博士論文

INTEGRATED EVALUATION OF ENERGY USE BY INTRODUCING THE DISTRIBUTED ENERGY RESOURCES IN THAILAND’S COMMERCIAL BUILDINGS

タイの非住宅建築物における
分散型エネルギーシステムの総合評価に関する研究

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Preface

This thesis research was performed at the Department of Architecture at The University of Kitakyushu. The interdisciplinary study presented in this thesis combines insights from the field of energy, technology, policy, and economic studies. The focus is set on the feasibility study of the introduction of Distributed Energy Resources (DERs) for Commercial buildings in Thailand in several aspects. This study was supported by Japanese Government (Monbukagakusho) Scholarship during 2011 to 2014. The thesis includes three papers which published in scientific journals.

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Finally, I sincerely want to thank to my parents and family who gave me the opportunity to study and greatly supported and affectionately accompanied me and to whom I would like to dedicate this work.

Suapphong Kritsanawonghong, *September 2014*

ABSTRACT

With the development of distributed energy resources (DERs) and the implementation of policies from government to encourage their applications, the introduction of combined heat and power system (CHP) is expected to play the important role of alternative energy supply in the commercial buildings in next 20 year regarding to the implementation plan city gas pipeline in Thailand. The Thai Government now has a provision on DG development in the country and provides a favorable investment for investor. Regulatory frameworks for Small Power Producer (SPP) and Very Small Power Producer (VSPP) have been set up to promote power generation from renewable fuels or cogeneration facilities in the private sector.

Implementation of alternative energy to support increased demand is one effective way to meet energy consumption needs and to reduce environmental pollution caused from the emissions being released. The cogeneration, which produces electricity with heat utilization, is also called CHP system, or combined heat and power, which makes electricity with heat utilization. This is a potentially a significant technology to provide effective energy utilization and environmental benefits for both the commercial and industrial sectors in Thailand. Compared with traditional central energy supply, distributed energy source can utilize a wide range of energy source, including biomass-based generators, combustion turbines, concentrating solar power and photovoltaic systems, fuel cell, wind turbines, micro turbines, diesel generator sets and electrical power storage and all kinds of thermal recovery technologies. Distributed energy system has the high primary energy efficiency. This means that lower fuel consumption takes place, and the energy is generated at a lower running cost, and in a more environmentally friendly way. Therefore, this thesis, "INTEGRATED EVALUATION OF ENERGY USE BY INTRODUCING THE DISTRIBUTED ENERGY RESOURCES IN THAILAND'S COMMERCIAL BUILDINGS" is one of the support information for DER implementation

Chapter 1, PREVIOUS STUDY AND PURPOSE OF THE STUDY, investigated the present situation of energy in Thailand including energy supply, final energy consumption, and overview of the potential for distributed energy generation technologies and their characteristics. In addition, the previous studies of this research are reviewed.

Chapter 2, INVESTIGATION OF DISTRIBUTED ENERGY RESOURCES IN THAILAND, reviewed the present situations and development of distributed energy technologies including the future potential in Thailand are described in details. Also, the

situation of key groups for the development of Distributed Energy Resources (DERs) in Thailand, namely Independent Power Producer (IPP), Small Power Producer (SPP), and Very Small Power Producer (VSPP) are reviewed in details.

Chapter 3, THAILAND'S ENERGY POLICY, reviewed the energy policies which related to the commercial buildings either the alternative energy policy or energy conservation policy. This chapter can be state for the readiness of Thailand's government for the development of DERs that have the support regulations and policies in order to strengthen the new era of energy supply in the future.

Chapter 4, PRESENT SITUATTION OF ENERGY USE IN THAILAND'S COMMMERCIAL BUILDINGS, reviewed the energy consumption of commercial buildings in Thailand by type for whole country from the database of the energy management report which submitted to Department of Alternative Energy Development and Energy Efficiency (DEDE) to understand the characteristics of energy consumption in each building type and potential for development from DERs concept.

Chapter 5, PERFORMANCE ASSESSMENT OF COMBINED HEAT AND POWER SYSTEM FOR THAILAND's COMMERCIAL BUILDING: proposed the assessment index for evaluation the performance of the CHP system for Thailand's commercial buildings. First, the evaluation of the energy performance should be performed for the first priority and also integrated with the assessment criteria of other two assessment indexes in order optimize the capacities of the CHP system under several conditions.

Chapter 6, FEASIBILITYY STUDY AND OPTIMIZATION ON THE INTRODUCTION OF CHP SYSTEM FOR THAILAND'S COMMERCIAL BUILDINGS, evaluated the potential of CHP implementation for Thailand's commercial buildings from 3 case-studies; office buildings, hotels, and convenience stores by considering the integrated evaluation index in order to analyse the benefit after implementation. It is found that, the selection of optimal sizing of CHP capacity and efficiency consequence to save the primary energy more than 20% in all case studies.

Chapter 7, CONCLUSIONS, the whole summary of each chapter has been presented.

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CHAPTER THREE: THAILAND'S ENERGY POLICY

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CHAPTER ONE: PREVIOUS STUDY AND PURPOSE OF THE STUDY

1-1 INTRODUCTION

According to the rapid growth of economic crisis, the development of the efficient energy conservation and generation technologies have become necessity due to the increasing concern for the depletion of the fossil fuel resources . The development of distributed energy resources (DERs) and the policies related implementation by the government in order to encourage the utilization of DERs, in Thailand, the introduction of combined heat and power system (CHP) is expected to play the important role of alternative energy supply in the commercial buildings in near future regarding to the implementation plan city gas pipeline from the energy policies. The Thai Government now has a provision on DG development in the country and provides a favorable investment for investor. Regulatory frameworks for Small Power Producer (SPP) and Very Small Power Producer (VSPP) have been set up to promote power generation from renewable fuels or cogeneration facilities in the private sector [1].

Distributed Energy Resources (DERs), which also called as "Decentralized energy Generation" is the utilization of an on-site energy source to provide electricity and other energy to one or more facilities. The application of DERs can utilize a wide range of power generators including: biomass-based generators、combustion turbines、concentrating solar power and photovoltaic systems、fuel cell、wind turbines、micro turbines、diesel generator sets; hybrid systems and、electrical power storage and all kinds of thermal recovery technologies [2]. For the utility-side consideration, distributed energy resource can help to avoid concerns about transmission and distribution upgrades and under certain conditions can provide voltage support and distribution network stability. Also for the end-user consideration, the power quality and reliability from the energy generation can be achieved, also provide the choice and potentially lower energy costs. From the aforementioned reasons were guaranteed for the DERs utilization in many developed and developing countries experience an increasing contribution of distributed generation to their electricity supply [3-6].

This research reviewed the present situation of country's available energy and also the overview of the problems of DERs, and technologies in Thailand including the barrier of the problems of the implementation of DERs in the future. The analysis of case studies for the benefit of the implementation of DERs in commercial buildings also performed in this study.

1-2 ENERGY SITUATIONS IN THAILAND

1-2-1 PRIMARY ENERGY SUPPLY

Figure 1-1 shows the statistical data of domestic primary energy supply from 1992 to 2012 (Commercial energy). Total primary energy production in 2012 was 54,074 ktoe, which increase of 6.7% from 2011 and about 3.52 times of primary energy production in 1992. Of this amount, the total production of natural gas was 58.34% of the total domestically commercial energy production which is the highest productions, followed by Lignite, Crude oil, Condensate, and Hydropower about 16.63%, 12.54%, 8.23%, and 4.26%, respectively [7,8]

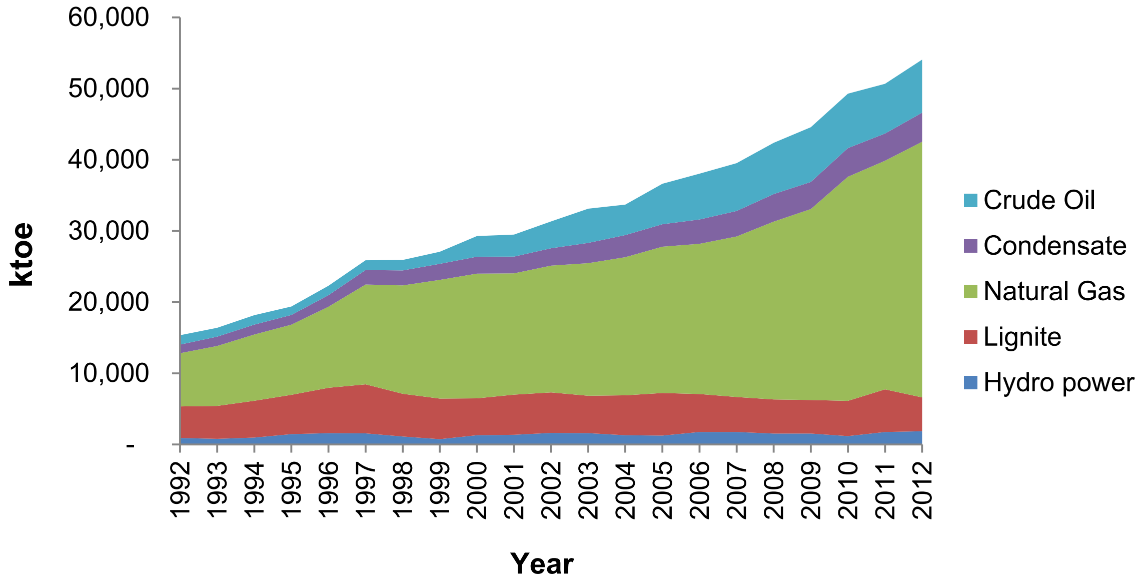

Figure 1-1. Statistical data of primary energy supply in Thailand (Year 1992 – 2012) [7, 8]

Considering the production from renewable energy, Thailand is an agricultural country which has lots of agricultural wastes and products that can be used as energy production, e.g. biomass, biodiesel, biogas, etc. In 2012, the total production of renewable energy was 7,825 ktoe, which increased of 18.1% from 2011. Of this total was including solar, fuel wood, paddy husk, bagasse, agricultural waste, MSW, and biogas. However, the total production from traditional renewable energy (fuel wood, charcoal, paddy husk, agriculture waste) was 13,245 ktoe, decreased of 5.7% from 2011.[9]

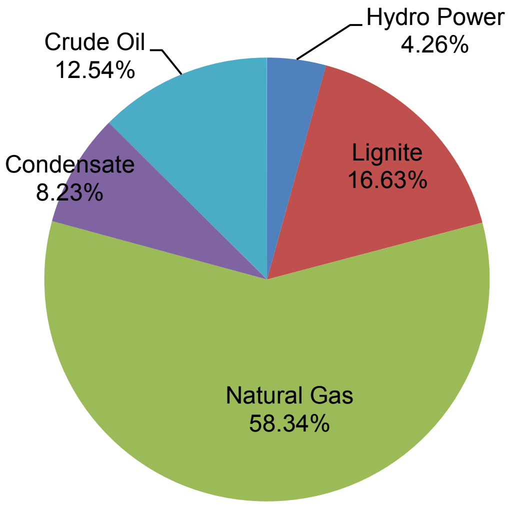

Figure 1-2 Domestic primary energy production in Thailand (Commercial Energy) [9]

1-2-2 FINAL ENERGY CONSUMPTION

1-2-2-1 Final energy consumption by fuel type

Total final commercial energy consumption by considering different type of fuel is illustrated in Figure 1-3. The natural gas consumption is highest significantly increased every year, followed by the petroleum consumption is also steadily increased but not high rate as of natural gas. However, considering the sharing percentage, petroleum products consumption played the greatest proportion 49% of the final energy consumption, followed by natural gas, lignite, imported coal, and import electricity shared 33%, 9%, 6% and 3%, respectively [10, 11].

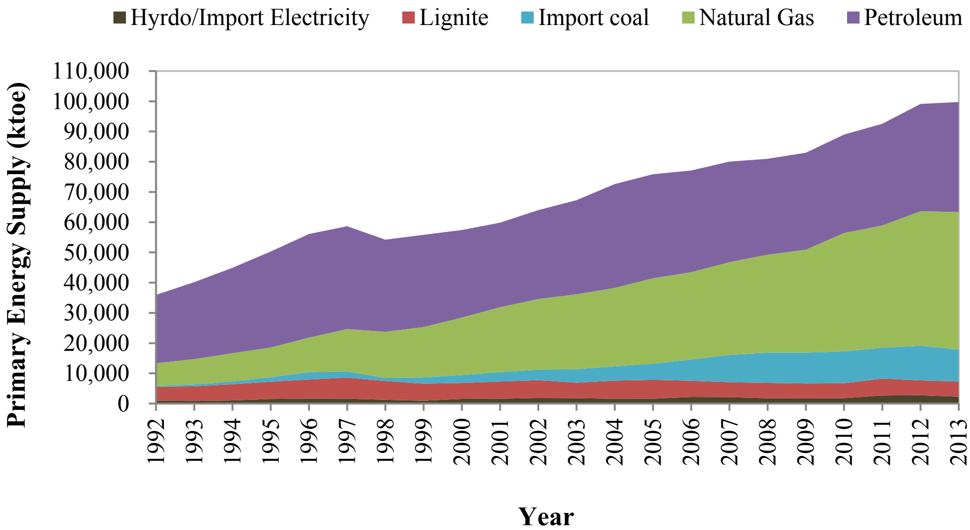

Figure 1-3 Statistical data of final energy consumption by fuel type (Year 1992 – 2013)

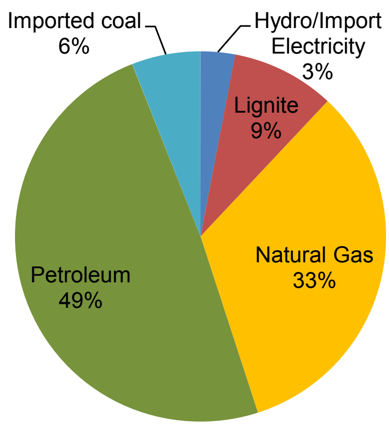

Figure 1-4 Sharing of final energy consumption by fuel type

In 2012, the final energy consumption of Thailand in 2012 was about 73,316 ktoe [8], an increase of 13% [8] from 2007. The total value of the final energy consumption was US$57,545.21 million. Considering the trends in primary energy supply (excluding energy exports) and final energy consumption from 2007 to 2012, it is observed that the primary energy supply increases year-by-year. In 2012, the amount of primary energy supplies was 130,848 ktoe [8]. For primary energy supplies classified by energy type, the highest share, which contributed 82.8% of the total primary energy supply, was from commercial energy (crude oil, lignite, natural gas, and soon), followed by renewable energy, biofuels (ethanol and biodiesel), and other forms of energy (black liquor and residual gas), at 16.2%, 0.8%, and 0.2%, respectively.

1-2-2-2 Final energy consumption by economic sector

Considering the final energy consumption by economic sector from 1992 to 2012, energy demand in Thailand increased continuously at an annual average rate of 5.6%. In 2012, final energy consumption was 73,316 thousand tons of crude oil equivalent (ktoe). The growth rate of the consumption corresponded with the economic growth rate, of which the annual average rate was 4.1%, accounted for the energy elasticity at 1.02 which defined as the ratio of energy consumption growth rate to the national GDP growth rate. The economic sectors for which the high energy consumption growth rates were the commercial building and industrial sectors, with final energy consumption in 2012 being 3.82 and 2.5 times that of in year 1992, respectively [8].

Thailand's electricity consumption was 162,668 GWh [8] in 2012. Most of this electrical energy, equal to 82,068GWh, was consumed by the industrial sector. The commercial sector (including government, non-profit organizations, and street lighting), residential sector, agricultural sector, transportation sector, and other sectors (temporary customers) used 47,210 GWh, 32,097 GWh, 70 GWh, and 930 GWh, respectively. [10]

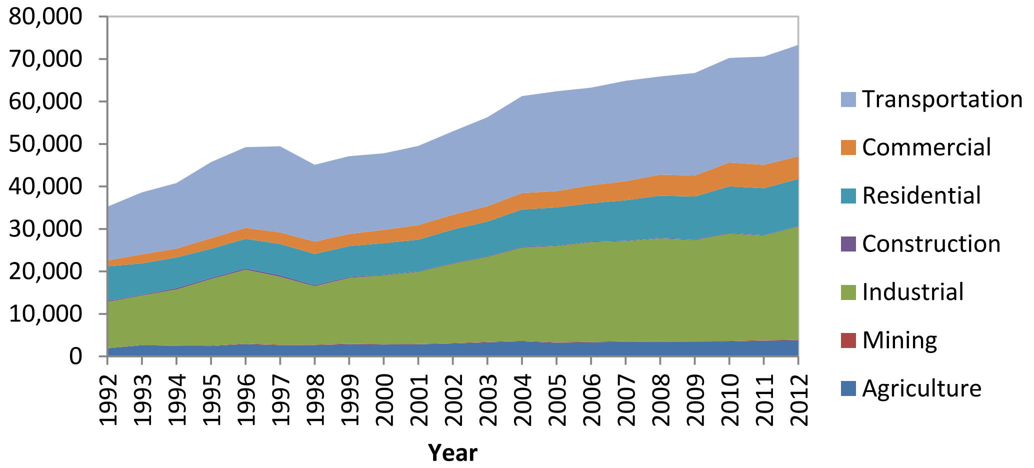

Figure 1-5 Statistic data of final energy consumption by economic sector (Year 1992 – 2013)

Final energy consumption of transportation sector is the greatest share of 37.17%, followed by industrial sector, residential sector, commercial sector, agricultural sector, construction, and mining shared 34.75%, 15.47%, 6.54%, 5.52%, 0.35% and 0.2%, respectively.

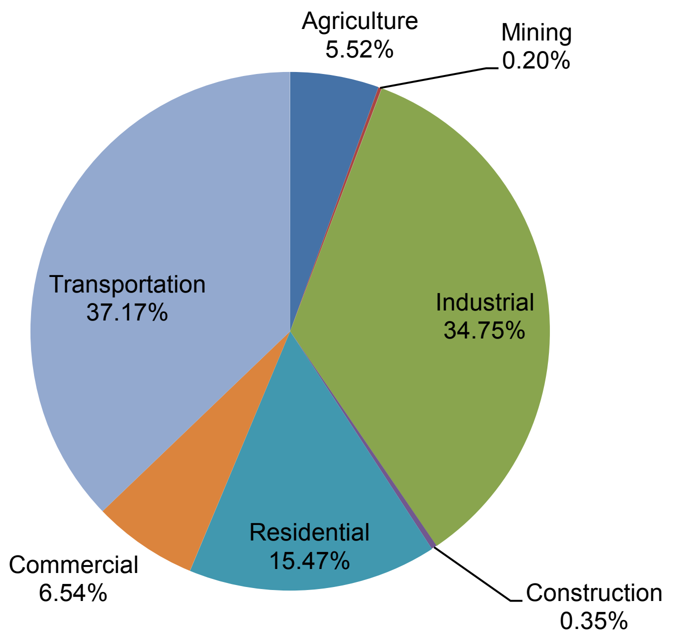

Figure 1-6 Sharing of final energy consumption by economic sector [8]

1-2-3 TREND OF FUTURE ENERGY DEMAND

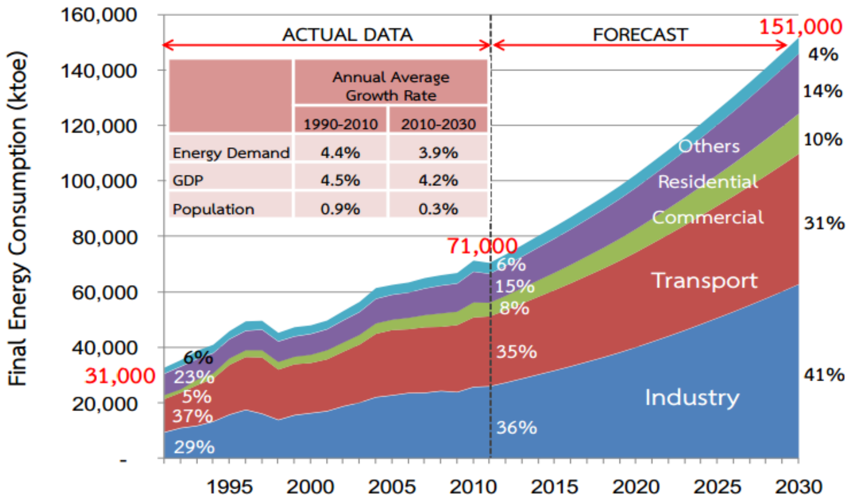

Figure 1-7 Trend of future energy demand under BAU case [11,12]

From the future energy demand forecast by Thailand's Ministry of Energy , in 2030, if there is no energy conservation or energy efficiency improvement measures or no significant reform of the industrial structure and transportation system, energy demand under the business-as-usual (BAU) scenario will increase from 71,000 ktoe/year at present, to 151,000 ktoe, or about 2.1 times the present amount, accounting for an annual average growth rate of 3.9%, under the assumption that the GDP will grow at an annual average rate of 4.2% [11]. The demand in the industrial and commercial sectors will still increase at a higher rate than other sectors. Hence, greenhouse gas emission from the energy sector will tend to increase accordingly. [11,12]

The target of energy conservation has been set with a view to strengthening regional energy security and addressing climate change problems, by reducing "energy intensity," or the amount of energy used per unit of GDP, by 25% in the year 2030 compared with the 2005 base year [11]. Since Thailand's energy intensity in 2005 was 16.2 ktoe per billion baht GDP (at 1988 constant value), if Thailand is determined to implement energy conservation measures pursuant to the mentioned agreement, the overall energy intensity of the country in 2030 must not exceed 12.1 ktoe per billion baht GDP, or the final energy consumption in that year must not exceed 121,000 ktoe (under the assumption that the annual economic growth rate will be at 4.2% in average). The energy demand must be 30,000 ktoe lower than that in the BAU case, or 20% lower than the demand in the BAU case [11,12].

1-3 RESEARCH BACKGROUND AND SIGNIFICANT

1-3-1 CONCEPT OF DISTRIBUTED ENERGY RESOURCES

Due to the limitation of country's energy resources and highly consumption of energy demand, the management of energy demand & supply is one of the most significant roles in order to maintain the energy security in each country. Several methods were purposed under the criteria in each place, e.g. the amount of energy demand – supply, technologies provided, economic factors, etc. The reliability of the energy supply is one of the important factors for energy management. The traditional energy generation or central generating electricity power plant cannot satisfy the requirement of energy demand from the customer especially rural area and specific place. Also for the future demands of energy power system especially electrical energy shortages, power quality problems, blackouts, and electricity price spikes from the utilization of customers to seek other sources of high-quality and reliability energy. [13-15]. Therefore, the solution of distributed energy resources (DER), or decentralized energy supply (DES), is one of effective way to solve the aforementioned issues which is the utilization of an on-site energy source to provide electricity and other energy to one or more buildings or facilities. In addition, distributed energy source can utilize a wide range of power generators including: biomass-based generators、combustion turbines、concentrating solar power and photovoltaic systems、fuel cell、wind turbines、micro turbines、diesel generator sets; hybrid systems and、electrical power storage and all kinds of thermal recovery technologies [16]. Distributed energy source benefits both the utility and the end user. For the utility, distributed energy source can help to avoid concerns about transmission and distribution upgrades and under certain conditions can provide voltage support and distribution network stability. Benefits to the customer or end-user included power quality and reliability, peak shaving, choice and potentially lower energy costs. [16]

Generally, DERs is an electric generation units within the electric distribution system at or near the end user which paralleled to the electric utility or stand-alone units. The utilization of "DERs" in this Resource Page refers to the broadest range of technologies that can provide power to the user outside of the grid, and includes demand-side measures. Comparing to the terms of Distributed Generation (DG), that of defined as anything outside of the conventional utility grid that produces electricity. DG technologies include internal combustion engines, fuel cells, gas turbines and micro-turbines, hydro and micro-hydro applications, photovoltaic, wind energy, solar energy, and waste/biomass fuel sources and also including non-utility combined heat and power plants. For the Distributed Power (DP) concept, DP encompasses all of the technologies included in distributed generation as well as electrical storage technologies. DP includes batteries, flywheels, modular pumped hydro-electric power, regenerative fuel cells, superconducting magnetic energy storage, etc. DER includes all technologies in DG and DP and also includes demand-side measures. It is noted combined heating and power (CHP) technologies represent a special area within the realm of distributed generation. CHP systems that are installed at or near the point of use for off-grid applications are considered to be distributed generation systems. However, large central station CHP units are not included in DG. That is to say, it is not included in DER in this paper. The size of this type of unit is typically between 50–400 megawatts (MW) [17-20].

1-3-2 DISRIBUTED ENERGY RESOURCE TECHNOLOGIES [16, 17]

The common DER technologies consist of energy generation system and storage systems placed at or nearby the point of use. DER also involves power electronic interfaces, as well as communications and control devices for efficient dispatch and operation of single generating units, multiple system packages, and aggregated blocks of power.

The primary fuel for many distributed generation systems is natural gas, hydrogen (may play an important role in the future due to the properties of clean energy and high power generation). Renewable energy technologies—such as solar electricity, biomass power, and wind turbines—are also commonly used. [17]

- **Microturbines**

Micro-turbines are small electricity generators that burn gaseous and liquid fuels to create high-speed rotation that turns an electrical generator. The size range for micro-turbines available and in development is from 30 to 400 kilowatts (kW), while conventional gas turbine sizes range from 500 kW to 350 megawatts (MW). Micro-turbines run at high speeds and, like larger gas turbines, can be used in power-only generation or in combined heat and power (CHP) systems. Normally, the power output from Microturbines is produced between 25 kW and 500 kW.

- **Combustion turbines**

The conventional combustion turbine generators typically range in size from about 500 kW up to 25 MW for DER, and up to approximately 250 MW for central power generation. They are fueled by natural gas, oil, or a combination of fuels. Modern single-cycle combustion turbine units typically have efficiencies in the range of 20 to 45% at full load. Efficiency is somewhat lower at less than full load.

- **Reciprocating engines**

The reciprocating engines are used for all types of power generation, from small portable gensets to larger industrial engines that power generators of several megawatts. Spark ignition engines for power generation use natural gas as the preferred fuel – although they can be set up to run on propane or gasoline.

A reciprocating, or internal combustion (IC), engine converts the energy contained in a fuel into mechanical power. This mechanical power is used to turn a shaft in the engine. A generator is attached to the IC engine to convert the rotational motion into power. A variety of stationary engine products are available for a range of power generation market applications and duty cycles including standby and emergency power, peaking service, intermediate and base load power, and combined heat and power (CHP). Gas-fired reciprocating engines are well suited for packaged CHP in commercial and light industrial applications of less than 5 MW. Smaller engine systems produce hot water. Larger systems can be designed to produce low-pressure steam.

Diesel-cycle, compression ignition engines operate on diesel fuel or heavy oil, or can be set up in a dual-fuel configuration that can burn primarily natural gas with a small amount of diesel pilot fuel. Reciprocating engines offer low first cost, easy start-up, proven reliability when properly maintained, and good load-following characteristics. Drawbacks of reciprocating engines include relatively high noise levels, relatively high air emissions, and the need for regular maintenance. The emissions profiles of reciprocating engines have been improved significantly in recent years by the use of exhaust catalysts and through better design and control of the combustion process.

There are two basic types of reciprocating engines - spark ignition (SI) and compression ignition (CI). Spark ignition engines for power generation use natural gas as the preferred fuel, although they can be set up to run on propane, gasoline, or landfill gas. Reciprocating engines use commonly available fuels such as gasoline, natural gas, and diesel fuel. Compression ignition engines (often called diesel engines) operate on diesel fuel or heavy oil, or they can be set up to run in a dual-fuel configuration that burns primarily natural gas with a small amount of diesel pilot fuel.

Diesel engines have historically been the most popular type of reciprocating engine for both small and large power generation applications. At the present, the natural gas-fueled SI engine is now a popular choice for the higher-duty-cycle stationary power market.

- **Stirling Engines**

Stirling engines are classed as external combustion engines. They are sealed systems with an inert working fluid, usually either helium or hydrogen. They are generally found in small sizes (1-25 kW) and are currently being produced in small quantities for specialized applications in the space and marine industries.

- **Gas Turbines**

Gas turbines produce high-quality heat that can be used to generate steam for on-site use or for additional power generation (combined-cycle configuration). Gas turbines can be set up to burn natural gas, a variety of petroleum fuels or can have a dual-fuel configuration. Gas turbine emissions can be controlled to very low levels using water or steam injection, advanced dry combustion techniques, or exhaust treatment. Alternatively, this high temperature heat can be recuperated to improve the efficiency of power generation or used to generate steam and drive a steam turbine in a combined-cycle plant. The available in sizes ranging from several hundred kW to over several hundred MW but for the low maintenance and high-quality waste heat make gas turbines an excellent match for industrial or commercial CHP applications larger than 5 MW.

- **Steam Turbines**

Steam turbines convert steam energy into shaft power and are one of the most versatile and oldest prime mover technologies used to drive generators or mechanical machinery. The capacity of steam turbines can range from fractional horsepower to several hundred MW for large utility power plants. A steam turbine is captive to a separate heat source and does not directly convert a fuel source to electric energy. Steam turbines require a source of high-pressure steam that is produced in a boiler or heat recovery steam generator (HRSG). Boiler fuels can include fossil fuels such as coal, oil, or natural gas or renewable fuels like wood or municipal waste.

- **Micro Turbines**

Micro-turbines are small electricity generators that burn gaseous and liquid fuels to create high-speed rotation that turns an electrical generator. The size range for micro-turbines available and in development is from 30 to 400 kW, while conventional gas turbine sizes range from 500 kW to 350 MW. Micro-turbines run at high speeds and, like larger gas turbines, can be used in power-only generation or in combined heat and power (CHP) systems.

- **Fuel cells**

Fuel cell power systems are quiet, clean, highly efficient on-site electrical generators that use an electrochemical process—not combustion—to convert fuel into electricity, more like batteries than conventional generating systems. In addition to providing power, they can supply a thermal energy source for water and space heating, or absorption cooling. In demonstration projects, fuel cells have been shown to reduce facility energy service costs by 20% to 40% over conventional energy service.

As with most new technologies, fuel cell systems have several disadvantages, such as product immaturity, over-engineered system complexities, and unproven product durability and reliability. These translate into high capital cost, lack of support infrastructure, and technical risk for early adopters, which in turn cause market resistances that propagate the disadvantages. Fuel cells produce power electrochemically from hydrogen delivered to the negative pole (anode) of the cell and oxygen delivered to the positive pole (cathode). The hydrogen can come from a variety of sources, but the most economic method is by reforming of natural gas or liquid fuels. There are several different liquid and solid media that support these electrochemical reactions - phosphoric acid (PAFC), molten carbonate (MCFC), solid oxide (SOFC), and proton exchange membrane (PEM) are the most common systems. Fuel cells promise higher efficiency than generation technologies based on heat engine prime movers. In addition, fuel cells are inherently quiet and extremely clean running. Similar to microturbines, fuel cells require power electronics to convert direct current to 60-Hz alternating current. Many fuel cell technologies are modular and capable of application in small commercial and even residential markets; other technology operates at high temperatures in larger sized systems that would be well suited to industrial CHP applications.

- **Biomass energy**

Biomass is considered as renewable source of energy as it is CO2 neutral with in its entire life cycle. During their growth, plants absorb CO2 from the air and convert it by photosynthesis into complex biochemical compounds, like cellulose and lignin. Sunlight provides the energy for this process. In fact, solar energy is stored by means of biomass. At a later stage this energy can be released and used. The conversion of biomass into energy can beachieved in a number of ways. To provide a fuel suitable for direct use in spark ignition gas engines (s.i.g.e.), the fuel must be provided in either a gaseous, or a liquid form. Production of a gaseous fuel from biomass can be achieved by the application of a number of technologies, each with its specific requirements, advantages and disadvantages. For electricity generation, the potential energy stored in biomass is typically extracted in one of the following ways: (1) Direct combustion of the biomass within a boiler can produce steam to drive a steam turbine. In this case, only certain biomass materials are used in order to avoid ash buildup, which decreases efficiency and increases costs and (2) Processing the biomass through a gasifier, which converts the liquids and solids into a combustible gas. This gas can then be used as a fuel for a gas turbine.

- **Photovoltaic system (PV system)**

Photovoltaic (PV) cells, convert sunlight directly into electricity. PV cells are assembled into flat plate systems that can be mounted on rooftops or other sunny areas. They generate electricity with no moving parts, operate quietly with no emissions, and require little maintenance and require minimal maintenance to operate. They are currently available from a number of manufacturers for both residential and commercial applications, and manufacturers continue to reduce installed costs and increase efficiency. Applications for remote power are quite common.

Photovoltaic systems are commonly known as solar panels. Photovoltaic (PV) solar panels are made up of discrete cells connected together that convert light radiation into electricity. The PV cells produce direct-current (DC) electricity, which must then be inverted for use in an AC system. Current units have efficiencies of 24% in the lab and 10% in actual use, below the 30% maximum theoretical efficiency that can be attained by a PV cell.

- **Wind system (wind turbine)**

Wind turbines use the wind to produce electrical power. A turbine with fan blades is placed at the top of a tall tower. The tower is tall in order to harness the wind at a greater velocity, free of turbulence caused by interference from obstacles such as trees, hills, and buildings. As the turbine rotates in the wind, a generator produces electrical power by connvert the kinetic energy of wind into electricity. Wind turbines, basically windmills dedicated to producing electricity, were considered the most economically viable choice within the renewable energy portfolio. Wind turbines produce electricity without requiring additional investments in infrastructure such as new transmission lines, and are thus commonly employed for remote power applications. Wind turbines are packaged systems that include the rotor, generator, turbine blades, and drive or coupling device. A single wind turbine can range in size from a few kW for residential applications to more than 5 MW.

1-3-3 DISTRIBUTED ENERGY RESOURCE POTENTIAL IN THAILAND

Until now, electricity generation in Thailand is mainly based on Centralized Generation about 91% which produced by the Electricity Generating Authority of Thailand (EGAT) 50%, followed by Independent Power Producers (IPP), Small Power Producers (SPP), and imported from neighboring countries, mainly Laos and Malaysia by 41%, 7%, and 2%, respectively [1, 18].

Distributed generation or decentralized Generation (DG) is the generation of electricity at or near consumer sites and integrated with the distribution systems including SPPs and VSPPs. These power plants are Gas CHP 8,425 GWh, Biomass 2,281 GWh, Coal CHP 2,058 GWh, Small hydropower 189 GWh, Biogas 120 GWh, Oil CHP 48 GWh, and others (wind, solar, waste to energy) 55 GWh. From now, the Thai Government now has a provision on DG development in the country in next 20 years to provides the investment for investor. Regulatory frameworks for Small Power Producer (SPP) and Very Small Power Producer (VSPP) have been set up to promote power generation from renewable fuels or cogeneration facilities in the private sector. Centralized Generation (CG) generally happens not at the place where the load is and therefore requires long transmission lines to the users. With existing high CG share, the losses on transmission are higher than for a DG. [1,21-24]

One of the key parameter to strengthen the DER concept in Thailand is about the city gas pipeline. At the present, the natural gas industry in Thailand is dominated by Petroleum Authority of Thailand (PTT) which covers the full range of natural gas business i.e. exploration, production from domestic and import sources, transportation, gas separation and marketing. PTT has a transmission pipeline with a current natural gas supply of 4,380 MSCF/day. The existing total pipeline length is 3,372 km with 1,397 km located onshore and 1,975 km offshore. In year 2012, the extension of the transmission pipeline will increase the gas supply to 6,980 MSCF/day.[26]

The natural gas and electricity prices are key factors affecting on economics of DER projects especially CHP projects. The change of natural gas prices during the past 10 years (1998–2008) is shown in Figure 8. The average annual growth rate over the past 10 years is around 8.9%. However, in the last five years, the growth rate increased dramatically to 13%. Nevertheless, the electricity price is dependent on natural gas price. A 10% change in the natural gas price would change the electricity tariff by 3.5% [14].

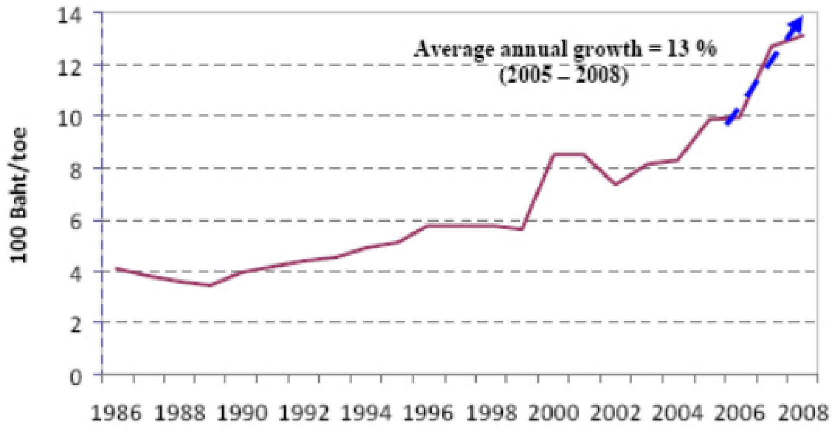

Figure 1-8: Trend of average natural gas price in Thailand during 1986 – 2008

In terms of DER with renewable energy, Thailand was implemented a comprehensive long term strategy and feed-in-tariff (FIT) for renewable in electricity production. High potentials for the power and heat production from solar energy and biomass exist due to location for solar irradiation and lots of farmlands. But the development of DER system combined with RE still on going with slow process due to several barriers which cannot be solved until now.

By 2022, Thailand aims at producing 14 % of its electricity from non-large hydro renewable energy by increasing its renewable generation capacity to 0.8 GW of wind power, 0.5 GW of solar power, 4.0 GW of biomass power, 0.3 GW of small hydropower, and 0.3 GW of other renewable sources. [27]

Therefore, the integration of DER with RE in Thailand also could be an option to ensure energy security and reduce dependence on foreign energy resources. With relatively good solar irradiation and large domestic biomass resources, as well as high potentials for decentralized power production, there are still various opportunities for the country to achieve its renewable energy targets. The high number of applications for solar power projects under the feed-in tariff has indicated considerable interest of investors.

1-4 PREVIOUS STUDY ON DISTRIBUTED ENERGY RESOURCES

1-4-1 STUDY ON DISTRIBUTED ENERGY RESOURCE SYSTEM

Study on the distributed energy resource system (DERs) have been in focused in many research due to the development of energy generation rather than the traditional generation system, centralized facilities. Distributed energy technologies are playing an increasingly important role in the nation's energy portfolio.

The benefit from the utilization of DER is about the grid-connected distributed energy resources which can be strengthen the central-station model of electricity generation, transmission, and distribution. While the central generating plant continues to provide most of the power to the grid, the distributed resources can be used to meet the peak demands of local distribution feeder lines or major customers.

Many researches have been conducted about DERs and also integrated with smart grid system. A. Sheikhi Fini et al. [28] developed the dynamic model to investigate the impacts of multi-resource regulatory policies on distributed energy resource (DER) expansion planning. DERs usually include a variety of renewable and fossil based generation technologies such as wind and gas engine resources, combined heat and power (CHP), demand response (DR) and energy storage. It is founded that, in single-resource support case, price-based variable support scheme from resources has caused more persuasion for investors than the fixed one. In multi-resource, support case, fixed support was more persuasive than price-based variable support scheme in terms of investment. In variable support, in order to reach the desirable penetration, much more support was required than the fixed case. In order to achieve similar penetration rates of single resource support scheme; the amount of the incentive should be higher in the case of multi resources. In addition, the results of individual supporting policy cannot be generalized at all and, if the policy maker wants to support multiple resources at the same time.

Linfeng Z. et al. [29] studied the energy management in microgrid with DER in order to introduced Microgrid performance metrics from the comprehensive aspects: cost, environmental effect, and the service quality. Here, service quality is supply/demand ratio. With the performance metrics, the optimum design and operation of the MG can be achieved.

Akomeno O. et al [30] created the mixed integer liner programming model for the design (i.e. technology selection, unitizing, unit location, and distribution network structure) of a distributed energy system that meets the electricity and heating demands of a cluster of commercial and residential buildings while minimizing annual investment and operating cost.

The model is used to analyze the economic and environmental impacts of distributed energy systems at the neighborhood scale in comparison to conventional centralized energy generation systems. The results showed that DER systems have the potential to lead to significant reductions in annual CO_2 emissions, unfortunately the most environmentally beneficial technologies (CHP, wind turbines, biomass boilers, and photovoltaic) are considerably more expensive than conventional centralized generation. Energy subsidies are therefore critical if these technologies are to be financially competitive.

Xiangxiang G. [31] studied the optimization of the DER capacity for residential buildings in Japan in order to reduce the energy consumption of the residential buildings and expense by presenting a methodology for integrating electricity and hot water supply, and also determining the optimum installed capacities of DERs which consist of PV system, a solar water heating system, and fuel cell system. The results stated that the integration and optimization methodology proposed can be applied to help the residents reform their existing DER systems with actual energy demands, and also help the designers in designing the hardware of the DER systems on the basis of overall system performance with load profiles estimated by researching and marketing.

1-4-2 STUDY ON COGENERATION SYSTEM

The cogeneration system, which is also called combined heat and power or CHP system, which produces electricity with heat utilization from a single fuel source, is a significant potential technology to provide effective energy utilization and environmental benefits. CHP system also provides high quality and reliable electricity supply.

Utilization of the cogeneration system in several building types which require power, cooling, and heating (i.e., shopping malls, supermarkets, department stores, hospitals, and hotels) for energy saving and the environmental load reduction purposes have been the focus of many research projects.

CHP system is also recognized as the key alternative for de-centralized power generation in order to improve the nation's energy security, i.e. Thailand, the energy consumptions for most residential and commercial buildings are supplied from centralized power generation plant over the electricity grid. From the previous studies [32-33], the utilization of CHP system for Thailand's commercial buildings by using gas engines together with absorption chillers, this system is effective method in order to reduce Thailand's peak generation requirements.

The success of CHP system is well proven in industrial and large-scale applications and is being further investigated to meet the needs of small-scale commercial and residential applications [34]. Many studies have been reported on this topic. H. Ren et al. [35] developed the nonlinear programming model to minimize the annual cost of energy system for residential building which equipped with the CHP plant integrated with the storage tank and a back-up boiler in order to introduced the optimal sizing for CHP system and storage tank from the consideration of economic assessment. The results showed that capital cost, energy prices and electricity buy backs are the significant parameters affect the optimal sizing of CHP capacity. Sizing of the storage tank is also affect by the operating time of CHP plant and tariff structure. Rusbeh R. and Reinhard H. [36] investigated the optimal configuration of micro-cogeneration systems for residential buildings in Austria by the minimization of heat generation costs (investment, operational and maintenance costs) and embedded energy (for manufacturing and operation of micro-cogeneration plants). The results showed that the substitution of reference system with a dual system result in a higher efficiency in the heat supply of buildings for both economic and energy saving concerns.

Kyle S. et al. [37] evaluated the economic improvement from the introduction of small-scale cogeneration system for the hospital in New Jersey by considered the expected returns from demand response, capacity and regulation markets, pricing CO2 emissions and net metering. It was found that the uncertainty of fuel and electricity prices is the significant risk to cogeneration projects but can be mitigated by the feed-in tariffs system. Sun, Z.-G. [38] studied energy efficiency and economic analysis of the cogeneration system driven by gas engine in China by compared the Primary Energy Rate (PER) and primary energy saving to evaluate the performances with conventional system. It is found that at the required energy flows, the comparative primary energy saving of the cogeneration system is more than 37% compared to conventional system. Furthermore, the payback periods of the cogeneration system are 4.52 and 2.65 years based on energy prices in Jiangsu Province and Sichuan Province, respectively.

The research studies of CHP system for commercial buildings in Thailand is also implemented by Somcharoenwattana et al., the authors studied the potential of the implantation of natural-gas cogeneration for public buildings in Thailand upon the completion of the natural gas pipeline plan in the city in 2020. The authors have proved in some buildings such as Thailand's Suvarnabhumi Airport, the overall efficiency and primary energy saving can be improved by 10% and 24%, respectively, and electricity can be sold back to the grid to gain more revenue [39]. The benefits of the implementation of the co-generation system integrated with an absorption chiller in the Supercenter Building in Thailand have been studied from Sommart and Chullapong [40] by varying 2 types of cogeneration systems and 3 types of absorption chillers by considering the payback period as the economic assessment index. The results showed that the average payback period is about 8.9 - 35.5 years from the integrated system between gas turbine cogeneration with all absorption chillers.

The environmental benefits from the utilization of CHP system for commercial buildings has been examined by Pedro and Amanda [41], who investigated seven different types of buildings in the United States for potential CO2, NOx, and CH4 emissions reduction and primary energy saving by using the cogeneration system. They found that a cogeneration system would reduce carbon equivalent emissions for all buildings more than 21%, and that primary energy saving leading to a decrease in operation costs can be achieved in some buildings. Yingjun et al. [2] developed a model of distributed generation technologies for four different types of commercial buildings in Japan by considering the energy consumption characteristics and technical features of the equipment. The analysis results showed that the implementation of the CHP system is suitable for hotels and hospitals due to the characteristics of thermal load demand and heat-to-power ratio. However, upon the consideration of the technical features of equipment, some buildings are suitable only to some specific distributed generation technologies. Ziher and Poredos [42] has also carried out an economic analysis of the optimization of cooling production by using a profitability index evaluation method of the implementation of a cogeneration system based on a natural-gas turbine and absorption chiller in a hospital.

Energy efficiency utilization for small scale buildings such as convenience stores, minimarts, small restaurants, etc. has not been the subject of much research due to the high investment costs and lack of skilled workers for implementation and maintenance. Also, the implementation of a co-generation system for such buildings is rarely found. A number of studies, however, were conducted by considering the utilization of micro co-generation system for some small scale buildings Hongbo et al. (2008) [44] developed a model for economical optimization of the CHP system in residential buildings in Japan including the optimal size of storage tanks. They found that the capacity of the CHP system is sensitive to capital costs, energy prices, carbon taxes, and the electrical selling prices. Godefroy et al. (2007) [45] proposed small CHP-ejector trigeneration for a research centre in the United Kingdom. In his study, overall efficiency around 50% was achieved with simultaneous requirements for heat and cooling. Qunyin et al (2012) [46] proposed an alternative design and management of CCHP (combined cooling, heating and power) systems for residential buildings in Shanghai, which considered energy, economic, and environmental assessments. The results showed that gas engines and fuel cells based on CCHP (combined cooling, heating and power) technology are feasible options from the energy and environmental viewpoints, but are not economically feasible. Hongbo and Weijun (2010) [47] analyzed the economic and environmental evaluation of the micro CHP system for residential buildings in Japan. The analysis results from a fuel cell system recognized them as a better option for residential buildings in Japan from both environmental and economic viewpoints. The results also showed optimal economic benefits, with annual energy costs being reduced by about 26%. On the contrary, while maximizing the environmental merits, annual CO2 emissions were reduced by about 9%. Michele et al. (2012) [48] also proposed general guidelines for the design of micro-CHP systems for heating residential buildings. The results showed that CHP units with a thermal storage system can meet overall thermal energy demands with a primary energy saving index of about 15-45%. Also, from the economic view, the results showed the size of the CHP systems can be increased up to 5 kWe and 30-50 kWe, respectively, for single family houses and a block of flats.

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CHAPTER 2 INVESTIGATION ON DISTRIBUTED ENERGY RESOURCES IN THAILAND

2-1 INTRODUCTION

Due to the next 20-year energy efficiency action plan from the government which aims to reduce the energy intensity by 25%, the utilization of renewable energy integration with distributed energy resource systems is one of the most important development methods that should be established as soon as possible [1]. At end of 2011, the Department of Mineral Fuel reported proven reserves of petroleum both onshore and offshore at 215 million barrels of crude oil, 239 million barrels of condensate, and 284 billion cubic metres (10.06 trillion cubic feet) of natural gas. Thailand's Ministry of Energy also launched the 10-Year Alternative Energy Development Plan (AEDP 2012-2021) which aimed to increase the utilization fo renewable energy in 2021 by 25% in order to strengthen the energy security [2]. Based on 2011 production rates, crude oil reserves will last another four years, condensate reserves another seven years, and natural gas reserves will be depleted in less than 15 years. Although Thailand's coal reserves are large, most of the proven coal reserves are lignite coal of low calorific value. There has been to date no significant assessment of Thailand's unconventional oil and gas resources [1].

Conservative assumptions suggest that Thailand will need to continue to increase imports of oil and gas from neighboring economies. Within Thailand, the total natural gas network covers 4056 km and natural gas is distributed to power generators, including the Electricity Authority of Thailand (EGAT), independent power producers (IPP) and small power producers (SPP), as well as to 272 industrial users (PTT, 2011a). In addition, it also the good challenge for development the electricity generating from renewable energy, especially solar, biomass and wind energy and development the cogeneration system by using the effectiveness utilization of natural gas through city gas pipeline. [3]

However, several barriers e.g. the public concern after constructions and tax incentives are the key parameters for the implementation of combined heat and power (CHP) system and renewable energy system for decentralized power generation either for suppliers or consumers.

This chapter presents the preliminary investigation results from many available sources to show the potential of the implementation of distributed energy resources either combined heat or power (CHP) system or renewable energy system integration.

2-2 PRESENT SITUATION OF DISTRIBUTED ENERGY RESOURCE IN THAILAND

2-2-1 POTENTIAL OF RENEWABLE ENERGY RESOURCE IN THAILAND[4-14]

- **Solar Energy [8-9]**

Figure 2-1 shows data of monthly global solar radiation which collected from year 1990 to 2010. The average sunlight of the whole country is 18 MJ/m^2-day. The variation of solar radiation depends on location and time of the year. The area in Northeastern and some area in Central part have highest radiation about 20-22 MJ/m2-day. During March to April, solar radiation become highest throughout the year and is gradually lower during May to September; yet still higher comparing to the value of solar radiation during winter from October to January.

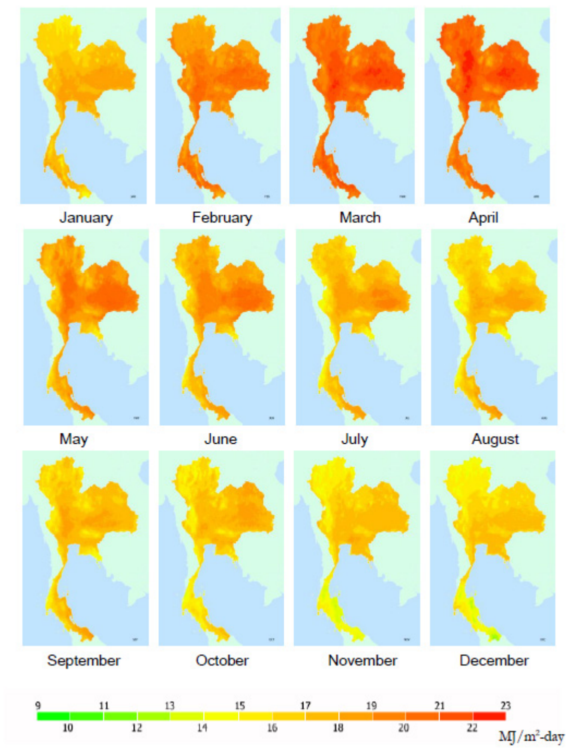

Figure 2-1 Monthly average global solar radiation maps

The yearly average of solar radiation map in Thailand is shown in Figure 2-2. Thailand's Department of Alternative Energy Development and Efficiency (DEDE) evaluates that there would be 55 MWe and 500 MWe installed capacity by the year 2011 and 2022, respectively, with 10 years incentives of adder cost for solar power generation developer at 6.50 Baht/kWh (the new adder cost rate reduced from 8.50 Baht/kWh since June 2010).

Comparing with the electric hot water (water heater), the utilization of solar thermal still not widely used due to the excessive cost of the investment. From the statistics stated that, in 2006, more than 50,000 m^2 of flat plate collectors were installed on commercial buildings, hotels, hospitals and private residences. Solar thermal capacity ranged from 3,000 to 3,500 m2 of solar water heaters per year in 2006. Most solar panels were made for export, but private firms are now beginning to market solar roofing and smaller-scale systems for residential and commercial use in the domestic market. However, due to the decrease of the equipment price for solar PV and the 30% direct subsidy by DEDE, thermal energy production by solar thermal is increased to be approximately 5 ktoe of in 2010 and expected to be 38 ktoe by 2022.

Solar power application in Thailand

- Off-grid PV system: Most of this systems were installed in rural and un-electrified remote areas which always used for lighting, telecommunications, water pumping, electricity generation for schools and healthcare clinics. During 2004 – 2005, the “Solar home program” was introduced, 2,003,000 units of solar home systems were installed by Provincial Electricity Authority (PEA) throughout the country. In 2011, the cumulative installation capacity of the off-grid PV systems is about 29.65 MW.
- On-grid PV system: Electricity Generating Authority of Thailand (EGAT) introduced solar rooftop projects for 10 systems during 1997-1998 and also 50 systems during 2002-2004. In 2004, first large grid supported PV power plant of 500 kW in Mae Hong Son Province was installed. In addition, installation of large PV rooftop of 460 kW was first introduced in commercial building in Thailand by installation at Tesco Lotus Department Store which located in Bangkok. Since 2007, the on-grid PV system was growth in rapid rate from the adoption of the adder or Feed-in Premium. In 2011, the installed capacity of on-grid PV systems is about 70.74 MW.

- **Wind energy [10-12]**

From the recorded data of 15-year period of hourly wind speed by DEDE and Department of Meteorology, it is found that the monthly maps revealed that wind speed and direction in the country are mainly influenced by the northeast and the southwest monsoons and local geography. Wind speed increases with the increase of the elevation. For instance, at the elevation of 10 meters, the wind speed is in the range of 3-4 m/s, while at the elevation of 40 meters, the wind speed increased to 4-5 m/s for most parts of the country. In the case of geometer elevation, the relatively high wind speed of 6 m/s is found in mountain ranges, mainly in the South, the Northeast and the Western part of the Central region as shown in Figure 2-2.

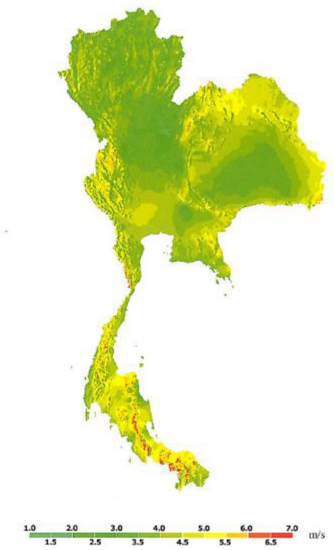

Figure 2-2. The average wind power classes and percentage in Thailand

Table 2-1 Wind energy potential in Thailand

	Poor (< 6 m/s)	Fair (6-7 m/s)	Good (7-8 m/s)	Very good (8-9 m/s)	Excellent (> 9 m/s)
Land area (km^2)	447,157	37,337	748	13	0
% of total land area	92.60%	7.20%	0.20%	0.00%	0.00%
MW potential	NA	149,348	2,992	52	0

Table 2-1 estimates the wind energy potential available for power generation in the country. The wind energy potential is along the coasts of the Southern Thailand. Even though the technology for electricity generation from wind energy is readily available, it is relatively new to Thailand. Implementation is rather limited due to the local wind condition and the high cost of producing energy from a wind turbine. The government also sets up the adder cost for 10 years incentives for wind power developers at 4.50 Baht/kWh (for less than 50 kW installed capacity) and 3.50 Baht/kWh (for more than 50 kW). From the adder cost incentives, the low-cost wind technology from China can compete in Thailand's wind market from its low investment cost in the forthcoming 200 to 300 MWe installation from eight wind farms in Thailand in 2011.

- **Biomass Energy [13-14]**

Thailand is one of the major food producing and supplying country of the world. The agricultural products and their residues become the resources for biomass exploitation. Recently, utilization of biomass sources has been continuously used in both households and generation. The average annual amount of agricultural waste is approximately 61 million tons. However, about 41 million tons of residues that can produce 426 PJ of energy are still unused.

The most significant energy sources of biomass in Thailand are forestry and agricultural residue. Rice husk, bagasse, oil palm residue, forest industry, and residential are the major sources with high availability that contribute to high feasibility of heat-power co-generation. The technology used for biomass which is direct and thermo-chemical combustion is the most applicable methods used in commercial heat and power generation. From the Thailand's renewable energy development plan (REDP), biomass is considered the main potential renewable energy with the existing 1,644 MW electricity generation. Approximately 2,749 MW installed capacity has been planned for the year 2011.

However, many obstacles still need to encounter for the development of Thailand's biomass, e.g. poor raw material management from the severe competition and a risk to procure materials at reasonable prices has affected project viability considerably. Lack of knowledge on gas emission including environmental issues among local people is another drawback which has led to public resistance.

- **Biogas Energy [8]**

In Thailand, waste water and waste from industries, farms and communities have to be treated with waste water and waste treatment standard and measure before being discharged. Treatment by using Anaerobic Digestion will yield biogas that consists of 60-70% by volume of Methane Gas (CH_4), 30-50% of Carbon dioxide Gas (CO_2) and a small portion of Ammonia (NH_3), Hydrogen sulfide (H_2S) and water vapor. Biogas can be used to replace conventional fuels like heavy oil or firewood. Moreover, biogas production from anaerobic digester presents the additional advantage of treating organic waste and reduces the environmental impact caused by these wastes. It contributes to a better image of the agro-industries and farming community while reducing odor, pathogens and weeds from the manure and producing an enhanced fertilizer that can be easily assimilated by plants.

At present, biogas energy is normally used for producing heat and generating electricity for supplying to manufacturing process and also selling to the grid. In 2007, about 10,000 food factories and 20 million heads of livestock in Thailand generated wastes and wastewater suitable for biogas production. The existing power generation from biogas is 66.15 MW and 243 ktoe for thermal use. Most is from wastewater treatment of cassava and crude palm oil industry and swine manure. Ministry of Energy plans to increase the power generation to 60 MW and the thermal/heat generation to 470 ktoe from the remaining swine manure, cassava and palm oil wastewater. This expands to include new industries such as ethanol, food and rubber by the year 2011.

Table 2-2. Estimate of viable renewable energy power under expected feed-in policies

	Installed capacity (MW)		
	2005	2011	2016
Biomass residues	2191	3229	4938
Biogas for heat and power	4	519	384
Small hydro	53	338	338
Wind	0	194	1783
Solar PV	26	60	120

2-2-2 POTENTIAL OF COMBINED HEAT AND POWER IN THAILAND

Many research studies investigated that Thailand has lots of potential for the implementation of combined heat and power system by making the effective use of waste heat from the combustion processes used to generate the electricity. One of the effective results from the studies by the Thai Ministry of Energy's Energy Planning and Policy Office (EPPO) and carried out by the Joint Graduate School on Energy and Environment (JGSEE). The study estimated the quantity of commercially viable new CHP in 817 existing factories and 966 existing commercial buildings located in areas that will be served by planned Thai natural gas pipeline expansion [18] The study is thorough, but is likely to underestimate potential by year 2015 because (a) it overlooks opportunities for CHP in large government buildings, residences, etc; (b) because the study disregards hundreds of potential industrial and commercial sites for which data was incomplete; and (c) and because the study considers only existing buildings and not new facilities that will be built between now and 2015. Results derived from preliminary study findings are shown below in Table 2-4. Commercially viable CHP new potential capacity is estimated to be 3,271MW. [15-17]

Table 2-4. Estimate of commercially viable power and energy saving through CHP in commercial buildings and industry.

Type of facility	No.	Commercially viable CHP generating capacity (MW)	Peak load offset through avoided electrical A/C demand (MW)	Total (MW)	Total energy saving (GWh/yr)	Payback period (yr)
Factories	817	2771	0	2771	30667	3-5
Commercial buildings	966	500	147	647	1354	5-6
Total (commercial viable)				3418	32021	

The research results from the consideration of small CHP units with capacity less than 5 MW in commercial buildings, the study assumes that heat-driven absorption chillers have a coefficient of performance (COP) of 0.75 and replace electric air conditioners that have a COP of 2.8. CHP in commercial buildings is assumed to run 3,500 hours per year, and is dispatched according to air conditioning needs in the building. Since Thailand's peak electricity consumption is also driven by air conditioning, this overlap is perfect for reducing Thailand's peak generation requirements. Also for the case of factories, the study considered natural gas combustion engines and gas turbines with waste steam used to offset natural gas, heavy fuel oil, or coal in steam boilers.

From the study results of Wantana S. et al. [18] illustrated that at present, the potential of cogeneration system for buildings in the city is impossible to reach with the existing gas pipeline, however, if the natural gas pipeline extension plan within year 2020 is successful, the development of cogeneration system in both commercial and industrial sector can be developed successfully. Also, concerning the current small power plants (SPP) regulation schemes in Thailand which are adopted from EU CHP Directive, the generator will get support "adder" at maximum rate of 0.0103 US$/kWh if the system presents overall efficiency of CHP ≥ 45% and Primary Energy Saving (PES) ≥ 10%. It is noticeable that overall efficiency of the system used in Thailand is much lower than the efficiency benchmark in EU Directive, which is around 75–80% depending on the type of plant. It is acceptable for operating plant in Thailand to have lower system efficiency than operating plant in Europe because of the climate condition and technology development. However, setting up the benchmark at 45% efficiency would be too low to achieve high efficiency CHP utilization. It is recommended that the benchmark of overall efficiency at 45% should be improved in order to move into the right direction in promoting real CHP with high efficiency and primary energy saving. In addition, one of the main obstacle for the construction of city gas pipeline in Thailand is about the public concern because Thai people never have the experience about the city gas pipeline and do not have enough understanding of the system regarding its safety and reliability. Therefore, to convince people to accept this new city gas, the government should provide more information about reliability of the technology and show some experiences from other developed countries and advantages that can be obtained. The authors stated two typical examples of applying cogeneration in public buildings, certainly very typical for Thailand –Suvarnabhumi Airport (Main airport in Thailand) and new government office building complex.

In case of Suvarnabhumi Airport, the District Cooling System and Power Plant (DCAP) is designed for supplying electricity, steam and chilled water for cooling purposes at the airport area with a total capacity of 52.5MW electrical power and 25,240 RT (88,765kW) of cooling. The improvement of plant efficiency by replacing old gas turbines with new ones provides overall efficiency improvement of 10% and results in the significant amount of primary energy saving by 24% and CO2 emissions reduced by 27%. After improvement, the system also provides greater amount of electricity which can be sold to the grid. More revenue has increased the profit to 24.80 Million US$ and results in shorter payback period. The efficiency improvement then benefits in both environmental and economic aspects.

In case of new government office building complex, the cogeneration plant in the new government office building complex which was designed to supply electricity and cooling for the building complex. The building complex is comprised of offices, restaurants, shops with the main office buildings open from 8:00AM to 5:00PM from Monday to Friday. The plant is natural gas based cogeneration with 9.9MW electricity and 6000 RT (21,000kW) cooling capacity. The total air conditioned area is 500,000m2 out of totally 1,000,000m2 belonging to building complex. The purpose of cogeneration in this building want to presents the concept where the operation mode can be flexible by applying chilled water storage tank. The chilled water storage tank can fulfill peak demand during peak period and/or at most critical times. Based on financial calculations for this case study, it can be concluded that operating hours both for gas turbine and absorption chillers are important factor that influences the economics of the project. Plan 5 generates the largest profit with an increase of 1.27 Million US$/a in relation to base case and shorter payback period (9.18 years). It can be concluded that the operating time of absorption chillers and gas turbines requires long period of operation to get the most revenue from chilled water and electricity production, leading to best benefits. The more electricity and chilled water produced, the more profit and better payback period will be achieved. Unfortunately, the time of office buildings usage is limited to 8:00–17:00 h. These are rather low operating hours for the cogeneration plant to achieve its maximum profits under such circumstances.

2-3 BARRIERS OF THE IMPLEMENTATION OF DISTRIBUTED ENERGY RESOURCES IN THAILAND [16]

Because the distributed energy resources system in Thailand is not widespread for whole country, the management and technology utilization are one of the key parameters in order to implement the DER system, e.g. the integrated power electronics technology that provides the foundation of the interconnection package is advancing quickly, with functional performance available today that was not possible even a year ago. Developments in digital design and advanced processors have boosted performance to impressive levels, and a convergence of software and hardware engineering is equipping state-of-the-art digital technology to provide protective relaying and coordination functions at lower cost and higher reliability.

As mentioned in previous section, in order to develop the DERs integrating with CHP system in the city, the distributed of city gas pipeline is the main parameter that need to be done as the first priority. Also, the problems about CHP policy, prices, and public concern should be followed for the implementation. For example, the awareness of the city gas pipeline should be well understand for the users in order to guarantee the safety and reliability. Therefore, to convince people to accept this new city gas, the government should provide more information about reliability of the technology and show some experiences from other developed countries and advantages that can be obtained. Public relations for the city gas plan should be taken as the first priority. As an alternative of the development plan, the central CHP district cooling at the outskirts of Bangkok close to the city is also an option. Since the main natural gas pipeline is already there, implementation of chilled water or heat distribution network will be easier and cause less stress to people than implementing gas pipeline network in the city. The government should make a serious study regarding this option. Nevertheless, in order to promote cogeneration in buildings within existing building categories based on energy demand, designated buildings, particularly those located close to natural gas pipeline network, should be encouraged to consider cogeneration plant as their first choice energy supply because of energy efficiency and because it is a secure supply source [18].

For the barriers to the development with DERs with RE system, first is about cost of renewable energy. The incremental financial costs between RE and fossil fuels. The costs and tariffs for small hydro, wind, and solar energies in Thailand are substantially higher than those in other countries. The government is quite concerned that the high costs of RE would increase financial burdens on consumers, and maintains a ceiling on the increase in consumer electricity prices. Therefore, future RE development in Thailand needs to focus on cost reduction.

For the consideration of biomass energy, the most abundant RE resource in Thailand at an affordable cost, and is the largest contributor to the RE target for heating, transport fuels, and power in the REDP. But it ran into difficulties with fuel supply. Balancing food and energy security is a key challenge for biofuel supply in the transport sector. To that end, biofuel policies need to coordinate energy and transport policies with agriculture, forestry, and land-use policies to manage the competing demands of water and land for food. If energy crops take land away from agriculture, the “medicine” of the requisite interventions might be worse than the “disease” in the sense that mitigation might heighten climate risks. In addition, biomass has been falling behind other RE resources in recent years, due to the shortage of materials for larger, and hence, a more economic, scale of power plant. Given that large-scale biomass plants are mostly built, the future trend is going to be small-scale biomass plants. But these plants face the challenges of insufficient fuel supply, unproven technologies, and a lack of community awareness [14, 19].

2-4 CURRENT STATUS OF POWER GENERATION UTILITY IN THAILAND [5,6,15]

2-4-1 ELECTRICITY GENERATING AUTHORITY OF THAILAND (EGAT)

The Electricity Generating Authority of Thailand is the state enterprise under the Ministry of Energy. EGAT presently manage most energy production in Thailand including builds, owns and operates the power plants, and also purchases electric power from private power companies and neighboring countries.

Under the national long-term power development plan (PDP 2010), EGAT and private power producers were implemented power projects, imported capacity from neighboring countries, as well as transmission system development projects to timely accommodate the power expansion programs as the following:

- During the short-term period of 2010 - 2015, new power projects totaling 3,234.70 MW will be developed by EGAT comprising 4 natural gas-fired combined cycle power projects totaling 3,070 MW, and 18 renewable energy projects totaling 164.70 MW
- The power purchase from small power producers (SPPs) using cogeneration systems or renewable energy technologies. Under the government's 2007 Regulation for the Purchase of Power from SPPs, the purchase capacity from SPPs during 2010 - 2014 is 1,919 MW consisting of 1,604 MW from firm energy contract SPPs using co-generation systems and 315 MW from SPPs using renewable technologies. For the 2015 - 2021 periods, the purchase capacity from SPPs (under the 2010 Regulation) will increase to 3,500 MW in response to the government's policy to promote power generation using cogeneration systems.
- The development of new transmission system to increase the capability of transmission lines and ensure the continuity and reliability of the power supply system. A number of transmission system interconnection projects have also been developed to receive electric power from domestic IPP projects as well as IPP projects in neighboring countries.
- Development of REDP (Renewable Energy Development Plan) and renewable energy generation such as Wind Turbine Power Plant at Lam Takhong, Wind Turbine Power Plant at Promthep Alternative Energy Station, Solar Power Plant at Pha Bong, and Solar Power Plant at Sirindhorn dam. Development of small hydropower projects at existing dams of the Royal Irrigation Department (RID) since 2004 in order to maximize the utilization of water resource with hydropower generation.

2-4-2 INDEPENDENT POWER PRODUCER (IPP)

Since 1992, the government promoted private sector to participate in the generation business in order to promote the competition of power industry in the form of Small Power Producers (SPPs) and Independent Power Producers (IPPs) and need to sell electricity to EGAT that subsequently transmits to the distributors.

- **Small Power Producers (SPPs)**

SPP generators are divided into two categories: firm and non-firm, depending on their ability to guarantee availability. Firm fossil fuel-fired SPPs must generate for at least 7,008 hours per year and must generate during the months March, April, May, June, September and October. SPPs could sell up to 90 MW of capacity and employ Combined Heat and Power (CHP) or Cogeneration systems burning conventional fuels (i.e. natural gas and coal) or renewable technologies using non-conventional resources (i.e. waste, agricultural residues, biomass and solar energy) to generate electricity.

For the renewable energy production from SPPs, government was implemented the "adder" incentive in order to encourage the power generation from RE sources.

For the Cogeneration system from SPPs, National Energy Policy Council (NEPC) had a resolution to promote power generation by cogeneration system in 2009 which aimed to receive power from Cogeneration SPPs under Firm Contract up to 2,000 MW in 2015 – 2021 and more in the future year. As of January 2010, the contract capacity of 50 potential SPPs using cogeneration system was 3,600 MW comprising 3,391 MW Firm Contracts (43 projects) and 209 MW Non-Firm Contracts (7 projects). Among these, only 31 projects with a total capacity of 1,956 MW were commissioned including 25 Firm Contracts (1,788 MW) and 6 Non-Firm Contracts (169 MW). The other 19 upcoming projects consisted of 18 Firm Contracts (1,604 MW) and 1 Non-Firm Contract (40 MW). Both IPPs and SPPs have long-term power purchase agreements with EGAT as the single buyer. The Power Purchase Agreements allocate market risk to EGAT (and its captive ratepayers) leaving SPPs and IPPs to manage the operating and fuel price risks. SPP contracts are between 5 and 25 years with terms and specifications set by EGAT, the national power monopoly. EGAT has defined two types of purchasing rates for buying SPP power, non-firm and firm power.

- **Very Small Power Producers (VSPPs)**

For the renewable energy system, the Very Small Power Producers (VSPPs) are private power producers selling electricity to the Metropolitan Electricity Authority (MEA) or the Provincial Electricity Authority (PEA) with generating capacity of less than 10 MW. They can be Combined Heat and Power (CHP) or Cogeneration systems or renewable technologies using non-conventional resources (i.e. waste, agricultural residues, biomass, and solar energy). Considering the advancements and high potential of renewable technologies, it was found that VSPPs using renewable energy are also feasible for the generating capacity greater than 1 MW. As a result, NEPC agreed to enlarge the VSPP's contract capacity from 1 MW to 10 MW in 2006. As well as SPPs using renewable technologies, all VSPPs are eligible for the "Adder" scheme. It was anticipated that power generation from renewable energy would increase dramatically and be strategically important to the sustainable development of the country. On 6 December 2006, the government approved the Adder Rates for ≤10 MW VSPPs that supply power to the grid, at the following "fixed rates":

From the above information, IPP, SPP and VSPP schemes are essential parts to promote the distributed energy generation and power producer and eventually to support the development of Smart Grid in Thailand. Therefore, the promotion and improvement of policy for IPP, SPP and VSPP is inevitably necessary as infrastructure for smart grid development and deployment in Thailand.

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CHAPTER THREE THAILAND'S ENERGY POLICY

3-1 INTRODUCTION

In order to keep the national energy security, Thailand has created many energy saving and alternative energy policies and regulations to implemented to be discipline as a national culture and also encouraged energy conservation in all sectors - household, industrial, commercial, and transportation through several campaigns. The economy also keeps promoting efficient use of energy by providing incentives to attract the private sector to opt for energy-saving appliances. Incentive measures have also been set to reduce electricity use during the peak period. Four major energy saving initiatives have been launched to stimulate decision-making of entrepreneurs to implement energy efficiency improvement, i.e. Revolving Fund for both energy efficiency (EE) & renewable energy (RE) projects, ESCO venture capital fund, Tax Incentives for energy saving and DSM Bidding. This chapter summarizes the main policies and regulations which related to promoting the enhancement of energy efficiencies for commercial buildings in Thailand.

Thailand's government has adopted a range of comprehensive measures covering the oil, gas and electricity sectors. The policy development includes comprehensive and careful study of nuclear energy as another option for increasing the stability of the economy's future electricity supply. According to the original Power Development Plan 2010 (PDP 2010), the Electricity Generating Authority of Thailand (EGAT) has estimated that nuclear power could contribute up to 10% of the economy's total electricity generation from 2023 (EGAT, 2010). The Renewable and Alternative Energy Development Plan (2012–2021) sets a framework for Thailand to increase the share of renewable and alternative energy to 25% of total energy consumption by 2021 (DEDE, 2011). The plan states the Thai government will encourage the use of indigenous resources including renewable and alternative energy (particularly for power and heat generation). [1]

In order to strengthen the energy efficiency, the government has adopted a 20-year Energy Efficiency Development Plan 2011–2030 (EEDP). This plan sets a target of 25% reduction of energy intensity by 2030, compared with 2010 levels (APERC, 2012). If the energy conservation measures can be successfully implemented, energy elasticity (the percentage change in energy consumption to achieve a 1% change in the economy's GDP) will results in final energy saving about 289,000 ktoe by 2030. [2]

This chapter revise the policy and regulation related to building energy efficiency in Thailand in order to prioritize the potential of energy saving methods for implementation.

3-2 REVIEW OF THAILAND'S BUILDING ENERGY STANDARDS

3-2-1 NATIONAL ENERGY POLICY [3,4]

5-strategies on Thailand's National Energy Policy were focused: energy security, alternative energy, supervise energy prices and safety, energy conservation and efficiency, and environmental protection.

Under the policy "encouraging energy conservation and efficiency in the household, industrial, service and transportation sectors" in 2010, several campaigns fostering energy-saving discipline and conscience and promoting effective energy use were proposed, i.e.

- Incentives to induce private sector investment for energy-saving appliances
- R&D and set the standard for electrical appliances and energy-saving buildings
- Set standards, rules, regulations for energy-saving equipments, materials
  - Announce Minimum Energy Performance Standards (MEPs)of 15 electrical appliances by 2009.
  - Expedite the issuance of Ministerial Orders, particularly on the Building Energy Code and ISO standards
- Promote the creation of prototype networking – to make "Thailand Energy Awards" recognized by general target groups.

3-2-2 THE ENERGY CONSERVATION PROMOTION ACT 1992 & ENERGY CONSERVATION PROMOTION FUND [3,4]

The Energy Conservation Promotion Act (ECP Act) of Thailand was promulgated in 1992 with the objective to promote the energy conservation discipline and energy conservation investment in factories and buildings. Ministerial Regulations detailing requirements in accordance with Building Energy Code (BEC) for large commercial buildings, and a fund created to support energy conservation activities (ENCON Fund) to government agencies, state enterprises, non-government organizations, individuals, and businesses that wish to implement measures to increase efficiency in energy utilization and the punishment for owners of any designated factory or building who fails to comply with the standards, criteria and procedures as provided by related ministerial regulations issued under the Act. The ECP Act has the following objectives:

1. Established energy conservation promotion fund
2. Set up compulsory program for designated facilities

3. Set up energy performance standards
4. set up promotional activities for energy conservation

Thailand's government leaders in the energy sector recognize that one important aspect to make energy efficiency the "norm" in residential and commercial sector is that some consumer behavior requires change. Thailand has taken a significant policy and program approach to making these two sectors more energy efficient by:

Thailand has taken a significant policy and program approach to making these two sectors more energy efficient by:

- Provide strong foundation of broad policy and legislative actions to drive energy efficiency and investment into these sectors.
  - Improve 1992 ECP Act with 2007 Revision
  - Focus on energy management standard with ISO standard
  - Create local energy offices to share info for local citizens
- Implementing specific policies and programs that would directly drive more energy efficiency and investment into these sectors.
  - Implement educational energy lab for school children
  - Developing building energy codes for commercial sectors
  - Improve efficiency label
  - Building some very low energy using government facilities
  - Initiative voluntary building label program

In addition, in 2010, the Ministry of Energy has proposed a 15-year alternative energy development and energy efficiency plans, and a 20-year power development plan (PDP2010) that includes green electricity from renewable energy for up to 5% of total generation. These policies show the importance of a low-carbon Thailand.

3-2-3 DEMAND SIDE MANAGEMENT PROGRAM [3,4]

The Demand Side Management (DSM) Office, which promotes energy efficiency in appliances and equipment, primarily through a national standards and labeling program comes under the charge of Generating Authority of Thailand (EGAT). DSM office uses a collaborative approach in its market transformation strategy by stimulating local manufacturers, importers and distributors to consider the production and import of more efficient appliances and to encourage consumers to buy more energy efficient appliances as they become available in the market. Example of the promotion of high-efficiency equipment such as the promotion of high efficiency CFLs no.5 (increased by 11.9 million units compared between 2007 and 2006) and high efficiency T5 fluorescent lamps (28W) from T5 fluorescent lamps (36W) [9]. In addition, public awareness campaigns, i.e. booklets, TV spots, radio sports, etc is also responsible by DSM office as well.

3-2-4 POLICY FOR PROMOTION OF MITIGATION MEASURES IN COMMERCIAL SECTOR OF LCS 2030 [5,6]

In order to promote GHG mitigation measures in the residential and commercial sectors, it would require policies related to building design, building codes, energy efficient equipment and use of renewable energy. Figure 3-1 shows key policies; i.e., energy performance standard of buildings, building insulation, building codes, energy efficiency labeling of electric devices, and green purchasing policy of the government.

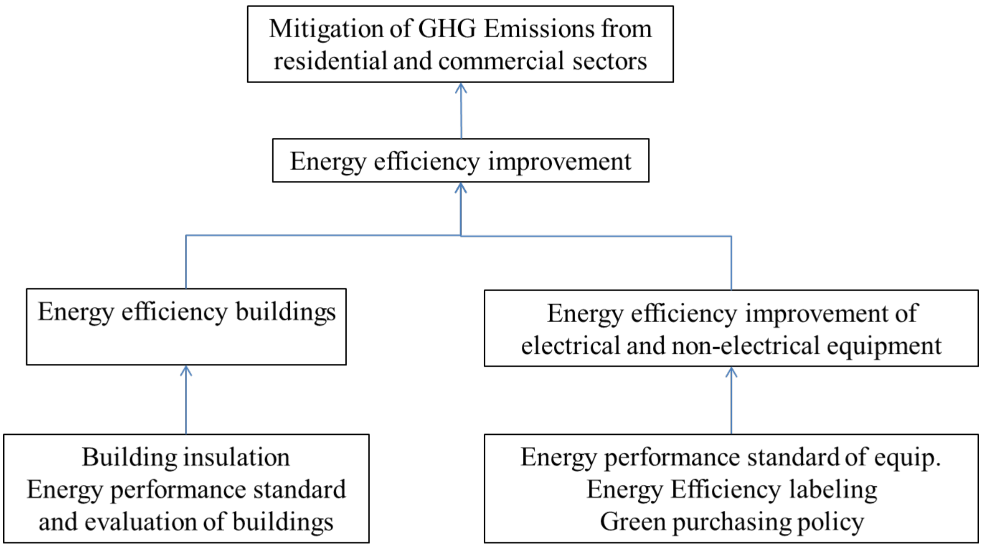

Figure 3-1. Mitigation measures and policies for Thailand's buildings [6]

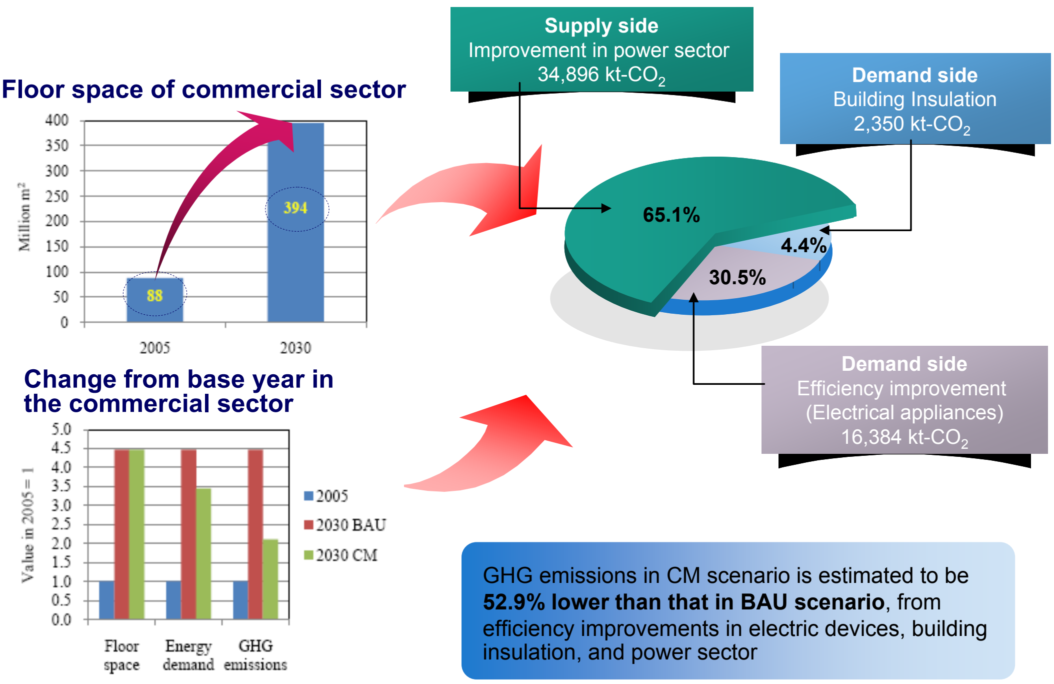

Figure 3-2. Estimated results of GHG mitigation for commercial sector [6]

The demand-side management (DSM) programs of the Ministry of Energy, Thailand could play an important role in energy efficiency labeling, and funding companies need to adopt corporate social responsibilities in energy efficiency improvement and promotion of the use of renewable energy. In addition, the more advanced DSM activities in Thailand would also contribute larger energy saving and more GHG reduction.[7]

Floor space of the buildings is the index for identify the energy demand of commercial sector. If the policy is driven smoothly, in 2030, it will increase to 4.5 times greater than 2005. In the BAU scenario, energy consumption in this sector would increase to 14,771 ktoe and GHG emissions would increase to 101,391 kt-CO2, i.e., 4.5 times greater than that in 2005, respectively. The emissions in this sector under the CM scenario, would be 53,630 kt-CO2 or 52.9% lower than that in the BAU scenario.

3-2-5 ENERGY EFFICIENCY MEASURES FOR BUILDINGS [7-9]

Energy efficiency measures in Thailand's building are categorized into 2 main programs:

- Mandatory Program
  - Building Energy Codes - The development of building energy code from the past is shown below details:
    - In commercial sector, any buildings over 2,000 sq.m. are categorized as "designated facilities" (DFs) must comply with mandatory building energy codes.
    - In 2003 – 2006, each DF has to appoint a "Person Responsible for Energy" (PRE) and a Target and Plan to reduce energy use reported on and updated every 3 yrs.
    - 2007 ECP Act requires that each DF that uses more than 3,000 kW of electricity need to have two PREs in place (one is Senior PRE) and the annual energy audit must reported to DEDE.
    - Building insulation and building envelope must comply with Thailand's building codes 2010. New buildings must comply with this code. It is assumed that penetration rates will be up to 100% in 2030. The new Thailand building codes could readily achieve this target.
    - Although the BEC has been implemented mandatorily in Thailand for nearly two decades, there is still no voluntary program of building energy labeling (BEL) implemented complementarily to further promote the higher energy efficient buildings in accordance with the concept of mandatory push & promotion pull mechanism as shown in Figure 3-3.[8]

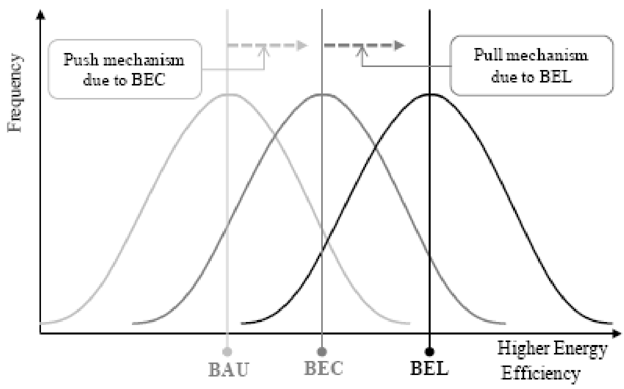

Figure 3-3: Push & Pull Mechanism [8]

- The current code (or the revised code) still adopts performance indicators to evaluate the three major building systems, but its values are now enabled for calculating annual energy consumption of a building when its detailed plans are given. The code distinguishes three different times and durations of use of different categories of commercial buildings:[8]
- Daytime or office pattern, 08:00 – 17:00 (2,340 hrs/year)
- Late daytime to nighttime or department store or restaurant pattern, 10:00 – 22:00 (4,380 hrs/year)
- Day and night or hotel pattern. 24 hrs (8,760 hrs/year)
- Minimum allowable energy performance for building envelope is defined, shown in Table 3-2.
- Allowable rated power density for lighting is defined, shown in Table 3-3.
- Air-conditioning system: For a large air-conditioning system, the main equipment that consumes 65% of power is the chiller. Minimum allowable values for coefficient of performance (COP) of large electric chillers vary from 2.7 for small air-cooled chillers to 5.67 for large water-cooled chillers. For unitary air-conditioners, requirement on coefficient of performance is made for each set. For a large air-conditioning system, maximum allowable value of rated power of the air-handling system, condenser water cooling system, and chilled water transport system taken together is 0.5 kW/TR.
- Hot water generating system: minimum efficiency of each type are shown in Table 3-4
- Use of renewable energy in the calculation of energy performance of the building, i.e.
- Use of daylighting can be taken as a credit for the reduction of lighting equipments in lighting system
- Using PV can be taken as a credit for reduction in whole building performance
- Whole building performance can be taken as the calculation to be another options, shown in Figure 3-4. However, there are some criteria need to followed such as,
  - The building which fails to comply with any one of major codes (Building envelope, Lighting system, A/C system) has to comply for whole building performance.

- The overall energy consumption f the proposed building must less than the overall consumption of reference building.

Table 3-2: Minimum allowable energy performance for building envelope [10]

Building category	Requirement on OTTV and RTTV (W/m^2)
Wall (OTTV)	
Office and school	Less than 50
Department store, hypermarket, and miscellaneous	Less than 40
Hotel, hospital, condominium, and hostel	Less than 30
Roof (RTTV)	
Office and school	Less than 15
Department store, hypermarket, and miscellaneous	Less than 12
Hotel, hospital, condominium, and hostel	Less than 10

Table 3-3:Allowable rated power density for lighting [10]

Building category	Allowable rated power (W/m^2 of utilized area)
Office and school	14
Department store, hypermarket, and miscellaneous	18
Hotel, hospital, condominium, and hostel	12

Table 3-4: Min. efficiency of hot water generating system (steam boiler/hot water boiler [10]

Type	Minimum Efficiency
Oil fired steam boiler	85
Oil fired hot water boiler	80
Gas fired steam boiler	80
Gas fired hot water boiler	80

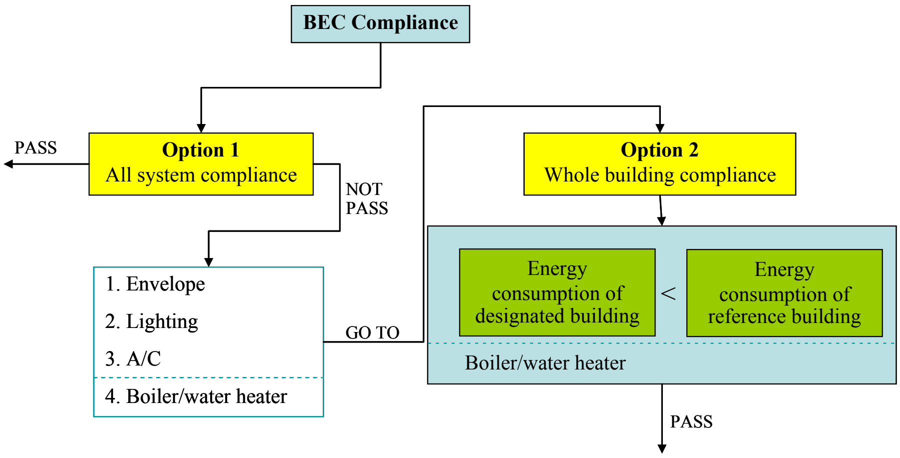

Figure 3-4: Calculation of whole building performance [10]

- Minimum Energy Performance Standard (MEPs) – promote efficient use of energy by providing financial incentives to attract the private sector to opt for energy-saving appliances.

Table 3-5: Performance indicators for electric appliances under MEPs

	Consumer NPV (million baht)	B/C	GWh	MW	CO_2 (ktonnes)
Refrigerator (original standards)	7.8	4.1	790	119	447
Refrigerator (comprised standards)	4.5	4.2	423	64	239
Air-conditioning	5.2	15.5	344	68	195
Motors	5.2	7.0	552	117	312
Lighting	13.2	4.7	1,526	357	883
Grand Total	**31.0**	**5.3**	**3,213**	**661**	**1,837**

- Voluntary Program
  - Building Labeling [11] – currently a voluntary program, the objectives are to encourage energy conservation in houses and commercial & residential buildings by using labels and make buyers and renters of houses and commercial & residential buildings realize the significances of energy saving. The building label program has been devised in a manner similar to the United States Green Building Council's method of awarding a LEED rating for buildings that meet specific

sustainability and energy criteria. 3 levels of labels have been identified for both residential and non-residential buildings:

Table 3-6: Score and evaluation's criteria in building labels program [11]

Evaluation Criteria	Residential Building *energy (environment)*	Non-Residential Building *energy (environment)*
1. Building site	*4 (2)*	*5 (5)*
2. Landscape architecture	*8 (8)*	*6 (6)*
3. Building Envelop	*40 (-)*	*34 (-)*
4. Air conditioning system	*10 (2)*	*15 (8)*
5. Lighting system	*12 (1)*	*15 (1)*
6. Alternative energy & Energy management	*12 (5)*	*12 (3)*
7. Sanitation system	*4 (5)*	*5 (7)*
8. Materials and construction	*- (5)*	*- (7)*
9. Advanced technology and Innovation	*10 (5)*	*8 (4)*

Table 3-7: Label level and scores [11]

Label Level	Score of Evaluation		Percent of Energy Saving	
	Residential	Non-Residential	Residential	Non-Residential
Bronze	40-54	45-59	15-24	15-20
Silver	55-69	60-74	25-30	21-30
Gold	≥ 70	≥ 75	> 30	> 30

Gold Silver Bronze

Figure 3-5: Labeling of Residential Building [11]

Gold Silver Bronze

Figure 3-6: Labeling of Non-Residential Building [11]

There are other organizations are implementing Green Building in Thailand as follows:

1. Pollution Control Department (PCD) – developing criteria for green government building which divided criteria into 2 types, new and existing building.
2. Thai Green Building Institute (TGBI) - developing criteria for green building (new construction)
3. Green Leaf Foundation – certification for hotel building by considering the environmental conservation.
4. Thailand Environmental Institute (TEI) and Thailand Greenhouse Gas Management Organization (TGO) – carbon reduction label for building, considering how much an existing building contributes to the reduction of greenhouse gas emissions [11].
   - Thailand Energy Awards
   - The EE Housing Competition
   - High Energy Performance Standard (HEPs) – high-efficiency levels for energy-using equipment. EGAT has been running a voluntary energy labeling program covering several types of household appliances and equipment since 1994. The voluntary measure has boosted the market transformation of appliances and equipment market into high energy-efficient. To further improve and enhance the energy efficiency improvement of appliances and equipment, the Thai Government decides to use a mandatory intervention tool i.e. MEPS, labeling for high-efficiency appliances and equipment

Table 3-8: Example of high-energy efficiency building by Government [11]

<table>
<tr><th colspan="4">Energy Demonstration Center</th><th>EGAT Headquarters Building</th></tr>
<tr><td></td><td>Energy Consumption of Bldg</td><td>Energy Consumption per ECP Act</td><td>Avg. Energy Use</td><td rowspan="4">• The Electricity Generating Authority of Thailand (EGAT) has built and occupied a multi-story headquarters office building that also demonstrates many of today’s energy efficiency and renewable energy technologies that significantly reduce its energy consumption.

• Estimation of electrical consumption of this building is 109 $kWh/m^2/yr$, 45% less than energy consumption of standard office building.</td></tr>
<tr><td>Overall Thermal Transfer Value</td><td>18 W/m^2</td><td>45 W/m^2</td><td>65 W/m^2</td></tr>
<tr><td>Energy Consumption of Lighting</td><td>8 W/m^2</td><td>16 W/m^2</td><td>25 W/m^2</td></tr>
<tr><td colspan="4">• Major training centre and information dissemination centre displaying 54 technologies in industrial, residential and commercial settings and interactive node for public to use and learn how to operate.</td></tr>
</table>

3-3 REVIEW OF THAILAND 20-YEAR ENERGY EFFICIENCY DEVELOPMENT PLAN [1, 10]

From the agreement with Thailand's government and APEC Leaders in 2007, the target of "energy intensity reduction" or the amount of energy used per GDP by 25% in year 2030 compared to base year 2005 has been set as the energy conservation target. Since Thailand's energy intensity in 2005 was 16.2 ktoe per billion baht GDP (at 1988 constant value), if Thailand is determined to implement energy conservation measures pursuant to the mentioned agreement, the overall energy intensity of the country in 2030 must not exceed 12.1 ktoe per billion baht GDP, or the final energy consumption in that year must not exceed 121,000 ktoe (under the assumption that the annual economic growth rate will be at 4.2% in average). That is, energy demand must be 30,000 ktoe lower than that in the BAU case, or 20% lower than the demand in the BAU case as shown in Figure 3-7.

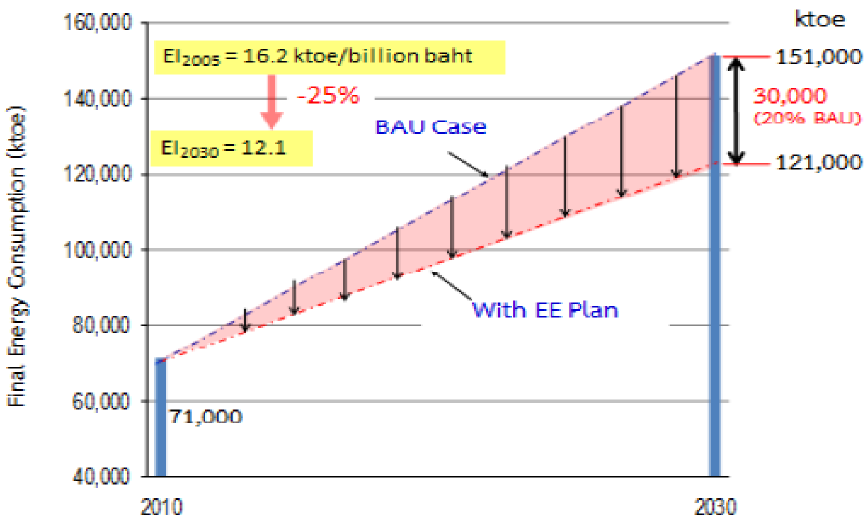

Figure 3-7: Energy Saving Amount to Be Achieved by Thailand by 2030

The assessment of electricity saving potential is based on the comparison between the average energy consumption rate/space unit/year of individual building types at present, called the "Reference Case," and such a rate in the case where the minimum energy consumption efficiency standard of buildings, or "Building Energy Code (BEC)," is enforced, including the case where a higher standard in the future is enforced. The average energy consumption rate under the Reference Case is derived from the energy consumption modeling representing each building type, based on the official data from energy consumption inspection. Energy efficiency standards which are higher than the BEC comprise the following three levels:

1. HEPS (High Energy Performance Standard) – the high energy efficiency standard of various systems which can be achievable by using current technologies

2. Econ (Economic building) – the target in the near future when the technologies of equipment and various systems are developed to be more energy efficient

3. ZEB (Zero Energy Building) – the long-term target when the need for external energy supply to the buildings is near zero because the energy demand of such buildings is very low and there is also on-site energy generation from renewable energy.

The parameters that are modified or changed to achieve greater energy efficiency are the heat transmission via building envelope, air-conditioning efficiency, lighting and electrical equipment/appliance efficiency, and air ventilation. Table 3-9 shows the values of net energy consumption of each commercial building types under the above criteria from the analysis of study's results of government's report:

Table 3-9: Net Energy Consumption Derived from Modeling Each Building Type under Each Level of Energy Saving Capability

Building type	Energy consumption capacity (kWh/m2/y)				
	Reference	BEC	HEPs	Econ	ZEB
Office building	219	171	141	82	57
Department store	308	231	194	146	112
Retail & wholesale business	370	298	266	161	126
Hotel	271	199	160	116	97
Condominium	256	211	198	132	95
Medical center	244	195	168	115	81
Educational	102	85	72	58	39
Others	182	134	110	66	53

The outcome of the electricity saving potential assessment in 2030 for large commercial building group is shown in Table 3-10. It indicates that office buildings, educational institutions, department stores and hotels have higher potential than other building types. As for the assessment of fuel saving potential, the outcome is shown in Table 3-11.

Table 3-10. Electricity saving potential for large commercial building

Building type	Demand in 2030, BAU case (GWh)	Demand in 2030, BEC case (GWh)	Saving potential (GWh)	% Share
Office building	11,211	4,178	7,033	26
Department store	8,466	4,372	4,094	15
Retail & wholesale business	3,265	1,401	1,864	7
Hotel	7,366	3,197	4,169	15
Condominium	1,931	907	1,024	4
Medical center	2,163	1,228	935	3
Educational	12,947	6,150	6,797	25
Others	2,356	857	1,499	5
Total	49,705	22,289	27,416	100

Table 3-11. Electricity saving potential for large commercial building

Equipment	Demand in 2030, BAU case (GWh)	Demand in 2030, BEC case (GWh)	Saving potential (GWh)	% Share
LPG burner	831	477	354	87
Liquid fuel burner	118	67	51	13
Total	949	544	405	100

The overall energy conservation potential in the commercial building and residential sector in 2030 can be summarized in Table 3-12. It will be noticed that both large commercial building and small commercial building and residential groups have a high electricity saving potential. The total potential in this sector is about 6,410 ktoe.

Table 3-12: Energy conservation potential in commercial building (comparing with small building & residential buildings)

Building group	Energy type	Energy conservation potential in 2030	% share
Large commercial building	Electricity	2335	37
	Fuel	405	6
Small commercial building & residential	Electricity	1978	31
	Fuel	1693	26
Total		6411	100

3-4 REVIEW OF THAILAND POWER DEVELOPMENT PLAN (2012 - 2030) [12]

As mentioned in previous chapters, Thailand has relied on natural gas as the major primary energy resource which accounts for more than 70% of the total primary energy supply for electric power generation since 2001. Recently, the Ministry of Energy of Thailand found that the reserve of natural gas in Thailand will be depleted within 10 years .

The total power capacity from the new coal-fired power plants is 8,400 MW. The Ministry of Energy of Thailand expects deploy eight new clean coal technology power plants of supercritical steam power. Bituminous coal is proposed as the fuel supply. They will be equipped with flue gas desulfurization (FGD) units to reduce SO2 emission. As of December 2009, the total capacity of existing power plants in Thailand was 29,212 MW. It is expected that a total accumulated capacity of 17,671MW of currently operating power plants will be retired within 20 years. Moreover, Electricity Generating Authority of Thailand (EGAT) projects that within 20 years, economic development will drive electricity demands for an additional 54,067.6 MW. Therefore, the total accumulated capacity of power plants in 2030 is estimated to be 65,608.6 MW. The final PDP report in 2010 elaborates further on the plans for power plant development until 2030 [12].

Total added capacity during 2012 – 2019 composes of all projects planned with commitment and agreement. The total added capacity will be about 23,325 MW detailed as the following: Power purchases from renewable energy-8,194 MW, Cogeneration-5,107 MW, Combined cycle power plants-6,551 MW, Thermal power plants (coal/lignite)-3,473 MW.

Total added capacity during 2020 – 2030 comprises all projects planned for serving future power demand increasing annually and also replacement of the retired power plants. The total added capacity during this period will be about 31,805 MW summarized as the following: Power purchases from renewable energy-6,387 MW, Cogeneration-1,368 MW, Gas turbine power plant-750 MW, Combined cycle power plants-18,900 MW, Thermal power plants (coal)-2,400 MW, Thermal power plants (nuclear)-2,000 MW

For the renewable energy generation, from the government policy targeting on increasing the share of renewable energy and alternative energy uses by 25 percent instead of fossil fuels within the next 10 years, new projects of renewable energy development are initiated into PDP2010: Revision 3. Hence, at the end of 2030, total capacity of renewable energy will be around 20,546.3 MW (or 29 percent of total generating capacity in the power system) comprising total existing capacity amounting 6,340.2 MW, total added capacity of renewable energy of 14,580.4 MW and deduction of the retired capacity of renewable energy totaling 374.3 MW. The 20,546.3 MW capacity of renewable energy can be classified into domestic renewable energy of 13,688 MW and renewable energy from neighboring countries of 6,858 MW. The renewable energy power project development during 2022 – 2030 will be considered in accordance with its potential detailed as the following:

- ☐ Solar power 1,995.7 MW
- ☐ Wind power 199.4 MW
- ☐ Hydro power 2,742.5 MW
- ☐ Biomass 223.5 MW
- ☐ Biogas 24.1 MW
- ☐ Municipal solid waste (MSW) 17.8 MW

3-5 REVIEW OF THAILAND RENEWABLE ENERGY POLICY [13-17]

In terms of renewable energy policy, Thailand has already set a very ambitious target for the promotion of renewable energy, especially for the photovoltaic (PV) system. However, there are still some challenges for the further implementation of solar energy application in Thailand, such as local industry chain, grid connection, professional skills, management, etc. These hurdles can be overcome through various actions including setting up an accreditation system and making sure that there are a sufficient number of professional engineers and skilled workers to set up and monitor PV systems and the like.

Under the AEDP there is a detailed plan for the development of hydro power, and many successful projects have been completed, which encourages future utilization. It is important however that as hydropower utilization increases that there is stricter monitoring of hydro power plants‟, including small hydro plants‟ compliance with environmental regulation. According to the PDP, for next 20 years, a forecast of load growth, the additional capacity of power plants to be built to meet the forecasted load growth, the types of energy sources for new generation capacity, and the share of investment by EGAT and IPPs. The REDP seeks to bring renewable energy to 20% of final energy consumption by 2020 and sets targets for different forms of renewable energy. The two plans were prepared by different government departments and motivated by different policy drivers. As a result, the plans have set diverging targets for renewable power generation.

Table 3-13: Renewable goals in Thailand's 15-year Renewable Energy Development Plan (REDP 2008 – 2022)

Energy type	Potential	Capacity in 2008	Target in 2008-2011	Target in 2012-2016	Target in 2017-2022
	MW	MW	MW	MW	MW
Solar	50,000	32	55	6	500
Wind	1,600	1	115	13	800
Hydro	700	56	165	43	324
Biomass	4,400	1,610	2800	1463	3,700
Biogas	190	46	60	27	120
MSW	400	5	78	35	160
Hydrogen	-	-	-	-	3.5
Total	57,290	1,750	3,273	4,191	5,607.5

As illustrated in Table 3-13, the REDP has set goals to achieve specified capacity for different types of renewable energy, including 500 MW of solar power, 800 MW of wind, 324 MW of hydro power, 3,700 MW of biomass power, 120 MW of biogas power, 160 MW of MSW power, and 3.5 MW of hydrogen power by 2020. Table 3-14 shows that the achievement of these targets has been mixed, with on-grid capacity exceeding short-term targets for solar and biogas, and capacity far below targets for other types of renewables.

Table 3-14: Thailand's renewable energy target and status in 2011

RE type	15-year target (until 2022), MW	Target in 2008 – 2011, MW	Actual on grid capacity (SPP + VSPP) as Dec 2011	% Difference
Solar	500	55	110.97	+101.76%
Wind	800	115	0.38	-99.67%
Small/Hydro power	324	165	13.28	-91.95%
Biomass	3700	2,800	724.72	-74.12%
Biogas	120	60	98.69	+64.49%
MSW	160	78	37.33	-52.14%
Hydrogen	3.5	0	0	N/A

Until now, the most immediate manifestations of this policy ambivalence has been discontinuous support for the Adder measure, which – when operational –is one of the major mechanisms that will help the country meet its renewable energy targets. Discontinuous support for the Adder, in turn, has created a high level of uncertainty for investors.

Thailand's adder program gives incentives for private investors to invest in renewable energy projects by guaranteeing attractive power purchasing rates. Eligible participants enter into long-term contracts with the local utility to sell renewable electricity at a pre-specified tariff for a pre-specified period of time. The three utilities purchase electricity from renewable electricity generators using two types of regulations:

1. VSPP (Very Small Power Producers) regulations: for generators sized less than or equal to 10 MW
2. SPP (Small Power Producers) regulations: for generators sized greater than 10 MW and less than 90 MW

In conclusion, the AEDP will lead to many advantages in multiple sectors, for example:

- Energy sector: If we reach the alternative energy production target, 25% of total energy consumption, it means we are getting 9,201 MW of electricity, 9,335 ktoe of heat and 39.97 million liters per day of biofuel.
- Economic sector: The plan trends to reduce oil imports for 574,000 million baht and to promote private sector investment about 442,000 million baht.
- Environmental sector: The CO_2 emission will be decreased for 76 million tons/year within 2021, moreover, there will be possibility of income from trading carbon credit approximately 23,000 million baht.

3-6 PRESENT STATUS OF THAILAND'S BUILDINGS ACCORDING TO ENERGY POLICY [18, 19]

The buildings sector, which essentially consists of the commercial and residential sectors, is a significant user of energy in Thailand. It accounted more than 20% every year for Thailand's total energy consumption. Comparing between residential and commercial sector for total energy consumption, residential sector consumed more than double that of commercial sector due to the amount of new and renewable energy consumption almost 60% for past 7 years and follows by electrical energy and renewable energy for the rest. Figure 3-9 illustrates the total energy consumption for building sector in Thailand from year 2005 – 2011. However, if considered for the electrical energy consumption which is the major commercial energy in Thailand, the consumption of electrical energy for commercial sector is more than that of residential sector about 35-40% from the usage of air-conditioning system.

Until now, there are no precise recorded data to determine the number of buildings in Thailand due to lack of data collection and responsible agency to collect it which consequence to make the difficulties for implement the energy conservation methods because need to be done separately by the owner of these buildings. However, from the energy development and promotion Act 2007.

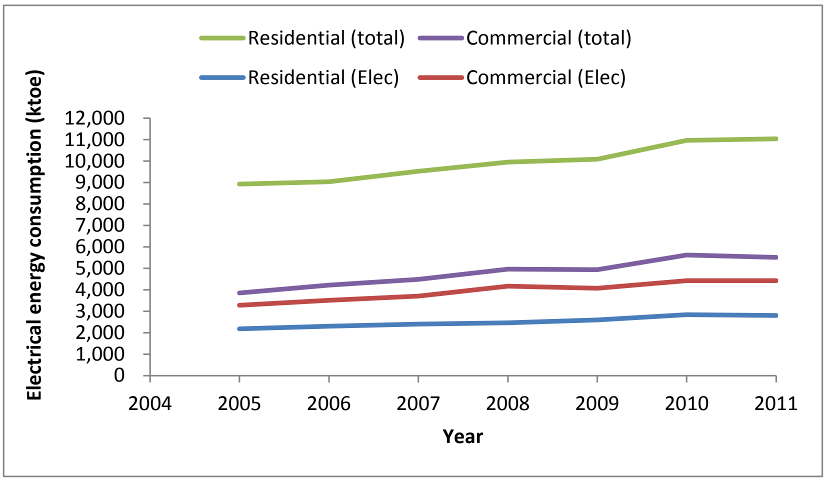

Figure 3-9. Statistic of total and electrical energy consumption in 2005-2011

The owner of designated buildings in Thailand are forced to implement and administer energy program under the energy development and promotion Act 2007. The success of energy conservation promotion for the designated government buildings can induce the owner of the designated buildings of private-sector to implement the energy management program under the law.

In 2011, the number of designated government buildings is 824 buildings which composed of 137 Hospitals, 185 Educational institutes. 485 Offices, and 17 buildings for other types. These buildings are the pilot project of promotion and conducting the energy conservation regulation and supervision of designated government buildings which launched in 2010 by provided the experts on energy management system according to the law to give guidance for the staff of the buildings. Also, the agency of the buildings has been forced to implement the energy conservation activities. The results of implementation of energy conservation regulation in 2011 are shown in below details [19]:

- Assignment of responsible expertise for energy management

1. Completed: 624 buildings (76%)
2. Uncompleted: 156 buildings (19%)
3. No expertise: 34 buildings (4%)

- Status of report submission for energy management

1. Completed: 807 buildings (99.3%)
2. Uncompleted: 6 buildings (6%)

From the cooperation and controllable data from the designated government buildings, the precise estimated results of energy conservation can be done as shown in Table 3-17.

Table 3-17. Results of energy conservation of designated government building in 2010

Conservation measure	Investment (MB)	Energy conservation results (ktoe/yr)	Return on investment (yr)	Co2 reduction (ton/yr)
Electrical	2,085	22.66	2.36	
Heat	15	0.40	0.76	
Total	2,100	23.06	2.33	136,066

The conservations methods for these designated government buildings are categorized into 3 main parts – utilization of current system to be highest efficiency, minor changes and major replacements for current system. The major replacements for current systems composed of 3 main projects:

1. Utilization of High EER for air-conditioning system: already completed for 86 buildings (energy saving about 1.018 ktoe/yr) and under implementation for 334 buildings (expected results for energy saving about 5.245 ktoe/yr)
2. Replacement of lighting system from T8 to T5: already completed for 199 buildings (energy saving about 3.277 ktoe/yr) and under implementation for 364 buildings

(expected results for energy saving about 4.248 ktoe/yr)

3. Replacement of high efficiency chiller system: already completed for 7 buildings (energy saving about 0.188 ktoe/yr) and under implementation for 26 buildings (expected results for energy saving about 0.815 ktoe/yr)

However, there are many buildings which are not categorized into designated facilities and no requirement to complied with mandatory building energy codes, i.e. the buildings which have area less than 2000 sq.m. and consumption of electrical energy less than 3000 kW. In the present situation, even these buildings are categorized as "Designated facilities" but only annual energy audit reports have been submitted to Department of Alternative Energy and Efficiency (DEDE) but still cannot control and implemented the conservation methods.

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CHAPTER FOUR PRESENT SITUATION OF ENERGY USE IN THAILAND'S COMMERCIAL BUILDINGS

4-1 INTRODUCTION

The characteristics of energy used in commercial buildings are different for all buildings due to many affect parameters, e.g. no. of people in buildings, functions of buildings, location, type of machine, efficiency of machines, age of buildings, etc. In this part, the concept of main parameters that affect the energy used in commercial buildings in Thailand will be explained. Furthermore, the analysis of energy used characteristics in each building type is performed in next section.

4-1-1 GEOGRAPHY AND TOPOGRAPHY OF THAILAND

Thailand is a unitary state which consists of seventy-six provinces and *one special administrative area representing the capital Bangkok*. The provinces are part of the provincial government, whilst Bangkok is part of the local government. Six geographical regions are separated based on natural features including landforms and drainage, as well as human cultural patterns, namely: the North Region, the Northeast Region, the Central Region, the East Region, the West Region and the South Region of Thailand as shown in Figure 4-1. [1]

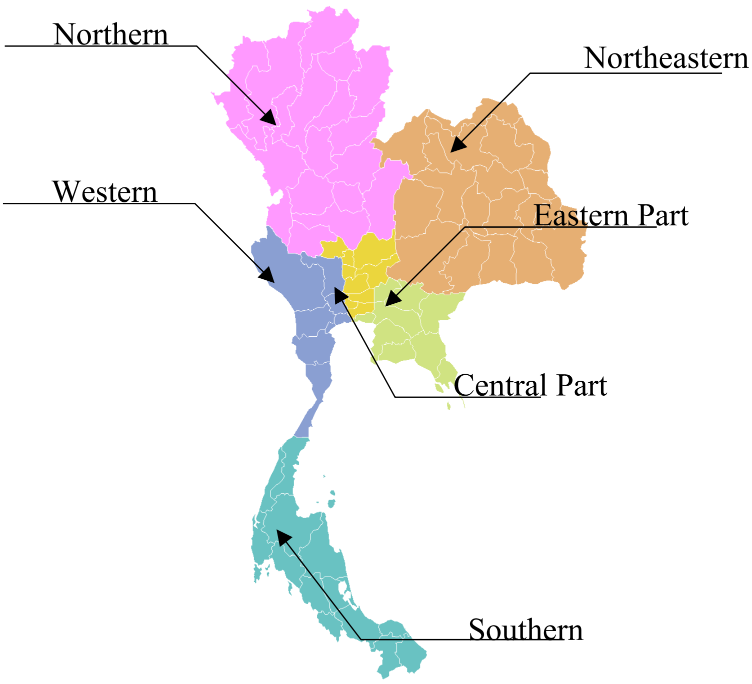

Figure 4-1 Thailand Geography Map [1]

Although Bangkok geographically is part of the central plain, as the capital and largest city this metropolitan area may be considered in other respects a separate region. Each of the six geographical regions differs from the others in population, basic resources, natural features, and level of social and economic development. The characteristics of energy used and pattern of usage are different according to the location of the buildings in each region.

4-1-2 THAILAND'S CLIMATE [2]

In general, three different seasons can be recognized as follows:

1. The rainy season in Thailand corresponds to the prevailing southwest monsoon. Rainfall peaks occur during the retreat of the monsoon, generally from August to September. Abundant rainfall from tropical cyclones also occurs from August to October.
2. Winter season corresponds to the prevailing northeast monsoon, occurring from mid-October to mid-February. The amount of rainfall received during this season is much less than that during the southwest monsoon season, with December usually being the driest month. The eastern edges of Southern peninsular usually receive much more rainfall than the western, leeward side. Thus, cool and dry weather is experienced elsewhere in Upper Thailand. Rain is widespread only over Peninsular Thailand, especially along the eastern coast.
3. Summer season is about three months period, from mid-February to mid-May. This season can be considered to be a transition period, as primary influence shifts from the northeast to southwest monsoon. The hottest month is usually around April.

Considering the surface temperature in Thailand, the upper part of Thailand i.e. the Northern, Northeastern, Central and Eastern Parts usually experiences a long period of warm weather because of its inland nature and tropical latitude zone. March to May, the hottest period of the year, maximum temperatures usually reach near 40°C or more except along coastal areas where sea breezes will moderate afternoon temperatures. The onset of rainy season also significantly reduces the temperatures from mid-May and they are usually lower than 40°C. In winter the outbreaks of cold air from China occasionally reduce temperatures to fairly low values, especially in the Northern and Northeastern Parts where temperatures may decrease to near or below zero. Table 4-1 shows the extreme maximum temperature in each region according to period 1951 -2011. It is found that the maximum temperature in Thailand can be increased up to 44.5°C, located in northern part of Thailand around the end of April. However, the temperatures in Southern part are generally mild throughout the year because of the maritime characteristic of this region.

Table 4-1 maximum temperature during summer (based on period 1951 – 2011)

Region	Max. temp	Period	Location
North	44.5	27 Apr 1960	Uttaradit
Northeast	43.9	28 Apr 1960	Kanchanaburi
Central	43.5	29 Apr 1960	Prachin Buri
East	42.9	20 Apr 1992	Prachuap Khiri Khan
South	41.2	15 Apr 1998	Trang

4-1-3 BUILDING CLASSIFICATION [3]

In terms of building functions, including the service hours in each building affect to different energy consumption. According to latest building energy code (BEC) in Thailand, three patterns of use of a building are identified, daytime only, late daytime to nighttime, and day and night. In current code [under Energy Conservation Act No.2 B.E. 2550 (2007)] adopts performance indicators to evaluate three major building systems and categorized building type by time of use as the following:

1. Office or educational place pattern: 8:00 – 17:00 usage time / 2,340 hrs per year.

2. Department store, hypermarket or restaurant pattern: 10:00 – 22:00 usage time / 4,380 hrs per year.

3. Hotel or hospital or condominium pattern: 24 hrs usage time / 8,760 hrs per year.

Every building in Thailand use electrical energy as the major energy in order to provide the energy consumption for air-conditioning system, lighting system, equipment, and others especially in big city, air-conditioning system consumed about 40-60% of total electrical energy consumption in each building especially Department Store, Hypermarket, and hotel. Although the proportion of the consumption for office building, hospital, and educational institution didn't have 100% HVAC area, however, the tendency is higher every year. Figure 4-2 shows the index of electrical energy consumption per area and HVAC area in each building type [4].

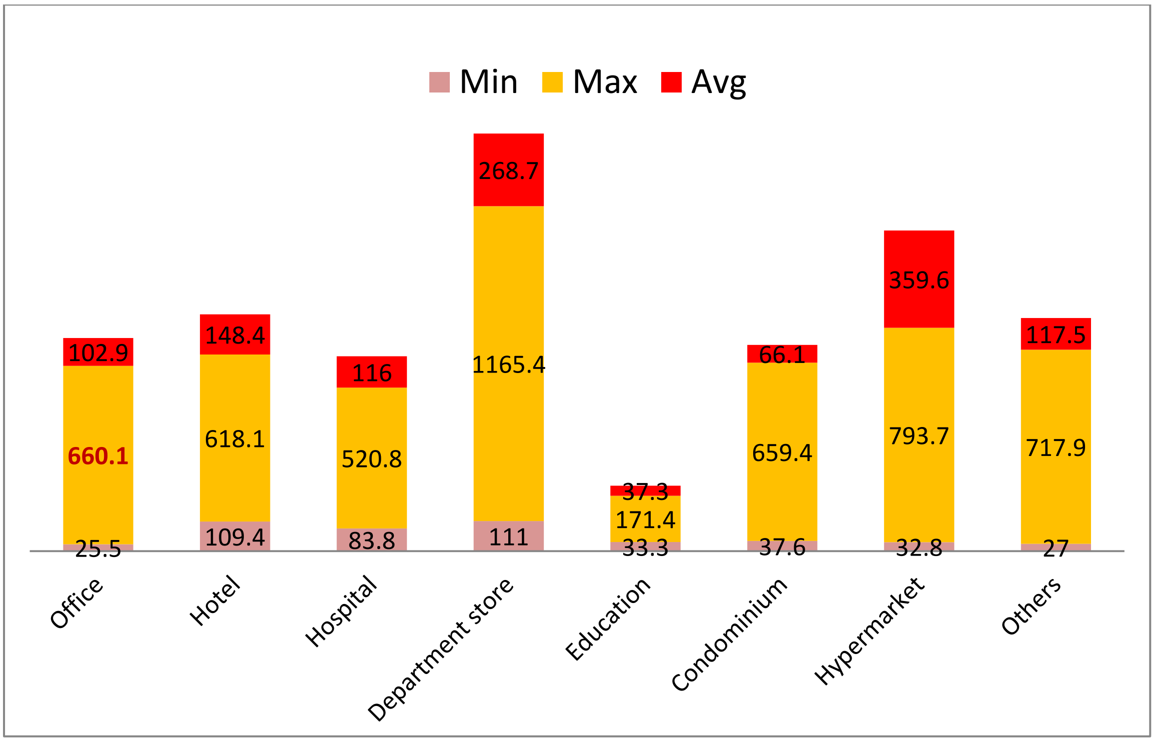

Figure 4-2 Annual Electrical energy consumption and proportion of HVAC area for commercial building

The building which have high proportion of HVAC area will consume high energy but in case of office buildings, even though they have low proportion of HVAC area same as educational buildings and condominium, but the average and peak value of energy consumption is high due to the performance of machine and several factors that affect the efficiency of air-conditioning system. [5]

Type of air-conditioning system depends on type and size of each building. Most of designated building except small-scale government building and educational buildings' air-conditioning system always use water cooled central air-conditioning system and constant air volume (CAV) for chiller. In HVAC area, centrifugal chiller system with sizing 120-500 RT, reciprocating chiller system with sizing 80-200 RT were installed in order to provide thermal comfort inside the building. For small-scale buildings and educational buildings, Split type and Package Unit type of air-conditioning systems mostly found in these building types. Performance of each air-conditioning system from survey results are shown in Table 4-2.

Table 4-2 Performance of Air-conditioning system for Thailand's commercial buildings

No. of split type/package unit A/C	776
Range of EER (Btu/hr/Watt)	2.2-17.6
Average (Btu/hr/Watt)	7.4
No. of centrifugal chillers	120
Range of chiller performance (kW/RT)	0.59-1.37
Average (kW/RT)	0.796
No. of reciprocating chillers	29
Range of chiller performance (kW/RT)	0.93-2.037
Average (kW/RT)	1.346

The energy efficiency rating (EER) for split type/package unit air-conditioning system which announced by Electricity Generating Authority of Thailand (EGAT) can be categorized by level number. A/C with level no. 5 can defined as the highest performance [5,6]

Table 4-3. EER indicators for split type/package A/C

Cooling capacity	Energy efficiency ratio (EER)		
	No.3	No.4	No.5
≤8000W (27,926 BTU/hr)	9.6	10.6	11.6
>8000-12000W (>27,926-40,944W)	9.6	10.6	11.0

For large air-conditioning system, minimum allowable values for coefficient of performance (COP) for large electric chillers vary from 2.7 for small air-cooled chillers to 5.67 for large water-cooled chillers. For unitary air-conditioners, requirement on COP is made for each set. It can be seen that the utilization of high performance of A/C system is still low for all types of A/C system.

Electrical energy consumption for lighting system in Thailand still not high because mostly use fluorescent in every building. Department store consumed high energy consumption for lighting system due to the usage of high electric power and long operating time comparing to other types of building. Table 4-4 shows the value of rated power density, and illumination of lighting system of utilized area

Table 4-4. Rated power density and illumination values

Building type	Rated power density (W/m2)			Illumination range (lux)
	Min.	Max.	Avg.	Range
Office	2.0	29.5	9.3	130-580
Hotel	4.5	28.8	7.8	190-350
Hospital	2.0	50.6	7.7	200-400
Dept. store	3.4	30.2	14.6	450-1200
Education	3.7	33.7	9.5	200-550

As mentioned in chapter, in order to develop the energy security in Thailand to maintain the effectiveness of energy utilization in commercial building, the Government of Thailand established the Energy Conservation Fund (ENCON Fund) in 1992 to foster the expansion of energy efficiency (EE) and renewable energy (RE) projects by mobilizing and leveraging additional investments in mitigation projects. The ENCON Fund was initially available to large-scale industrial and commercial facilities and later opened up to ESCOs and small-to-medium sized enterprises to be the 3rd party service provider who engages in the performance based contract to implement measures to reduce energy consumption and costs in a technically and financially viable manner. The Act outlined three major program areas: a compulsory program that required commercial **designated buildings** to increase energy efficiency, a voluntary program targeted at small-to-medium enterprises, and a complementary program covering research and development and publicity initiatives.

The "**Designated buildings**" are the building that installed power meter (power demand) over 1,000 kW or the total transformer capacity over 1,075 kVA or the total annual energy consumption for all types of energy more than 20,000,000 MJ / year. These designated buildings shall submit energy data to Department of Alternative Energy Development and Efficiency (DEDE) in form of energy management report conform to energy conservation regulations 1992 which focus for the production and energy consumption in fuel and electricity, also set the target and plan according to the energy management methods implementations. [3,7,8]

From the beginning of the regulation implementation, the designated buildings have to perform in 3 activities according to regulation that are appoint person responsible for energy in their organization, set the target and plan for submission the semi-annual energy consumption and production of that organization / or that of building. However, the collected data until 2009 of every buildings still on paper work and cannot controlled for data collection. The research from P. Wangskan [9] also found that some government agencies of the designated buildings were unable to conduct the energy management system according to the law by lack of personnel who has knowledge and experience.

Therefore, the pilot project of promotion and conducting the energy conservation regulation and supervision of designated government buildings was first lauched in 2010 [] by provided the experts on energy management system according to the law to give guidance for the staff of such buildings. The agency of the buildings has been forced to implement the energy conservation activities. Also for the data collection that the designated buildings have to submitted to DEDE, more effective collection methods were performed by using computerized system for the center instead of paper work in order to preventing the data loss and uncontrollable data collection.

In this chapter, the evaluation of characteristics of energy consumption for designated commercial buildings in Thailand is performed according to raw data of reports submission from designated buildings to DEDE from fiscal year 2010 and 2011 in order to know the trends and characteristics of energy used by considering the several affect parameters from the submitted data.

4-2 ANALYSIS OF ENERGY CONSUMPTION FOR COMMERCIAL BUILDINGS IN THAILAND [10,11]

After the implementation of building energy code as prescribed in the Energy Conservation Promotion Act B.E. 2535 for designated buildings, the owners of designated buildings have the main duties to conserve the energy as the following:

- Implement the energy conservation to be complied with the specified standard

- Appoint at least 1 Person Responsible for Energy (PRE) to work full-time at that designated building

- Submit data of Energy generation, consumption and conservation to Department of Alternative Energy Development and Efficiency, Ministry of Energy (DEDE)

- Record data of energy consumption, data of installation or the modification of equipment or machinery affecting energy consumption and conservation of that building.

- Establish the energy conservation target & plan and submit to DEDE

- Audit and analyze the implementation of energy conservation target and plan

From the aforementioned about building energy report submission, from the record of DEDE found that many of designated buildings still not performed the energy conservation or ignored to this Act, e.g. the energy conservation and consumption data are not realistic as recorded, not submitted the annual reports, etc.

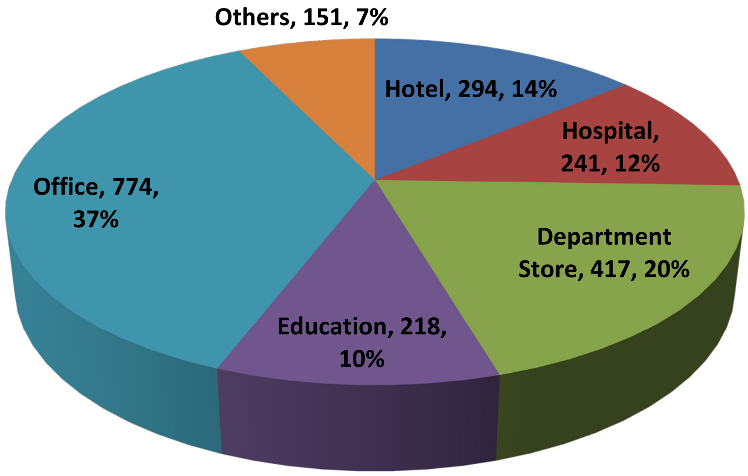

Figure 4-3 Proportion of each designated buildings separated by function in 2011

As illustrated in Figure 4-3, total number of registered designated buildings in year 2011 is 2095 buildings, which can be divided into categories as follows:

a) Office buildings: 774 buildings (37% of total)
b) Educational buildings: 218 buildings (10% of total)
c) Department stores: 417 buildings (20% of total)
d) Hospitals: 241 buildings (12% of total)
e) Hotel: 294 buildings (14% of total)
f) Others: 151 buildings (7% of total)

However, from the record of the report submission, it is founded that total number of designated buildings that submitted the energy reports is 1716 buildings, which decreased from total registered no. of buildings by 379 buildings or 18.1%, which can be divided as follows:

g) Office buildings: 635 buildings (37.0% of total)
h) Educational buildings: 208 buildings (12.1% of total)
i) Department stores: 372 buildings (21.7% of total)
j) Hospitals: 214 buildings (12.5% of total)
k) Hotel: 200 buildings (11.7% of total)
l) Others: 87 buildings (5.1% of total)

In this study, from the cooperation between the Kitakyushu University and Thailand's Department of Alternative Energy Development and Efficiency, the database of the energy consumption of commercial building in Thailand was conducted in 2010 and 2011 in order to investigate the characteristics of energy consumption in each type of buildings. In addition, the pattern of primary energy consumption for energy production in the buildings also investigated. However, the results of the energy conservations are not included in this research.

4-2-1 OUTLINE OF THE DATABASE

From the recorded data of designated buildings' energy data, we used the database in 2010 as the base year in order to perform the analysis in this study. The location of designated buildings are located every regions of the country which can be divided in to 6 main regions, namely Northern, Northeastern, Southern, Central, Eastern, and Western regions.

In this study, the regions of Thailand are divided according to the administrative districts, which is the same method as Thailand's National Statistic Office – total number of regions in Thailand can be divided into 4 main regions only, namely Northern, Northeastern, Southern, Central regions. It is noted that Bangkok is located in Central region but the province can be specified as the "special administrative area" which is not belong to central region.

Five types of designated commercial buildings are considered in this study – Office buildings, Hospitals, Department Stores, Hotels, and Educational Institutes. The investigated data of the database are shown in Table 4-5, which divided into 2 major categories – Outline of the buildings and details of primary energy consumption.

Table 4-5 Investigated items

Categories	Contents
Outline of buildings	Building name (represented by building ID.)
	Registered year (2010, 2011)
	Building type (Office buildings, Hospitals, Department Stores, Hotels, and Educational Institutes)
	Sector type (Government, Private)
	Location (region)
	The completion year
	Average building use time (hr/day)
	Area – HVAC area
	Area – Non HVAC area
	Area – Total area
	Energy use – A/C system (kWh/yr)
	Energy use – Lighting system (kWh/yr)
	Energy use – Refrigeration system (kWh/yr)
	Energy use – Other systems (kWh/yr)
	Energy use – Total energy use (kWh/yr)
Primary Energy consumption (kWh/yr, MJ/yr)	System – Air compressed system
	System – Generator system

	System – Air conditioning system
	System – Lighting system
	System – Refrigeration system
	System – Steam generator system
	System – Other systems
	Fuel type (Benzene, Biodiesel, Biomass, Fuel oil, etc)

The recorded data from the database of DEDE still need to screen due to the error of the input and unavailable data by using screening method and excluding the unusual data values based on the Statistic methods.

From the summary of the database in 2010, the available data for energy consumptions and primary of the designated buildings in Thailand was recorded for 1,287 buildings which used as the raw data in this study. Data filtering process from the raw data of 1287 designated buildings in Thailand are chosen the effective data for analysis by using statistical method as illustrated in Figure 4-4. The filter process comprise of two major steps. First, the buildings with no data or over/underestimated data for building areas, time of completion, and electricity data are removed and defined as invalid data. Second, the buildings which energy consumptions per unit area over 10 times of average or below one-tenth of average values are removed and can get the data of 1043 designated buildings as the effective numbers, which accounted for 81% from total and used as the data for the analysis in this study, as illustrated in Table 4-6. [12,13]

Table 4-6 Effective numbers of designated buildings with different building types and location

	Effective number /Total number						Effective rate
	North	Northeast	Central	South	Bangkok	Total	
Department store	35/39	45/50	202/212	31/33	96/102	313/334	93.7%
Education	10/15	20/26	36/68	6/12	22/43	72/121	59.5%
Hospital	21/26	18/24	72/101	11/17	39/50	122/168	72.6%
Hotel	8/10	9/16	95/111	30/36	70/82	142/173	82.1%
Office	17/26	32/38	333/402	12/20	238/285	394/491	80.2%
Total	1043/1287						81.0%

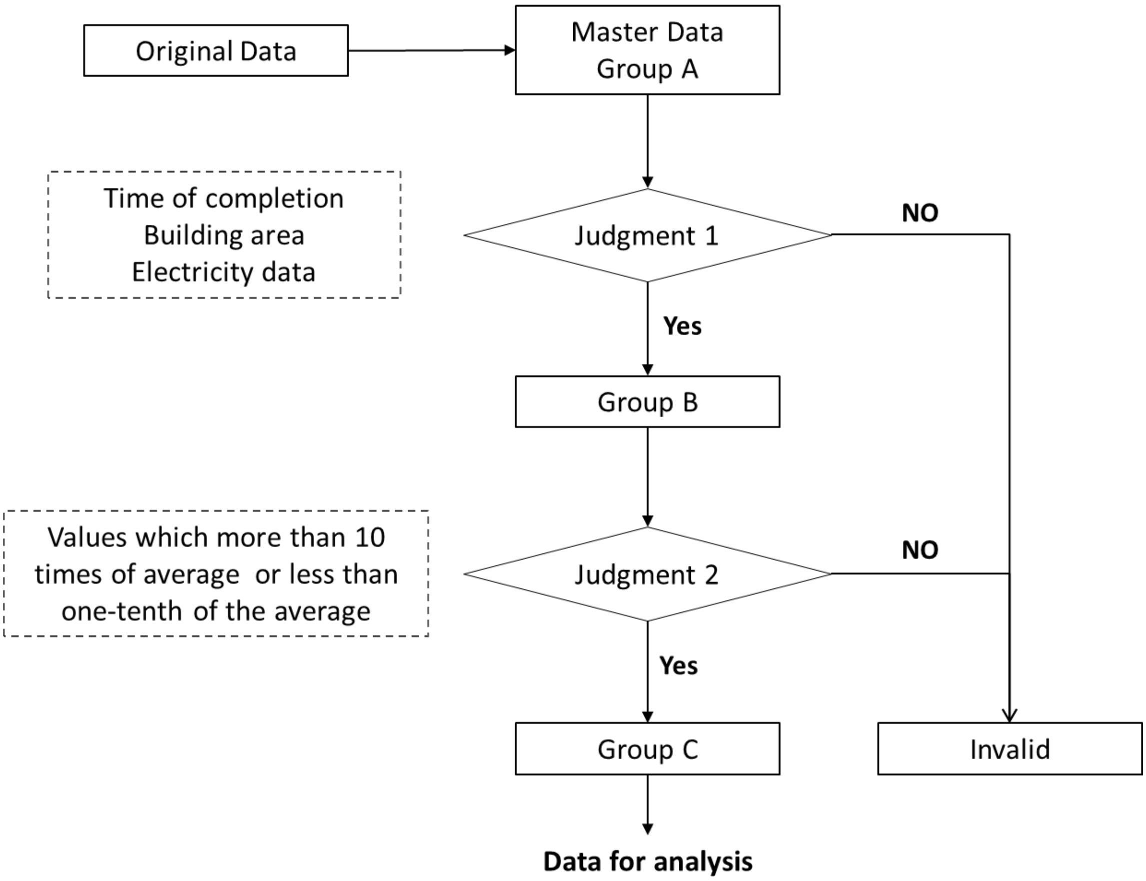

Figure 4-4 Selection methods for effective number of designated buildings

As shown in Table 4-6, the number of designated in central region is the highest proportion about 84.5% of total number of buildings in whole country and followed by that of Northeast region, North region, and Southern region, which accounted for 8.1%, 4.3%, and 3.0%, respectively. It is noted that even though the highest proportion of designated buildings are in the Central region but more than 60% of total buildings are located in Bangkok which accounted for 47.5%, 61.1%, 54.2%, 73.7%, 71.5%, and 63.0% from Department Stores, Educational Institutes, Hospitals, Hotels, and Office buildings, respectively. In addition, the percentage of every building types in Bangkok also more than that of other regions which accounted for 30-60% from total number of designated buildings in whole country.

4-2-2 BUILDING SCALE

For National scale, most of designated buildings have total floor area more than 10,000 m2, which accounted for 87% of total number of designated building for whole country. As shown in Figure 4-5, for office buildings, hotels, and hospitals, the no. of buildings with total floor area between 10,000 – 20,000 m^2 are accounted for the highest proportion for all building types. In case of Educational Institutes, the buildings with floor area between 50,000-100,000 m2 shared the highest proportion, which accounted for 33% of the total number of hospitals. Area of Department stores in Thailand are varied by the location and the owner of the stores, normally the area of the stores are varied between 10000-30000 m2 but the highest proportion are the stores with total area between 20000-30000 m2.

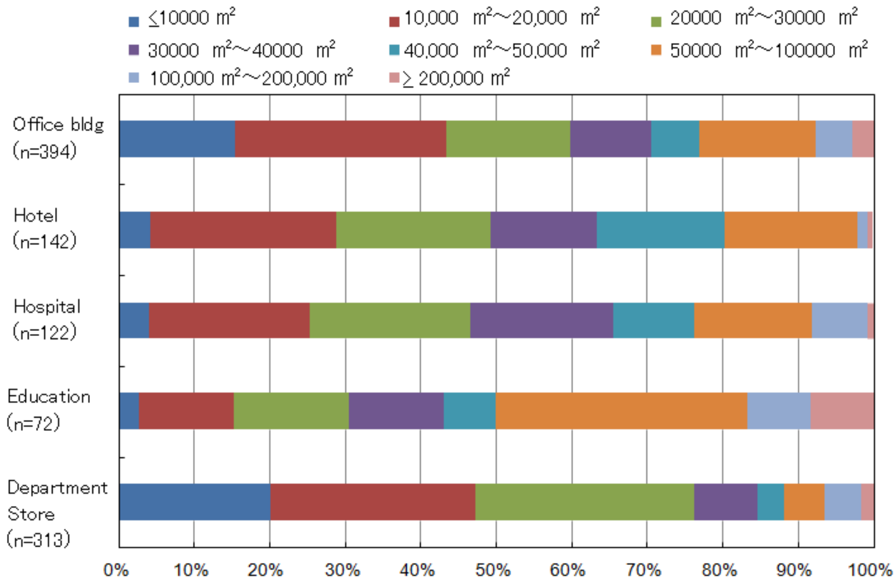

Figure 4-5 Proportion of building scales in each designated building type in Thailand

In Bangkok, even though the proportion of each building type is the highest comparing with other region, but the construction area is different from other regions. For example, the office buildings with total area less than 10,000 m2 accounted about 9% of total office buildings in Bangkok. Hotels with total area between 50000 – 100000 m2 which can be ranked as 5-stars hotel becomes highest proportion in Bangkok. In case of hospital, same situation as hotels, the hospitals with total area between 50000-100000 m2 are the highest proportion of total hospitals in Bangkok. For Educational Institutions with area between 30000-40000 m2 are the highest proportion, which accounted for 24% of total number of educational institutes in Bangkok. In case of Department store, the stores with area between 20000-30000 m2 are the highest proportion same as non-Bangkok area but the proportion in Bangkok is about 40% from the total number of Department stores in Bangkok. Figure 4-6 illustrated the proportion of building scales in each building type in Bangkok.

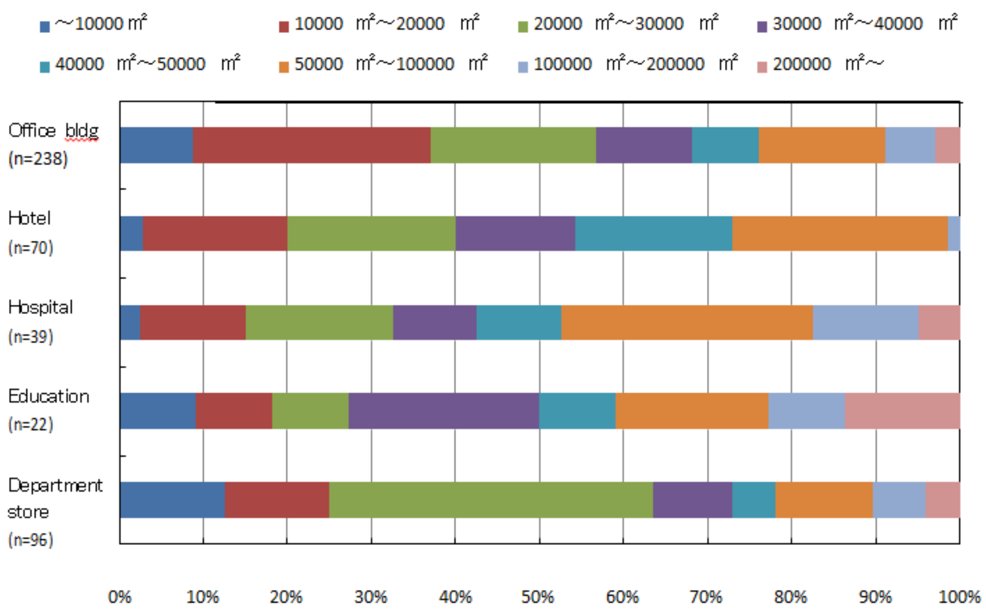

Figure 4-6 Proportion of building scales in each designated building type in Bangkok

4-2-3 BUILDING AGE

Building age or life cycle of the building is one of the key parameters that should be emphasized for considering the energy consumption and conservation methods of such buildings. Generally, construction cost of new building is cheaper than the retrofitting old buildings due to the maintenance methods and high technology involved during the retrofitted. Nowadays, most of new buildings use high technology for energy management in order to control and manage easier than the past, e.g. the utilization of BEM (Building Energy Management) will become one of new effective technology for energy control of the buildings at the present and near future.

Theoretically, old buildings will consume higher energy than that of new buildings due to the quality of the materials and machine, design, and other parameters affect the energy consumption. For example, low quality of glass windows or air-conditioning system inside the buildings will affect the energy consumption from HVAC system become high due to the load through the buildings is high and the efficiency of air-conditioning system is not enough in order to adjust the temperature inside the buildings. In case of Thailand, many buildings either designated buildings and other buildings still faced this problems and always solved the problems case-by-case due to the budget allocation and no expertise to control the energy management in that building.

In this study, the database from the report submission to DEDE of designated buildings is also include the time of completion of the construction of the building. However, from the survey by the author, it was found that the data of building age cannot reflect the proportion of energy consumption of each building due to many parameters, e.g. wrong data, installation of machines or system that not match to the load of the buildings, systems inside the buildings are lower / much higher specification than the specification in the report, etc.

Figure 4-7 illustrated the time of completion in each building types in national scale, it is found that office buildings, hospitals, and educational institutes have the highest proportions from the buildings which completed the construction during 1995-1999. For the hotel, more than 57% are the hotels that already constructed for 14-23 years (as of 2013). However, for the department stores, the stores which completed the construction after 2005 shares the highest proportion from the total number of department stores in Thailand and old stores which constructed more than 25 years (as of 2013) accounted for 20% from the total Department stores in whole country.

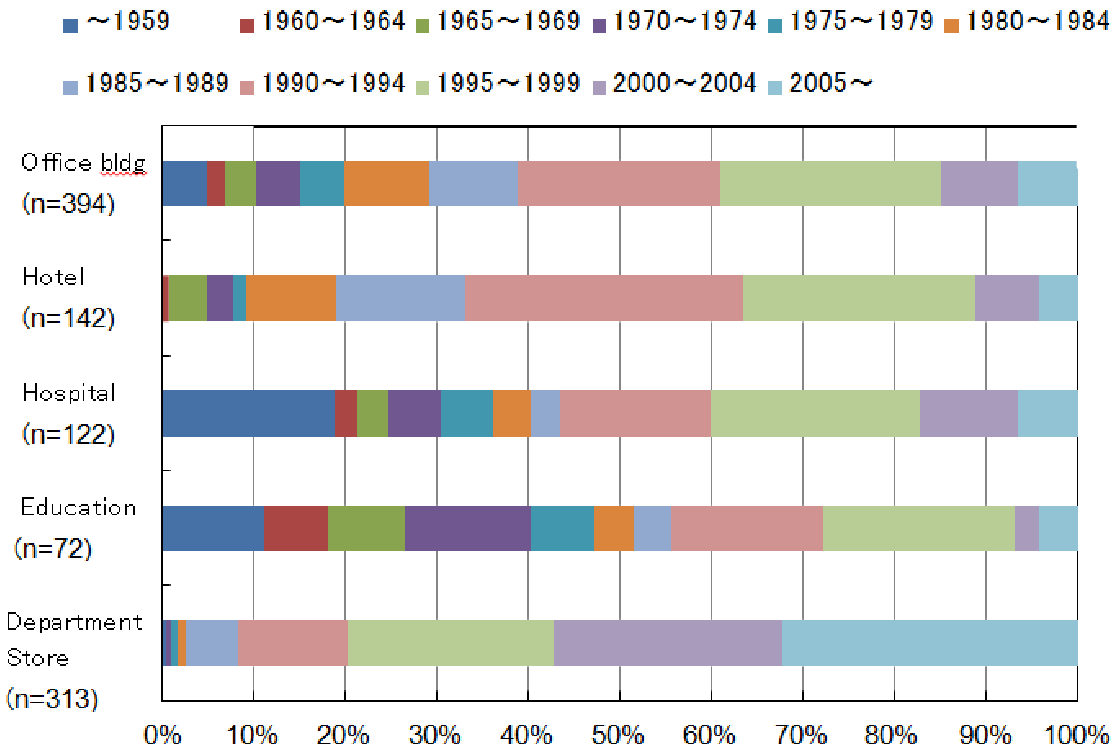

Figure 4-7 Time of completion of each designated building in Bangkok

Considering time of completion of the construction in Bangkok for Office buildings, hospital, and hotel-time of completion of the construction around 1990-1994 plays the highest proportions in those 3 types of buildings which similar to situation of whole country. However, Educational Institutes which finished the construction during 1990-1994 plays the highest proportions in Bangkok from total number of educational institutes in Bangkok area. For the Department Stores, the stores which complete the construction during 2000-2004 are the highest proportion from total number of stores in Bangkok. Figure 4-8 illustrated the time of completion of the construction of each designated building type in Bangkok area.

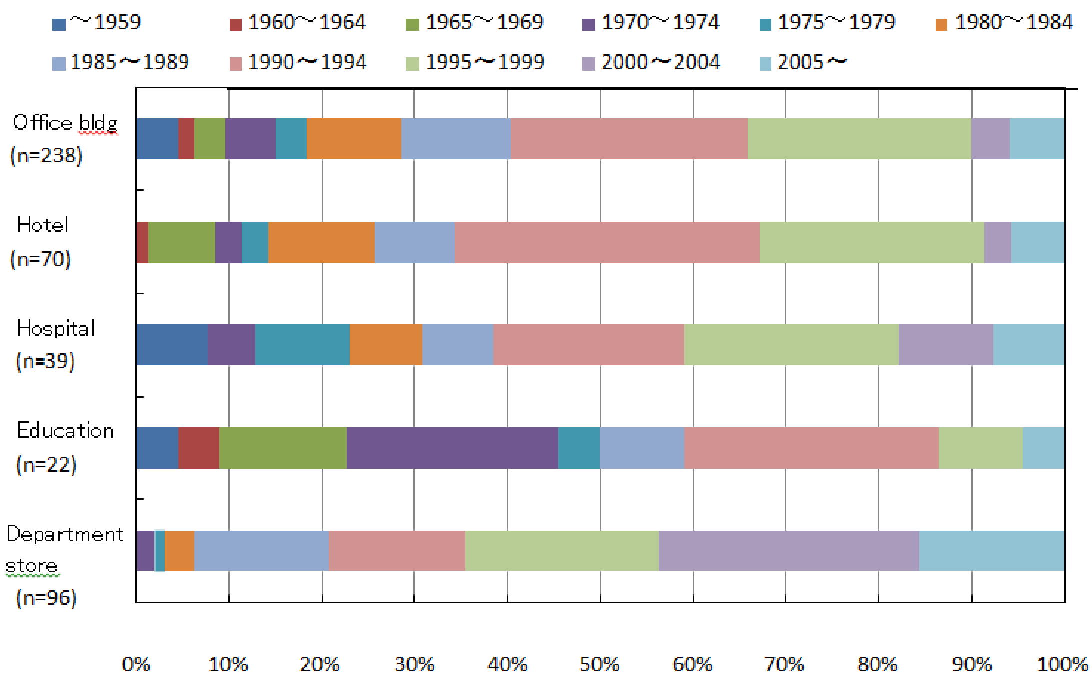

Figure 4-8 Time of completion of each designated building type in Bangkok

4-2-4 PROPORTION OF HVAC AREA

As mentioned earlier, according to the Thailand's climate consequence to the utilization of air-conditioning system is very essential in most buildings. Figure 4-9 shows the statistical data of monthly average temperature in Central region during year 2009 – 2011. Average temperature is about 30°C, whereas the maximum value is increase up to 38.2°C. The effect of temperature becomes serious problems that every building need to provide the cooling inside the building which affect to increase the load from the cooling system.

In each building type, the average HVAC area is accounted for 60% of total area from all of designated buildings. Most of building types utilized HVAC area more than 50%. Especially, HVAC area in department stores is about 85% from total area of the stores. For the hotel, HVAC area is about 70% from all total area of the hotels. However, in case of educational institutes, HVAC area is only about 40% from the total area of the buildings due to the utilization of fan instead of air-conditioning system in order to reduce the expense from the electricity charge. Figure 4-9 shows the proportion of HVAC area and Non-HVAC area for all building types in Thailand.

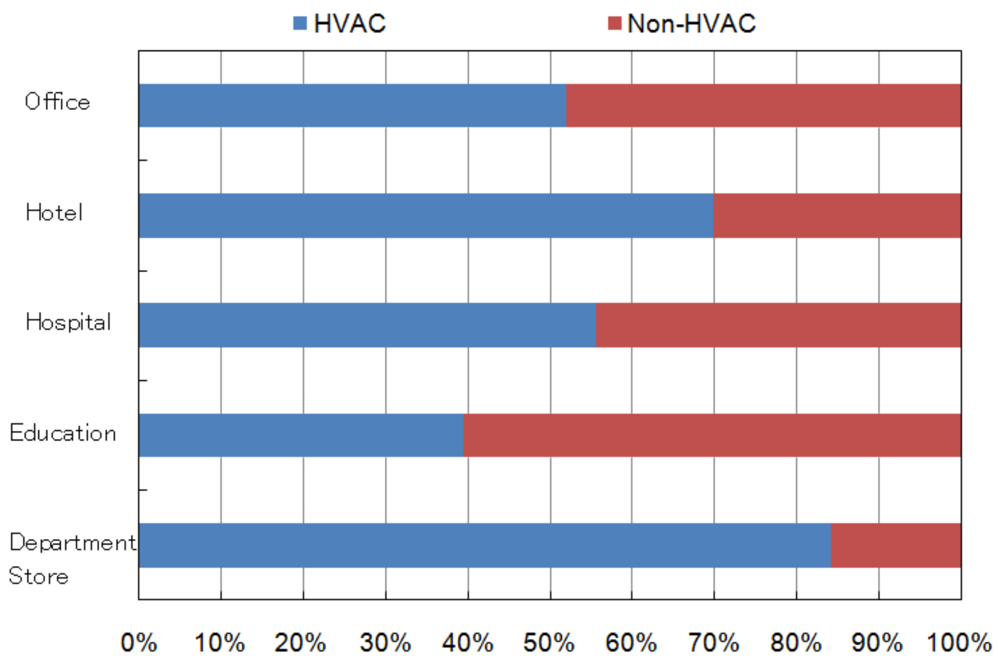

Figure 4-9 Proportion of HVAC area and Non-HVAC area for designated buildings

4-2-5 UTILIZATION OF ENERGY IN BUILDING'S SYSTEMS

Energy consumption in buildings usually from several systems either direct or indirect way, e.g. the heat transfer from lighting system will affect by increasing the cooling load from air-conditioning system of the buildings, the efficiencies of the equipment inside the buildings are also the key parameters affect the performance of the energy consumption in the building. Therefore, the energy conservation regulations, the promotion of renewable energy, and others programs were launched by the government in order to strengthen the energy efficiency of the buildings.

Generally, many building systems utilized the energy consumption, e.g. the air-conditioning system, lighting system, equipment system, steam generation system, refrigeration system, etc. The performance, capacity, and efficiency in each building are different according to the characteristics of buildings, location, systems maintenance, etc.

In this study, the systems that utilized the energy consumption for the buildings are divided into 3 major systems – Air conditioning system, lighting system, and other systems (including equipment and other systems) in order to see the characteristics of energy utilization between each building type as illustrated in Figure4-10.

It is found that, air-conditioning system is accounted about 37.1% from the total energy consumption in the buildings. Lighting system and other systems are accounted for 19.95% and 42.14%, respectively from the total energy consumption.

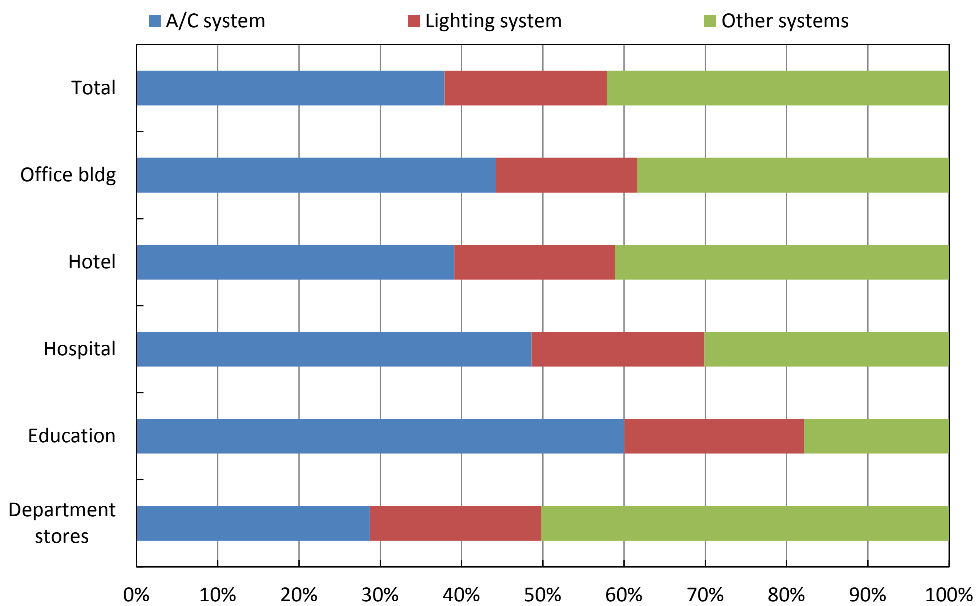

Figure 4-10 Proportion of energy consumption separated by system in designated buildings in Thailand

For Thailand's office buildings, air-conditioning systems is the highest proportion among three systems which accounted for 44.3%, followed by other systems and lighting system about 38.4%, and 17.3%, respectively. Air-conditioning system and other systems in hotels consumed energy consumption nearly the same proportion, about 39-41% and lighting system consumed energy about 20% from total energy consumption. Educational institutes consumed energy from air-conditioning system as the highest proportion, which accounted for 60%, followed by lighting system and other systems about 22.1%, and 17.9%, respectively. Due to the 24-hour operating period, the energy consumption in hospitals mainly from air-conditioning system which accounted for 48% from total consumption, followed by other systems and lighting system about 30.1%, and 21.3%, respectively. For the energy consumption of the department stores, even though the HVAC is large comparing with other building types but the efficiencies and performance of air-conditioning systems still need to maintenance carefully for the commercial purpose. Also with the limited time for closing, normally around 9-10 p.m., the proportion of energy consumption for air-conditioning system is about 28.7%, lighting system and other systems (including equipment) consumed energy about 21.12% and 50.2%, respectively from the total energy consumption of the stores.

4-2-6 ENERGY SUPPLY OF THE BUILDINGS

The utilization of energy for the buildings came from the energy supply by several sources. Mostly from the utility grid but also the other energy supply or fuel sources still need to provide in order to drive the systems in the buildings. Figure 4-11 shows the combination of fuel sources which utilized in each building type. For the office buildings, around 62% of total number of buildings use electricity from the utility grid as the main energy supply only, followed by the buildings used electricity and petroleum together as the energy supply which accounted for 35% of total number of office buildings. The rests are using the mix used between electricity and gas and also petroleum. For the hotels, around 52% of total number of hotels in Thailand using mixed fuel supply between electricity, gas, and petroleum as the energy supply in order to provide the energy for the building systems as different functions. Only 15% of the total number of hotels in Thailand using electricity only as the supply energy source. Similar situation for the hospital, around 45% and 40% of the total number of hospitals in Thailand using mixed fuel supply between electricity & gas & petroleum and mixed fuel between electricity & petroleum, respectively, as the energy supply in order to provide the energy for the building systems as different functions. In Department Stores, around 52% of the total number of stores using electricity only as the energy supply, followed by the combination between mixed fuel supply between electricity & petroleum and mixed fuel between electricity & gas & petroleum about 27% and 18%, respectively.

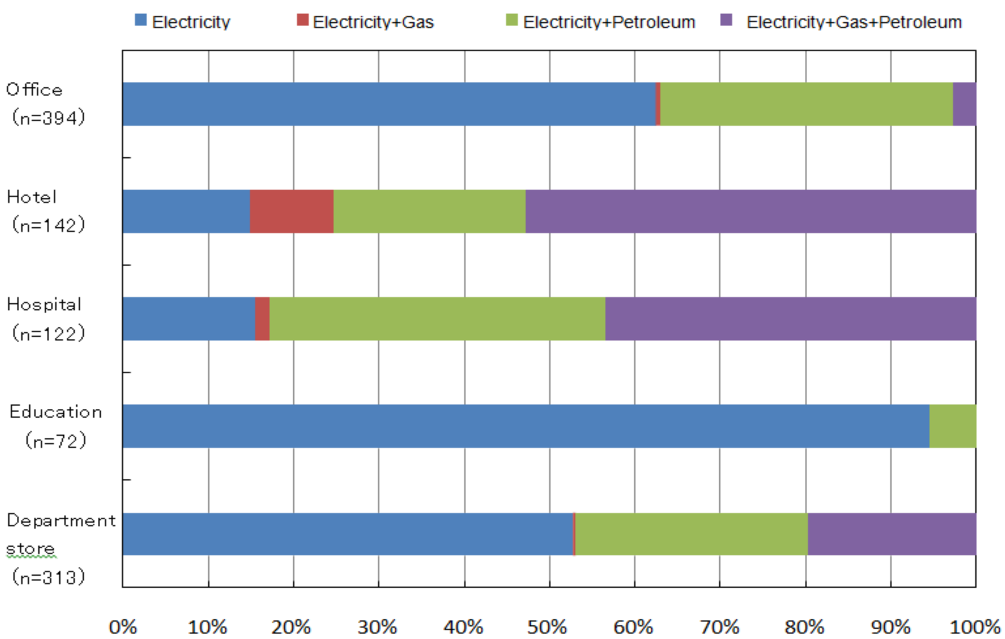

Figure 4-11 Proportion of energy supply sources separated by system in designated buildings in Thailand

However, for the educational institute, almost 95% of total number of educational institutes use only electricity for supply the energy in order to utilize the systems in the buildings. There are very few educational institutes using mixed fuel between gas and others as the energy supply.

Considering the secondary energy data, the utilization energy in every type of buildings in Thailand mostly used electricity as the major energy for every systems in the buildings which accounted for 94% of the total number of buildings. However, in hotels and hospitals and some portion in department stores still used oil and gas for specific purposed or drive the special machine, e.g. for the hygienic purpose. Figure 4-12 shows the type of energy consumptions separated by building types in Thailand.

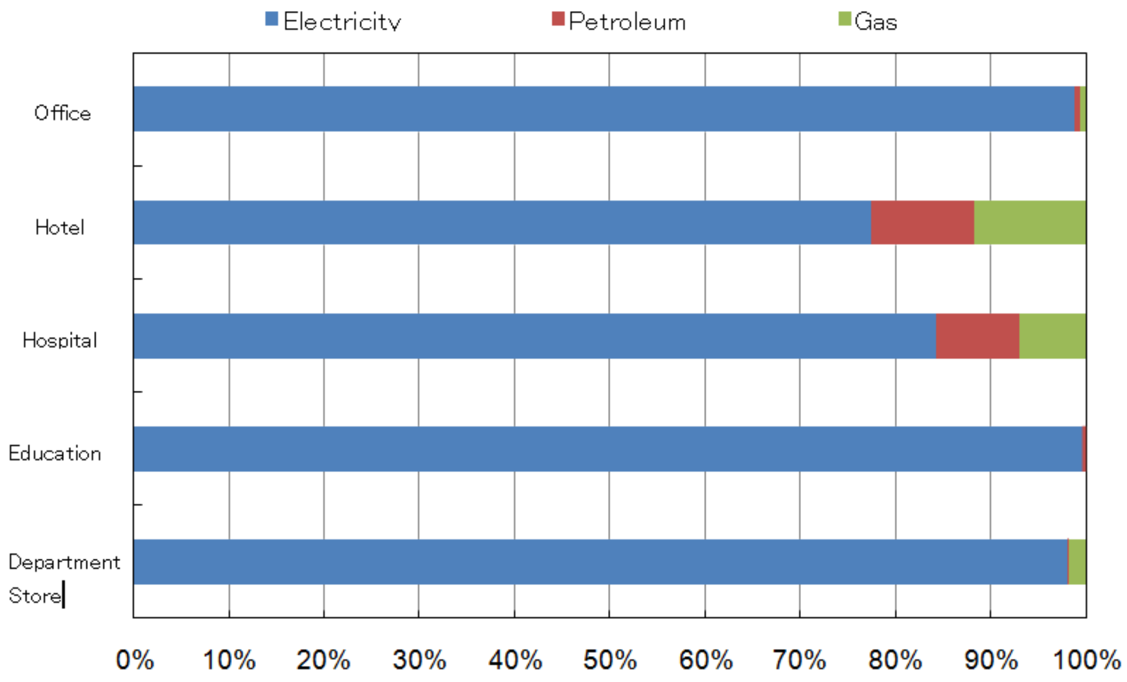

Figure 4-12 Secondary energy consumption in each building type

4-2-7 PRIMARY ENERGY CONSUMPTION PER UNIT

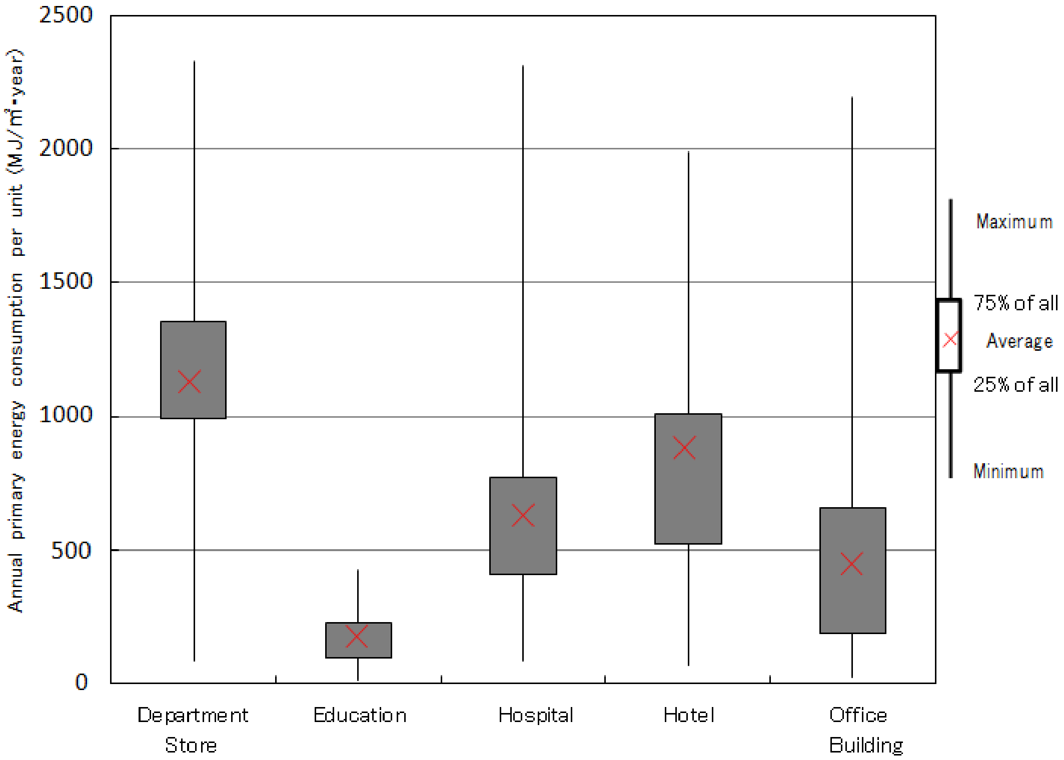

Figure 4-2-7 Primary Energy consumption per unit of each designated building type

Due to the utilization of equipment, machine, and several functions in Department stores, this building type consumed the highest primary energy comparing with other building types about 88.7 – 1351.2 MJ/m²-years even though the average opening time of the Department stores in Thailand is about 12-16 hrs per day. The analysis results shown that working hours of each buildings is one of key parameters that affect energy consumption. For example, in case of hotels, more than 95% for hotels in Thailand operated 24 hrs every day, which affect the operation of every buildings' systems especially air-conditioning systems and lighting systems all the time. The results of primary energy consumption per unit showed that Hotels in Thailand consumed primary energy about 66.3 – 1006.5 MJ/m²-years. Similar to the characteristics of energy used for hospitals, more than 70% of Thailand's hospitals operated 24 hours. The primary energy consumption in hospitals is about 83.4 – 772.9 MJ/m²-years.

The average working hours for office buildings and educational institutes is about 8-12 hours but the utilization of equipment and air-conditioning systems in office buildings is very high compared with other building types, which affect to high energy consumption for this building type. Thailand's office buildings consumed primary energy about 22.1 – 658.1 MJ/m²-years. But for educational institutes, most of the energy always utilized for air-conditioning systems during the operating period only as illustrated in Figure 4-10, the primary energy consumption for this building type become the lowest comparing with other building types, which accounted for 15.9 – 226.9 MJ/m²-years. Figure 4-13 shows the distribution data of primary consumption for each building types in Thailand.

4-2-8 TENDENCY & CHANGE OF PRIMARY ENERGY CONSUMPTION OF DESIGNATED BUILDINGS IN 2011

The primary energy consumption per unit is one of index that can reflect the characteristic of energy use of each building type under the circumstances of economic situation, fuel prices, etc. of the country. It is found that the average value of primary energy consumption per unit for all designated building types is not significant changed from that of year 2010 even though the Thailand's EEDP was implemented already.

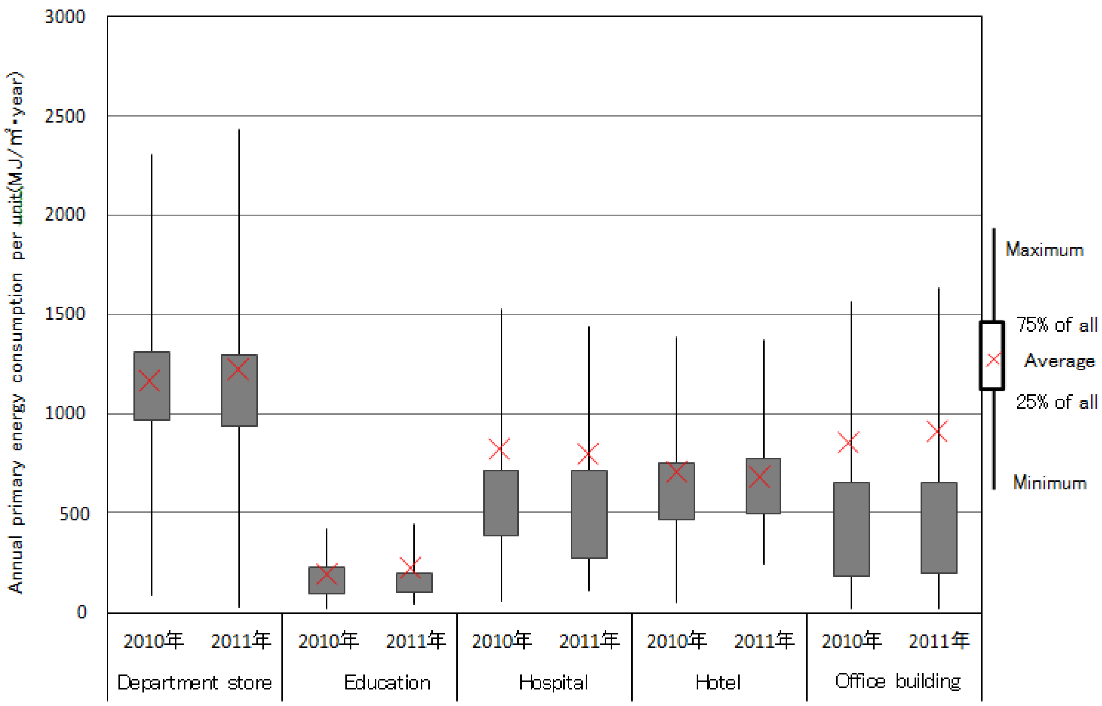

Figure 4-14 Primary energy consumption comparison between year 2010 and 2011 in each designated building type in Thailand

The analysis results shown that the average primary consumption of office buildings in year 2011 is about 824.1 MJ/m²-years which increased from previous year about 3.8%. In case of Department stores, the average primary consumption in year 2011 is about 1230.4 MJ/m²-year, increased from year 2010 about 2.9%. The primary energy consumption in

Educational institutes in year 2011 consumed about 242.6 MJ/m²-year, accounted for 10.5% increased from that of year 2010.

However, the consumption of primary energy in hospitals and hotels are slightly decreased from that of year 2010. For hospital, the primary energy consumption in year 2011 is about 771.7 MJ/m²-year, which decreased from that of year 2010 about 2.2%. For the primary energy consumption from hotels in year 2011, it was found that the consumption in 2011 decreased from that of year 2010 about 1.5%.

From all of above supported reason, two-case studies were analyzed in order to study the potential of developing the utilization of energy of commercial buildings - Office buildings and hotels. Finally, the implementation of distributed energy resources or decentralization of energy supply can be one of effective method in order to reduce the primary energy consumption of commercial buildings in Thailand by using parallel with the implementation of the regulation for energy conservation of commercial buildings according to Thailand's EEDP, Energy conservation Act, and Building Energy Code (BEC) together in order to strengthen the energy security of the country in near future.

4-3 ANALYSIS OF ENERGY USED IN OFFICE BUILDINGS

The Energy Conservation Promotion Act (ECP Act) of Thailand was promulgated in 1992. The Ministerial Regulations detailing the requirements in accordance with BEC for large commercial buildings, and a fund created to support energy conservation activities (ENCON Fund) became operational in 1995[7]. However, the energy conservation effort for commercial buildings in Thailand has been considered to have achieved limited success.

As mentioned in previous sections, Thailand's ECP Act was applied to designated buildings only which categorized Thailand's office buildings from physical characteristics into 4 groups as follows:

1) The buildings with total floor area less than 10,000 m^2 and height of building less than 23 m. (not high-rise building) are categorized as "building category (A)"
2) The buildings with total floor area between 2,000 m^2 < Area < 10000 m^2 and height of buildings $\geq$ 23 m., also can defined as "large and high-rise buildings" are categorized as "designated building category (B)"
3) The buildings with total floor area $\geq$ 10000 m^2 and height of buildings < 23 m., also can defined as "very large and not high-rise buildings" are categorized as "designated building category (C)"
4) The buildings with total floor area $\geq$ 10000 m^2 and height of buildings $\geq$ 23 m., also can defined as "very large and high-rise buildings" are categorized as "designated building category (D)"

However, from the record data of submitted report from designated buildings to DEDE didn't included the information of building height, therefore, the definition of designated office buildings in this study would like to change the categories of office buildings from that of Thailand ECP Act's definition from 4 to 3 categories as follows:

1) The buildings with total floor area less than 10,000 m^2 are categorized as "designated building category (A.1)"
2) The buildings with total floor area between 2,000 m^2 < Area < 10000 m^2, also can defined as "large buildings" are categorized as "designated building category (B.1)"
3) The buildings with total floor area $\geq$ 10000 m^2, also can defined as "very large buildings" are categorized as "designated building category (C.1)"

From the database of DEDE reported as described in section 4.2, after filtered the building database that can be used for analysis found that the no. of designated office buildings in 2010 and 2011 in "building category (C.1)" shared the greatest proportion among three categories. Table 4-7 summarizes the number of effective designated office buildings which categorized by physical characteristics of buildings.

Table 4-7 Number of designated office buildings in year 2010 and 2011 in Thailand

Type	Number
Designated building category (A.1) – floor area < 2,000 m^2	1
Designated building category (B.1) - 2,000 m^2 < floor area < 10,000 m^2	56
Designated building category (C.1) – floor area $\geq$ 10,000 m^2	304
Total	361

It is found that the designated office buildings with floor area less than 2,000 sq.m. accounted for the lowest share from total number of total designated office buildings about 0.3% and the designated buildings with floor area more than 10,000 sq.m. shared the highest proportion about 84.2% from the total designated office buildings in Thailand. Therefore, the study of the development of energy utilization for office buildings in this study will focus more for designated buildings in category (C.1).

4-3-1 BENCHMARKING ENERGY USE IN OFFICE BUILDING [10]

In order to benchmarking the energy use for office building, the annual energy consumption of designated office buildings in Thailand from database of year 2010 will be used for the analysis in order to know the characteristics of energy consumption in each building categories and indexing the energy use of Thailand's office buildings as the following:

Table 4-8 Annual energy use for Thailand's designated office buildings in year 2010 which categorized from Building's Physical characteristics

Type	Maximum energy used (GWh/yr/bldg.)	Minimum energy used (GWh/yr/bldg.)	Average energy used (GWh/yr/bldg.)	Number
Designated building category (A.1) – floor area < 2,000 m^2	0.24	0.24	0.24	1
Designated building category (B.1) - 2,000 m^2 < floor area < 10,000 m^2	2.66	0.05	0.85	56
Designated building category (C.1) – floor area $\geq$ 10,000 m^2	67.9	0.19	5.5	304

From the cooperation between Thailand's Department of Alternative Energy Development and Efficiency (DEDE), Educational Institutes, and Energy expertise, the implementation of Energy use index for industrial and commercial sectors was done by using "SEC" number as the standard energy index for each designated building types which also developed according to building energy code that described in Chapter 3.

The Energy use index of reference building and standard building from Energy Conservation Act B.E. 2551 was defined in Table 4-9. The building owner should retrofitted the buildings which have the energy use index higher than that of reference buildings. Furthermore, for the designated buildings which have the total floor area more than 2,000 m2 have to perform the energy regulation according to Energy Conservation Act B.E. 2551 in all items, e.g. OTTV, RTTV, A/C system, Lighting system, etc. or overall building performance have to pass the standard from Building energy code.

Table 4-9 Standard of energy use index for each building type

Building type	Reference building (kWh/m^2-year)	Standard building from EnCon ACT (kWh/m^2-year)
Office building	146.4	98.7
Hotel	173.2	117.0
Hospital	148.8	123.9
Department Store	556.0	394.3
Educational Institute	94.0	79.3
Wholesale and retail stores	394.7	300.9
Others	139.7	117.2

Energy use Index for office buildings [15] can be categorized into 3 categories in this research as follows:

1. Total Energy Use Index (SEC_{TOTAL}): can be calculated from the summation of total energy consumption of 12 months in each building per total floor area of building, which can defined as the following equation:

$$\mathrm{SEC}_{TOTAL} = \frac{Total\ annual\ energy\ used\ (kWh_{TOTAL}/year)}{\%\ Occupancy \times Total\ floor\ area\ (m^2)}$$

2. Air-conditioning energy use index ($SEC_{A/C}$): calculated from the annual energy consumption of air-conditioning system of the building from the measurement at the period of time divided the HVAC area of the building, as illustrated in the following equation:

$$\mathrm{SEC}_{A/C} = \frac{Annual\ energy\ used\ in\ A/C\ system\ \left(kWh_{A/C}/year\right)}{\%\ Occupancy \times Total\ HVAC\ area\ (m^2)}$$

3. Lighting energy use index (SEC_{LI}): calculated from the annual energy consumption of Lighting system of the building from the measurement at the period of time divided the total area of the building (excluding parking area), as illustrated in the following equation:

$$\mathrm{SEC}_{LI} = \frac{Annual\ energy\ used\ in\ Lighting\ system\ (kWh_{LI}/year)}{\%\ Occupancy \times Total\ floor\ area\ (m^2)}$$

The analysis of Energy use index for all three indexes has been performed according to the value of energy consumption per unit area. However, not only the building's floor area can be represented as the indicator for energy consumption of that building. In this research, the other parameters also performed in the analysis in order to strengthen the accuracy of the calculation of SEC values for define the energy performance of the building as follows:

a) The ownership of the building: This parameter effects the decision making of the budget allocation for retrofitting the buildings to improve the energy performance of the buildings in several way – ownership by Private sector and Government.
b) Location of the building: The location of the buildings influence the characteristics of the design and energy pattern of the buildings according to the different climate and economic concern, e.g. buildings in tourism area and industrial area have different energy pattern. – Separated into Bangkok region, Central region (Non-Bangkok), East region, North Region, Northeast Region, South Region, and West Region.

4-3-2 ANALYSIS OF ENERGY USE INDEX OF OFFICE BUILDINGS – GOVERNMENT OWNERSHIP

Figure 4-15 shows the distribution of SEC_{TOTAL} values for all designated office buildings in Thailand which belong to government. It is found that about 22.5% of designated office buildings in Thailand cannot pass the criteria of the standard total energy use index (SEC_{TOTAL}) of the reference building. Furthermore, almost 40% of total designated office building in Thailand cannot pass the standard of total energy use index (SEC_{TOTAL}) from the values defined by EnCon Act. Figure 4-16 and 4-17 show the distribution of $SEC_{A/C}$ and SEC_{LI} for all designated office buildings in Thailand which belong to government. However, the standard of energy use index for air-conditioning and lighting already changed according to Thailand Building Energy Code by using the efficiency of the equipment instead.

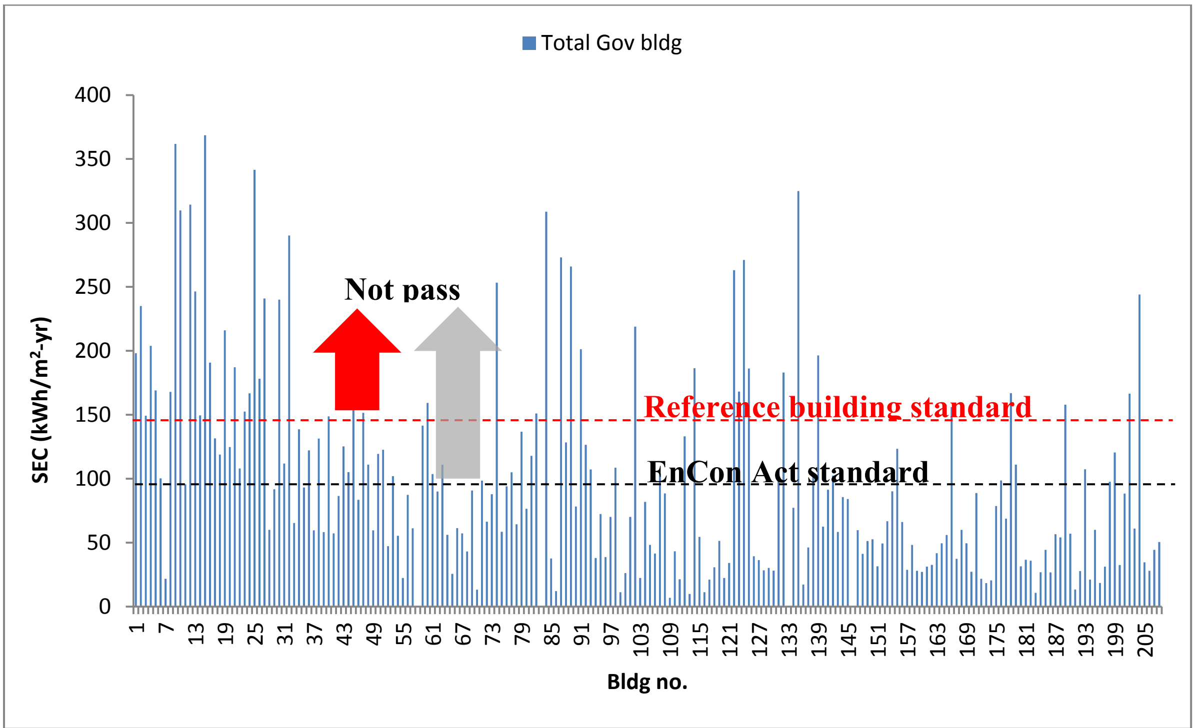

Figure 4-15 SEC_{TOTAL} values of designated office buildings in Thailand

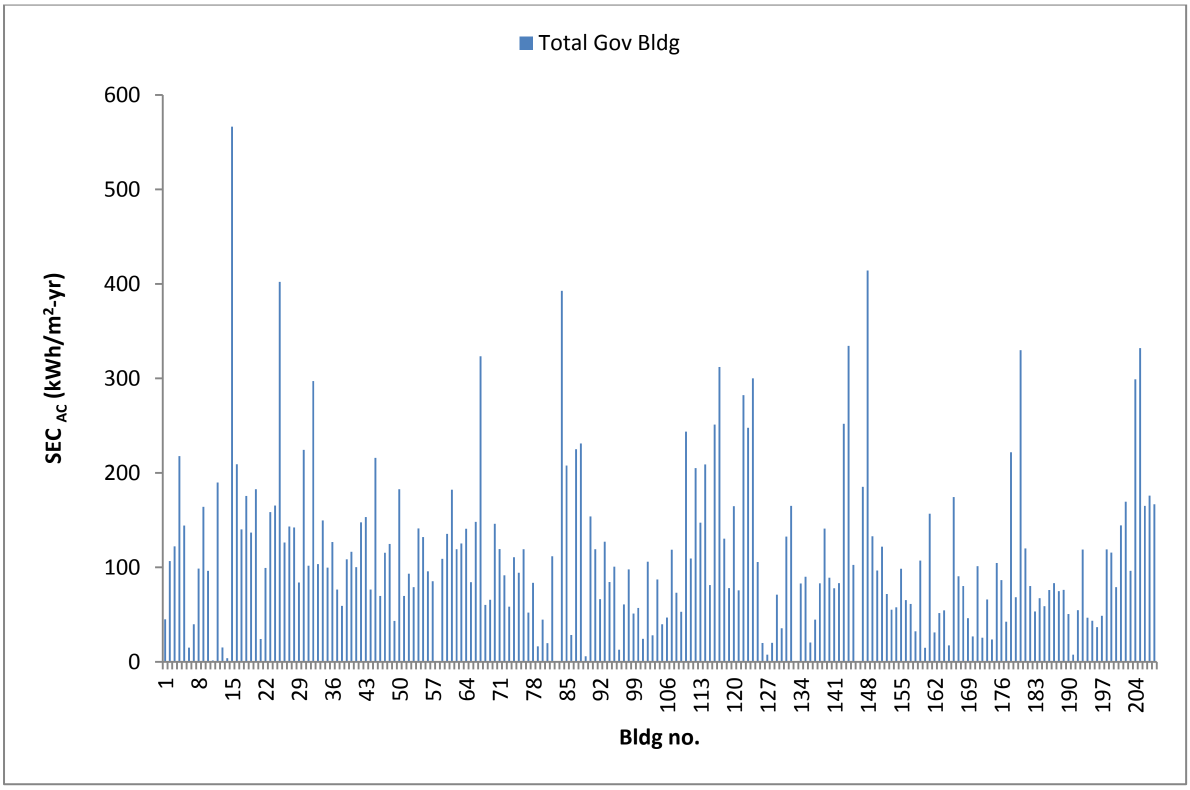

Figure 4-16 $SEC_{A/C}$ values of designated office buildings in Thailand-Government as ownership

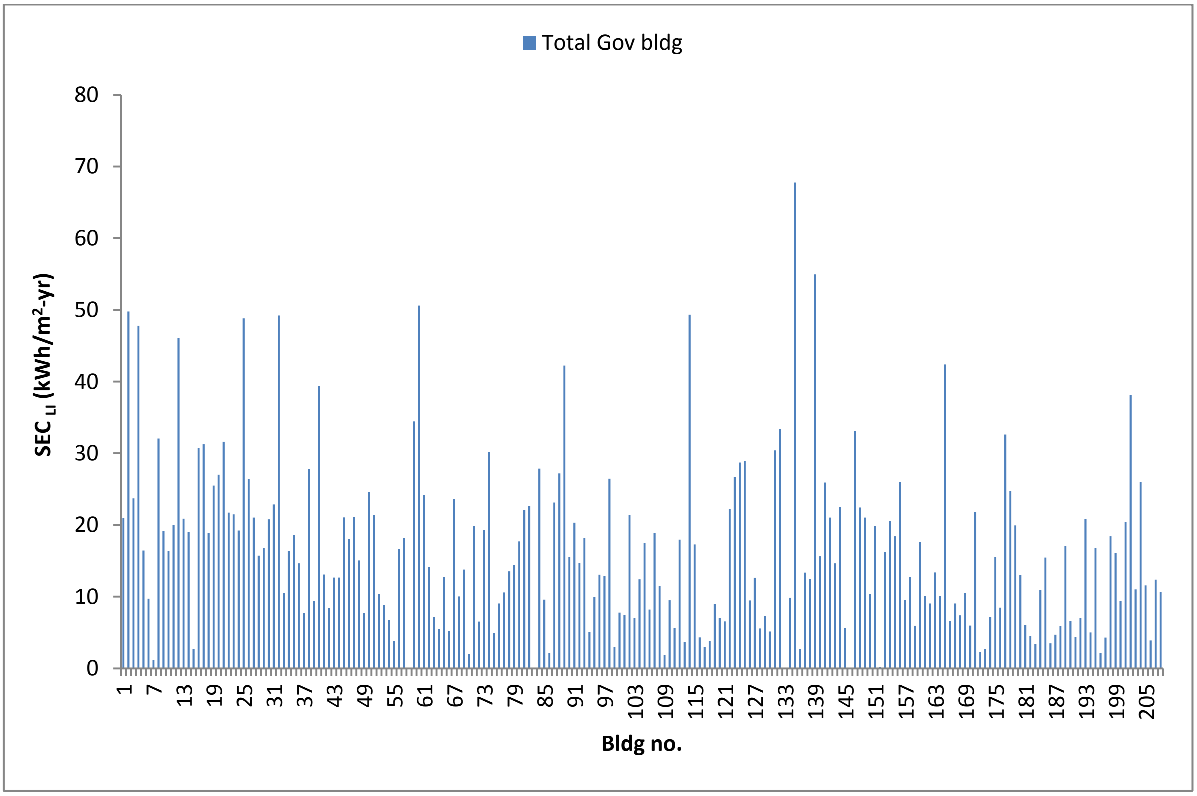

Figure 4-17 SEC_{LI} values of designated office buildings in Thailand – Government as ownership

It is found that the average value of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of designated office buildings which belong to government are 100.65, 173.04, and 16.97, respectively. From the consideration of the location of these office buildings, the energy use indexes for office buildings in Bangkok are not pass both standards. But the energy use indexes for office buildings in other regions except Bangkok pass the standard for both reference buildings and EnCon Act standard. Table 4-10 shows the value of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of designated office buildings in every region which belong to government.

Table 4-10 Values of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of designated office buildings in every region which belong to government.

Region	Number	SEC	SEC_{AC}	SEC_{LI}
Central - BKK	82	132.46	164.02	19.61
Central - NonBKK	48	97.69	139.91	15.66
E	21	88.44	500.12	21.59
N	10	55.87	72.10	13.74
NE	31	56.84	78.90	11.37
S	11	73.14	92.59	14.78
W	5	80.28	227.79	12.90

4-3-3 ANALYSIS OF ENERGY USE INDEX OF OFFICE BUILDINGS – PRIVATE SECTOR OWNERSHIP

Figure 4-18 shows the distribution of SEC_{TOTAL} values for all designated office buildings in Thailand which belong to private sector. It is found that among these buildings about 68% of designated office buildings in Thailand cannot pass the criteria of the standard total energy use index (SEC_{TOTAL}) of the reference building. Furthermore, almost 80% of total designated office building in Thailand cannot pass the standard of total energy use index (SEC_{TOTAL}) from the values defined by EnCon Act. Figure 4-19 and 4-20 show the distribution of $SEC_{A/C}$ and SEC_{LI} for all designated office buildings in Thailand which belong to government.

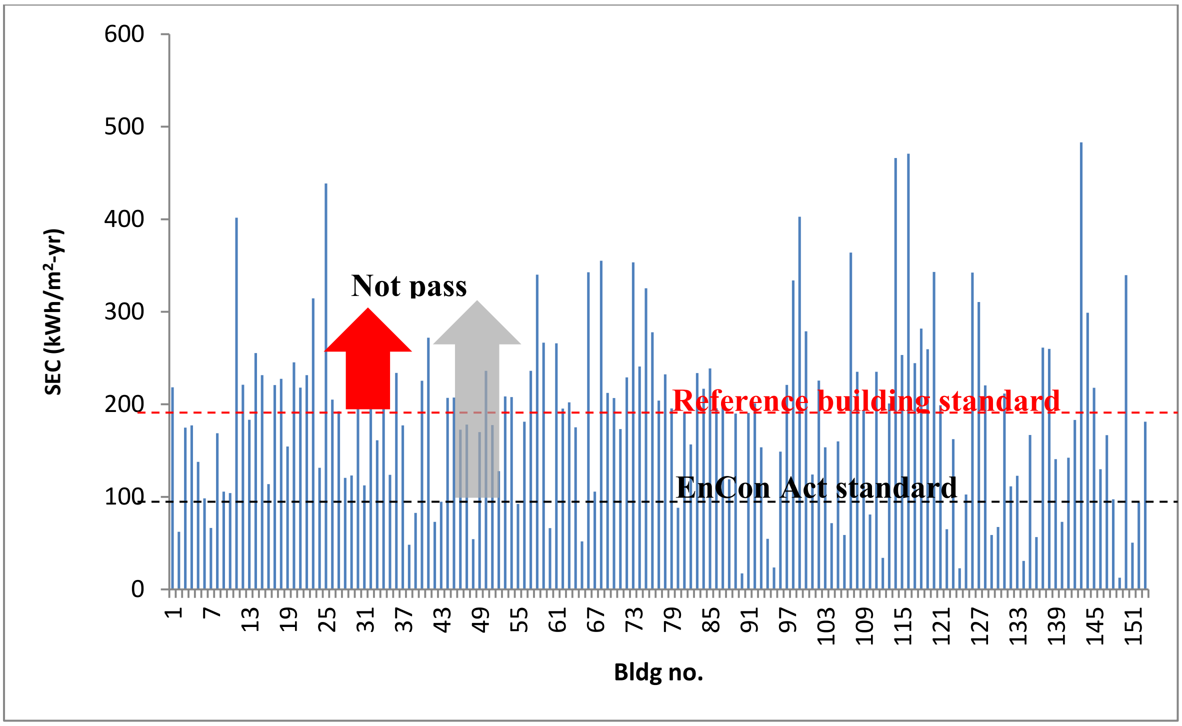

Figure 4-18 SEC_{TOTAL} values of designated office buildings in Thailand – Private sector as ownership

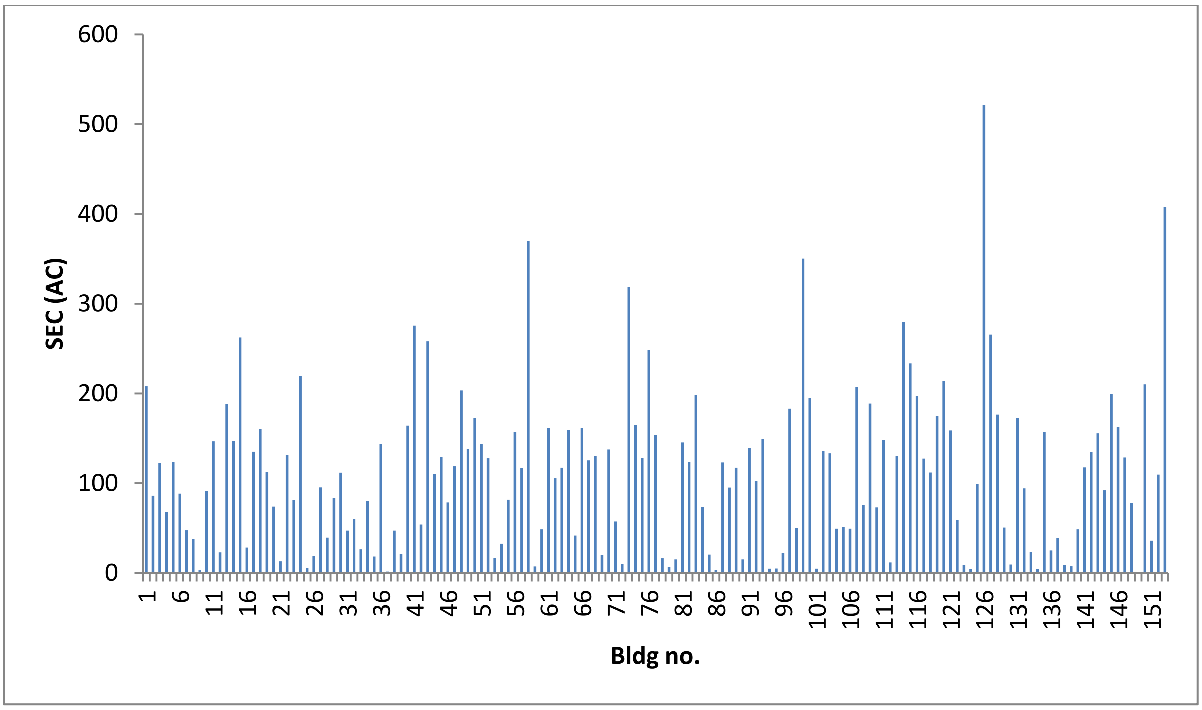

Figure 4-19 $SEC_{A/C}$ values of designated office buildings in Thailand- Private sector as ownership

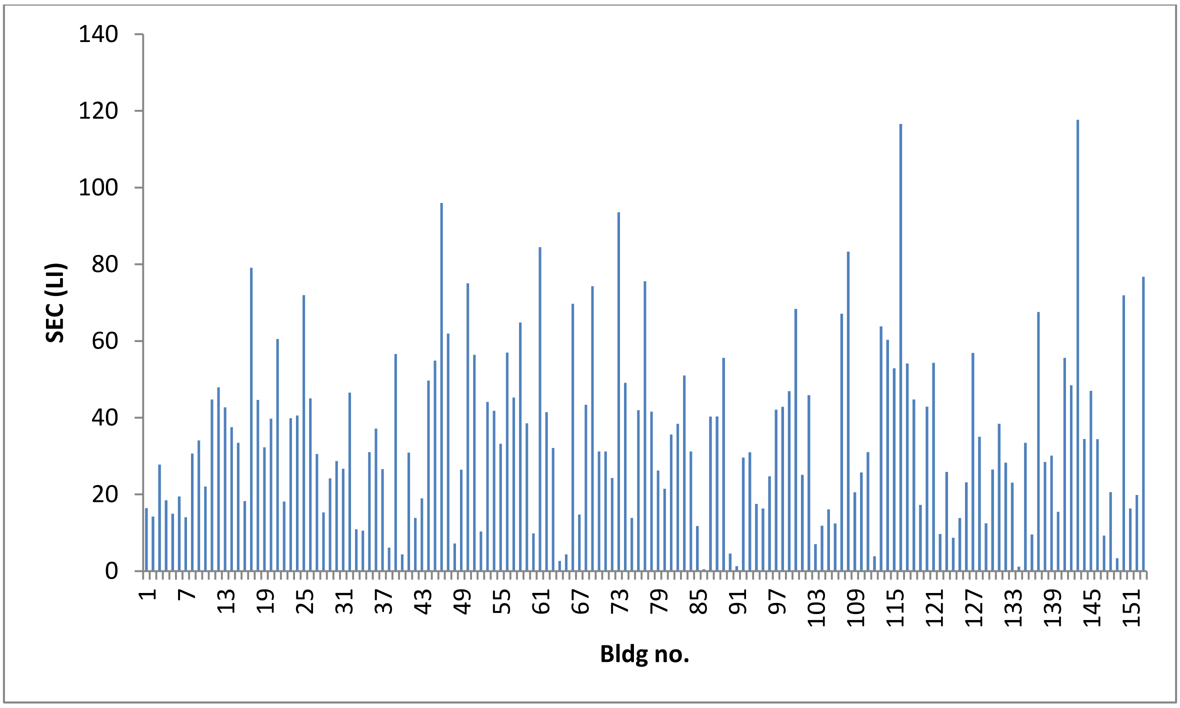

Figure 4-17 SEC_{LI} values of designated office buildings in Thailand – Private sector as ownership

It is found that the average value of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of designated office buildings which belong to government are 189.4, 110.9, and 35.6, respectively. From the consideration of the location of these office buildings, the energy use indexes for office buildings in Bangkok are not pass both standards. But the energy use indexes for office buildings in other regions except Bangkok pass the standard for both reference buildings and EnCon Act standard. Table 4-11 shows the value of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of designated office buildings in every region which belong to government.

Table 4-11 Values of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of designated office buildings in every region which belong to government.

Region	Number	SEC	SEC_{AC}	SEC_{LI}
Central - BKK	133	192.39	111.57	35.38
Central - NonBKK	12	192.85	82.48	40.74
E	6	132.76	102.79	25.97
N	1	93.80	109.59	19.86
NE	0	0	0	0
S	0	0	0	0
W	133	192.39	111.57	35.38

In summary, the energy use index for office buildings in Thailand is lower than standard from the reference buildings by 5% but higher than the standard from Energy Conservation Act by 40% in the national point of view. However, according to the ownership of the designated office buildings, the average energy use index from the buildings belong to the government is lower than standard from the reference buildings by 31% but higher than the standard from Energy Conservation Act by 2% only. But in case of the ownership of the designated office buildings by private sector, the average energy use index from the buildings belong to the private sector is higher than standard from the reference buildings by 29% and also too much higher than the standard from Energy Conservation Act by 91%. These means the office buildings in Thailand still need to considered for the energy audit and conservation methods carefully in very near future in order to follow the Thailand's 20-year EEDP Plan.

4-4 ANALYSIS OF ENERGY USE IN HOTEL

The lodging industry is one of high-energy usage buildings among the commercial buildings due to the "24/7" nature of hotels – (operating 24 hours, 7 days), the variety of services they provide and the transient and often wasteful energy-use habits of guests, etc – these factors consequence to high energy consumption which need to be considered for energy improvement as one of the first priority.

It is found that the energy use and efficiency improvement opportunities for hotels are closely related to the geographical location and the nature of the operation within the facility. Climate is also one of major factor affect the energy consumption of the hotel, e.g. in Northern area, hotels can utilized the cooling system less than the hot zones by using outdoor environment factors together with air-conditioning system [16].

Table 4-12 General information of Thailand's Hotels and Guest houses in 2010 [16]

	Hotel Type	**No. of hotels**	**No. of rooms**	**No. of officers**
THAILAND	< 60 rooms	3495	93437	38203
	60-149 rooms	1034	91274	51304
	>150 rooms	441	118443	90924
	Total	5420	303154	180431
BKK	< 60 rooms	58	2169	777
	60-149 rooms	92	8740	3643
	>150 rooms	144	47677	29808
	Total	294	58586	34228
Central & East	< 60 rooms	58	2169	777
	60-149 rooms	92	8740	3643
	>150 rooms	144	47677	29808
	Total	294	58586	34228
North	< 60 rooms	864	18316	777
	60-149 rooms	167	14331	3643
	>150 rooms	47	11142	29808
	Total	1091	43789	34228
Northeast	< 60 rooms	930	17983	5863
	60-149 rooms	130	11772	6995
	>150 rooms	31	5818	4199
	Total	1091	35573	17057
South	< 60 rooms	1080	26801	13673
	60-149 rooms	309	26829	18206
	>150 rooms	101	24404	27289
	Total	1490	78034	59168

Nowadays, many projects were implemented from government and private sectors in order to stimulate the owners of hotels and lodging industry to considered for energy and environmental conservation e.g. the implementation of "green hotel" project, which aimed to reduce the amount of carbon-dioxide to the environment due to the high-energy consumption.

From the record of National Statistical Office of Thailand in 2010, the total number of registered hotels and guesthouse in Thailand is about 5420 hotels which divided into regions and categories as shown in Table 4-12. It is found that in Southern region of Thailand has highest number of hotels according to high number of traveling spots. However, in Bangkok has highest number of rooms per hotel comparing with other regions.

The main energy consumption activities in hotel are different from office buildings in some activities, e.g. space cooling / heating systems, lighting system, hot water, food preparation, hygienic systems, re-creation zones, and other energy consuming activities by guests. From the information of energy consumption by building types in Thailand as described earlier, space cooling and air-conditioning is the largest single end-user in the hotels- it is thus widely accepted that outdoor weather conditions and floor areas are among the main factors affecting energy use in hotels. The indoor temperature levels also greatly influence the quantity of energy consumed in a building.

Equipment (including domestic hot water) is commonly the second largest user, accounting for up to 40 per cent of the total energy demand. Lighting system energy consumption is accounted about 20 percent of a hotel's total energy consumption and can be fluctuate depending on the category of the establishment. Services such as catering and laundry also account for a considerable share of energy consumption, particularly considering that they are commonly the least energy-efficient.

From the survey of Thailand's hotel energy index of Arun Chai Seri Consltant [], Thailand's hotel can categorized the Energy Weighting factor by service types as illustrated in Figure 4-18. It is found that hotel room accounted for highest energy weighting factor comparing to other service types, followed by recreation zones, laundry service, conference room, dining room, and office zone about 21.93, 18.49, 7.25, 5.30, 3.91, and 0.79, respectively.

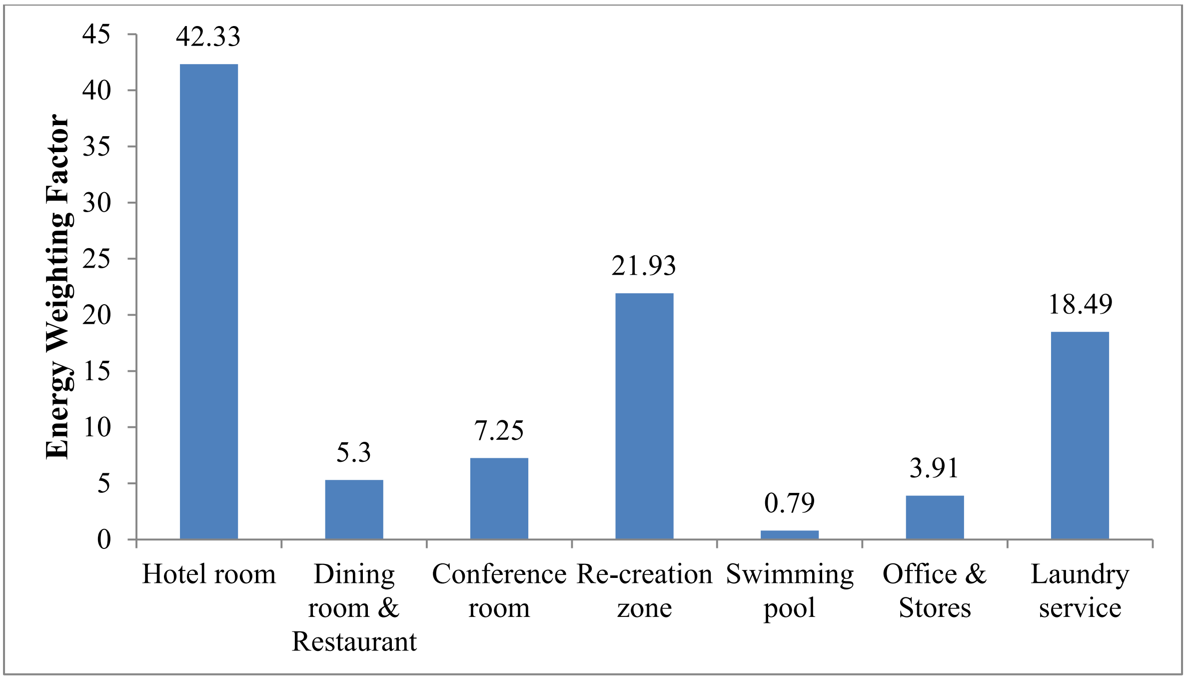

Figure 4-18 Average Energy Weighting Factor by service types for Thailand's Hotel [16]

4-4-1 BENCHMARKING ENERGY USE IN HOTEL

In order to categorized the type of hotel in Thailand, since the Hotel Act came into force in 2005, most small-sized hotels have encountered problems in applying for a hotel licence due to the criteria and conditions prescribed by the Building Control Act B.E. 2522 ("Building Control Act") which, in connection with the Hotel Act, dictates the regulations and laws on building structures, safety and environmental measures applying to hotels. 4 types of hotel can classified as follows [18]:

- Type 1: hotels providing accommodation only, the number of rooms does not exceed 50, the size of each room is not less than 8 square meters;

- Type 2: hotels providing accommodation and catering or restaurant services, the size of each room is not less than 8 square meters;

- Type 3: hotels providing accommodation, catering or restaurant services, the size of each room is not less than 14 square meters, and which has either conference rooms or entertainment venues which under the Place of Service Act B.E. 2509 could be a place for dancing, bars and nightclubs, spa;

- Type 4: hotels providing accommodation, catering or restaurant services, conference rooms and entertainment venues, the size of each room is not less than 14 square meters.

For Type 3 and 4 hotels, no entertainment venues will be allowed unless these hotels operate more than 80 rooms. However this restriction will be waived if the hotels are located in entertainment areas or if the entertainment venues are operated by a hotel which serves food, alcohol or entertainment only, and has opening hours after 12 p.m.

There is no requirement for categorized type of hotel due to area or building height same as office building. However, the energy use index standard have to enforced to use Energy Conservation Act B.E. 2551 and also Building Energy code as described in Table 4-9.

The calculations of Energy use index for hotel are similar to that of office buildings but the area for calculation have to use the area which can be used, which can be calculated for the area from below equation [16]:

$$\text{Area}_{net} = Total\ floor\ area - Unused\ area\ in\ hotel$$

Calculation of Energy Use Index (SEC_{TOTAL}), Air-conditioning energy use Index ($SEC_{A/C}$), and Lighting energy use Index (SEC_{LI}) for hotel are illustrated as follow:

$$\text{SEC}_{TOTAL} = \frac{Total\ annual\ energy\ used\ (kWh_{TOTAL}/year)}{\%\ Occupancy \times Area_{net}\ (m^2)}$$

$$\text{SEC}_{A/C} = \frac{Annual\ energy\ used\ in\ A/C\ system\ \left(kWh_{A/C}/year\right)}{\%\ Occupancy \times Total\ HVAC\ area\ (m^2)}$$

$$\text{SEC}_{LI} = \frac{Annual\ energy\ used\ in\ Lighting\ system\ (kWh_{LI}/year)}{\%\ Occupancy \times Area_{net}\ (m^2)}$$

However, the ownership of hotels in Thailand mostly belongs to private sector about 99%. In this study, the analysis of energy use index will perform without consideration the ownership as the parameters as done in office building. From total 128 hotels from the record data of DEDE, there are 6 hotels with total floor area less than 10000 sq.m. (accounted for 4.7% of total hotel in record data), 94 hotels with total floor area between 10000 – 50000 sq.m. (which accounted for 73.4% of total hotel in record data), and 27 hotels with floor area more than 50000 sq.m. which accounted for 21.1% of total hotel in record data. Figure 4-19 shows the distribution of SEC_{TOTAL} values for hotels in Thailand.

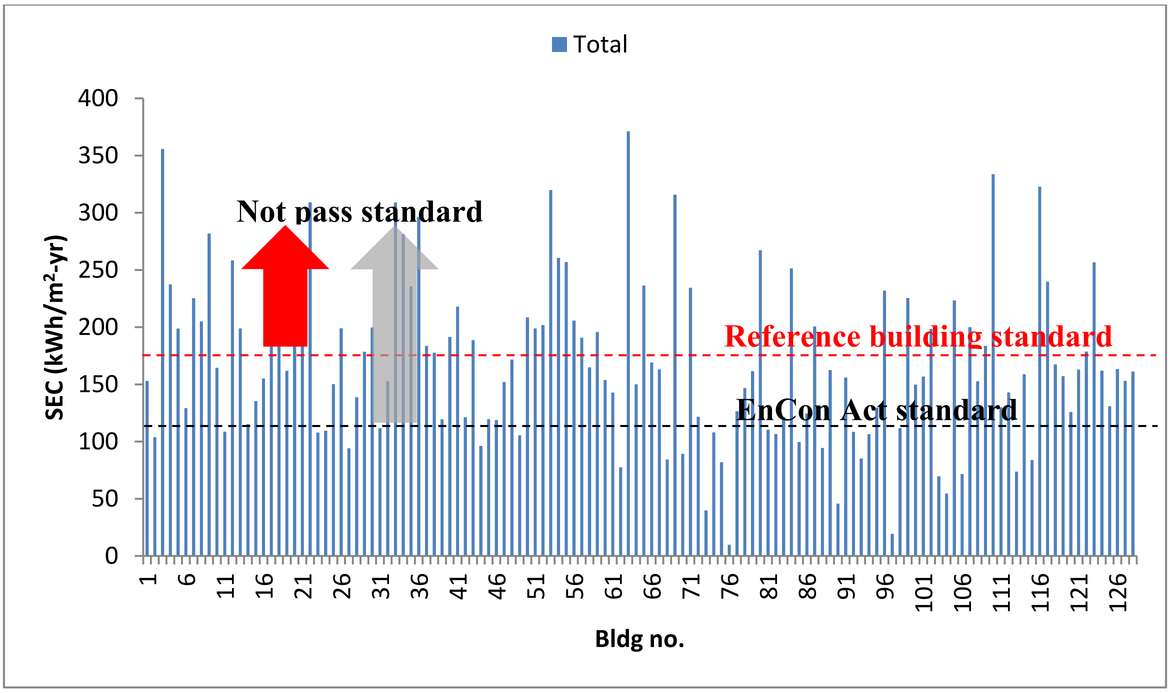

Figure 4-19 SEC_{TOTAL} values of hotels in Thailand

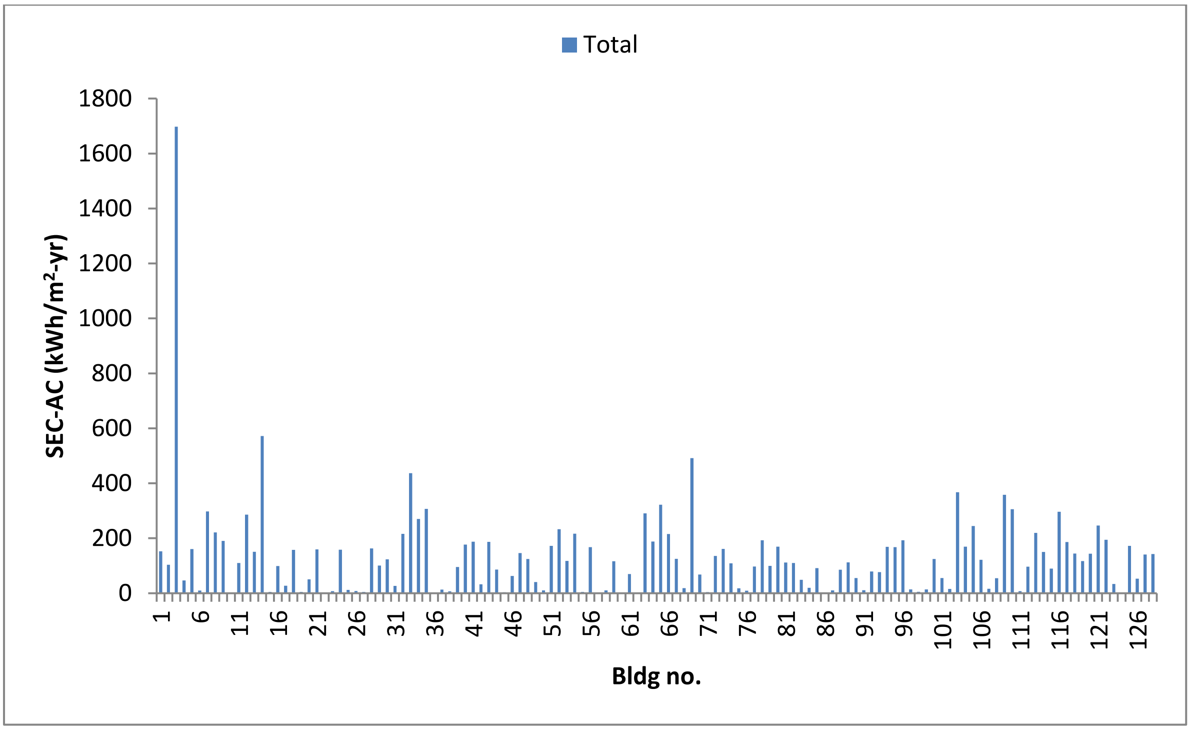

Figure 4-20 $SEC_{A/C}$ values of hotels in Thailand

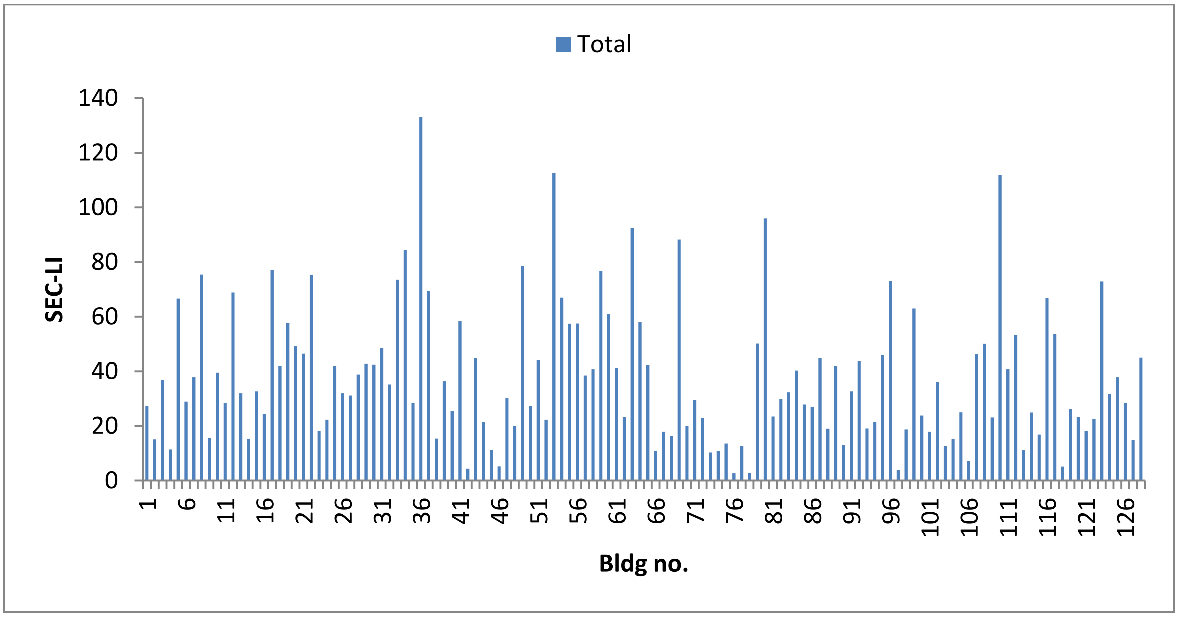

Figure 4-21 SEC_{LI} values of hotels in Thailand

The analysis of energy use index for hotel in Thailand found that about 41% of hotels (designated buildings) in Thailand did not pass the standard SEC_{TOTAL} of reference buildings and about 75.6 % cannot pass the standard of SEC_{TOTAL} of value which defined by EnCon Act. Figure 4-20 and 4-21 show the distribution of energy use index for air-conditioning system ($SEC_{A/C}$) and energy use index for lighting system (SEC_{LI}) of Thailand's hotels (designated buildings only) in year 2010. It is found that the average value of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of hotels are about 168.43, 132.7, and 37.8, respectively.

Table 4-13 Values of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of hotels in all regions

Region	Number	SEC	SEC_{AC}	SEC_{LI}
Central - BKK	63	187.18	141.51	43.80
Central - NonBKK	3	185.25	241.75	37.08
E	14	139.37	121.42	28.12
N	7	144.95	56.35	32.22
NE	8	111.12	94.51	29.62
S	26	163.71	147.19	33.97
W	6	171.24	90.46	38.47

Similar to analysis of office buildings, from the consideration of the location of these buildings, the energy use indexes for hotels in Central region for both Bangkok and non-Bangkok area are not pass both standards. But the energy use indexes for hotels in other regions pass the standard of both reference buildings, however, the standard from EnCon Act, only hotels in Northeast region only pass this standard. Table 4-13 shows the value of SEC_{TOTAL}, $SEC_{A/C}$, SEC_{LI} of hotels in every region.

In summary, the energy use index for hotels in Thailand is lower than standard from the reference buildings by 2.8% but higher than the standard from Energy Conservation Act by 30.5% in the national point of view. Bangkok and Southern Region are the major concerns for energy utilization of the hotels in Thailand due to high proportion and high energy consumption comparing to other regions. Development of energy conservation due to Energy conservation Act have to be perform promptly in order to reduce the energy consumption to strengthen the energy security of the country.

4-5 ANALYSIS OF ENERGY USE IN CONVENIENCE STORES IN THAILAND [14]

After the crisis of Thailand's economic recession in 1987, there is big change of retail business by the investment of mega chain retailers from foreign investors continuously which consequence to changing of retail business in Thailand from "Traditional trade" style (family business with Thai owner, small investment) to "Modern trade" style by the leading of discount stores. However, from the constraints about zoning of construction of discount stores with large size is difficult to be done as defined in Town Act, construction of small scale stores is easier to do and can be expand to residential communities rather than shopping mall or large scale discount store by increase number of stores but decrease stores' sizing under the concept of mini-supermarket or convenience stores. Figure 4-22 shows the number of convenience stores in Thailand during 2004 to 2013 (1st quarter). The biggest convenience store chain in Thailand by far is still 7-Eleven, with more than 6,000 outlets. Including the rest, totally over 9,000 new stores were opened in whole country until present.

Figure 4-22. Expansion of convenience stores in Thailand during 2004 – 2013

4-5-1 ENERGY CONSUMPTION OF CONVENIENCE STORE [14]

Characteristic of the energy consumption of the convenience store can be categorized among the pattern of residential and commercial buildings' consumption. Even though the peak load is not high, similar to many residential buildings but total consumption is considerable high due to the operation time and equipment of the store. Several methods of energy conservation were proposed in order to reduce the energy consumption, i.e. the utilization of high efficiency of equipment inside the store, the renovation of store's envelope such as the improvement of sizing and pattern or opening for auto-door in order to reduce the leakage of indoor air to maintain the cooling comfort of the store, the replacement of lighting system from fluorescent tubes to LED which have been proposed in some countries such as Japan, Taiwan, however, the investment is still needed at the present because of the excessive price of LED technology is high comparing to common fluorescent tube. Kitti et al. (2011) conducted the experiment for the energy management of lighting system in Thailand's convenience store by enhanced the energy efficiency by proposed 2 systems – T8 (common system) with dimmer device and T5 with electronic ballast by considering both energy consumption and investment index. From the results of the earlier studies, the improvement of store's envelope is one of effective and easy method to enhance the energy efficiency of the convenience store due to the reduction of cooling load which affect from solar heat gain through the store's envelope. It is found that the improvement of store's envelope can reduce the cooling load up to 18% which rely on each parameter, i.e. length of shading device, U-value of glass, insulation properties of roof, store's orientation, etc.

Considered the energy consumption of convenience store, there are 3 major systems utilized high energy consumption which similar as other commercial building – air conditioning system, lighting system, and equipment of the store. Generally, same as most educational building and small commercial building in Thailand, the air conditioning system of convenience store use only split-system in order to provide the cooling inside the store. From the author's survey's result, one convenience store normally used 3 sets or more of air-conditioning system with capacity 44,000 BTU (spec-in from head quarter) inside sales area only. Lighting system of Thailand's convenience store mostly used T8 fluorescent lamp (36 Watt and 18 Watt) in order to provide lighting inside the store for both sales and non-sales area. Even though the consumption of fluorescent tube is not high, most convenience store in Thailand always use excessive number of fluorescent tubes inside the store and operate for 24 hours even in sunny day. Although the promotion of the utilization of T5 fluorescent lamps with electronic ballast was implemented by the government in order to enhance the energy conservation of lighting system, however, only some stores have replaced the lighting system. Until now, there is no plan to use daylight incorporate with lighting system of the store in order to save the energy because of the excessive glare and solar heat gain from the climate condition. Equipment of the store can be categorized into 2 types – refrigerating and heating. Unlike the convenience store in other countries, space heating is not necessary for the Thailand's convenience store, therefore, equipment for heating purpose will focus for the food preparation only, i.e. microwave, dim sum oven, roller grill machine, toaster, electric hot pot for instant noodle, coffee brewing equipment (some store), etc. Equipment for refrigerating purpose is one of major system that consume high energy of the store which compose of bento refrigerator, ice and ice cream refrigerator, vertical multi shelf refrigerated display case (air-curtain), closed door reach-in refrigerator (for beverage) with freezer in storage zone, beverage brewers, etc. Typical layout and building geometry of convenience store are shown in Figure 4-23.

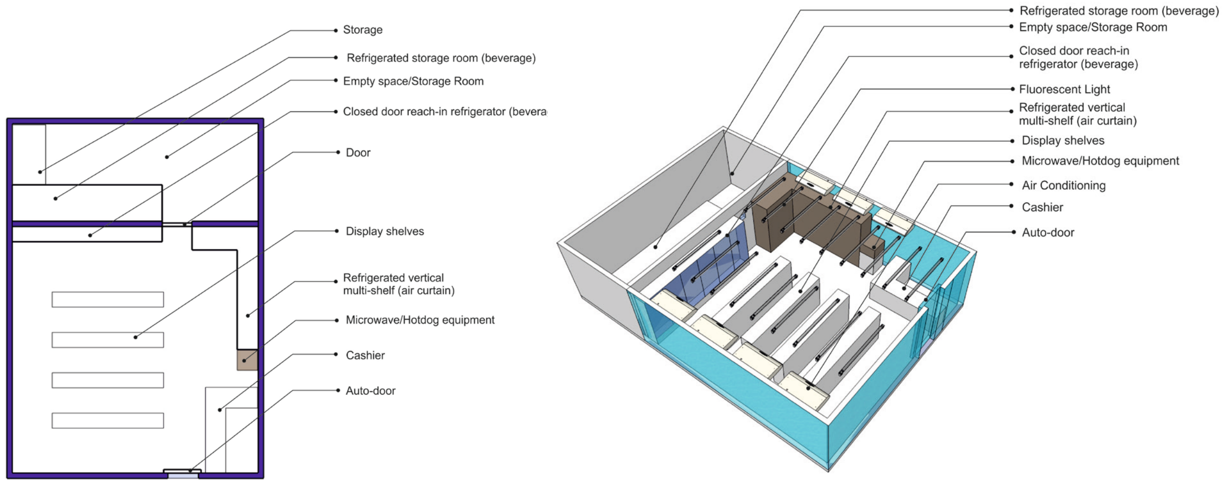

Figure 4-23. Typical layout and geometry of convenience store

From the measurement data of earlier research and survey results from CP CP All Public Company Limited, the proportion of energy consumption of overall system in the store, refrigeration system is highest proportion which consumed almost 40%, followed by air-conditioning system, lighting system, heating system (from equipment), and others about 31%, 14%, 9%, and 6%, respectively. Average energy consumption in 1 day is shown in Figure 4-24.

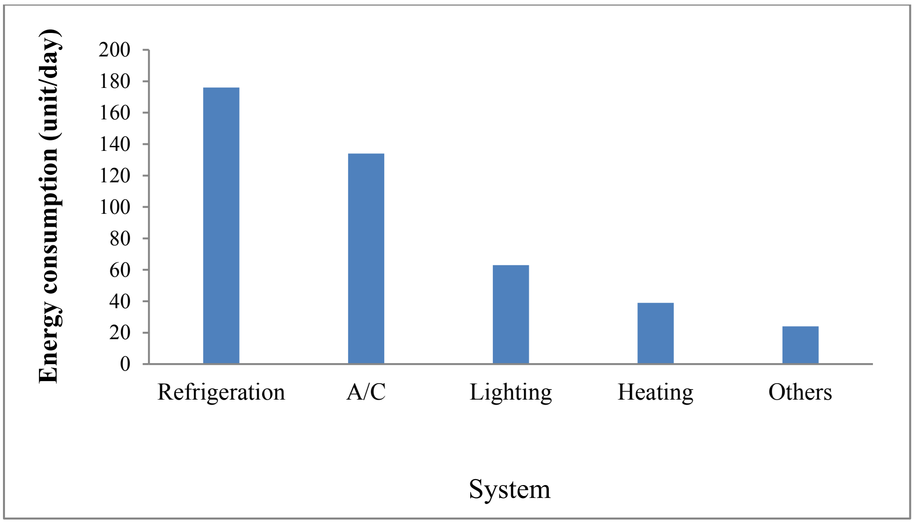

Figure 4-24. Energy consumption per day in each system (unit/day)

Air-conditioning system and refrigeration system are two highest major systems which consume electrical energy, however, it is obvious that the interaction between sales and non-sales area is irrelevant for the air-conditioning system. In non-sales area, refrigeration system from the refrigerated storage room is the major system that consumes high energy. Even though there is lighting system in this area but comparing with no. of fluorescent tubes in sales area, the proportion is too small which also has no effect to air-conditioning system? Figure 4-25 shows the relationship of the utilization of energy between each system for both sales and non-sales area.

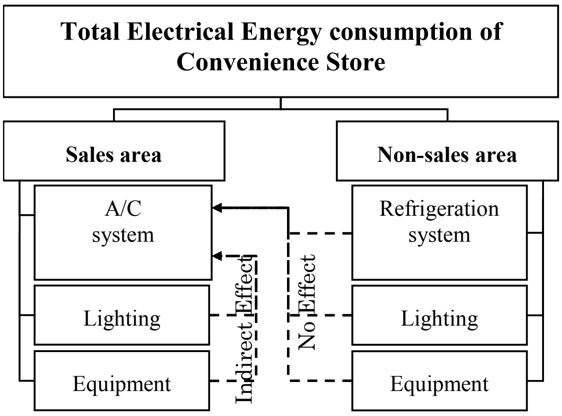

Figure 4-25. Utilization systems affect total energy consumption of the convenience store

It is found that the energy consumption in sales area is sharing about 62% from total energy use of the store. Air-conditioning system played the highest proportion about 46.2%, followed by equipment and lighting system as 34.6% and 19.2%, respectively.

Most of convenience stores in Thailand consume electrical energy about 1,324.6 kWh/m2 per year on the average with their 24-hr operation. Their energy consumption is 3-4 times higher than those of other office buildings and 1.3 times higher than those of general department store based on the same scale (floor area). The consumption of electrical energy is considerably huge due to the operation of the air-conditioning system inside the stores especially in supper period. However, the energy consumption of convenience stores also depend on store format, business practices, shopping activity, and equipment used for in-store food preservation and display () also affect the consumption for both direct and indirect way. Even though this building type cannot be categorized as designated buildings due to the sizing of the store is small, but from the expansion rate and energy consumption per unit of the stores is very high, therefore, this is one of considering building which should be perform the energy development strategies as soon as possible.

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CHAPTER FIVE PERFORMANCEASSESSMENT OF COMBINED HEAT AND POWER SYSTEM FOR THAILAND'S COMMERCIAL BUILDINGS

5-1 INTRODUCTION

Combined Heat and Power or Cogeneration system, one of effective system which generate electricity with heat utilization from a single fuel source, is a significant potential technology to provide effective energy utilization and environmental benefits. CHP system also provides high quality and reliable electricity supply. [1]

In order to realize high economical and energy-saving potentials of local energy system, it is necessary to determine its structure rationally by selecting some kinds of equipment from many alternative ones so that they match energy demand requirements for an objective user. It is also important to determine rationally the number and capacities of each kind of equipment selected, and the system's annual operating strategies corresponding to hourly variations in energy demands. Therefore, the optimization in order to reveal the best design and operational point of local energy system under the specific criteria and constraints is very crucial issue before utilization.[2,3]

Energy models have been widely used for solving this problem. A major goal of energy modeling is to create tools for decision support in energy planning and policy making. Energy models are generalized descriptions of the physical energy systems. Depending upon the purpose for modeling, the level of detail needed and the assumptions made, the components of a system can be modeled by taking into consideration physical characteristics and phenomena as well as complex relations between system parameters.

Theoretically, the physical systems can be modeled in many different ways, depending upon the needs for decision support. A model, once built, can be used in different planning situations to support decisions at different levels (operative, tactical or strategic). Energy models can offer information about costs, emission quantities, losses etc. Although these are basic criteria in any analysis, in many real decision situations local planners weigh many other aspects when making decisions, as has been shown.

From the characteristics of energy utilization in Thailand, in order to develop the energy security of the country, the maximizing of the electricity generation efficiency is the most important issue that needs to be considered which can be achieved by the reasonable selection of the effective type and size of the generating equipment or prime mover for the fuel and load profiles.

This chapter attempts to develop the evaluation system for the integration of cogeneration system regarding the energy saving, minimization of economic and carbon dioxide emissions while guarantee the operation system of CHP system under the specific constraints.

5-2 METHODOLOGY FOR EVALUATION OF COGENERATION SYSTEM

5-2-1 EVALUATION STEP

Figure 5-1 illustrated the flow chart of the model for evaluation the cogeneration system. The objective function is to minimize the annual cost after utilized the proposed system under the condition of fuel prices either electricity or gas prices. Finally, the results from the proposed system can be determined for the consideration of primary energy saving, minimization of cost saving for the economic concern, also for the maximum environmental saving under the selection of reasonable prime mover capacity and efficiencies of the machines.

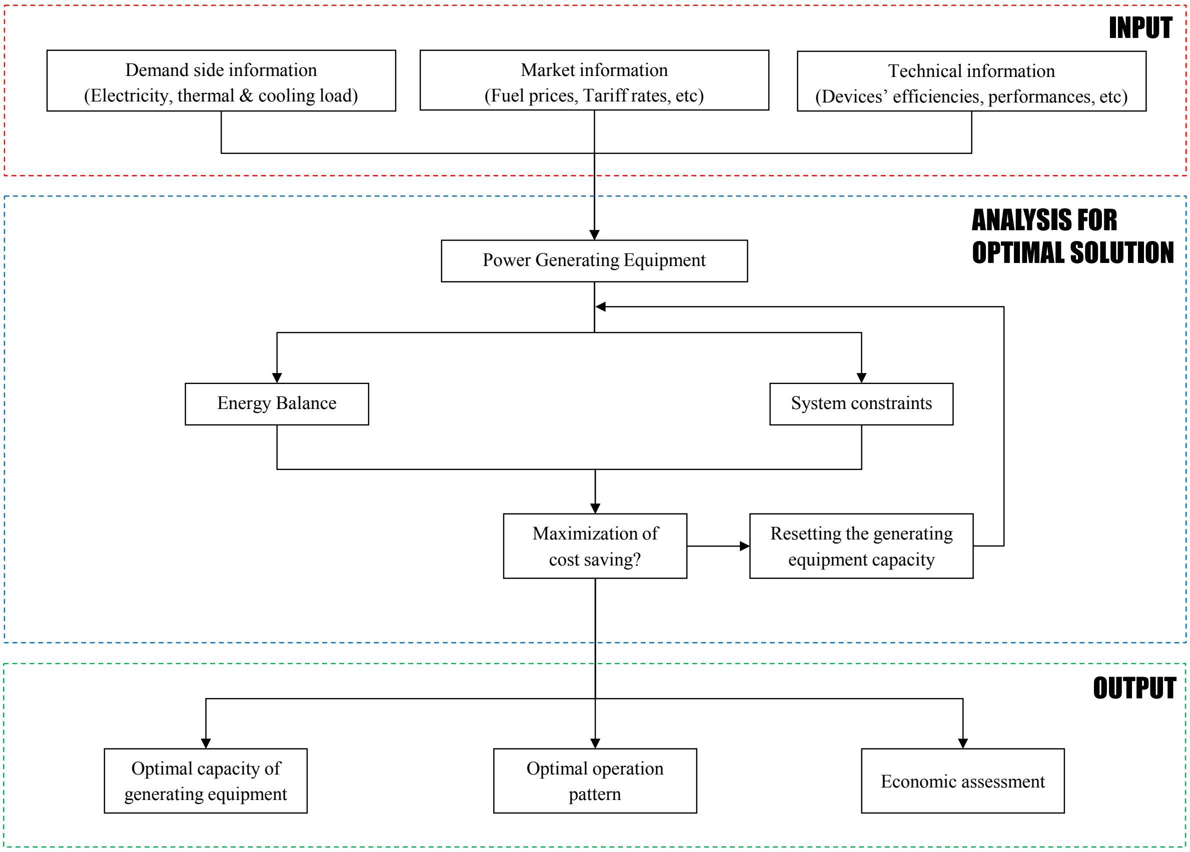

Figure 5-1 Evaluation step of cogeneration system

For the input data, the information of the energy utilization of the building is one of the most important parameter that need to be considered for the analysis. The energy of the buildings can be defined as the hourly load characteristics which separated by system for both thermal and electricity loads.

In case of no information about hourly load data, the information about energy consumption unit need to be considered for substitution in order to estimate the hourly load profile from any analysis methods which regarding to the building information, e.g. building type, weather information, building envelope, etc. Figure 5-2 illustrated the analysis methods to find out the load profile of the buildings in this research.

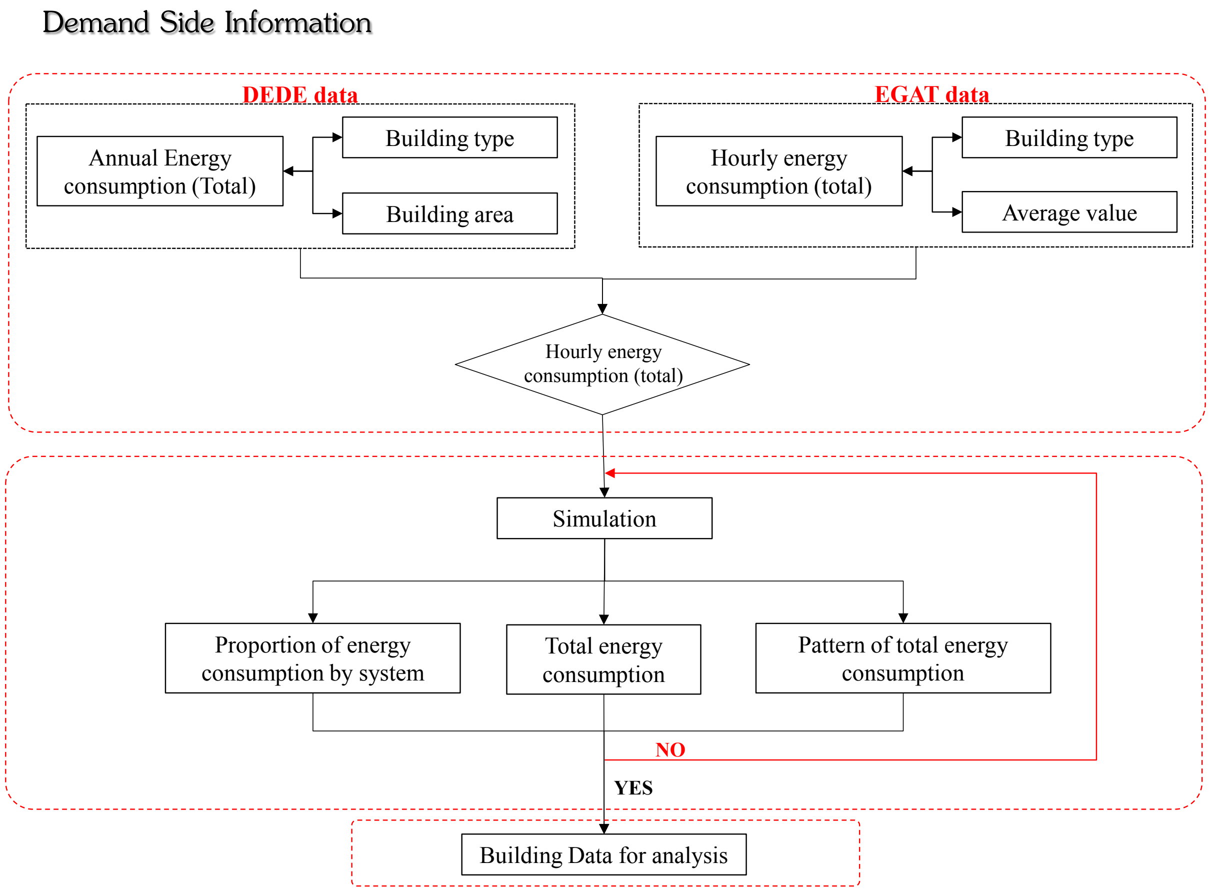

Figure 5-2 Analysis step to obtain the load profile of the buildings

For the optimization of the economic assessment, the consideration of market information need to provide the information of the cost of the machines for the investment cost, electricity and gas prices, including tariff rates of selected fuels are the parameters for analyse the running cost of the system.

The selection of the generating equipment is one of proper method for considered the DER technologies, also for the absorption chillers, boilers, and other equipment that affect the performance of energy saving and also cost concerned. The capacity of the prime mover including the efficiencies of the equipment are the major parameters affect the selection of the operating period of the proposed system.

The model for the analysis in this study need to be considered the maximization of the energy balanced for the first under the system constraints as the first priority. The selection of underestimated size or capacity of the prime mover will affect the energy balance that cannot reach the target of maximization of energy saving. However, the selection of overestimated size of prime mover will affect the economic concerned by wasting the unused performance of the machine. After that the size of the selected prime mover will take to considered for the analysis of economic assessment to analyse the maximum cost saving after investment. If the analysis results of the capacity of prime mover from energy balance analysis and economic assessment analysis is not match, the selection of prime mover size and efficiencies need to concerned for the analysis again in order to get the proper solution for evaluation the performance of cogeneration system.

Finally, the evaluation of the cogeneration system can be performed by comparing with the conventional system (present system). The evaluation indexes consist of energy performance evaluation, environmental assessment evaluation, and economic assessment evaluation. In this study, the energy evaluation use primary energy saving ratio as the index for evaluate the energy performance, as well as the CO_2 reduction ratio comparing with the conventional system is also used to evaluate as the environmental assessment index. The economic assessment evaluation, normally use payback period and also the cost saving ratio which considered for the cost of investments and running cost of the fuel as the major parameters for the analysis.

Even though the selection of prime mover size from energy saving aspect can be achieved but the investment of the systems may not pass the criteria of cost saving or environmental concerned. Therefore, the optimization of the system selection needs to be considered carefully under the specific situation in all aspects, e.g. fuel price, tariffs, etc.

5-2-2 DESCRIPTION OF THE COGENERATION SYSTEM

According to the climate condition in Thailand affect the utilization of the energy in most commercial buildings for heating purpose is unnecessary but some heating load still used for general purpose, e.g. hot water for bathing and cooking. According to end-used demand data of hourly electrical energy consumption from on-site measurement data, the comparative study between conventional system and CHP system is executed by using conventional system as a baseline. The energy flows of both systems are illustrated in Figure 5-3 and Figure 5-4. Two major energy demands have been considered in this study – direct electrical energy demand (from equipment and other systems) and cooling demand (from A/C system). Three major energy flows, namely, primary energy flow, electricity flow, and thermal flow are executed in different stages as shown in in Figure 5-3 and Figure 5-4. [2,4,5]

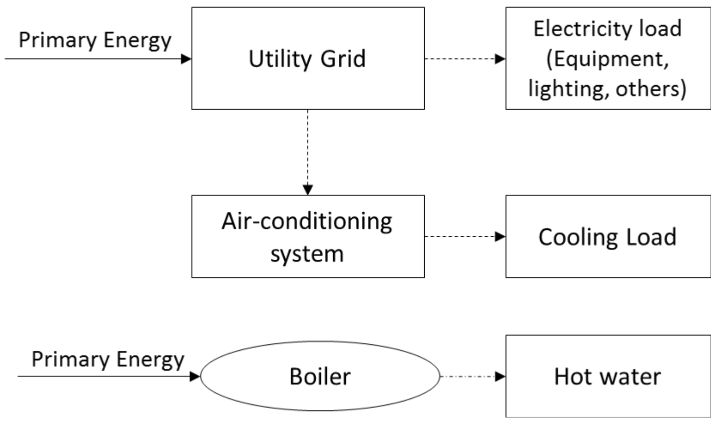

Figure 5-3 Description of conventional system

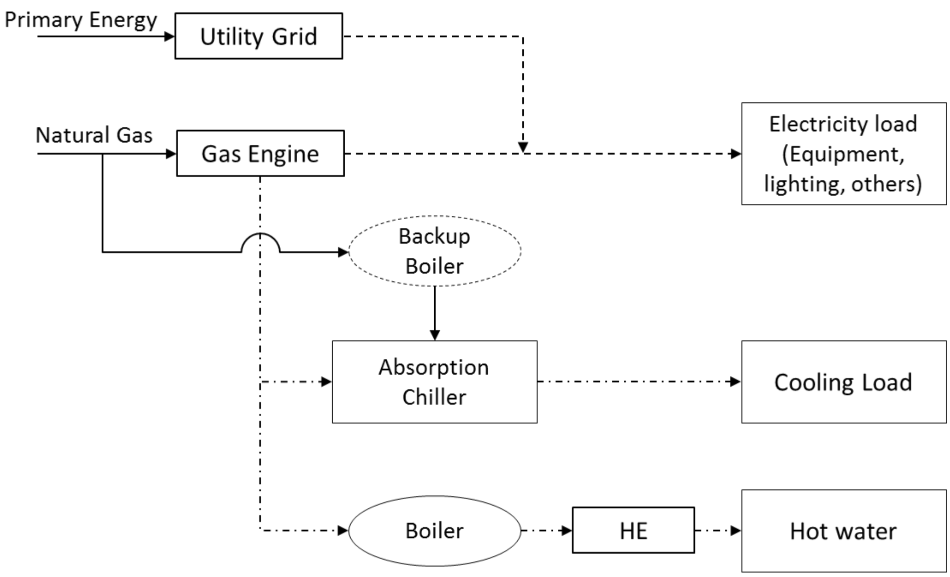

Figure 5-4 Description of cogeneration system

In conventional system, all of the electrical energy demand either direct power consumption for equipment system or space cooling via the operation of A/C system is employed by utility grid only. For cogeneration system, we used gas engine as the prime mover and absorption chiller as two major components in order to meet the energy demands either electricity or cooling demands. The gas engine is used to meet the electrical load for equipment system and also meet the cooling load with the use of air-conditioning system through the operation of absorption chiller. It is noted that, if the recovery of thermal energy from gas engine does not completely satisfy the absorption chiller's needs, a backup-boiler is used. Otherwise, the surplus energy is released into the atmosphere in case of recovery of thermal energy exceeds the load demands.

5-3 ASSESSMENT CRITERIA

Three assessment indices (a primary energy saving index, an environmental assessment index, and economic assessment index) were considered in this study in order to determine the optimal solution for the selection of the cogeneration capacity and efficiencies in Thailand's office buildings.

The consideration of energy characteristics and requirements which executed hourly throughout a one-year (8760 period hrs), and technical information about electricity, as well as cogeneration performance characteristics were employed. In order to investigate the reasonable solutions for primary energy saving and maximum environmental benefits through the reduction of CO2 emission in this study, the operation of cogeneration system was assumed to track the electricity need.

5-3-1 PRIMARY ENERGY SAVING INDEX [3,4]

The energy performance index is one of the most important evaluation indices for determining the benefit of the cogeneration system, which is expressed by the calculation of the primary energy saving ratio (PES). The PES is defined as the ratio of the difference between primary energy input in the conventional energy system and the cogeneration system, to the primary energy input in the conventional system. It can be expressed as follows:

$$PES = [(Q_{CONV} - Q_{CHP})/Q_{CONV}] \cdot 100\% \quad (5\text{-}1)$$

where Q_{CONV} and Q_{CHP} are the primary energy input in the conventional energy system and the cogeneration system, respectively. Total annual primary energy consumption by the conventional system in this study is composed of the power consumption for electricity and cooling loads only, as shown in the following equation:

$$Q_{CONV} = \left(Q_{POWER}^{LOAD}/\eta_{GRID}\right) + \left(Q_{COOLING}^{LOAD}/COP_{COOLING}^{A/C} \cdot \eta_{GRID}\right) \quad (5\text{-}2)$$

where Q_{POWER}^{LOAD} and $Q_{COOLING}^{LOAD}$ are the electricity load for equipment and the space cooling of the store, respectively. η_{GRID} denotes the efficiency of the utility grid. $COP_{COOLING}^{A/C}$ indicates the coefficient of the performance of the air-conditioning system which is utilized in the conventional system.

The total primary energy consumption of the micro co-generation system in this study is composed of the electrical energy consumption from the utility grid, the on-site power generation, and the direct fuel combustion for the back-up boiler, as illustrated in the following equation:

$$Q_{CHP} = \left(Q_{POWER}^{GRID}/\eta_{GRID}\right) + \left(Q_{POWER}^{CHP}/\eta_{E}\right) + \left(Q_{COOLING}^{BOILER}/\eta_{BOILER}\right) \quad (5\text{-}3)$$

where Q_{POWER}^{GRID} and Q_{POWER}^{CHP} are the power purchased from the utility grid and power generation of the micro co-generation system, respectively. $Q_{COOLING}^{BOILER}$ is the purchased power from the natural gas supply for the back-up boiler in order to satisfy the heat demand for the absorption chiller. η_E and η_{BOILER} denotes the electricity efficiency of the micro co-generation system and the efficiency of back-up boiler, respectively.
Therefore, the calculation of PES value can be summarized as illustrated in Equation (5-4):

$$PES = \frac{\left(\frac{Q_{POWER}^{LOAD}}{\eta_{GRID}} + \frac{Q_{COOLING}^{LOAD}}{COP_{COOLING}^{A/C}\cdot\eta_{GRID}}\right) - \left(\frac{Q_{POWER}^{GRID}}{\eta_{GRID}} + \frac{Q_{POWER}^{\mu CHP}}{\eta_{E}} + \frac{Q_{COOLING}^{BOILER}}{\eta_{BOILER}}\right)}{\left(\frac{Q_{POWER}^{LOAD}}{\eta_{GRID}} + \frac{Q_{COOLING}^{LOAD}}{COP_{COOLING}^{A/C}\cdot\eta_{GRID}}\right)} \times 100\% \quad (5\text{-}4)$$

5-3-2 ENVIRONMENTAL ASSESSMENT INDEX [3,4,5,6]

Reducing environmental pollution is one of incentives for the introduction of the micro co-generation system. In this study, the CO_2 emission reduction ratio (CER) is used to evaluate the environmental effect of the cogeneration system, and is defined as the ratio of the difference between CO_2 emissions from the conventional system and the cogeneration system, to the CO_2 emissions from the conventional system:

$$CER = \left[\left(E_{CONV}^{CO_2} - E_{CHP}^{CO_2}\right)/E_{CONV}^{CO_2}\right] \cdot 100\% \quad (5\text{-}5)$$

where $E_{CONV}^{CO_2}$ and $E_{CHP}^{CO_2}$ are the annual CO_2 emissions of the conventional system and the micro co-generation system, respectively. Calculations of the annual CO_2 emissions for both systems are based on the results from the primary energy input multiplied by the carbon contents of grid electricity (CC_{ELEC}) and natural gas (CC_{GAS}), which are illustrated in the following equations:

$$E_{CONV}^{CO_2} = \left[\left(Q_{POWER}^{LOAD}/\eta_{GRID}\right) + \left(Q_{COOLING}^{LOAD}/COP_{COOLING}^{A/C} \cdot \eta_{GRID}\right)\right] \cdot CC_{ELEC} \quad (5\text{-}6)$$

$$E_{CHP}^{CO_2} = \left[\left(Q_{POWER}^{GRID}/\eta_{GRID}\right) \cdot CC_{ELEC}\right] + \left[\left(Q_{POWER}^{CHP}/\eta_E\right) + \left(Q_{COOLING}^{BOILER}/\eta_{BOILER}\right)\right] \cdot CC_{GAS} \quad (5\text{-}7)$$

5-3-3 ECONOMIC ASSESSMENT [4,5,6,7,8]

In this study, cost saving ratio (CSR) is used as one of economic assessment index which express the profitability of the cogeneration system and also defined as the rate of total energy cost difference between the cogeneration and the conventional system to the annual energy cost of the conventional system, as illustrated in Equation (5-8).

$$\mathrm{CSR} = \frac{\mathrm{C_{CONV}} - \mathrm{C_{CHP}}}{\mathrm{C_{CONV}}} \times 100\% \qquad (5\text{-}8)$$

where $\mathrm{C_{CONV}}$ and $\mathrm{C_{CHP}}$ are the annual energy cost of the conventional system and cogeneration system, respectively. Both energy costs are mainly composed of the combination between investment cost (initial cost) and running costs which can be defined as Equation (5-9) and (5-10):

$$\mathrm{C_{CONV}} = \mathrm{C_{CONV}^{INV}} + \mathrm{C_{CONV}^{ELEC}} \qquad (5\text{-}9)$$

$$\mathrm{C_{CHP}} = \mathrm{C_{CHP}^{INV}} + \mathrm{C_{CHP}^{ELEC}} + \mathrm{C_{CHP}^{GAS}} \qquad (5\text{-}10)$$

where $\mathrm{C_{CONV}^{INV}}$, $\mathrm{C_{CONV}^{ELEC}}$ are annualized investment cost and electricity purchase (running cost), respectively for conventional system. $\mathrm{C_{CHP}^{INV}}$, $\mathrm{C_{CHP}^{ELEC}}$, $\mathrm{C_{CHP}^{GAS}}$ are the annualized investment cost, utility grid electricity cost (running cost), and city gas cost (running cost), respectively, for the cogeneration system.

Annual investment costs of conventional and cogeneration systems are described in Equation (5-11) and (5-12). Investment cost is calculated from the annualized capital cost which spreading the initial cost of an option across the life time of that option while accounting for the time value of money. The cost of capital is annualized as if it were being paid off as a loan at a particular interest of discount rate over the life time of the option [4,9-11].

$$\mathrm{C_{CONV}^{INV}} = \mathrm{C_C^{A/C}} \cdot \mathrm{C_P^{A/C}} \cdot \frac{\mathrm{I}}{1 - \frac{1}{(1+\mathrm{I})^{\mathrm{T_{A/C}}}}} \qquad (5\text{-}11)$$

$$C_{\mu CHP}^{INV} = \left(C_C^{ABS} \cdot C_P^{ABS} \cdot \frac{I}{1 - \frac{1}{(1+I)^{T_{ABS}}}} \right) + \left(C_C^{\mu CHP} \cdot C_P^{\mu CHP} \cdot \frac{I}{1 - \frac{1}{(1+I)^{T_{\mu CHP}}}} \right) \tag{5-12}$$

where $C_C^{A/C}$, C_C^{ABS}, C_C^{CHP} denote capital cost of air-conditioning system, absorption chiller, and cogeneration system, respectively. $C_P^{A/C}$, C_P^{ABS}, C_P^{CHP} denote the machine's capacity of air-conditioning system, absorption chiller, and cogeneration system, respectively. I indicates the interest rates of each machine. $T_{A/C}$,T_{ABS}, and T_{CHP} illustrate the life time of the air-conditioning system, absorption chiller, and cogeneration system, respectively. The investment cost for conventional system in this study is considered for air-conditioning system only. On the other hand, the consideration of absorption chiller and cogeneration system are taken into account for determine the investment cost of cogeneration system. The annual running cost conventional system and cogeneration system are described in Equation (5-13) to (5-15). Calculation of running cost is mainly from the cumulative fuel consumption for each period of both systems multiplied by the fuel price.

$$C_{CONV}^{ELEC} = \sum_d \sum_h E_{d,h}^{A/C} \cdot P_{ELEC,h} + \sum_d \sum_h E_{d,h}^{EQUIP} \cdot P_{ELEC,h} \tag{5-13}$$

$$C_{CHP}^{ELEC} = \sum_d \sum_h E_{d,h}^{\mu CHP} \cdot P_{ELEC,h} \tag{5-14}$$

$$C_{CHP}^{GAS} = \sum_d \sum_h E_{d,h}^{CHP} \cdot \left(\frac{P_{GAS}}{\eta_E \cdot HR} \right) + \sum_d \sum_h H_{d,h}^{BOILER} \cdot \left(\frac{P_{GAS}}{\eta_{BOILER} \cdot HR} \right) \tag{5-15}$$

where $E_{d,h}^{A/C}$, $E_{d,h}^{EQUIP}$, $E_{d,h}^{CHP}$ denote hourly electricity load of air-conditioning system, equipment demand, and cogeneration system, respectively. $P_{ELEC,h}$ and P_{GAS} are electricity price and gas price. $H_{d,h}^{BOILER}$ is heat load input to boiler, kW. HR denotes the heat rate, kWh/m3. η_E and η_{BOILER} are electricity efficiency of cogeneration system and boiler efficiency, respectively.

The payback period (PBP) is one of widely accepted method for assess economic performance, is also employed in this study. It reflects the length of time required for a project to return its investment through the net savings realized which can be reflect the time frame necessary for the net energy cost saving to pay the installation cost of cogeneration system. Calculation of payback period can be illustrated in Equation (5-16):

$$\mathrm{PBP} = \frac{C_{CHP}^{INI} - C_{CONV}^{INI}}{C_{CONV}^{RUN} - C_{CHP}^{RUN}} = \frac{\left(C_{\mu CHP}^{INV} + C_{ABS}^{INV}\right) - C_{A/C}^{INV}}{C_{CONV}^{ELEC} - \left(C_{CHP}^{ELEC} + C_{CHP}^{GAS}\right)} \qquad (5\text{-}13)$$

where C_{CHP}^{INI} , C_{CONV}^{INI} are investment cost of cogeneration and conventional system, respectively. C_{CONV}^{RUN} , C_{CHP}^{RUN} denote the running cost (purchase cost) of electricity for conventional and cogeneration systems and gas for cogeneration system only.

- **Utility Tariffs [12]**

Utility electricity and gas tariffs are the key parameters that need to take into account for the calculation in order to analyze the economic benefits of the cogeneration implementation regarding to the effect of running cost for the cogeneration system and also for the conventional system. In this study, the natural gas is selected as the primary fuel for utilize the prime mover, so, the fluctuation of utility tariff will affect the operation period of cogeneration system due to the consideration of gas and electricity price. In case of high rate of gas tariffs or gas price, the selection of power generation from utility grid is better choice comparing with the utilization of power generation from cogeneration system with Gas Engine as the prime mover technology.

- Gas tariffs

Because of the present situation has no city gas pipeline, therefore, gas tariff information in this study is assumed to be the same rate for industrial customers as 350 THB/MMBTU which provided by PTT Public Co. Ltd. only. If the city gas pipeline is successfully implemented in 2020 [], the gas utility company can be provide gas tariff rate in cheaper price than the present in order to encourage customers to use gas as the alternative energy for both residential and commercial sectors.

- Electricity tariffs

Electricity service in Bangkok and vicinity areas is mainly provided by Metropolitan Electricity Authority (MEA) []. The electricity tariffs can be categorized as eight types regarding to the service type and peak demand of the electricity consumption. The electricity tariff structures in each service type can be divided into 2 parts: Base tariff and Automatic tariff adjustment (Ft). The owner of buildings or service type can choose the tariff rates by themselves between normal tariff and Time-of-Use (TOU) tariff rates according to the electricity usage pattern in each building.

Base tariff is the tariff rate that reflect cost of construct power plants transmission and distribution system including fuel and O&M . Under the assumptions of power consumption, fuel prices, exchange rate and inflation rates. Component customers which divide by categories as shown in Table 5-3-1

Table 5-3-1 Base Tariff for each service type

	Energy Charge (THB / kWh)	Demand Charge (THB / kW)	Service Charge (THB /Month)	Power Factor Charge (THB / kVAR)
Residential service	✓	-	✓	-
Small general service	✓	-	✓	-
Medium general service	✓	✓	✓	✓
Large general service	✓	✓	✓	✓
Specific business service	✓	✓	✓	✓
Non-profit organizations	✓	✓ (TOU rate only)	✓	-
Water pumping for agricultural purposes	✓	✓ (TOU rate only)	✓	-
Temporary tariff	✓	-	✓	-

Automatic tariff adjustment (Ft) is variable tariff or tariff derived from the Automatic Tariff Adjustment Mechanism formula. It is reflected the change in uncontrolled cost of the utilities such as fuel cost and purchasing power which are only differ from base tariff. Preferably adjusted every 4 months. Ft is variable tariff or tariff derived from the Automatic Tariff Adjustment Mechanism formula . It had been several revised and now is particularly important to encourage efficient procurement of generation from EGAT's own plant and EGAT's power purchasing from independent power producers (IPPs) , small power producers (SPPs) and neighbor countries (Laos and Malaysia) as generation costs are the largest component of electricity costs. Ft is also included the expense occurred from Government Policies. Calculation of Ft formula comprises the fuel cost and power purchasing price that differ from the assumptions initially used for determining the base tariff. The fuel cost and power purchasing price include the following:

1) The fuel costs of power plants of EGAT (fuel oil, diesel, natural gas, lignite ,imported coal, etc.)

2) The cost of power purchase from Independent Power Producers (IPPs) and Small Power Producers (SPPs), covering both the availability payments and the energy payment.

3) The cost of power purchase from neighboring countries (Lao PDR, Malaysia and others)

$$F_t = (EFC - BFC) + AF \quad (5\text{-}14)$$

$$EFC = \frac{\sum(P_i \times Q_i)_t}{U_i} \quad (5\text{-}15)$$

where

EFC = Estimated Fuel Costs and Energy Payments for current 4-month period

BFC = Base Fuel Costs and Energy Payments as of May – August 2011 (2.1028 THB/kWh)

AF = Accumulated Energy Adjustment Charge for previous 4-month period

t = 1st, 2nd, 3rd, and 4th month

i = fuel or purchase number *i*

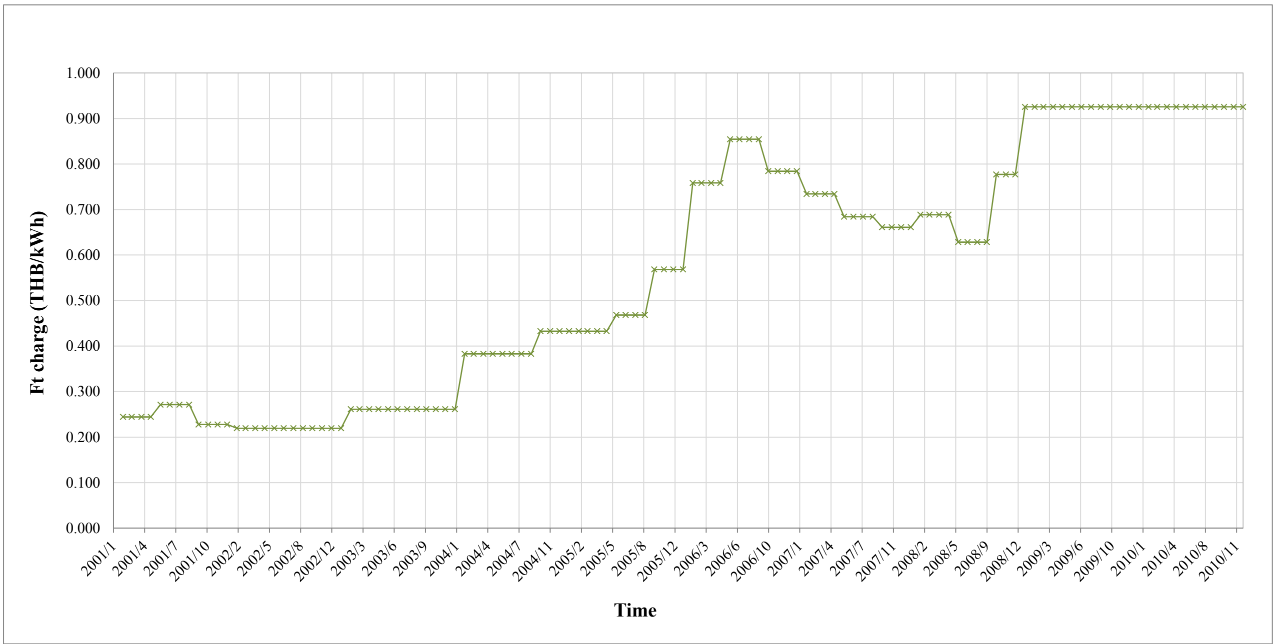

Figure 5-3-1 Statistics data of Ft value since January 2001 to December 2010

In this study, the electricity used for commercial buildings can be determined from three service types which depend on service types and maximum integrated demand value – small general service, medium general service, and large general service type.

Electrical tariff for small general service type can be divided into 2 tariff rates – normal tariff and Time of Use (TOU) tariff. This schedule of tariff is applicable to a business enterprise, business enterprise cum residence, industrial, government institutions and state enterprise or the alike, including its compound, with a maximum 15-minute integrated demand of less than 30 kilowatt through a single Watt-hour meter. Details of demand charge can be explained as follows:

Table 5-3-2 Normal tariff for Small General Service type

Voltage Level	Energy Charge (Baht/kWh)	Service Charge (Baht/month)
1) 12 - 24 kV	3.4230	312.24
2) Below 12 kV		46.16
- First 150 kWh (1st – 150th)	2.7628	
- Next 250 kWh (151st – 400th)	3.7362	
- Over 400 kWh (up from 401st)	3.9361	

Table 5-3-3 Time of Use (TOU) tariff for Small General Service type

Voltage Level	Energy Charge (Baht/kWh)		Service Charge (Baht/month)
	On peak	Off Peak	
1) 12 - 24 kV	4.5827	2.1495	312.24
2) Below 12 kV	5.2674	2.1827	46.16

On Peak : Monday – Friday from 09.00 AM to 10.00 PM
Off Peak : Monday – Friday from 10.00 PM to 09.00 AM
: Saturday – Sunday, National Labor Day and normal public holiday

In case of Medium general service's tariff rate, this schedule of tariff is applicable to a business, industrial, government institutions and state enterprise, as well as the foreigner entities and international organizations including its compound, with a maximum 15-minute integrated demand from 30 to 999 kilowatts. Of which the average energy consumption for 3 consecutive months through a single Watt-hour meter does not exceed 250,000 kWh per month. Details of demand charge can be explained as follows:

Table 5-3-4 Normal tariff for Medium General Service type

Voltage level	Demand Charge (Baht/kW)	Energy Charge (Baht/kWh)	Service Charge (Baht/month)
1) 69 kV and over	175.70	2.6506	312.24
2) 12-24 kV	196.26	2.6880	312.24
3) Below 12 kV	221.50	2.7160	312.24

Table 5-3-5 Time of Use (TOU) tariff for Medium General Service type

Voltage level	Demand Charge (Baht/kW)		Energy Charge (Baht/kWh)		Service Charge (Baht/month)
	On Peak	Off Peak	On Peak	Off Peak	
1) 69 kV and over	74.14	0	3.5982	2.1572	312.24
2) 12-24 kV	132.93	0	3.6796	2.1760	312.24
3) Below 12 kV	210.00	0	3.8254	2.2092	312.24

On Peak : Monday – Friday from 09.00 AM to 10.00 PM
Off Peak : Monday – Friday from 10.00 PM to 09.00 AM
: Saturday – Sunday, National Labor Day and normal public holiday

For the Large General Service's tariff rate, this schedule of tariff is applicable to a business, industrial, government institutions, state enterprise, foreign entities and international organizations including its compound, with a maximum 15-minute integrated demand over1,000 kilowatt, or the energy consumption for three (3) average consecutive months through a single Watt-hour meter exceeds 250,000 kWh per month. The electricity tariff rate of this service is different than that of others by using Time of Day (TOD) tariff instead of normal tariff for calculation. Details of demand charge can be explained as follows:

Table 5-3-6 Time of Day (TOD) tariff for Large General Service type

Voltage level	Demand Charge (Baht/kW)			Energy Charge (Baht/kWh)	Service Charge (Baht/month)
	On Peak	Partial Peak	Off Peak	All Times	
1) 69 kV and over	224.30	29.91	0	2.6506	312.24
2) 12 - 24 kV	285.05	58.88	0	2.6880	312.24
3) Below 12 kV	332.71	68.22	0	2.7160	312.24

On Peak : Every day from 06.30 PM to 09.30 PM
Partial Peak : Every day from 08.00 AM to 06.30 PM (only the amount of demand that is in excess of the On-Peak maximum demand will be applicable.)
Off Peak : Every day from 09.30 PM to 08.00 AM (No demand charge)

Table 5-3-7 Time of Use (TOU) tariff for Large General Service type

Voltage level	Demand Charge (Baht/kW)		Energy Charge (Baht/kWh)		Service Charge (Baht/month)
	On Peak	Off Peak	On Peak	Off Peak	
1) 69 kV and over	74.14	0	3.5982	2.1572	312.24
2) 12-24 kV	132.93	0	3.6796	2.1760	312.24
3) Below 12 kV	210.00	0	3.8254	2.2092	312.24

On Peak : Monday – Friday from 09.00 AM to 10.00 PM
Off Peak : Monday – Friday from 10.00 PM to 09.00 AM
: Saturday – Sunday, National Labor Day and normal public holiday

Generally, many buildings select the electricity charge by using TOU rate for building's electricity charge. The electricity change is imposed a variation by time (day time and night time) and also for holiday consideration (weekend and weekday period). Calculation of electricity tariff in this study is shown in Equation (5-16).

$$\text{Annual electricity tariff} = \sum_{h}\sum_{d} E_C + \sum_{m} E_S + \sum_{m} F_t + E_D + VAT \qquad (5\text{-}16)$$

where E_C is electricity charge which vary by time of utilization. E_S and E_D are service charge and demand charge, respectively. *h*, *d*, and *m* denote hours in a day, days in a year, and months in a year, respectively. The Automatic Tariff Adjustment (Ft) is the mechanism for adjusting the power tariff which reflects the policy expense and the fuel cost of power generation at a given period of time.

5-4 SUMMARIES

In order to implement the distributed energy resource system like the utilization of cogeneration system, the evaluation of the benefit after utilization of the system is very important for decision making of the system utilization comparing with the conventional system at present situation. The consideration of surrounding parameters including environment, energy, and also economic aspects are the purpose for the implementation of DER system.

In this chapter, the evaluation step of the cogeneration system has been introduced by considering the factors of buildings, market information, and technical information. The hourly load profile for whole year for every systems including cooling / heating , hot water, and electricity load need to be concerned case-by-case according to specific characteristics of each building.

Finally, three major evaluation indexes, namely, energy evaluation, economic evaluation, as well as environmental evaluation has been developed in order to evaluate the overall feasibility of the introduction of cogeneration system to the building which can replace the present system and also develop the energy security of the country from the optimization of the proposed system.

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CHAPTER SIX FEASIBILITY STUDY AND OPTIMIZATION ON THE INTRODUCTION OF DISTRIBUTED ENERGY RESOURCES FOR THAILAND'S COMMERCIAL BUILDINGS

6-1 INTRODUCTION

Thailand has long been seeking to reduce its dependence on foreign fossil fuel energy sources, improve energy conservation in buildings, and increase the percent of national electricity produced from renewable energy sources [1,2]. The Thai Ministry of Energy recently set goals to meet 25% of its total domestic electricity supply through alternative energy sources and technology by the year 2021 [1]. In Thailand, office buildings are estimated to account for approximately 44% of the total annual electricity consumption in the commercial sector, and an increase in new building construction of approximately 35% was seen in the three year span from 2002 to 2005 [3]. Thus, it can be seen that electricity consumption in buildings is a prime sector for the Ministry of Energy to promote their alternative energy goals through. Of building energy consumption, building cooling loads are estimated to account for approximately 60% of an office building's total energy demand [4]. Additionally, local residents of tropical regions are found to spend approximately 90% of their time in cooled buildings [5], and thermal comfort is found to have significant effects on occupant work performance, mood, and attentiveness [6]. Development of alternative energy supply, e.g. the distribution energy resources to decentralized the energy resources in order to reduce the primary energy cooperate with absorption chiller is one of technology that can significantly reduce fossil fuel based electricity use in Thailand's commercial buildings. In order to fulfill plan of natural gas pipeline extension and promotion of the utilization of renewable energy to become successful, the study of the optimization of the DER system by considering the energy, economic, and environmental performance of DER system accounting for different design and management is necessary.

In this chapter, the evaluation step of the DER system for commercial buildings in Thailand were purposed from the implementation of CHP, Micro-CHP, and PV system to different types of buildings - office buildings, hotels, convenience stores. From the building energy consumption unit, the energy load profiles were analysed, utility tariff structure, as well as technical and market information are used to selecting the reasonable capacity of CHP system and also determining the operating schedules by considering 3 aspects – energy performance, environmental, and economic aspects.

6-2 OUTLINE OF THE EVALUATION METHODOLOGY

The data and characteristics of load profiles by separating system is the first crucial parameters in order to analyze the performance evaluation of cogeneration system for commercial buildings. However, only special case for buildings in Thailand that focused for the pattern of energy use in separated system due to high investment for measurements and unused information after investigation. [6]

Two major government organizations are responsible for this issue by focusing the different point of view.

1. Department of Alternative Energy Development and Energy Efficiency (DEDE) [7]:

DEDE has stored the data on total energy consumption (both fuels and electricity) in 8 industrial sub-sectors from the energy management report submission of designated buildings which started from 2010. However, the energy data at DEDE does not include off-grid electricity (electricity generated by individual factories or provided by industrial estates). However, for the natural gas consumption, DEDE has obtained the data from PTT Public Co., Ltd. who is solely the producer and the supplier in Thailand. The data of fuel consumption, the DEDE has conducted a paper-based survey for the energy consumption with industries every 5 years.

2. Metropolitan Electricity Association (MEA) [8]:

MEA provides services on power distribution and sale of power to the public, business and industrial sector within Bangkok, Nonthaburi and Samut Prakarn. The MEA has collected and analyzed the electricity data for generation, consumption, power plant capacity, energy source for metropolitan area.

Another responsibility of MEA is about the peak load investigation of residential and commercial buildings under the sub-sector of MEA. The investigation of hourly load profile for the total energy use of each service type will performed by random checking in order to control the peak-load consumption from the customers. However, the investigation of load profiles from MEA cannot break down by utilization systems.

From the available data from above description, the assessment of load profile by system can be performed from 2 possible methods – direct investigation and data from the simulation results. In this study, the results energy consumption of office buildings and hotels were performed from simulation software, namely ENER-WIN. But the hourly energy use of convenience stores were performed by direct measurement. Figure 6-1 shows the flow charts of the evaluation methods for performance assessment of CHP system.

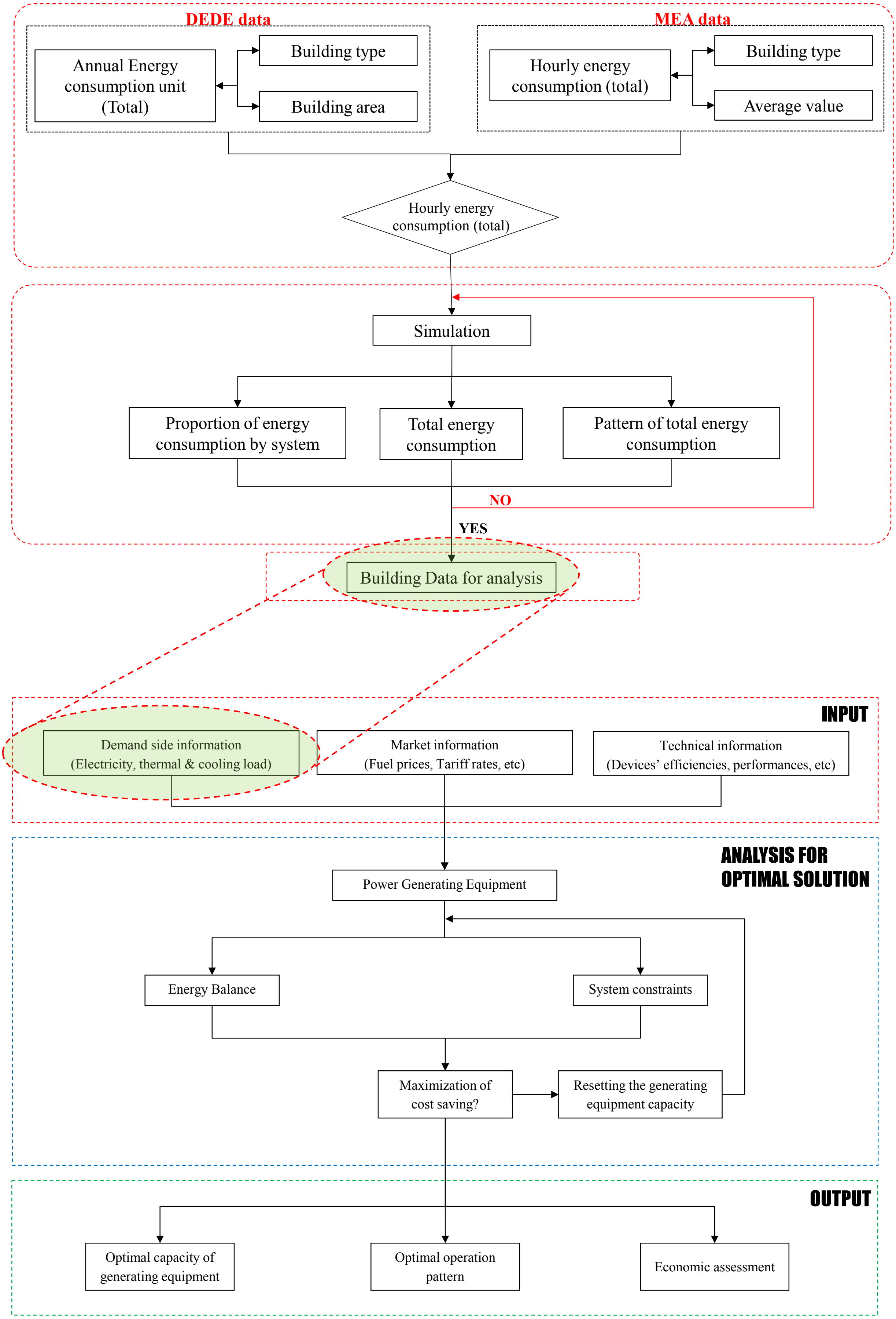


Figure 6-1 Performance Evaluation flow chart of the implementation of CHP system

6-3 DESCRIPTION OF SIMULATION SOFTWARE FOR DETERMINING LOAD PROFILES

- **GENERAL VIEW OF ENER-WIN SOFTWARRE [9]**

The ENER-WIN simulation software evaluates the comfort level of buildings with and without mechanical systems. It assesses the energy performance of buildings in energy units and in dollars required to achieve designated climatic conditions by performing an hour-by-hour energy simulation based on given climatic, building, and economic data.

The software includes a weather database of more than 280 U.S. and foreign cities, an envelope-materials catalog, and numerous user profiles. The program performs zone and building geometry processing, load calculations, energy summations, and life-cycle cost predictions based on present value and escalation factors for the building and its energy use.

The ENER-WIN program is written in two major modules – a user interface (written in Visual Basic) and a simulation program (written in FORTRAN). This guide will outline the steps necessary to use the interface and will also describe generally what the simulation program will do with the inputs entered through the user interface. The overall modules in ENER-WIN are shown below in Figure 6-3-1.

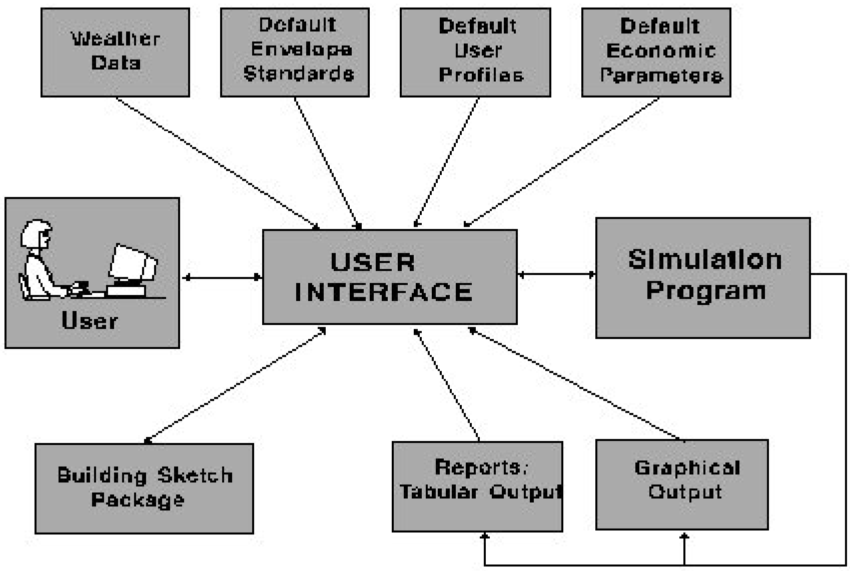


Figure 6-3-1 Module linkage in ENER-WIN

Analytical components of ENER-WIN are organized into 8 main categories:

1. Weather data generation:

Weather data generation is done hour-by-hour, producing hourly values for dry-bulb temperature, dew point temperature, wind speed, sun angles, cloud cover fraction, and direct and diffuse insolation. Figure 6-2 shows the ENER-WIN's weather data screen input.

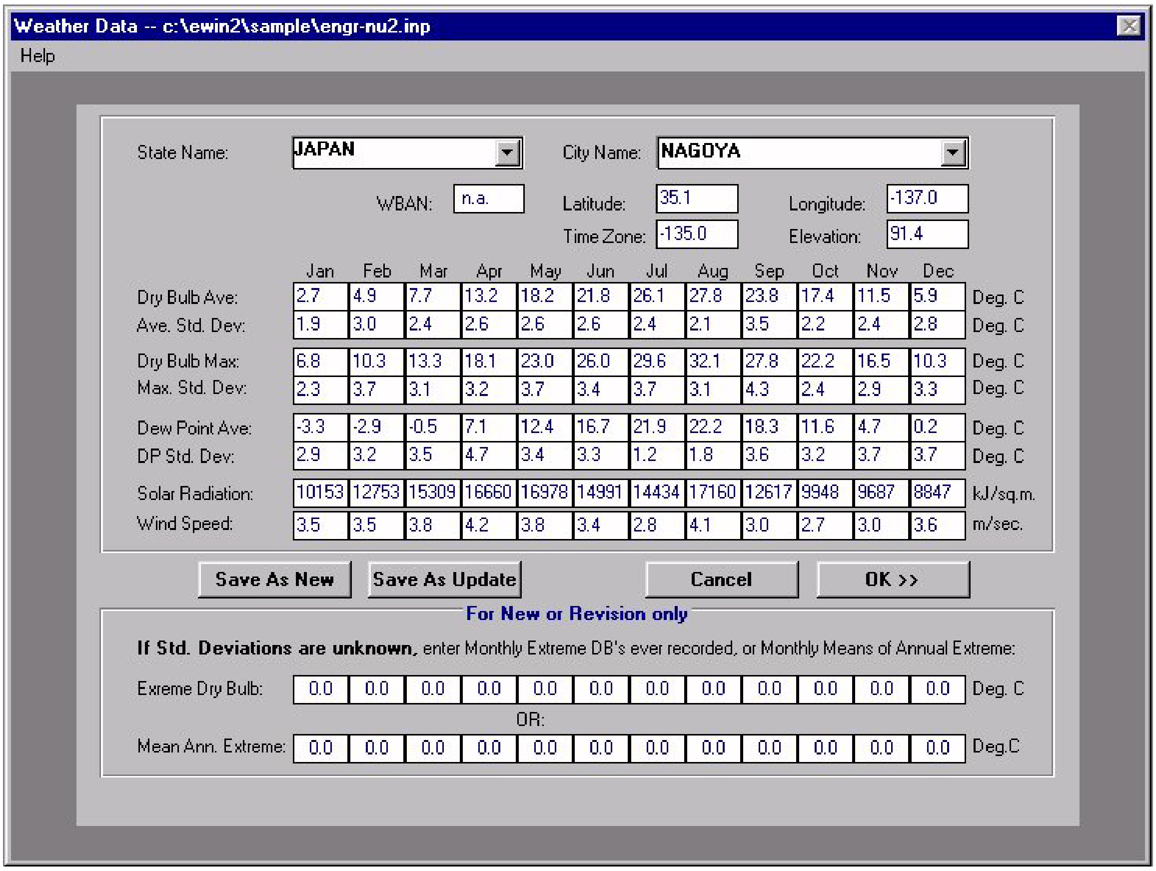


Figure 6-2 Weather data screen in ENER-WIN simulation software

2. Envelope material cataloging

The envelope material cataloging permits any wall, roof, or glazing assembly to be specified and entered in simple, numbered catalog. The material specifications require the assembly's thermal conductance, thermal capacitance, and the absorptivity of the outside surface to solar radiation.

3. User profile adjustment

The user profile data of the software permits the user to specify the hourly patterns of occupancy, hot water usage, lighting, electric loads, ventilation rates, seasoning temperature setting (summer, winter), and holiday & work day setting. Figure 6-3 shows example of user profile setting from the software.

4. Zone processing

The zone processing involves linking the zones to the profile numbers and specifying the other zone related parameters. These parameters include the floor area, ceiling height, interior mass, usage schedule / profiles, lighting type, mechanical system type, heating fuel type, economizer cooling, and daylighting parameters. Figures 6-3-4 shows the example of ENER-WIN screen for zone description input.

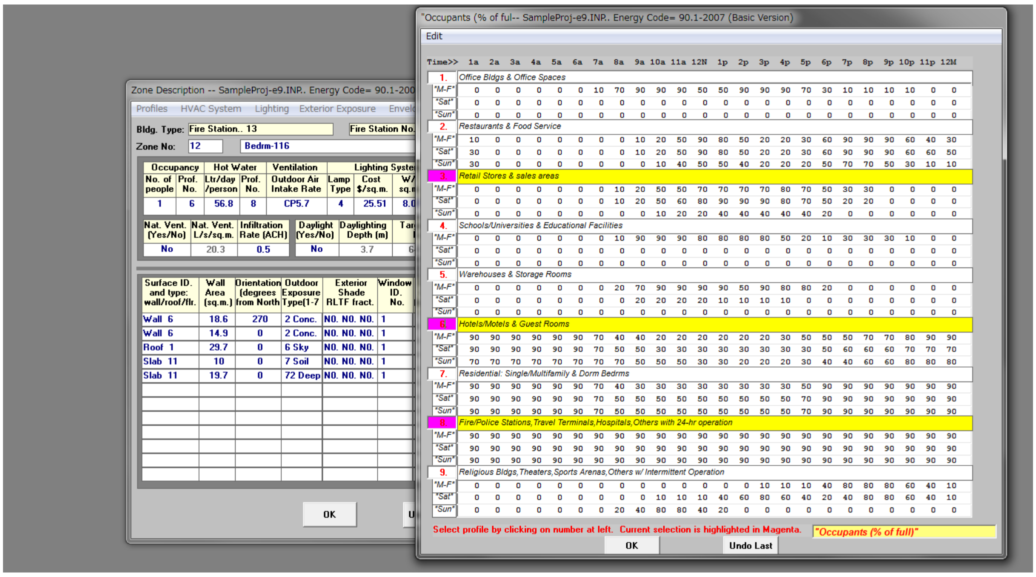


Figure 6-3 User profile adjustment screen

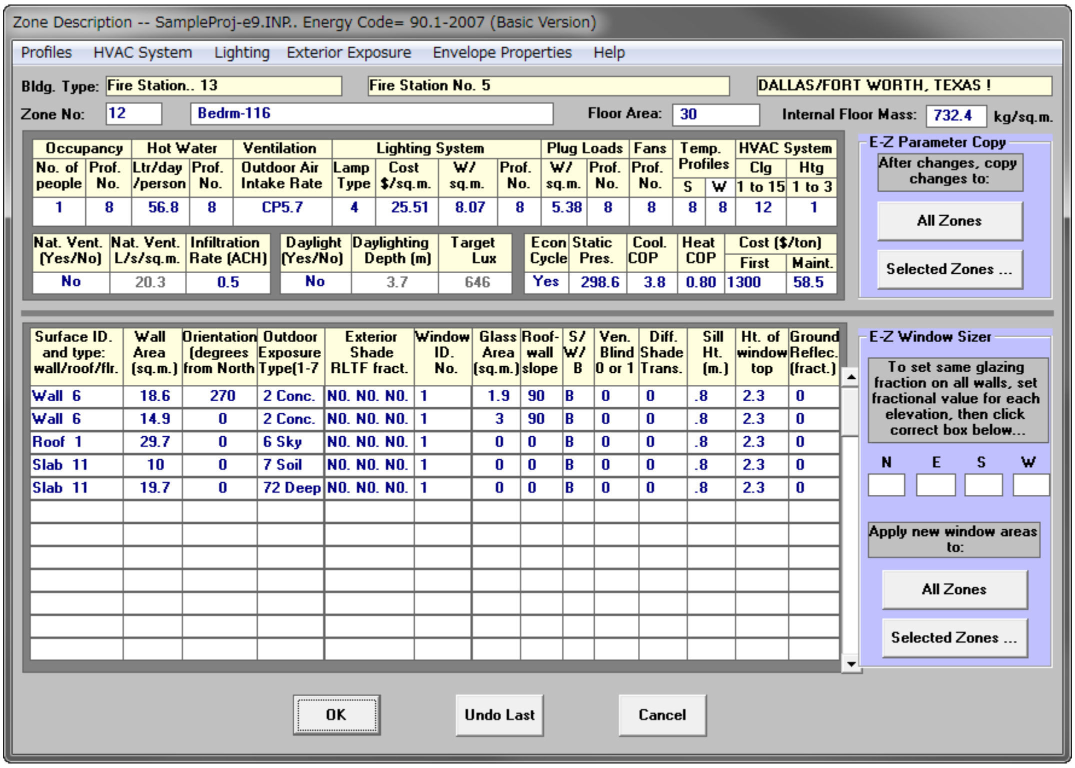


Figure 6-4 Zone description screen

5. Building geometry processing

This process is conducted in a set of routines which link the previously defined envelop to the walls and roofs of each building zone. The geometry routines also manipulate the envelope's areas, orientations, slope, shading, and exposure to the specified ground cover. Shade types include diffuse screens, overhangs, adjacent building, and trees. Figure 6-5 shows the example of building geometry processing of ENER-WIN.

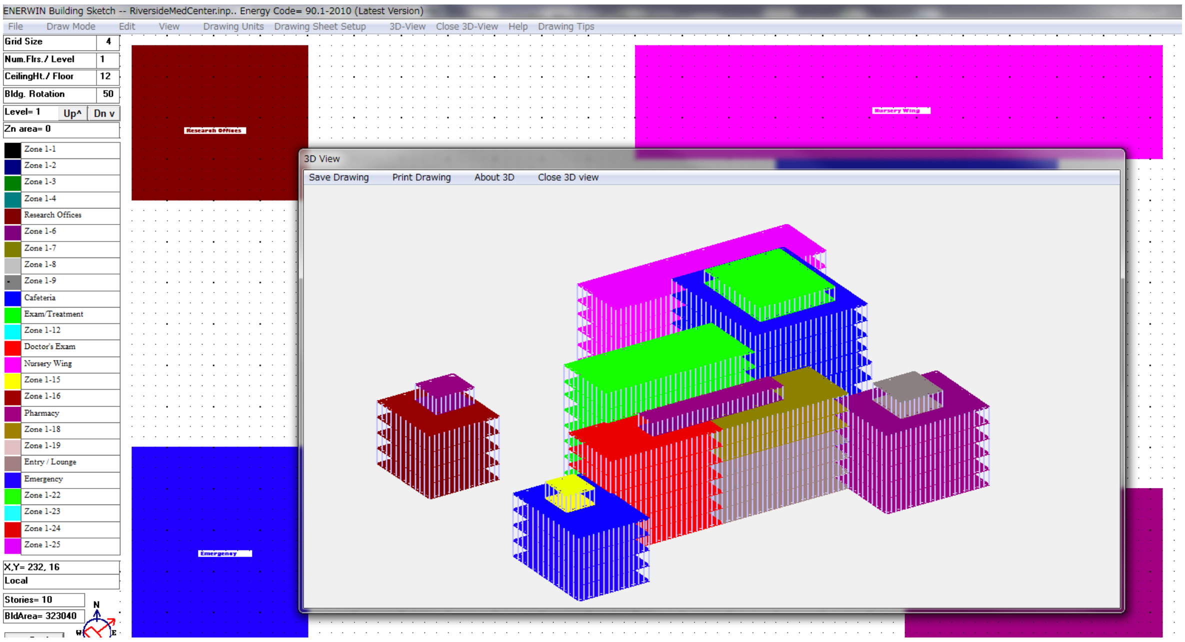


Figure 6-5 Building geometry processing

6. Load calculations

For the load calculations of ENER-WIN simulation software, the energy summations are performed simultaneously for each of the 8760 hours in a year beginning at 1:00 a.m on January 1 and are based on the generated exterior weather conditions and the interior temperature profiles and loads.

7. System simulations

The system is initially sized for the hottest day in a year, but may be resized numerous times, if necessary, when a new peak load is encountered. The energy calculations are based on embedded system efficiencies typical of the system chosen. Simulation methods can be selected for simplified output or hourly output as shown in Figure 6-6.

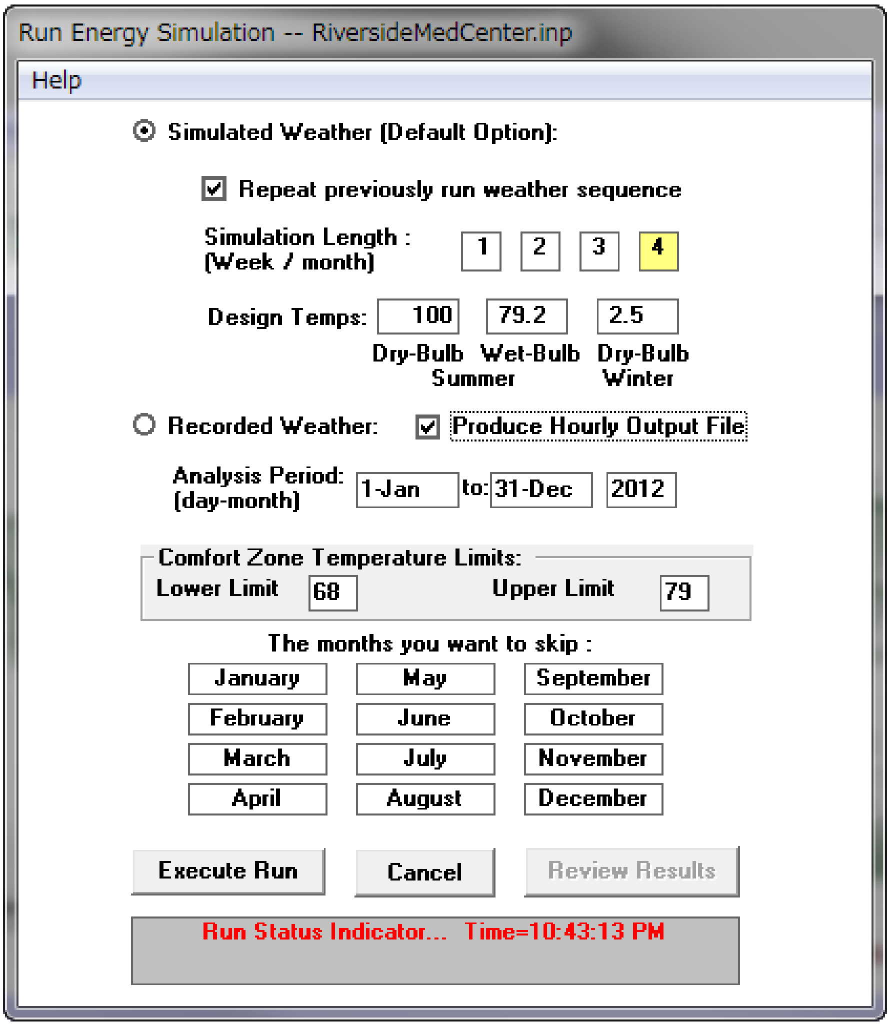


Figure 6-6 Selection of simulation details

8. Energy summations

The program outputs a monthly summary of the various categories of energy use, as well as peak demands and utility bills. The output from ENER-WIN also shows the monthly energy use and charges, which broken down into space heating / cooling, fan motors, water heating, lighting, and equipment. As well as the output of annual energy use and charge will also showed the cost saving from the use of daylighting as shown in Figures 6-7, 6-8, and 6-9.

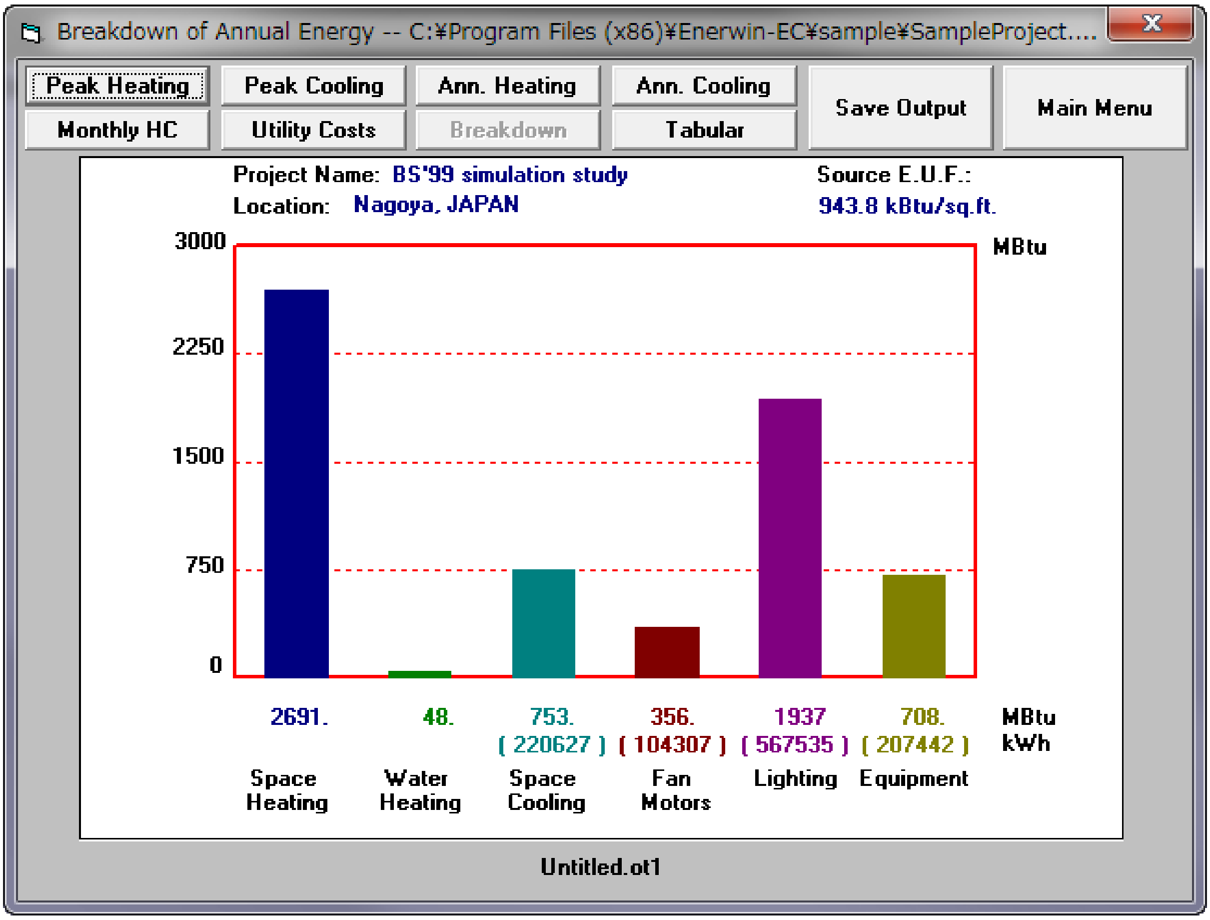
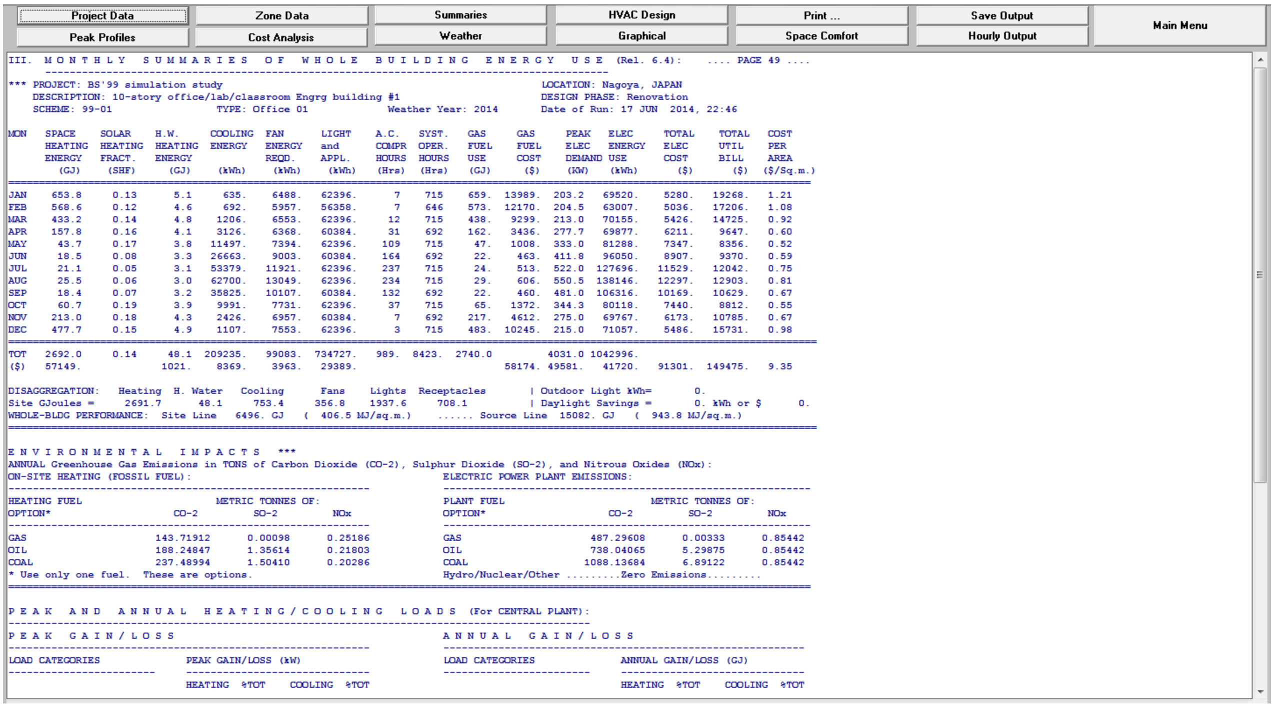


Figure 6-7 Example of Annual energy output from the simulation



III. M O N T H L Y S U M M A R I E S O F W H O L E B U I L D I N G E N E R G Y U S E (Rel. 6.4): .... PAGE 49 ....

*** PROJECT: BS'99 simulation study LOCATION: Nagoya, JAPAN
DESCRIPTION: 10-story office/lab/classroom Engrg building #1 DESIGN PHASE: Renovation
SCHEME: 99-01 TYPE: Office 01 Weather Year: 2014 Date of Run: 17 JUN 2014, 22:46

MON	SPACE HEATING ENERGY (GJ)	SOLAR HEATING FRACT. (SHF)	H.W. HEATING ENERGY (GJ)	COOLING ENERGY (kWh)	FAN ENERGY REQD. (kWh)	LIGHT and APPL. (kWh)	A.C. COMPR HOURS (Hrs)	SYST. OPER. HOURS (Hrs)	GAS FUEL USE (GJ)	GAS FUEL COST ($)	PEAK ELEC DEMAND (KW)	ELEC ENERGY USE (kWh)	TOTAL ELEC COST ($)	TOTAL UTIL BILL ($)	COST PER AREA ($/Sq.m.)
JAN	653.8	0.13	5.1	635.	6488.	62396.	7	715	659.	13989.	203.2	69520.	5280.	19268.	1.21
FEB	568.6	0.12	4.6	692.	5957.	56358.	7	646	573.	12170.	204.5	63007.	5036.	17206.	1.08
MAR	433.2	0.14	4.8	1206.	6553.	62396.	12	715	438.	9299.	213.0	70155.	5426.	14725.	0.92
APR	157.8	0.16	4.1	3126.	6368.	60384.	31	692	162.	3436.	277.7	69877.	6211.	9647.	0.60
MAY	43.7	0.17	3.8	11497.	7394.	62396.	109	715	47.	1008.	333.0	81288.	7347.	8356.	0.52
JUN	18.5	0.08	3.3	26663.	9003.	60384.	164	692	22.	463.	411.8	96050.	8907.	9370.	0.59
JUL	21.1	0.05	3.1	53379.	11921.	62396.	237	715	24.	513.	522.0	127696.	11529.	12042.	0.75
AUG	25.5	0.06	3.0	62700.	13049.	62396.	234	715	29.	606.	550.5	138146.	12297.	12903.	0.81
SEP	18.4	0.07	3.2	35825.	10107.	60384.	132	692	22.	460.	481.0	106316.	10169.	10629.	0.67
OCT	60.7	0.19	3.9	9991.	7731.	62396.	37	715	65.	1372.	344.3	80118.	7440.	8812.	0.55
NOV	213.0	0.18	4.3	2426.	6957.	60384.	7	692	217.	4612.	275.0	69767.	6173.	10785.	0.67
DEC	477.7	0.15	4.9	1107.	7553.	62396.	3	715	483.	10245.	215.0	71057.	5486.	15731.	0.98
TOT	2692.0	0.14	48.1	209235.	99083.	734727.	989.	8423.	2740.0		4031.0	1042996.			
($)	57149.		1021.	8369.	3963.	29389.				58174.	49581.	41720.	91301.	149475.	9.35

DISAGGREGATION: Heating H. Water Cooling Fans Lights Receptacles | Outdoor Light kWh= 0.
Site GJoules = 2691.7 48.1 753.4 356.8 1937.6 708.1 | Daylight Savings = 0. kWh or $ 0.
WHOLE-BLDG PERFORMANCE: Site Line 6496. GJ (406.5 MJ/sq.m.) ...... Source Line 15082. GJ (943.8 MJ/sq.m.)

E N V I R O N M E N T A L I M P A C T S ***
ANNUAL Greenhouse Gas Emissions in TONS of Carbon Dioxide (CO-2), Sulphur Dioxide (SO-2), and Nitrous Oxides (NOx):

ON-SITE HEATING (FOSSIL FUEL):

HEATING FUEL OPTION*	METRIC TONNES OF: CO-2	SO-2	NOx
GAS	143.71912	0.00098	0.25186
OIL	188.24847	1.35614	0.21803
COAL	237.48994	1.50410	0.20286

* Use only one fuel. These are options.

ELECTRIC POWER PLANT EMISSIONS:

PLANT FUEL OPTION*	METRIC TONNES OF: CO-2	SO-2	NOx
GAS	487.29608	0.00333	0.85442
OIL	738.04065	5.29875	0.85442
COAL	1088.13684	6.89122	0.85442

Hydro/Nuclear/Other ....Zero Emissions.........

P E A K A N D A N N U A L H E A T I N G / C O O L I N G L O A D S (For CENTRAL PLANT):

P E A K G A I N / L O S S
LOAD CATEGORIES PEAK GAIN/LOSS (kW)
HEATING %TOT COOLING %TOT

A N N U A L G A I N / L O S S
LOAD CATEGORIES ANNUAL GAIN/LOSS (GJ)
HEATING %TOT COOLING %TOT

Figure 6-8 Example of Monthly energy output from the simulation

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	*** PROJECT: BS'99 simulation study					LOCATION: NAGOYA, JAPAN !									
2	PLAN: NNV	TYPE: Office		Year: 1999	Date of Run: 4 MAR 2002										
3	HOURLY WEATHER AND SOLAR DATA:														
4	WBAN Station I.D.: n.a.														
5						*Solar Angles, Radiation & Sky Cover*									
6	Date	Time	DB	WB	DP	Sun	Sun	Direct	Direct	Diff.	Total	Cloud	Wind	Stn	
7			temp	temp	temp	alt.	azimuth	normal	horiz	horiz	horiz	cover	speed	PB	
8			(øC)	(øC)	(øC)			(Whr per sq m.)				(%)	(m/s)	(kPa)	
4281	28-Jun	1	19.4	18.1	17.4	0	0	0	0	0	0	100	2.3	100.14	
4282	28-Jun	2	18.3	17.6	17.2	0									
4283	28-Jun	3	17.6	17.3	17	0									
4284	28-Jun	4	17.1	17	16.9	0									
4285	28-Jun	5	16.9	16.9	16.9	2.8									
4286	28-Jun	6	17.2	17	16.8	14.1									
4287	28-Jun	7	18	17.1	16.7	26									
4288	28-Jun	8	19.3	17.3	16.4	38.1									
4289	28-Jun	9	20.9	17.6	16	50.4									
4290	28-Jun	10	22.6	18	15.6	62.4									
4291	28-Jun	11	24.4	18.5	15.2	73.2									
4292	28-Jun	12	26	18.8	14.9	78.2									
4293	28-Jun	13	27.3	19	14.6	71.6									
4294	28-Jun	14	28.1	19.2	14.4	60.5									
4295	28-Jun	15	28.4	19.2	14.4	48.4									
4296	28-Jun	16	28.3	19.2	14.4	36.1									
4297	28-Jun	17	28	19.2	14.5	24									
4298	28-Jun	18	27.5	19.1	14.7	12.2									
4299	28-Jun	19	26.8	19.1	14.9	1									
4300	28-Jun	20	26	19	15.2	0									
4301	28-Jun	21	25.2	18.9	15.5	0									
4302	28-Jun	22	24.2	18.8	15.8	0	0	0	0	0	0	100	3.5	100.34	
4303	28-Jun	23	23.3	18.7	16.2	0	0	0	0	0	0	100	5.3	100.31	
4304	28-Jun	24	22.5	18.4	16.5	0	0	0	0	0	0	100	2.7	100.28	
4305	29-Jun	1	21.7	18.3	16.7	0	0	0	0	0	0	76	3.3	99.94	
4306	29-Jun	2	21	18.3	17	0	0	0	0	0	0	76	1.5	99.9	
4307	29-Jun	3	20.5	18.2	17.1	0	0	0	0	0	0	76	2.8	99.88	

EWETH$

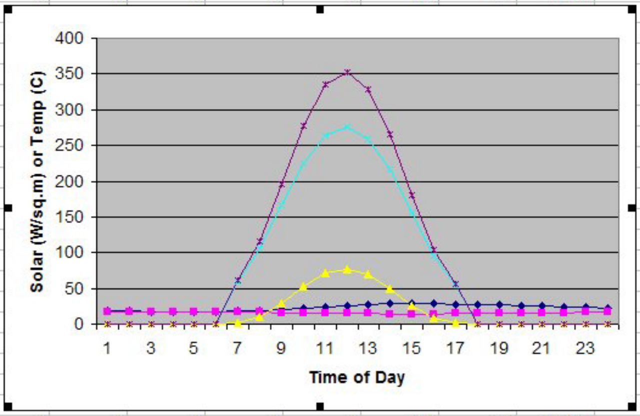


Figure 6-9 Example of Hourly energy output from the simulation

6-4 CASE STUDY 1 - FEASIBILITY STUDY ON INTRODUCTION OF COGENERATION SYSTEM FOR THAILAND'S OFFICE BUILDING

6-4-1 LOAD PROFILE ASSESSMENT AND CHARACTERISTICS ANALYSIS

According to the investigation of peak load profile for the total energy consumption of the office buildings in Bangkok from Metropolitan Electricity Association (MEA), the author choose the building which have load profiles with similar total consumption which should be consequence to the energy consumption unit data from the database of Department of Alternative Energy Development and Energy Efficiency (DEDE). The pattern of load profiles of office building in this study is shown in Figure 6-10. [7,8]

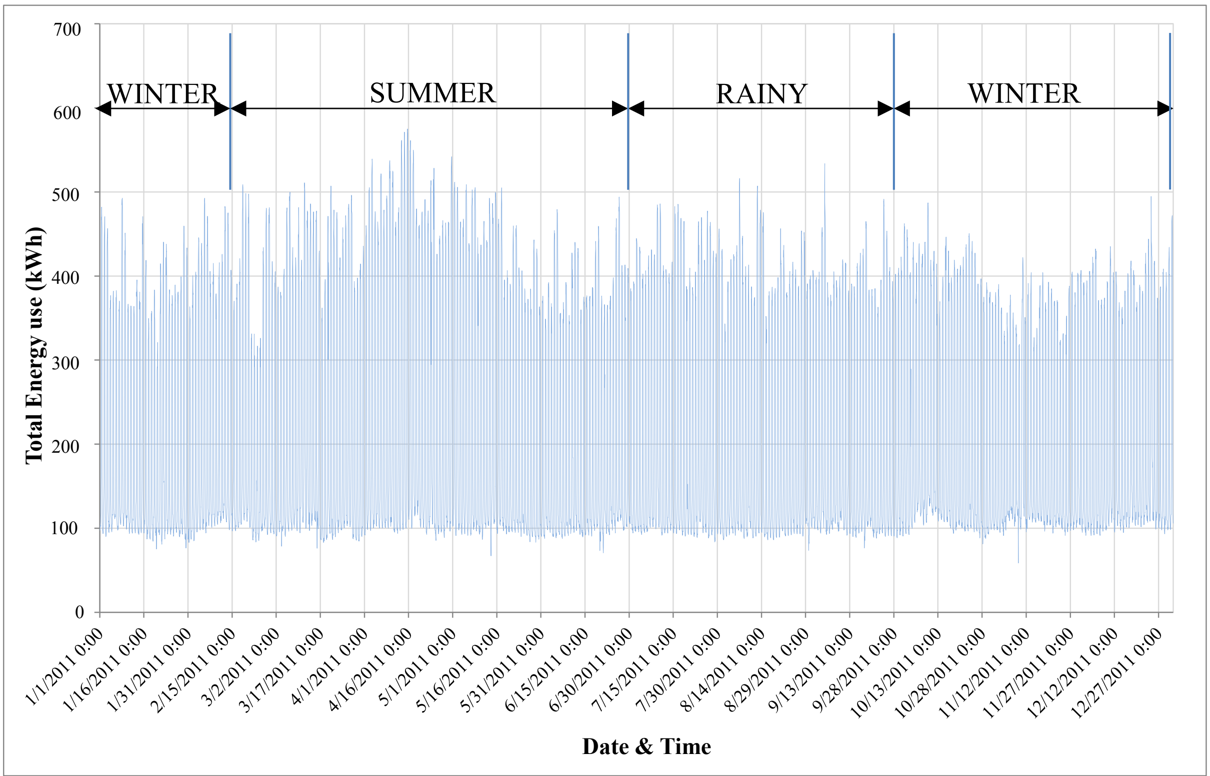


Figure 6-10 Hourly load profile of total energy use of Thailand's office building

Considering the fluctuation of energy consumption from the office buildings, peak consumption is in the summer season, from Mid-April to early of May because of the reason as mentioned from the analysis in Chapter 4, Air-conditioning system consumed the highest proportion of the energy utilization for office buildings in Thailand. However, due to the different of the temperature for every climates in Central part of Thailand cannot see much difference, the consumption in other periods are similar but may different from the characteristics of energy use in that period as shown in Figure 6-11, the average values of total energy use which separated by month found that from January to April, the energy consumption will gradually increase and become peak consumption in April. After that, the consumption will decrease in high rate from April to June and finally become slightly change until December.

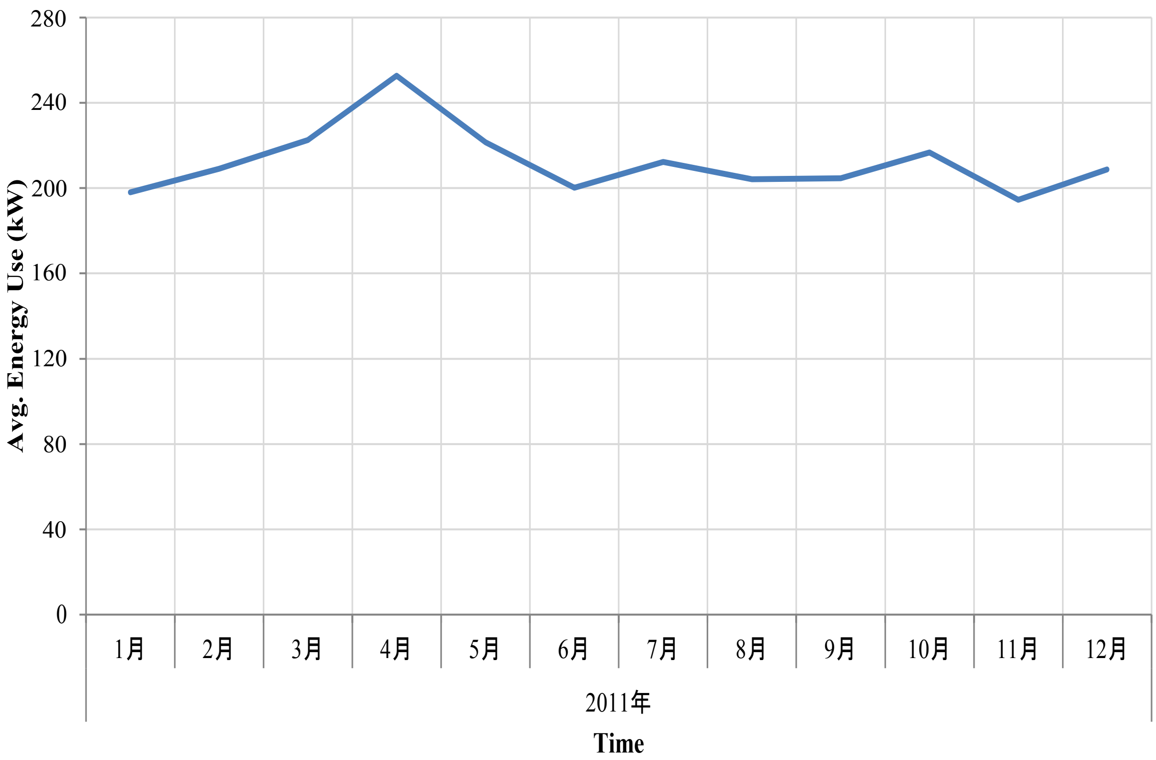


Figure 6-11 Average value of total energy consumption by Month for Office building

Considering the energy consumption by day, the load profile of average energy use per day is slightly increase from 7:00-8:00 A.M and increase with high rate and become stable from12:00 due to the utilization of air-conditioning system, equipment inside the office buildings, lighting systems, and other systems. The utilization of peak consumption is slightly change until evening (18:00 or 18:30 P.M) and decrease to lowest point around 21:00 P.M. Figure 6-12 illustrates the daily average energy consumption which represented in hourly consumption. Pattern of the consumption in every month is similar manner but different for the amount of consumption due to the characteristics of energy use in specific time as shown in Figure 6-13.

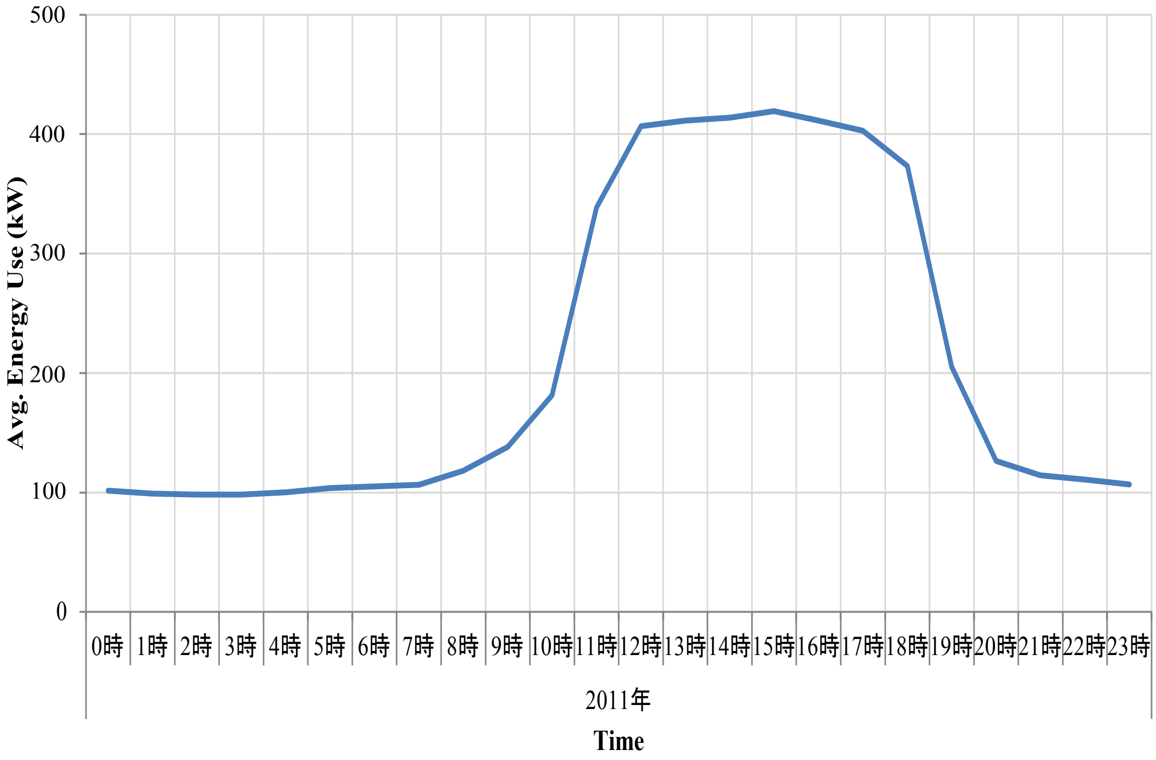


Figure 6-12 Average hourly consumption per day for office building

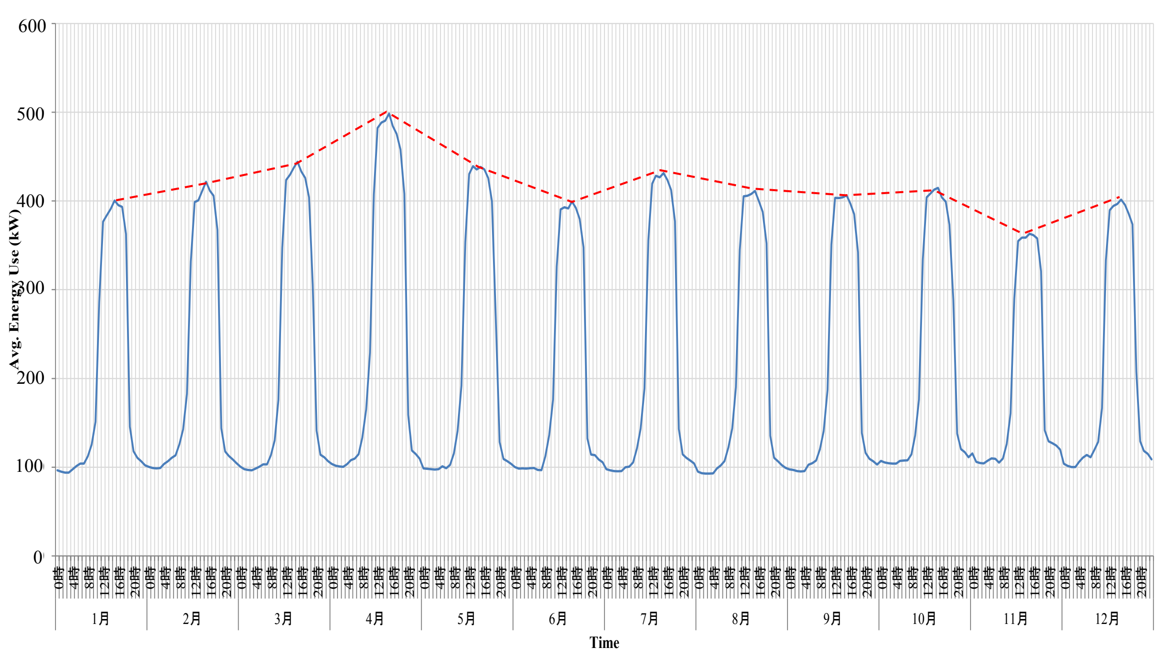


Figure 6-13 Average hourly consumption per day for office building in one year

6-4-2 LOAD ASSESSMENT RESULTS FROM SIMULATION

In this study, the simulation of energy use of the office building was conducted by ENER-WIN simulation software. The simulated building is a 20-storey 18580.6 m^2 office building with service core at the middle with area 929.03 m^2. Figure 6-14 is the 3D view of the building generated with 3D Design Software. The dimension of the office building is 30.5m × 30.5 m × 4m per floor level.

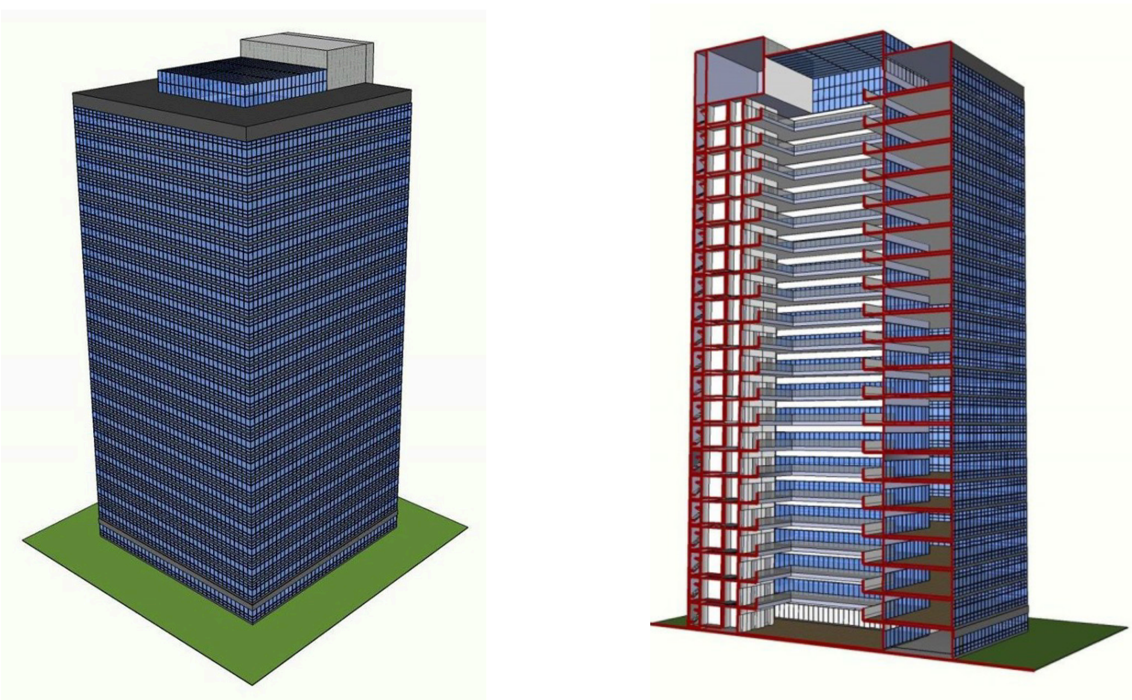


Figure 6-14 3D view and cross section of office building for analysis

The load density of the data center model consisting of office equipment and lignthing load was specified to be 14 W/m2 for all service time from 7:00 – 21:00 every day but all the time in some zone (8760 hr per year) from the minimum allowable value from Thailand's Building Energy code. The HVAC system used was a packaged single sone (PSZ) direct expansion (DX) system. Similar to the load schedule, the fan schedule was also assumed to be on in service hour. In service core zone, has no HVAC system installed but lighting system still operated all the time.

6-4-2-1 MODEL CALIBRATION

Simulation is commonly held to be the best practice approach to performance analysis in the building industry. However, there are significant discrepancies between simulation results and the actual measured consumption of real buildings.

In this study the graphical and statistical methods for calibration which based on the specific graphical representations and comparative displays of the results to orient the calibration process in order to use the energy consumption data for acceptable values for office building's energy consumption.

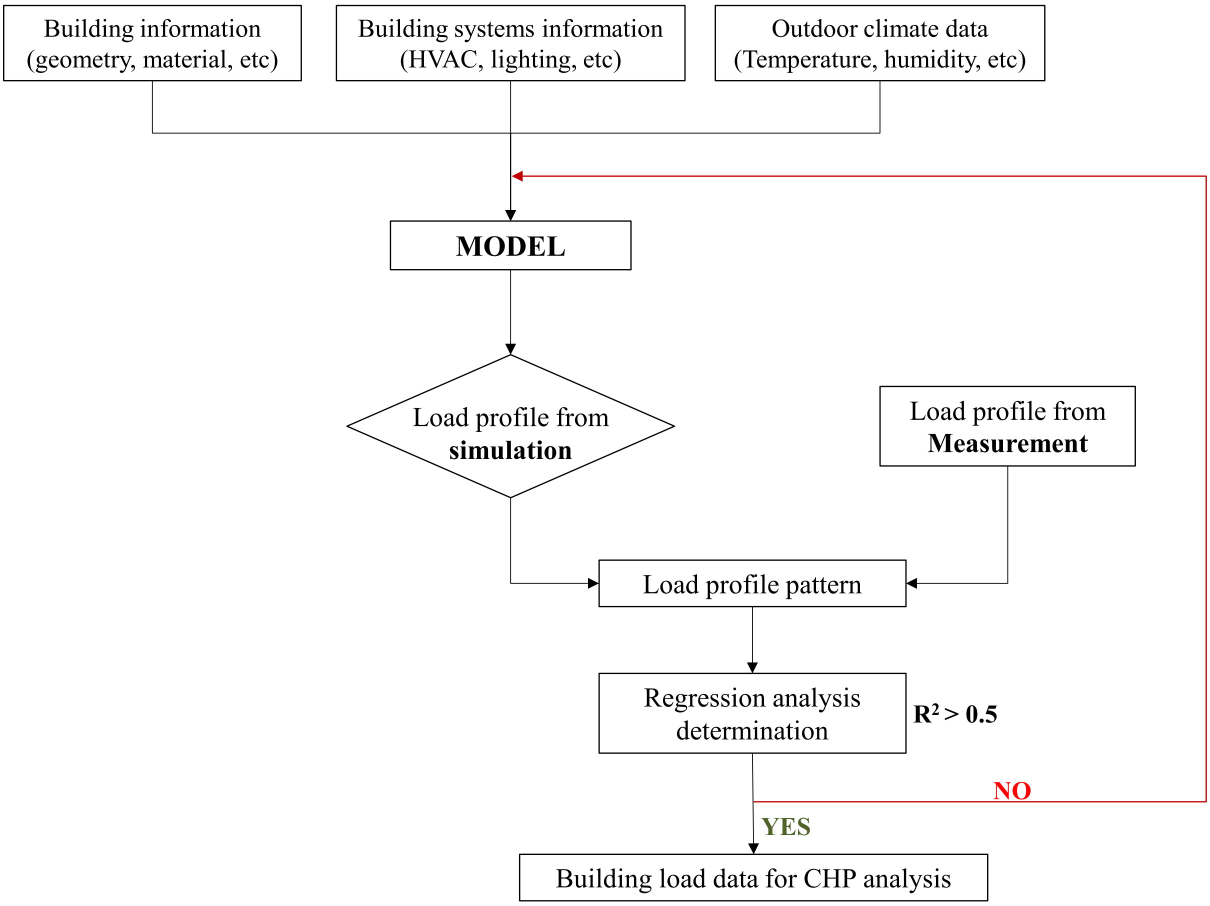


Figure 6-15 Model calibration flow chart

The comparison of the results of energy consumption data from simulation and that of real buildings as shown in Figure 6-1 can be acceptable if the coefficient of determination from statistical methods, which represented by R-squared (R^2) from 2 sources (simulation and real data) is more than 0.5. Otherwise, the model from the simulation need to be revised again by adjust some unknown parameters, e.g. no. of occupancy, operation schedule o HVAC and lighting system, temperature adjustment, etc. until the value of R^2 becomes more than 0.5. The flow chart of the model calibration is shown in Figure 6-15. It is noted that the comparison between simulation results and real data will use the monthly energy consumption to verify the regression analysis of the model.

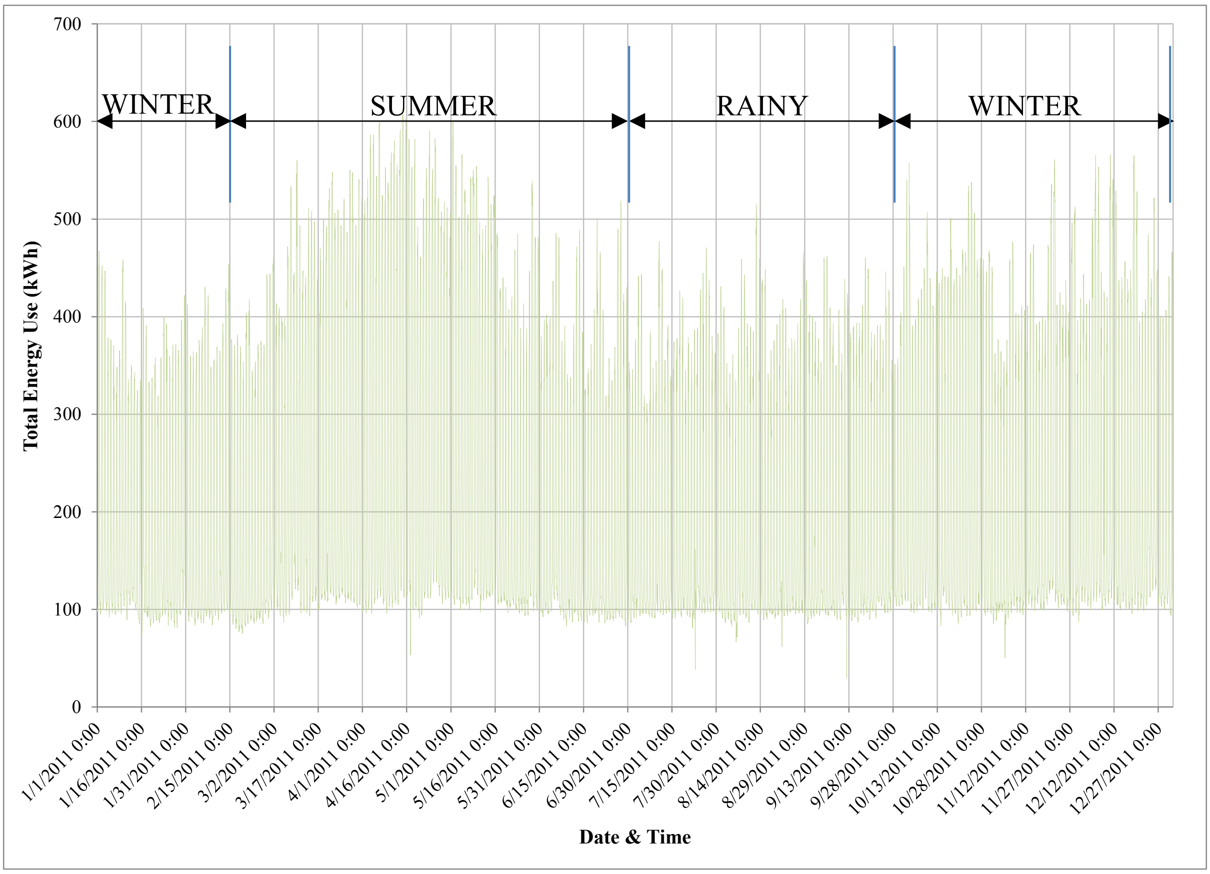


Figure 6-16 Hourly load profile of total energy use from the simulation

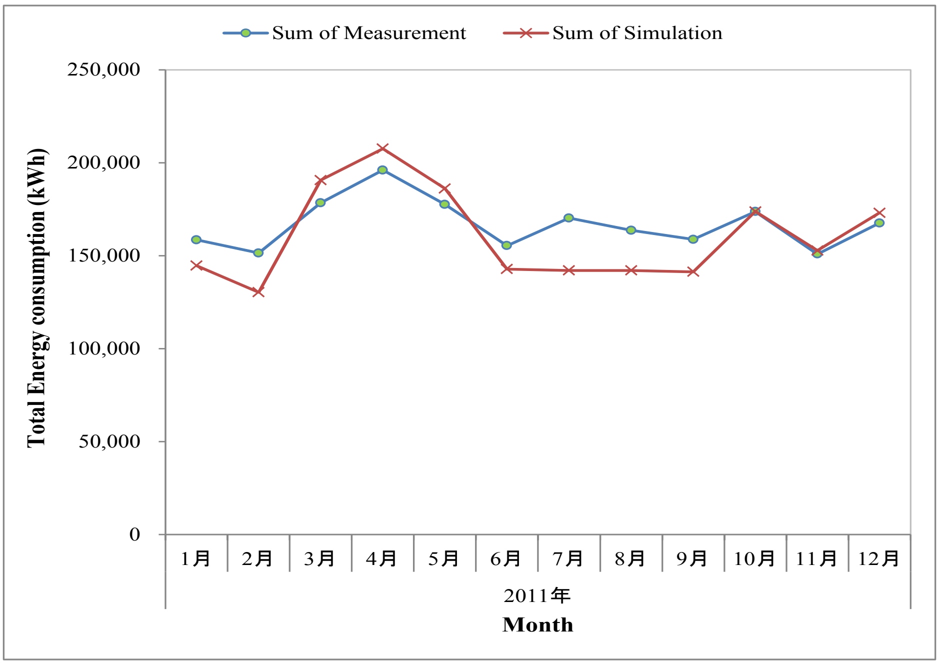


Figure 6-17 Monthly Load profile pattern comparison in one year

From the calibration of the building simulations, the value of R-squared from regression analysis from the relationship between measurement data and simulation data is equal to 0.78 which acceptable for the energy consumption data. Figure 6-18 shows the regression analysis results of energy consumption data between simulation and data from measurement.

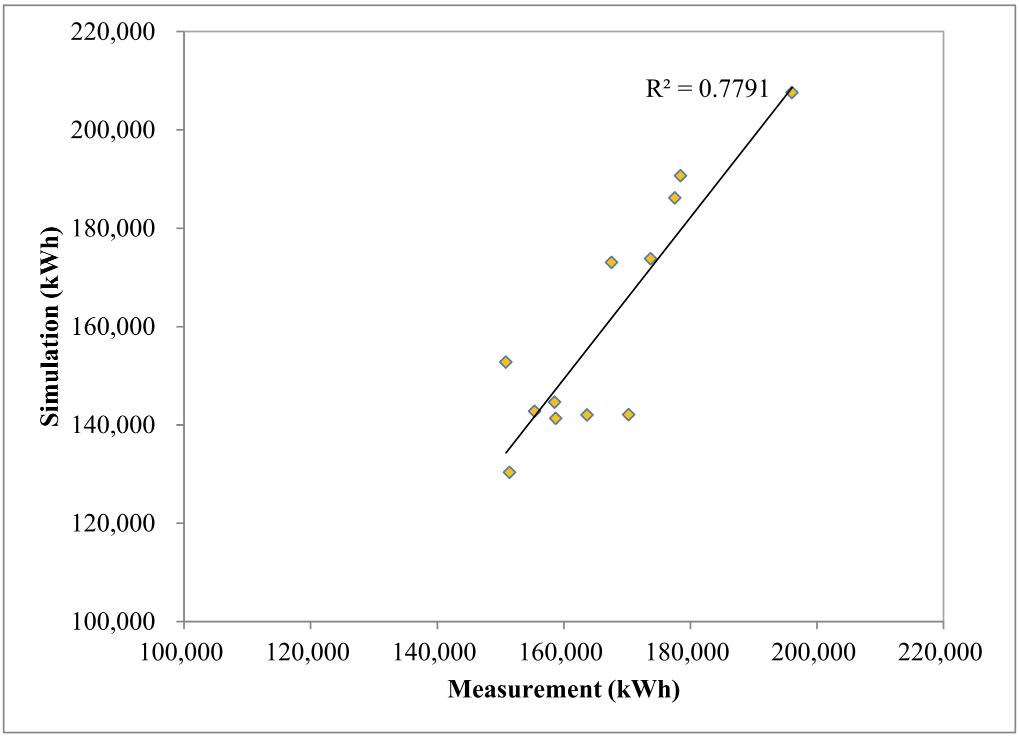


Figure 6-18 Regression analysis results of the energy consumption for office building

In summary, there are 3 major systems which consume significant energy in a typical office building – the air conditioning (A/C) system, the lighting system, and the equipment (including other systems). Figure 6-19 to 6-21 show the average value of load pattern in each system in 1-day. It is found that peak load of cooling demand, equipment demand, and lighting demand are 418.5 kW, 377.52 kW, and 127.5 kW, respectively. From this profiles, the following characteristics were derived:

1. The hourly load from lighting system and cooling system is increase and decrease in the same period due to the working hour of the office buildings but the consumption from cooling demand is high comparing with the demand from lighting system
2. Except the working hour, cooling demand of the office buildings becomes zero (or almost zero) regarding to the unoccupied period of time which different from lighting system still have remains consumption all the time either working or non-working time. But the non-working time, the consumption is low due to the opening lighting for some zones only.

3. The hourly load from equipment, even though the peak load is not high as the energy from cooling demand but the operation needs to be operated 24-hours for whole year.

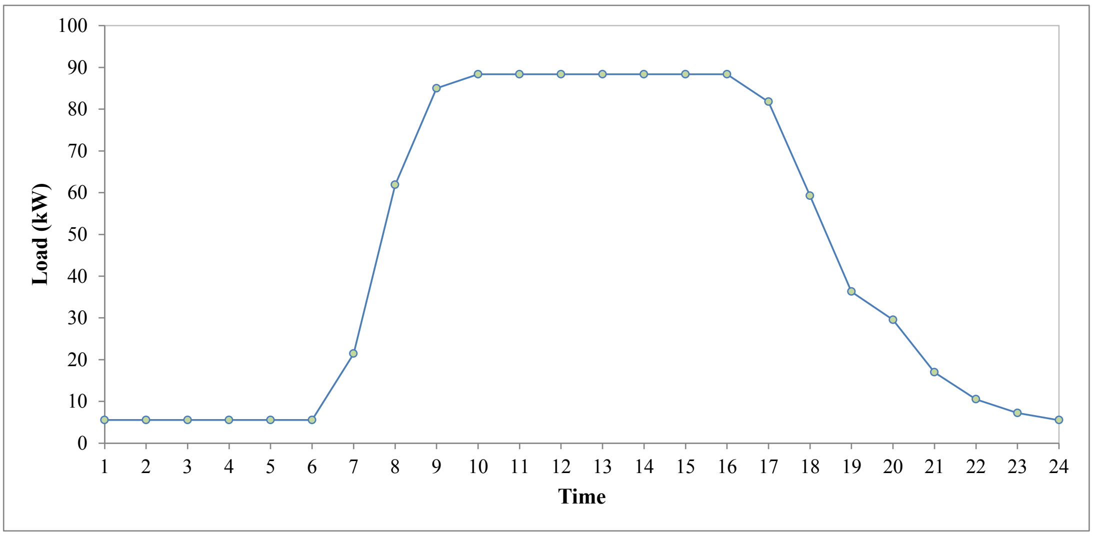


Figure 6-19Average value of energy consumption from lighting system

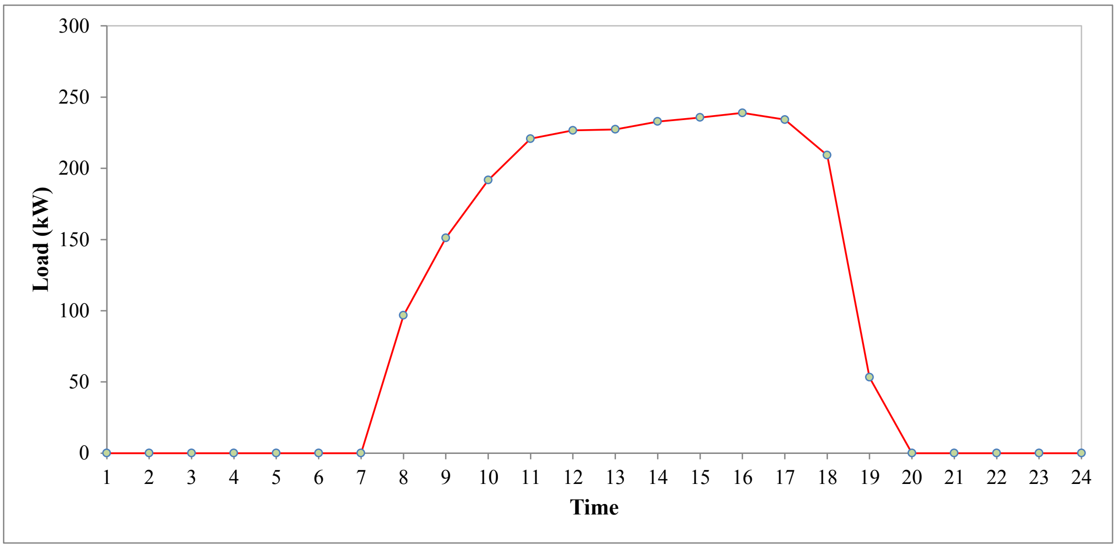


Figure 6-20 Average value of energy consumption from Cooling system

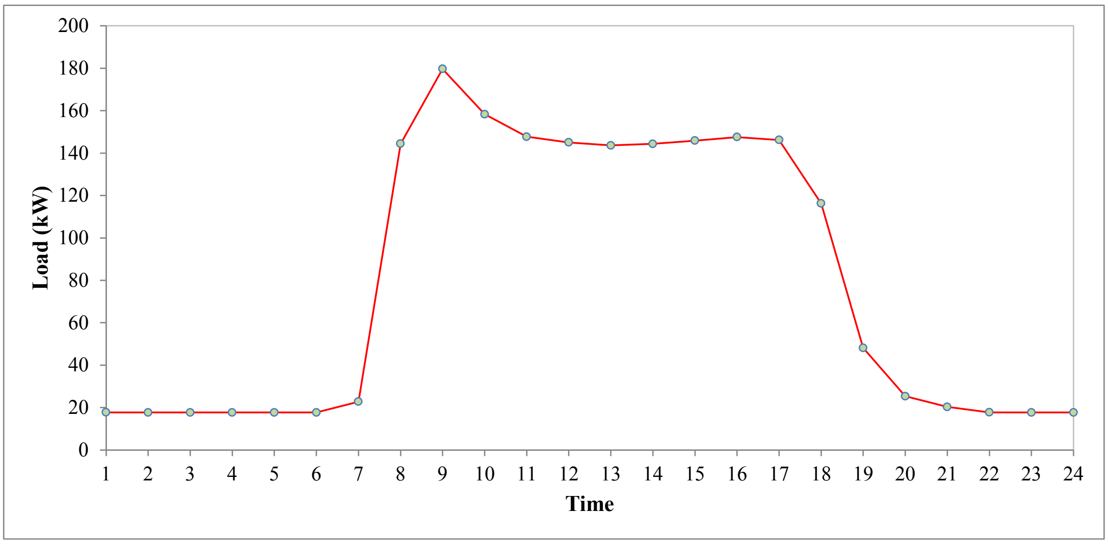


Figure 6-21 Average value of energy consumption from Equipment

Figure 6-22 illustrates the hourly energy demand for all systems which represented by load-duration curve (monotonic curve) which starting with the largest to smallest consumption values in 1-year consumption of cooling, equipment, and lighting demands, respectively. Table 6-4-1 summarizes the maximum value, minimum value, and average values of all systems for office building's energy consumption

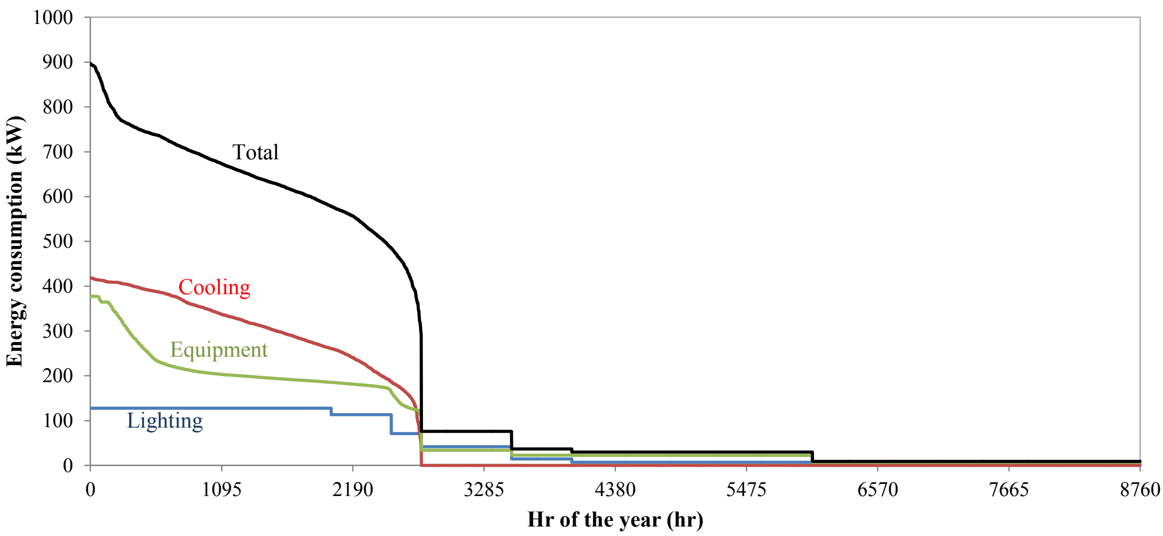


Figure 6-22 Load-duration curves of energy demand separated by system of office building

Table 6-4-1 Summary of max, min, and average load consumption of office building

	Total used (kW)	A/C demand (kW)	Equipment demand (kW)	Lighting demand (kW)	Hot water demand (kW)
Max.	897.10	418.50	377.52	127.50	-
Min.	8.92	0	6.79	2.12	-
Sum	1,927,329.27	846,214.9 [43.9%]	691,687.4 [35.9%]	389,426.9 [20.2%]	-

6-4-3 CASE SETTING AND SIMULATION METHOD

6-4-3-1 MODELING OF CHP SYSTEM

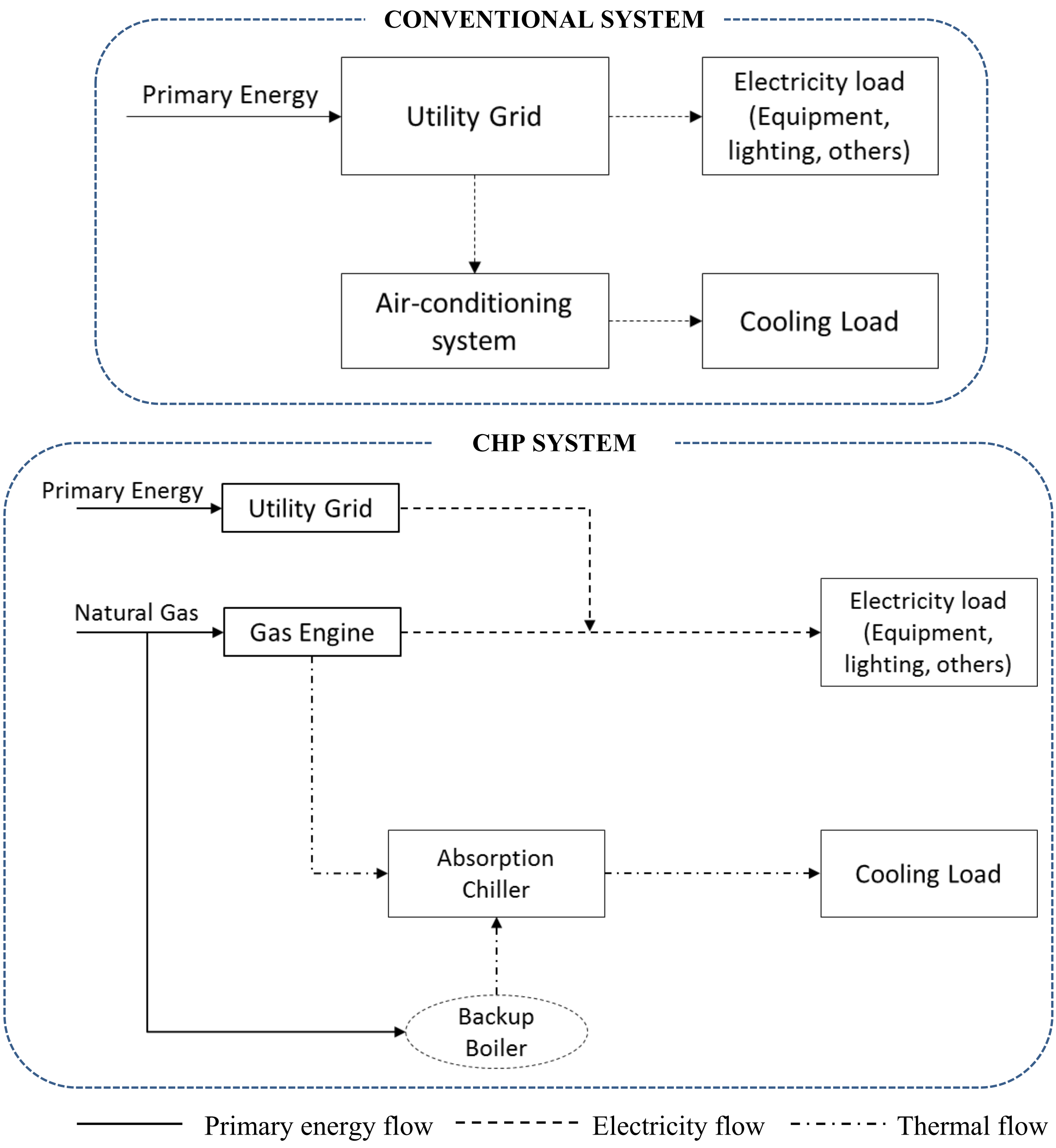


Figure 6-23 Energy flow diagrams of conventional energy supply system and CHP energy supply system

According to end-used demand data of hourly in Figure 6-23, the comparative study between conventional system and CHP system is executed by using conventional system as a baseline. For the conventional system, the utility grid serves all electrical demand which is used for not only direct power consumption, but also for space cooling load through the operation of the building's air-conditioning system. CHP system in this energy diagram consists of a gas engine and absorption chiller. The mode of the gas engine is electricity tracking. The gas engine is used to meet the electrical and cooling loads with the use of an air-conditioning system through the absorption chiller. If the recovery of thermal energy from the gas engine does not fully satisfy the absorption chiller's needs, an additional boiler is used. However, if the recovered thermal energy goes over local needs, the surplus energy is released into the atmosphere.

6-4-3-2 INPUT ASSUMPTIONS OF THE CASE STUDY [10,11]

For the evaluation of the introduction of cogeneration system for Thailand's office building from case study, the prime mover of the CHP system using gas engine for consideration, combining with the utility electricity, back-up boiler and air conditioning system to accommodate the customer requirements. Some main assumed data for this analysis is summarized in Table 6-4-2 and by using data in Japan as the reference for pricing and efficiency of Gas engine, air-conditioning system (centralized chiller system), and Table 6-4-3 for others related parameters for analysis.

Table 6-4-2 Data assumption for the analysis of Gas engine

Item	**capacity**	**Electrical efficiency, η_E**	**Thermal efficiency, η_H**	**Investment cost (万円)**
GE-1	100	0.30	0.48	2000
GE-2	150	0.31	0.47	2925
GE-3	200	0.32	0.46	3800
GE-4	250	0.33	0.45	4625
GE-5	300	0.34	0.44	5400
GE-6	350	0.35	0.43	6125
GE-7	400	0.36	0.42	6800

GE: Gas Engine

Table 6-4-3 Data assumption for other related parameters

Machine	Capacity (kW)		COP		Inv. Cost (万円)
	Cooling	Thermal	Cooling	Thermal	
ABS-1	400	260	1.45	0.88	1920
ABS-2	450	300	1.45	0.88	2160
ABS-3	500	330	1.45	0.88	2400
TC-1	800	-	6	-	3000
TC-2	850	-	6	-	3100
TC-3	900	-	6	-	3200
GB-1	-	50		0.9	150
GB-2	-	100		0.9	280
GB-3	-	150		0.9	390

Note: ABS: Absorption chiller TC: Turbo chiller GB: Gas boiler

Table 6-4-4 Data assumption for other related parameters (cont.)

Item	Data assumptions	Value
Electricity utility grid	Efficiency (%)	30
	Service charge (THB/kWh)	312.24
	Demand charge (THB/kW)	132.93
	Energy price – on peak / off peak (THB/kWh)	2.176 / 3.6796
Natural gas	Energy price (THB/mmBTU)	350
Air-conditioning system	Coefficient of performance (COP)	3
	Lifetime (year)	10
	Capital cost ($\times 10^3$ THB/kW)	5.2
Absorption chiller	Coefficient of performance (COP)	1.1
	Lifetime (year)	15
	Capital cost ($\times 10^3$ THB/kW)	15.48
Back-up natural gas boiler	Efficiency (%)	85
	Lifetime (year)	15
Cogeneration Plant	Capacity (kW)	varied
	Electricity efficiency, η_E (%)	25,30,35,40,45
	Heat recovery efficiency, η_H (%)	25,30,35,40,45

	Capital cost ($\times 10^3$ THB/kW)	64.52
	Lifetime (year)	15
Others	Interest rate (%)	2

6-4-4 ANALYSIS RESULTS AND DISCUSSIONS

6-4-4-1 EVALUATION OF ENERGY PERFORMANCE [12-15]

Generally, there are many methods to verify the reasonable sizing of the cogeneration refers to the choice in the rated electric and thermal power of the cogeneration unit. The common reasoning in the sizing of the thermal power of cogeneration unit is to maximize its thermal output as pursued in the "maximum rectangle rule" from the heat load-duration curve. However, the evaluation of the sizing of the cogeneration plant will not recognized for the operation time as the point of concern. The evaluation of the optimal sizing of cogeneration plant for this case study is based on the design stage to verify the effect of cogeneration capacity to the saving performance of primary energy supply under the constraints of the building's demand.

As mentioned in Chapter 5, the evaluation of the energy performance of the cogeneration system in this study in order to find out the optimal capacity of the prime mover by using Primary Saving Ratio as the evaluation index for energy performance will performed as the first step to analyse the performance before considering the other aspects.

The electrical efficiency (η_E) and thermal efficiency (η_H) of the CHP system is assumed to be 35% and 45%, respectively. Figure 6-24 shows the results of PES values under various cogeneration capacities. The analysis results of PES values showed that below 310 kW of the CHP capacity, the increase of CHP's capacity results in a significant energy saving. Above 310 kW of the CHP capacity, the change of PES becomes slower and finally, the PES value becomes stable about 29.10% from the utilization of the CHP capacity above 510 kW.

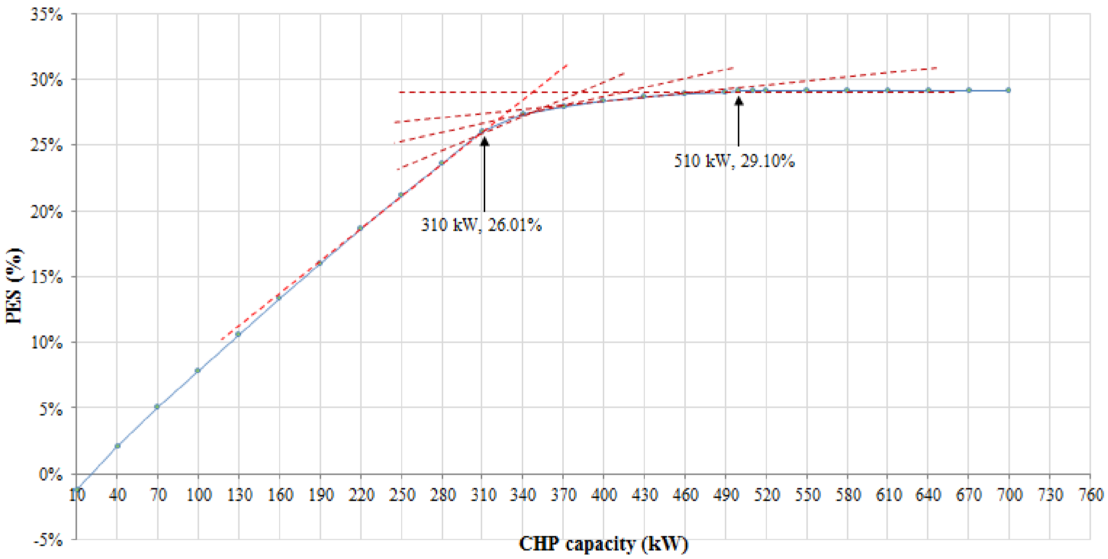


Figure 6-24 PES values with various CHP Capacities

The analysis of PES values under the utilization of various CHP capacities showed that sizing of CHP system is the key point for judgment of the decision making of the implementation of CHP system. If the CHP sizing is underestimated means the saving of the primary energy supply cannot be done well performed. However, if the sizing of the CHP system is overestimated will affect the investment cost while the performance of CHP machine can perform similar with that of CHP machine with optimal size. However, the consideration of other aspects should also performed before final decision of the implementation of the system.

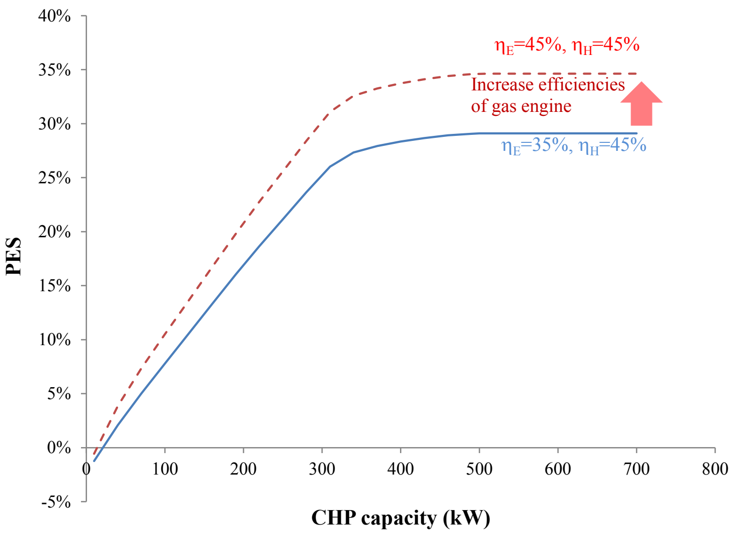


Figure 6-25 PES values with different GE's efficiencies

Generally, the efficiencies of CHP machines also significant affect the performance of CHP system under the demand characteristics of the building. In this case, PES values can be increased up to 35% from the variation of the gas engine's efficiencies as illustrated in Figure 6-25. In this case study, there is no heat demand for the office in Thailand, effect from the variation of electricity efficiency (η_E) will affect the performance of CHP system more than that of variation of thermal efficiency (η_H) in general as illustrated in Figure 6-26

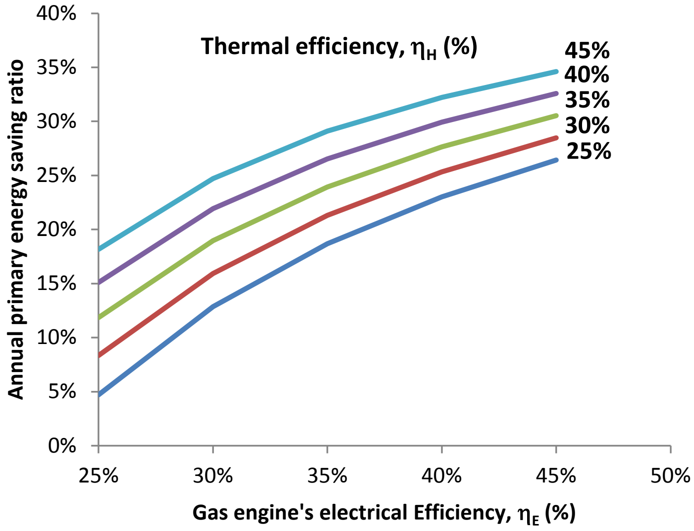


Figure 6-26 PES values with GE's efficiencies

6-4-4-2 EVALUATION OF ENVIRONMENTAL PERFORMANCE [12,14,15,]

Figure 6-27 shows the CO2 emission reduction ratio (CER) values for various capacities of cogeneration system. Similar to the phenomena of energy performance, increasing the CHP's capacity results in a significant reduction of CO2 emission below 310 kW. Above 310 kW for the CHP's capacity, the change in CER value becomes slower but not steep slope as results from PES. Finally, the CER value becomes stable about 85.1% from the CHP's capacity above 510 kW. It was found that the CO2 emission reduction ratio can be increased up to 86.2% from the variation of the gas engine's efficiencies which are slightly changed.

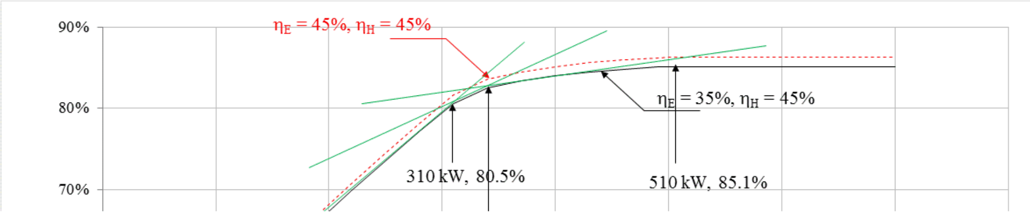


Figure 6-27 CER values with various CHP Capacities

Considering the effect of electricity efficiency (η_E) and thermal efficiency (η_H) of Gas Engine, similar phenomena as the effect of GE's efficiencies to PES values. It is also found that the thermal efficiency (η_H) of gas engines has less effect on the CER value for all rates of efficiency. Increasing the η_H at lower rates results in a slight change of CER value but increasing the η_H at higher rates also results in a slight change of CER value as illustrated in Figure 6-28.

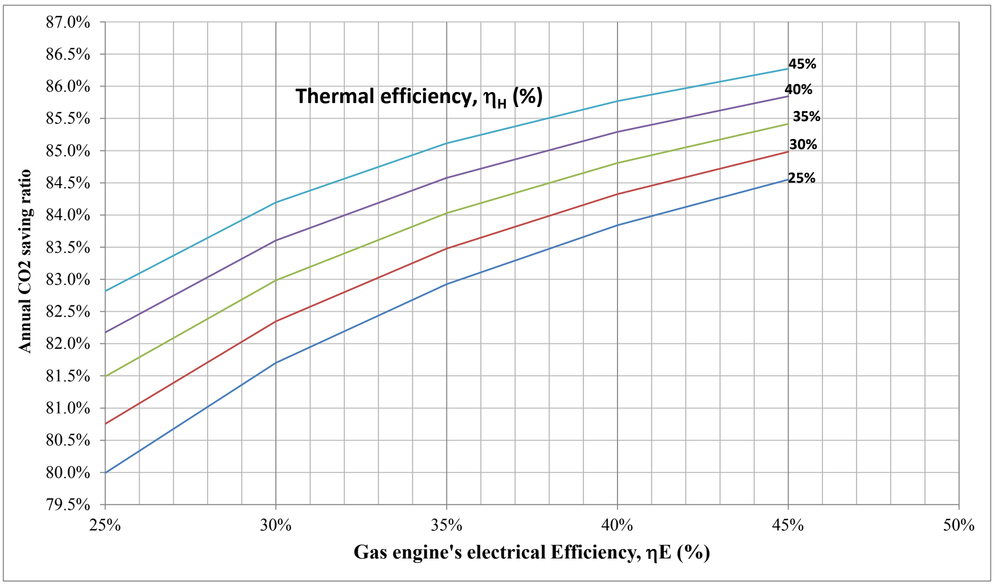


Figure 6-28 CER values with GE's efficiencies

6-4-4-3 EVALUATION OF ECONOMIC PERFORMANCE [13,14,16,17]

Economic evaluation is also one of important considerations for the judgment for the implementation of cogeneration system. As described in flow chart for decision making of the optimization methods of this study, even though the sizing of CHP capacity is selected from the results of Energy performance and Environmental Performance assessments, but if that selected CHP sizing is not worth for investment, the selection of reasonable sizing of CHP should be performed again. Using the developed the mathematical mode, the changes in annual cost structures for the commercial building energy system by introducing CHP system also calculated.

- Effect of CHP capacity to the Annual cost structure

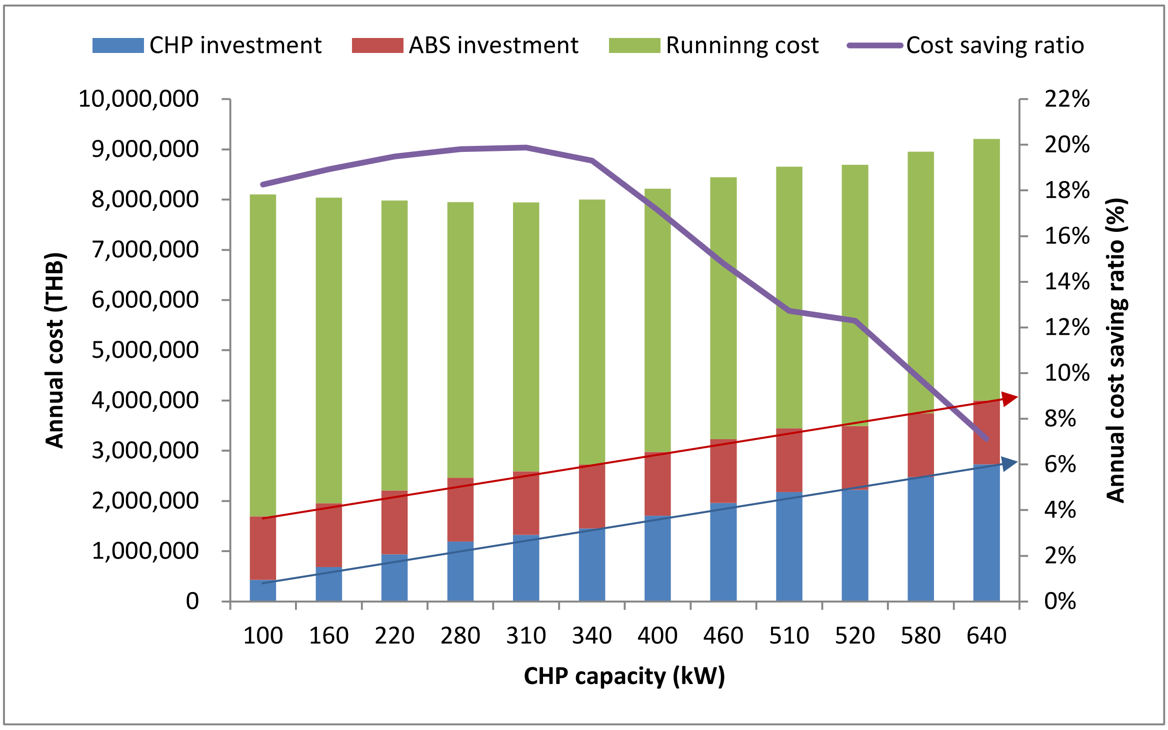


Figure 6-29 Annual cost structures and cost saving ratio with various CHP capacities

Figure 6-29 shows the estimated investment cost and running cost of CHP and the tendency of annual cost saving ratio (CSR). It is found that, the investment cost of CHP has linear increase to the capacity. The running cost (purchased energy cost) is decreased as the increase of CHP capacity and slightly decrease from 310 kW and become stable from 400 kW or higher capacity. Considering the annual cost saving, increase the capacity of CHP does not always lead to more cost saving. As shown in Figure 6-30, it can be seen that the annual cost saving ratio reaches the maximum point when the capacity of CHP is about 310 kW. A rise of capacity leads to decrease of marginal revenue and the marginal cost is almost constant, which causes the net marginal benefit to decrease from a positive value to a negative one [2].

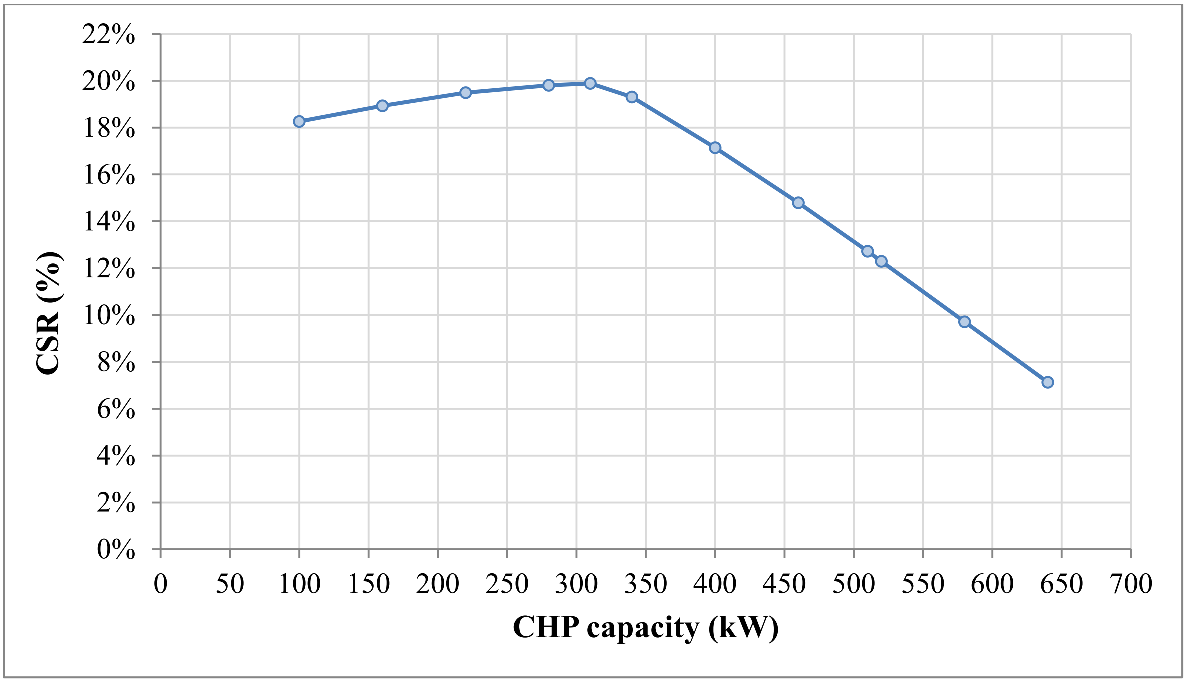


Figure 6-30 Cost saving ratio with various CHP capacities

The results can be explained from the marginal value phenomena, if the capacity of CHP system less than 1 kW, the customer could benefit overall by introduce more. This is because the gains to the customer exceed the costs to him. There will be a net gain to the customer of the difference between the marginal revenue and marginal cost. On the other hand, if the capacity is more than 310 kW, the customer could benefit by introduce less. This is because when the capacity is reduced, the marginal revenue will increase, which leads to an increase of net marginal benefit.

- Fuel price sensitivity analysis of optimal CHP capacity

Electricity and gas price are the key parameters influence the decision of implementing the CHP system by considering the economic benefits to judge for the installation and also capacity and efficiencies of CHP system in the building. In this study, the profitability index, Cost saving ratio (CSR) has been analyzed due effect of the price sensitivity for both gas and electricity in order to find out the optimal capacity for CHP system under the circumstance of price variation in the future.

- **Electricity price sensitivity**

Increasing of electricity price due to the depletion of natural resource for electricity generation is possible in near future. One of main parameter affect the adoption of CHP system to office building which related to annual cost saving is about the electricity price. The electricity price is one of the key parameter to induce customer for selection of power purchase from grid or on-site generation. Furthermore, the changing of electricity price is also the parameter affect the selection of optimal size of CHP system as shown in Figure 6-31 and 6-32.

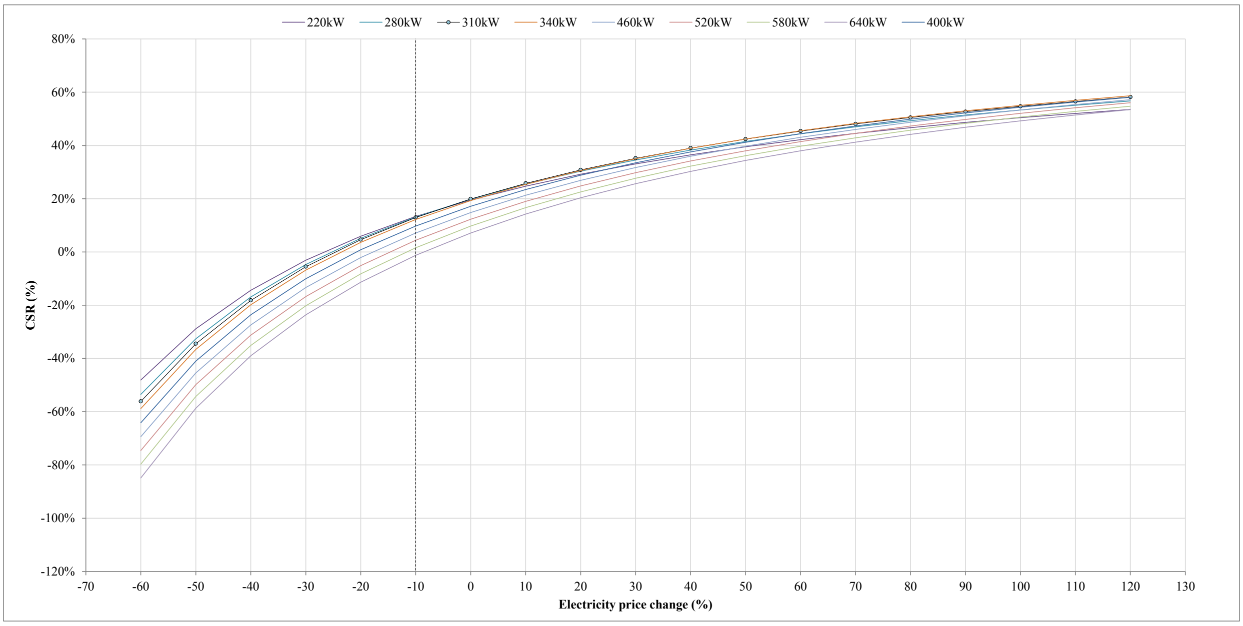


Figure 6-31 Effect of electricity price to optimal sizing of CHP system

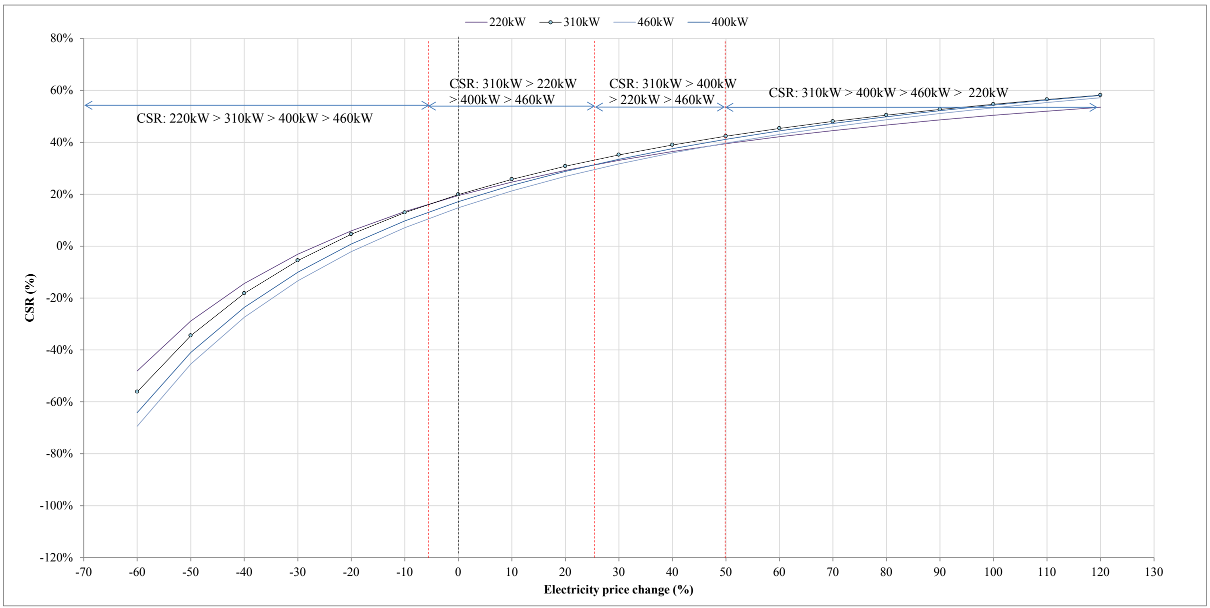


Figure 6-32 Selection of optimal sizing of CHP system under the electricity price sensitivity

From Figure 6-32, the zoning of CHP capacity selection by considering the effect of electricity price sensitivity on CSR values are illustrated. It can be seen that if electricity price is decrease about 5 – 60 percent, CSR value from the selection of CHP capacity with 220kW > that of 310kW > that of 400kW > that of 460kW. In case of electricity price change in the range -5% to +25%, CSR value from the selection of CHP capacity with 310kW > that of 200kW > that of 400kW > that of 460kW. However, if the electricity price is increase about +25 to +50%, CSR value from the selection of CHP capacity with 310kW > that of 400kW > that of 220kW > that of 460kW. Finally, if the electricity price is increase more than 50%, CSR value from the selection of CHP capacity with 310kW > that of 400kW > that of 460kW > that of 220kW.

- **Natural gas price sensitivity**

As illustrated in Figure 6-33, contrary to the analysis results from sensitivity of electricity price, higher CSR value can be obtained if gas price is decreasing in linear tendency. However, increasing of natural gas price will also induce customer to purchase electricity from grid rather than utilize CHP by natural gas. It can be seen that zoning of CHP capacity selection by considering the effect of natural gas price sensitivity on annual energy cost saving ratio is also analyze in this study. If natural gas price is decrease about 25 – 60 percent, CSR value from the selection of CHP capacity with 310kW > that of 220kW > that of 400kW > that of 160kW. In case of the natural gas price is in the range -25% to +20%, CSR value from the selection of CHP capacity with 310kW > that of 220kW > that of 160kW > that of

400kW. However, if the natural gas price is increase about 20 – 60%, CSR value from the selection of CHP capacity with 160kW > that of 220kW > that of 310kW > that of 400kW, respectively due to the high investment cost consideration.

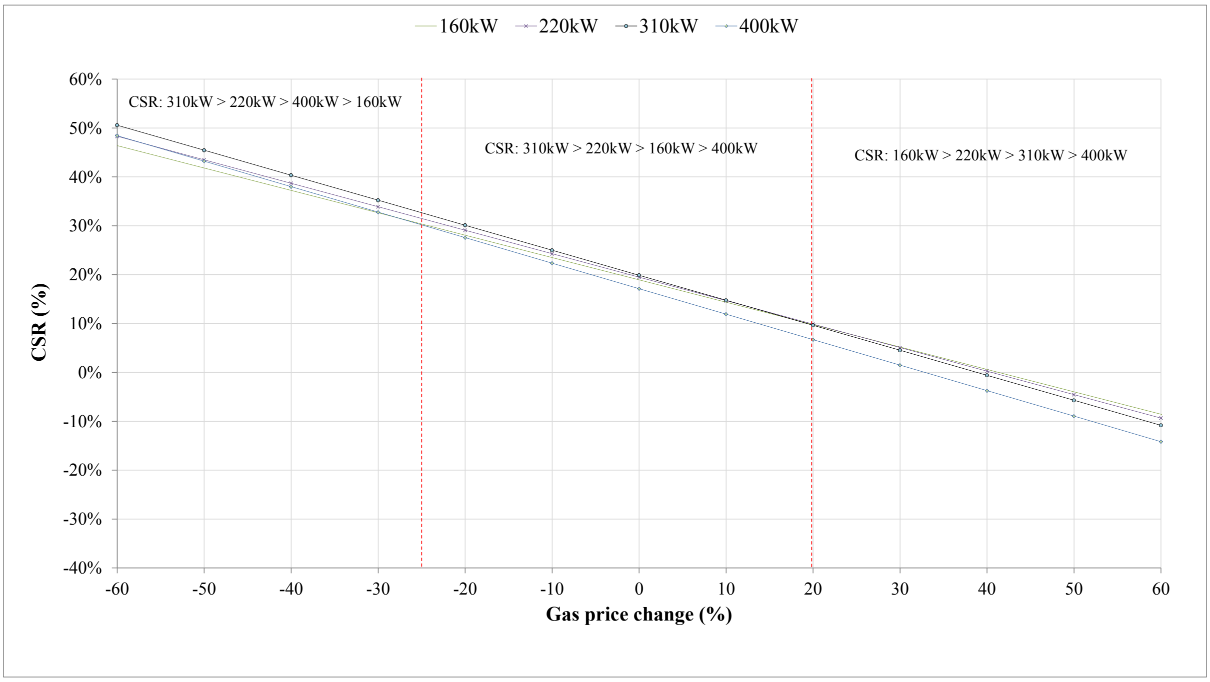


Figure 6-33 Selection of optimal sizing of CHP system under the gas price sensitivity

6-4-5 SUMMARIES FOR THE EVALUATION OF CHP SYSTEM FOR OFFICE BUILDINGS

From the consideration of the selection of optimal capacity of cogeneration system for case study of Thailand's office building, for the energy performance aspect, selection of CHP capacity among 310 kW to 510 kW is the optimal solution for primary energy saving concern but also need to considered for other aspects. In case of environmental performance assessment, the values of CER after utilization of CHP capacity from 310 kW will slightly increase and become stable at 510 kW but still not high difference. Finally, for the economic consideration, either the present situation of fuel prices, tariff rates, and the consideration of price sensitivity of gas and electricity price, the selection of CHP capacity with 310 kW is optimal choice for economic concern.

The objective function of selection of CHP capacity can be determined by the following equation:

$$f_{CHP} = \int (PES_{max}, CER_{max}, CSR_{max})$$

In this case study, the optimal solution for CHP capacity from the consideration of energy, environmental, and economic aspect is 310 kW.

6-5 CASE STUDY 2 - FEASIBILITY STUDY ON INTRODUCTION OF COGENERATION SYSTEM FOR THAILAND'S HOTELS

6-5-1 LOAD PROFILE ASSESSMENT AND CHARACTERISTICS ANALYSIS

The data of load profile also from the same source that of the office building, the investigation of peak load profile of total energy consumption of hotels in Bangkok by Metropolitan Electricity Association (MEA) and associate with the information of energy consumption unit of the database from Department of Alternative Energy Development and Energy Efficiency (DEDE). Figure 6-34 shows the 1-year load pattern profiles of the hotel in this study.

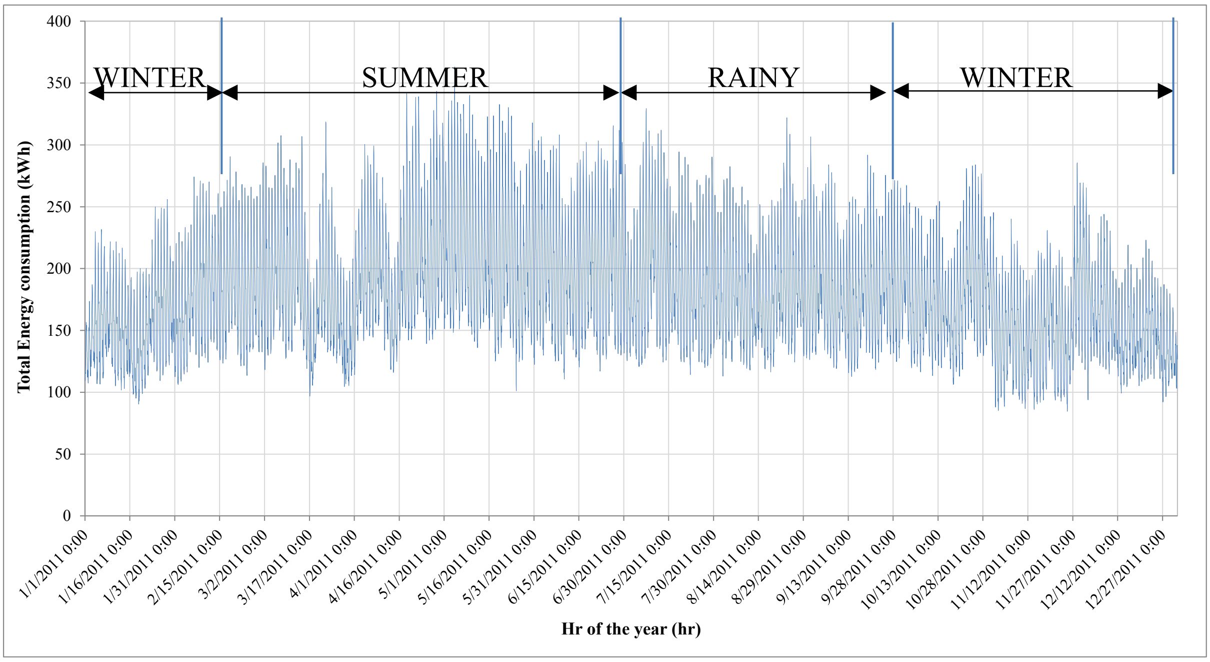


Figure 6-34 Hourly load profile of total energy use of Thailand's hotel

The characteristic of energy use of hotel is different from that of office building according to the 24 hr operation time everyday which affect the energy consumption per unit is quite high. Peak consumption is in the period of summer season and become gradually decrease until winter season. Figure 6-35 shows the average values of monthly energy use by considering the total consumption. It is found that even though the peak consumption is in April-May but the peak consumption in other months is not much different from that of May. The results can be explained by the higher cooling load that need to keep the setting temperature in order to provide the thermal comfort inside the hotel.

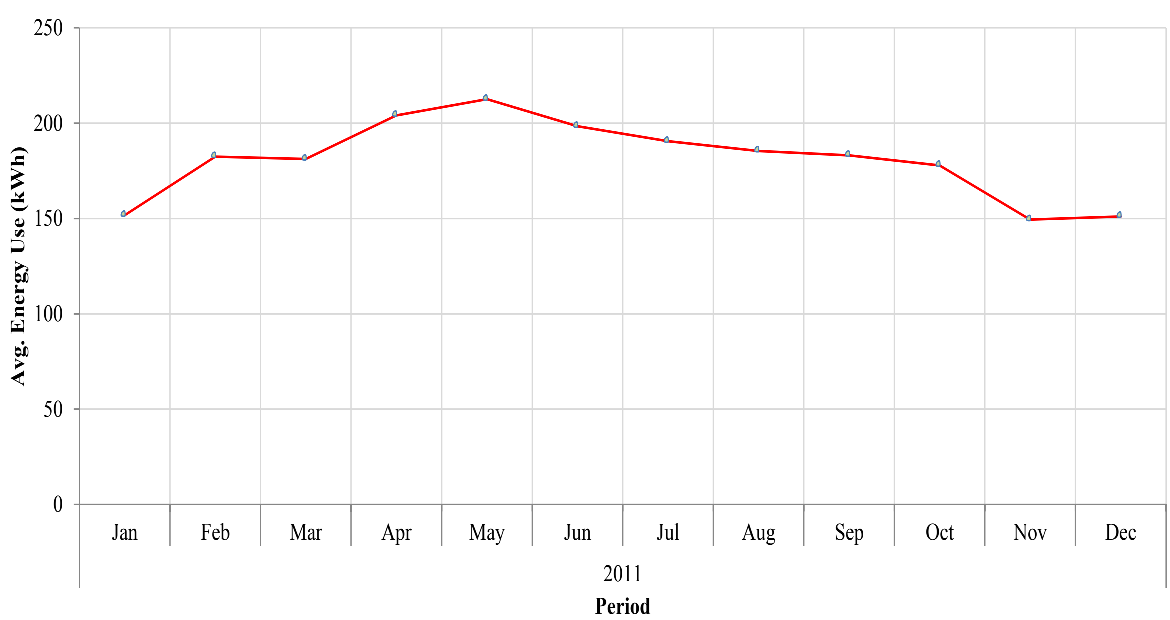


Figure 6-35 Average value of total energy consumption by month for hotel

Due to the operation time of the hotel, lighting and air-conditioning system need to utilized all the time but different regarding to the hotel type, characteristics, and sizing of the hotel. For example, in case of conference hotel, the utilization of equipment for the conference rooms should consumed higher than that of accommodation which consequence to the energy consumption in day time becomes higher than that of night time. The average energy consumption by time as illustrated in Figure 6-36 shows that the hotel in this case study should be categorized as hotel type 3 or 4 as mentioned in chapter 4. Energy use in the hotel is increase from 6:00 AM and become peak around 12:00 P.M. After that, the energy consumption become slightly decrease until midnight and stable until morning (5:00 - 6:00 A.M). Therefore, the characteristics of energy consumption of the hotel should be perform the investigation carefully which different from office buildings, the pattern of energy consumption is similar for general type of office building. Pattern of monthly energy consumption is shown in Figure 6-37, energy use pattern in every month is utilized in similar pattern but different consumption scale due to the climate and internal factors.

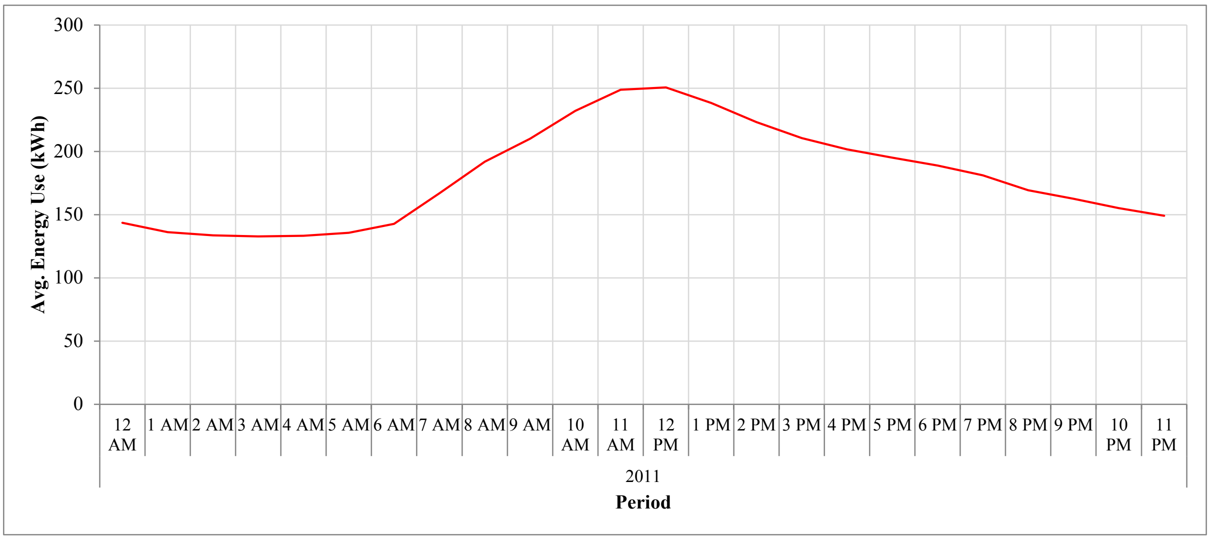


Figure 6-36 Average hourly energy consumption in 1-day for hotel

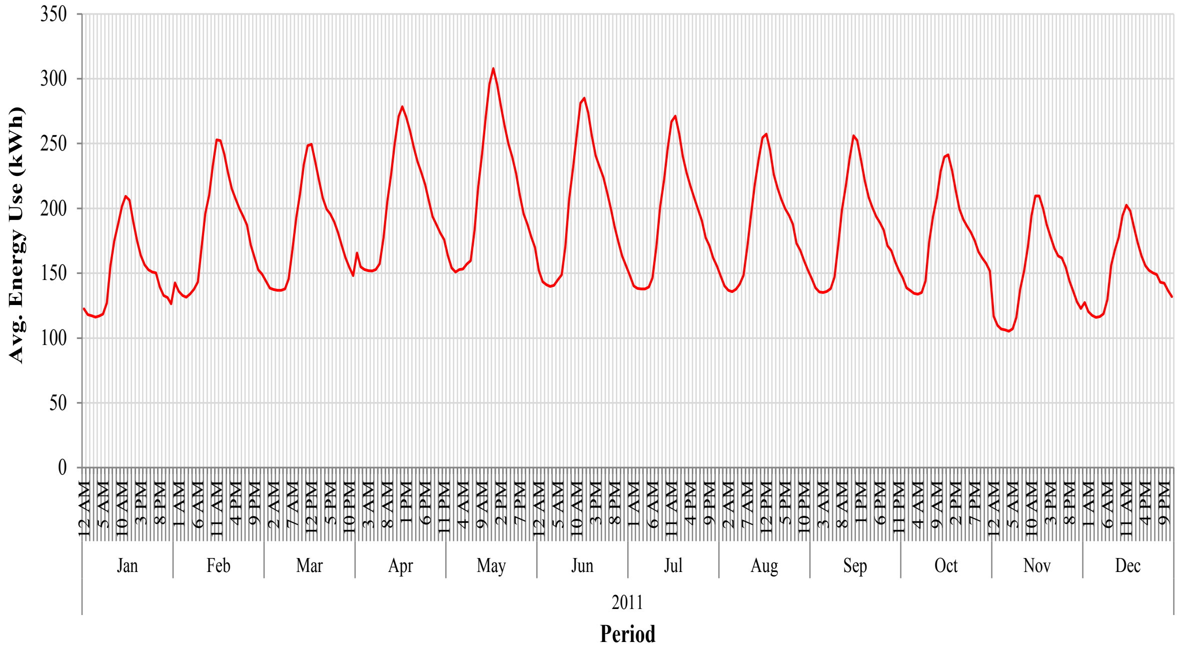


Figure 6-37 Average hourly energy consumption per day for hotel in 1-year

6-5-2 LOAD ASSESSMENT RESULTS FROM SIMULATION

Simulation of energy utilization for hotel was conducted by ENER-WIN simulation software. First, hotel type for selection is categorized as type 4 - hotels providing accommodation, catering or restaurant services, conference rooms and entertainment venues, the size of each room is not less than 14 square meters. The simulated hotel is a 10-storey T-shape, 11,000 m^2 with 26 rooms per floor. The hotel's service core is located at the centered of the building. Figure 6-38 shows 3D view of the hotel generated by 3D design software.

Figure 6-38 3D view and cross section of the hotel for analysis

The load density of the data center model consisting of office equipment and lignthing load was specified to be 12 W/m2 24 hrs every day (8760 hr per year) from the minimum allowable value from Thailand's Building Energy code. The HVAC system used was a packaged single sone (PSZ) direct expansion (DX) system. The fan schedule was also assumed to be on in service hour. In service core zone, has no HVAC system installed but lighting system still operated all the time.

6-5-2-1 MODEL CALIBRATION

The calibration method of the simulation model of the hotel is the same as the calibration method which described in case study of the office building. The comparison of the results of energy consumption data from simulation and that of real buildings as shown in Figure 6-34 can be acceptable if the coefficient of determination from statistical methods, which represented by R-squared (R^2) from 2 sources (simulation and real data) is more than 0.5. Otherwise, the model from the simulation need to be revised again by adjust some unknown parameters, e.g. no. of occupancy, operation schedule o HVAC and lighting system, temperature adjustment, etc. until the value of R^2 becomes more than 0.5. The flow chart of the model calibration is shown in Figure 6-38. It is noted that the comparison between simulation results and real data will use the monthly energy consumption to verify the regression analysis of the model.

It is found that the tendency of the load pattern for 1st simulation is not similar with the tendency from the real data due to the effect of ambient temperature that in the simulation software is lower than real data as shown in Figure 6-39, the level of lowest energy consumption around the middle zone should not be flat, so, after re-analysis by adjusting the temperature data, the tendency of total energy consumption become better that previous one as shown in Figure 6-40. Finally, tendency of monthly energy consumption between simulation data and real measurement data become similar tendency as illustrated in Figure 6-41.

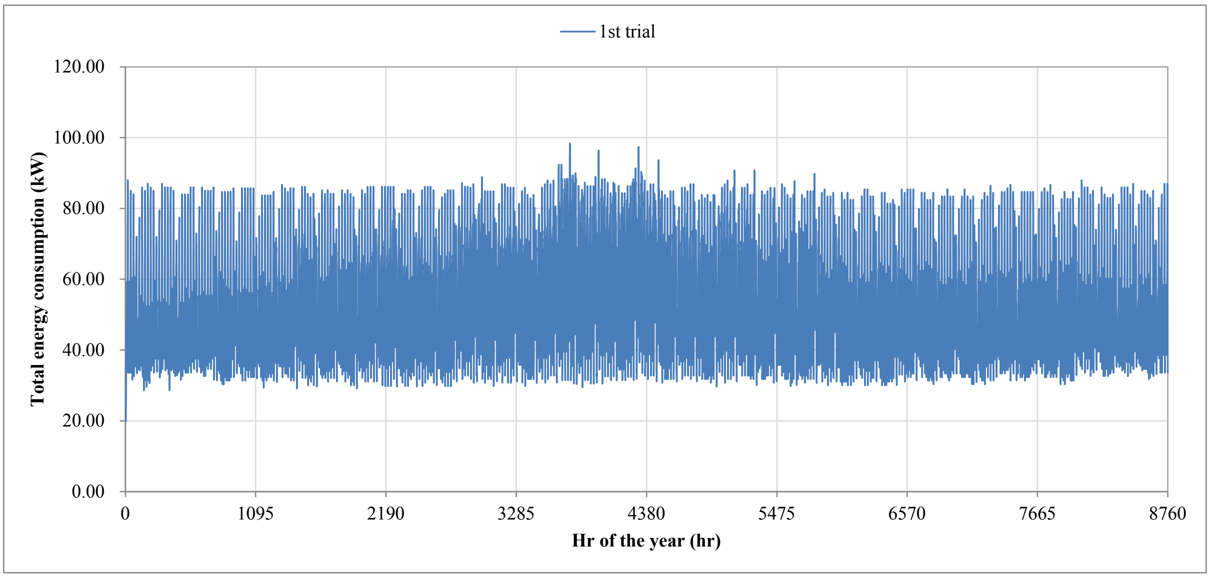


Figure 6-39 Hourly load profile of total energy use from 1st simulation

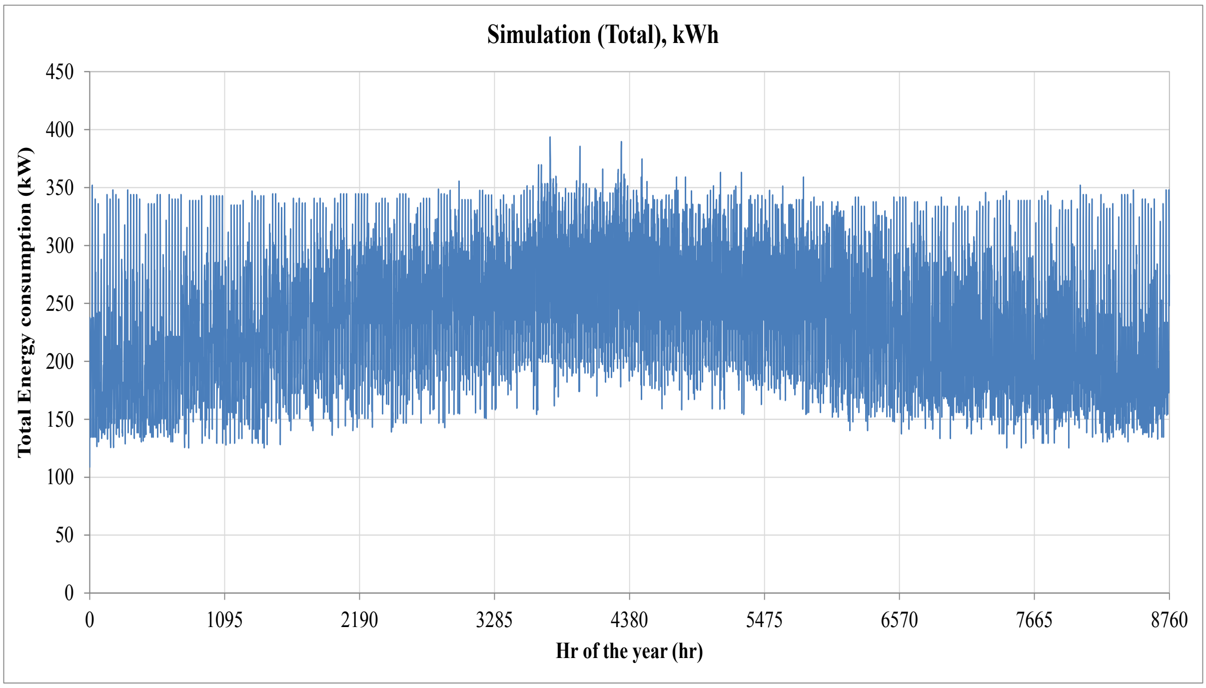


Figure 6-40 Hourly load profile of total energy use after adjusting temperature data

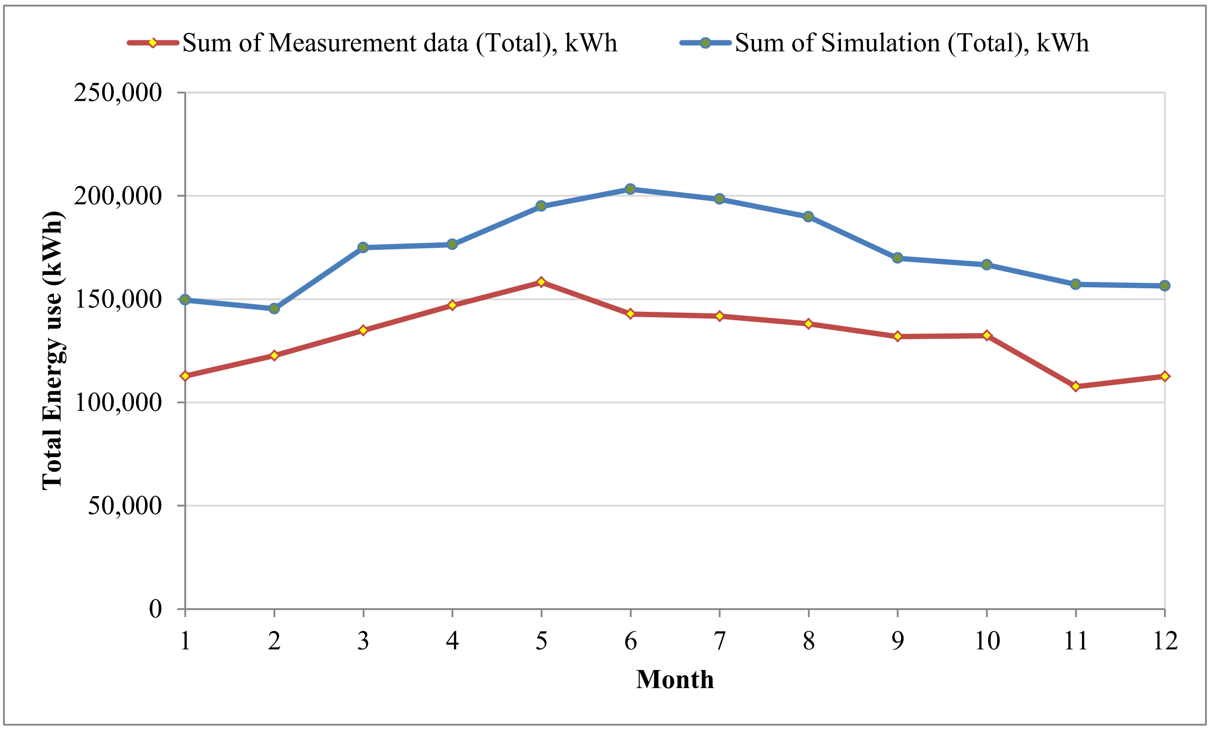


Figure 6-41 Monthly load profile pattern comparison in 1 year

From the calibration of the building simulations, the value of R-squared from regression analysis from the relationship between measurement data and simulation data is equal to 0.67 which acceptable for the energy consumption data. Figure 6-42 shows the regression analysis results of energy consumption data between simulation and data from measurement.

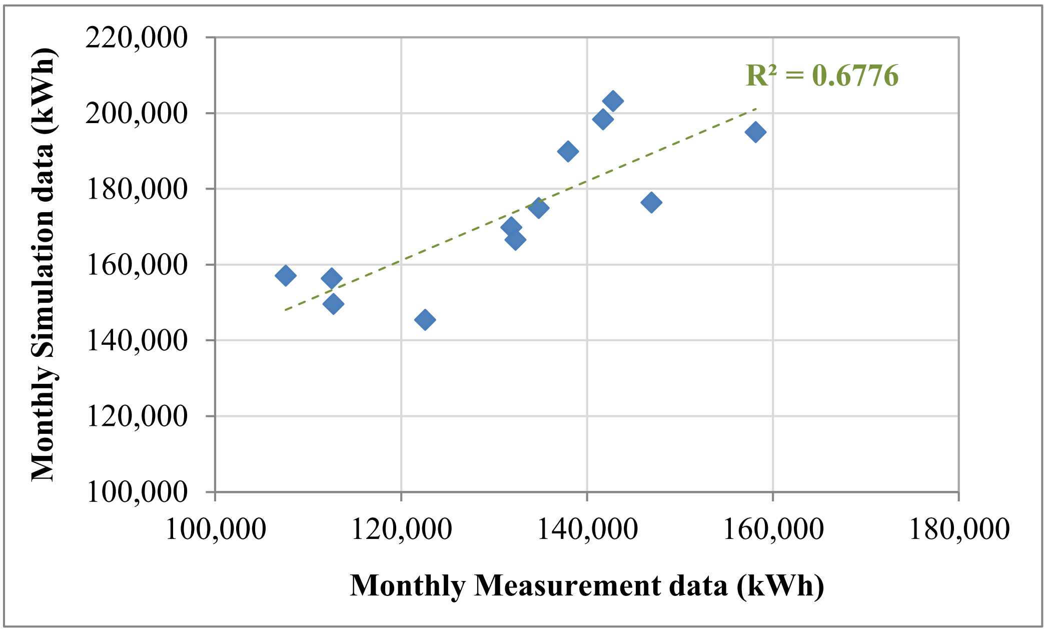


Figure 6-42 Regression analysis results of the energy consumption for hotel

In summary, 4 major systems which consume significant energy in typical hotel in this study – the air conditioning system, lighting system, equipment, and hot water. Figure 6-43 illustrates the average values of load patterns of each energy consumed system in 1 day. From the load patterns, the following characteristics can be derived:

1. The load pattern of air-conditioning system is slightly fluctuate but become highest around 12:00 due to climate effect. However, the cooling system become decrease during night time by the adjustment of the thermostat.
2. The tendency of equipment, lighting, and hot water demand are the same tendency (similar direction but different scale) due to the utilization from the customer in different time. However, from 7:00 P.M, these load demands become higher until 11:00 P.M and slightly decrease after midnight.

It is noted that different characteristics of hotel, different energy pattern may found. The characteristics of the energy consumption of the hotel may not be the same even though the similar type of hotel according to many affect parameters.

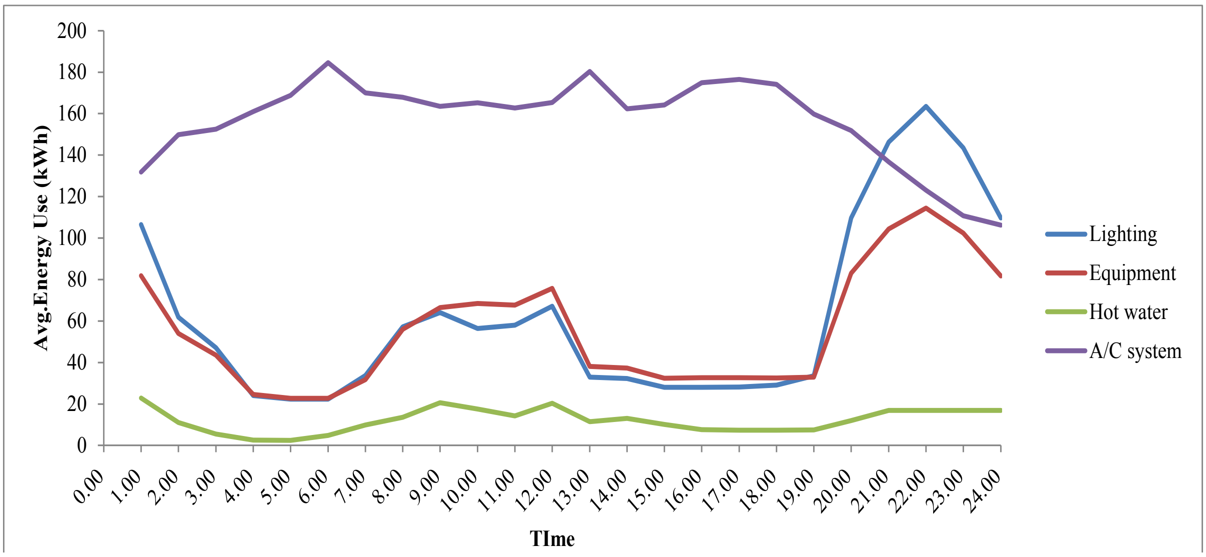


Figure 6-43 Average values of energy consumption in each system in 1 day

The representative of load-duration curve (monotonic curve) of hotel energy consumption is illustrated in Figure 6-44 which starting from the largest to smallest consumption values in 1-year cooling load, equipment, lighting, hot water demands, respectively. Table 6-5-1 summarized the maximum, minimum, and average values of all systems for Hotel's energy consumption for this case study

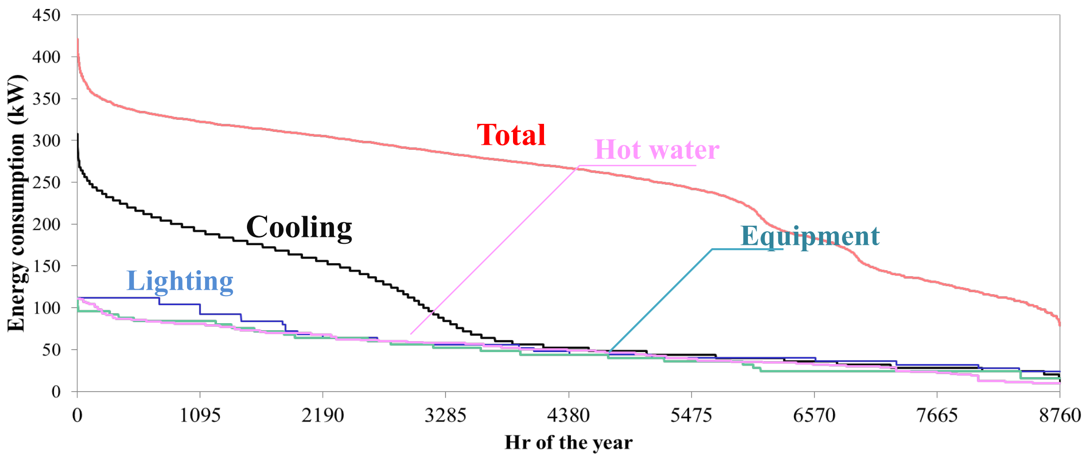


Figure 6-44Load-duration curves of energy demand separated by system for hotel

Table 6-5-1 Summary of energy demand of hotel

	Total demand (kWh)	**Cooling demand (kWh)**	**Equip. demand (kWh)**	**Lighting demand (kWh)**	**Hot water demand (kWh)**
Max.	420.8	308.0	112.0	112.0	111.1
Min.	79.1	12.0	16.0	24.0	10.0
Sum.	2143990.8	793,956.0 **[37%]**	420,432.0 **[19.6%]**	493,384.0 **[23%]**	436,218.8 **[20.4%]**

6-5-3 CASE SETTING AND SIMULATION METHOD

6-5-3-1 MODELING OF CHP SYSTEM

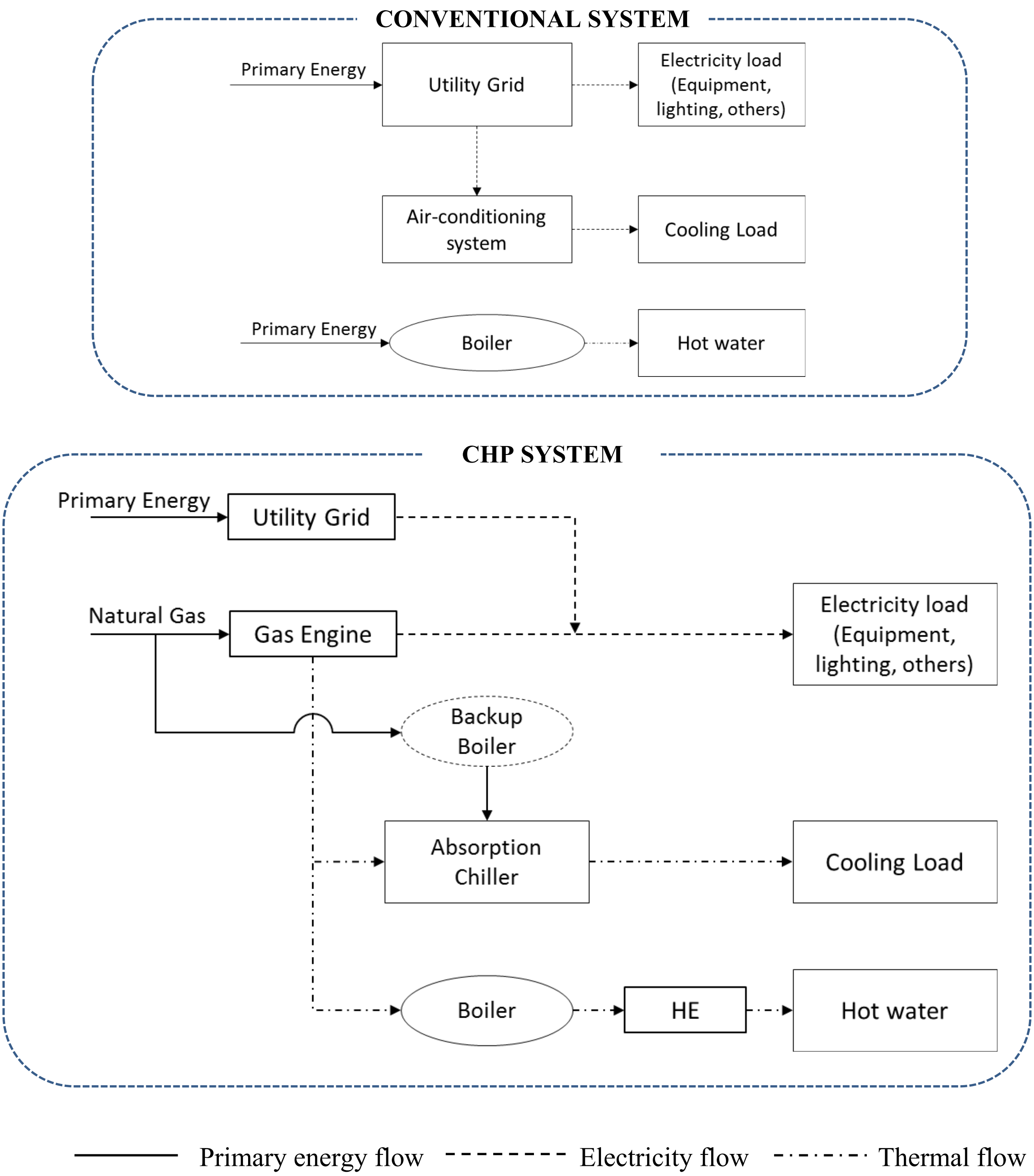


Figure 6-45 Energy flow diagrams of conventional energy supply system and CHP energy supply system

According to end-used demand data of hourly in Figure 6-44, the comparative study between conventional system and CHP system is executed by using conventional system as a baseline. For the conventional system, the utility grid serves all electrical demand which is used for not only direct power consumption, but also for space cooling load through the operation of the building's air-conditioning system. However, the primary energy consumption for Hot water system is using crude oil through the boiler to provide the hot water demand. CHP system in this energy diagram consists of a gas engine and absorption chiller. Because of the proportion of heat demand for hot water system is quite low comparing to the A/C and other demands, so, the mode of the gas engine is electricity tracking. The gas engine is used to meet the electrical and cooling loads with the use of an air-conditioning system through the absorption chiller. If the recovery of thermal energy from the gas engine does not fully satisfy the absorption chiller's needs, an additional boiler is used. However, if the recovered thermal energy goes over local needs, the surplus energy is released into the atmosphere. In this case, gas engine also used to meet the hot water demand to substitute the consumption of crude oil through the boiler and heat exchanger to provide the hot water to the hotel.

6-5-3-2 INPUT ASSUMPTIONS OF THE CASE STUDY

Similar to the assumption parameters of office building evaluation, the prime mover of the CHP system using gas engine for consideration, combining with the utility electricity, back-up boiler and air conditioning system to accommodate the customer requirements. Some main assumed data for this analysis is summarized in Table 6-5-2 and by using data in Japan as the reference for pricing and efficiency of Gas engine, air-conditioning system (centralized chiller system), and Table 6-5-3 for others related parameters for analysis.

Table 6-5-2 Data assumption for the analysis of Gas engine

Item	**capacity**	**Electrical efficiency, η_E**	**Thermal efficiency, η_H**	**Investment cost (万円)**
GE-1	100	0.30	0.48	2000
GE-2	150	0.31	0.47	2925
GE-3	200	0.32	0.46	3800
GE-4	250	0.33	0.45	4625
GE-5	300	0.34	0.44	5400
GE-6	350	0.35	0.43	6125
GE-7	400	0.36	0.42	6800

GE: Gas Engine

Table 6-5-3 Data assumption for other related parameters

Machine	**Capacity (kW)**		**COP**		**Inv. Cost (万円)**
	Cooling	**Thermal**	**Cooling**	**Thermal**	
ABS-1	400	260	1.45	0.88	1920
ABS-2	450	300	1.45	0.88	2160
ABS-3	500	330	1.45	0.88	2400
TC-1	800	-	6	-	3000
TC-2	850	-	6	-	3100
TC-3	900	-	6	-	3200
GB-1	-	50		0.9	150
GB-2	-	100		0.9	280
GB-3	-	150		0.9	390

Note: ABS: Absorption chiller TC: Turbo chiller GB: Gas boiler

Table 6-5-4 Data assumption for other related parameters (cont.)

Item	Data assumptions	Value
Electricity utility grid	Efficiency (%)	30
	Service charge (THB/kWh)	312.24
	Demand charge (THB/kW)	132.93
	Energy price – on peak / off peak (THB/kWh)	2.176 / 3.6796
Natural gas	Energy price (THB/mmBTU)	350
Air-conditioning system	Coefficient of performance (COP)	3
	Lifetime (year)	10
	Capital cost ($\times 10^3$ THB/kW)	5.2
Absorption chiller	Coefficient of performance (COP)	1.1
	Lifetime (year)	15
	Capital cost ($\times 10^3$ THB/kW)	15.48
Back-up natural gas boiler	Efficiency (%)	85
	Lifetime (year)	15
Cogeneration Plant	Capacity (kW)	varied
	Electricity efficiency, η_E (%)	25,30,35,40,45

	Heat recovery efficiency, η_H (%)	25,30,35,40,45
	Capital cost ($\times 10^3$ THB/kW)	64.52
	Lifetime (year)	15
Others	Interest rate (%)	2

6-5-4 ANALYSIS RESULTS AND DISCUSSIONS

6-5-4-1 EVALUATION OF ENERGY PERFORMANCE

The electrical efficiency (η_E) and thermal efficiency (η_H) of the CHP system is assumed to be 35% and 45%, respectively. Figure 6-46 shows the results of PES values under various cogeneration capacities. The analysis results of PES values showed that below 120 kW of the CHP capacity, the increase of CHP's capacity results in a significant energy saving. Above 300 kW of the CHP capacity, the change of PES becomes slower and finally, the PES value becomes stable about 21.42% from the utilization of the CHP capacity above 300 kW.

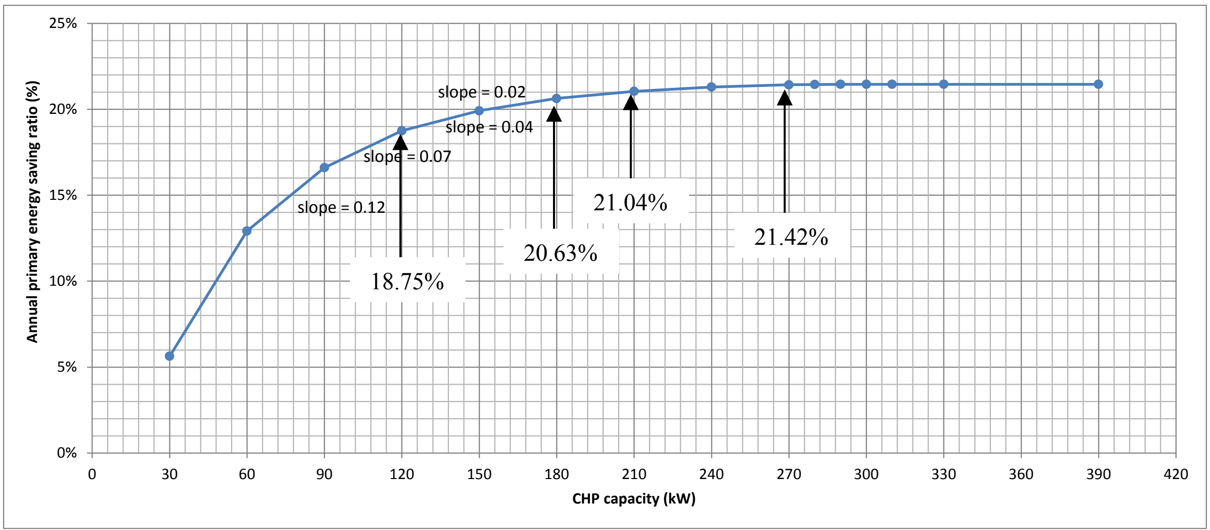


Figure 6-46 PES values with various CHP Capacities

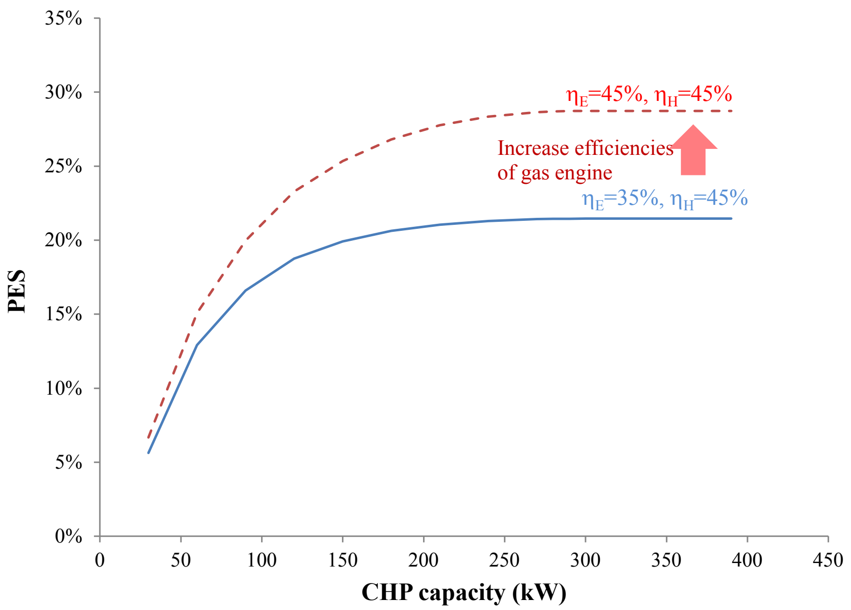


Figure 6-47 PES values with different GE's efficiencies

Generally, the efficiencies of CHP machines also significant affect the performance of CHP system under the demand characteristics of the building. In this case, PES values can be increased up to 28.73% from the variation of the gas engine's efficiencies as illustrated in Figure 6-47. In this case study, there is no heat demand for the office in Thailand, effect from the variation of electricity efficiency (η_E) will affect the performance of CHP system more than that of variation of thermal efficiency (η_H) in general as illustrated in Figure 6-48

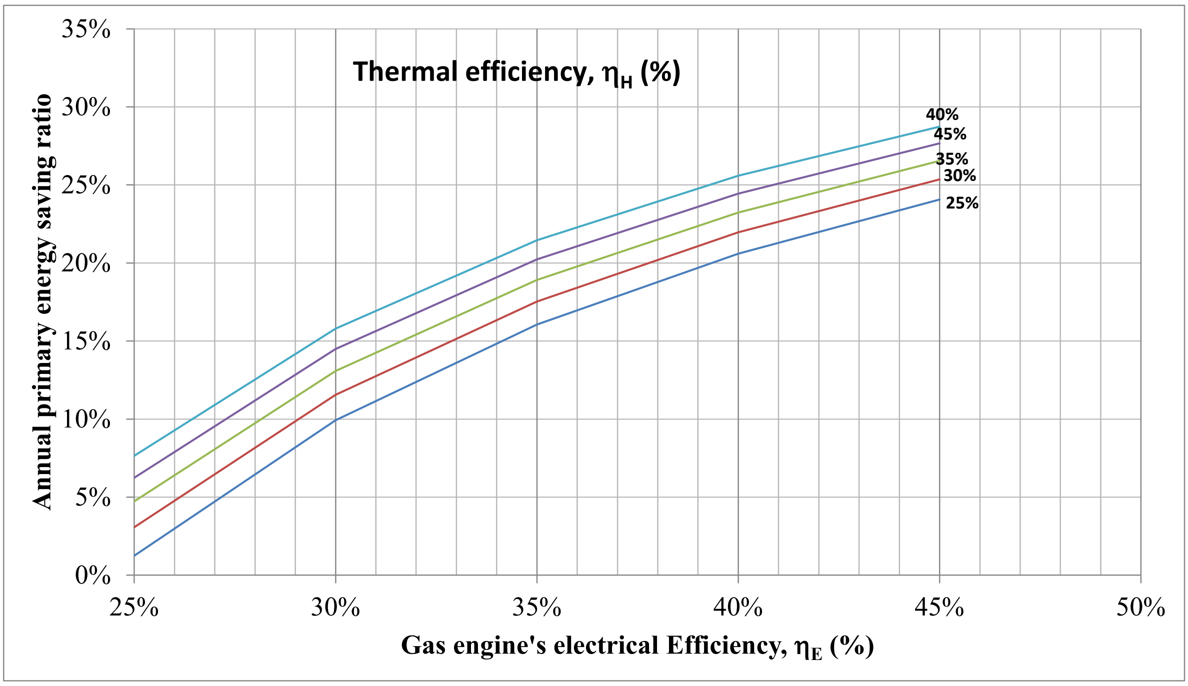


Figure 6-48 PES values with GE's efficiencies

6-5-4-2 EVALUATION OF ENVIRONMENTAL PERFORMANCE

Figure 6-49 shows the CO2 emission reduction ratio (CER) values for various capacities of cogeneration system. Similar to the phenomena of energy performance, increasing the CHP's capacity results in a significant reduction of CO2 emission below 180 kW. Above 180 kW for the CHP's capacity, the change in CER value becomes slower but not steep slope as results from PES. Finally, the CER value becomes stable about 83.5% from the CHP's capacity above 300 kW. It was found that the CO2 emission reduction ratio can be increased up to 85.1% from the variation of the gas engine's efficiencies which are slightly changed.

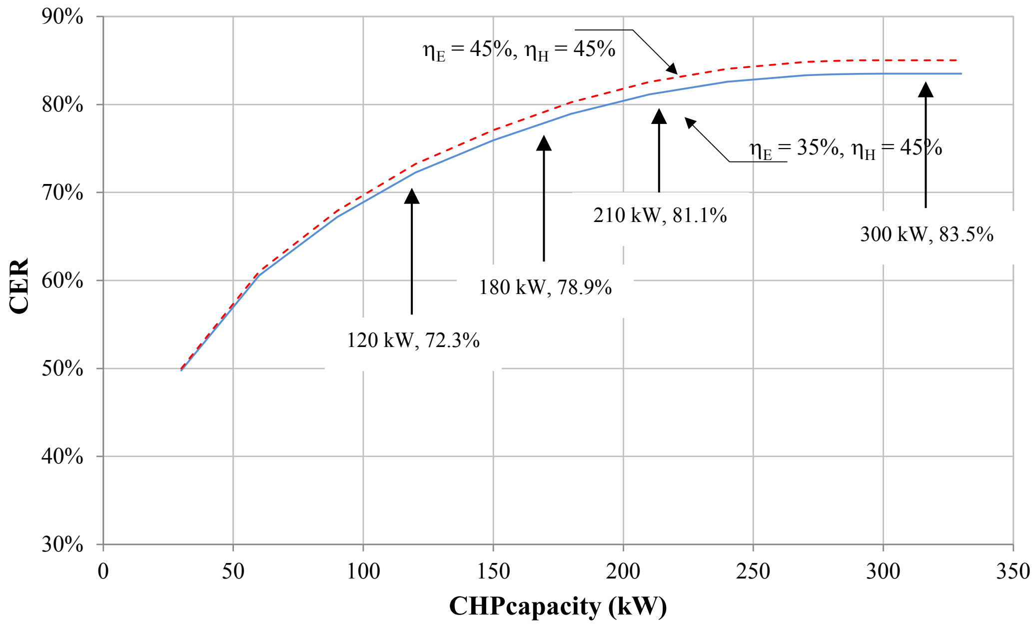


Figure 6-49 CER values with various CHP Capacities

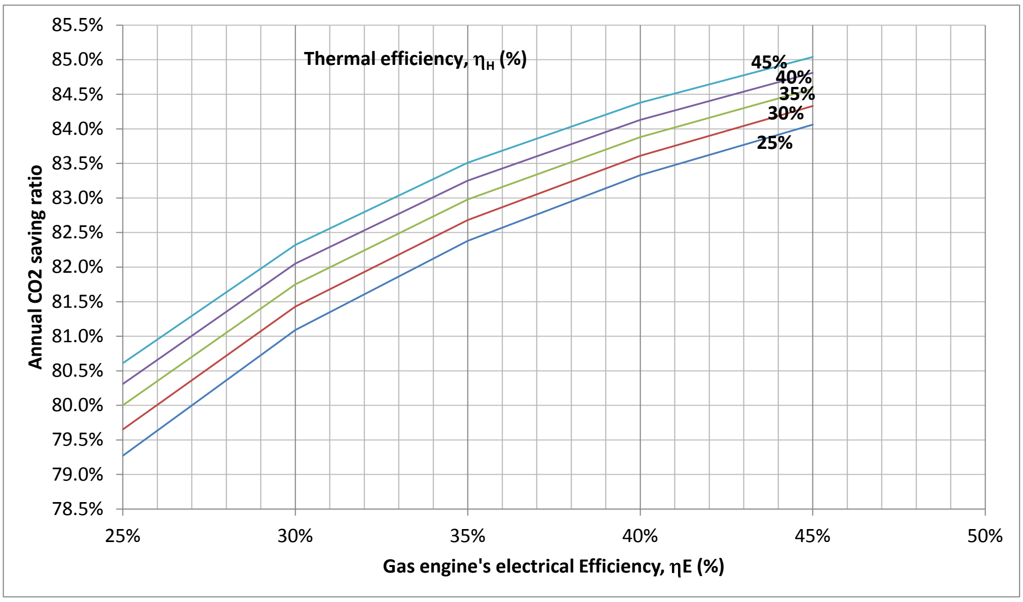


Figure 6-50 CER values with GE's efficiencies

Considering the effect of electricity efficiency (η_E) and thermal efficiency (η_H) of Gas Engine, similar phenomena as the effect of GE's efficiencies to PES values. It is also found that the thermal efficiency (η_H) of gas engines has less effect on the CER value for all rates of efficiency. Increasing the η_H at lower rates results in a slight change of CER value but increasing the η_H at higher rates also results in a slight change of CER value as illustrated in Figure 6-50.

6-5-4-3 EVALUATION OF ECONOMIC PERFORMANCE

- Effect of CHP capacity to the Annual cost structure

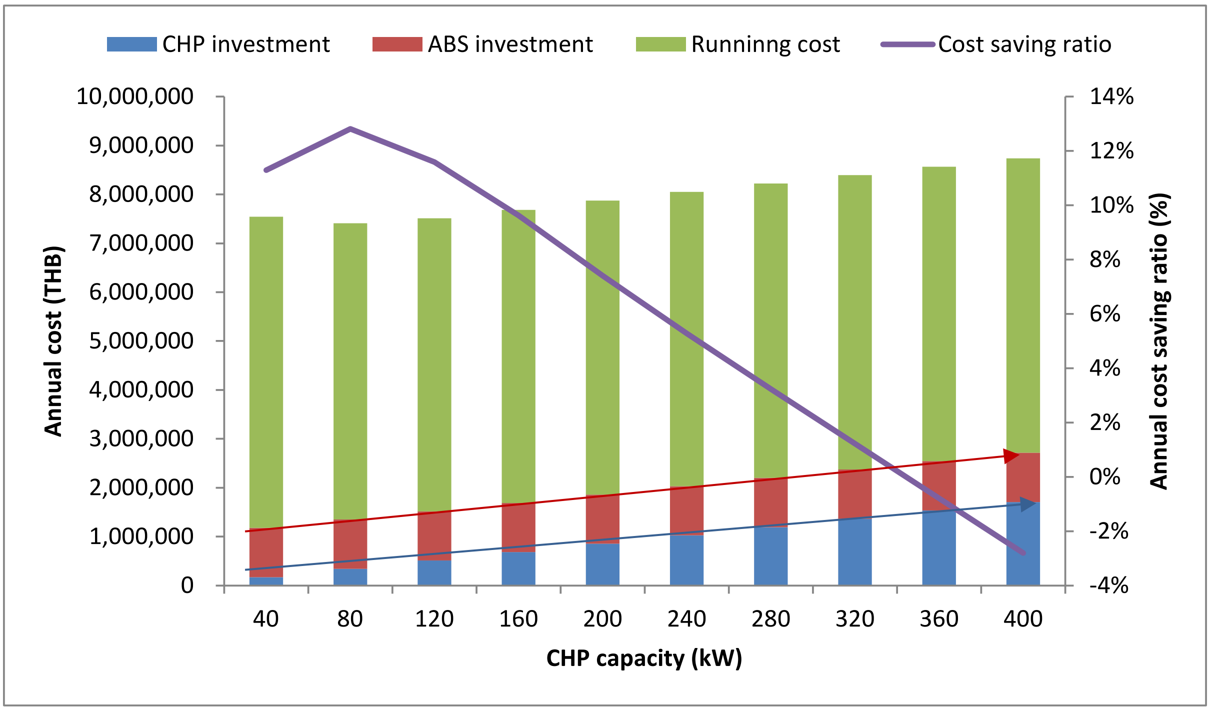


Figure 6-51 Annual cost structures and cost saving ratio with various CHP capacities

Figure 6-51 shows the estimated investment cost and running cost of CHP and the tendency of annual cost saving ratio (CSR). It is found that, the investment cost of CHP has linear increase to the capacity. The running cost is decreased as the increase of CHP capacity and slightly decrease from 120 kW and become stable from 240 kW or higher capacity. Considering the annual cost saving, increase the capacity of CHP does not always lead to more cost saving. As shown in Figure 6-52, it can be seen that the annual cost saving ratio reaches the maximum point when the capacity of CHP is about 80 kW. A rise of capacity leads to decrease of marginal revenue and the marginal cost is almost constant, which causes the net marginal benefit to decrease from a positive value to a negative one [2].

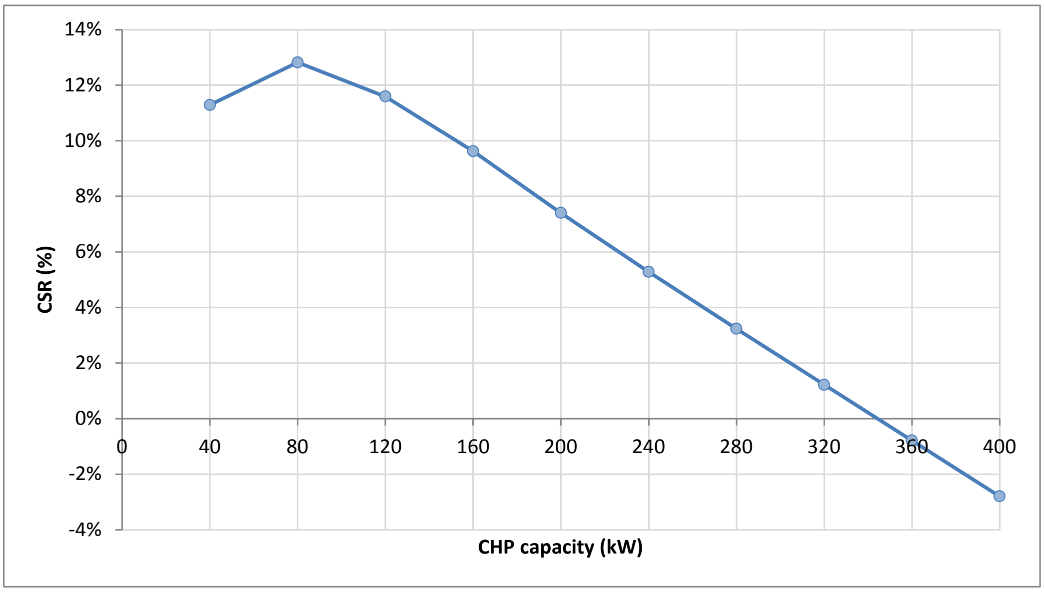


Figure 6-52 Cost saving ratio with various CHP capacities

- Fuel price sensitivity analysis of optimal CHP capacity

- Electricity price sensitivity

Increasing of electricity price due to the depletion of natural resource for electricity generation is possible in near future. One of main parameter affect the adoption of CHP system to hotel which related to annual cost saving is about the electricity price. The electricity price is one of the key parameter to induce customer for selection of power purchase from grid or on-site generation. Furthermore, the changing of electricity price is also the parameter affect the selection of optimal size of CHP system as shown in Figure 6-53 and 6-54.

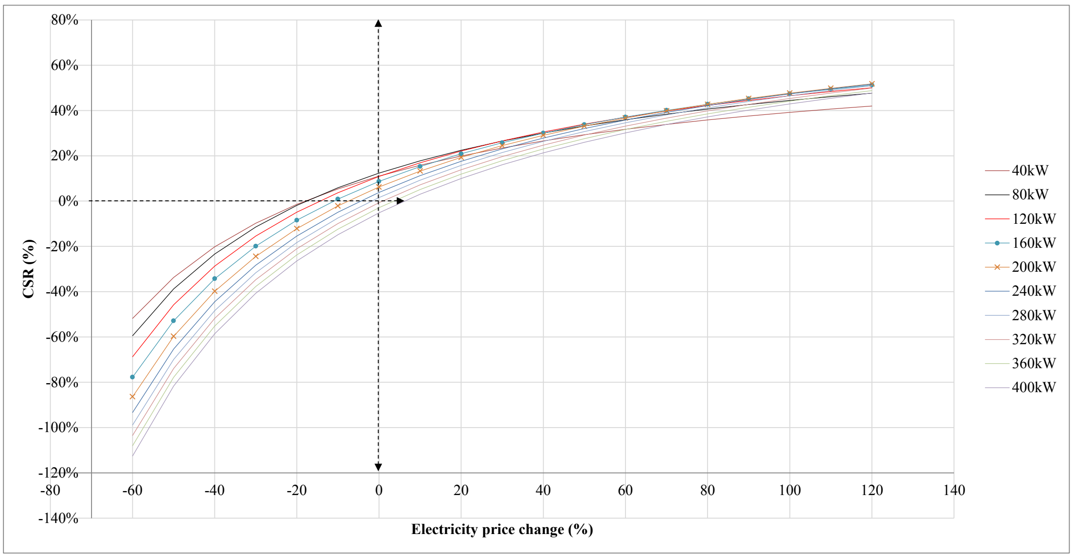


Figure 6-53 Effect of electricity price to optimal sizing of CHP system

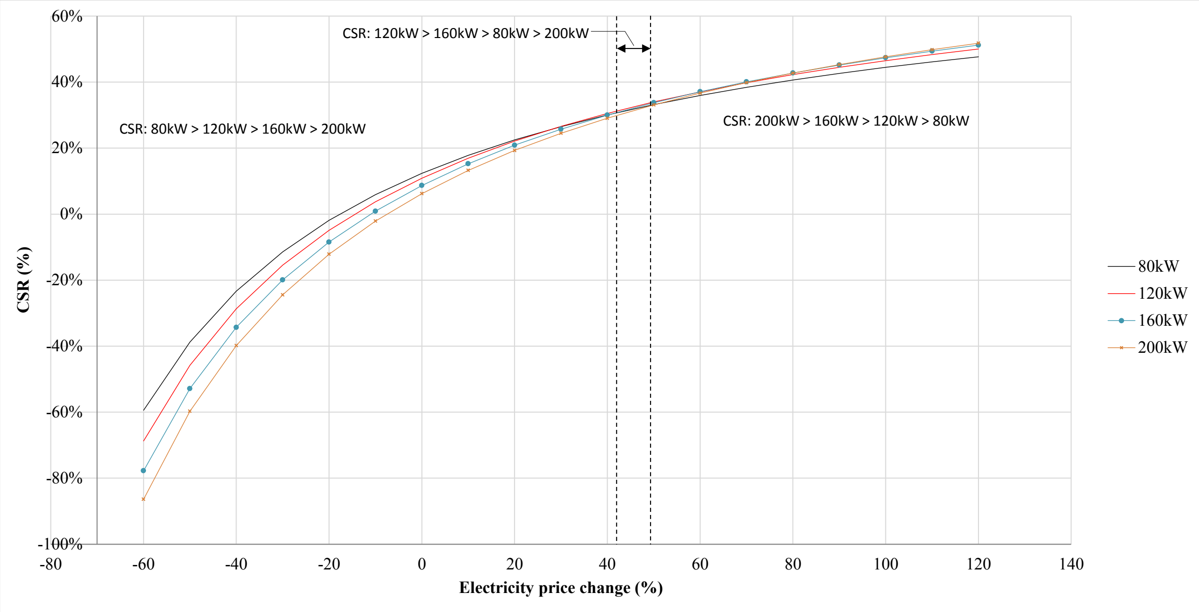


Figure 6-54 Selection of optimal sizing of CHP system under the electricity price sensitivity

From Figure 6-54, the zoning of CHP capacity selection by considering the effect of electricity price sensitivity on CSR values are illustrated. It can be seen that if electricity price is change about -60 to +40 percent, CSR value from the selection of CHP capacity with 80kW > that of 120kW > that of 160kW > that of 200kW. In case of electricity price change in the range +40% to +50%, CSR value from the selection of CHP capacity with 120kW > that of 160kW > that of 80kW > that of 200kW. Finally, if the electricity price is increase more than 50%, CSR value from the selection of CHP capacity with 200kW > that of 160kW > that of 120kW > that of 80kW. But the difference is not much changed.

- Natural gas price sensitivity

As illustrated in Figure 6-55, contrary to the analysis results from sensitivity of electricity price, higher CSR value can be obtained if gas price is decreasing in linear tendency. However, increasing of natural gas price will also induce customer to purchase electricity from grid rather than utilize CHP by natural gas. It can be seen that zoning of CHP capacity selection by considering the effect of natural gas price sensitivity on annual energy cost saving ratio is also analyze in this study. If natural gas price is decrease about 45 – 60 percent, CSR value from the selection of CHP capacity with 120kW > that of 160kW > that of 80kW > that of 200kW. In case of the natural gas price is in the range -35% to -45%, CSR value from the selection of CHP capacity with 120kW > that of 80kW > that of 160kW > that of 200kW. However, if the natural gas price is increase about -35 – 60%, CSR value from the selection of CHP capacity with 80kW > that of 120kW > that of 160kW > that of 200kW, respectively due to the investment cost consideration.

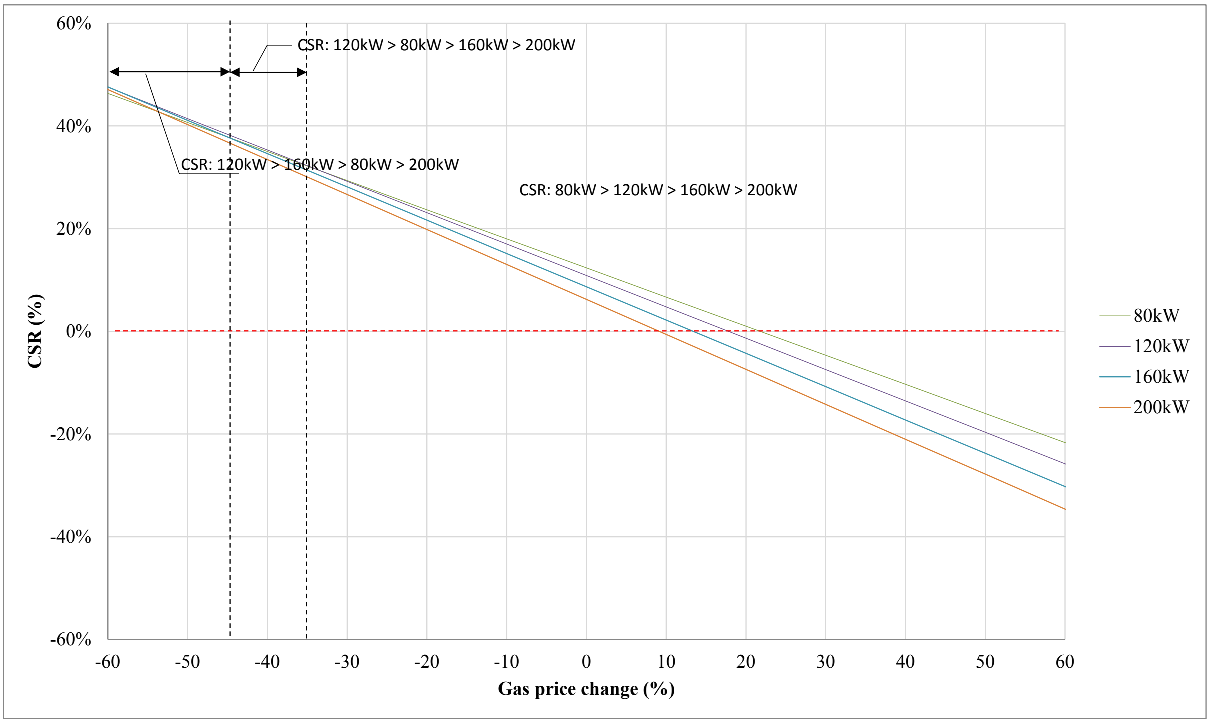


Figure 6-56 Selection of optimal sizing of CHP system under the gas price sensitivity

6-5-5 SUMMARIES FOR THE EVALUATION OF CHP SYSTEM FOR HOTEL

From the consideration of the selection of optimal capacity of cogeneration system for case study of Thailand's office building, for the energy performance aspect, selection of CHP capacity among 120 kW to 300 kW is the optimal solution for primary energy saving concern but also need to considered for other aspects. In case of environmental performance assessment, the values of CER after utilization of CHP capacity from 120 kW will slightly increase and become stable at 300 kW but still not high difference. Finally, for the economic consideration, either the present situation of fuel prices, tariff rates, and the consideration of price sensitivity of gas and electricity price, the selection of CHP capacity with 80-120 kW is optimal choice for economic concern.

In this case study, the optimal solution for CHP capacity from the consideration of energy, environmental, and economic aspect is 120 kW.

6-6 CASE STUDY 3 - FEASIBILITY STUDY ON INTRODUCTION OF COGENERATION SYSTEM FOR THAILAND'S CONVENIENCE STORES [18-20]

Energy efficiency utilization for small scale buildings such as convenience stores, minimarts, small restaurants. has not been the subject of much research due to the high investment costs and lack of skilled workers for implementation and maintenance. Also, the implementation of a CHP system for such buildings is rarely found. From the literatures, there is no research on the effects of a micro-CHP system for convenience stores in hot countries. Therefore, the purpose of this study is to investigate the influence by into a convenience store in Thailand. Firstly, the hourly energy demand has been investigated to see the characteristics of energy performance of convenience store in Thailand throughout the year 2011. Secondly, structures to gauge the energy flow of conventional system and μ-CHP system were developed in order to analyze the reasonable sizing and efficiencies of μ-CHP system for the store. Finally, an evaluation of primary energy savings and environmental benefits is undertaken by using assessment indices in the analysis methods.

6-6-1 CASE STUDY DESCRIPTION

This study examined a typical, real convenience store in Bangkok, Thailand, which is defined as a "stand alone" store. The store is in an isolated location without any other buildings or structures nearby the store. The layout of the store is shown in Figure 6-57.

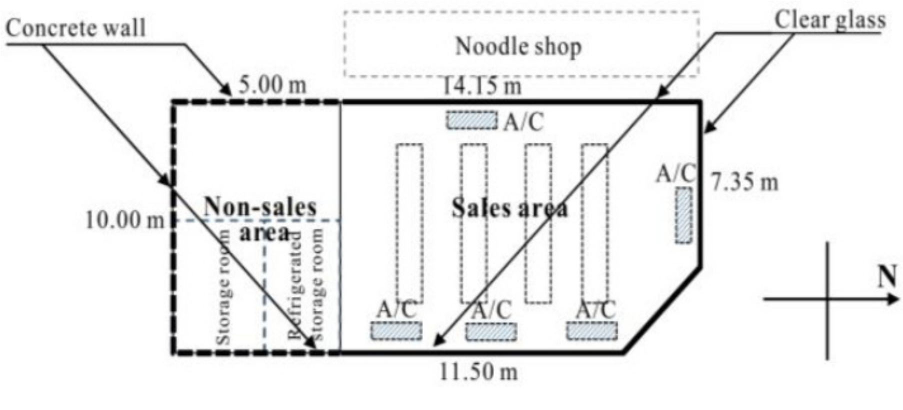


Figure 6-57 Store's layout

6-6-2 ENERGY DEMAND

There are 3 major systems which consume significant energy in a typical convenience store-the Air Conditioning (A/C) system, the lighting system and the equipment of the store. The A/C system in a convenience store in Thailand uses only a split-system in order to provide the cooling demand inside the sales area. From the author's survey's results, one convenience store normally used 3 or more A/C units with a capacity 44,000 BTU (7.08 kW) inside the sales area only. The lighting system in Thai convenience stores mostly use T8 fluorescent lamps (36 Watt and 18 Watt for the capacities) in order to provide lighting inside the store for both the sales and non-sales areas. Even though the energy consumption of fluorescent tubes is not high, most convenience stores in Thailand always use an excessive number of fluorescent tubes inside the store and use them for 24 h even on sunny days. Equipment in convenience stores can be categorized into 2 types-that for refrigerating and that for heating purposes. Equipment for heating purposes will focus on the food preparation only, i.e., microwave, dim sum oven, roller grill machine, toaster, electric hot pot for instant noodles, coffee brewing equipment (some store).

Equipment for refrigeration purposes including freezers for frozen food, ice and ice cream, upright multi-shelf refrigerated display case (air-curtain), closed door reach-in refrigerator (for drinks), storage freezer, is responsible for a high amount of energy consumption.

Figure 6-58 shows the relationship of the utilization of energy between each system for both the sales and non-sales areas. The analysis and investigation results from previous studies (Suapphong et al., 2012) found that the energy use in the sales area accounts for about 62% of total energy use in the store. The air-conditioning system used the highest amount of energy at about 46.2%, followed by the equipment and lighting systems at 34.6% and 19.2%, respectively.

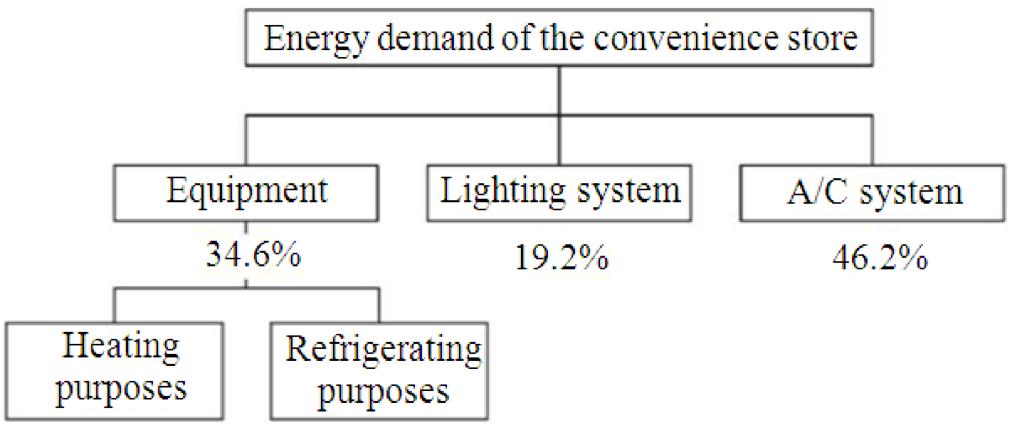


Figure 6-58 Utilization systems affect total energy consumption of the convenience store

In this study, on-site energy consumption in the store by equipment and the A/C system was measured throughout the year 2011 by installing a power meter on the panel board. Figure 6-59 illustrates the measured monthly electrical energy demand during 2011. Two major energy demands are described in this study-equipment energy and A/C system energy demands. The equipment energy demand in this study includes the demand from the refrigerating system and heating systems. The lighting system of the store was composed of 138 36-Watt fluorescent lamps and 8 18-Watt fluorescent lamps in the store sales and non-sales areas.

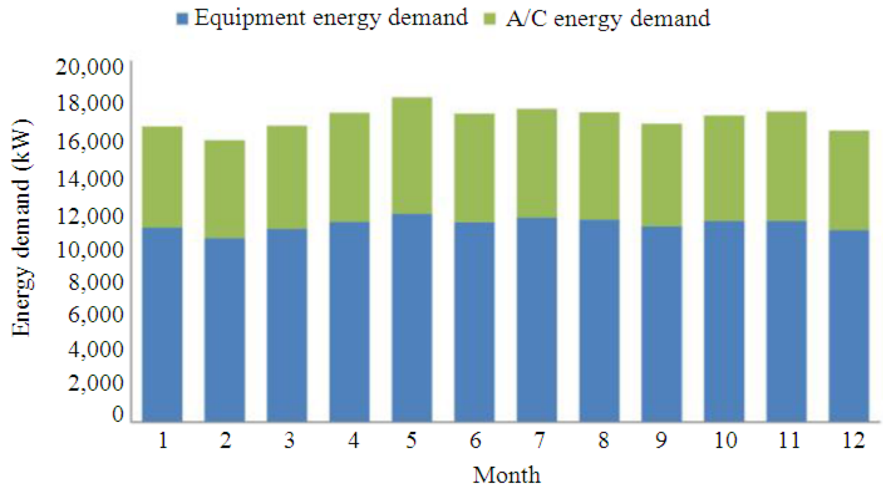


Figure 6-59. Monthly electrical demand of A/C and equipment

Figure 6-60 and 6-61 show the hourly and 1-day (average) load patterns of cooling and equipment (including lighting system) demands, respectively. It was found that peak load of equipment and cooling demands are 18.9 kW and 15.13 kW, respectively. The cooling demand of the store is sensitive to climate conditions which can be seen from the shift in the energy demands during day time and which gradually decrease at night beginning at 6 pm. It can be seen that the tendency of equipment energy demand in one day is almost flat compared with cooling demand. However, the energy consumption of equipment is a little higher from 6 pm due to the increase in customers after school and work.

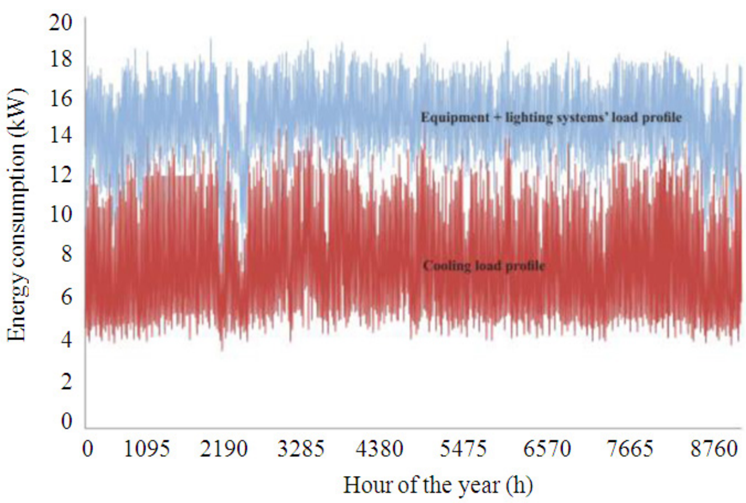


Figure 6-60 One-year load profiles of cooling, equipment and lighting energy demands

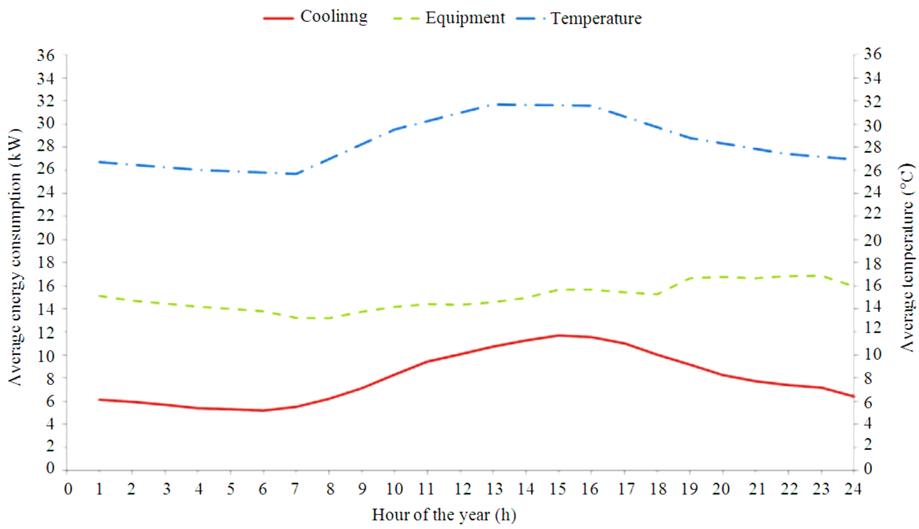


Figure 6-61 Average value of 1-day load pattern for equipment and cooling demand and outdoor temperature

Therefore, the hourly energy demand, represented by load-duration curve (monotonic curve) pattern which starting with largest to smallest consumption values for 1-year consumption of cooling and equipment (including lighting) demands, respectively is illustrated in Figure 6-62.

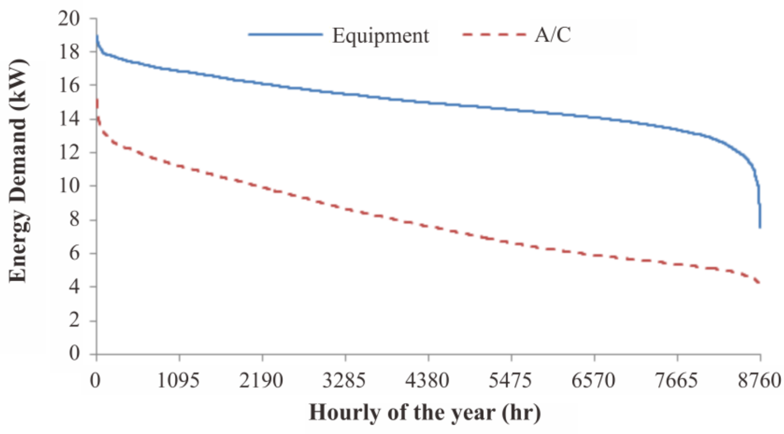


Figure 6-62. Load duration curves of equipment and cooling demand of the store

6-6-3 CASE SETTING AND SIMULATION METHOD

6-6-3-1 MODELING OF MICRO-CHP SYSTEM

The analysis of the μ-CHP system comparing it to the conventional system was executed based on end-used demand data of hourly electricity energy consumption as illustrated in Figure 6-63. Figure on the left is of the conventional system and the figure on the right is of the μ-CHP system. The energy demand can be categorized into 2 major demands, namely, direct electrical energy consumption by equipment (lighting demand and equipment load) and cooling demand have been addressed in this study.

For the conventional system, the utility grid serves all electrical demand which is used for not only direct power consumption, but also for space cooling load through the operation of the store's A/C system. For heating purposes, the store also uses electricity from the use of machines to provide hot water for noodles and frozen food. The μ-CHP system in this study consists of a gas engine and absorption chiller. The mode of the gas engine is electricity tracking. The gas engine is used to meet the electrical and cooling loads with the use of an A/C system through the absorption chiller. If the recovery of thermal energy from the gas engine does not fully satisfy the absorption chiller's needs, an additional boiler is used. However, if the recovered thermal energy goes over local needs, the surplus energy is released into the atmosphere.

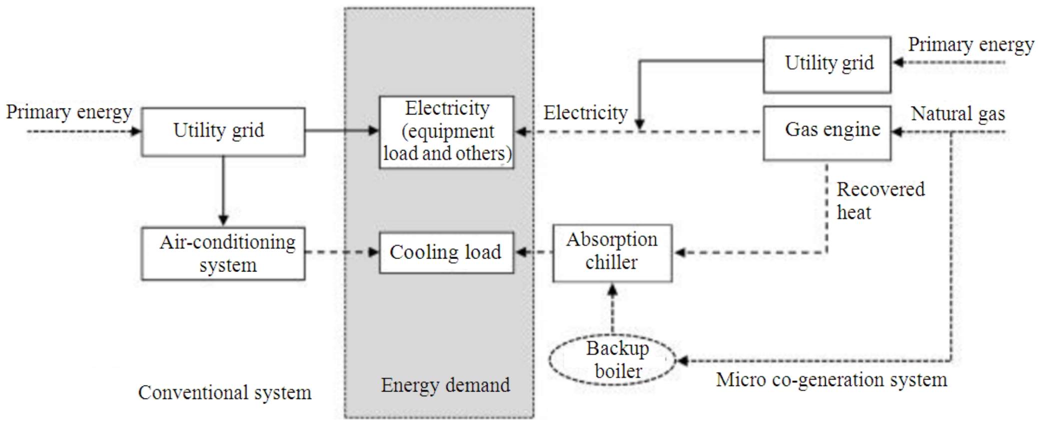


Figure 6-63 Conventional and μ-CHP energy supply systems

6-6-3-2 INPUT ASSUMPTIONS O THE CASE STUDY

The technical data for this analysis are summarized in Table 6-6-1.

Table 6-6-1. Investigated data and data assumption for the analysis

Item	Data assumptions	Value
Electricity utility grid	Efficiency (%)	30
	Service charge (THB/kWh)	312.24
	Demand charge (THB/kW)	132.93
	Energy price – on peak / off peak (THB/kWh)	2.176 / 3.6796
Natural gas	Energy price (THB/mmBTU)	350
Air-conditioning system	Coefficient of performance (COP)	3
	Lifetime (year)	10
	Capital cost ($\times 10^3$ THB/kW)	5.2
Absorption chiller	Coefficient of performance (COP)	1.1
	Lifetime (year)	15
	Capital cost ($\times 10^3$ THB/kW)	15.48
Back-up natural gas boiler	Efficiency (%)	85
	Lifetime (year)	15
Micro-cogeneration Plant	Capacity (kW)	3,6,9,12,15,18,21,24,27,30
	Electricity efficiency, η_E (%)	25,30,35,40,45
	Heat recovery efficiency, η_H (%)	25,30,35,40,45
	Capital cost ($\times 10^3$ THB/kW)	64.52
	Lifetime (year)	15
Others	Interest rate (%)	2

6-6-4 ANALYSIS RESULTS AND DISCUSSIONS

6-6-4-1 EVALUATION OF ENERGY PERFORMANCE

In this section, PES values for various options with different μ-CHP's capacity are calculated. The electrical efficiency (η_E) and thermal efficiency (η_H) of μ-CHP system is assumed to be 35% and 45%, respectively, in order to analyze the reasonable capacity for maximizing the PES. From Figure 6-64, below 15 kW, the increase of μ-CHP's capacity results in a significant energy saving. Above 15 kW for the μ-CHP's capacity, the change of PES becomes slower. Finally, the PES becomes stable from the utilization of μ-CHP's capacity above 18 kW. It is found that, the PES value can be increased up to 45% from the variation of the gas engine's efficiencies.

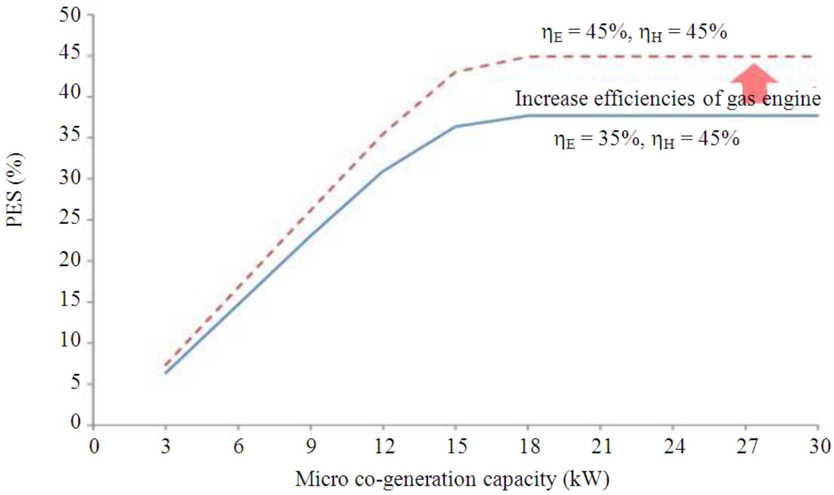


Figure 6-64 PES value with various μ-CHP capacities

Figure 6-65 represents the PES values of the μ-CHP system under the capacity of 15 kW with the η_E and η_H varied from 25% to 45%. It is found that, increasing of η_E of the μ-CHP at the low range of the efficiency will have a significant effect on the PES value, e.g., increasing of η_E from 25% to 30%, PES value can be increased by 8.9-10.6%. On the other hand, at high value of η_E, the increase of the efficiency results in a slight increase of PES value, e.g., increasing the η_E from 40% to 45%, only gives PES value an increase of 2.7-3.6%.

It is also found that the η_H of the μ-CHP affects the change of the PES value but is not as significant as the change in η_E. Increasing the η_H at a low rate results in a high change of PES value, e.g., with the increase of the η_H from 25% to 30%, PES value will increase by 2.8-4.1%. On the contrary, the increase of the η_H at a high rate results in a slight change of

PES value, e.g., with the increase of the η_H from 40% to 45%, PES value will be raised by 1.5-2.7%.

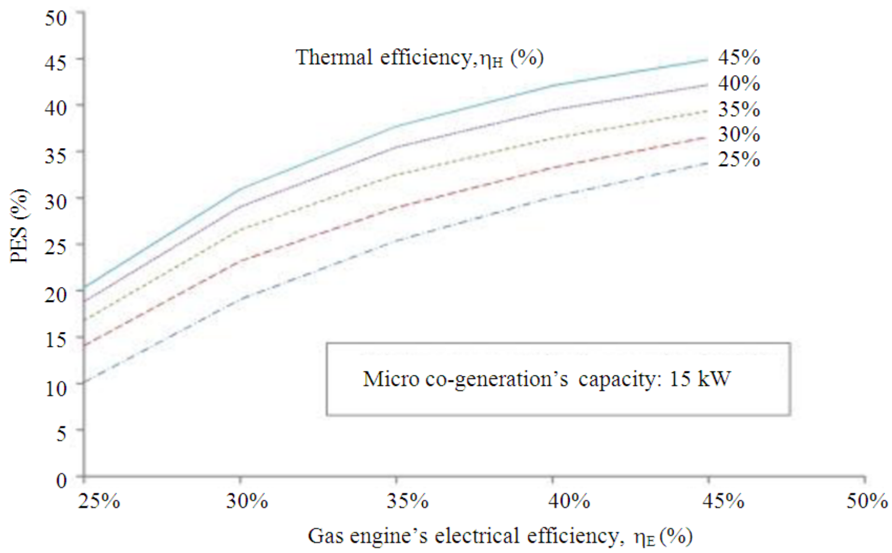


Figure 6-65 PES value with various gas engines' efficiencies

6-6-4-2 EVALUATION OF ENVIRONMENTAL PERFORMANCE

Figure 6-66 shows the CO_2 Emission Reduction Ratio (CER) values for various capacities of μ-CHP systems with η_E and η_H assumed at 35 and 45%, respectively. Similar to the phenomena of energy performance, increasing the μ-CHP's capacity results in a significant reduction of CO_2 emission below 15 kW. Above 15 kW for the μ-CHP's capacity, the change in CER value becomes slower. Finally, the CER value becomes stable from the μ-CHP's capacity above 18 kW. It was found that the CO_2 emission reduction ratio can be increased up to 88.4% from the variation of the gas engine's efficiencies.

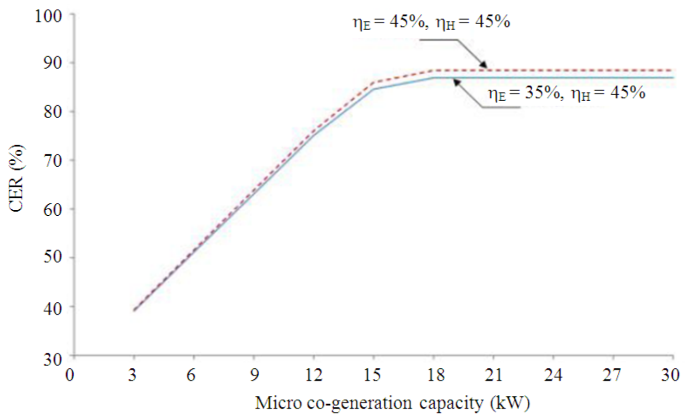


Figure 6-66 CER value with various μ-CHP capacities

Figure 6-67 illustrates the CO_2 emission Reduction Ratio (CER) from the μ-CHP system with the capacity 15 kW integrated with the η_E and η_H from 25% to 45%. Increase of η_E of μ-CHP at a low value results in a significant increase of CER value, e.g., with the increase of η_E from 25% to 30%, CER value can be increased by 1.9-2.2%. In contrast, at a high value, the change of the η_E results in a slight increase of CER value, e.g., with the increase of η_E from 40% to 45%, but CER value can be increased only by 0.6-0.8%.

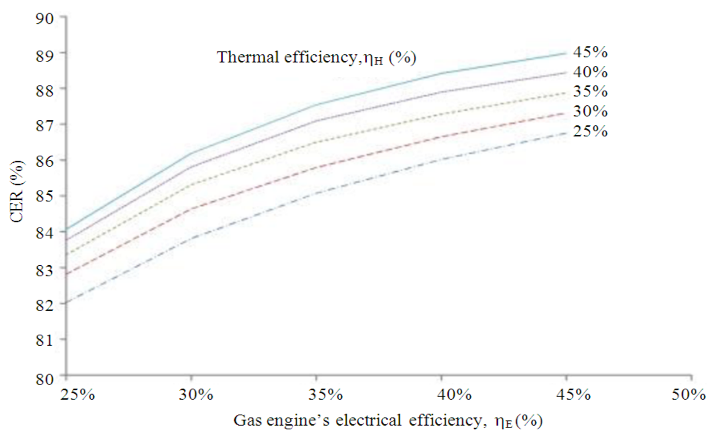


Figure 6-67. CER value with various gas engines' efficiencies

The thermal efficiency (η_H) of gas engines has less effect on the CER value for all rates of efficiency. Increasing the η_H at lower rates results in a slight change of CER value, e.g., with the increase of the η_H from 25% to 30%, the CER value is raised by 0.6-0.8%. Furthermore, increasing the η_H at higher rates also results in a slight change of CER value, e.g., with the increase of the η_H from 40% to 45%, CER value is raised by 0.3-0.6%

The results shown in Figures 6-64 and 6-66 can be explained from the consideration of load patterns of the convenience store and μ-CHP system for both equipment and the cooling load as illustrated in Figure 6-68 and 6-69. Figure 6-68 illustrates the load patterns of the equipment demand of the convenience store and electricity produced by the μ-CHP system. Zone 1 in this Figure denotes the amount of electricity that is still needed from the utility grid. It was found that increasing the μ-CHP's capacity will result in the reduction in zone 1, which means much more electricity for the equipment needs of the store can be supplied by a μ-CHP system. When the capacity is higher than 18 kW, full electricity for equipment can be produced by a μ-CHP system, which means the store is totally independent of the grid electricity supply.

Figure 6-69 illustrates the load duration curve of the cooling demand and supply from the μ-CHP system with a 15kW capacity, with 35 and 45% for η_E and η_H, respectively. Load duration curves of the cooling demand and production from the μ-CHP system of the store are divided into 3 zones, namely zone 1, 2 and 3 which represented the amount of heat use in different states. Zone 1 represents the amount of recovery heat which is produced by the μ-CHP system. Zone 2 represents the amount of heat from the back-up boiler which provides additional heat to produce the cooling energy. Zone 3 is the amount of surplus energy which is produced from the μ-CHP that exceeds the requirements and which is released into the atmosphere. It can be seen that increasing of the μ-CHP capacity will enlarge the area of zone 1 and reduce the size of zone 2, which means a large part of the cooling demand can be met by recovery heat from the μ-CHP system. However, with the increase of the μ-CHP capacity, the area of Zone 3 will also be increased, which means a lot of waste heat will be released into the environment. From the viewpoint of making good use of recovery heat, the optimum capacity of the μ-CHP system will be around 9 kW, at which the area of Zone 3 will be near zero and recovery heat from the μ-CHP system is totally used.

The analysis of results shows that considering the efficient energy saving, the μ-CHP sizing of 15 kW is the optimal solution for this convenience store. Above the 18 kW capacity, the electricity supply can be defined as a "grid independence" pattern, which means during operation, no electricity is supplied from the utility grid even though a high amount of surplus heat cannot be used. On the other hand, the consideration of the minimization of waste heat can lead to a decision to select a 9 kW μ-CHP system. But in this case, the additional electricity supply for the equipment load from the grid and heat supply from the back-up boiler is needed in order to satisfy the energy need.

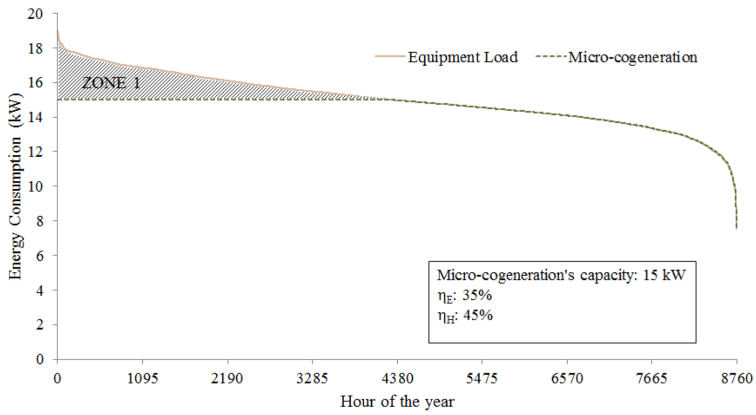


Figure 6-68 Load duration curves of the equipment demand and load production from the μ-CHP system

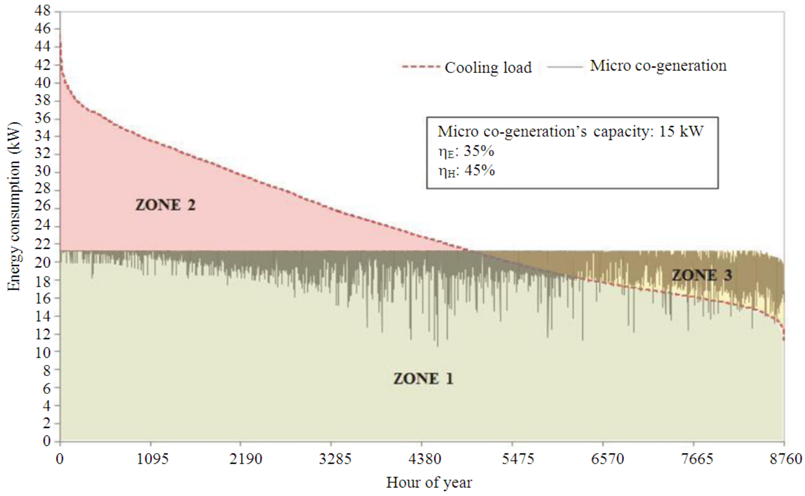


Figure 6-69 Load duration curves of the cooling demand and the load production from μ-CHP system

6-6-4-3 EVALUATION OF ECONOMIC PERFORMANCE

- Effect of micro-cogeneration capacity to annual cost structure

Figure 6-70 shows the estimated investment cost and running cost of μ-CHP and the tendency of annual cost saving ratio (CSR). Investment cost of μ-CHP has linear increase to the capacity. The running cost (purchased energy cost) is decreased as the increase of CHP capacity and become stable from 18kW or higher capacity. Considering the annual cost saving, increase the capacity of μ-CHP does not always lead to more cost saving. It can be seen that the annual cost saving ratio reaches the maximum point when the capacity of μ-CHP is about 15 kW.

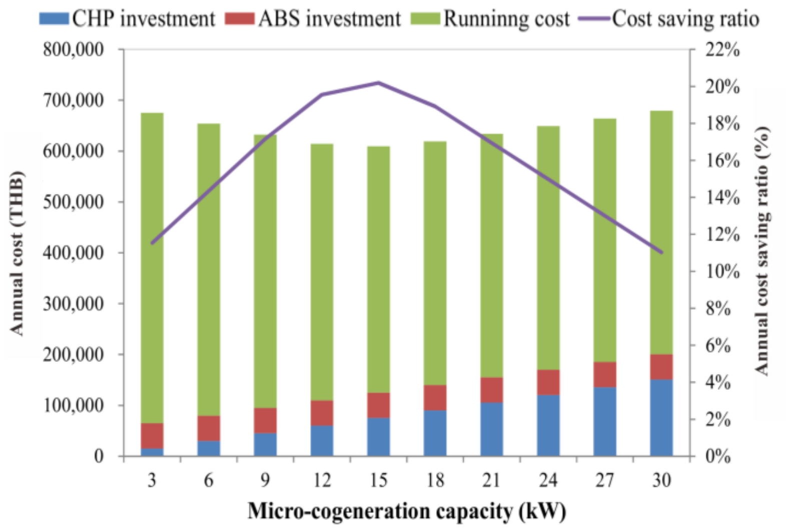


Figure 6-70. Annual cost structure and CSR value

- Fuel price sensitivity analysis of optimal micro-cogeneration capacity

Electricity and gas price are the key parameters influence the decision of implementing the μ-CHP system by considering the economic benefits to judge for the installation and also capacity and efficiencies of μ-CHP system in the convenience store. In this study, the profitability index e.g. Cost saving ratio (CSR) or Payback period (PBP) have been analyzed due effect of the price sensitivity for both gas and electricity in order to find out the optimal capacity for μ-CHP system under the circumstance of price variation in the future.

  - Electricity price sensitivity

Increasing of electricity price due to the depletion of natural resource for electricity generation is possible in near future. One of main parameter affect the adoption of μ-CHP system to convenience store which related to annual cost saving is about the electricity price.

The electricity price is one of the key parameter to induce customer for selection of power purchase from grid or on-site generation. Furthermore, the changing of electricity price is also the parameter affect the selection of optimal size of μ-CHP system as shown in Figure 6-71.

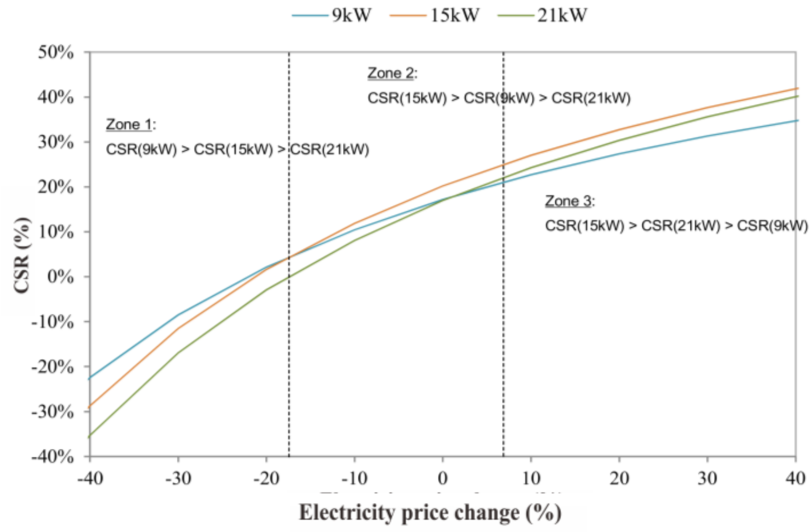


Figure 6-71. Effect of electricity price to CSR value

From Figure 6-71, the zoning of μ-CHP capacity selection by considering the effect of electricity price sensitivity on CSR values are illustrated. It can be seen that if electricity price is decrease about 18 – 40 percent (zone 1), CSR value from the selection of μ-CHP capacity with 9kW > that of 15 kW > that of 21 kW. In zone 2, the electricity price is in the range -18% to +8%, CSR value from the selection of μ-CHP capacity with 15kW > that of 9 kW > that of 21 kW. However, if the electricity price is increase about 8 – 40% which represented in zone 3, CSR value from the selection of μ-CHP capacity with 15kW > that of 9 kW > that of 21 kW.

- Natural gas price sensitivity

As illustrated in Figure 6-72, contrary to the analysis results from sensitivity of electricity price, higher CSR value can be obtained if gas price is decreasing in linear tendency. However, increasing of natural gas price will also induce customer to purchase electricity from grid rather than utilize μ-CHP by natural gas. It can be seen that zoning of μ-CHP capacity selection by considering the effect of natural gas price sensitivity on annual energy cost saving ratio is also analyze in this study. If natural gas price is decrease about 4 – 60 percent (zone 1), CSR value from the selection of μ-CHP capacity with 15kW > that of 21 kW > that of 9 kW. In zone 2, the natural gas price is in the range -4% to +28%, CSR value from the selection of μ-CHP capacity with 15kW > that of 9 kW > that of 21 kW. However, if the natural gas price is increase about 28 – 60% (zone 3), CSR value from the selection of μ-CHP capacity with 9 kW > that of 15 kW > that of 21 kW, respectively.

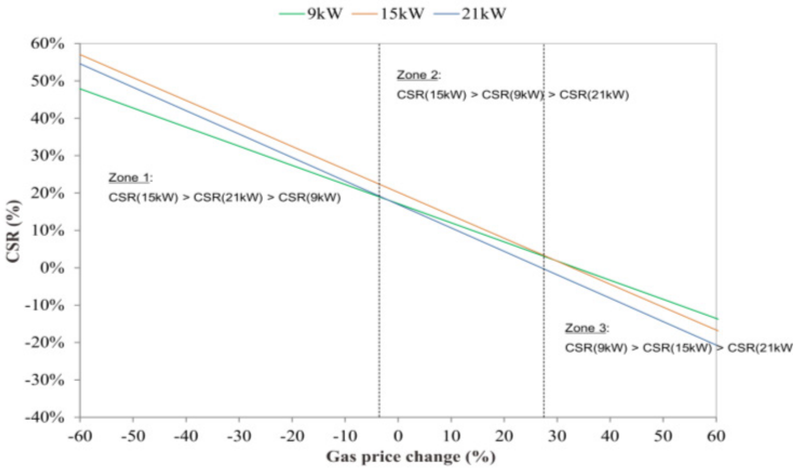


Figure 6-72 Effect of gas price to CSR value

6-6-5 SUMMARIES FOR THE EVALUATION OF MICRO CHP SYSTEM FOR CONVENIENCE STORE

In this study, the introduction of micro-cogeneration (μ-CHP) system for typical convenience stores in Thailand has been evaluated. The study case with 188 sq.m.-floor area was considered regarding to store's energy performance and hourly load profile throughout a year of electric and cooling load. Under the circumstance of electricity and cooling demands, the mathematical model has been developed in order to determining the optimal size of μ-CHP system. According to the analysis in this study the following conclusions can be drawn:

1. Energy efficiency consideration: selection of μ-CHP capacity of 15 kW is the optimal solution for efficient energy saving concern. However, in order to decentralize power generation from utility grid which so called "grid independence" pattern, selection of μ-CHP capacity of 18 kW is suitable for this purpose. On the other hand, the consideration of the minimization of waste heat can lead to a decision to select a 9 kW of the μ-CHP system. But in this case, the additional electricity supply for the equipment load from the grid and heat supply from the back-up boiler is needed in order to satisfy the energy need.
2. Economic consideration: under the present situation of fuel prices for both electricity and gas prices including tariff rates, 15 kW of the μ-CHP capacity is the reasonable solution by the consideration of lowest Cost saving ratio (CSR). However, 12 kW of μ-CHP capacity is also suitable for economic concerns from the payback period calculation results. It is noted that the sensitivity of fuel price and tariff structures either electricity price and natural gas price are the significant factors affect the selection of optimal sizing for μ-CHP system in order to achieve the economic benefits. Not only the selection of optimal sizing should be concern from the fluctuating fuel price, the operation schedules of μ-CHP system also need to be considered.

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CHAPTER SEVEN: CONCLUSIONS

Implementation of alternative energy to support increased demand is one effective way to meet energy consumption needs and to reduce environmental pollution caused from the emissions being released. The cogeneration, which produces electricity with heat utilization, is also called CHP system, or combined heat and power, which makes electricity with heat utilization. This is a potentially a significant technology to provide effective energy utilization and environmental benefits for both the commercial and industrial sectors in Thailand. Compared with traditional central energy supply, distributed energy source can utilize a wide range of energy source, including biomass-based generators, combustion turbines, concentrating solar power and photovoltaic systems, fuel cell, wind turbines, micro turbines, diesel generator sets and electrical power storage and all kinds of thermal recovery technologies. Distributed energy system has the high primary energy efficiency. This means that lower fuel consumption takes place, and the energy is generated at a lower running cost, and in a more environmentally friendly way. In order to preparation for above situation, the feasibility study of DERs including related parameters for the implementation of DERs is a key factor influencing the energy utilization efficiency of distributed energy system. Therefore, this thesis, "Integrated evaluation of energy use by introducing the distributed energy resources in Thailand's commercial buildings" is one of the support information for DER implementation

Chapter 1, PREVIOUS STUDY AND PURPOSE OF THE STUDY, investigated the present situation of energy in Thailand including energy supply, final energy consumption, and overview of the potential for distributed energy generation technologies and their characteristics. In addition, the previous studies of this research are reviewed.

Chapter 2, INVESTIGATION OF DISTRIBUTED ENERGY RESOURCES IN THAILAND, reviewed the present situations and development of distributed energy technologies including the future potential in Thailand are described in details. Also, the situation of key groups for the development of Distributed Energy Resources (DERs) in Thailand, namely Independent Power Producer (IPP), Small Power Producer (SPP), and Very Small Power Producer (VSPP) are reviewed in details.

Chapter 3, THAILAND'S ENERGY POLICY, reviewed the energy policies which related to the commercial buildings either the alternative energy policy or energy conservation policy. This chapter can be state for the readiness of Thailand's government for the development of DERs that have the support regulations and policies in order to strengthen the new era of energy supply in the future.

Chapter 4, PRESENT SITUATTION OF ENERGY USE IN THAILAND'S COMMMERCIAL BUILDINGS, reviewed the energy consumption of commercial buildings in Thailand by type for whole country from the database of the energy management report which submitted to Department of Alternative Energy Development and Energy Efficiency (DEDE) to understand the characteristics of energy consumption in each building type and potential for development from DERs concept.

Chapter 5, PERFORMANCE ASSESSMENT OF COMBINED HEAT AND POWER SYSTEM FOR THAILAND's COMMERCIAL BUILDING: proposed the assessment index for evaluation the performance of the CHP system for Thailand's commercial buildings. First, the evaluation of the energy performance should be performed for the first priority and also integrated with the assessment criteria of other two assessment indexes in order optimize the capacities of the CHP system under several conditions.

Chapter 6, FEASIBILITYY STUDY AND OPTIMIZATION ON THE INTRODUCTION OF CHP SYSTEM FOR THAILAND'S COMMERCIAL BUILDINGS, evaluated the potential of CHP implementation for Thailand's commercial buildings from 3 case-studies; office buildings, hotels, and convenience stores by considering the integrated evaluation index in order to analyse the benefit after implementation. It is found that, the selection of optimal sizing of CHP capacity and efficiency consequence to save the primary energy more than 20% in all case studies.

Chapter 7, CONCLUSIONS, the whole summary of each chapter has been presented.