Department of Mechanical Engineering

Renewable Energy System for Household in Thailand

Author:
Chatchawat Chungrakkiat

Supervisor:
Prof. Joseph Clarke

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Signed: Chatchawat Chungrakkiat Date: 9 September 2011

Abstract

This project aims to investigate the best match renewable energy system for Thai household to solve the electrical power distribution problem and reduce the fossil fuel consumption of electrical power generation for Thai residential sector. However, the cooling load is the most important section of Thai residential energy consumption. Therefore, this study also creates hourly cooling load data that can be a representative of the average cooling load demand of household in Thailand to implement the realistic matching renewable energy supply with electrical power demand.

In order to validate the electrical power consumption of house model in this study, the results of cooling load demand from ESP-r software and total electrical power demand were verified with the national statistic. This study also found that the cooling load demand of the house that bedrooms facing to the north could be lower than the cooling load demand of the house that bedrooms facing to the east approximately 2.9%. Furthermore, adding three inches of the fiberglass to the ceiling possibly reduce the cooling load demand by 19%.

Finally, this project represents that the solar power system, which composed of 3.145kW PVs connecting with twenty two 200Ah batteries, would be the best match renewable energy system for the average cooling load demand of households in Thailand. This renewable energy system probably serves the electricity to all electrical loads without the period of the energy deficit. Moreover, changing from AC cooling system to DC cooling system would help to decrease the energy loss of the power system by 20%.

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Renewable Energy System for Household in Thailand

Chapter1: Introduction

1.1 Overview

Electricity is one of the most significant infrastructures in Thailand. In 2009, total electrical power consumption in Thailand was approximately 135,209 GWh (Electrical Power in Thailand, 2009). In addition, electrical power generation from government sector was about 51% of total electrical power generation in Thailand. The electrical power generation from private sector was about 49% of total electrical power generation in Thailand. Most of electrical power was generated by thermal power plant, combined cycle power plant, gas turbine power plant, and co generation power plant. Consequently, main power generation sources in Thailand are fossil fuels such as natural gas, coal, and lignite. Electrical power production was generated from natural gas approximately 98,000 GWh. Electricity from gas was about 66% of total electrical power production in Thailand. Furthermore, Electrical power production from coal and lignite was approximately 19% of total electrical power production in Thailand. This proportion of electrical power was produced from 28,020 Gwh of coal and lignite. As a result, electrical power production has been relied on the fossil fuels. The price of fossil fuels in the world market has increased every year due to high demand.

Some fossil fuels, which have been used to produce the electrical power in Thailand, have been imported from the neighbor countries such as Myanmar. Thus, cost of electrical power tends to increase further. Due to the insufficient domestic fossil fuels, Thailand may face the problem of high electricity cost in the future.

In 2009, 135,209 GWh of electrical power consumption in Thailand was divided into six sectors, which are the industrial sector, commercial sector, residential sector, agricultural sector, transportation sector, and other sector (Electrical Power in Thailand, 2009). The major electricity consumers in Thailand are commercial sector and residential sector. The electrical power consumption of commercial sector was approximately 47,092 GWh or about 34.8% of total electrical power consumption in Thailand. From this statistic, commercial sector has been the biggest electrical power consumer. The residential sector is the second biggest consumer that consumed 30,371 GWh in 2009. The amount of electricity consumption by residential sector was about 22.5% of electricity consumption in Thailand. Although commercial sector was the biggest electricity consumer in 2009, the electrical power consumption of residential sector increased from electrical power consumption in 2008 by approximately 5.5%. The electricity consumption of commercial sector rose from electrical power consumption in 2008 by about 2.2%. In addition, the electrical power consumption of residential sector tends to enlarge further. Therefore, the residential sector is one of the important electrical power consumers in Thailand.

Because of the population and residential household expansion to the remote area, Thai government cannot distribute electrical power to all households in Thailand. Electrical Power in Thailand (2009) reported that there were about 21,143,975 households in 2009. In contrast, Thailand had 3,005,963 unelectrified households, which were about 14% of total households around Thailand. In addition, Thailand may face the energy shortage in the future.

Phupha et al. (2010) represented in their study that Thailand will have a chance to face the energy crisis in the future. Thailand may be in the dark world in the next twelve years. Their research found that Thailand could have the energy problem in 2016 because the electrical power consumption could be higher than the electrical power production in that year. They forecasted that the electrical power consumption in 2016 may be 44,585 MW while the electrical power production may be 44,562 MW. Therefore, Thailand could not have enough electrical power to serve to all consumers. Furthermore, their research stated that electrical power source in Thailand, such as natural gas from the gulf of Thailand, could be used up by 2030.

How can Thailand solve the electricity distribution problem of household and reduce the fossil fuel consumption from electrical power generation to prevent energy shortage in the future?

One solution is the renewable energy power system that can be used to generate electrical power for unelectrified households and reduce fossil fuel consumption from electricity generation.

1.2 Scope and Objective

This study aims to find the best match renewable energy system for the majority of Thai households. Due to the forecast of insufficient energy, the best match renewable energy system should be work well with average energy demand profile of households in Thailand throughout the year without the period of energy deficit. From the assumption about the best match renewable energy, the electrical power demand in this study should be the representative of average electricity demand of household in Thailand. Almost a half of electrical power consumption of household in hot and humid country like Thailand is the cooling load demand. In order to make the result of best match renewable energy system be more realistic, this study need hourly cooling demand of Thai household to do the matching of electrical power supply and electricity demand hour by hour. Another significant objective in this study is to create hourly cooling load demand that can be the representative of hourly average cooling load from households in Thailand.

Chapter2: Literature review

Two main objectives in this study are to create hourly cooling load data, which is the representative of average cooling load demand of households in Thailand, and investigate the best match renewable energy system for average energy demand of household in Thailand. Therefore, the literature review in this study was divided into two parts. First part is regarding the cooling load evaluation. Second is the potential of renewable energy resources in Thailand.

2.1 Cooling load and heat gain

Basically, Electrical power consumption of household in Thailand composed of lighting load, electrical appliance load, and cooling load. Approximately 42.8% of energy consumption in Thailand was the cooling load (PEER Review on Energy Efficiency in Thailand, 2010). Hence, cooling load is the important demand in the residential sector.

Air conditioning cooling system is the machine, which is designed to remove the heat within the building and control the temperature inside the building at desired temperature. Therefore, the cooling load can be estimated from the heat in the building. The more heat gains in the building, the more cooling load to remove heat in the building.

2.1.1 Two forms of heat

There are two forms of heat influencing the cooling load.

Sensible heat

Generally, the temperature of substance increases after it is heated. The heat energy, which is added to substance, is called sensible heat. In addition, heat is taken away from substance and the temperature of substance is dropped. It is also called sensible heat. Therefore, heat that changes the temperature of substance without changing state of substance is the sensible heat.

Latent heat

Heat that influences the substance changing state without changing the temperature is called latent heat. For example, the temperature of water is 100 degree Celsius while it is heated and water is still liquid. Heat which is added to 100 degree Celsius water is latent heat.

In the cooling system, the condensation is used to take latent heat away from the air in the building. Furthermore, latent capacity of the cooling system is significant to decrease the moisture in the building. Sensible capacity is important to reduce the zone temperature in the building (Daikin, n.d.).

2.1.2 Factors affect cooling load

Following factors influence heat gain and heat loss in the building, which affect the cooling load evaluation.

Internal heat gain

Basically, the internal heat gains come from the source as follow

- Occupant
- Lighting
- Electrical appliance

Heat gain from occupant composed of sensible heat gain and latent heat gain. Lighting can generate just the sensible heat to the building. Types of light bulb and lighting installation can influence the amount of heat gain in the building (Saikwong, 2010). Electrical appliance can produce only sensible heat or both sensible heat and latent heat to the building. The electrical appliances that generate steam or vapor, such as cooking appliances, can generate both sensible heat gain and latent heat gain in the building. In contrast, some electrical appliances, such as television, can generate only sensible heat gain in the building. Occupants that are doing different activities may generate different amount of sensible heat gain and latent heat gain to the building (Saikwong, 2010). Furthermore, building design also influence the heat gain from occupant as well.

External heat gain and heat loss

Infiltration

Infiltration is the natural air exchange through the cracks or space on the building envelopes such as wall, ceiling, door, window, and roof. Heat can transfer through this air exchange. This infiltration is influenced by the pressure of wind and the different density of ambient temperature and the temperature inside the building.

The estimation of infiltration rate is relatively difficult because

- It is difficult to know the exact area of cracks.
- The coefficient of wind and stack are difficult to be determined.
- The same building design may have different infiltration rate.

By the way, ASHRAE studied about the infiltration rate of various house designs, which have the infiltration rate from 0.4 air changes per hour to maximum infiltration rate3.5 air changes per hour. This organization guided that the old house design, which does not have the sealing of the gaps around the building envelopes or materials covered the gaps, could have the average infiltration rate about 0.9 air changes per hour. The new home designs, which have better construction and weather stripping, could have infiltration rate 0.5 air changes per hour (Turner and Doty, 2006).

Direct solar gain

Direct solar gain is the heat transmission directly by the solar radiation. Direct solar gain can go inward the building through the transparent building construction for instance window.

Heat gain through building envelopes

Heat gain through building envelopes can occur as follow. Heat from ambient transmits into the building through the building envelopes when ambient temperature is higher than temperature inside the building (Saikwong, 2010). In addition, Heat transmits outward to ambient when the temperature inside the building is higher than the ambient temperature.

Normally, Heat will flow from high temperature point to low temperature point. Moreover, heat movement can occur by following ways.

2.1.3 Heat transfer methods

Conduction

When the substance touches with other substance, the substance that has higher temperature will transfer heat energy to the substance that has lower temperature. This heat conduction can occur between direct contact substances. In addition, the factors such as the area of substance, the temperature of substance, the length of substance, and the material of substance can influence the rate of heat movement between substances. Solid can conduct heat greater than liquid and liquid can conduct heat greater than gas. So, gas is poor heat conductor. Furthermore, heat conduction does not require the bulk motion of substance.

Convection

The heat movement by the convection can occur in liquid or gas. Basically, the liquid or gas that has high temperature will rise to the liquid and gas that has lower temperature. Therefore, the risen liquid or gas is replaced with the liquid or gas that is lower temperature. Thus, hot liquid or gas will rise and cool liquid or gas will fall. Heat convection requires the movement of liquid or gas to transfer heat.

Radiation

Heat radiation does not have to contact with the substance like heat conduction and heat convection. Heat radiation transfers heat through the electromagnetic wave. For example, the sun transmits heat energy to the earth by the electromagnetic radiation.

2.1.4 Building energy performance simulation tool

ESP-r is the dynamic simulation tool for modeling heat flow, fluid flow, and electrical power flow within the desire building integrated the control system (Samuel et al., 2003). In addition, ESP-r can be used to determine the energy performance of the building. Moreover, ESP-r is able to generate hourly cooling load from the model. Many advantages of ESP-r are as follow.

- Weather data of many locations including Thailand are available to be imported to do the simulation in ESP-r.

- ESP-r allows user to model the complex building design, which is important to assess the energy performance of the building.
- The significant factors that affect the energy performance of the building are able to be defined in ESP-r. Therefore, the result of building energy performance is realistic with the simulation in ESP-r.
- ESP-r evaluates the energy performance of building in hourly data, which are appropriate for the further study with other software.

2.2 Renewable energy resources in Thailand and stand alone renewable energy system.

This section describes briefly some renewable energy resources that could be appropriate to the match power system and stand alone power system, which is suitable for this study.

2.2.1 Renewable energy resources in Thailand

2.2.1.1 Solar energy

The average solar radiation in Thailand can be estimated from the solar map of Thailand, which was developed by Department of Alternative Energy Development in 1999. Average solar radiation in Thailand was about 18.2 MJ/m2-day. The highest solar radiation in Thailand was from 20 MJ/m^2-day to 24 MJ/m^2-day or about 5.556-6.6672 kWh/m^2/d. Thailand received the highest range of solar radiation during the summer from April to May. Areas that received highest range of solar radiation were in Burirum, Sisaket, Yasothorn, Ubonratchathanee, NakornRatchasima, Surin, Roiet, and Udornthanee. These areas are in northeastern region of Thailand. Some areas in central region, such as Chainat, Lopburi, Suphanburi, and Ayuthaya, also received the highest solar radiation.

The average solar radiation in Thailand could be divided into three levels. The first level is from 19-20 MJ/m^2-day or about 5.278-5.556 kWh/m^2/d, which covered 14.3% of total area in Thailand. The second level is from 18-19 MJ/m^2-day or about 5.004-5.278 kWh/m^2/d, which covered 50.2% of total area in Thailand. Moreover, the third level is less than 18 MJ/m^2-day.

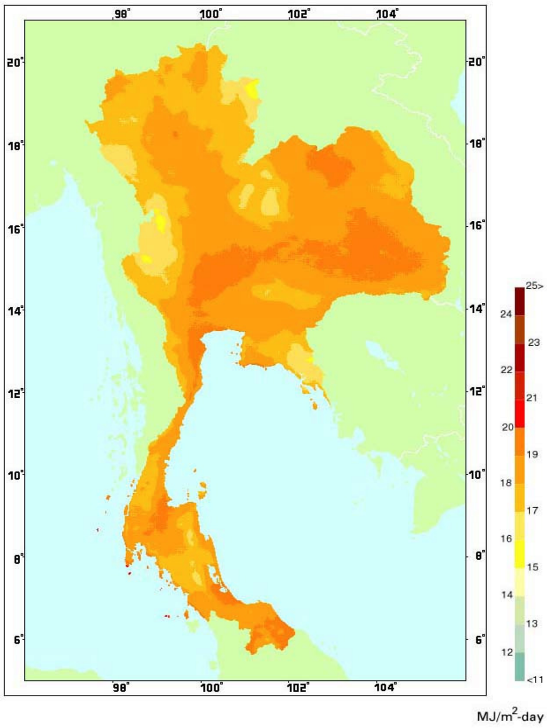

Figure1: Solar energy map of Thailand

Source: *Department of Alternative Energy Development and Efficiency of Thailand, 1999*

Solar energy in Thailand can be divided into two sections. The first section is solar energy to make hot water. There are some households in Thailand installed solar thermal system to produce hot water but they are just small proportion of total households in Thailand. Thermal solar hot water system in Thailand is not popular because the climate in Thailand is hot. However, solar hot water system in Thailand could succeed in large organization such as hospital and hotel.

Second section is Photovoltaic, which is used to generated electrical power. Most PVs in Thailand are stand alone system, which generate electricity for remote area. There is almost 10% of PVs are grid connected system. Total electrical power production form solar power system in Thailand is about 28800 MWh. Most solar power systems were implemented by government sector. At the moment, electricity from PV in Thailand is more expensive than grid electricity and other renewable energy resources such as hydro power.

2.2.1.2 Wind energy

The electrical power generation capacity from wind energy in Thailand is approximately more than 48 GW. The electrical power production from wind energy in Thailand is less than 0.001% of electrical power production in the world. The electrical power generation from wind energy in Thailand is very small scale because the wind speed in Thailand is unattractive.

Average wind speed and characteristic	Poor (<6m/s)	Fair (6-7m/s)	Good (7-8m/s)	Very Good (8-9m/s)	Excellent (>9m/s)
Land area (sq. km.)	477,157	37,337	748	13	0
% of Total land area	92.6	7.2	0.2	0	0

Table1: Wind potential in Thailand

Source: *Major et al., 2008*

Table1 shows the potential of wind energy in Thailand. About 0.2% of total area in Thailand has wind speed more than 7 m/s. the area that has wind speed from 6-7 m/s is 37,337 sq.km or about 7.2% of total area. Most area that is 477,157 sq.km or about 92.6% of total area has wind speed less than 6 m/s (Major et al., 2008). It can be concluded that Thailand has poor wind energy source.

Wind energy in Thailand would not be attractive energy resource when it is compared with other energy resources. Normal wind turbine would not be suitable to be installed in Thailand because normal wind turbine starts to produce energy at 5 m/s wind speed (Major et al., 2008). Thus, Thailand should investigate more about technology of low speed wind turbine to improve the energy production from the power system. Other equipment in wind energy system, such as battery, should be improved to increase energy performance as well.

In 2003, total electrical power capacity of onshore wind turbines in Thailand was about 95 MW. The size of wind turbine was less than 1MW. Most onshore wind turbines in Thailand were in northern region, northeastern region, and south region. Most of them are grid connected system to supply electrical power to households in local area (Renewable Energy Potential-Country Report of Thailand, 2006). Furthermore, cost of power production from wind energy is higher than solar energy and hydro power. However, Thailand expects to increase electrical power consumption from wind energy to be 5% of total electricity consumption in country. There is no offshore wind power in Thailand at the moment because lack of technology and power resource.

2.2.1.3 Hydro power

At the present, electrical power from hydro power in Thailand is the large scale hydro power plants, which were installed in big water resources around the country. However, there are about twenty one small hydro power plants in Thailand. Fifteen small hydro power plants are in northern region while another six small hydro power plants were installed in other parts of Thailand. Total 40,688 kW of hydro power capacity were installed in Thailand and can generate about 80.3 kWh (Chamamahattana et al., 2005). All small hydro power plants supply electrical to local households and grid. 11,809 households in Thailand consume electrical power from 75 micro hydro power plants, which were installed in small villages around the country. Four 125kW micro hydro power systems were installed after that. These four micro hydro power systems generate electricity to serve to 627 houses. In contrast, micro hydro power system can be installed in specific areas because of the limitation of water resources. As half of installed hydro power systems were manufactured in Thailand, cost of power production is relatively inexpensive in all renewable energy.

2.2.1.4 Biomass

Biomass is the significant energy source in rural area of Thailand. It is used to generate heat and electricity for consumers. It is also used to produce liquid fuel to be used instead of oil. Biomass in Thailand is from two resources.

First is biomass from agriculture. Thailand is agricultural country. As a country depending on an agricultural, there are many agricultural products and agricultural waste in industry. There are three main sources of biomass in the agricultural industry. First source is sugarcane, which can be found in central region, northeastern region, and north region. Second biomass source is rice, which is available in some regions of Thailand. Last main biomass source is oil palm, which most of them are produced in southern region.

Second is biomass from wood industry. Main biomass from this industry is wood waste and timber, which are from sawmills and plywood mills (Papong et al., n.d.)

In Thailand, bagasse is used as fuel to generate steam for electrical power generation. Oil palm is used for electricity generation as well. The most important biomass for electrical power generation in Thailand is wood waste. Wood waste is used as fuel to supply steam for electricity generation process. In Thailand, there are some villages that rely on the electrical power from biomass and some villages can sell electricity from biomass to the grid however it is still small scale. In addition, electrical power from biomass is cheap when compared with PV and Wind energy. Conversely, biomass power plants in Thailand are in the agricultural areas only.

2.2.2 Stand alone power system

Stand alone power systems are not connected to the grid. That's why they are called stand alone. In addition, the stand alone power systems generate electrical power the area that the grid connection cannot serve electricity and other energy resources are not available. Most of stand alone power systems are solar power system (Photovoltaic), which convert solar energy to electricity, because the solar power system is always the most effective option for the distant rural area. Some important applications such as military and telecommunication use stand alone power system to supply electrical power to their stations. Furthermore, the features of stand alone power system are represented below (Kaundinya et al., 2009).

- Electrical demand of local area is the most significant for stand alone power system.
- The power capacity of stand alone power system is corresponded and matched with the electrical demand of consumer.
- Stand alone power system has low power capacity.
- Stand alone power system is appropriate with distant area that has low electrical demand and needs stand alone power system to work for low load factors.
- Normally, stand alone power systems use renewable energy component such as solar panel to produce electrical power. Therefore, they can produce electrical in some periods.
- Stand alone power systems need the energy storage component, such as battery, to store energy while they can generate electrical power.
- The excess electrical power from stand alone power system is useless. It cannot be sold to the grid like grid connected power system.

Chapter3: Methodology

The objectives of this research are to estimate and create hourly average cooling load demand of household in Thailand and then the best match renewable energy system that is able to supply electrical power to average electrical power demand of Thai household without period of energy deficit.

Therefore, this research is divided into two main sections to correspond to those objectives.

3.1 Hourly cooling load data of household in Thailand

This section illustrates how to estimate and create average hourly cooling load data of Thai household. Normally, the electrical power consumption of household in hot and humid country like Thailand can be divided into cooling load and lighting with other electrical appliances. In addition, APEC Peer Review on Energy Efficiency in Thailand (2010) reported that almost half of electrical power consumption in Thai household is the cooling load and another half of electrical power consumption in Thailand is lighting and other electrical appliance load. Therefore, hourly cooling load data is one of the most important parts to make the final result of the matching of demand and supply realistic and accurate. In order to calculate sensible hourly cooling load data of household in Thailand, it cannot be calculated like other electrical appliance load that is able to be estimated by multiplying the wattage of electrical appliance with number of hours that it is operated because cooling air conditioning is not operated at the full capacity all the time. Consequently, this research used ESP-r to achieve the objective in this section. ESP-r is the modeling program that is able to simulate the building in various locations to estimate the energy performance of the building. Furthermore, ESP-r also has a function to generate hourly cooling load data of the building. Hence, ESP-r was used in this research to simulate a house model that is generally used in house construction at Thailand and do building energy performance simulation to generate sensible hourly cooling load data from that house model. By doing the simulation in ESP-r, ESP-r required the details of weather data, house model, occupants, and electrical appliances. Finally, ESP-r was expected to calculate and create hourly cooling load that can be used as a representative of average cooling load demand from Thai households. In order to validate the results from ESP-r, the cooling load results were compared with the national statistic to prove that the cooling load result from simulation is close to the average cooling load demand of household in Thailand. As a result, the house model was developed to improve the energy performance to make it closer to the real cooling load of Thai household. Finally, ESP-r was expected to generate three cooling load data from three cases that are the base case and another two developed cases.

3.2 Best match renewable energy system

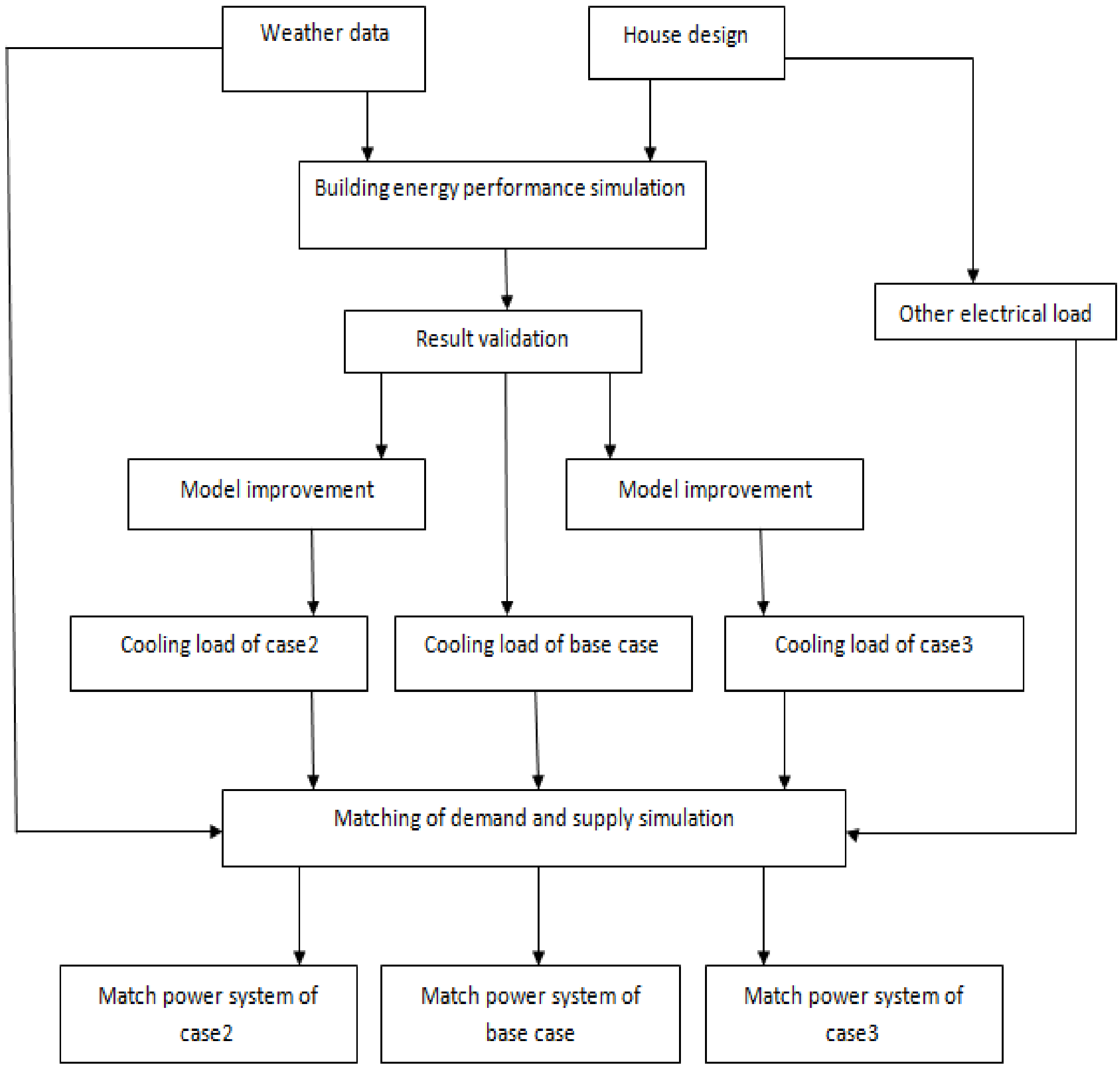

Figure2: Research design diagram

The second objective of this project is to estimate the best match renewable energy system for average energy consumption of household in Thailand. We first should determine what software would make this research to be able to achieve this objective? Homer is the software that can simulate the matching of demand profile and renewable energy system supply to estimate the match renewable energy options for grid connected or stand alone power system. Another reason that Homer was used in this research is hourly cooling load data from ESP-r is able to be imported to Homer through Excel file. Homer is able to match electrical power demand and power supply hour by hour. In addition, Homer required two main inputs except the demand profile to simulate the matching of demand and renewable energy power system supply. First, Homer needed the weather data such as solar radiation and wind speed of Thailand. This research used the same weather data as weather data were defined in ESP-r simulation. Second, Homer required electrical load data. Hourly cooling load data from ESP-r were transferred to Excel file and then it was imported to Homer. In addition, electrical loads from lighting and other electrical appliance were defined in Homer similar to they were defined in ESP-r. Finally, Homer was used to estimate the match renewable energy system options for three different cases. Then, the match renewable energy options from Homer was modeled in Merit to evaluate the match rate of renewable energy supply and electrical demand of Thai household to find best match renewable energy system, which has highest match rate. The match rate was assessed from electrical load profile and electrical supply profile.

Chapter4: Energy performance modeling and matching supply with demand simulation

This section explains the models of both building energy performance simulation to evaluate the cooling load and the matching demand with supply simulation to estimate the best match renewable energy system for Thai household.

4.1 Building energy performance simulation

Doing the simulation of building energy performance, ESP-r required many inputs such as weather data and model description. Therefore, this part explains all inputs defined in the simulation to calculate and generate cooling load data.

4.1.1 Weather data

This research is supposed to use the weather data of Thailand in the simulation. However, the weather data of Bangkok was used in the simulation as a representative of the weather data of Thailand because all parts of Thailand have the similar weather. Thailand is a small country which is situated in between 5° 30´ north latitude to 20° 30´ north latitude and 98° east longitude to 105° longitude. Due to the location of Thailand, the weather profile of most areas in Thailand is pretty the same. The electrical power report (2009) reported that the total electrical power consumptions of residential sector in Thailand were 30,371 GWh in 2009. 30.9% of total electrical power consumption by Thai residential sector was consumed in Bangkok Metropolitan region. Normally, Bangkok is the biggest electricity consumer in Thailand every year. Hence, most cooling load profile of Thailand was from the cooling load profile of Bangkok, which is affected by the weather profile. As a result, the weather data of Bangkok was used as the representative of Thai weather data. In order to prove the similarity of both weather profiles, three climate statistics of Thailand and Bangkok were assessed as follow.

4.1.1.1 Temperature

The statistics temperature in 2009, which were measured from seventy six stations around Thailand by Thai Meteorological Department, showed that annual average temperature in Thailand was approximately 27.2 degree Celsius. Furthermore, the annual average temperature in Bangkok was about 28.5 degree Celsius. Thus, the different temperature of Thailand and Bangkok was about 1.3 degree Celsius. Both statistic of Thailand and Bangkok were quite close.

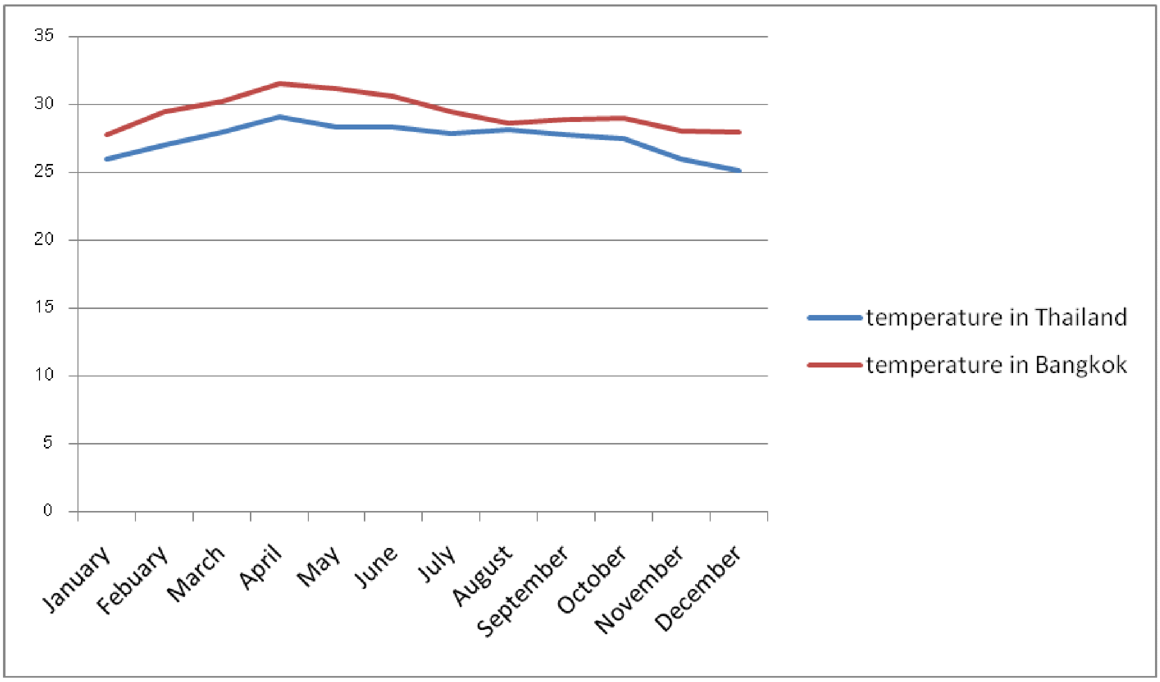

Figure3: Monthly average temperature in Thailand and Bangkok in 2009

The above chart shows monthly average temperature summary in 2009 from Thai Meteorological Department. The different temperature of Thailand and Bangkok was highest in May at about 2.8 degree Celsius. However, the different temperature of Thailand and Bangkok in each month was in the range between 0.6 -2.8 degree Celsius. The trend of monthly average temperature in Thailand and Bangkok also was quite similar.

4.1.1.2 Solar radiation

In 1999, Department of Alternative Energy Development and Efficiency of Thailand developed the solar radiation map of Thailand. This solar radiation map indicates that the annual average solar radiation in Thailand was in the range 18 – 19 MJ/m^2/day or about 5.004 – 5.278 kWh/m^2/d, which covered approximately 50.2% of total area in Thailand. The annual average solar radiation in Bangkok was in this range as well. The average solar radiation that covered about 35.5% of Thailand was slightly lower than 18 MJ/m2/d or 5.004 kWh/m^2/d. Moreover, average solar radiation that covered 14.3% of Thailand was in the range 19 – 20 MJ/m^2/day or about 5.2782 – 5.556 kWh/m^2/day. From these data, the average solar radiation in Thailand was approximately from 5.556 kWh/m^2/d to 5.004 kWh/m^2/day that is not a wide range.

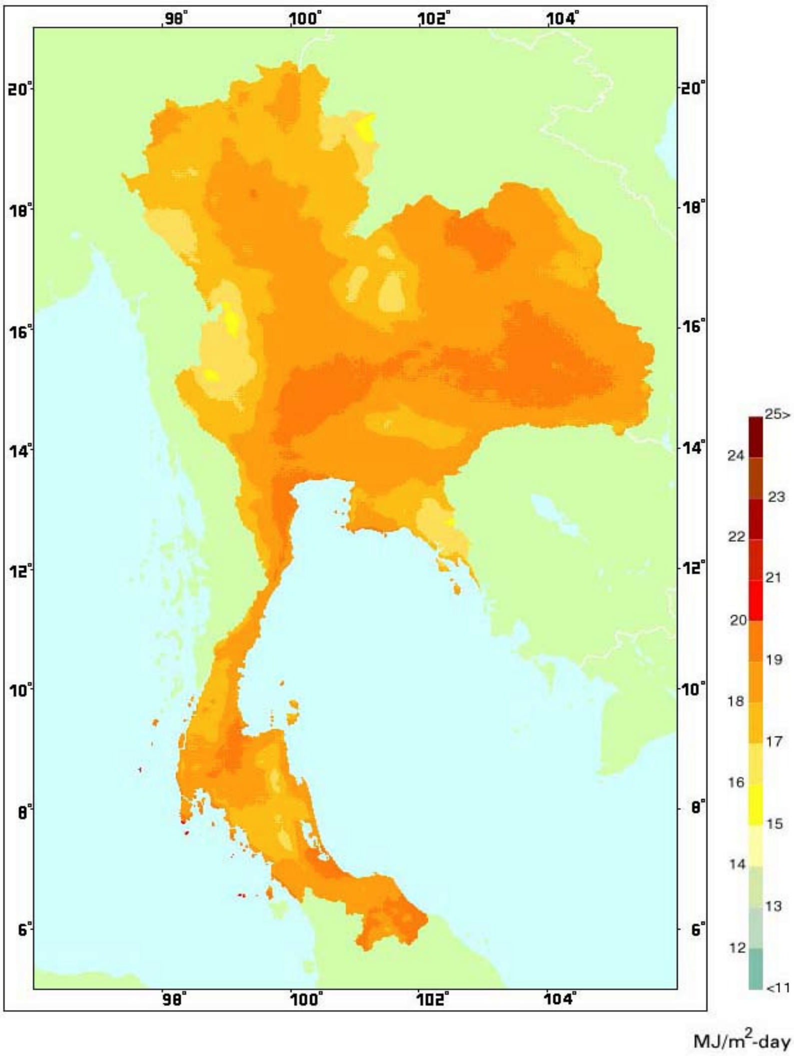

Figure4: Solar energy map of Thailand

Source: *Department of Alternative Energy Development and Efficiency of Thailand, 1999*

In 2004, Department of Alternative Energy Development and Efficiency of Thailand measured the solar radiation in 25 locations around the country. The department reported that the annual average solar radiation in Thailand was about 5.03 $kWh/m^2/d$ and the annual average solar radiation in Bangkok was about 4.83 $kWh/m^2/d$.

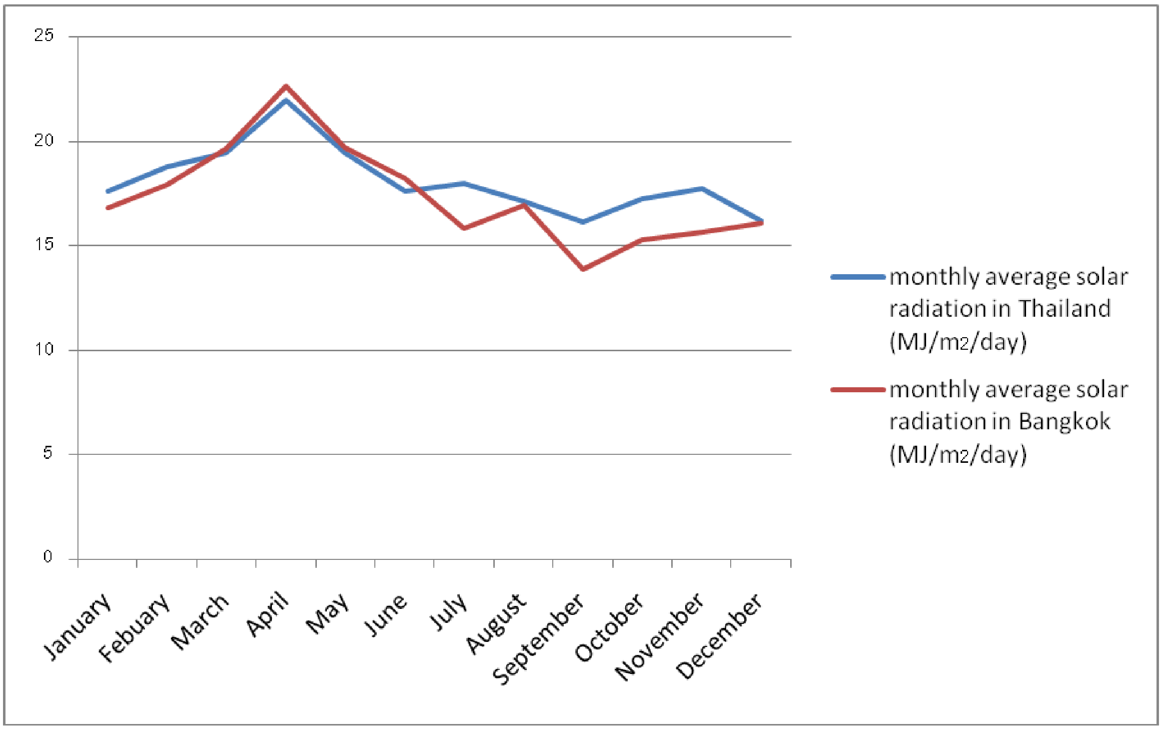

Figure5: Monthly average solar radiation in Thailand and Bangkok in 2004

Figure5 shows the monthly average solar radiation in Thailand and Bangkok in 2004, which was collected the solar radiation by Department of Alternative Energy Development and Efficiency of Thailand. This figure illustrates the indifferent trend of average solar radiation in Thailand and Bangkok.

Even though the statistics of the solar radiation from different year were assessed in this part, both statistics from different years show that average solar radiation in Thailand was close to the average solar radiation in Bangkok. In addition, the trend of solar radiation changing in each month of Thailand and Bangkok were quite the same.

4.1.1.3 Wind speed

Figure6: Wind map of Southeast Asia

Source: *TruWind Solutions, 2001*

In 2001, TruWind Solutions developed the wind map of Southeast Asian for World Bank. This map was developed by using Mesoscale Atmospheric Simulation System (MASS). This wind map of Southeast Asian shows that 92.6% of total area in Thailand or approximately 477,157 km^2 had wind speed below 6 m/s at 65 m measurement and the wind speed that is higher than 6 m/s was just about 7.4% of whole country. The wind speed in Bangkok was less than 6 m/s as well. Consequently, most area of Thailand had low wind resource.

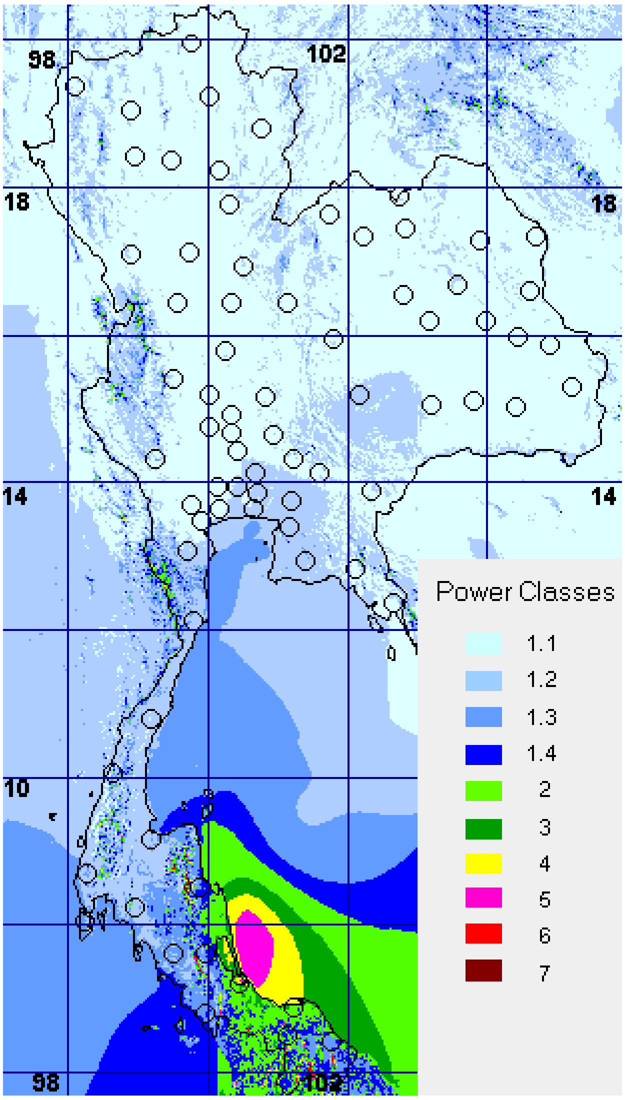

Figure7: Wind map of Thailand

Source: *Department of Alternative Energy Development and Efficiency of Thailand, (n.d.)*

Department of Alternative Energy Development and Efficiency of Thailand also represented the wind map of Thailand, which integrated the data of wind speed at 50 m above the ground. This map indicates that most area in Thailand had average wind speed less than 4.4 m/s or below class 1.3. There were some areas in south that had average wind speed than class 1.3 or higher than 4.4 m/s. Furthermore, the average wind speed in Bangkok was about class 1.2, which is about 3.6 m/s at 50 m.

All weather data that has been assessed in this part shows that the weather data of Thailand were quite the same as the weather data of Bangkok even though all weather data are assessed in different year. Therefore, the further study should examine the similarity of the weather in Thailand and Bangkok when additional weather data are available.

Then, the weather profile of Bangkok from U.S. Department of energy was used to be imported to ESP-r. The weather data from U.S. Department of Energy are appropriate to be used for building energy performance simulation to generate hourly cooling load because they are hourly weather data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (degree Celsius)	26.9	28	29.3	30.6	29.9	29.7	29	28.3	28.2	28	27.7	26.4
Wind speed (m/s)	2	3.2	3	3.7	3.1	4.2	3.1	3.1	2.5	2	2.2	2.4
Average Solar radiation (kWh/m2/d)	4.7	5.18	5.87	5.59	5.05	5.09	4.79	4.34	4.61	4.4	4.7	4.59

Table2: Weather data of Bangkok in 1983

The weather data of Bangkok in 1983 are presented in Table2 which was summarized from hourly weather data by U.S. Department of Energy. Table2 shows that average temperature in Bangkok was about 28.5 degree Celsius, which corresponds to the average temperature measured by Thai Meteorological Department in 2009, about 28.3 degree Celsius. The maximum temperature in Bangkok from U.S. Department of Energy was on 29th of April and minimum average temperature was on 25th of January.

The average wind speed in Bangkok was about 2.875 m/s at 12 m height in 1983. The maximum wind speed was 15.4 m/s occurred on 18th of March. Average solar radiation in 1983 was about 4.9 kWh/m^2/d that is quite similar to average solar radiation in 2004, which was 4.83 kWh/m^2/d. Thus, the weather data from U.S. Department of Energy are rather reliable.

The weather profile from U.S. Department of Energy also has other weather data that help the building energy performance simulation be more realistic, such as wind direction, relative humidity, ground temperature, dew point and heating and cooling degree day and hour.

4.1.2 Model description

4.1.2.1 House model

To make the cooling load result from the building energy performance simulation as the representative of average cooling demand of Thai household, one storey house design that was widely used by Thai people for house construction was used in this study. In addition, the majority of Thai people that was about 78% built their house from this design (National Statistical Office of Thailand, 2004). Therefore, almost cooling load profile of household in Thailand came from this house design. Due to the above assumption, this model therefore was used as a base case model in this research.

It is single-detached house model that consists of two bedrooms, one living room, one kitchen, and one bathroom. The usable area of first bedroom, second bedroom, living room, kitchen, and bathroom are about 16.4 m^2, 12.25 m^2, 30.2 m^2, 5.1 m^2, and 5.1 m^2. From the house model description, the usable area of this house is approximately 69 m^2. The height from ground to ceiling is about 2.9 m and the height from ceiling to roof is about 2.38 m.

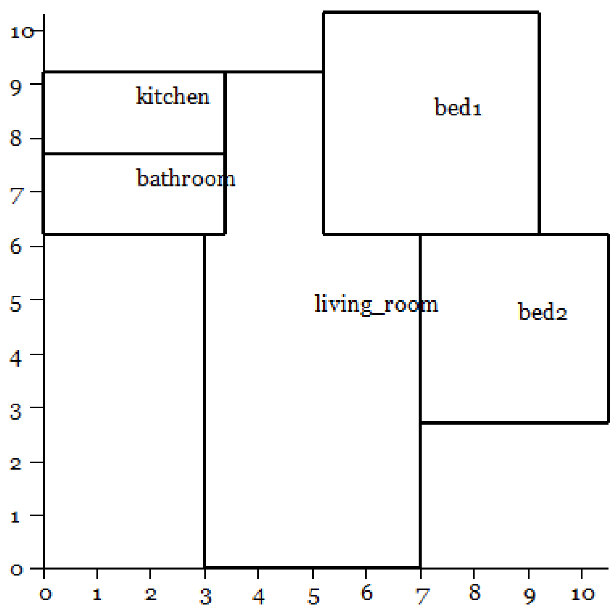

Figure8: Site plan of base case model

4.1.2.2 House construction

All details of constructions that are used in this research are explained in this section. All materials that are used in base case model are generally used for house construction in

Thailand. In each construction, U-value was calculated from material in each layer of construction. U-value represents the rate of heat loss through each construction. A heat loss rate of each construction is different upon the direction. Horizontal, upward, and downward U-value of the same construction are not the same.

All details of house construction in the base case model are shown in the table below.

House construction	Material	U-value of construction (W/m^2k)
Floor	100mm heavy mix concrete	2.349 upward
	300mm cement screed	2.017 downward
External wall	20mm dense plaster	2.182 horizontal
	200mm brown brick	
	20mm dense plaster	
Internal wall	20mm dense plaster	2.182 horizontal
	200mm brown brick	
	20mm dense plaster	
Ceiling	40mm wood	2.131 upward
	10mm gypsum board	1.855 downward
Roof	15mm concrete tile	2.239 upward
	5mm roofing felt	1.936 downward
	40mm wood	
Window	6mm plate glass	2.811 horizontal
	12mm air	
	6mm plate glass	
Door	25mm oak	3.316 horizontal

Table3: Constructions of base case model

Table3 shows the materials and U-value of each construction in the base case model. U-value of each construction is quite high, which will lead to quickly heat loss through each building envelope.

4.1.2.3 Building location and direction

The latitude and longitude of Bangkok was used to define the site location of the house. Therefore, the site location was set at 13° 55´ north latitude and 100° 35´ east longitude. The front door of the living room was facing to the south. The location and direction of the building affect the solar absorbed in the house.

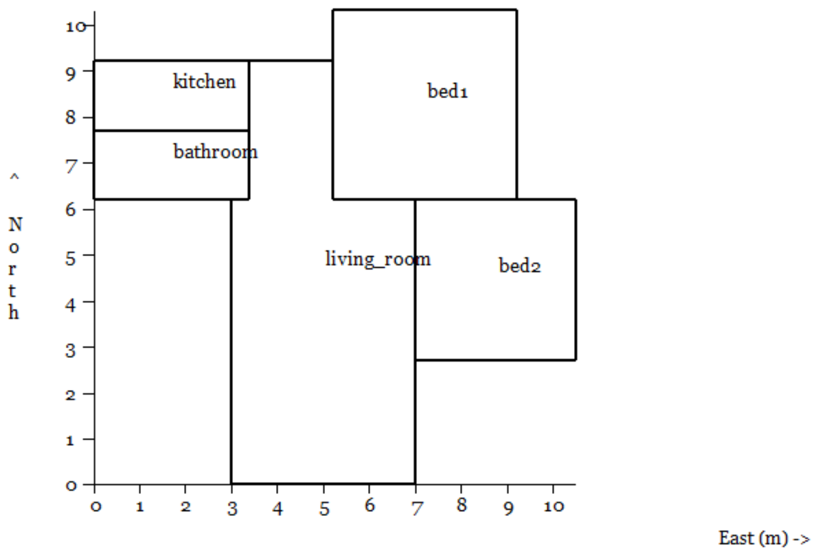

Figure9: Direction of base case model

4.1.2.4 Occupant

From the latest statistic in 2010 by The Bureau of Registration Administration of Thailand (BORA), number of population in Thailand was 63,878,267 people and there were 21,681,635 households in Thailand. These statistics illustrate that average number of occupant in each household was approximately three occupants. From the statistic, number of occupant also corresponds to number of bedroom in this base case model. As a result, three occupants were defined in this simulation. Two occupants were defined in bedroom1 because bedroom1 is a bit bigger than bedroom2 and one occupant was defined in bedroom2 during the night period.

4.1.2.5 Infiltration rate

Typically, the infiltration rate is the rate of uncontrollable airflow or air leakage through the cracks and small space between of building envelopes, which are always between each construction such as space between door and wall, space between window and wall, and the crack of the ceiling. These spaces between constructions lead to the air movement to or out of the building. Otherwise, the air leakage of building is difficult to be estimated because it is hard to know the exact size of space between each construction and area of each crack. Therefore, this study assumed three levels of infiltration rate depending on the standard of the house.

- High standard house that has better air sealing and constructions has low level of infiltration rate.
- Normal house has medium infiltration rate.
- Low standard house that has poor air sealing and constructions has high level of infiltration rate.

Then, the house model in this study is assumed to have medium infiltration rate.

4.1.2.6 Lighting and other electrical appliance

Normally, lighting and electrical appliances increase the heat gain in the building. Therefore, many electrical appliances and lighting cause the increasing of temperature in the building as well. The lighting and electrical appliances also affect the cooling load demand. Boonyachut (2001) did the research about behavior of Thai residence. She surveyed and gathered the data from several households in Thailand. She summarized that more than 50% of all households in Thailand had light bulb, washing machine, iron, refrigerator, fan, rice cooker, television, and electric kettle. Rice cooker and electric kettle are two kitchen appliances in this statistic because Thai people normally use gas as energy for cooking. Consequently, light bulbs, washing machine, iron, refrigerator, fan, rice cooker, television, and electric kettle were defined in this model corresponding to the study of Thai residential behavior.

Table4 shows all electrical appliances that were defined in the base case model to do the building energy performance simulation.

Electrical appliance	Power consumption
Light bulb	15 Watts/hour
Washing machine	460Watts/hour
Iron	1000 Watts/hour
Refrigerator	295 kWh/yr = 33.33 Watts/hour
Fan	34 Watts/hour
Rice cooker	650 Watts/hour
Television	108 Watts/hour
Electric kettle	1500 Watts/hour

Table4: Lighting and electrical appliances in base case model

The lighting and electrical appliances in Table4 were defined in the base case model for weekday and weekend to do the building energy performance of base case model.

4.1.2.7 Cooling control

Cooling control or air conditioning system was defined in the base case model to control and maintain zone temperature in the building. Normally, air conditioning in Thailand is AC system. Therefore, AC cooling control was defined in both bedroom1 and bedroom2 to maintain the dry bulb temperature during the night period. In order to set up the sensible cooling control in base case model, the following details were specified in the model.

4.1.2.7.1 Cooling set point

The cooling set point is the temperature that occupant desires the cooling system to maintain this temperature in the zone. If heat gain is increased and then temperature in zone goes beyond the cooling set point, the cooling system will cool the temperature in zone until the temperature goes down to the cooling set point. In order to make this base case model be the representative of household in Thailand, the comfortable temperature of Thai people was used to define the cooling set point of the base case model.

Yamtraipat et al. (2003) studied about the comfortable condition in Thailand. They did the survey from various representatives of each region in Thailand. Finally, they recommended that temperature at 26 degree Celsius should be the comfortable temperature and cooling set point of air conditioning system for Thailand. Hence, temperature at 26 degree Celsius was set as cooling set point of cooling control system in the base case model.

4.1.2.7.2 Maximum and minimum cooling capacity

The maximum cooling capacity is the maximum power of air conditioning system to cool the building. If the maximum cooling capacity is too small, the air conditioning could not have enough power to cool the building at the desired temperature. The maximum cooling capacity in this cooling system was defined at the large number 10000 W to let the air conditioning works freely follow the weather condition. The purpose of setting the maximum cooling capacity at large number is to find the maximum cooling capacity that would be appropriate for weather condition in Thailand. The size of air conditioning can also be estimated from the maximum cooling capacity. The minimum cooling capacity was set at 0 W.

4.1.2.7.3 Cooling period

The cooling period was used to specify the operating hours of air conditioning system. The question in this section is how to specify cooling period that can be a representative of residential cooling time in Thailand. Therefore, the cooling period should respond to the load profile of residential power consumption in Thailand. Thailand electrical power consumption forecasting (2007), by Energy Policy and Planning Office of Royal Thai Government reported about the load profile of residential power consumption in Thailand and indicated that the electrical power consumption of household started to increase from 6pm. and then the load profile was at the peak at 9pm because of the cooling load demand and then gradually decreased to normal consumption at 5am. Consequently, the cooling period of the base case model was defined from 9pm to 5am.

4.2 Matching supply with demand simulation

As mentioned in the second chapter, the final objective of this project is to find the best match renewable energy option for average electrical power consumption of Thai household. To achieve the final objective, this section describes about the simulation of matching supply with demand and the best match renewable energy system for average electrical power consumption of Thai households.

In order to achieve the final objective of this project, Homer was used to do the simulation of matching supply with demand. There are two significant reasons to use Homer in this research.

First, hourly cooling data from ESP-r can be easily transferred to Homer through Excel file. Second, Homer is able to match the renewable energy supply with electrical power demand of Thai household hour by hour. Match renewable energy system result would be sensible. Thus, this research expected Homer to estimate renewable energy option for electricity demand that was the representative of average energy consumption of household in Thailand. Then, Merit was used to find the match rate of electrical supply of each option from Homer and electrical load demand to assess the best match renewable energy system.

4.2.1 Renewable energy system design

The aim of this research is to find renewable energy power system that can be used with household for the whole country. Renewable energy resources that are available everywhere in Thailand are used to design the power system in this research. Hence, photovoltaic module, which converts solar energy to electrical power and wind turbine, that convert wind energy to electricity were used as power sources in the power system configuration. DC electrical power is generated by photovoltaic module and wind turbine. The storage system was considered. Because of the limitation of technology in Thailand, the battery is the only one power storage component that is appropriate for this model. Basically, all electrical appliances and air conditioning systems in Thailand are alternating current unit. The inverter was installed on this renewable energy system to convert direct current (DC) power to alternating current (AC) power. Consequently, the briefly processes of design renewable energy power system are as follow.

First, photovoltaic module and wind turbine generate DC electrical power from solar and wind energy to charge the battery bank. Next, DC electrical power from battery storage system is converted to AC electrical power through the inverter. Finally, AC electrical power is supplied to all AC electrical appliances and AC air conditioning system.

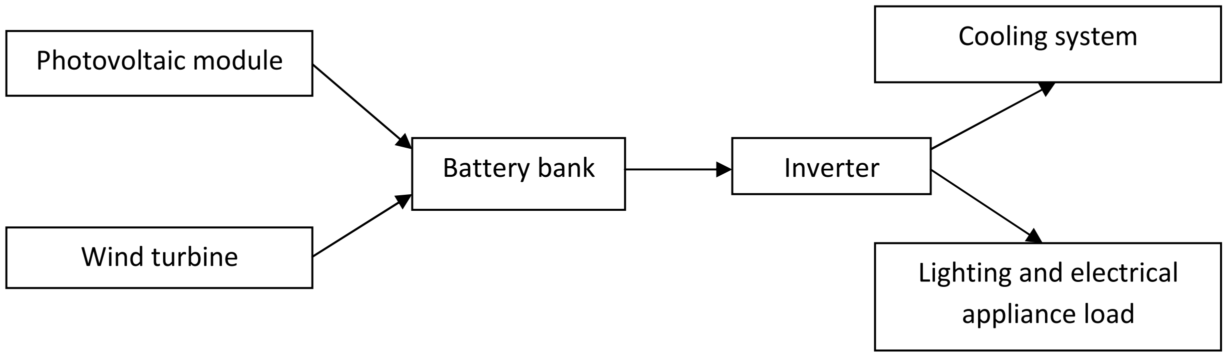

Figure10: Renewable energy system design

4.2.2 Model of matching supply with demand simulation

In order to estimate the match renewable energy system for electrical load demand, Homer was required to do the supply and demand matching. Therefore, the following inputs were required to be defined in Homer before running the matching supply and demand simulation.

4.2.2.1 Renewable energy system components

As mention in section 5.1.1, there are four components in the design renewable energy system. The detail of each component is described in this section.

Photovoltaic module

This objective of this research is to find the best match renewable energy system for average electrical power consumption of household in Thailand. Due to the objective, all system components that are in this research are from local manufacturer or available in Thailand. Solar panel from Sharp was selected. This 12V solar panel is crystalline silicon PV which has the maximum output about 185 W. In addition, it can also endure in the harsh environment.

Figure11: 185W 12V DC solar panel

Source: *http://www.sharpthai.co.th/solar_cell/solar_product.aspx?id=4*

Wind turbine

The appropriate wind turbine for Thailand should be the wind turbine that can generate electrical power from the low wind speed. From the above fact, 400W wind turbine, which was developed from local manufacturer, was selected. This wind turbine was designed for the weather condition in Thailand, which has low wind speed. This wind turbine can start capturing power at about 2.5 m/s wind speed. It can produce maximum output at 7m/s wind speed. The rotor diameter of wind turbine is about 3.2 m is relatively small. In brief, it would be suitable for the house in residential area, which is concerned about the impact of big wind turbine. Another advantage is this wind turbine has small noise pollution. This wind turbine is 12V DC system, which has the same system voltage as12V solar panel.

Figure12: 400W 12V DC low cut in speed wind turbine

Source: *http://www.prapai.co.th/eng/product_400.php*

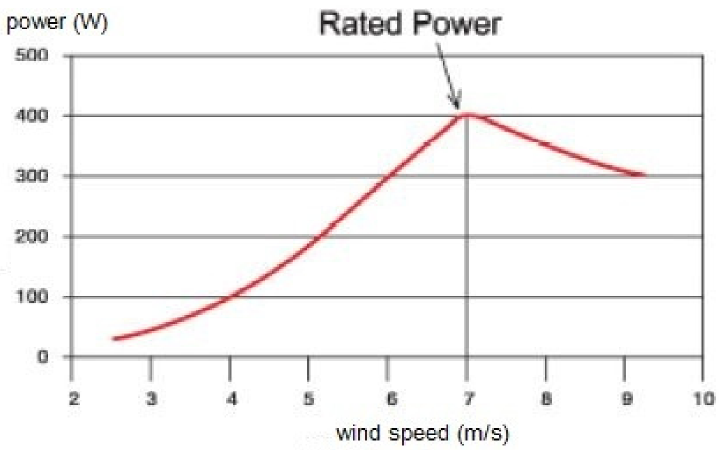

Figure13: Power curve of 400W 12V DC low cut in speed wind turbine

Source: *http://www.prapai.co.th/eng/product_400.php*

Figure13 shows power output of 400W wind turbine, which was used in the matching supply and demand simulation. The detail of this power curve was defined in Homer to create 400W low cut in speed wind turbine.

Battery bank

According to the specification of solar module and wind turbine, the bus voltage of the design renewable energy system is 12V DC. The battery bank should have 12V DC system voltage as well. Therefore, 12V 200Ah battery was selected for the renewable energy power system. The minimum state of charge of this battery is 40%, which means the power in the battery will not be lower than 40%. When the battery is fully charged, the usable power in the battery is 60% of total capacity.

Inverter

The inverter is one of the significant components in the renewable energy system. Normally, electrical power system is 220V AC and all electrical appliances in Thailand are also designed for this system voltage. The renewable energy system needs the inverter to convert 12V DC to 220V AC electrical power. In order to estimate the size of inverter that is suitable for the electrical load profile, all electrical appliance load and peak cooling load were assumed to occur at the same time to calculate the possible peak load. The possible peak load is not over 5kW. In other word, 5kW inverter is sufficient for the load profile of all cases in this study.

4.2.2.2 Renewable energy resources

Two renewable energy components in the design power system are solar panel and wind turbine. Due to the design of power system, Homer required solar resource and wind resource to do the matching supply with demand simulation. Solar radiation and wind speed data from U.S Department of Energy, which were used in ESP-r, were therefore used in Homer as well. The results from ESP-r and Homer are based on the same weather data.

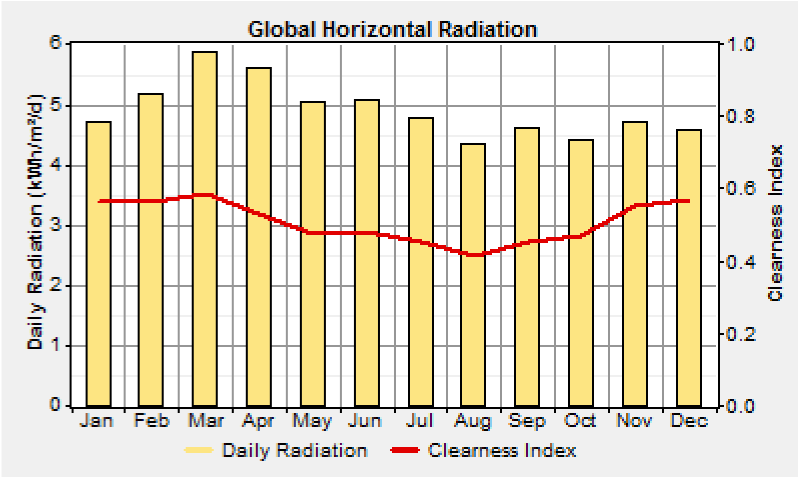

Figure14: Monthly average solar radiation in Bangkok

Figure14 shows the average solar radiation in summer period from February to May was high. The average solar radiation in summer was more than 5kWh/m^2/d. The average solar radiation in a year was about 4.915kWh/m^2/d, which is the same as climate data in ESP-r.

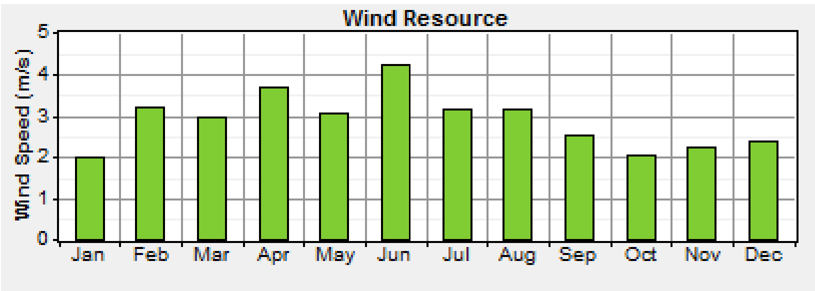

Figure15: Monthly average wind speed in Bangkok

Figure15 shows the monthly average wind speed in Bangkok which was measured at 60m height. The maximum average wind speed was more than 4 m/s in June and the lowest wind speed was about 2 m/. Average wind speed in Bangkok was about 2.88 m/s, which corresponds to the statistic from Department of Alternative Energy Development and Efficiency.

4.2.2.3 Electrical load demand

Two types of load data are defined in Homer. First, hourly cooling load data were copied to excel file. Then, excels file was imported to Homer. So, there are three cooling load profiles from three cases. Second, Hourly electrical appliance load was defined in Homer for weekday and weekend. This electrical appliance load is the same as the electrical appliances were defined in ESP-r. This electrical appliance load was used with each cooling load case to create the total energy consumption.

Three cases of cooling load demand are shown below

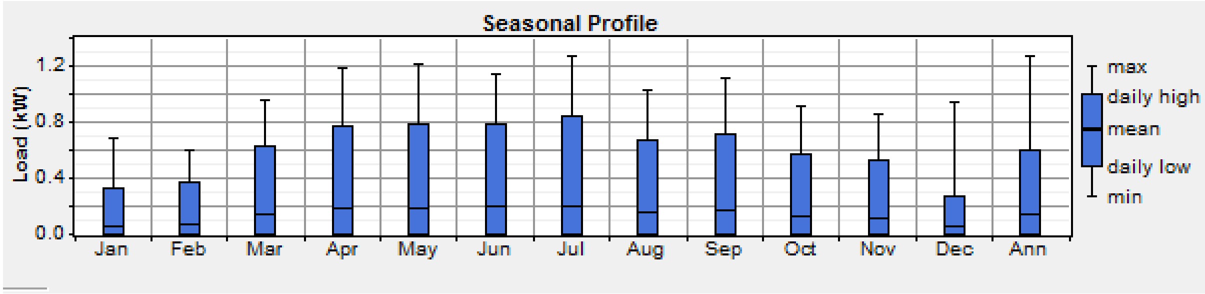

Figure16: Seasonal cooling load profile of base case

The average cooling load demand of base case is about 0.14 kW/h or 3.37 kWh/day.

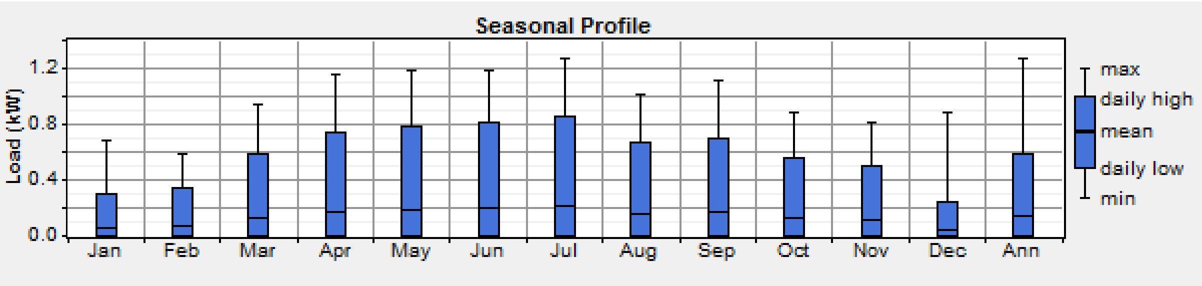

Figure17: Seasonal cooling load profile of Case2

The average cooling load demand of Case2 is about 0.136 kW/h or 3.27 kWh/day.

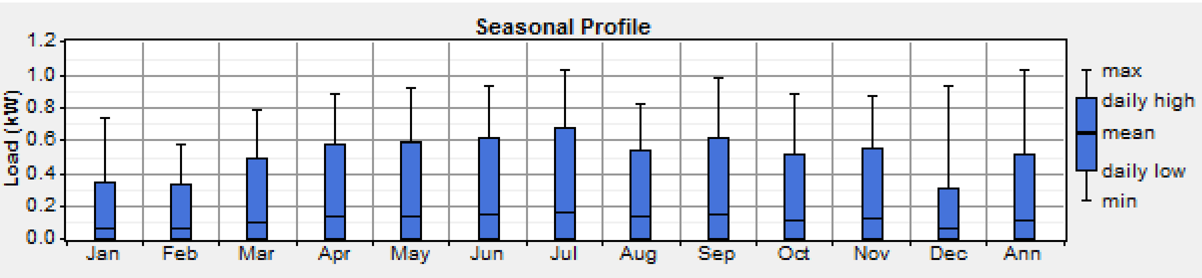

Figure18: Seasonal cooling load profile of Case3

The average cooling load demand of Case3 is about 0.115 kW/h or 2.75 kWh/day.

The lighting and other electrical load profile is shown below

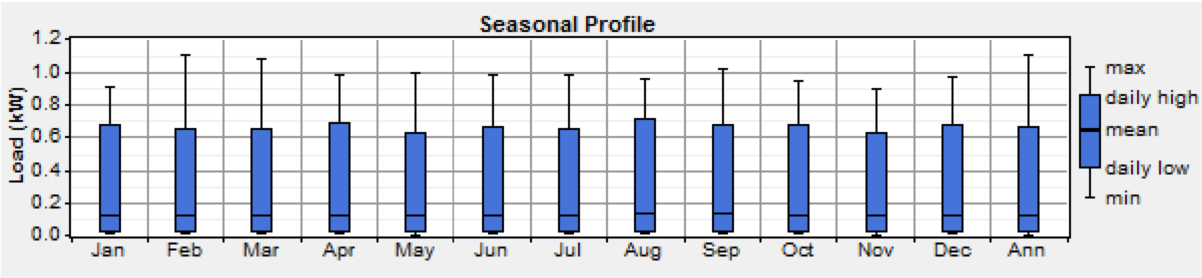

Figure19: Seasonal load profile of lighting and other electrical appliances

The average other electrical load demand of is about 0.125 kW/h or 2.99 kWh/day.

4.2.2.4 Size to consider

Size or quantity of all power system components such as size of PV, quantity of wind turbine, quantity of battery, and size of inverter, were defined in multiple values to create more options that would be the match renewable energy system. Homer will estimate the match options from those variable inputs. All size and quantity of system components were specified as below

PV array (kW)	Wind turbine (quantity)	Battery (quantity)	Inverter (W)
0	0	0	0
0.185	1	1	1
0.37	2	2	2
↓	↓	↓	↓
4.07	10	22	5

Table5: Range of all variable inputs

Table5 shows all range of variable inputs that were defined in Homer to create in the matching supply with demand simulation. The maximum size of inverter was defined from the case that has highest energy consumption. The maximum quantity of battery was defined for the case that power system can supply electrical power to all electrical loads for about 5 days. Then, Homer is expected to estimate size of PV and quantity of wind turbine from fixed range of battery and inverter.

4.2.3 Best match renewable energy system assessment

The match renewable energy system results from Homer will be further assessed to find the best match renewable energy system. All results from Homer will be assessed as follow.

First, the best match renewable energy system must not have unmet electrical load which means the best match renewable energy system must be able to supply electricity to all electrical load throughout the year without period of energy deficit. If all results from Homer simulation have unmet electrical load, the lowest unmet load system will be selected for further assessment and improvement until the power system can supply power to all electrical load.

Second, the best match renewable energy system must be able to supply all electrical loads for about four or five days when the battery bank is fully charged. This condition is for securing the energy supply when there are problems with the system.

Third, the best match renewable energy system must have some excess electricity to support the increasing of electrical demand in the future.

Fourth, the renewable energy system options from Homer will be simulated in Merit to evaluate the match rate between renewable energy supply and electrical demand to find the system that has highest match rate.

Chapter5: Model validation

This section describes the procedure to verify and validate the base case model in the building energy performance simulation. There are three steps in this section.

First, to verify that the base case model is sensible the total flux gain in each zone should be equal or be close to the total flux loss. Hence, the simulation of base case model was run for a year without the cooling control to calculate the energy balance in each zone. The assumption of this step is total energy gains from inside and outside the zone should go outward to the ambient.

zone	Heat gain (kWhrs)	Heat loss (kWhrs)
Bed1	764.826	764.824
Bed2	591.055	591.069
Living room	1386.624	1386.605
Bathroom	261.562	261.562
kitchen	394.552	394.552

Table6: Energy balance in each zone of base case model

The results in table6 indicate that total flux gain in a zone is equal or close to flux loss. Therefore, this validation gives more confidence on the model of this study.

Second, the ambient temperature in summer should be higher than the ambient temperature in winter because of higher solar radiation in summer. In addition, higher ambient temperature and solar radiation leads to higher heat gain in the building as well. Therefore, the dry bulb temperature in the building in summer should be higher than the dry bulb temperature in winter. From these relationships, the base case model was simulated without the cooling load to find ambient temperature, solar radiation, and dry bulb temperature in each zone in summer and winter.

Climate	Summer	Winter
Ambient temperature (degree Celsius)	29.73	27.35
Average direct solar radiation (W/m^2)	149.36	146.245
Average diffuse solar radiation (W/m^2)	121.67	57.4
Average solar radiation (W/m^2)	271.03	243.64

Table7: Average ambient temperature and solar radiation in summer and winter

Zone temperature (degree Celsius)	summer	Winter
Bed1	27.725	26.275
Bed2	28.072	27.125
Living room	28.208	26.7
Bathroom	28.253	26.351
kitchen	29.016	26.94

Table8: Average zone dry bulb temperature in summer and winter

The results in Table7 and Table8 illustrate that average solar radiation in summer is higher than average solar radiation in both winter. As a result, the ambient temperature in summer is higher than ambient temperature in winter as well. High solar radiation and ambient temperature leads to high heat go inward to each zone. Thus, the zone temperature in summer is higher than zone temperature in winter.

Third, the final step of validation is to prove that the cooling load of the base case model is sensible to be a representative of average cooling load demand of Thai household. Therefore, the cooling load demand of base case model should be close to the national statistic.

In 2009, the electrical power consumption in Thailand was about 30,371 GWh, which was higher than electrical power consumption in 2008 about 5.5%. In addition, there were about

18,138.012 electrified households in Thailand (Electrical power report of Thailand, 2009). Hence, each household consumed approximately 1,674.439 kWh/yr. About 42.8% of electrical power consumption was cooling load (PEER review of energy consumption in Thailand, 2010). These national statistics can be used to validate cooling load results from energy performance simulation of base case model.

In order to completely validate the base case model by this step, the cooling load result will be discussed in the next section after completely running simulation with cooling control to create cooling load demand.

Chapter6: Results and discussion

6.1 Cooling load demand

This section describes the result from the building energy performance simulation. The simulation is expected to calculate the cooling load demand of base case model and create hourly cooling load demand for further study in the next chapter.

6.1.1 Cooling load demand of base case model

The base case model was simulated with cooling control, which was mentioned in the previous chapter, to calculate the cooling load demand and create hourly cooling load demand of base case model for matching demand and supply simulation in the next chapter.

In this simulation, the cooling system was defined in bedroom1 and bedroom2 at 26 degree Celsius cooling set point. The cooling period was specified from 9pm to 5pm and there are two occupants in bedroom1 and one occupant in bedroom2 during the cooling period.

The results from the simulation illustrated that the average cooling load of bedroom1 is 0.07631 kW per hour and average cooling load of bedroom2 is 0.06407 kW per hour. Peak-cooling load of bedroom1 was 0.70203 kW and peak-cooling load of bedroom2 was 0.56998 kW that both peak cooling loads occurred on 10^{th} of July. The house in Thailand that has the same model and cooling period could use these peak cooling loads to select the size of air condition system. Therefore, the air condition that has 1000 W maximum cooling capacity would be appropriate for bedroom in the house like base case model. The average cooling load of bedroom1 was slightly higher than the average cooling load of bedroom2 because the number of occupant in bedroom1 is more than number of the occupant in bedroom2. As a result, higher heat gains in bedroom1 than in bedroom2. To prove this assumption, total occupant gains were checked. The average occupant gain in bedroom1 is 66.667 W meanwhile the average occupant gain in bedroom2 is 33.333 W. Thus, the assumption about heat gain from occupant was correct.

Total sensible cooling load of bedroom1 is 668.45 kWh/yr and total cooling load of bedroom2 is 561.26 kWh/yr. The cooling hours of bedroom1 are 2985 hours per year and cooling hours are 3000 hours per year. From the above information, the cooling load demand of base case model is therefore 1229.71 kWh/yr.

In order to validate this cooling load demand result, the total electrical power demand of base case model was required to compare with national statistic. Lighting and other electrical appliance load could not be estimated from the simulation. Therefore, the lighting and other electrical appliance load, which was computed by hand calculation, is about 1092 kWh/yr. Then, total cooling load was integrated with lighting and other electrical appliance load to calculate total electrical power consumption of the base case model. Total electrical power consumption of base case model is about 2321 kWh/yr. Then, all these energy consumptions were compared with the national statistic.

First, average electrical power consumption of Thai household was about 1674.44 kWh/yr and total energy consumption of base case model is 2321 kWh/yr. Even though total electrical power consumption of base case model is higher than average energy consumption from national statistic, the total electricity consumption of base case model is still sensible because normally some households in Thailand do not have air conditioning system. As a result, Thai electrical power consumptions are very low. We can conclude that majority of Thai households would consume electrical power more than the mean.

Second, the national statistic indicated that cooling load of Thai household was about 42.8% of total electrical power consumption. The cooling load of base case model is 1229.71 kWh/yr, which is about 52% of total electrical power consumption of base case model. Hence, the proportion of cooling load in base case model is close to the national statistic. It can be concluded that the results from the simulation of base case model is sensible to be representative of average cooling load demand of Thai household.

Although the cooling load demand of base case model is close to the average cooling load demand of Thai household, the base case model could be improved to make the cooling load be closer to the national statistic. Therefore, two improvement strategies were applied separately to the base case model to see how they affect to the cooling load of the base case model. Both strategies were recommended that they could improve the energy performance of building, by the public organization sector of Thailand.

6.1.2 Cooling load demand of Case2

First, The Choice of Building Material, Equipment, and Appliance to Conserve Energy by Department of Alternative Energy Development and Efficiency of Thailand mentioned about the relationship the relationship of the solar radiation and heat gain in the building. Almost heat in the building gains from the solar radiation. Heat from the solar radiation goes inward through the building envelopes to the air in the building. As a result, the temperature in the building is increased. The cooling system has to work harder to achieve the desire temperature if high solar radiation is absorbed in the building. Basically, different zone in the building absorbs different amount of solar radiation. The north was suggested to be the direction that receives least solar radiation in Thailand.

Initially, windows of two bedrooms in the base case faced the east. The base case model was rotated 90 degree to make the windows of two bedrooms face the north because the cooling system was defined in both bedrooms. According to the above reason, the simulation was run to estimate the cooling load. The results showed that the mean of solar absorbed in bedroom1is 47.058 W/h and the mean of solar absorbed in bedroom2 is 46.987 W/h.

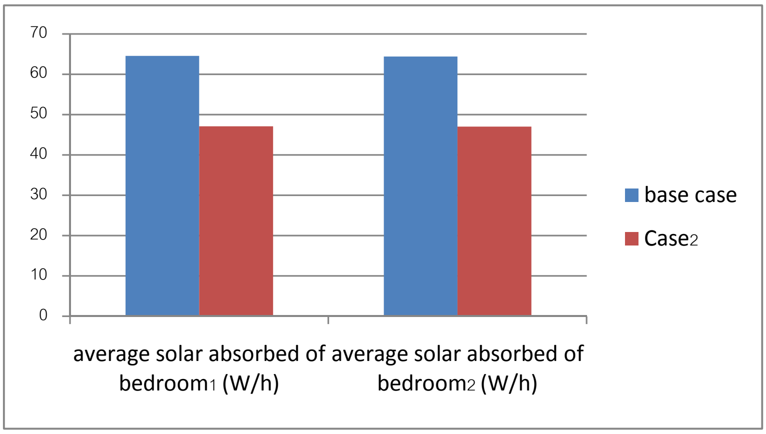

Figure20: Average solar absorbed in two bedrooms of base case and Case2

This bar chart illustrates the average solar absorbed in bedroom1 of Case2 is lower than average solar absorbed in bedroom1 of base case. In addition, average solar absorbed in bedroom2 of base case is higher than average solar absorbed in bedroom2 of Case2. The average solar entering from outside through glazing into each bedroom of Case2 is about 47.282 W/h. The average solar entering from outside through glazing into each bedroom of base case is 64.983 W/h, which is higher than the average solar entering from outside through glazing into each bedroom of Case2. As a result of the solar entering through bedrooms in each case, bedrooms of base case receive higher solar through opaque and transparent constructions than the bedrooms of Case2. Therefore, more heat gain in bedrooms of base cause higher temperature in both bedrooms of base case.

Average zone temperature (degree Celsius)	Case2	Base case
Bedroom1	26.47	26.56
Bedroom2	26.6	26.83

Table9: Average zone temperature in the bedrooms of Case2 and base case

Then, the average temperature in bedroom1of Case2 is 26.47 degree Celsius, which is lower than the average temperature in bedroom1 of base case. The average temperature in bedroom2 of Case2 is also less than average temperature in bedroom2 of base case. So, the cooling system of Case2 worked less than the cooling system of base case. Finally, total cooling load demand of Case2 is 1194.47 kWh/yr. The cooling load demand of Case2 is less than the cooling load demand of base case about 35 kWh/yr or about 2.9% of the cooling load of base case model. It can be summarized that the zone that is facing to north will receive the solar entering from outside less than the zone that is facing to the east. As a result, the cooling load demand of zone facing the north is lower than the cooling load of zone facing the east about 2.9%. In conclusion, the solar entering from outside into building can cause the cooling system work harder and lead to increase the cooling load.

6.1.3 Cooling load demand of Case3

The building envelope is another factor that can be used to reserve the energy consumption. According to The Choice of Building Material, Equipment, and Appliance to Conserve Energy by Department of Alternative Energy Development and Efficiency of Thailand, the ceiling that is applied with the three inch fiberglass could save the cooling load consumption of the building. The appropriate insulation can keep the building cool by reducing the rate of heat gain through the building envelope into the building. Insulation can reduce the heat gain in the building. For this reason, the cooling system does not have to work hard to cool the building.

The ceiling of base case model composed of gypsum board and plywood that leads to high U-value at 1.855 W/m^2K downward. From the U-value, the ceiling of base case model was installed three inch fiberglass between gypsum board and plywood to improve the cooling load consumption. In this case, U-value of new ceiling is about 0.392 W/m^2K. By changing the U-value of the new building, the heat would gain through the new ceiling slower than the ceiling of base case model. In summary, Case3 would have less cooling load demand.

Average zone temperature (degree Celsius)	Base case	Case3
Bedroom1	26.558	26.196
Bedroom2	26.827	26.668

Table10: Average zone temperature in two bedrooms of base case and Case3

Table10 shows the average zone dry bulb temperature of the base case model and Case3. The average zone temperature in bedroom1 of Case3 is lower than the average zone temperature in bedroom1 of base case. Besides, average zone temperature in bedroom2 of Case3 is also lower than the average zone temperature in bedroom2 of base case. From the table above, we can summarize that the insulation in the ceiling leads to low heat gain through the ceiling.

The peak cooling load of bedroom1 and bedroom2 in Case3 are 0.60279 kW and 0.52426 kW, respectively that are lowest peak cooling loads in three cases. The average cooling load of bedroom1 and bedroom2 in Case3 are 0.05758 kW/h and 0.05586 kW/h, respectively that are lowest average cooling loads in three cases as well. Total cooling load of bedroom1 is 504.37 kWh/yr. Total cooling load of bedroom2 is 489.32 kWh/yr. Moreover, total cooling load demand of Case3 is 993.7 kWh/yr. Total cooling load demand of Case3 is less than total cooling load of base case by 236 kWh/yr, which is about 19% of total cooling load of base case model. It can be concluded that insulation could be one factor to be used to reduce heat gain and zone temperature, which leads to the decrease in cooling load.

Conclusion

The objectives of this part are to estimate cooling load demand and create hourly cooling load data that can be used as the representative of average cooling demand of Thai household. There are three cases are as followed;

Base case

- Cooling loads of bedroom1 and bedroom2 are 668.45 kWh/yr and 561 kWh/yr, respectively.

- Total cooling load demand of base case is 1229.71 kWh/yr.

- Hourly cooling load data of base case is shown in the figure below

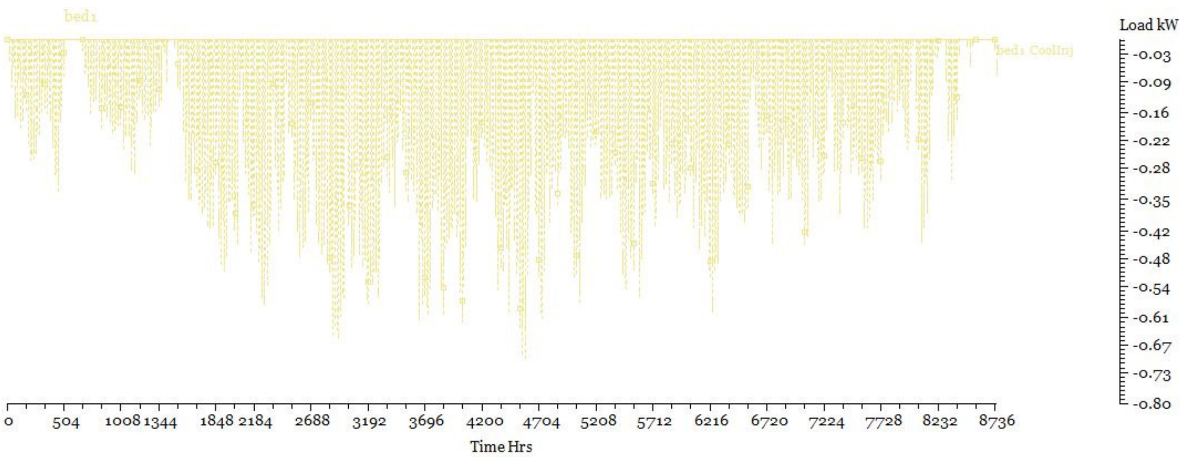

Figure21: Hourly cooling load of bedroom1 in base case

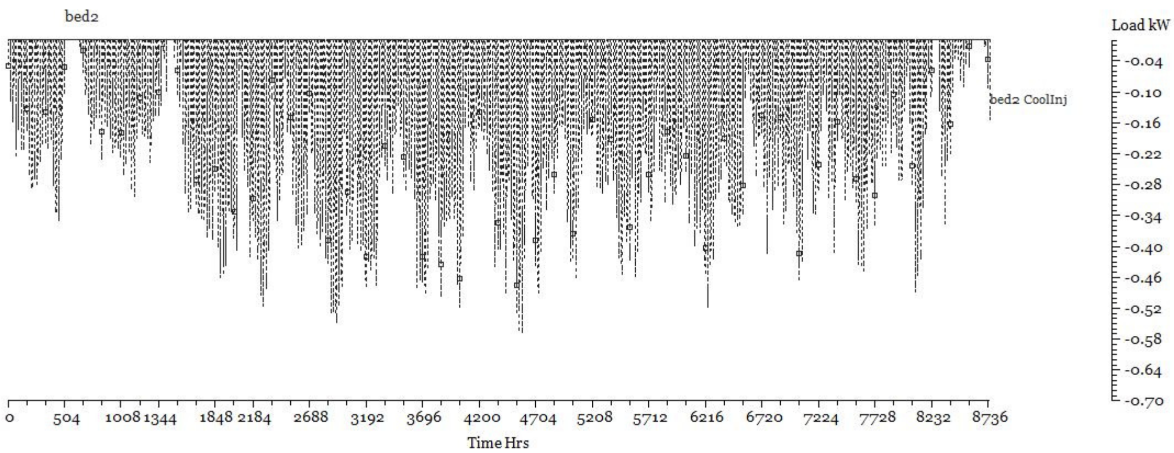

Figure22: Hourly cooling load of bedroom2 in base case

Case2

- Cooling loads of bedroom1 and bedroom2 are 670.28 kWh/yr and 524.19 kWh/yr, respectively.

- Total cooling load demand of Case2 is 1194.47 kWh/yr.

- Hourly cooling load data of Case2 is shown in the figure below.

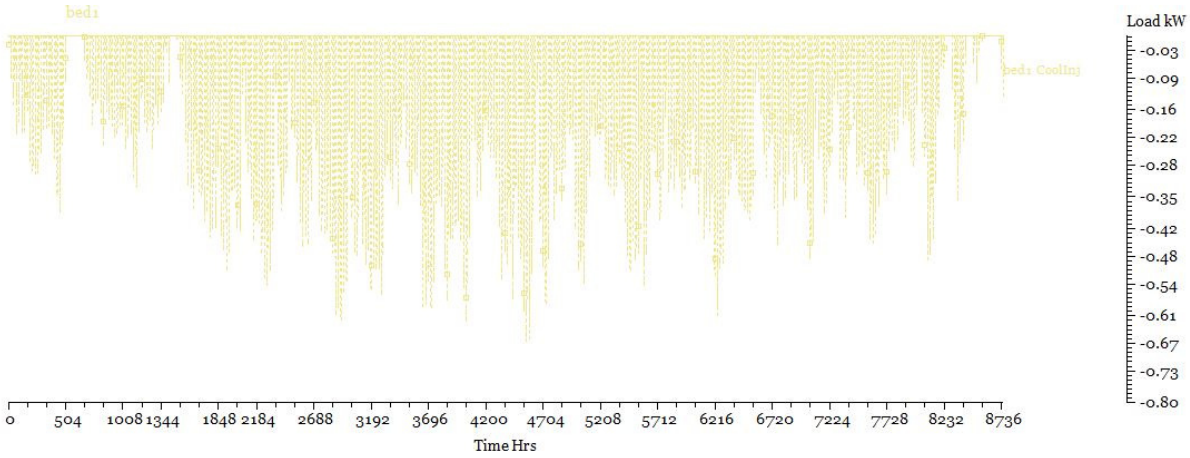

Figure23: Hourly cooling load of bedroom1 in Case2

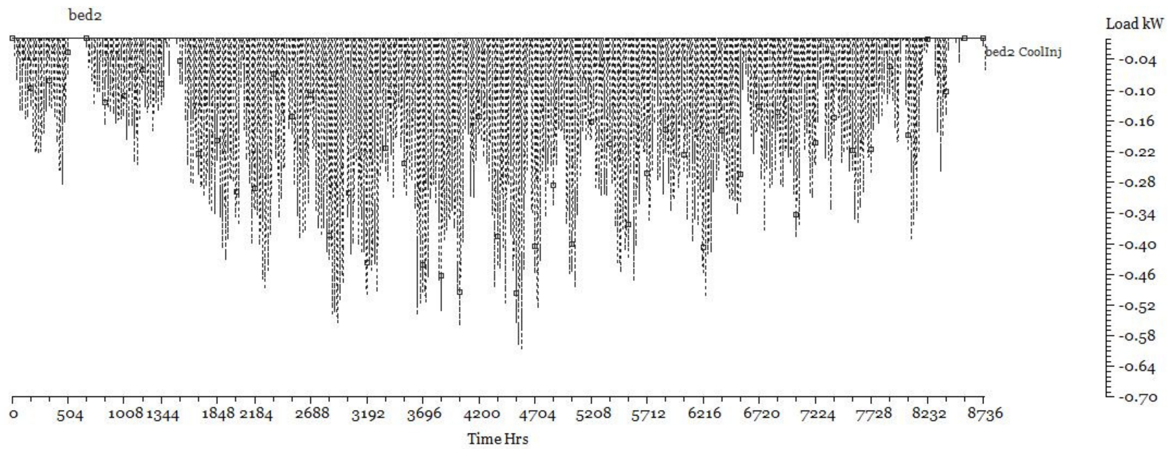

Figure24: Hourly cooling load of bedroom2 in Case2

Case3

- Cooling loads of bedroom1 and bedroom2 are 504.37 kWh/yr and 489.32 kWh/yr, respectively.

- Total cooling load demand of Case3 is 993.7 kWh/yr.

- Hourly cooling load data of Case3 is shown in the figure below.

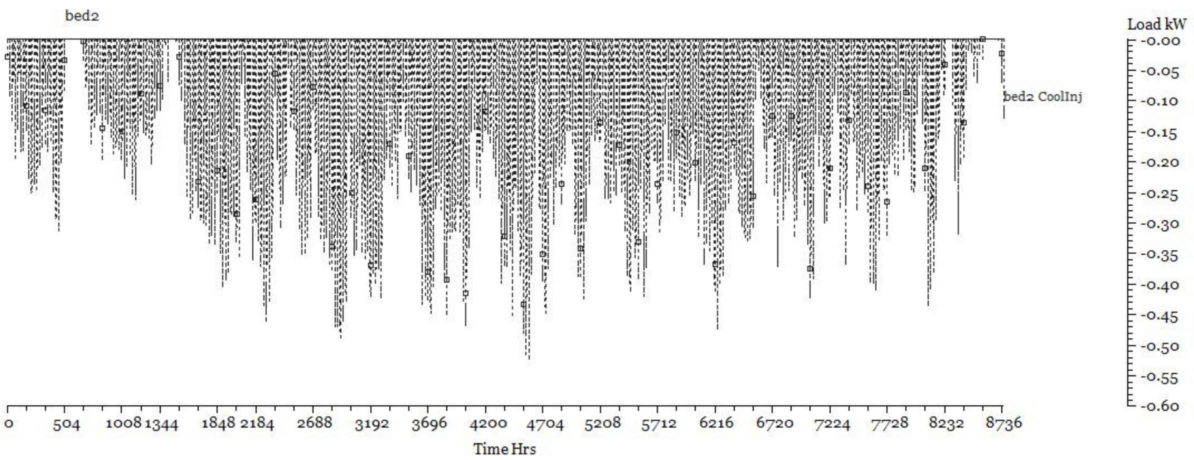

Figure25: Hourly cooling load of bedroom1 in Case3

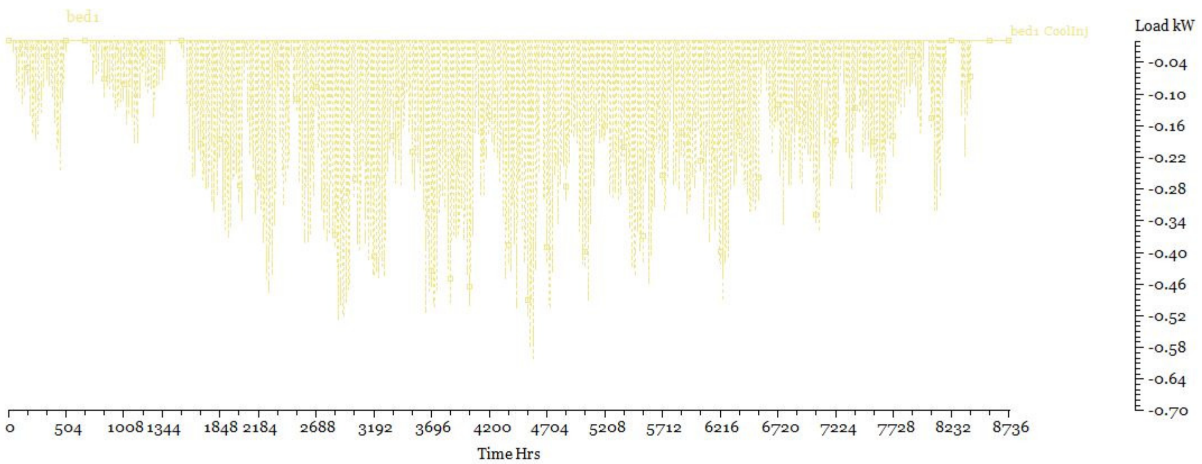

Figure26: Hourly cooling load of bedroom2 in Case3

From the cooling load results in this chapter, the cooling never go over 1 kW. With the cooling below 1kW, the house in Thailand that have same model, cooling period, and same cooling set point can use 1kW air conditioning system in their bedrooms. The cooling load results in Case2 and Case3 should be further validated with the national statistic if statistics about cooling load consumption with direction of house and insulation are available.

6.2 Best match renewable energy system

This section presents the match renewable energy options from matching supply with demand simulation. If the results from Homer cannot be the best match renewable energy system for average electrical power consumption of Thai household, they will be improved until this research get the best match system. Similarly, the energy system will be improved to reduce the energy loss in the system as well.

6.2.1 Best match renewable energy system for base case

The base case model requires approximately 6.4 kWh/day of electrical power to serve all electrical loads. The results from Homer simulation showed that two power system options would be match with the electrical load demand of base case model. The first option was seventeen 185W PVs (3.145kW) connecting with twenty one 200Ah batteries. The second option was fifteen 185W PVs (2.775 kW) and a 400W wind turbine connecting with twenty two 200Ah batteries. Both options were connected with a 2kW inverter because the maximum energy output from inverter required to serve electrical demand of base case was about 1.41 kW.

Assessment factors	1st option	2nd option
Unmet electrical load (kWh/yr)	0.727	0.936
Usable nominal capacity (kWh)	30.2	31.7
Excess electricity (kWh/yr)	1,502	1,417

Table11: Assessment factors of base case

Table11 shows that the fully charged battery storage system of 1st option has 30.2 kWh of usable capacity which can supply electrical load of base case about 4.7 days. The fully charged battery storage system of 2nd option has 31.7 kWh of usable capacity, which can supply to electrical load of base case about 5 days. 1st option and 2nd option have 1502 kWh/yr and 1417 kWh/yr, respectively of excess electricity to support the increase electrical power demand in the future. Therefore, both options meet the requirement of the best match renewable energy system. In contrast, the first option has 0.727 kWh/yr of unmet electrical load, which is lower than the unmet electrical load of 2nd option. As the above result, the first option was selected for further improvement to make it can supply electrical power to all electrical loads of base case throughout the year. The size of renewable energy component and size of battery storage system in 1st option are smaller than in 2nd option. That is to say, cost of 1st option would be cheaper than 2nd option.

The excess electricity shows that the first option can generate sufficient power to supply electrical load of base case however the quantity of battery could not be enough to stored DC electrical power. Accordingly, a 200Ah battery was added to 1st option to see whether 1st option with twenty two 200Ah batteries is able to supply all electrical loads of base case without period of energy deficit.

After a 200Ah battery was added to the 1st option, the first option is able to supply electrical power to base case demand without unmet electrical load. Seventeen 185W PVs connecting with twenty two 200Ah batteries and a 2kW inverter is the best match renewable energy system for electrical load demand of the base case model. This best match renewable energy system can generate 4,631 kWh/yr of electrical power from 3.145kW PV array to serve 2,321 kWh/yr of AC electrical load. In addition, the best match renewable system also has 1,501 kWh/yr of excess electricity which is about 32% of power production to support more electrical demand in the future. As a result, total energy losses in the system are about 809 kWh/yr or 17.4% of power production.

In order to be more confident with the result of best match renewable energy system, three options from Homer were simulated in Merit to find the match rate. Then, the results showed that the a renewable energy system ,which composed of seventeen 185W PVs (3.145kW) connecting with twenty two 200Ah batteries, has the highest match rate among three options. The match rate of this system is 42.97%. So, the energy supply of this system is the most similar to the demand of base case.

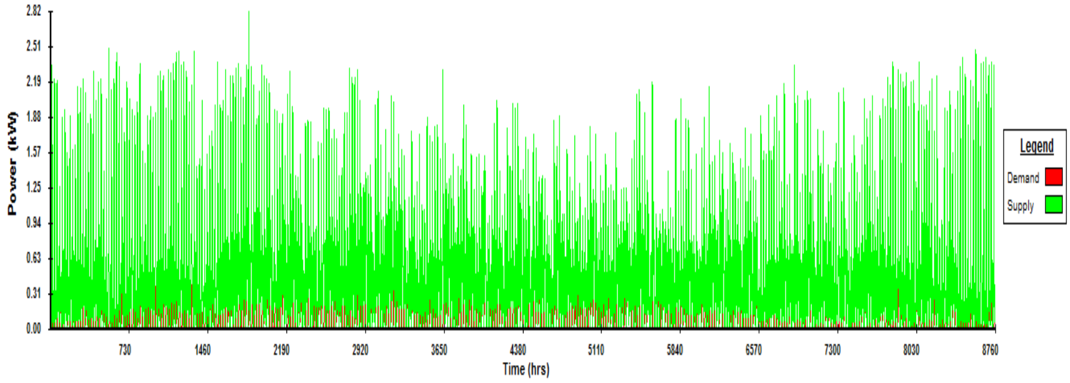

Figure27: Supply and demand of base case (system with AC cooling load)

To reduce the energy losses of the best match renewable energy system for electrical demand of base case, AC cooling system was replaced with DC air conditioning system to decrease the size of inverter. At this point, the energy losses from the energy conversion process in the inverter would be decreased. Homer then recommended that a power system which composed of sixteen 185W PVs connecting with twenty 200Ah batteries and a 1kW inverter would be the match renewable energy system for electrical load demand of base case model with DC cooling system. The details of recommended power system indicates that there is no unmet electrical load, which means this power system is able to supply electricity to AC and DC electrical loads in base case model with DC cooling system without the energy shortage. The usable nominal capacity of battery storage system is about 28.8 kWh. Therefore, this power system is able to supply electrical power to all electrical loads for 4.5 days when the battery bank is fully charged. This power system has 1,399 kWh/yr of excess electricity. So, the solar power system which composed of sixteen 185W PVs (2.96kW) connecting with twenty 200Ah batteries and a 1kW inverter is the best match renewable energy system for electrical power demand of base case with DC cooling system. Total energy losses of this power system is about 638 kWh/yr which is lower than energy losses of the best match power system of base case model (AC cooling system) about 171 kWh/yr. The decrease of energy losses comes from the lower AC electrical load and less quantity of battery. Therefore, energy losses from inverter and battery are reduced. The energy loss from inverter in this case is 121 kWh/yr and energy loss from battery storage system in this case is about 517 kWh/yr. The reduction of energy losses in base case with DC cooling system is about 21.137% of energy losses in base case with AC cooling system. It can be concluded that Most of energy losses in this renewable energy system come from the energy losses in the batteries.

6.2.2 Best match renewable energy system for Case2

The base case model was rotated to make the windows of two bedrooms facing the north. As a result, the cooling load demand of Case2 is about 3.3 kWh/d and total electrical power demand is about 6.3 kWh/day. After the simulation of Case2 was run in Homer to estimate the match renewable energy system, Homer recommended two power systems that would be the best match renewable energy system for electrical power demand of Case2. The first option was the renewable energy system, which composed of seventeen 185W PVs (3.145kW) connecting with twenty one 200Ah batteries and a 2kW inverter. The second option was the hybrid power system which composed of fifteen 185W PVs (2.775kW) and a 400W wind turbine connecting with twenty one 200Ah batteries and a 2kW inverter. Both options were connected with a 2kW inverter because the maximum output from inverter to electrical load is about 1.45 kW.

Assessment factors	1st option	2nd option
Unmet electrical load (kWh/yr)	0.847	1.63
Usable nominal capacity (kWh)	30.2	30.2
Excess electricity (kWh/yr)	1,553	1,468

Table12: Assessment factors of Case2

Table12 presents that the battery storage systems of 1st option and 2nd option have 30.2 kWh. When the battery bank of 1st option is fully charged, it can supply electricity to electrical load of Case2 for about 4.8 days. The battery storage system of 2nd option is able to supply electrical power for the same amount of days as well. The 1st option also has 1,553 kWh/yr of excess electricity and 2nd option has 1,468 kWh/yr of excess electricity. Even though the size of PV array in 1st option is smaller than size of power generation components in 2nd option that is PV array and wind turbine, 1st option has more excess electricity. Power production from solar energy is greater than power production from wind turbine. However, both options are unable to supply electricity to all electrical loads because they still have unmet electrical load. In addition, 1st option has less unmet electrical load. 1st option was selected for further improvement. A 200Ah battery was added to 1st option to improve the energy supply. Finally, a solar power system which composed of 3.145kW PV array (seventeen 185W PVs) connecting with twenty two batteries and a 2kW inverter can supply electrical power to all electrical loads without unmet electrical load. This solar power system has 1,552 kWh/yr of excess electricity, which is about 33.5% of power production. The fully charged battery storage system in this solar power system can supply electricity to electrical load of Case2 about 5 days. Due to the above information, a solar power system which composed of seventeen 185W PVs (3.145kW) connecting with twenty two 200Ah batteries. A 2kW inverter is the best match renewable energy system for electrical load demand of Case2. Power production of best match renewable energy system is 4,631 kWh/yr. Above all, this best match power system can supply 2,285 kWh/yr of AC electrical load throughout the year. Energy losses inverter is about 254 kWh/yr and energy losses in battery storage system is about 540 kWh/yr.

In order to be more confident with the result of best match renewable energy system, three options from Homer were simulated in Merit to find the match rate. Then, the results showed that the a renewable energy system ,which composed of seventeen 185W PVs (3.145kW) connecting with twenty two 200Ah batteries, has the highest match rate among three option. The match rate of this system is 42.33%.

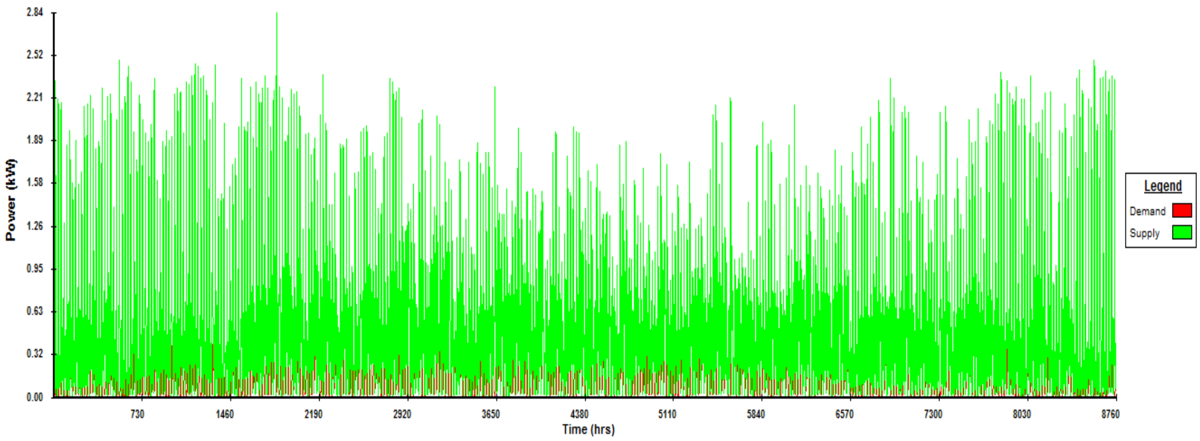

Figure28: Supply and demand of Case2 (system with AC cooling load)

After AC cooling system in Case2 was replaced with DC cooling system to reduce some energy losses in the system, Homer recommended a power system which composed of sixteen 185W PVs (2.96kW) connecting with twenty 200Ah batteries and a 1kW inverter would be the best match renewable energy system for electrical load demand of Case2 with DC cooling system. This recommended renewable energy system does not have any unmet electrical load. As the recommendation, it can supply power to all electrical loads without period of energy deficit. It also has 1,445 kWh/yr of excess electricity. The excess electricity is about 33.2% of power production to support the increasing of power demand. When the batteries are fully charged, the power system can supply power about 4.6 days without charging. This recommended solar power system from Homer is the best match renewable energy system, which can generate 4,358 kWh/yr of electrical power to serve 1091 kWh/yr of AC electrical load and 1194 kWh/yr of DC cooling load. Total energy losses in this best match renewable energy system is about 628 kWh/yr, which consists of 121 kWh/yr of energy losses in inverter, and 507 kWh/yr of energy losses in batteries. As a result, changing from AC cooling to DC cooling in this case causes the decreasing of energy losses about 20%.

6.2.3 Best match renewable energy system for Case3

Case3 was developed from the base case model by adding three inch fiberglass to the ceiling of the house. The cooling demand of this case is about 2.7 kWh/d, which is the lowest cooling load demand in three cases. Therefore, average energy demand of Case3 is about 5.7 kWh/d. Homer recommended two match renewable energy systems for the electrical power demand of Case3. First recommended renewable energy system was solar power system which composed of fourteen 185W PVs (2.59kW) connecting with twenty 200Ah batteries and a 2kW inverter. Second recommended renewable energy system was hybrid power system which composed of twelve 185W PVs (2.22kW) and a 400W wind turbine connecting with twenty one 200Ah batteries and 2kW inverter. The maximum output from inverter to electrical load was about 1.2 kW.

Assessment factors	1st option	2nd option
Unmet electrical load (kWh/yr)	1.34	1.78
Usable nominal capacity (kWh)	28.8	30.2
Excess electricity (kWh/yr)	998	913

Table13: Assessment factors of Case3

Table13 shows that the first recommended renewable energy system and the second recommended renewable energy system can serve the electrical load of Case3 for about 5 days. First recommended power system has 998 kWh/yr of excess electricity, which is higher than second recommended power system although the size of renewable energy component (PV + wind turbine) in second recommended system is bigger than the size of renewable energy component (PV) in first recommended power system. As the data in the table, power production from PV is better than power production from wind turbine. In brief, the solar energy in Thailand would be more reliable than wind energy. Unmet electrical load of first recommended power system is less than the unmet electrical load in second recommended power system. The first recommended system would have more chance to be able to serve electrical power to all electrical demand. Thus, first recommended power system was added a 200 Ah battery to make it be able to supply power without period of energy deficit. Finally, a solar power system which composed of fourteen 185W PVs (2.59kW) connecting with twenty one 200Ah batteries can serve electrical power to all electrical loads without period of energy deficit. This solar power system is the best match renewable energy for the electrical demand of Case3. This best match solar power system can produce 3,814 kWh/yr of electricity to supply 2,095 kWh/yr of AC electrical load. Total excess electricity in the system is approximately 996 kWh/yr or about 26.1% of total electrical power production to secure energy supply in the future. Total energy losses in this system are about 723 kWh/yr.

In order to be more confident with the result of best match renewable energy system, three options from Homer were simulated in Merit to find the match rate. Then, the results showed that the a renewable energy system ,which composed of fourteen 185W PVs (2.59kW) connecting with twenty one 200Ah batteries, has the highest match rate among three option. The match rate of this system is 46.01%.

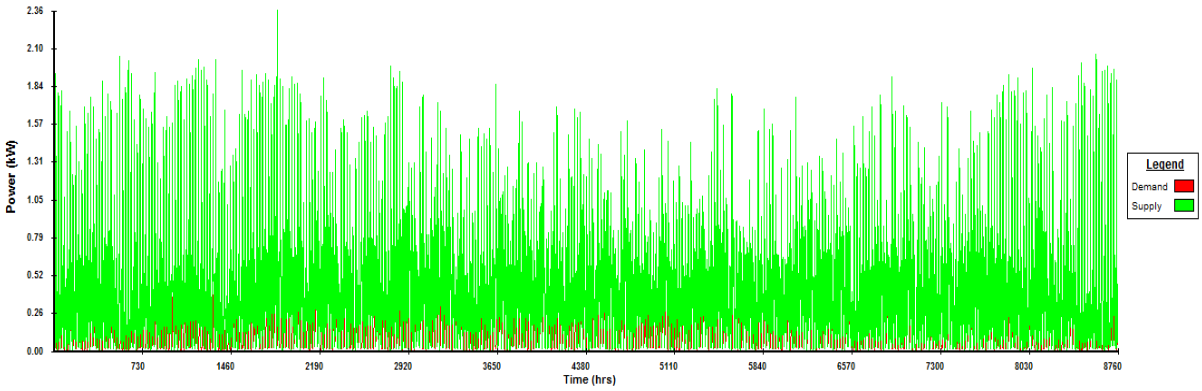

Figure29: Supply and demand of Case3 (system with AC cooling load)

AC air conditioning in Case3 was substituted with DC air conditioning system similar to the previous two cases. Homer recommended a solar energy system which composed of thirteen 185W PVs (2.405kW) connecting with twenty 200Ah batteries and a 1kW inverter would be the best match power system for electrical demand of Case3 with DC air conditioning system. This solar power system does not have any unmet electrical load so it can serve the electricity to all electrical loads throughout the year. In addition, this solar power system can produce 3,541 kWh/yr of electricity to supply 1,091 kWh/yr of AC electrical load and 1,004 kWh/yr of DC electrical load. It can supply electrical power to all AC and DC loads for about 5.3 days when batteries are fully charged. This power system which composed of thirteen 185W PVs (2.405kW) connecting with twenty 200Ah batteries and a 1kW inverter is the best match renewable energy system for electrical load demand of Case3 with DC cooling system. The energy losses in this best match power system is about 503 kWh/yr which less than energy losses in the best match power system for Case3 (AC cooling system) about 140 kWh/yr. DC cooling in this case causes the reduction of energy losses in power system about 20% of energy losses in the best match power system for (AC cooling system).

Chapter7: Conclusion and recommendation

The main objectives of this research are to create hourly cooling load demand data that can be the representative of average cooling load demand of households in Thailand and to investigate the best match renewable energy system for average electricity demand of Thai household. From the information about the electrical power consumption in Thai household, almost a half of that consumption in Thai household is the cooling load. Cooling load demand is one significant factor to create the sensible and realistic best match renewable energy system. As a fact about the electrical power consumption, this study gave much importance to building energy performance simulation in ESP-r that was used to create hourly cooling load.

The first section in this research is about to create cooling load data. In order to produce hourly cooling load data of Thai household, house design and all modeling inputs that are the representative of Thailand were used in the building energy performance simulation.

The base case model was created from house design, which was widely used in Thailand, has the cooling load demand about 1229.71 kWh/yr or about 3.4 kWh/d. Although the cooling load demand of base case model is close to the average cooling load demand of household in Thailand and sensible to be average cooling load consumption in Thai household, base case model was further developed to make the cooling load results from building energy performance be closer to the national statistic. Two strategies that were recommended that they can be used to reduce the cooling load of household in Thailand, by a department of Thai government were applied separately to the base case model.

The base case, which was rotated 90 degree to make windows of bedrooms facing the north, is the second case in this research. The cooling load demand of this case is about 1,194.4 kWh/yr or about 3.3 kWh/d. Therefore, the house facing direction strategy in this case can reduce 35.3 kWh/yr of cooling load from the cooling load of base case model. From this case, it can be concluded that the direction can cause the decrease of heat gain in the building that can reduce the cooling load as well. If bedrooms of the house that is the same model and design as base case face to the north, the cooling load consumption could be less than the house that bedrooms face to the east about 2.9% of the cooling load of base case model.

Furthermore, the base case model that was added 3 inch fiberglass to the ceiling of the house is the third case in this research. The cooling load demand of this case is about 993.7 kWh/yr or about 2.7 kWh/d. The improvement by adding fiberglass in this case can reduce the cooling load about 19% of the cooling load of base case model. The cooling load in this case decreased because fiberglass slows down the rate of heat pass through the ceiling. Therefore, the heat gain in the building is decreased as well. As a result, the cooling load does not work hard to cool the building at the desired temperature. This insulation strategy is much more effective than the house facing direction strategy.

This research has three cooling load data from three cases. Hourly cooling load data from three cases indicates that the maximum cooling load is not over 1kW. From the three cases of cooling load data in this research, Thai households that have same house design and cooling control details similar to the house model in this research can use 1kW air conditioning system for their bedrooms.

Each hourly cooling load data of three cases were copied separately to Excel files. Three Excel files were imported separately to Homer to do the matching supply with demand simulation to estimate the match renewable energy system that can supply electrical power to each electrical load profile. In Homer, hourly cooling load was integrated with lighting and other electrical load to form three electrical load profiles from three cases.

The match renewable energy results from Homer were assessed whether they are the best match renewable energy systems. Some results from Homer could not be the best match renewable energy system so they were improved until they are the best match renewable energy system. Then, match power system options from Homer were simulated in Merit to evaluate the match rate of supply and demand determine the best match renewable energy system for each case.

The best match renewable energy system for the electrical load demand of base case is the solar power system, which composed of seventeen 185W PVs (3.145kW) connecting with twenty two 200Ah batteries and a 2kW inverter.

Moreover, the best match renewable energy system for the electrical load demand of the second case is the solar power system which composed of seventeen 185W PVs (3.145kW) connecting with twenty two 200Ah batteries and a 2kW inverter.

Furthermore, the best match renewable energy system for the electrical load demand of the third case is the solar power system which composed of fourteen 185W PVs (2.59kW) connecting with twenty one 200Ah batteries and a 2kW inverter.

Consequently, the solar power system, which composed of seventeen 185W PVs (3.145kW) connecting with twenty two 200Ah batteries and a 2kW inverter, is the best match renewable energy system for average electrical power demand of household in Thailand. It would be able to serve electrical power to average electricity demand of household in Thailand without period of energy deficit.

After that the AC cooling systems in three cases were replaced with DC cooling systems to reduce the energy losses in the power system. As a result, the best match renewable energy systems of electrical loads of three cases are as follow.

The best match renewable energy system of base case model, which was installed DC air conditioning system is solar power system, which composed of sixteen 18W PVs (2.96kW) connecting with twenty 200Ah batteries and a 1kW inverter. Energy losses in this power system is less than energy losses in base case model, which was installed AC cooling system about 171 kWh/yr or about 21%.

Next, the best match renewable energy system of the second case model, which was installed DC air conditioning system, is solar power system that composed of sixteen 18W PVs (2.96kW) connecting with twenty 200Ah batteries and a 1kW inverter. Energy losses in this power system is less than energy losses in the second case model, which was installed AC cooling system, about 166 kWh/yr or about 20%.

Furthermore, The best match renewable energy system of the third case model, which was installed DC air conditioning system, is solar power system, which composed of thirteen 18W PVs (2.405kW) connecting with twenty 200Ah batteries and a 1kW inverter. Energy losses in this power system is less than energy losses in the third case model, which was installed AC cooling system, about 140 kWh/yr or about 20%.

Therefore, DC cooling load in the model can cause the decreasing of energy losses approximately20% of energy losses in the system, which was installed AC cooling system. This energy loss reduction comes from the decrease of inverter size and the decrease of battery quantity in the renewable energy system.

For the design renewable energy system in this research, the solar energy in Thailand is more reliable than the wind energy because 400W of PV array in this design system would be able to produce 588.8 kWh/yr or approximately 1.6kWh/d. On the other hand, 400W wind turbine in this design renewable energy system can generate 425 kWh/yr or about 1.16 kWh/d. Therefore, best match renewable energy for each case is solar power system.

This research created hourly cooling load demand data that would be the representative of average household energy consumption in Thailand and investigated the best match renewable energy system of average electricity demand of household in Thailand. The base case model is assumed as the representative of house in Thailand. Thus, the base case model should be improved in the future to get better energy performance and the best match renewable energy system that are more sensible than the current model. In addition, the base case model in this research can be adjusted to create specific house model to estimate energy performance of specific house design. Further study may create a community in Thailand that consists of many house and use electricity demand of base case in this research to estimate total energy consumption. In addition, the community can be estimated the power system supply from the best match renewable energy system in this research. The solar power system of all household in that community should be connected as one system for the whole community to find whether the big system for whole community is better than many separated power systems of all households in the community.

Chapter8: References

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