 m^2 for a common apartment type in Korea has about 11.8 TOE embodied energy and 45.1 ton-CO_2 emission. The CO_2 emissions from steel and concrete were 424.2–584.2 kg-CO_2/m^2 for apartment units, occupying more than 82% of the total CO_2 emissions. The results are valuable for the sustainable design of apartment complexes and are used as technical measures for the CO_2 reduction strategy of the building sector.

In Japan, Suzuki *et al.* (1995) applied basic sector classification Input/Output Tables in 1988 provided from Japan Research Committee of International Trade and Industry to quantify the total energy consumption and CO_2 emission including direct and indirect effects due to the construction of various types of houses. As a result, energy consumption for construction is calculated as 8–10 GJ per square meter of floor area for multi-family SRC (steel reinforced concrete) houses, 3 GJ for wooden single-family houses, 4.5 GJ for lightweight steel structure single-family houses. CO_2 emission resulting from construction is 850, 250 and 400 kg/m^2, respectively.

According to these studies, embodies energy and greenhouse gas emission of construction materials especially cement and steel play a major role in climate change. The development of low carbon embedded materials has been widely researched. Kenneth (2012) studied the environmental impacts of hemp–lime walls made in UK. The study follows assessment procedures and guidelines of international (ISO14040) and UK (PAS2050) standards. The functional unit defined for the hemp–lime wall construction is 1 m square in area, 300 mm thick with timber frame support inside. Primary data were collected for processes and materials that have no existing information. Other processes with impact data available from credible database were adapted in the assessment by taking into account the conditions and practice in the UK. Assessment was carried out using the SimaPro LCA tool over a lifetime of 100 years. Within the boundary and assumptions made, results showed the functional unit could sequestrate 82.7 kg of carbon dioxide with a net life cycle reduction of greenhouse gas emission of 36.08 kg CO_2e.

In Sweden, the complete life cycle of the construction materials for new and multi-storey building with a wood frame called "WaKlluddena", in Vaxjo, southern Sweden was investigated by Borjesson, *et al*. (2000). The building being studied has 16 apartments on 4 floors with an average living area per apartment of 65 m^2.The foundations consist of concrete slabs, and there is no basement. Two-thirds of the facade is plastered with stucco. The facades of the stairwells and the window surrounds are covered in wood panelling. The outer walls consist of three layers, including plaster on plaster-compatible mineral wool panels, 120 mm deep timber studs with mineral wool between the studs, and a wiring and plumbing installation layer with 70 mm deep timber studs and mineral wool. The floor frame consists of light timber joists, consisting of several layers to provide a total thickness of 420 mm. All rooms, except for the bathroom, have parquet floors. The analysis includes the environmental impacts from the recovery of raw materials, via manufacturing of building materials, to the handling of demolition waste. The net GHG balances will then mainly be a function of: (i) fossil-fuel consumption in the production of construction materials, (ii) changes in biological carbon stocks in forests, (iii) methods used for the processing of demolition wood, and (iv) the CO_2 released from the chemical processes taking place in the production of cement and the rebinding of CO_2 in hardened concrete during carbonization. The results found that the primary energy input, assumed to be based mainly on fossil fuels, in the production of building materials needed in the WaKlludden building would be about 60-80% higher when concrete frames are used instead of wood frames. If concrete frames are used, the net greenhouse gas balance will be higher, about 60-70 tons carbon equivalents for the emission of CO_2 released from fossil energy systems and for the chemical processes in the production of cement.

References

B. Upton, R. Miner, M. Spinney and L. S. Heath, 2008, "The greenhouse gas and energy impacts of using wood instead of alternatives in residential construction in the

Carbon Trust, 2008, Guide to PAS 2050 How to assess the carbon footprint of goods and services: British Standards Institution, PAS 2050:2011.

Carbon Trust, 2014, Carbon footprinting guide, online, http://www.carbontrust.com, Feb 20, 2014.

Carbonfootprint Ltd., 2014, Search emission factor database, online, http://www.carbonfootprint.com/factors.aspx, Feb 21, 2014.

C. Mao, 2013, "Comparative study of greenhouse gas emissions between off-siteprefabrication and conventional construction methods: Two casestudies of residential projects", **Energy and Buildings**, Vol.66, pp. 165-176.

E. Selvig, Civitas Consultants, 2008, Greenhouse Gas Emission Accounting Tool for Buildings, online, http://ostfoldforskning.no/uploads/dokumenter/NorLCA/Presentasjon/NorLCA_Selvig.pdf, Feb 20, 14.

G. Hammond and C. Jones, 2011, The Inventory of Carbon and Energy (ICE), University of Bath, UK.

Global Footprint Network, 2014, Carbon footprint, online, http://www.footprintnetwork.org/en/index.php/gfn/page/carbon_footprint/, Feb 20, 2014.

H. Yan., Q. Shen, L. C.H. Fan, Y. Wang and L. Zhang, 2010, "Greenhouse gas emission in building construction: A case study of One Peking in Hong Kong", **Building and Environment**, Vol. 45, pp. 949-955.

J. Barrett and T. Wiedmann, 2007, A Comparative Carbon Footprint Analysis of On-Site Construction and an Off-Site Manufactured House, Research Report 07-04, Stockholm Environment Institute and ISAUK Research & Consulting.

K. Aransiri, 2553, “Greenhouse Gas Emission from Building Construction Materials and Process”, Thesis of Master of Engineering in Environmental Technology, School of Energy, Environment and Materials, King Mongkut’s university of Technology Thonburi.

K. Ip, 2012, “Life cycle greenhouse gas emissions of hemp–lime wall constructions in the UK”, **Resources Conservation and Recycling**, Vol.69, pp. 1-9.

M. J. Gonzalez and J. G. Navarro, 2006, “Assessment of the decrease of CO2 emissions in construction field through the selection of materials: Practical case study of three houses of low environmental impact”, **Building and Environment**, Vol. 41, pp. 902-909.

M. Suzuki, T. Oka, and K. Okada, 1995, “The estimation of energy consumption and CO_2 emission due to housing construction in Japan”, **Energy and Buildings**, Vol.22, pp. 165-169.

N. Aneksaen, 2554, “Carbon Intensity of Residential Buildings in Thailand”, Thesis of Master of Engineering in Environmental Technology, School of Energy, Environment and Materials, King Mongkut’s university of Technology Thonburi

P. Borjesson and L. Gustavsson, 2000, “Greenhouse gas balances in building construction:wood versus concrete from life-cycle and forest land-use perspectives”, **Energy Policy,** Vol.28, pp.575-588.

S. Lundie, M. Schulz, G. Peters, 2009, Carbon Footprint Measurement, Centre for Water and Waste Technology, Scion and AgResearch.

The Intergovernmental Panel on Climate Change (IPCC), 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, the National Greenhouse Gas Inventories Programme, Institute for Global Environmental Strategies, Japan.

The Department for Planning, Transport and Infrastructure (DPTI), 2012, Greenhouse Gas Accounting Tool for Construction Guidelines, Adelaide, SA 5000.

United States”, **Biomass and Bioenergy**, Vol.32, pp 1-10.

World Resources Institute and World Business Council for Sustainable Development (WRI/WBCSD), 2014, Greenhouse Gas Protocol Product/Supply Chain Initiative:List of Available Data Sources, online, http://www.theclimateregistry.org/downloads/2010/02/GHG-Protocol-List-of-Data-Sources-February-2010.pdf, Feb 21, 14.

Y.S. Jeong, S.E. Lee and J.H. Huh, 2012, “Estimation of CO2 emission of apartment buildings due to major construction materials in the Republic of Korea”, **Energy and Buildings**, Vol.49, pp. 437-442.

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