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Environmental and economic evaluation of distributed energy resources technology in buildings

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CHAPTER ONE

RESEARCH BACKGROUND AND RESEARCH OBJECTIVE

1.1 Research background

1.1.1 Energy usage situation

The energy consumption of the world has been continued to increase with economic growth, continued to increase at 2.6% per year on average from 3.8 billion tons in1965, it has been reached 11.3 billion tons in 2008.

World energy consumption shows the hot points at this stage: ①By the influence of economic development and population growth, the primary energy consumption of the world has been continuously increased. ②World energy consumption presents different patterns of growth, because of developed countries has entered into post-industrial society, the economy develops to low-power, high-yield industrial structure. Energy consumption growth rate of developed countries is significantly less than developing countries. ③World energy consumption structures tend to high quality, but still have large regional differences. ④Energy resources of the world are still relatively abundant, but energy trade and transport pressure increase. For the future, along with continuously increase in energy consumption and energy resources of distribution concentration. Competitions for the energy resources will grow increasingly fierce, the ways of competition are complex; at the same time, the influence of fossil fuels to environment pollution and global climate will become increasingly serious.

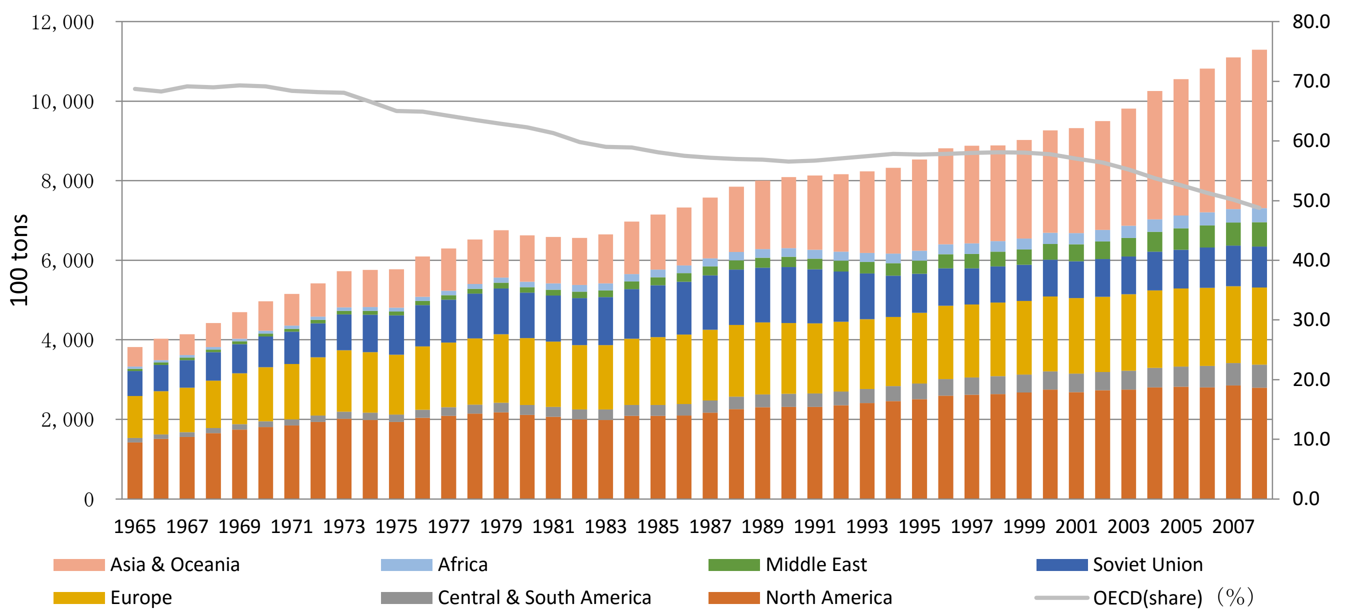


Figure 1-1-1 World energy consumption trend in different regions

(Source: BP, Statistical Review of World Energy 2009)

From the energy growth, regional differences exist, developed regions have low growth rate, and on the other hand developing regions have high growth rate. Figure 1-1-1 shows the world energy consumption trend in different regions. From 1965 to 2008, the percentage of OECD countries energy consumption has down from 69% to 48.8%, almost reduce about 20%. From the energy consumption structure in different regions point of view, the developed countries change a little. However, developing countries like Asia and Oceania change a lot increase from 493 tons in 1965 to 3982 tons in 2008. So we can know that, the part of increase almost from the developing countries.

In 1965, the largest proportion of parts is North America, but in 2008, the largest proportion of parts is Asia and Oceania. Because the developing countries have their own high development, another is more and more developed countries set up their factories in the developing countries. Also the developed countries have high energy utilization efficiency.

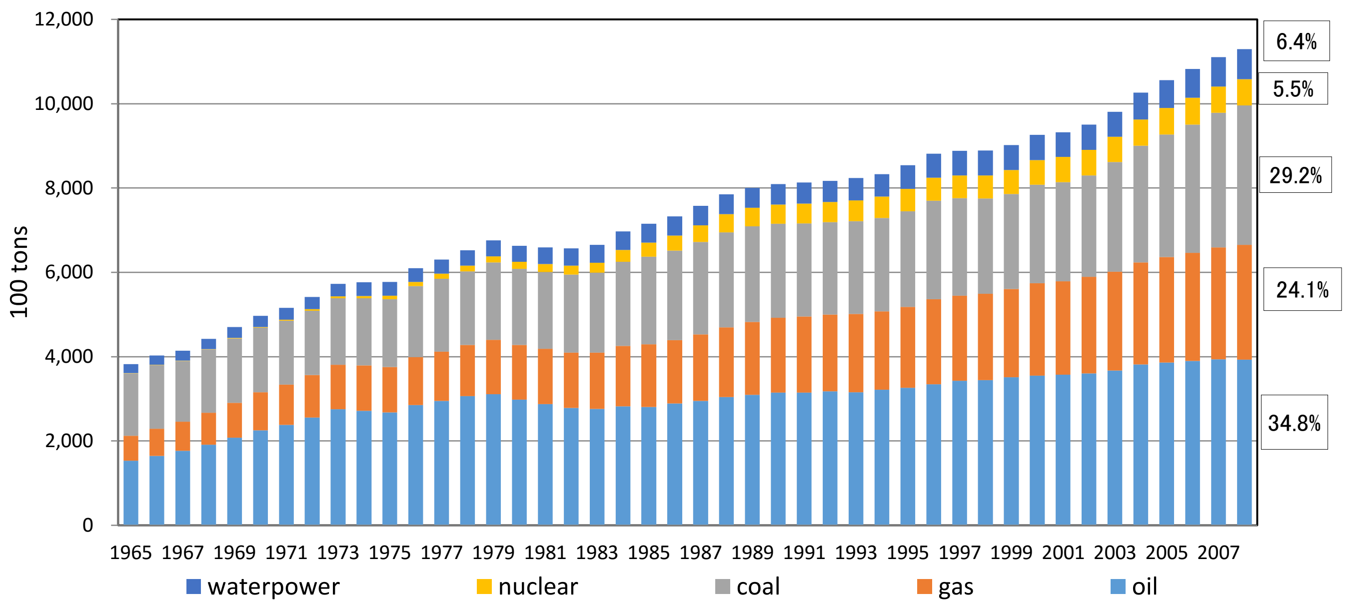


Figure 1-1-2 World energy consumption trend use in different energy source

(Source: BP, Statistical Review of World Energy 2009)

Figure 1-1-2 shows the world energy consumption trend use in different energy source. Until today, oil is still the center of world energy consumption. Convert other energy sources to promote power generation, support the strong transport fuel consumption. From 1965 to 2008, the average growth rate almost at 2.2% of the total energy consumption growth rate, account for 34.8% of the total energy consumption in 2008. During this time, especially as alternative energy source instead of oil increase very fast such as natural gas and nuclear power, the average annual growth rate of the same period has respectively reached 11.5% and 3.6%. According to this result, from 1965 to

2008 the proportion of natural gas in total energy consumption increase from 15.6% to 24.1%, and the proportion of nuclear power in total energy consumption increase from 0.2% to 5.5%. On the other hand, another mainstay is coal, the average growth rate almost at 1.9% of the total energy consumption growth rate. From 1965 to 2008, the proportion of coal in total energy consumption has down from 38.7% to 29.2%. Hydropower as a renewable energy, from 1965 to 2008 the proportion of hydropower in total energy consumption has increased from 5.5% to 6.4%.

Because of energy shortage, primary energy consumption gets less and less; the renewable energy will become main stream. Such as waterpower and solar power, we need to put more attention on this field.

1.1.2 Global warming problem

The Sun powers Earth's climate, radiating energy at very short wavelengths, predominately in the visible or near-visible part of the spectrum. Roughly one-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space. The remaining two-thirds is absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the absorbed incoming energy, the Earth must, on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum. Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is the greenhouse effect. The glass walls in a greenhouse reduce airflow and increase the temperature of the air inside.

However, human activities, primarily the burning of fossil fuels and clearing of forests, have greatly intensified the natural greenhouse effect, causing global warming. The primary cause of global warming is Carbon Dioxide emissions. CO_2 is being pumped into our atmosphere at an insane pace; 8 billion tons of CO_2 entered the air last year. Of course, some of this is due to natural activity such as volcanic eruptions and people breathing. But the Earth is equipped to easily absorb those into the normal regenerative process. The beginning of global warming was caused by fossil fuels being burned and emitting plenty of CO_2.

Currently in the world, 40% of all CO_2 emissions are caused by power plants. There are burning coal, natural gas and diesel fuel. Some power plants burn garbage. Some burn methane made from garbage. And discounting those super green electrical generating plants designed to issue negligible pollutants, all of our power plants let loose into the atmosphere CO_2.

We plan to offer honest value comparisons of products such as hybrid cars. If the carbon footprint made from producing a hybrid is ten times larger than that it erases it is news that should be shared. We will find solutions to the problem of global warming by asking countless questions about the processes we rely upon to live. We answer these questions on a personal level by changing the habits, which build each of our carbon footprints and on a global level by insisting that social and governmental structure acknowledge the need for environmental protection.

1.1.3 Renewable energy

We need to promote the rapid widespread deployment of advanced, clean, and sustainable energy sources across our imperiled planet. This transformation in the way our civilization generates and uses energy provides the best physical means to protect the biosphere, remediate ecological damage, and enhance the health and well-being of the global human family.

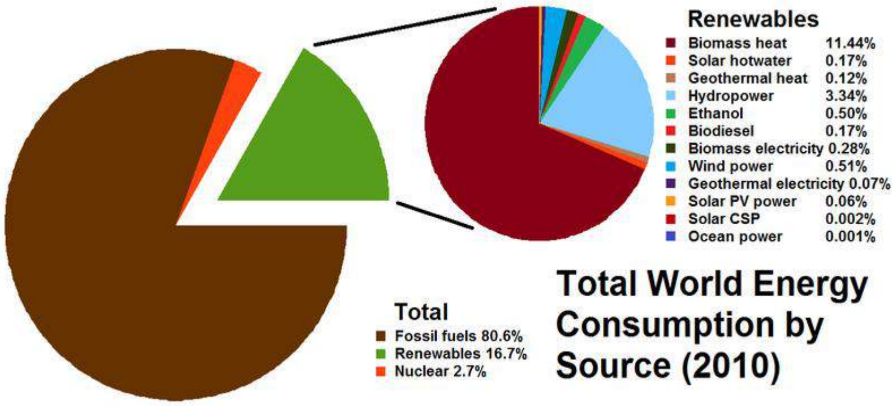


Figure 1-1-3 Total world energy consumption by source
(Source: IPCC)

Figure 1-1-3 shows the total world energy consumption by source in 2010. Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable. About 16.7% of global final energy consumption comes from renewable, with 11.44% coming from traditional biomass, which is mainly used for heating, and 3.34% from hydroelectricity. New renewable (small hydro, modern biomass, wind, solar, geothermal, and bio-fuel) accounted for another 3% and are growing very rapidly. Renewable energy replaces fossil and nuclear fuels in four distinct markets: power generation, heating and cooling, transport fuels, and rural/off-grid energy services.

This growth was driven primarily by China, which accounted for 50% of global capacity additions in 2010, up from 4.4% in 2005.China added 18.9 GW of new wind capacity, a 37% increase over the 2009 market, bringing the country into the global lead with a total of 44.7 GW. However, about 13 GW of this total capacity had not yet been commercially certified by year-end, although all but 2 GW was in fact already feeding electricity into the grid. The process of finalizing the test phase and getting a commercial contract with the system operator takes somewhat longer, accounting for the delays in reporting. More than 30% of China's installed capacity was in the Inner Mongolia Autonomous Region, followed by Gansu(10%), Hebei (10%) and Liaoning (9%) provinces.

Hydropower (from hydro meaning water) is energy that comes from the force of moving water. The fall and movement of water is part of a continuous natural cycle called the water cycle. Energy from the sun evaporates water in the Earth's oceans and rivers and draws it upward as water vapor. When the water vapor reaches the cooler air in the atmosphere, it condenses and forms clouds. The moisture eventually falls to the Earth as rain or snow, replenishing the water in the oceans and rivers. Gravity drives the water, moving it from high ground to low ground. The force of moving water can be extremely powerful. Hydropower is called a renewable energy source because the water on Earth is continuously replenished by precipitation. As long as the water cycle continues, we won't run out of this energy source.

Table 1-1-1 shows the top ten countries were installed hydropower capacity and generation share. Global installed hydropower capacity was estimated to be between 926 GW and 956 GW in 2009/2010, excluding pumped storage hydropower capacity. Pumped hydro capacity was estimated to be between 120 GW and 150 GW with a central estimate of 136 GW. In 2010, 30 GW of new hydro capacity was added. The global production of electricity from hydro was estimated to have increased by more than 5 % in 2010. This was driven by new capacity additions and above the average hydro in flows in China. The world leaders in hydropower are China, Brazil, Canada, the United States and Russia. Together these countries account for 52 % of total installed capacity.

Figure 1-1-4 shows the hydropower generation by region. Hydropower is the largest source of renewable power generation worldwide. In 2009/2010 11000 hydropower plants in 15 countries were generating electricity. The total electricity generated by hydropower in 2009 reached 3329 TWh, 16.5% of global electricity production. And there is around 85 of total renewable electricity generation and provide more than one billion people with power.

Norway's generation system is almost 100% hydro, with hydro accounting for 97% of generation in 2009 and 99% in 2010. In 2010, hydro accounted for 84% of total generation in Brazil and 74% in Venezuela. Central and South America generate nearly 64% of all their electricity from hydropower. There are a number of countries in Africa that produce close to 100% of their grid-based electricity from hydro. Russia has an estimated 50 to 55 GW of installed hydropower capacity, which represents about one-fifth of the country's total electric capacity.

Asia accounts for the largest share of global installed hydropower capacity, followed by

Table 1-1-1 Top ten countries by installed hydropower capacity and generation share (Source: IHA, 2012 and IPCC, 2011)

	Installed capacity (GW)		Hydropower's share of total generation (%)
China	210	Norway	99
Brazil	84	Brazil	84
USA	79	Venezuela	74
Canada	74	Canada	59
Russia	50	Sweden	49
India	38	Russia	19
Norway	30	India	18
Japan	28	China	16
France	21	Italy	14
Italy	20	France	8
Rest of world	302	Rest of world	14
World	936	World	16

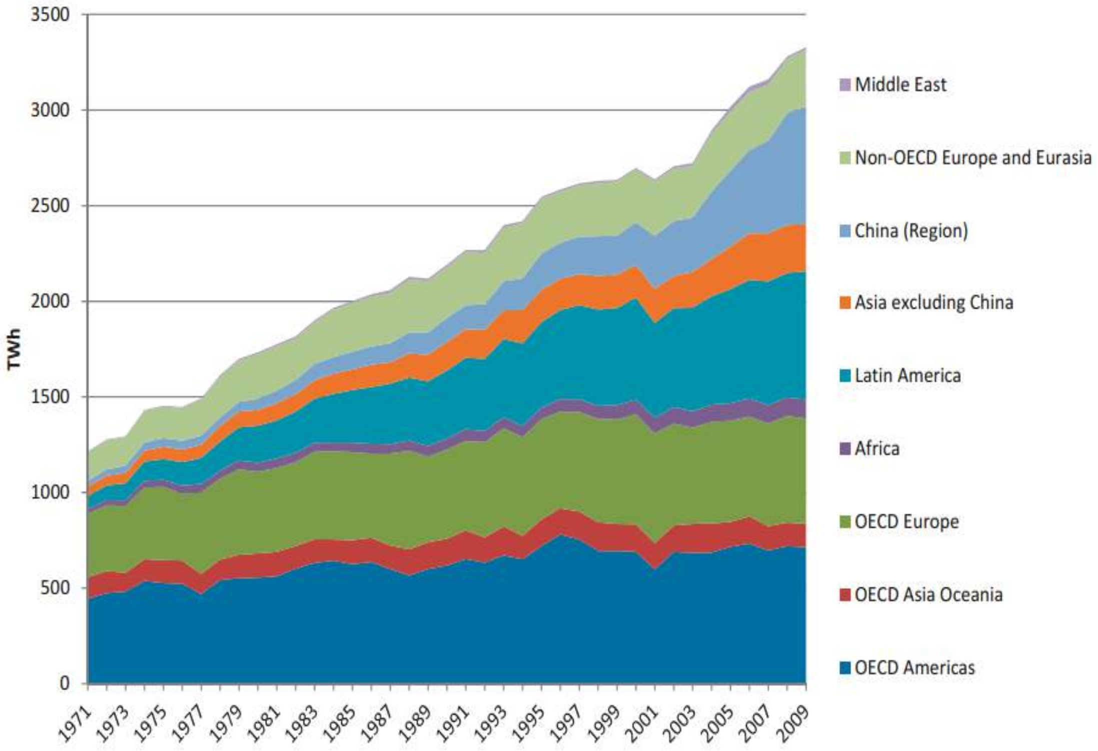


Figure 1-1-4 Hydropower generation by region

(Source: IEA)

Europe, then North and South America, then Africa. China's installed hydropower capacity reached an estimated 210 GW in 2010, a significant increase over the 117 GW in operation at the end of 2005. Despite having the largest installed capacity of hydropower plants in the world, only around 16% to 17% of China's total generation needs come from hydro. Hydropower in Africa currently accounts for some 32% of current capacity, but this capacity is just 3% to 7% of the technical potential on the continent.

Energy from the sun falls on our planet on a daily basis. The warmth of the sun creates conditions on earth conducive to life. The weather patterns that occur on the earth are driven by the sun's energy. Step outside on a sunny day and one is instantly aware of the power of the sun. Spend too much time out in the sun and this energy can actually burn your skin as effectively as an open flame. The sun drives the process of photosynthesis that all plants depend on. The sun is essentially an inexhaustible supply of energy. It is a gigantic continuous nuclear reaction that has been ongoing for the last 5 billion years. Humans have recently developed technology to directly tap the sun's energy, although, in many ways we have been using the sun's energy all along. The energy we get from our food is derived directly or indirectly from plants and most life forms on this planet owes their existence to the sun.

Solar energy technologies have significantly improved over the last 20 years. These systems are more efficient, reliable and less expensive. Solar energy systems do not produce air or water pollution during operation, can be applied in remote locations and are a renewable source of energy. Some solar energy systems convert the sun's radiant energy to electrical power that can be used for heating and cooling and even have applications in our transportation systems. As our need for energy increases and our ability to use fossil fuels decreases, solar energy will provide a viable option to meet our future energy needs.

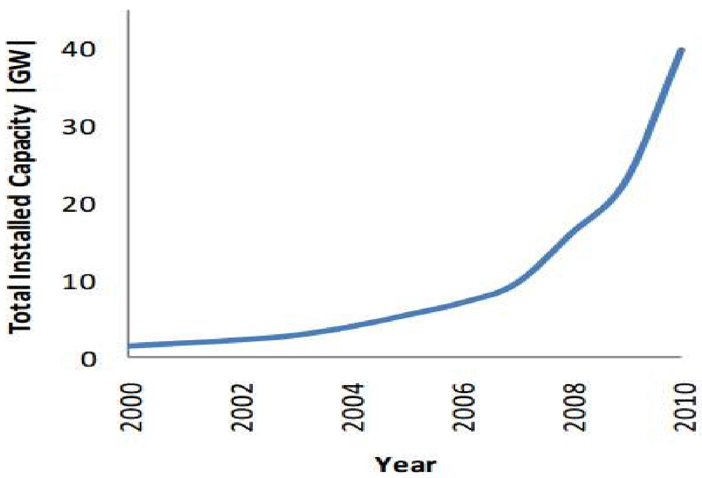


Figure 1-1-5 Trend of global installed capacity

(Source: REN21, 2011)

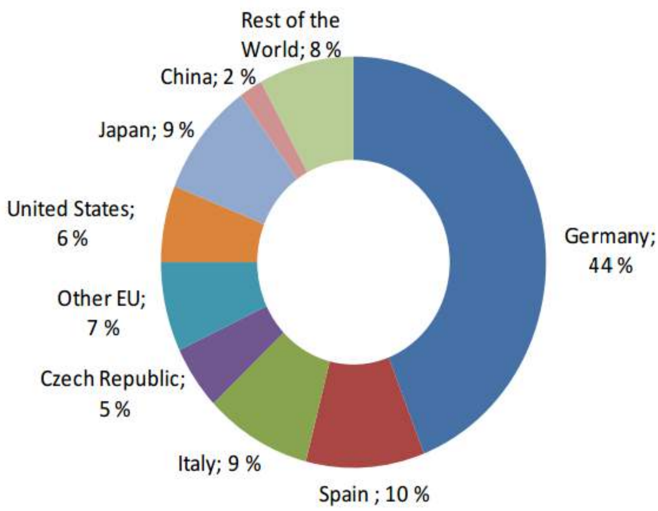


Figure 1-1-6 Country share in the global installation in 2010

(Source: REN21, 2011)

By December 2010, global installed capacity of PV had reached around 40 GW of which 85% grid connected and remaining 15% off-grid. As the figure 1-1-6, a handful of countries dominate the market for PV. However, a number of countries are experiencing a significant market growth. Notably, Czech Republic had installed nearly 2 GW of solar PV by December 2010, up from almost zero in 2008. India had a cumulative installed PV capacity of 102 MW and China had a cumulative capacity of 893 MW at the end of 2010.

The recent trend is strong growth in centralized PV development with installations that are over 200 kW, operating as centralized power plants. The leading markets for these applications include Germany, Italy, Spain and the United States. After exhibiting poor growth for a number of years, annual installations in the Spanish market grow from about 4.8 MW in 2000 to approximately 950 MW at the end of 2007 before dropping to 17 MW in 2009 and bouncing back to around 370 MW in 2010. The off-grid applications kicked off an earlier wave of PV commercialization in the 1970s, but in recent years, this market has been overtaken by grid-connected systems. While grid-connected systems dominate in the OECD countries, developing country markets, led by India and China, presently favor off-grid systems. This trend could be a reflection of their large rural populations, with developing countries adopting an approach to solar PV that emphasizes PV to fulfill basic demands for electricity that are unmet by the conventional grid.

Today, more people than ever before derive energy from renewable as capacity continues to grow, prices continue to fall, and shares of global energy from renewable energy continue to increase.

1.2 Research objective and outline

The world energy consumption has strong increase year after year; we need to improve the efficiency of energy conservation and stored energy.

Chapter 1 mentions the energy usage background in the world. As we know, the fossil fuel is gradually dry up, also caused the global warming problems. In order to control the damage of the environment and do sustainable development for the environment. Renewable energy has been taken further attention by everyone. Make use of characteristics of the energy, energy problems has been effectively relieved. Then it will introduce the energy management and the effect of the smart community.

Chapter 2 describes the distributed energy resources include distributed generation and additionally energy storages and flexible loads connected to regulated medium voltage and low voltage networks. Distributed Energy Resources are considered to be a resource for active power. Also active network often use monitoring, regulation and control mechanisms to influence the network parameters during operation of the network with contribution of generators, loads and storage devices. In an active grid, the loads, generators and storage devices can be controlled in real time by means of information and communication technology.

Chapter 3 describes the detached house in Kitakyushu as the research object. Combine with hydrogen fuel cell energy system, photovoltaic power generation and storage battery as the proposal. Then compare with the conventional systems and other cases to discuss the introduction effect.

Chapter 4 introduces PV, FC, and FH in the residential house, analyze the annual cost and the optimal introduction capacity of each power generation equipment. Also annual cost and optimal introduction capacity of each power generation equipment will be used by sensitivity analysis. Sensitivity analysis is a method to examine the influence trend of the annual cost, electricity price for the optimal introduction capacity of each power generation equipment, electricity sales price, carbon tax, gas price and fluctuation of hydrogen price.

Chapter 5 aggregate the rebuilding policy, promote the conversion of significant land use such as the effective use of the remaining land. The concept of "Low carbon advanced model block" along with the infrastructure of good urban development, about 400 units of detached houses, 800 units of amalgamated dwelling total about 1200 units are planned. Introduce energy conservation houses and long term high-quality houses.

Chapter 6 introduces the capacity of CGS used a method called "maximum cuboid method" to select the CGS capacity of each case. Specifically, the electrical load is based on the accumulation curve (heat tracking mode follows heating load), based on the criteria that maximize annual amount of power generation with fixed capacity (heat tracking mode follows the waste heat) to decide the capacity of facility. And analyze the operation pattern of system from electricity consumption and heat consumption. According to the operation situation in JONO area, do the energy conservation, environmental and economic assessment and discuss these results in different cases.

1.3 Previous research

Hongbo Ren research the growing worldwide demand for less polluting forms of energy has led to a renewed interest in the use of micro combined heat and power (CHP) technologies in the residential sector. [1] Napoleon Enteria and Leif Gustavsson research the operation of micro CHP system results in simultaneous production of heat and power in a detached house as small energy conversion units. The heat may be used for space and water heating and possibly for cooling use if combined with an absorption chiller and the electricity is used within the house. [2] [3] Michel De Paepe and Anna Joelsson research each building type, the energy demands for electricity and heat are dynamically determined. Using these load profiles, several CHP systems are designed for each building type. [4] [5]

S. Rasoul Asaee research the Primary energy and electricity consumption, associated greenhouse gas emissions and tolerable capital cost are used as indicators. [6] A whole building simulation model was used to simulate the performance of a commonly used cogeneration system with thermal storage in typical single detached houses located in Japan. A high efficiency gas boiler is included to supply heat when cogeneration unit capacity is not sufficient to meet the heating load. The effect of thermal storage capacity, interest rate and acceptable payback period on the overall performance was evaluated through a sensitivity analysis.

G. Bruni, Sunliang Cao et al. research the maximum exploitation of local renewable energy sources is a key feature of DER systems: to this aim, Hybrid Power Systems, integrating renewable and non-renewable power sources with local energy storage may represent an effective solution, although they may require an optimum utilization of the different sub-systems, for example if including fuel cell. [7] [8] [9] [10] Henrik Lund, E. Entchev et al. Setting new applicable sustainable design guidelines for detached houses, the basic assumption is that heating and cooling has played an important role in future sustainable energy systems. [11-16]

S. Amiri, Viktor Dorer research the DER system in the detached house as micro-cogeneration, also termed micro combined heat and power or residential cogeneration, is an emerging technology with the potential to provide energy efficiency and environmental benefits by reducing primary energy consumption and associated greenhouse gas emissions. The distributed generation nature of the technology also has the potential to reduce losses due to electrical transmission and distribution inefficiencies and to alleviate utility peak demand problems. [17] [18]

Electricity was first sold to consumers about 130 years ago and since then the electrical industry has reached a stage where it encompasses so many branches and specialties that the range of career opportunities seems limitless. The technological advancement of a community can be fairly accurately assessed by the amount of electrical energy it uses.

The 20th century of electricity generation was characterized by ever larger and more distant central power plants. But a 21st century technological dynamic offers the possibility of a dramatically different electricity future: millions of widely dispersed renewable energy plants and storage systems tied into a smart grid. It's a more democratic and participatory paradigm, with homes and businesses and communities becoming energy producers as well as consumers actively involved in designing the rules for the new electricity system.

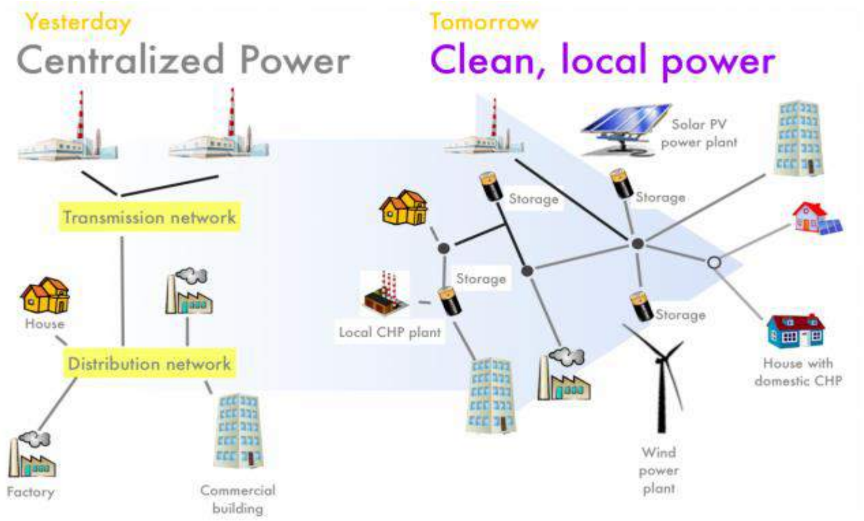


Figure 1-3-1 History of electricity system

(Source: grist http://grist.org/)

Figure 1-3-1 shows the history of the electricity system. Electrical energy cannot be stored in large quantities. Therefore, bulk supplies of electrical energy must be fed directly from the generating station through a transmission and distribution system to the consumer. This need led to the development of the electricity supply industry.

The bulk of electrical energy produced today is obtained from a rotating turbine attached to an electrical generator. Energy used to drive turbines is extracted from steam, flowing water, hot gases and wind. In Australia, as in most other countries, the prime source for producing steam to drive turbines is coal. However, there are exceptions, such as France, where coal contributes less than 4 percent and nuclear energy is the prime source. Other fuels used to produce steam are natural gas, petroleum and concentrated sunlight.

Hydroelectric systems use the controlled flow of water from dams to drive turbine generators. In some suitable coastal locations the energy from tidal flows is another source used to drive turbine generators.

In gas turbine generators the hot gases produced by burning natural gas or oil are used to directly drive the turbine. More recently these have been supplemented with a variety of renewable energy sources.

Modern generating systems fall into the following groups:

① Power stations using thermal energy released from burning coal, oil or natural gas to produce steam or hot gases, known as thermal stations.

② Power stations using thermal energy released by nuclear reaction, known as nuclear power stations.

③ Power stations using the kinetic energy of moving water, known as hydroelectric stations, the most common form of renewable energy.

④ Other renewable energy sources such as biogas from landfill, geothermal, solar energy or kinetic energy from wind and wave movement.

In addition, there are many small diesel-engine driven generators for electricity supply in areas remote from the main power network and these are becoming more common as a standby supply in non-domestic installations.

Thermal power stations utilize the heat energy derived from burning coal, oil or natural gas to convert water to steam and the steam is used at high pressure to drive a turbine that is directly coupled to an alternator producing electrical energy. Coal and nuclear thermal power plants may take many hours, if not days, to achieve a steady state power output. Since they require a long period of time to heat up to operating temperature, these plants are used to supply large amounts of base-load demand.

Although nuclear power stations are similar in many respects to thermal power stations, they are identified separately because of the additional equipment required to control the process, the associated risk of a nuclear accident, and the problems of nuclear waste containment. However, nuclear electricity generation is well established in the USA, Canada, Europe, India, Japan and China.

In the present era, due to increased power demand to meet up the industrial requirements, the shortfalls in power generation have been attempted to mitigate between supply and demand through developments of National Grid connected systems where all the national power generation sources are connected to National grid and on the basis of the zonal requirement, the energy management is implemented. An "electricity grid" is not a single entity but an aggregate of multiple networks and multiple power generation companies with multiple operators employing varying levels of communication and coordination, most of which is manually controlled.

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies.

A smart grid is an umbrella term that covers modernization of both the transmission and distribution grids. The concept of a smart grid is that of a "digital upgrade" of distribution and long distance transmission grids to both optimize current operations by reducing the losses, as well as open up new markets for alternative energy production.

The problem of smart grid:

①The electricity systems of developed countries are astoundingly capable of delivering massive amounts of electrons in a reliable way. But these complex ecosystems were designed to encourage consumption and to meet peak demand, making them bloated and inefficient.

②Because grid systems were historically built around the mantra of "more," there is a lot of excess capacity that sits unused until consumers push demand way up at certain times of the day or year.

③Without the ability for utilities to actively communicate with customers during times of peak usage, it becomes difficult to manage demand and understand what's actually happening on the grid. Most of the time, the only option is to bring as much expensive reserve capacity online as possible and generate more power

Solution of smart grid:

①The next-generation grid will be based on dealing with electrons on the informational level, not just on the atomic level.

②With a better communications infrastructure, grid-operators, utilities and consumers could better manage demand in real time, thus smoothing out the peaks, reducing the strain on the system and creating a platform for distributed renewable to thrive.

CHAPTER TWO

THE EVALUATION METHODS ON THE DISTRIBUTED ENERGY RESOURCE IN BUILDINGS

2.1 Introduction

Distributed generation applications today are primarily for markets where additional power quality is desired or local onsite generation is desired. In some cases, the distributed energy resource is designated for backup and peak power shaving conditions. Frequently, these generators are in an inoperative state for long periods until the needs of the load or the local utility require additional generation. Thus, distributed generation can be installed and maintained expensively, and operate for most commercial customers. There are several contributing factors lead to high costs, including the high cost of natural gas, lack of a standard installation process. Two directions for achieving cost-effectiveness for distributed energy resources, reduce the cost and installation costs of the systems and take advantage of additional ancillary services that distributed energy can be provided possibly.

Integration of distributed generation is one of the main drivers for major changes within the electricity distribution systems and the path towards active network operation. The distributed generation system integration related terms and possible benefits of active networks will be defined. In the future, network operation, technical, economical and regulatory framework should be discussed. A smart grid of intelligent system and this system composed of grid which based on energy conversion, transmission, distribution and control system to balance the cost and energy efficient between a high numbers of consumers. Generators have more storage in the future.

Smart grid objective is the integration of a high share of distributed generation. Distributed generation includes low power capacity generation units which are connected to medium or low voltage networks.

Distributed energy resources include distributed generation and additional energy storages and flexible loads connected to regulated medium voltage and low voltage networks. Distributed energy resources is considered to be a resource for active power. Also active network often uses monitoring, regulation and control mechanisms to influence the network parameters during operation of the network with the contribution of generators, loads and storage devices. In an active grid, the loads, generators and storage devices can be controlled in real time by means of information and communication technology.

Distributed energy resources offer many benefits; some of them are readily quantified. However, other benefits are less easily quantifiable because they may require site-specific information about the distributed energy resources project or analysis of the electrical system which the distributed energy resources is connected.

Benefits from distributed energy resources:

① lower cost: Saving based on electricity and thermal saving cost of distributed energy resources. We can change the marginal cost based on reduction versus to reduce sales revenue.

② reliability: Increased reliability through adding electricity source also it can backup from the grid. Multiple small resources lower needed reserve for equivalent reliability.

③ ancillary services: Selling ancillary services in market to add revenue. Distributed generation may be lower source of ancillary services.

④ emissions reductions: Owner can get credit for net reductions in area emissions. Utility needs fewer emissions permits to meet caps.

⑤ transmission and distribution: Saving based on marginal cost and expansion versus embedded cost.

2.2 Concept of micro grid

Generators covers all sources possible at the scales and within the context of a micro grid, for example fossil or biomass-fired small-scale combined heat and power (CHP), photovoltaic modules (PV), small wind turbines, mini-hydro, etc.

Storage devices includes all of electrical, pressure, gravitation, flywheel, and heat storage technologies. While the micro grid concept focuses on a power system, heat storage can be relevant to its operation whenever its existence affects operation of the micro grid. For example, the availability of heat storage will alter the desirable operating schedule of a CHP system when the electrical and heat loads are decoupled. Similarly, the pre-cooling or heating of buildings will alter the load shape of heating ventilation and air conditioning (HVAC) system, and the requirement will face by electricity supply resources.

Controlled loads, such as automatically dimmable lighting or delayed pumping are particularly important to micro grid and simply by merit of their scale. Load variability will be more extreme than utility-scale systems in small power systems inevitably. The corollary is that load control can make a particularly valuable contribution to micro grid.

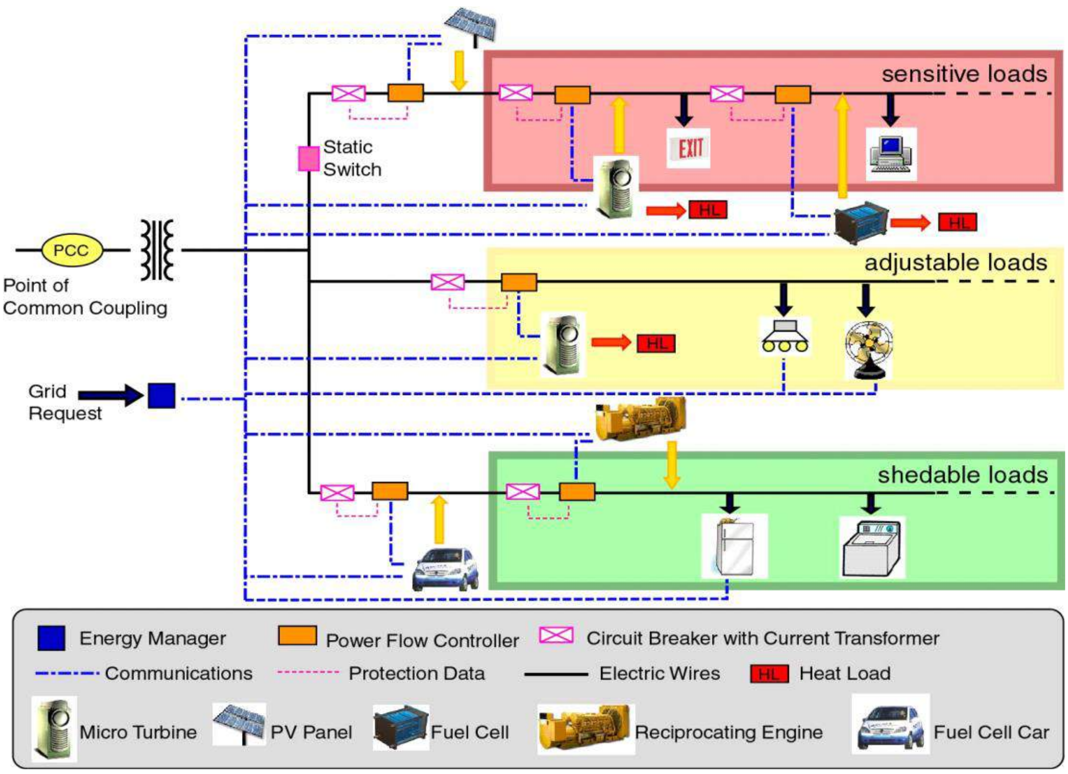


Figure 2-2-1 Concept of micro grid

(Source: LBL)

2.3 Concept of der-plan

DER-PLAN is a program to build optimal distributed energy system, and DER-PLAN use mathematical programming method, investigate and prepare the information of different buildings in Japan, energy supply charge system such as electricity and gas, heat and electricity load in different use buildings, information of distributes energy system and air conditioning technology. This is a software program that can calculate the minimize energy cost of distributed energy resources from technology selection of consumer side (power user), economics of technology combination, and the appropriate operation schedule of electricity load. This is the underlying concept of micro grid.

DER-PLAN run as MILP (mathematical programming) in LINGO (commercial software package for solving the mathematical programming).

Figure 2-2 shows the image of DER-PLAN. As the figure shown, we consider the introduction of building equipment system, the most economical power resource, in order to investigate the heat resource equipment selection. Consider the demand of demand-side in this case, market information, and overall consider the current technology

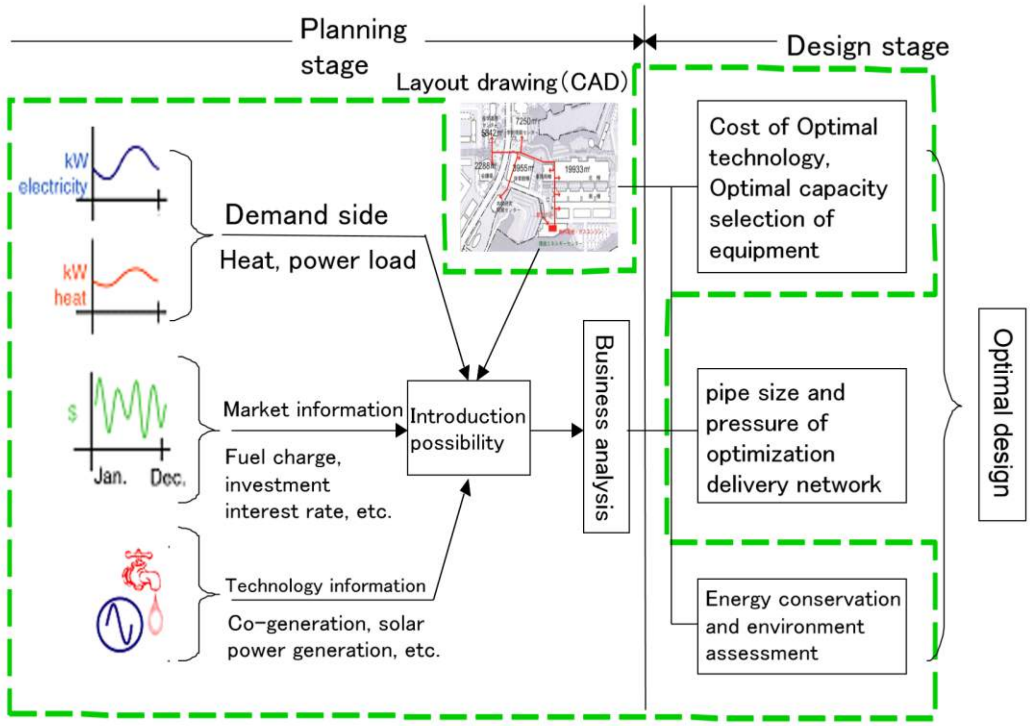


Figure 2-3-1 Image of DER-PLAN

information, we need to explore the optimal design.

The DER-PLAN optimize the technology selection of distributed energy sources and minimize the energy costs of a particular customers. We need to collect these things as following.

(1) Sell electricity and heat to consumers when we introduce the micro grid, and select the equipment to minimize the annual cost of business entities (model, number).

(2) Calculate the primary energy consumption and CO_2 emission reduction amount in the whole region.

(3) Calculate the electricity and heat sales price [yen/MJ] in order to obtain income that we do not minus the annual cash flow. When it is sold at this price, payback period and the equipment life are same if the initial cost is full borrowing. It becomes impossible payback when cannot get full borrowing, we need to consider payback period in varying special bids.

Among these, the cost of the consumers consist of items concretely as following.

Initial investment [yen] = initial cost (equipment price + construction cost) except borrowing

Annual expenditure [yen/year] =initial cost (equipment price + construction cost) include borrowing [yen]/life [year] + maintenance cost [yen/year] + city gas and commercial electricity purchase cost [yen/year]

Annual income [yen/year] = electricity and heat sales price [yen/year]

2.4 DER-PLAN structure

Figure 2-3 shows the flow chart structure of DER-PLAN. We need to investigate and prepare for the variety building in Japan, electricity, energy supply charge system such as gas, heat in different buildings, electricity load, distributed energy resources, air conditioning and heating technology. Use modeling tool to optimize them, construct a scenario to optimize the energy consumption patterns for each type in different buildings when the distributed energy resources is introduced, and evaluate the system.

Investigate the energy charge of electricity in different areas, use the commercial charge of the gas company, different distributed energy resources, air conditioning and heating technology equipment from manufacturer and dealer. Technical data include capacity, efficiency, initial investment and maintenance cost. In addition, financial information such as subsidies and tax relating to the introduction of distributed energy resources.

Input to the model by collecting the necessary data, compare with the operation, we need to select technology with more economical, energy conservation and low environmental load for the objective buildings.

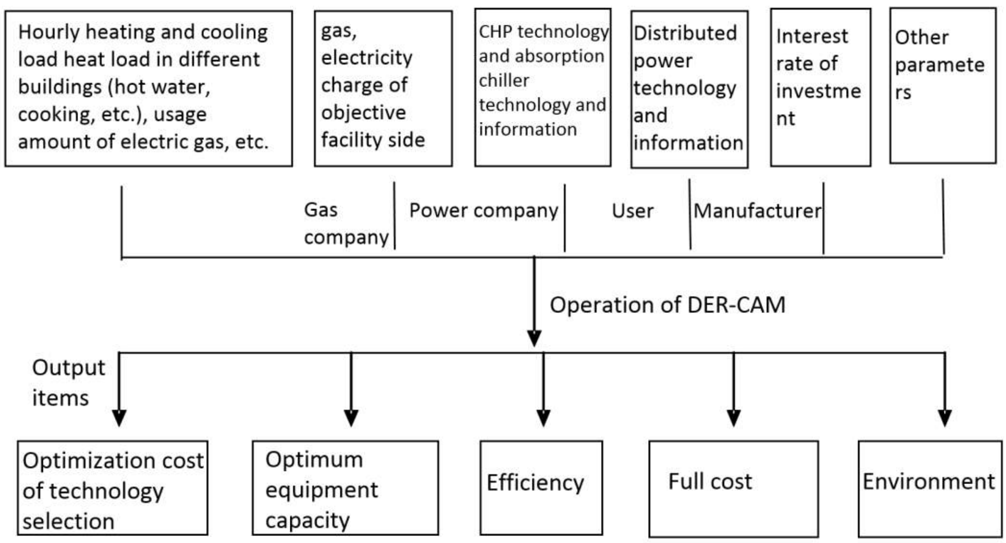


Figure 2-4-1 Flow chart of DER-PLAN

Input items which consist of 5 main items as following.

(1) Usage amount of cooling load, heating load (water heating and cooking, etc.), electricity, gas and so on.

Usage amount such as cooling, heating load and electricity of buildings, the situation of energy use are important points to introduce the distributed energy to evaluate the environment, energy conservation, economics and ability.

Therefore the energy consumption data of selection building is necessary in LINGO. Specifically, the consumption data (for 365 days *24) for cooling, heating, water heating, refrigeration in different time of year in buildings are necessary. Even it is possible to classify the current type of energy, and it is difficult to separate the type of end-use energy in different use. It is also possible to calculate energy consumption unit in different time and usage of buildings with simulation in record region.

(2) Initial gas, electricity charge in user side

It is necessary to check the distributed energy, we can see further economical elements of particular introduction cogeneration, energy charge of electricity and gas when the consumers purchase them. Electricity charge is used from Kyushu power and gas charge is used from gas company in this study, as usually basic charge and energy charge are available for business plan. Compare with contract plan, we divides into such as seasonal, peak time and off-peak time. Even in the world the gas charge in Japan is very high, compare other contracts that charge system of cogeneration is relatively cheap which has been installed recently. By the way, there are membership charge for contract, based on basic charge of electricity (gas) contract and energy charge for actual use which include three types in America. Also electricity charge in summer is separated with other seasons, it become a separate charge that divide one day into 3 time period.

(3) Distributed energy technology and information

When we introduce the distributed energy, we need to grasp the information such as capacity of equipment which sold gas engines, gas turbines, fuel cell, etc. and the fixed amount of power generation, life and cost. In addition, we need to grasp the necessary cost such as maintenance, management, repair etc.

(4) Information of co-generation technology and absorption chiller technology

It is necessary to grasp the CHP technology of waste heat utilization, absorption chiller for using waste heat and cooing, and it is necessary to clear known the main use types of equipment, capacity, performance efficiency, basic investment cost and maintenance cost in current time.

(5) Interest rate of investment

It has necessary parts to evaluate the overall benefit, investment situation of introduction distributed energy and CHP, interest rate of financing, tax structure, national and local governments have spread subsidy or not when introducing the distributed energy.

Solution of cost optimization as energy resources to provide its own load when introducing the distributed energy technology, or items of DER-PLAN as output items are received as following.

(1) Cost optimization of technology selection

DER-PLAN is received the technology selection of distributed energy to minimize the cost of energy.

(2) Optimum capacity

We operate cost optimization by introducing different capacity of power when introducing DER technology in energy system.

(3) Annual benefit

The entire operation cost of each selection are the sum of "all initial investment of each system" and "operation cost of one year".

(4) Energy efficiency

If we received the same electricity load when introducing the distributed energy system, it means we have saved the natural resources. We use the same fuel to get the load, then utilize collection the waste heat to save energy resources.

2.5 Calculation method of DER-PLAN

DER-PLAN means use LINGO to operate the calculation with complex input items.

LINGO is a common (general), for algebraic operation (algebraic), and a programming language for model structure (model system). Its features include ①strong iterative calculation. In FORTRAN of DO loops and C for the loop, the initial value, final value, specify the increment, for(i=1;i<=n;i++){..........} such as must be iterative, LINGO is running by semi-automatically. ② we have adapted to the array of data. The size of the array determines the sequence of automatically data, will be store the data. ③ variety of solving routines are rich. There is no need to write the solution of the program by ourselves.

2.5.1 Establish parameter

According to DER-PLAN, we will explain the calculation method by mathematical formula.

First, represent the input function to define.

Index

Item	Definition
h	hour{1,2,…,24}
i	distributed technology {select technology}
m	month {1,2,…,,12}
d	day
u	end use{electricity only, cooling, heating, hot water supply, gas only}

Data about customer

Cloadm,d,h,u	customer load (electricity, heat) (kW)
SRm,d,h	amount of solar radiation (kW/m^2)
Vm,d,h	wind velocity (m/s)

Technology information of distributed energy system

Item	Definition
$Fmaxp_i$	electricity rated output of distributed technology i (kW)
$Fminp_i$	electricity minimum output of distributed technology i (kW)
Fff_i	power generation efficiency of distributed technology i (%)
$FLTime_i$	useful life of distributed technology i (a)
$FCost_i$	equipment cost of distributed technology i (yen/kW)
$FOMf_i$	annual operation repair cost of distributed technology i (fixed) (yen/kW)
$FOMv_i$	annual operation repair cost of distributed technology i (variable) (nen/kWh)
$FMTime_i$	maximum operation time of distributed technology i
FF_i	pension coefficient of distributed technology i
DCCap	capacity of gas absorption chiller (kW)
DCCost	cost of gas absorption chiller (nen/kWh)
DCLTime	useful life of gas absorption chiller
YDCF	pension coefficient of gas absorption chiller
YHSF	pension coefficient of thermal storage tank
HSLTime	useful life of thermal storage tank
HSCost	equipment cost of thermal storage tank (nen/kWh)
$PVLnt_i$	rated output of solar generation module (kW/m^2)
ηi	power generation efficiency of solar generation technology i (%)
U(i)	end use goal of technology i

Market information

Item	Definition
$EPrice_{m,d,h}$	electricity purchase price in different time (nen/kWh)
EDCharge	fixed cost of electricity purchase price based on demand (nen/kWh)
$SPrice_{m,d,h}$	electricity sales price (nen/kWh)
ELInt	carbon release rate of energy purchase from market (kg/kWh)
CTax	carbon tax (yen/kg)
GCInt	carbon release rate from gas burning (nen/kWh)
GBase	month demand charge of gas (yen/month)
GPrice	gas price (yen/m^3)
GDChargem	basic charge of flow rate of gas (yen/m^3)

Other parameter

Item	Definition
ERate	investment interest
MDays	days of month
$PVp_{i,m,d,h}$	power generation capacity of solar power generation technology i kW
GHRate	gas heat rate (kWh/m^3)
α_i	per 1kW of waste heat by utilizing electricity technology
β_u	per 1kW of waste heat by utilizing gas technology
$\gamma_{i,u}$	effective waste heat
δ_u	utilization ratio of thermal storage
ε	preservation ratio of thermal storage tank
$PVArea_i$	area of solar power generation module (m^2)
$Wp_{i,,m,d,h}$	power generation capacity of wind power generation technology (kW)

Decision variable

Item	Definition
$Operate_{i,m,d,h}$	equipment operation quantity of distributed technology
$PElec_{m,d,h,u}$	electricity purchase amount from distributed energy company (kW)
DC	equipment index of gas absorption chiller
$EGen_{i,m,d,h,u}$	power generation capacity of distributed energy system (kW)
$PGas_{m,d,h,u}$	purchase amount of gas (m^3)
$Iheat_{i,m,d,h}$	thermal storage capacity (kW)
$RHeat_{i,m,d,h,u}$	waste heat from distributed technology (kW)
$NInv_i$	equipment introduction quantity of distributed technology
$OHwat_{m,d,h,u}$	waste heat from thermal storage tank (kW)
$SHeaten_{m,d,h}$	heat storage capacity in thermal storage tank (kWh)
HSmax	capacity of thermal storage tank (kW)
$Esal_{i,m,d,h}$	electricity sales capacity (kW)

2.5.2 Assumption calculation

In order to construct the DER-PLAN tools, DER-PLAN use the following assumptions.

- Decision of customers is the only economic indicators. Customers get the benefits from the reduction of electricity charge.
- Residual power from customers' side will sell to the power grid. Ignore the technical limitations of selling electricity to the power grid.
- In addition, when the demand is greater than supply, we can purchase electricity from power grid according to the contract.
- The price and performance of equipment is provided by maker. Ignore the deterioration of equipment within repayment period.
- Also we do not consider other cost such as initial investment of installation and authorization.
- We do not consider about the reliability of supply demand that due to the different capacity of the same technology and the operation cost of scale economics.

According to the assumption, figure up the minimum value by the next objective function.

$$\text{Min} \quad C_{total} = C_{Elec} + C_{Gas} + C_{Inv} + C_{OM} + C_{CTax} - C_{Sal} \qquad (1)$$

Equation (1) is the objective function, we utilize the distributed system to minimize the overall cost of customers. Items of equation (cost) are comprised as following.

Purchase electricity cost:

$$C_{Elec} = \sum_{m} \text{EDCharge} \cdot \max\left(\sum_{u} PElec_{m,d,h,u} \right) + \sum_{m} \sum_{d} \sum_{h} \sum_{u} PElec_{m,d,h,u} \cdot \text{EPrice}_{m,d,h}$$

Gas cost:

$$C_{Gas} = \sum_{m} GBase + \sum_{m} GDCharge_{m} \cdot \max\left(\frac{\sum_{u} PGas_{m,d,h,u} + \sum_{i} \frac{\sum_{u} EGen_{i,m,d,h,u} + ESal_{i,m,d,h}}{Eff_{i}}}{GHRate} \right)$$

$$+ \sum_{m} \sum_{d} \sum_{h} \sum_{u} \frac{PGas_{m,d,h,u}}{GHRate} \cdot G\,\text{Price}$$

$$+ \sum_{i} \frac{\sum_{m} \sum_{d} \sum_{h} \left(\sum_{u} EGen_{i,m,d,h,u} + ESal_{i,m,d,h} \right)}{Eff_{i} \cdot GHRate} \cdot G\,\text{Price}$$

Initial investment cost of distributed energy:

$$C_{Inv} = \sum_i NInv_i \cdot F\max p_i \cdot FCost_i \cdot YF_i + YHSF \cdot HSCost \cdot HS\max$$
$$+ YDCF \cdot DCCap \cdot DC$$

Annual investment conversion:

$$YF_i = \frac{IRate}{(1 - \frac{1}{(1+IRate)^{FLTime_i}})} \qquad \forall i$$

$$YDCF = \frac{IRate}{(1 - \frac{1}{(1+IRate)^{DCLTime}})}$$

$$YHSF = \frac{IRate}{(1 - \frac{1}{(1+IRate)^{HSLTime}})}$$

Operation and administration cost of on-site power generation:

$$C_{OM} = \sum_i \sum_m \sum_d \sum_h (\sum_u EGen_{i,m,d,h,u} + ESal_{i,m,d,h}) \cdot FOMv_i + \sum_i NInv_i \cdot F\max p_i \cdot FOMf_i$$

Carbon tax charge:

$$C_{Ctax} = \sum_m \sum_d \sum_h \sum_u PElec_{m,d,h,u} \cdot CTax \cdot ECInt$$
$$+ (\sum_i \frac{\sum_m \sum_d \sum_h (\sum_u EGen_{i,m,d,h,u} + ESal_{i,m,d,h})}{Eff_i} + \sum_m \sum_d \sum_h \sum_u PGas_{m,d,h,u}) \cdot CTax \cdot GCInt$$

Electricity sales earnings:

$$C_{Sal} = \sum_i \sum_m \sum_d \sum_h ESal_{i,m,d,h} \cdot SPrice_{m,d,h}$$

2.5.3 Constraint conditions

With regard to equation (1), constraint conditions represent by (2) to (29).

$$Cload_{m,d,h,u} = \sum_i EGen_{i,m,d,h,u} + PElec_{m,d,h,u} + \beta_u \cdot PGas_{m,d,h,u} + \sum_i (\gamma_{i,u} \cdot RHeat_{i,m,d,h,u}) + \delta_u \cdot OHeat_{m,d,h,u} \quad \forall m,d,h,u \tag{2}$$

$$\sum_u EGen_{i,m,d,h,u} + ESal_{i,m,d,h} \le Operate_{i,m,d,h} \cdot F\max p_i \quad \forall i,m,d,h \tag{3}$$

$$\sum_u EGen_{i,m,d,h,u} + ESal_{i,m,d,h} \ge Operate_{i,m,d,h} \cdot F\min p_i \quad \forall i,m,d,h \tag{4}$$

$$\sum_m \sum_d \sum_h Operate_{i,m,d,h} \le NInv_i \cdot FMTime_i \quad \forall i \tag{5}$$

$$Operate_{i,m,d,h} \in \{0,1,2 \cdots NInv_i\} \quad \forall i,m,d,h \tag{6}$$

$$\sum_u EGen_{i,m,d,h,u} + ESal_{i,m,d,h} \le NInv_i \cdot PVp_{i,m,d,h} \quad \forall i \in PV,m,d,h \tag{7}$$

$$PVp_{i,m,d,h} = \min\{F\max p_i, SR_{m,d,h} \cdot PVArea_i \cdot \eta_i\} \quad \forall i \in PV,m,d,h \tag{8}$$

$$PVArea_i \cdot PVInt_i = F\max p_i \quad \forall i \in PV \tag{9}$$

$$\sum_u EGen_{i,m,d,h,u} + ESal_{i,m,d,h} \le NInv_i \cdot Wp_{i,m,d,h} \quad \forall i \in wind,m,d,h \tag{10}$$

$$Wp_{i,m,d,h} = F\max p_i \cdot \frac{V_{m,d,h}{}^k - V_{c_i}^k}{V_{r_i}^k - V_{c_i}^k} \quad \forall i \in wind, V_{c_i} \le V_{m,d,h} \le V_{r_i} \tag{11}$$

$$Wp_{i,m,d,h} = F\max p_i \quad \forall i \in wind, V_{r_i} \le V_{m,d,h} \le V_{f_i} \tag{12}$$

$$Wp_{i,m,d,h} = 0 \quad \forall i \in wind, V_{m,d,h} < V_{c_i} \cup V_{m,d,h} > V_{f_i} \tag{13}$$

$$\sum_u RHeat_{i,m,d,h,u} + IHeat_{i,m,d,h} \le \alpha_i \cdot (\sum_u EGen_{i,m,d,h,u} + ESal_{i,m,d,h}) \quad \forall i,m,d,h \tag{14}$$

$$SHeat_{m,d,h+1} = \varepsilon \cdot SHeat_{m,d,h} + \sum_i IHeat_{i,m,d,h} - \sum_u OHeat_{m,d,h,u} \quad \forall m,d,h \quad if \quad h \ne '24' \tag{15}$$

$$SHeat_{m,d+1,1} = \varepsilon \cdot SHeat_{m,d,24} + \sum_i IHeat_{i,m,d,24} - \sum_u OHeat_{m,d,24,u} \quad \forall m,d \quad if \quad d \ne ' MDays' \tag{16}$$

$$SHeat_{m+1,1,1} = \varepsilon \cdot SHeat_{m,MDays_m,24} + \sum_i IHeat_{i,m,MDays_m,24} - \sum_u OHeat_{m,MDays_m,24,u} \quad \forall m \quad if \quad m \ne '12' \tag{17}$$

$$OHeat_{m,d,h,u} = 0 \quad \forall m,d,h \quad if \quad u \in \{electricity\_only\} \tag{18}$$

$$SHeat_{m,d,h} \le HS\max \quad \forall m,d,h \tag{19}$$

$$SHeat_{1,1,1} = 0 \tag{20}$$

$$OHeat_{1,1,1,u} = 0 \quad \forall u \tag{21}$$

$$\sum_{u} OHeat_{m,d,h,u} \le SHeat_{m,d,h} \qquad \forall m,d,h \tag{22}$$

$$\delta_u \cdot OHeat_{m,d,h,u} + \sum_i \gamma_{i,u} \cdot RHeat_{i,m,d,h,u} \le \sum_i \alpha_i \cdot \gamma_{i,u} \cdot OPerate_{i,m,d,h} \cdot F\max p_i \qquad \forall m,d,h,u \tag{23}$$

$$RHeat_{i,m,d,h,u} = 0 \qquad \forall i,m,d,h \quad if \quad u \notin U(i) \tag{24}$$

$$EGen_{i,m,d,h,u} = 0 \qquad \forall i,m,d,h \quad if \quad u \in \{space\_heating, water\_heating\} \tag{25}$$

$$PGas_{m,d,h,u} = 0 \qquad \forall m,d,h \quad if \quad u \in \{electricity\_only\} \tag{26}$$

$$PGas_{m,d,h,u} \le DCCap \cdot DC \qquad \forall m,d,h \quad if \quad u \in \{cooling\} \tag{27}$$

$$PElec_{m,d,h,u} = 0 \qquad \forall m,d,h \quad if \quad u \in \{space\_heating, water\_heating\} \tag{28}$$

$$ESal_{i,m,d,h} = 0 \qquad if \sum_u \sum_i EGen_{i,m,d,h,u} < \sum_u Cload_{m,d,h,u} \quad \forall i,m,d,h \qquad if \quad u \in \{electricity\_only\} \tag{29}$$

Equation 2 means to implement the demand balance of energy.

Equation 3 and equation 4 are the limitation of power generation capacity.

Equation 5 and equation 6 are the limitation about annual operation time.

Equation 7-9 are the limitation of solar power generation capacity.

Equation 10-13 are the limitation of wind power generation capacity.

Equation 14 is the limitation of waste heat from power generation technology.

Equation 15-22 are the limitation of thermal storage tank.

Equation 23 means to prevent when it is large than rated output of waste heat technology.

Equation 24 means that cannot utilize the waste heat with some technology.

Equation 25 and equation 28 are the limitation of supply the heat demand from power grid.

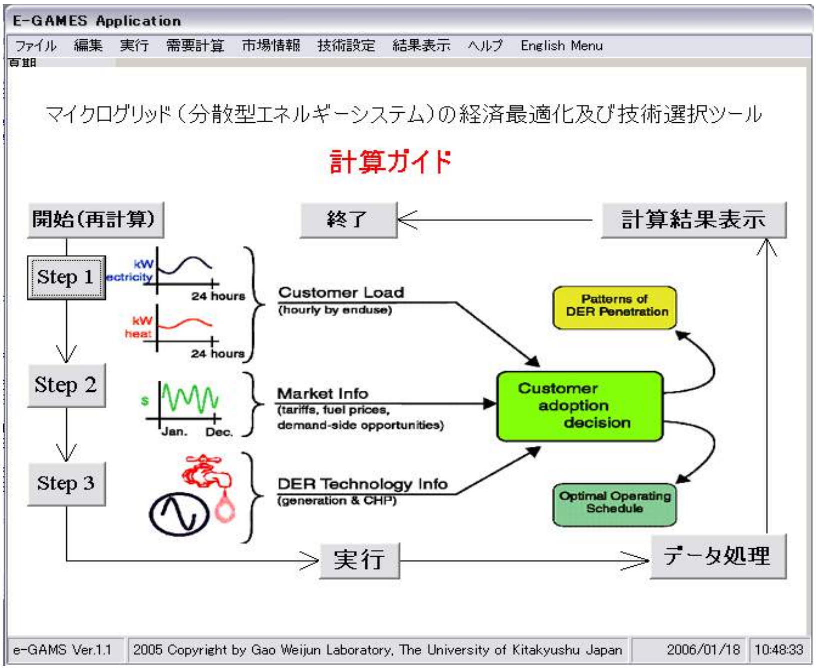
Equation 26 is the limitation of supply directly electricity demand from gas.

Equation 27 do not introduce the absorption chiller and do not use waste heat for cooling.

Equation 29 is the limitation of purchase electricity and sale electricity at the same time.

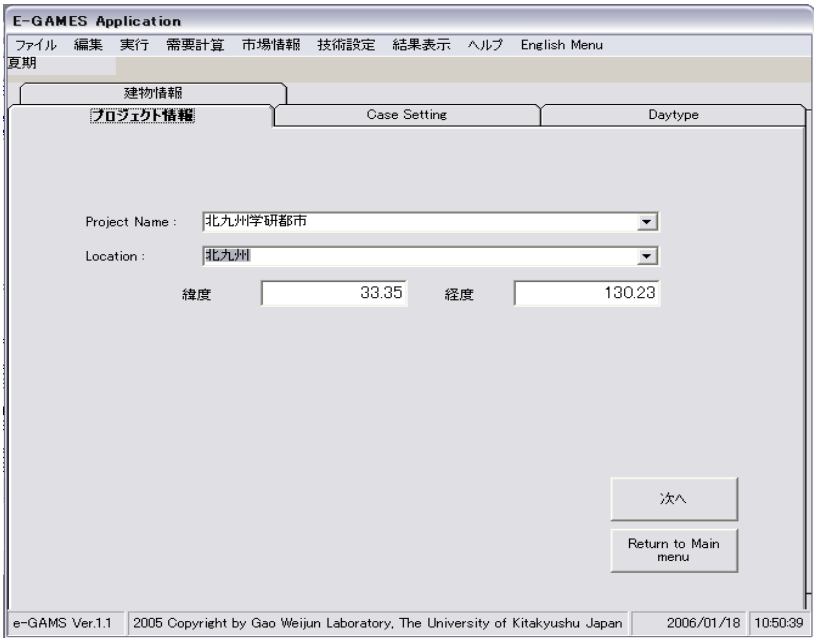
2.6 Usage method of der-plan

The usage method of optimization program DER-PLAN, actual implementation image are shown from figure 2-4 to figure 2-13. Follow the instructions as the start image, it's easy to operate.



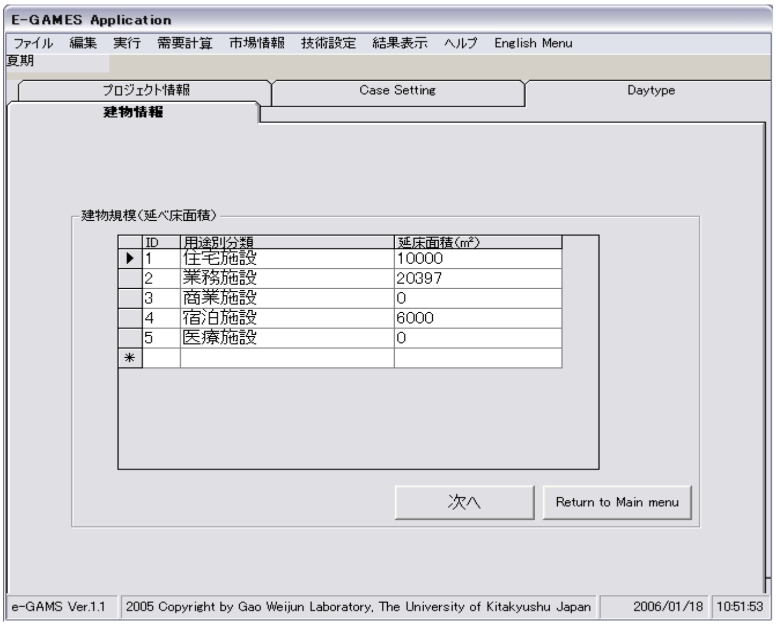
Start image

① Enter the name of project and the location



Project information image

② Enter the total floor area of buildings and the facilities in this area.

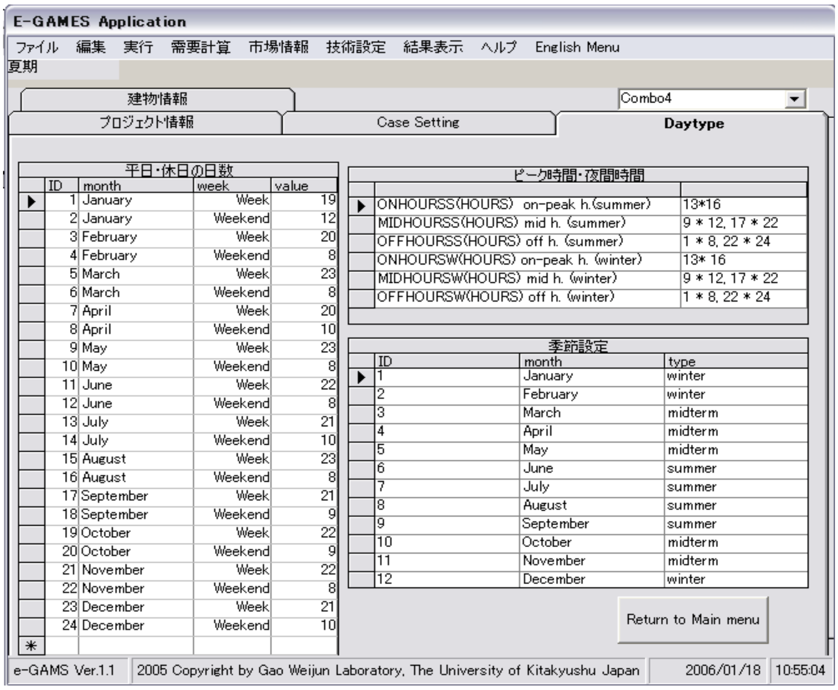


Building information image

③ Set up the calculation case

Set up cases image

④ Set up the weekdays and weekend, charge period selection, seasons.



Time type image

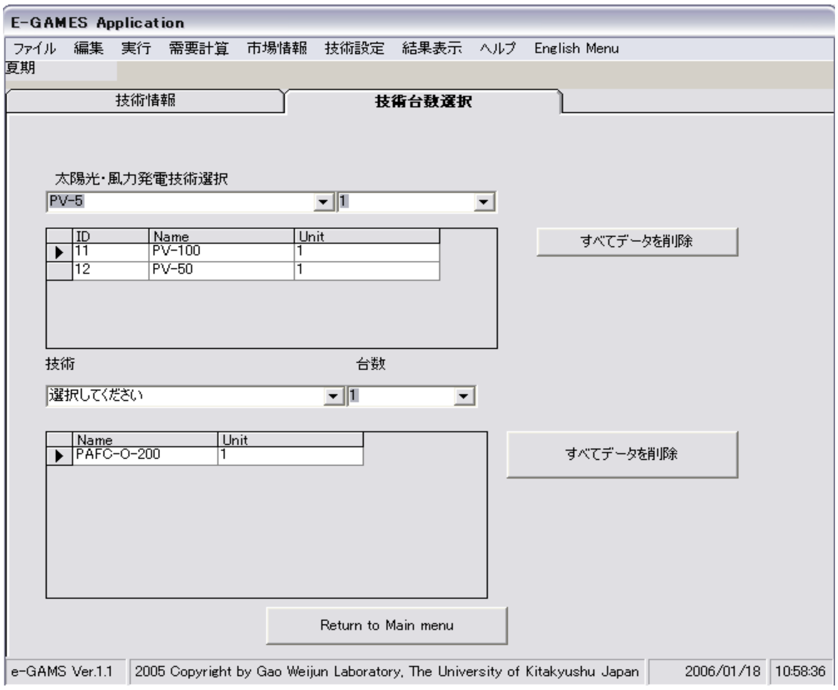
⑤ Set up the energy charge. (Current Kyushu electric power, Saibu gas charge)

Set up charge image

⑥ Set up the technical information

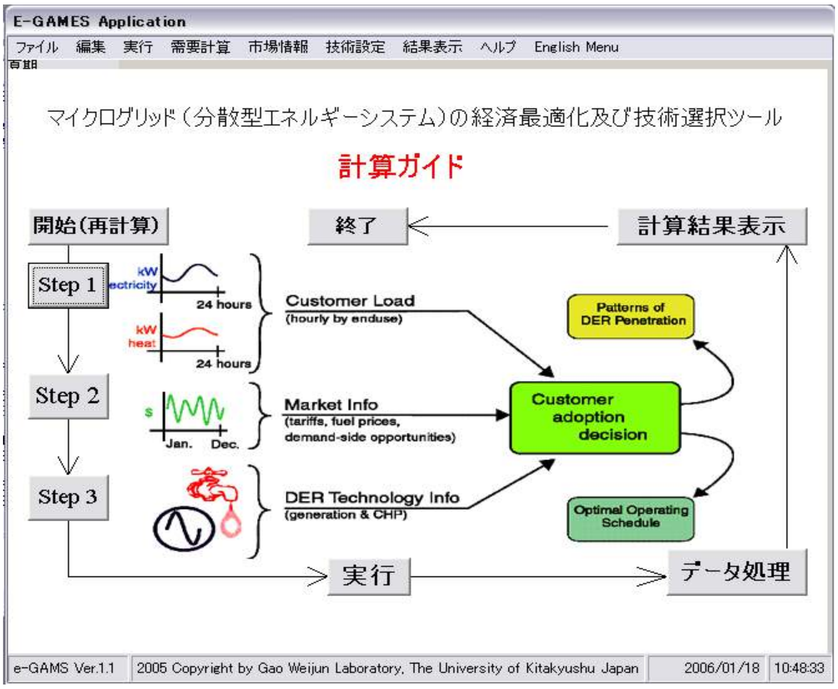
Technical information image

⑦ Set up the solar and wind power generation technology



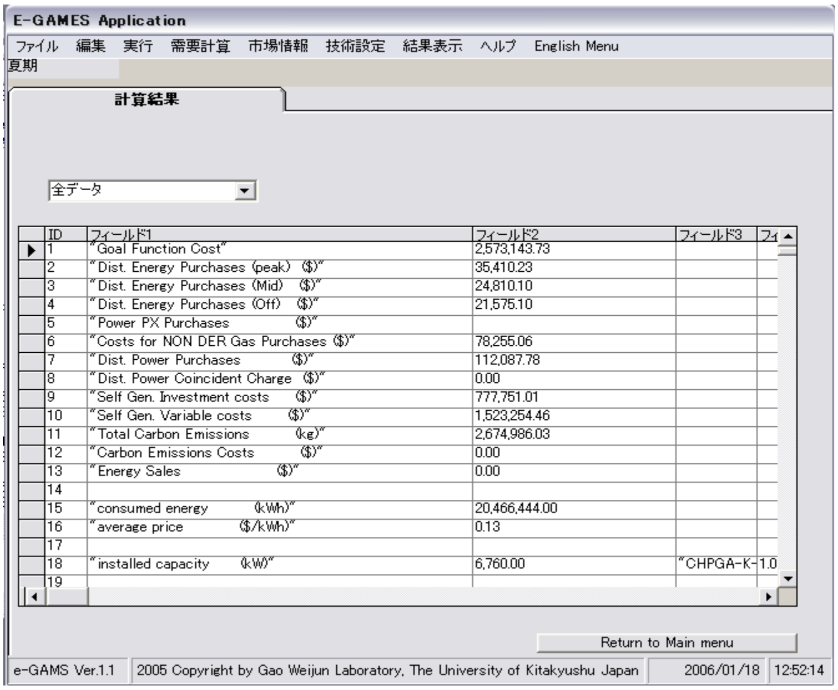
Technology number selection image

⑧ Calculation operation



Operation image

⑨ Display the calculation results



Calculation results image

CHAPTER THREE

THE EFFECT OF HYDROGEN CO-GENERATION SYSTEM ON THE ENERGY CONSERVATION IN THE DETACHED HOUSE

3.1 Introduction

The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change, aimed at fighting global warming. The UNFCCC is an international environmental treaty with the goal of achieving the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

Like Japan, America, Europe and other developed countries, aim to reduce greenhouse gas at least 5% from 2008 to 2012, compared to average emissions in 1990 (6 types). Therefore, energy use becomes a big question in society, energy conservation measures in the field of construction becomes a large task.

Base on this background, in this study, we use a detached house in Kitakyushu as the research object. We proposed a system which combines with hydrogen fuel cell energy system, photovoltaic power generation and storage battery. Then we compare the system with the conventional systems and other cases to discuss the introduction effect.

First we will investigate the basic information about the detached house, such as electricity load, cooling load, heating load and water heating load. Consider about this situation, we select the appropriate equipment of each case to simulate. Analysis the operation patterns in different cases, get the results to compare with conventional case.

Second also in each case, we will divide into two kinds of operation mode to simulate. One is electricity tracking mode, it means that fuel cell power generation follow the change of electricity load. The power generation from fuel cell will not have residual and the heat production from fuel cell may have residual which do not make full use. Another is heat tracking mode, it means that fuel cell heat production follow the change of heating load. The heat production from the fuel cell will not have residual and the power generation from fuel cell may have residual which do not make full use.

Third after the simulation of each case, we compare with the past case. We can know the energy conservation, power usage, heat usage and energy cut rate about each case. If there are storage batteries in the cases, we can know the situation of power control.

Last we will analysis and discuss these results in different cases, according to the energy usage situation of detached house.

3.2 Survey project

3.2.1 Basic survey

Today we are using large amounts of electricity and oil, live in a convenient society. As a result, a lot of greenhouse gases have been discharged such as carbon dioxide and so on.

Figure 3-2-1 Image of detached house
(http://www.city.kitakyushu.lg.jp/kankyou/file_0298.html)

A detached house comes in three different styles, bungalow, split (side and back) and two story, construction may be in brick, stucco, aluminum, vinyl, wood or a combination of them. In addition to their styles, their architectural design and location such as water front or golf course governs their price from the most budgeted mind up to Senior Executive level. Figure 3-2-1 shows the image of detached house. This type of housing can be thought of as being a half-way state between terraced or row housing and single-family detached homes. Terraced housing is constituted by continuous row houses with open spaces at the front and back, while semi-detached houses have front, rear and any one side open spaces, and individual detached houses have open spaces on all sides

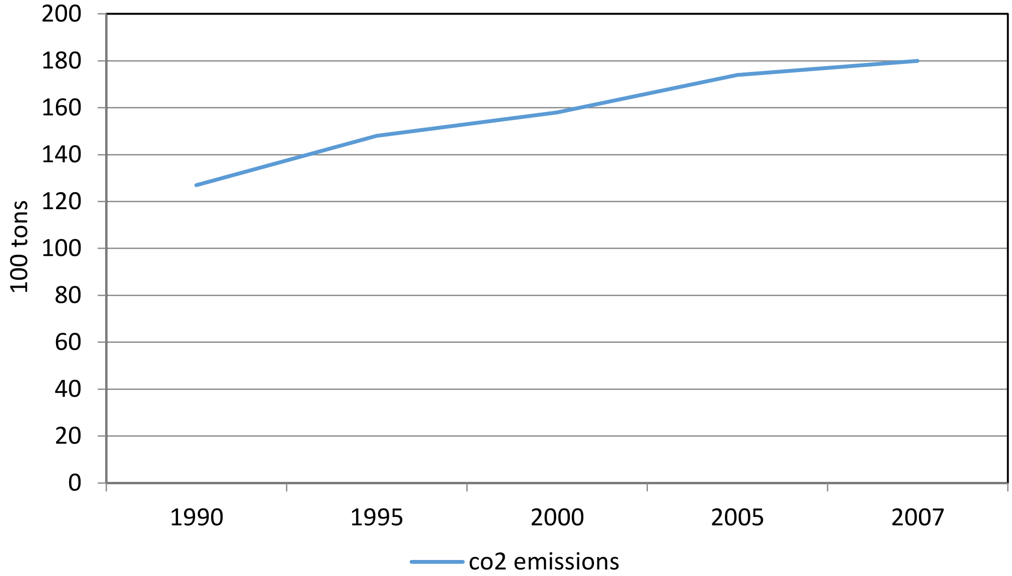


Figure 3-2-2 Residential sector CO_2 emissions in Japan

Figure 3-2-2 shows the residential sector CO_2 emissions in Japan. Compare with CO_2 emissions in 1990, increase by 41.2% in 2007. In order to reduce the CO_2 emissions of residential sector, we need to improve the energy system of residence houses.

3.2.2 Energy load

According to the energy consumption in unit area of detached house, we calculate the load of this detached house. We can know the energy consumption clearly about the detached house yearly.

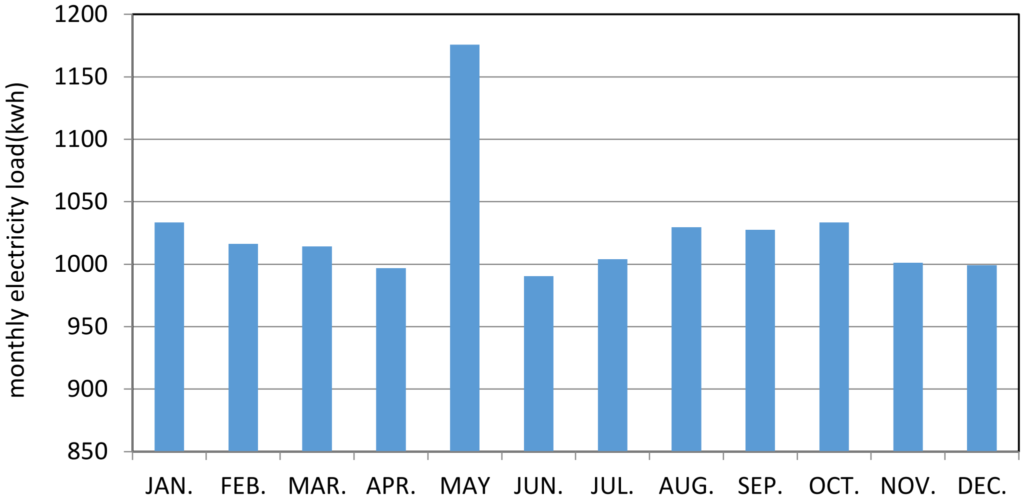


Figure 3-2-3 Electricity load of detached house

Figure 3-2-3 shows the monthly electricity load of detached house. We can know the electricity load in each month is stable at around 1000 kWh, do not change so much. But in the May, the value is higher than other months, reach 1175 kWh. And the minimum value is 990 kWh come from the June.

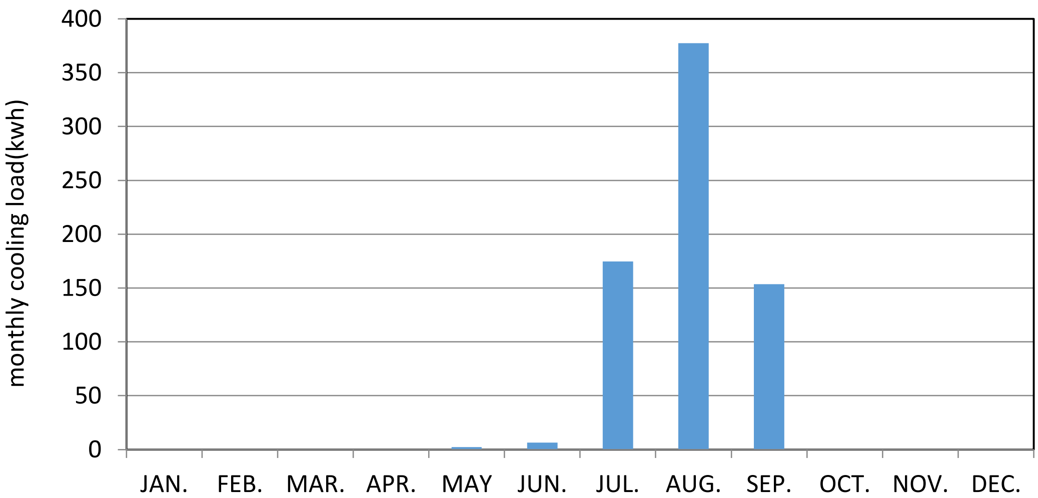


Figure 3-2-4 Cooling load of detached house

Figure 3-2-4 shows the monthly cooling load of detached house. We can know the value of August is the highest one that compare with other months. It can reach 377 kWh, August is hotter than other months. And certain days in May need to consume the cooling load, but the value is only 2 kWh.

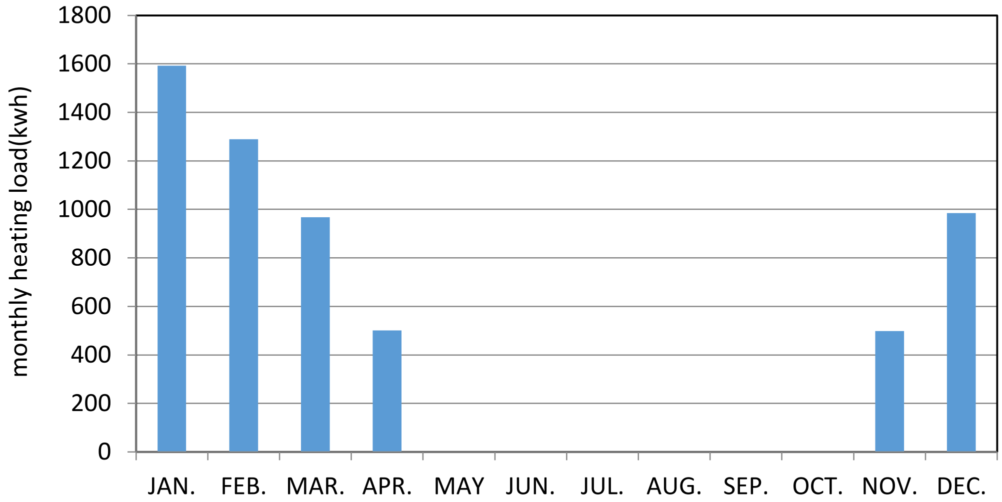


Figure 3-2-5 Heating load of detached house

Figure 3-2-5 shows the monthly heating load of detached house. There are about six months need to heating in that time, and the value of each months change a lot. The maximum value is 1592 kWh come from January, and the minimum value is 498 kWh come from November. So the heating load consume in large quantities.

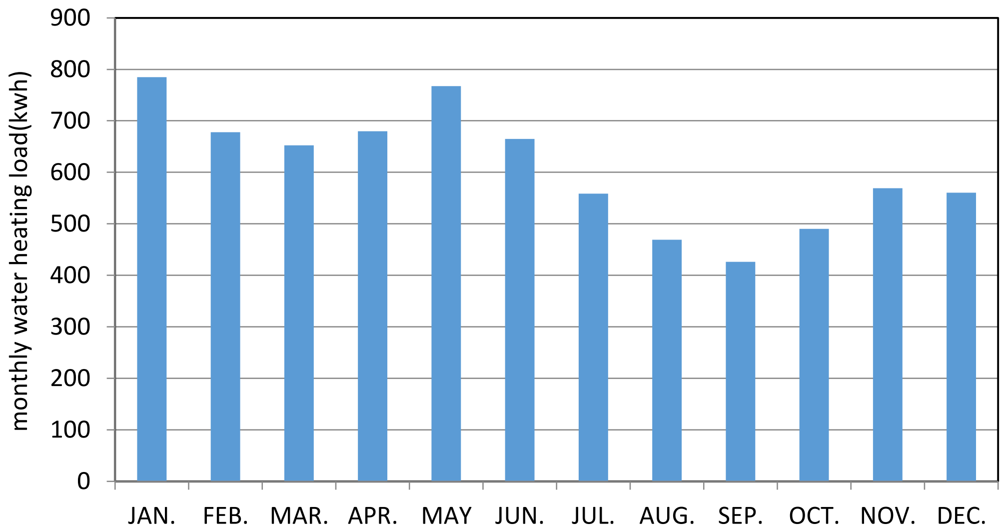


Figure 3-2-6 Water heating load of detached house

Figure 3-2-6 shows the monthly water heating load of detached house. We can know the electricity load in each month is stable at around 500 kWh, do not change so much. The maximum value is 784 kWh come from January, and the minimum value is 426 kWh come from September.

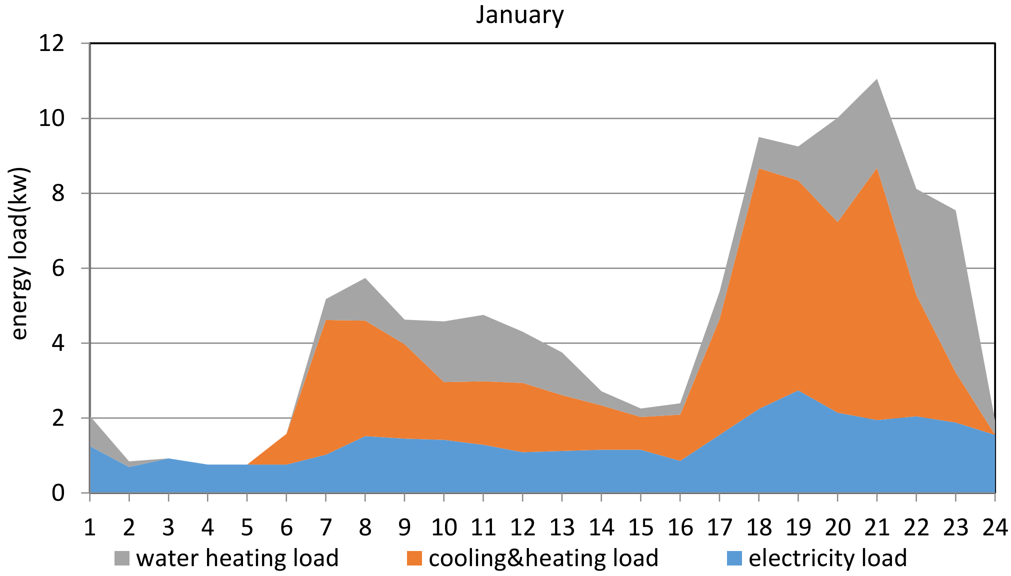


Figure 3-2-7 Energy load of detached house in January

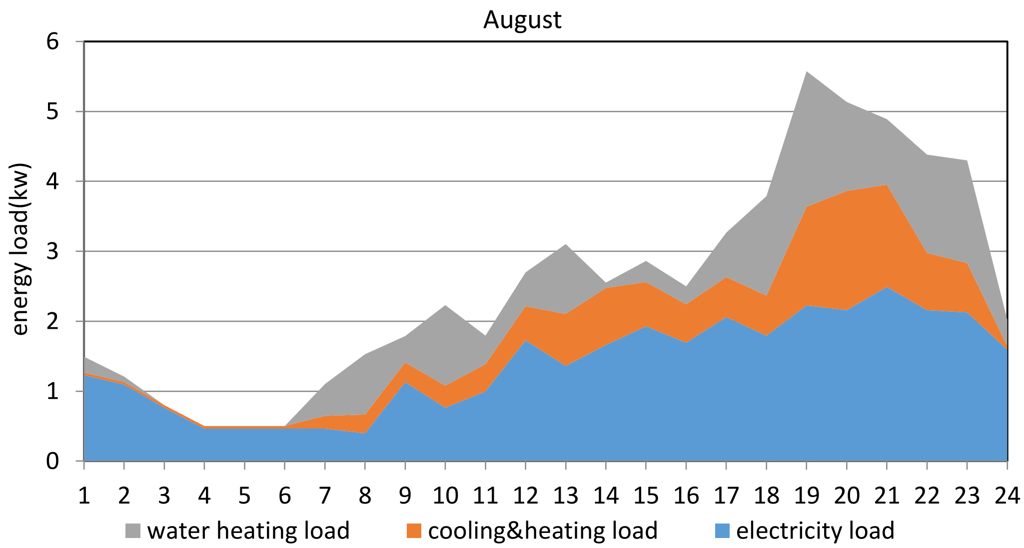


Figure 3-2-8 Energy load of detached house in August

We select January, August and October as the representative months; then analyzed characteristics of energy load in winter, summer and interim period. Figure 3-2-7 shows the average hourly value of detached house energy load in winter period. From the electricity load, it does not change a lot during a day. From 18 o'clock to 23 o'clock is the peak period. From the cooling and heating load, because of winter just has heating load. It has two peaks during a day: one is from 7 o'clock to 9 o'clock in the morning; another is from 17 o'clock to 22 o'clock in the evening. From the water heating load, it does not consume so much in the morning until in the evening from 20 o'clock to 23 o'clock.

Figure 3-2-8 shows the hourly energy load of detached house in summer period. Among the 3 types of energy load, the maximum value is electricity load. From the electricity load, it also does not change a lot during a day. From 19 o'clock to 23 o'clock is the peak period. From the cooling and heating load, because of summer just has cooling load. The peak is from 19 o'clock to 21 o'clock in the evening. From the water heating load, it does not consume so much in the morning until in the evening from 18 o'clock to 23 o'clock.

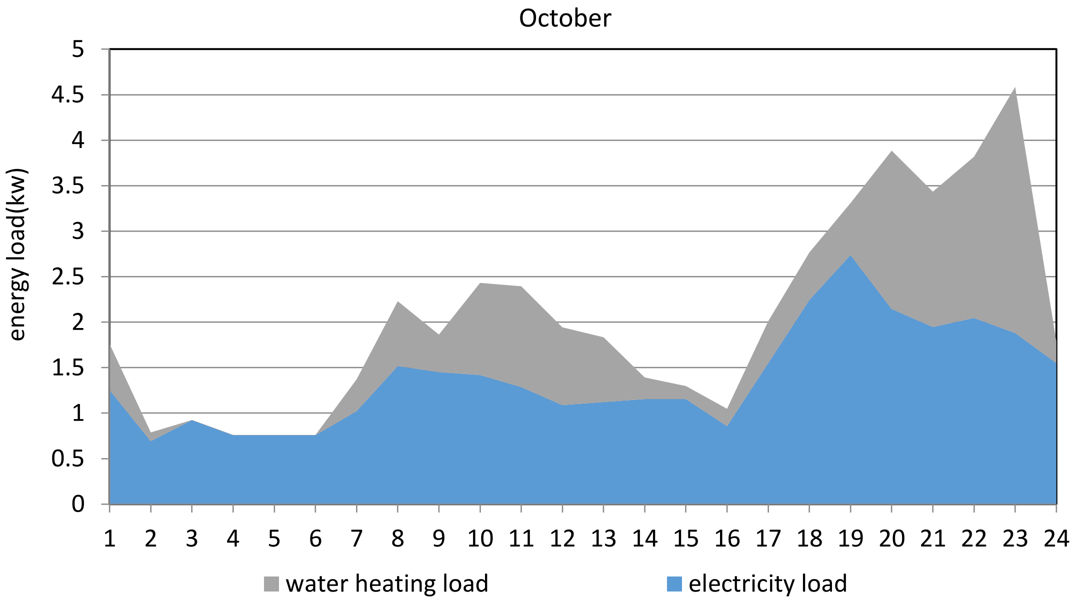


Figure 3-2-9 Energy load of detached house in October

Figure 3-2-9 shows the hourly energy load of detached house in interim period. There is no cooling and heating load in the October. And electricity load is higher than the water heating load. From 18 o'clock to 23 o'clock is the peak period in electricity load. From the water heating load, it has two peaks during a day: one is from 10 o'clock to 11 o'clock in the morning; another is from 20 o'clock to 23 o'clock in the evening.

3.3 Energy system selection and conditions

3.3.1 Systems setting

According to the basic survey about this detached house, we have set 6 cases to analysis energy utilization conditions. Different equipment provide electricity load, cooling load, heating load and water heating load for the detached house.

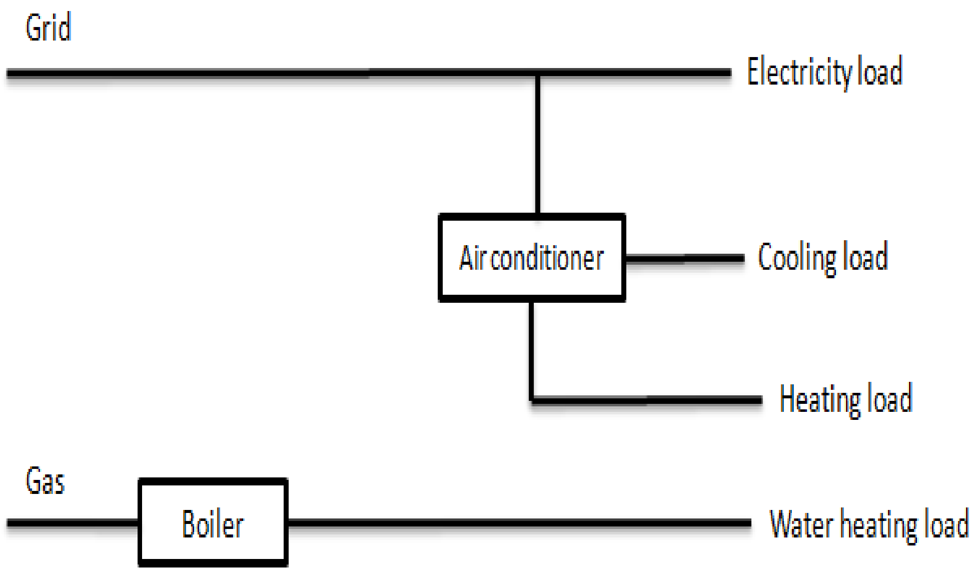


Figure 3-3-1 Conventional energy supply case (case 1, past case)

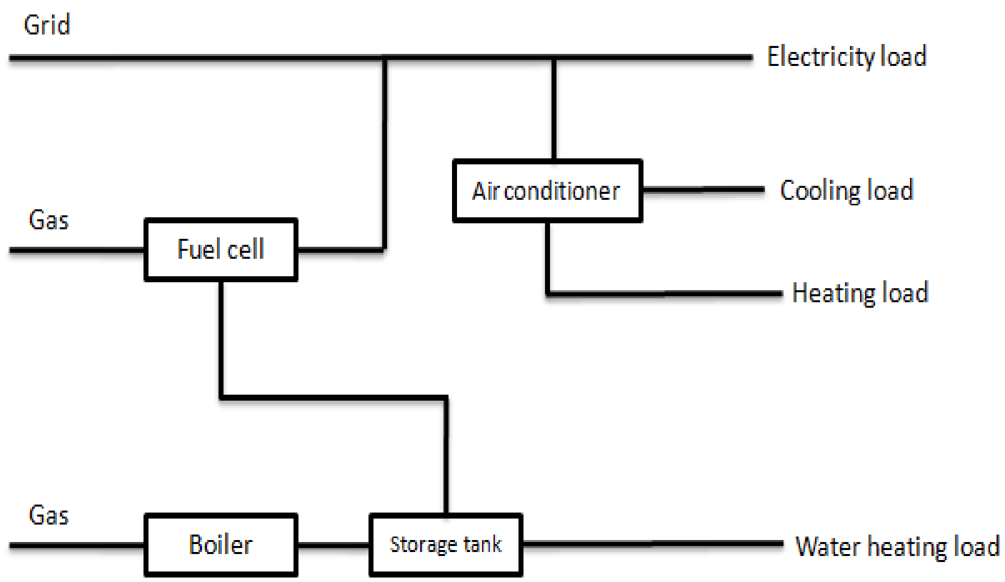


Figure 3-3-2 The case to introduce gas fuel cell (case 2, CHP by gas)

Figure 3-3-1 shows the past energy utilization in the detached house. In generally, electricity load is directly supply by the power grid. Cooling load and heating load are supply by air conditioner, but the energy source is also from power grid. Water heating load is supply by boiler, and the energy source is from gas.

Figure 3-3-2 shows the case 2 that use city gas fuel cell to supply energy to the detached house. When gas fuel cell is working, the temperature is very high, and the power generation efficiency is high. On the other hand, the temperature of waste heat also is high. We can know that the overall efficiency is much higher than the power generation efficiency from power plant.

From case 2, a part of the electricity load is from the fuel cell power generation, the other is from grid power generation. First it has two operation modes. One is electricity tracking mode, it means that fuel cell power generation follow the change of electricity load. The power generation from fuel cell will not have residual and the heat production from fuel cell may have residual which do not make full use. Another is heat tracking mode, it means that fuel cell heat production follow the change of heating load. The heat production from the fuel cell will not have residual and the power generation from fuel cell may have residual which do not make full use.

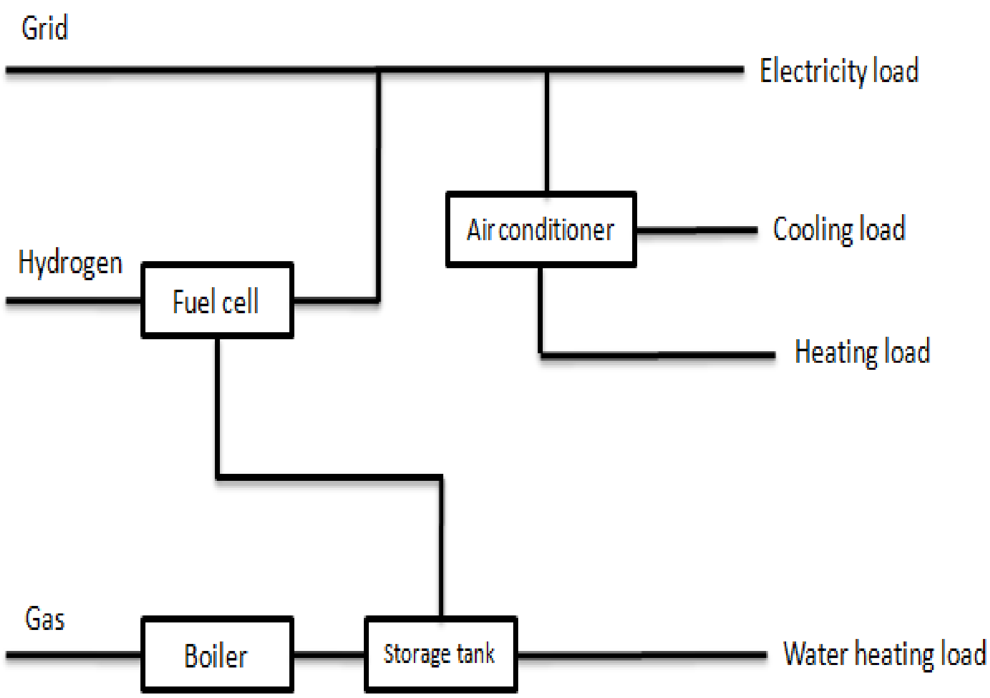


Figure 3-3-3 The case to introduce hydrogen fuel cell (case 3, CHP by hydrogen)

From case 3, the energy source of fuel cell is hydrogen. We can know that hydrogen is one of clean energy, and do not have carbon dioxide emissions. Both of the power generation efficiency and heat production efficiency are higher than other fuel cells. Because of the overall efficiency is high, we can know that it can reduce energy consumption. The Start-up time of hydrogen fuel cell is very short, only takes 5 minutes. Also the energy consumption in the Start-up time is a little. This fuel cell can be set in compact community, detached houses and collective houses.

Electricity load is supply by the power grid and hydrogen fuel cell. Cooling load and heating load are supply by air conditioner; the energy source is can from power grid and hydrogen fuel cell. Water heating load is supply by boiler and hydrogen fuel cell, and the energy source is from gas and hydrogen. The operation modes are the same as case 2.

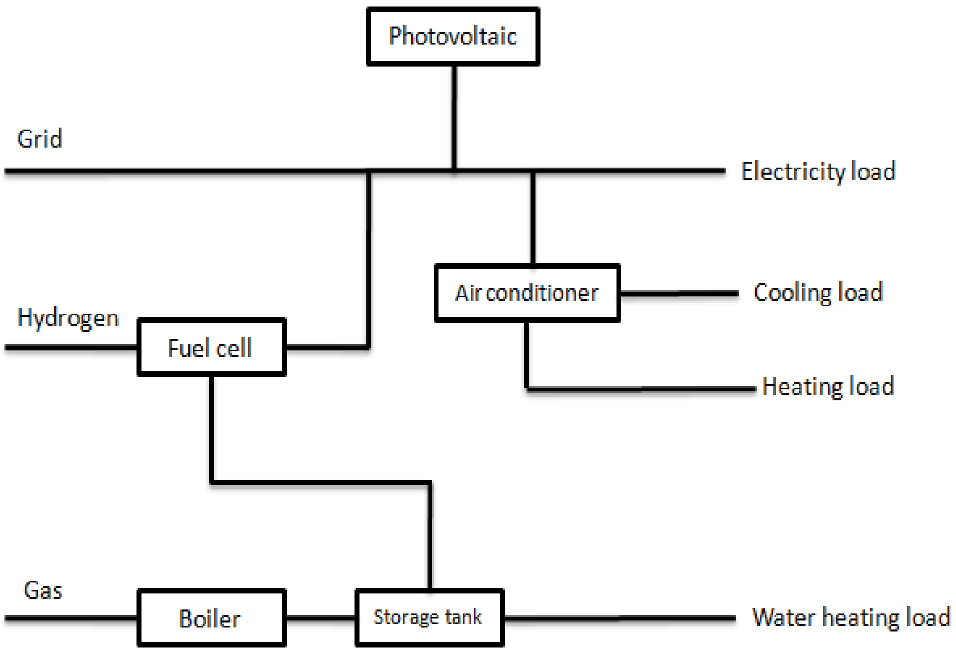


Figure 3-3-4 The case to introduce hydrogen fuel cell and PV (case 4, CHP +PV)

From case 4, in order to consider about the energy conservation, we have set photovoltaic in detached house. In the daytime, solar panel can absorb the sunshine to convert to electricity. Sometime the electricity from solar panel is higher than electricity load, but power generation has large influence by the weather.

Electricity load is supply by the power grid, hydrogen fuel cell and solar panel. Cooling load and heating load are supply by air conditioner; the energy source is can from power grid, hydrogen fuel cell and solar panel. Water heating load is supply by boiler and hydrogen fuel cell, and the energy source is from gas and hydrogen. And it also has the electricity tracking mode and heat tracking mode.

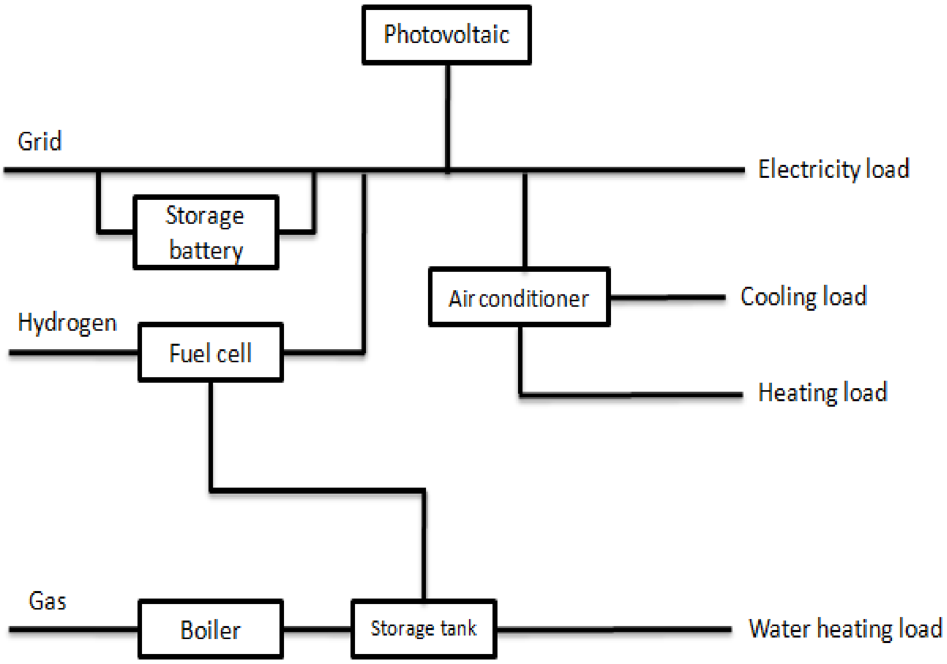


Figure 3-3-5 The case to introduce hydrogen fuel cell, PV and SB (case 5, CHP +PV+SB)

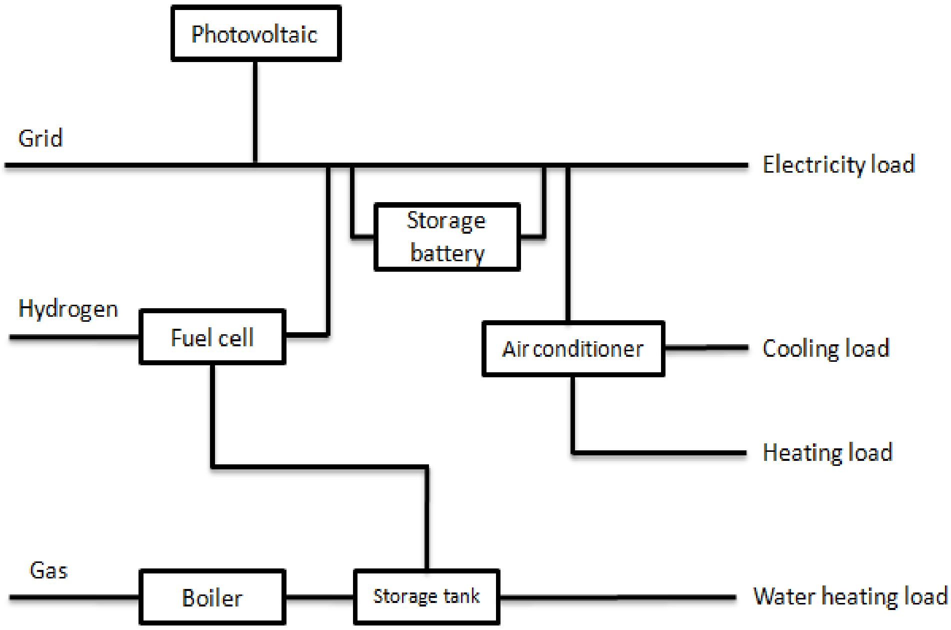


Figure 3-3-6 The case to introduce hydrogen fuel cell, PV and SB (case 6, CHP +PV+SB)

From case 5, during the daytime, there have energy loss and do not make full use of the energy conservation. In order to save the energy, we set the storage batteries in the detached house. Because of the energy shortage, we can use the storage batteries to make peak cut. In this case, the charging time and discharging time are stationary. And the power source of storage batteries is only from power grid in the night, it does not store the energy from solar panel.

In the daytime, electricity load is from 4 parts: power grid, solar panel, fuel cell and storage batteries. In the evening, electricity load is supply by power grid and fuel cell. Cooling load and heating load are supply by air conditioner; the energy source is can from power grid, hydrogen fuel cell, solar panel and storage batteries. Water heating load is supply by boiler and hydrogen fuel cell, and the energy source is from gas and hydrogen. We set the charging time of storage batteries from 2 o'clock to 6 o'clock, total is 5 hours. Set the discharging time of storage batteries from 17 o'clock to 24 o'clock, total is 7 hours.

From case 6, the energy source of storage batteries can be from power grid, solar panel and fuel cell. So the energy utilization condition of storage batteries is a bit complex. In this case electricity tracking mode it means that fuel cell power generation follow the change of electricity load. First the charge quantity of storage batteries is from residual solar power generation and second is from the power grid in the night. Discharging time period is the time that electricity load is greater than solar power generation quantity plus the fuel cell power generation quantity. The power generation from fuel cell will not have residual and the heat production from fuel cell may have residual which do not make full use.

Another is heat tracking mode, it means that fuel cell heat production follow the change of heating load. The heat production from the fuel cell will not have residual and the power generation from fuel cell does not have residual too. First the charge quantity of storage batteries is from excess fuel cell power generation, second is from the power grid and solar power generation. Discharging time period is the time that electricity load is greater than solar power generation quantity plus the fuel cell power generation quantity.

In the daytime, electricity load is from 4 parts: power grid, solar panel, fuel cell and storage batteries. In the evening, electricity load is supply by power grid and fuel cell. Cooling load and heating load are supply by air conditioner; the energy source is can from power grid, hydrogen fuel cell, solar panel and storage batteries. The electricity of storage batteries is being regulated and controlled. Water heating load is supply by boiler and hydrogen fuel cell, and the energy source is from gas and hydrogen. We set the charging time and discharging time follow the change of electricity load.

Except case 1, from case 2 to case 6, each of them has two operation modes. And the electricity utilization conditions and heat utilization conditions should be survey and analysis.

3.3.2 Operating conditions and machine selection

When we finish the cases setting, we need to judge operating conditions of each case and set parameters of each equipment. We make the power flow chat to explain it.

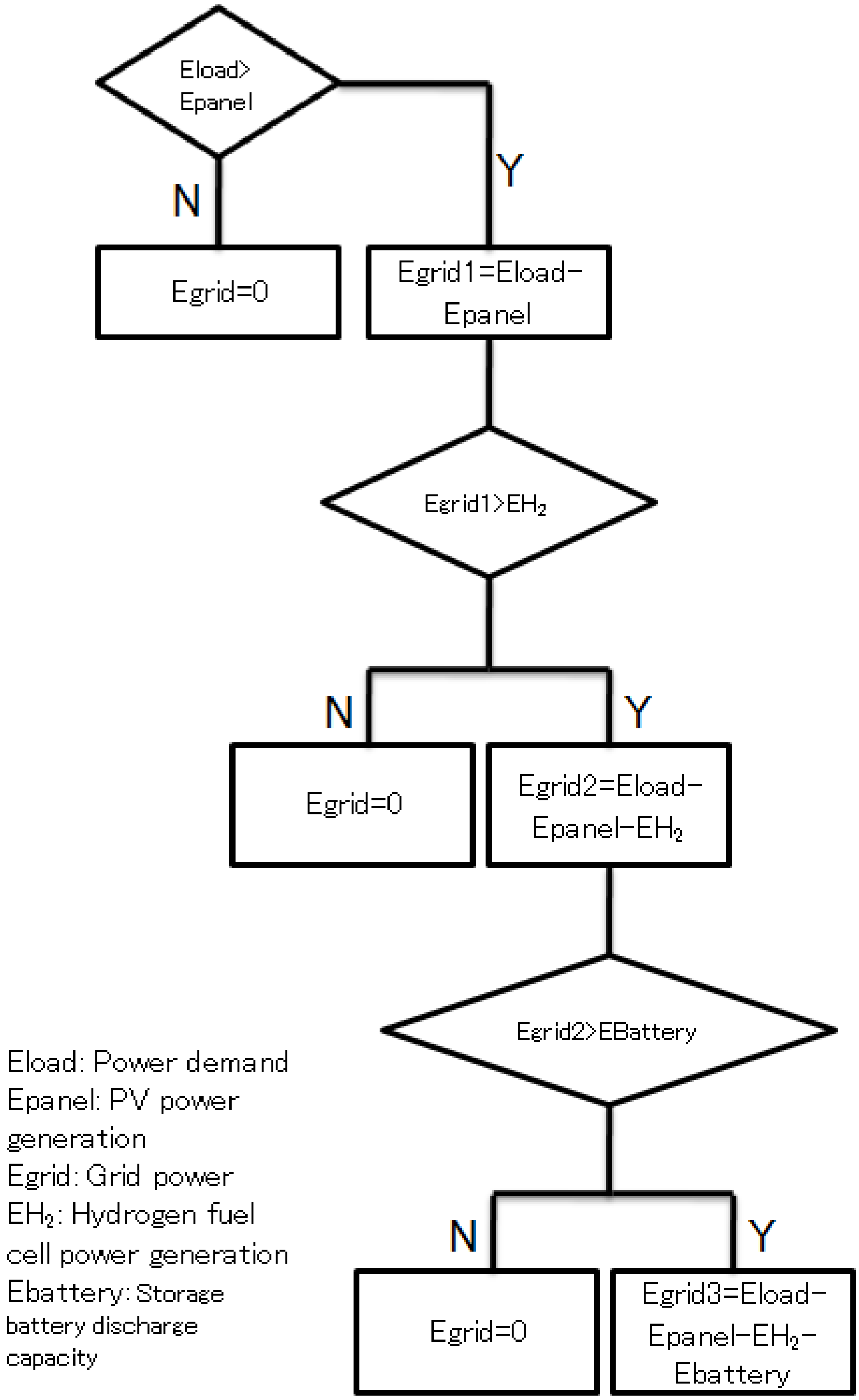


Figure 3-3-7 Power flow chart

We choose the case 6 to explain the operating conditions. Firstly, we compare with the electricity and solar panel power generation. If the electricity load is large, it will move to direction Yes, residual electricity is Egrid1. If the solar panel power generation is large, it will move to direction No, do not need any power from power grid.

Secondly, we compare with power generation from hydrogen fuel cell. If the residual electricity is large, it will move to direction Yes. If not, it will move to direction No.

Thirdly, we compare with quantity of electricity from storage battery. If the residual electricity is large, it will move to direction Yes. If not, it will move to direction No.

At last, electricity load is larger than outside power. The system will use the electricity from the power grid.

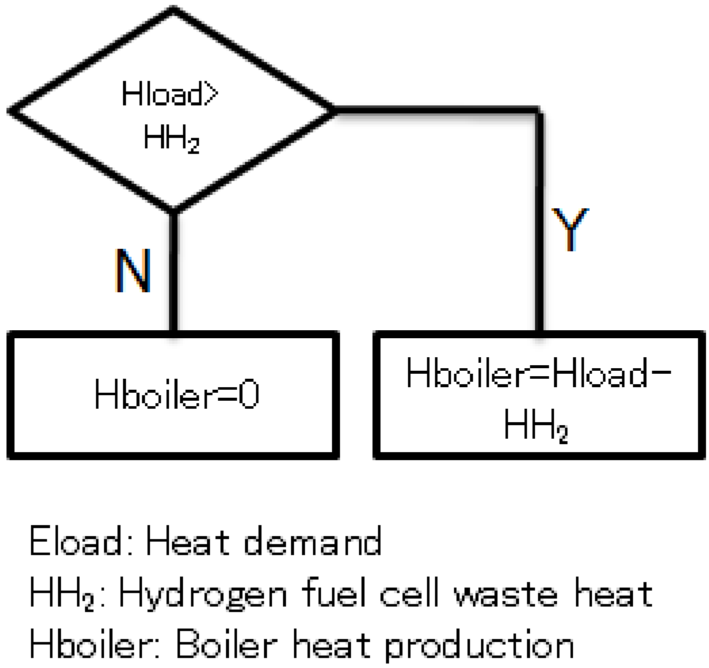


Figure 3-3-8 Heat flow chart

Figure 3-3-8 shows the heat flow chart. If the water heating load is larger than the heat quantity from hydrogen fuel cell. It will move to the direction Yes. Residual water heating load need to use the heat quantity from boiler. If not, it proves that the heat quantity from hydrogen fuel cell is enough to provide to the detached house.

According to the 6 cases' conditions of the detached house, we need to set up the main equipment of each case. Fuel cell has the power generation efficiency and waste heat utilization. Based on the rated output, we calculate power generation and heat production from fuel cell.

Table 3-3-1 Parameter of each facility

	Fuel cell specifications		
	Power generation efficiency	Waste heat utilization	Rated output
Gas(FC)	0.36	0.5	0.7kw
H_2(FC)	0.48	0.42	0.7kw

	Conversion factor of calorific value	Conversion factor of CO_2 emissions
Power	9.97MJ/kwh	0.369kg/kwh
Gas	46.06MJ/m^3	2.26kg/m^3

	Efficiency of each facility
Boiler	0.9
PV	0.145
SB	0.92
Air conditioner	4

Then based on conversion factor of calorific value and conversion factor of CO_2 emissions, we can know the total energy consumption of energy and the total CO_2 emissions.

Last we investigate the efficiency of each facility. We calculate the equipment use electricity or gas to determine how much the energy can be generated. And we simulate the energy operating conditions of this detached house.

3.4 Simulation results for the distribution energy resource

3.4.1 Power utilization and heat utilization

In case 1, all of the electricity load, cooling load and heating load are supply by electricity, water heating load is supply by gas. It is the past case that does not have other equipment to supply energy. From other cases, we consider about the contribution of different equipment in power utilization and heat utilization. Also we can know influence of the energy utilization and use situations of each device. In every mode of each case, power utilization and heat utilization have the change.

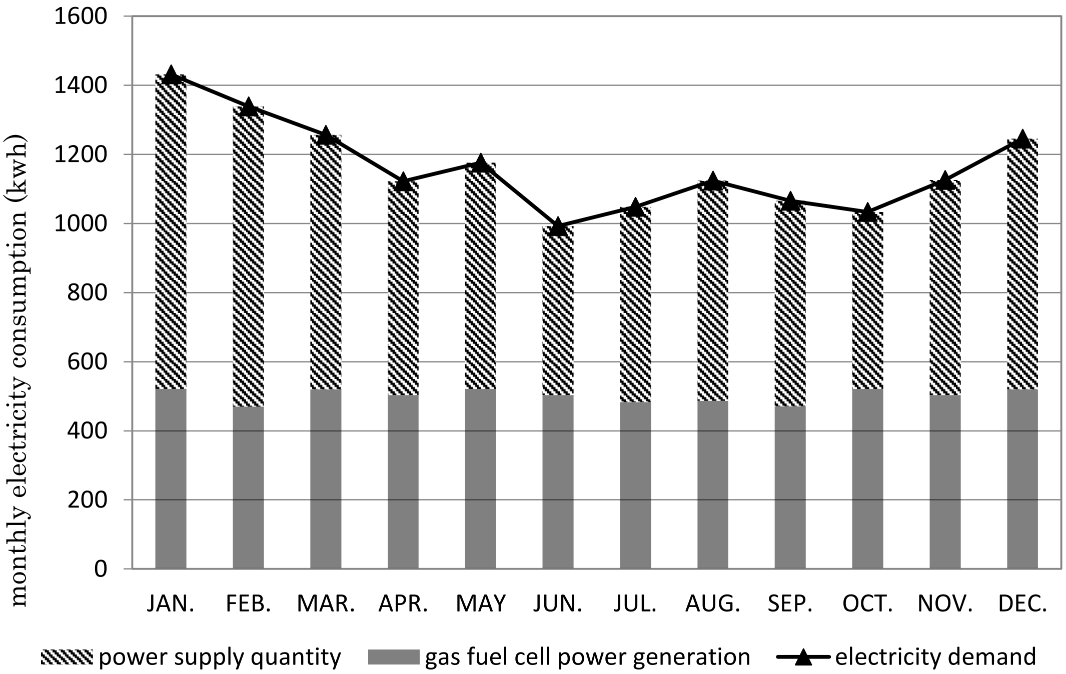


Figure 3-4-1 Monthly electricity consumption in case 2 (electricity tracking mode)

Figure 3-4-1 shows the monthly electricity consumption in case 2. From this case, because of electricity tracking mode, it does not have residual electricity; just have the residual heat quantity. The power generation of gas fuel cell follows the change of electricity load. In the most of time, electricity demand is larger than the power generation of gas fuel cell. So the power generation is almost the same as rated output. January has the largest power generation quantity which reaches 520 kWh. February has the least power generation quantity which reaches 470 kWh. Power supply quantity in January reaches 911 kWh which is the maximum value. Power supply quantity in June reaches 488 kWh which is the minimum value.

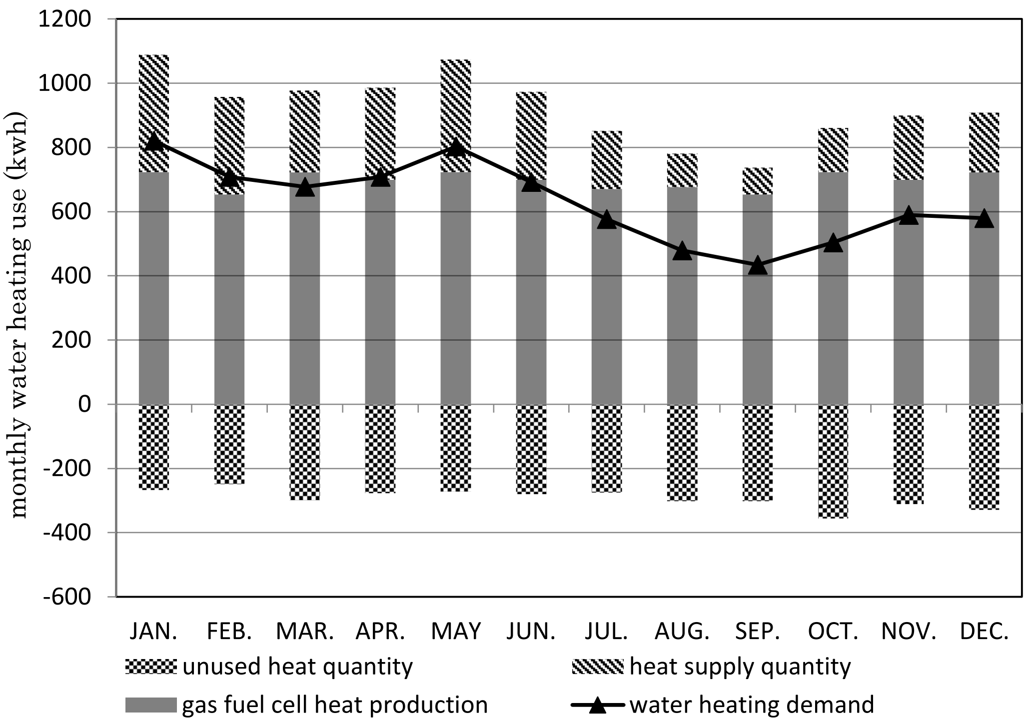


Figure 3-4-2 Monthly water heating use in case 2 (electricity tracking mode)

Figure 3-4-2 shows the monthly water heating use in case 2. From this case, we can know that gas fuel cell power generation supply most water heating load. But sometimes the gas fuel cell heat production is larger than water heating demand. So it leads to that there will be have the unused heat quantity. October has the largest unused heat quantity which reaches 356 kWh. February has the least unused heat quantity which reaches 249 kWh. Unused heat quantity does not change a lot during this year.

From this figure, in August, September and October, the gas fuel cell heat production is much larger than the water heating demand. But it does not cause more unused heating quantity. Almost in every month, the time period that gas fuel cell heat production is larger than water hear demand does not change a lot. The extra parts are including in unused heat quantity.

May has the largest gas fuel cell heat production which reaches 723 kWh. February has the least gas fuel cell heat production which reaches 653 kWh. Heat supply quantity in January reaches 365 kWh which is the maximum value. Heat supply quantity in September reaches 83 kWh which is the minimum value.

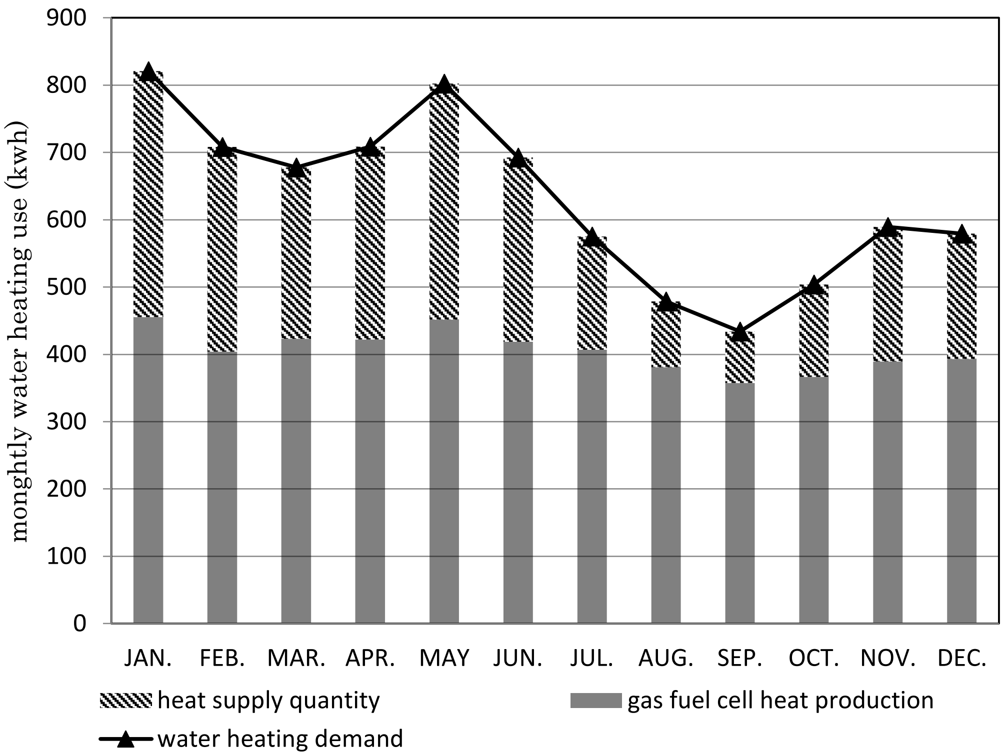


Figure 3-4-3 Monthly water heating use in case 2 (heat tracking mode)

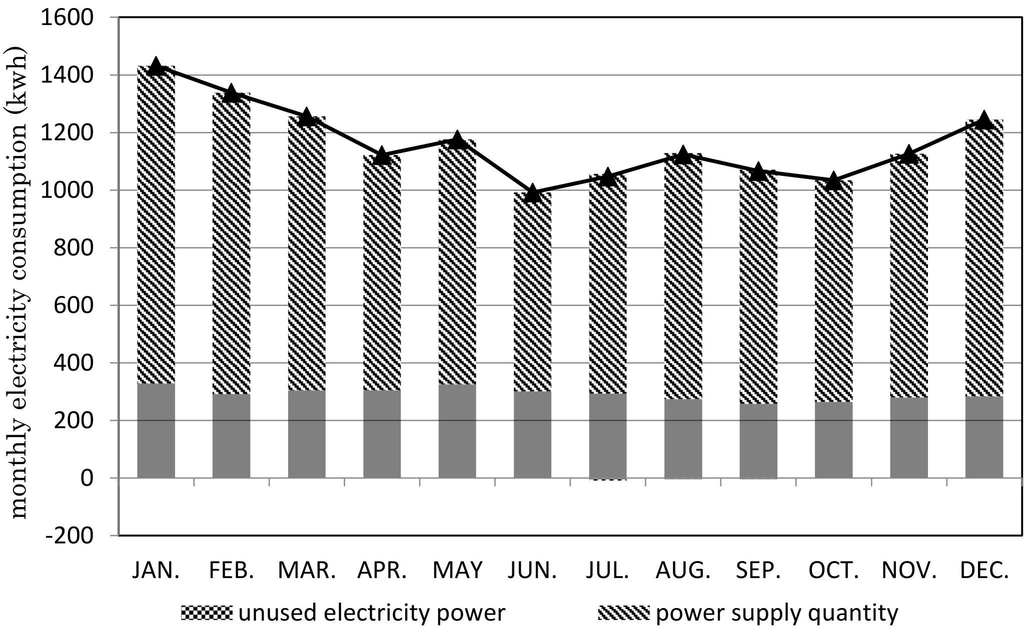


Figure 3-4-4 Monthly electricity consumption in case 2 (electricity tracking mode)

Figure 3-4-3 and figure 3-4-4 are the energy use situation in case 2. Both of them are the heat tracking mode that gas fuel cell heat production follow the change of heating load.

From figure 3-4-3, it does not have residual heat quantity. Gas fuel cell heat production is less than the value from figure 3-4-2; the value is around 400 kWh. January has the largest gas fuel cell heat production which reaches 455 kWh. October has the least gas fuel cell heat production which reaches 366 kWh. Heat supply quantity in January reaches 365 kWh which is the maximum value. Heat supply quantity in September reaches 76 kWh which is the minimum value.

In this case, because of heat tracking mode, when the gas fuel cell supply the heat quantity, the power generation does not exceed the electricity demand a lot. It causes that little unused electricity power. It only has 8 kWh in July. Gas fuel cell power generation is less than the value from figure 3-4-1; the value is only around 300 kWh. January has the largest gas fuel cell power generation which reaches 328 kWh. September has the least gas fuel cell power generation which reaches 257 kWh. Power supply quantity in January reaches 1103 kWh which is the maximum value. Power supply quantity in June reaches 690 kWh which is the minimum value.

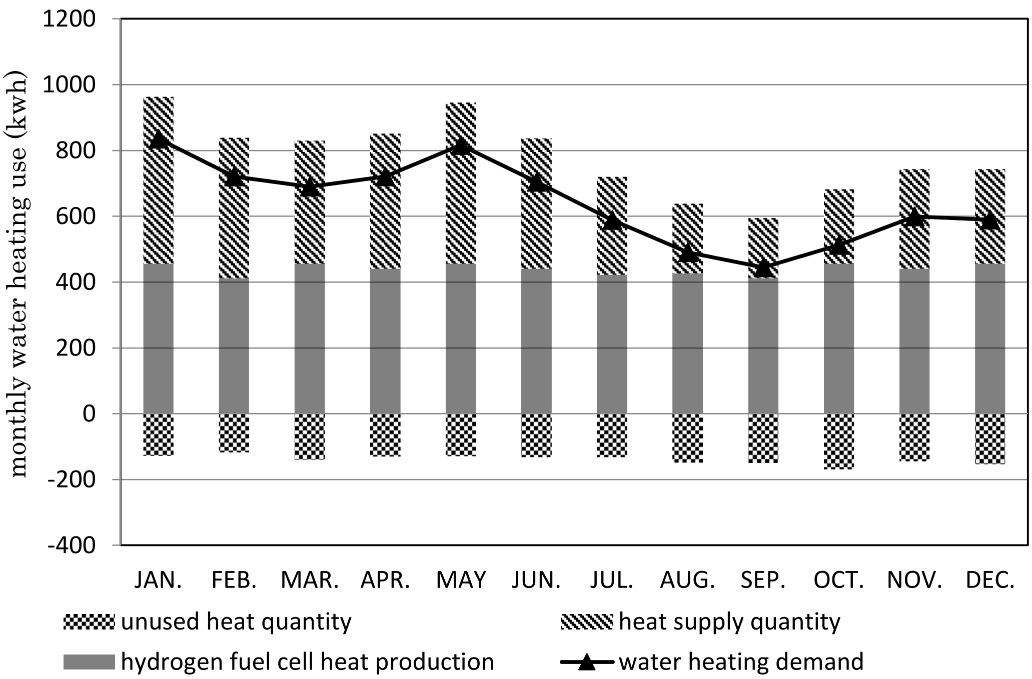


Figure 3-4-5 Monthly water heating use in case 3 (electricity tracking mode)

Figure 3-4-5 is the electricity tracking mode that hydrogen fuel cell power generation follows the change of electricity load, monthly water heating use in case 3. From figure 3-4-5, because of hydrogen fuel cell, it compares with gas fuel cell has different power generation efficiency and waste heat utilization. The power generation efficiency is greater than gas fuel cell, and the waste heat utilization is less than gas fuel cell. But the rated output of hydrogen fuel cell is the same as gas fuel cell. So the power usage situation is the same as figure 3-4-1. The unused heat quantity is less than the value from figure 3-4-2; the value is around 150 kWh. October has the largest unused heat quantity which reaches 169 kWh. February has the least unused heat quantity which reaches 117 kWh.

From this figure, the water heating demand is larger than the hydrogen fuel cell heat production in every month. So we can know that all of the unused heat quantity is from hydrogen fuel cell heat production.

May has the largest hydrogen fuel cell heat production which reaches 455 kWh. February has the least hydrogen fuel cell heat production which reaches 411 kWh. Heat supply quantity in January reaches 507 kWh which is the maximum value. Heat supply quantity in September reaches 182 kWh which is the minimum value.

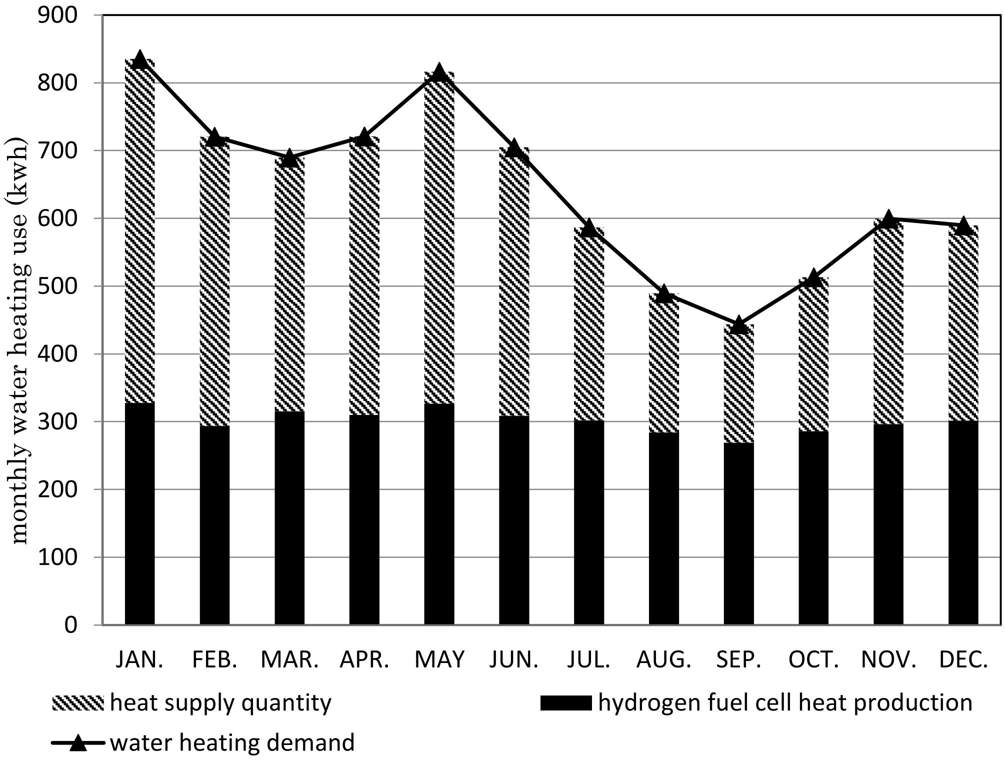


Figure 3-4-6 Monthly water heating use in case 3 (heat tracking mode)

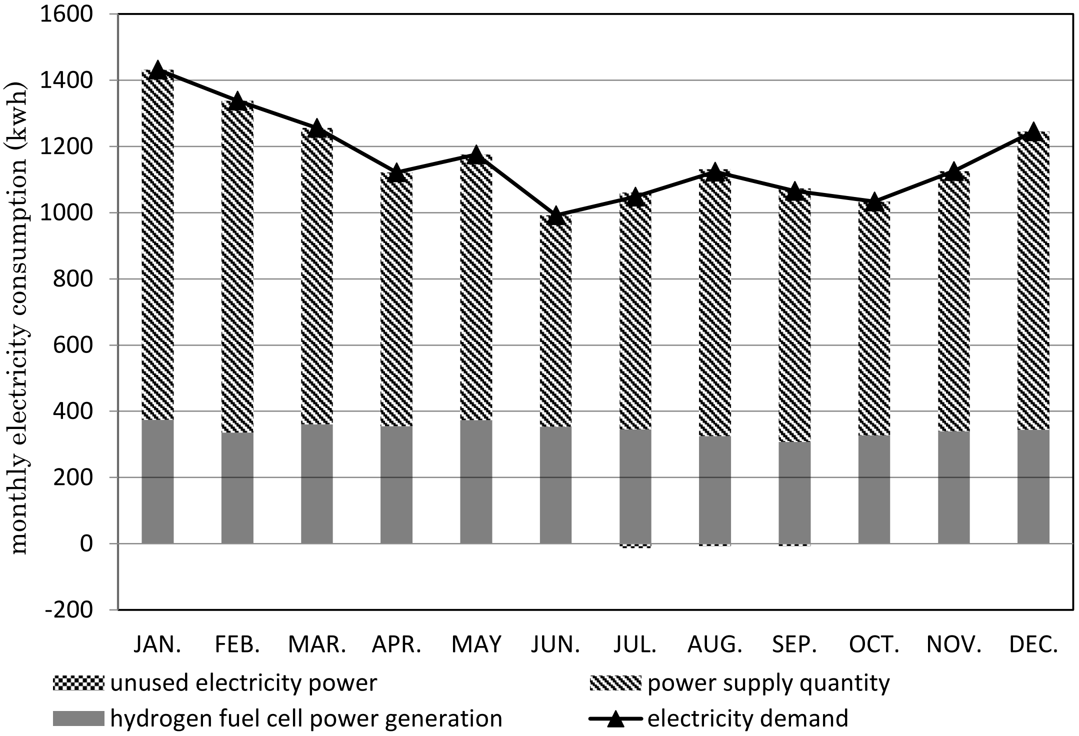


Figure 3-4-7 Monthly electricity consumption in case 3 (heat tracking mode)

Figure 3-4-6 and figure 3-4-7 are the energy use situation in case 3. Both of them are the heat tracking mode that hydrogen fuel cell heat production follows the change of heating load. From figure 3-4-6, it does not have residual heat quantity. Hydrogen fuel cell heat production is less than the value from figure 3-4-3; the value is around 300 kWh. January has the largest hydrogen fuel cell heat production which reaches 327 kWh. September has the least hydrogen fuel cell heat production which reaches 268 kWh. Heat supply quantity in January reaches 507 kWh which is the maximum value. Heat supply quantity in September reaches 174 kWh which is the minimum value.

In this case, because of heat tracking mode, when the hydrogen fuel cell supply the heat quantity, the power generation does not exceed the electricity demand a lot. It causes that little unused electricity power. It only has 13 kWh in July. Hydrogen fuel cell power generation is greater than the value from figure 3-4-4; the value is only around 350 kWh. January has the largest hydrogen fuel cell power generation which reaches 374 kWh. September has the least hydrogen fuel cell power generation which reaches 307 kWh. Power supply quantity in January reaches 1057 kWh which is the maximum value. Power supply quantity in June reaches 639 kWh which is the minimum value.

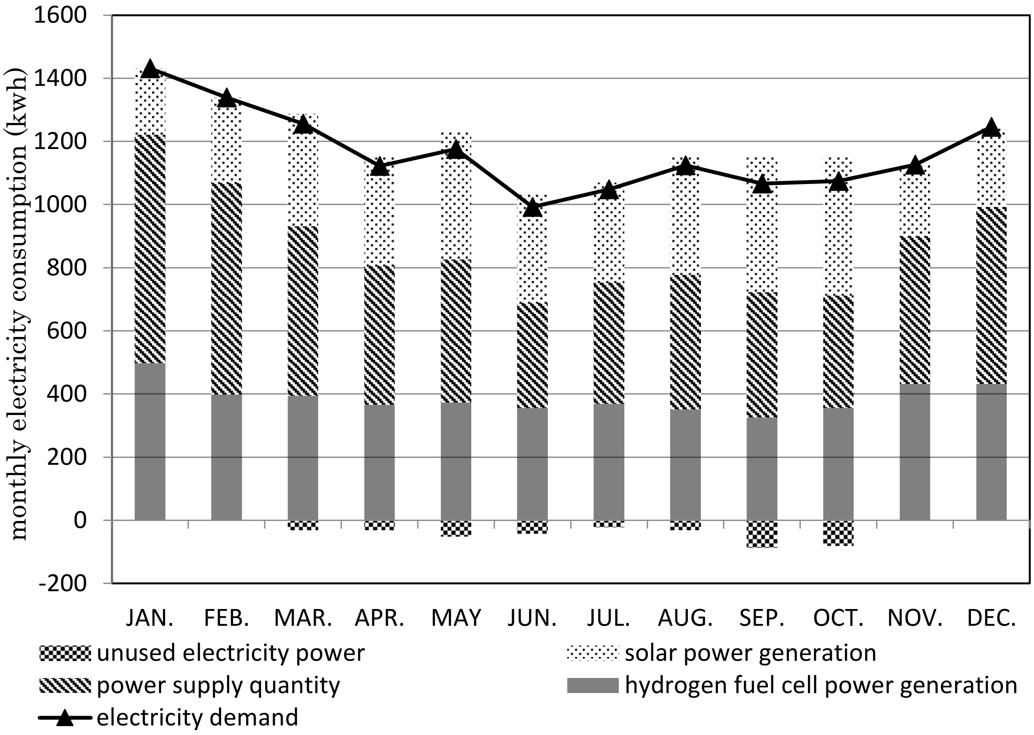


Figure 3-4-8 Monthly electricity consumption in case 4 (electricity tracking mode)

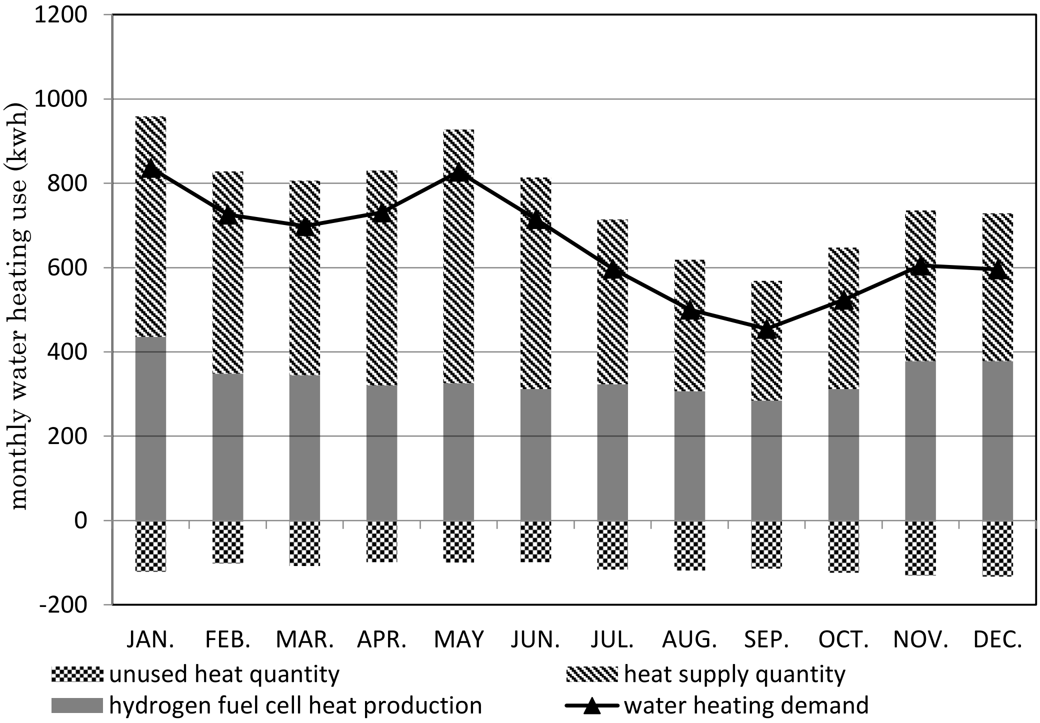


Figure 3-4-9 Monthly water heating use in case 4 (heat tracking mode)

Figure 3-4-8 and figure 3-4-9 are the energy use situation in case 4. Both of them are the electricity tracking mode that hydrogen fuel cell power generation follows the change of electricity load. Figure 3-4-8 shows power usage situation. From this case, we set the solar panel in the detached house. During the daytime, the solar power generation is greater than the electricity demand in some times. So it leads to that there will be have the unused power quantity. We can see that the solar power generation accounts for a large part of the electricity demand. In some months, the solar power generation even more than one third of electricity demand. September has the largest unused electricity power which reaches 87 kWh. January and February do not have the unused electricity power. Solar power generation in October reaches 442 kWh which is the maximum value. Solar power generation in January reaches 210 kWh which is the minimum value.

The power generation of hydrogen fuel cell follows the change of electricity load. In the most of time, electricity demand is larger than the power generation of hydrogen fuel cell. So the power generation is almost the same as rated output. January has the largest hydrogen fuel cell power generation quantity which reaches 497 kWh. September has the least hydrogen fuel cell power generation quantity which reaches 325 kWh. Power supply quantity in January reaches 722 kWh which is the maximum value. Power supply quantity in June reaches 332 kWh which is the minimum value.

Figure 3-4-9 is the electricity tracking mode that hydrogen fuel cell power generation follows the change of electricity load, energy usage situation of case 4. From figure 3-4-9, it compares with figure 3-4-5, the hydrogen fuel cell heat production and unused heat quantity change a little. The unused heat quantity is close to the value from figure 3-4-5; the value is around 100 kWh. December has the largest unused heat quantity which reaches 132 kWh. June has the least unused heat quantity which reaches 98 kWh.

From this figure, the water heating demand is larger than the hydrogen fuel cell heat production in every month. So we can know that all of the unused heat quantity is from hydrogen fuel cell heat production.

January has the largest hydrogen fuel cell heat production which reaches 435 kWh. September has the least hydrogen fuel cell heat production which reaches 284 kWh. Heat supply quantity in May reaches 601 kWh which is the maximum value. Heat supply quantity in September reaches 283 kWh which is the minimum value.

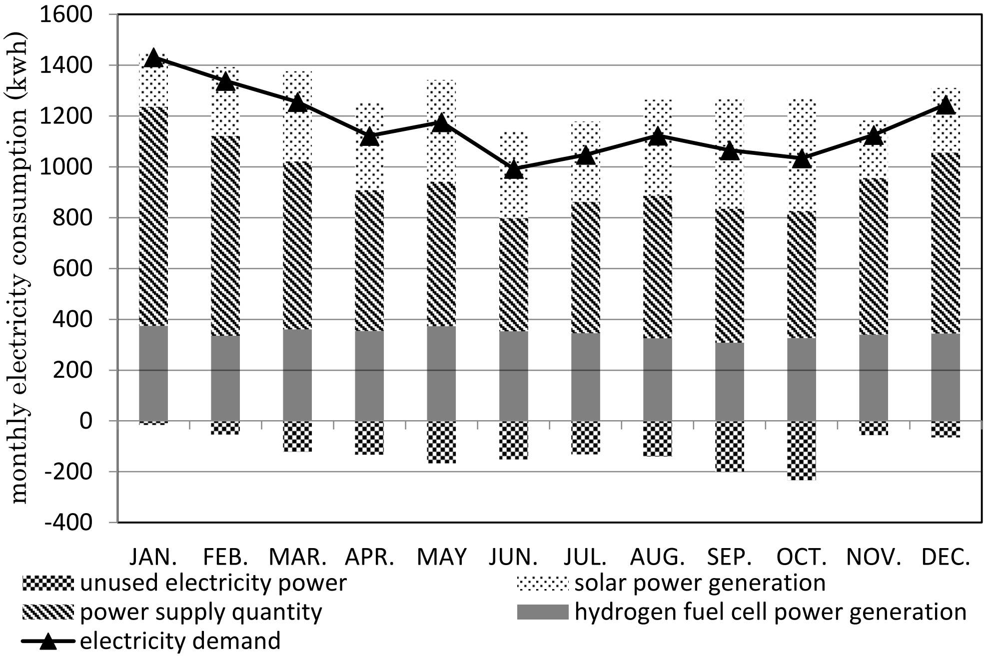


Figure 3-4-10 Monthly electricity consumption in case 4 (heat tracking mode)

Figure 3-4-10 is the monthly electricity consumption in case 4. It is the heat tracking mode that hydrogen fuel cell heat production follows the change of heating load. When the hydrogen fuel cell supply the heat quantity, the power generation does not exceed the electricity demand a lot. On the other hand, solar power generation is greater than the electricity demand in some times. These two sides cause the unused electricity power. October has the largest unused electricity power which reaches 233 kWh. January has the least unused electricity power which reaches 15 kWh. We can see that the unused electricity is larger than the value from figure 3-4-8.

January has the largest hydrogen fuel cell power generation which reaches 374 kWh. September has the least hydrogen fuel cell power generation which reaches 307 kWh. Power supply quantity in January reaches 862 kWh which is the maximum value. Power supply quantity in June reaches 445 kWh which is the minimum value. And October has the largest solar power generation which reaches 442 kWh. January has the least solar power generation which reaches 210 kWh.

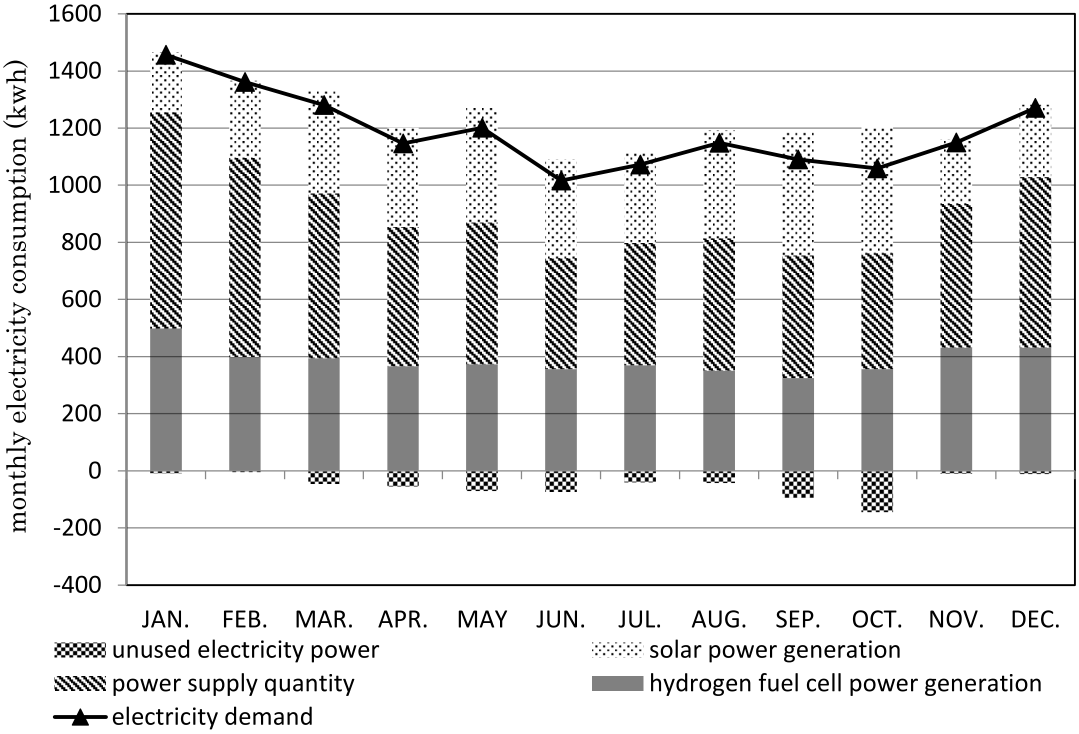


Figure 3-4-11 Monthly electricity consumption in case 5 (electricity tracking mode)

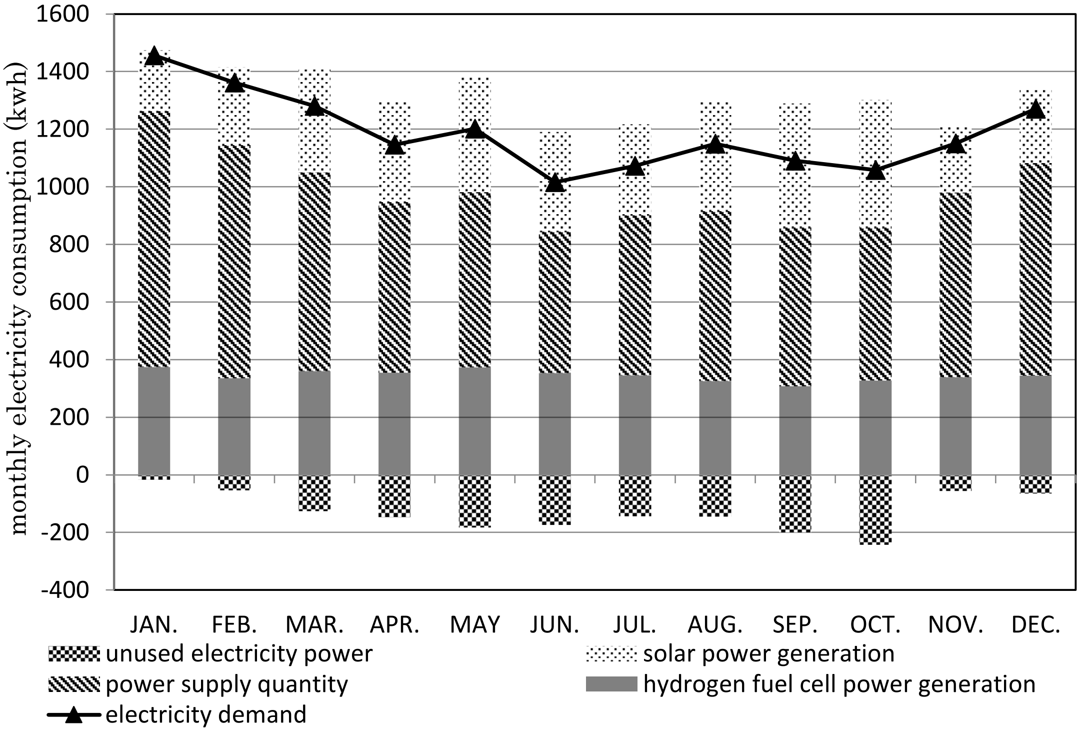


Figure 3-4-12 Monthly electricity consumption in case 5 (heat tracking mode)

Figure 3-4-11 and figure 3-4-12 are the energy usage situation in case 5. One is power usage situation in electricity tracking mode, the other in heat tracking mode. The heat usage situation of case 5 in electricity tracking mode is the same as figure 3-4-9. And the heat usage situation of case 5 in heat tracking mode is the same as figure 3-4-6.

In this case, we set the storage batteries in the detached house. Charging time is 5 hours and discharging time is 8 hours. All the power is from grid, because of conversion efficiency, the power supply demand is greater than before. And the unused electricity power is from solar power generation and residual discharge quantity of storage batteries. October has the largest unused electricity power which reaches 145 kWh. February has the least unused electricity power which reaches 4 kWh.

January has the largest hydrogen fuel cell power generation which reaches 497 kWh. September has the least hydrogen fuel cell power generation which reaches 325 kWh. Power supply quantity in January reaches 757 kWh which is the maximum value. Power supply quantity in June reaches 388 kWh which is the minimum value. And October has the largest solar power generation which reaches 442 kWh. January has the least solar power generation which reaches 210 kWh.

From figure 3-4-12, it is the heat tracking mode, so the unused electricity power is from solar power generation, hydrogen fuel cell power generation and residual discharge quantity of storage batteries. The discharging time of storage batteries is fixed, because the discharging time is in the power consumption peaks, but it also can have residual. October has the largest unused electricity power which reaches 242 kWh. January has the least unused electricity power which reaches 16 kWh.

January has the largest hydrogen fuel cell power generation which reaches 374 kWh. September has the least hydrogen fuel cell power generation which reaches 307 kWh. Power supply quantity in January reaches 888 kWh which is the maximum value. Power supply quantity in June reaches 492 kWh which is the minimum value. And October has the largest solar power generation which reaches 442 kWh. January has the least solar power generation which reaches 210 kWh.

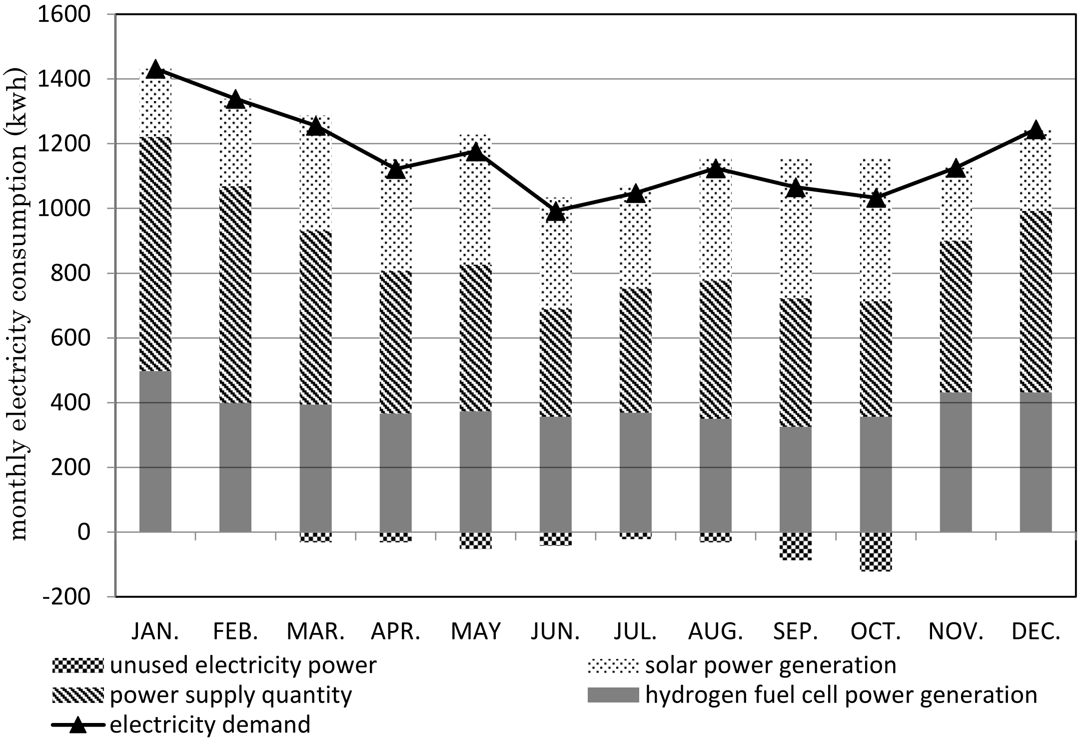


Figure 3-4-13 Monthly electricity consumption in case 6 (electricity tracking mode)

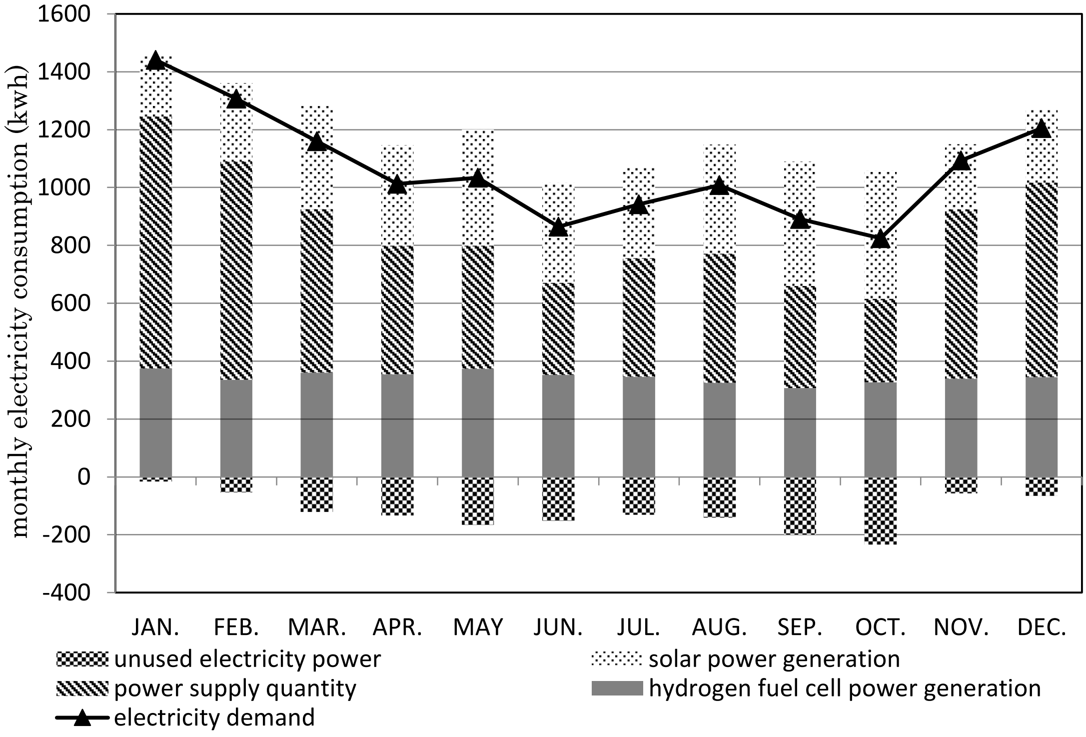


Figure 3-4-14 Monthly electricity consumption in case 6 (heat tracking mode)

Figure 3-4-13 and figure 3-4-14 are the monthly electricity consumption in case 6. One is power usage situation in electricity tracking mode, the other in heat tracking mode.

The heat usage situation of case 6 in electricity tracking mode is the same as figure 3-4-9. And the heat usage situation of case 6 in heat tracking mode is the same as figure 3-4-6.

From figure 3-4-13, the charging time and discharging time of storage batteries follow the electricity load. Charge quantity is from grid and solar power generation, so the unused electricity power will be further reduce. October has the largest unused electricity power which reaches 121 kWh. January and February do not have the unused electricity power.

January has the largest hydrogen fuel cell power generation which reaches 497 kWh. September has the least hydrogen fuel cell power generation which reaches 325 kWh. Power supply quantity in January reaches 722 kWh which is the maximum value. Power supply quantity in June reaches 332 kWh which is the minimum value. And October has the largest solar power generation which reaches 442 kWh. January has the least solar power generation which reaches 210 kWh.

From figure 3-4-14, it is the heat tracking mode, so the unused electricity power is from solar power generation and hydrogen fuel cell power generation. Charge quantity of storage batteries is from grid, solar power generation and hydrogen fuel cell power generation. The charging time and discharging time of storage batteries are not fixed, so it does not have residual. October has the largest unused electricity power which reaches 233 kWh. January has the least unused electricity power which reaches 15 kWh.

January has the largest hydrogen fuel cell power generation which reaches 374 kWh. September has the least hydrogen fuel cell power generation which reaches 307 kWh. Power supply quantity in January reaches 871 kWh which is the maximum value. Power supply quantity in October reaches 289 kWh which is the minimum value. And October has the largest solar power generation which reaches 442 kWh. January has the least solar power generation which reaches 210 kWh.

3.4.2 Energy conservation

We compare with energy consumption in different equipment and Calculate the primary energy consumption in each case.

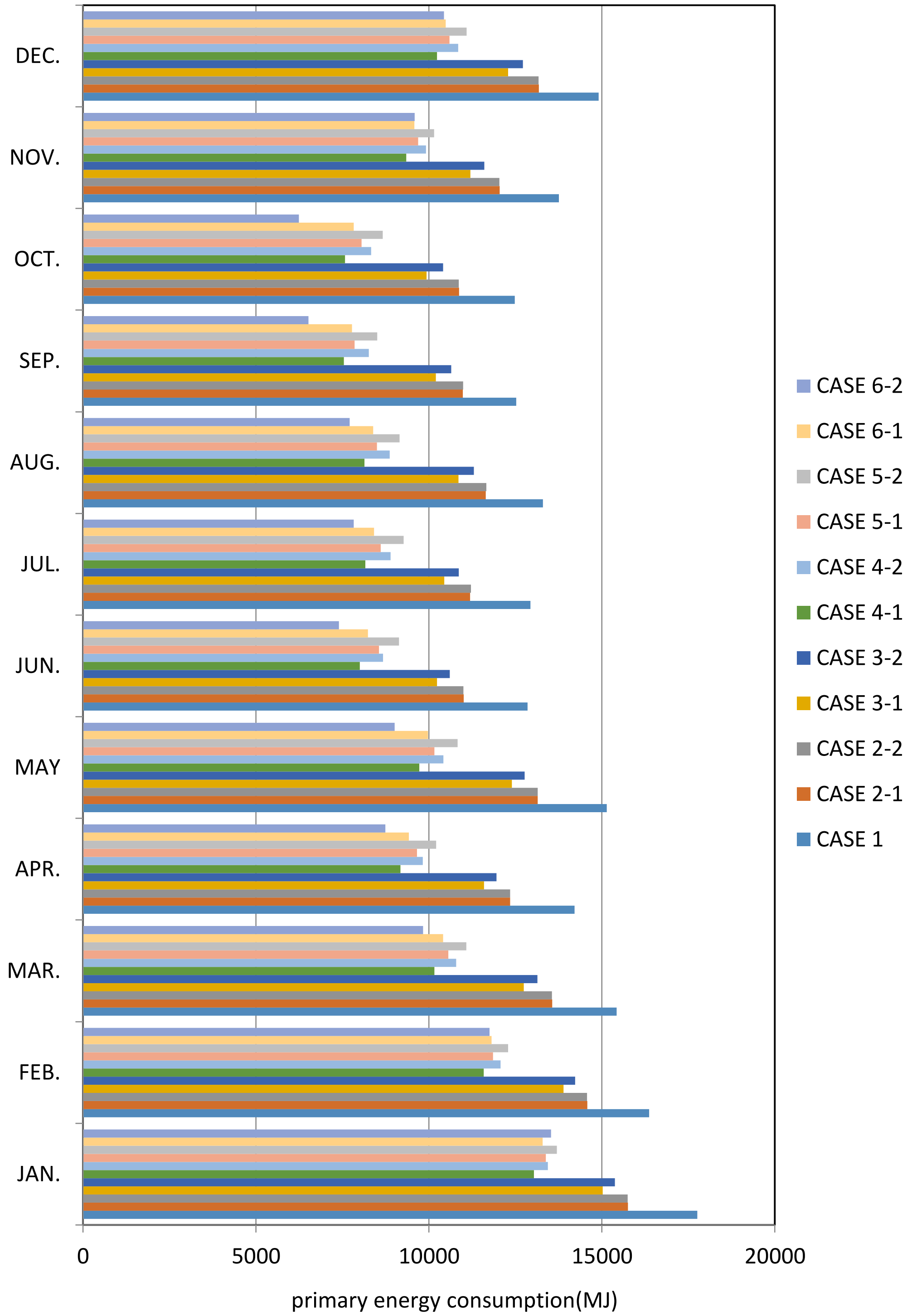


Figure 3-4-15 Primary energy consumption per month

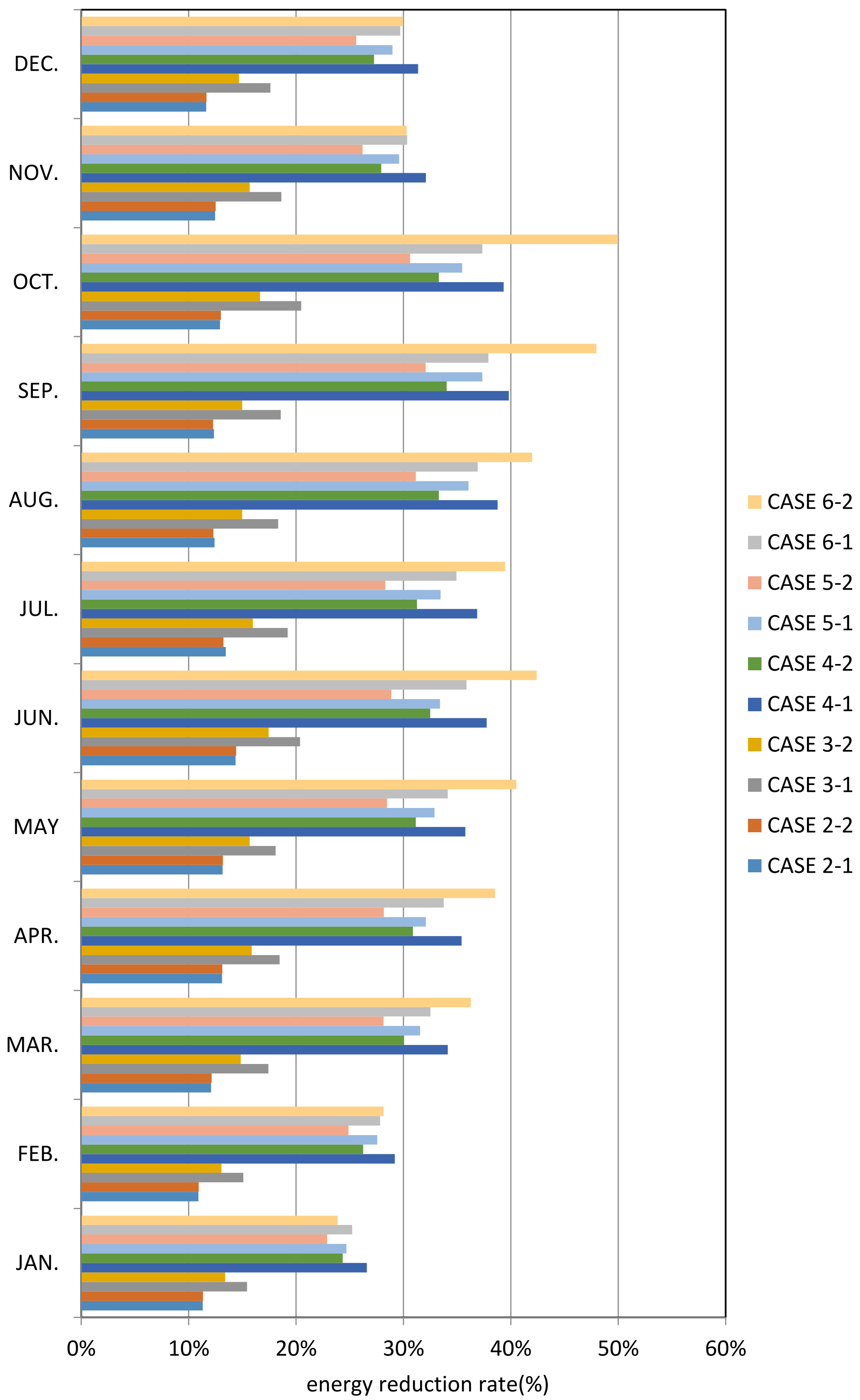


Figure 3-4-16 Energy reduction rate per month

Figure 3-4-15 shows primary energy consumption per month and figure 3-4-16 shows energy reduction rate per month. There is no doubt that the primary energy consumption of past case is the maximum value. When we introduce the fuel cell, solar panel and storage batteries in the system, the primary energy consumption is less than previous case. The value is particularly low in some months, because power generation and heat production from fuel cell can make more use of energy. Solar power generation is larger than before or storage batteries can store more residual electricity quantity.

Energy reduction rate of hydrogen fuel cell is less than gas fuel cell. Energy consumption of fuel cell power generation in the heat tracking mode should waste more than fuel cell heat production in electricity tracking mode. When we set the PV system in the detached house, the energy reduction rate can reach more than 30% and also have the waste. Storage batteries can make peak cut but the energy reduction rate does not increase but decrease. Regulate and control the charging time and discharging time in heat tracking mode can make the energy reduction rate larger than before.

3.4.3 Regulate storage batteries

As the example of case 6, we will discuss the regulation of storage batteries in 2 operation modes. And the time of storage batteries is not fixed; it will follow the change of electricity demand.

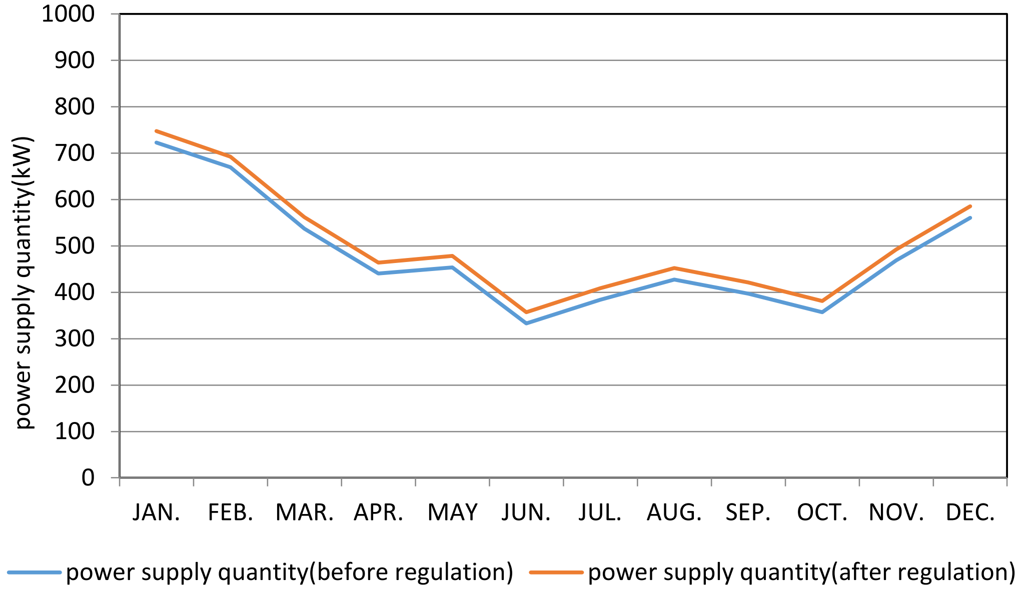


Figure 3-4-17 Change of storage batteries in a year (electricity tracking mode)

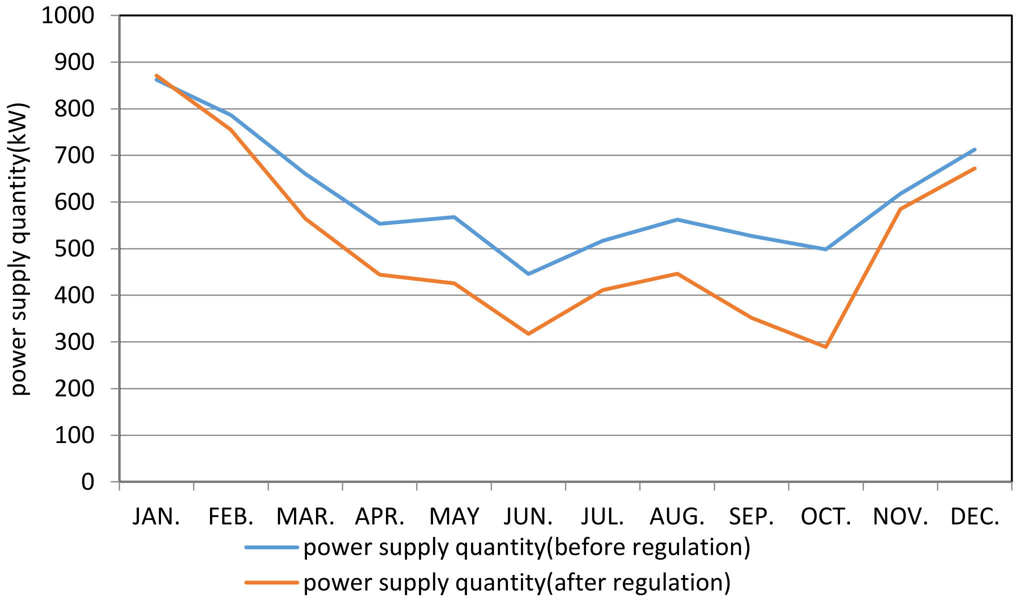


Figure 3-4-18 Change of storage batteries in a year (heat tracking mode)

Figure 3-4-17 and 3-4-18 shows the change of storage batteries in a year. In electricity tracking mode, because of the conversion efficiency, power supply quantity after regulation should greater than power supply before regulation. But in heat tracking mode, unused electricity from solar panel, fuel cell are greater than the energy loss of conversion efficiency.

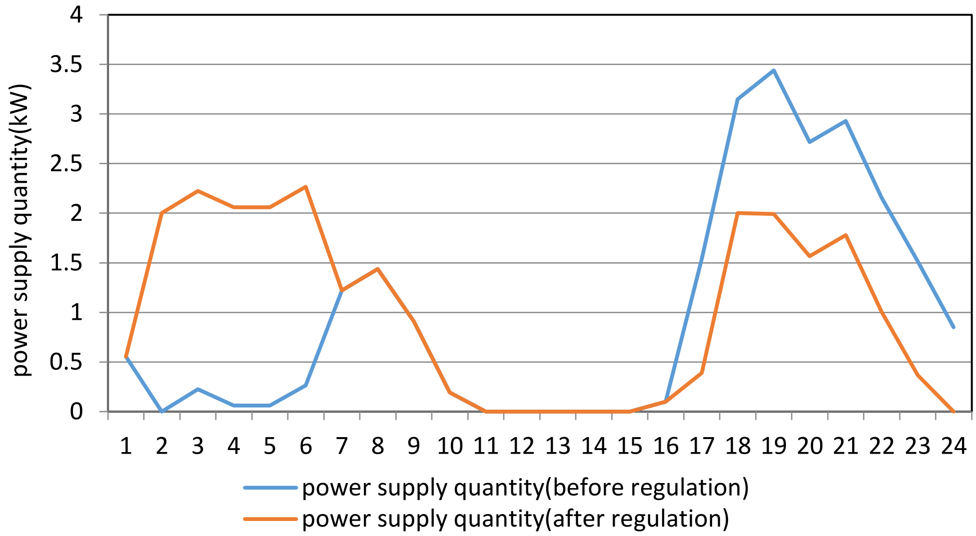


Figure 3-4-19 Change of storage batteries in a day (electricity tracking mode in winter period)

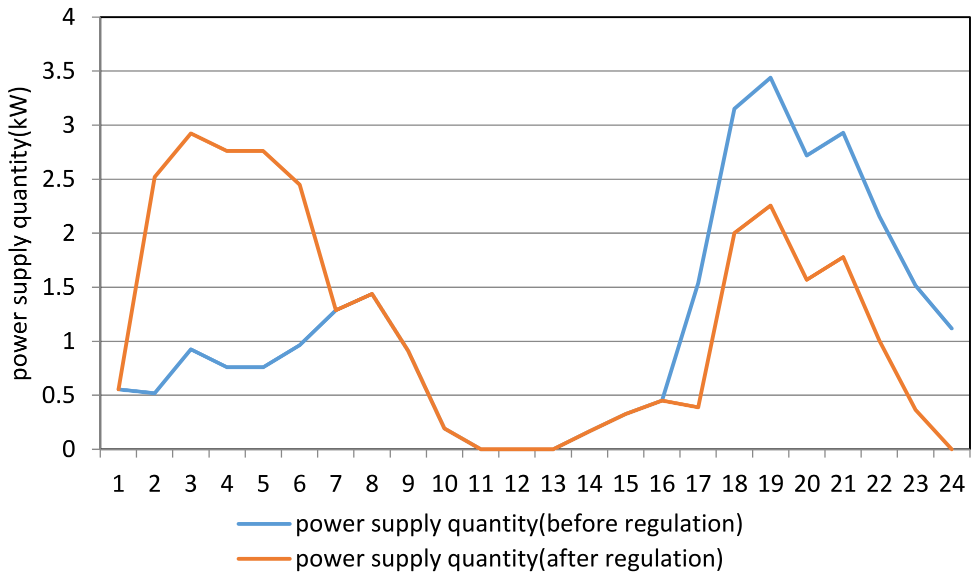


Figure 3-4-20 Change of storage batteries in a day (heat tracking mode in winter period)

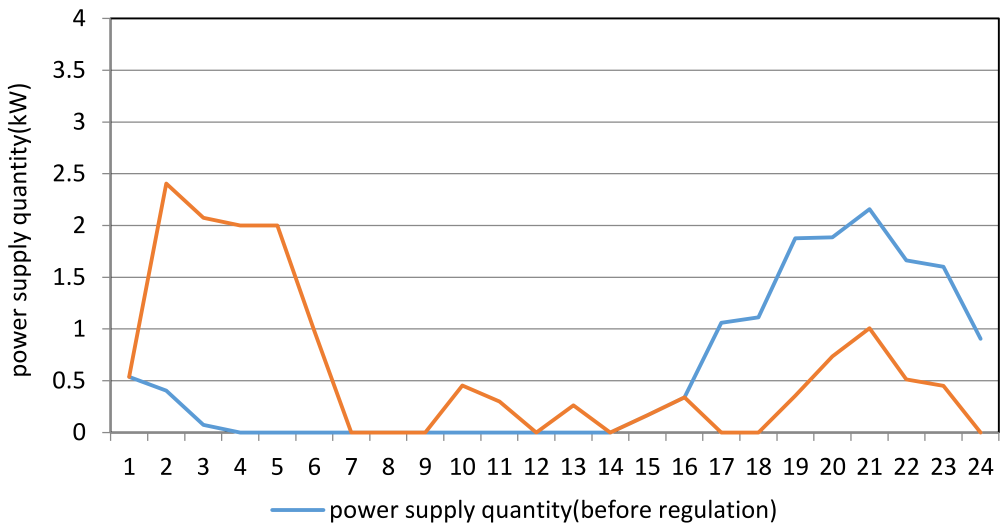


Figure 3-4-21 Change of storage batteries in a day (electricity tracking mode in summer period)

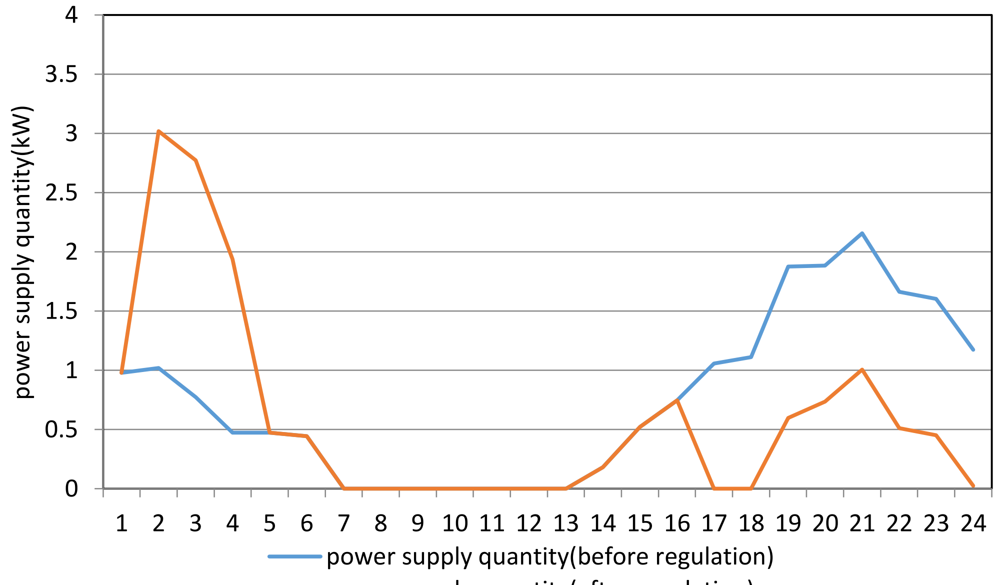


Figure 3-4-22 Change of storage batteries in a day (heat tracking mode in summer period)

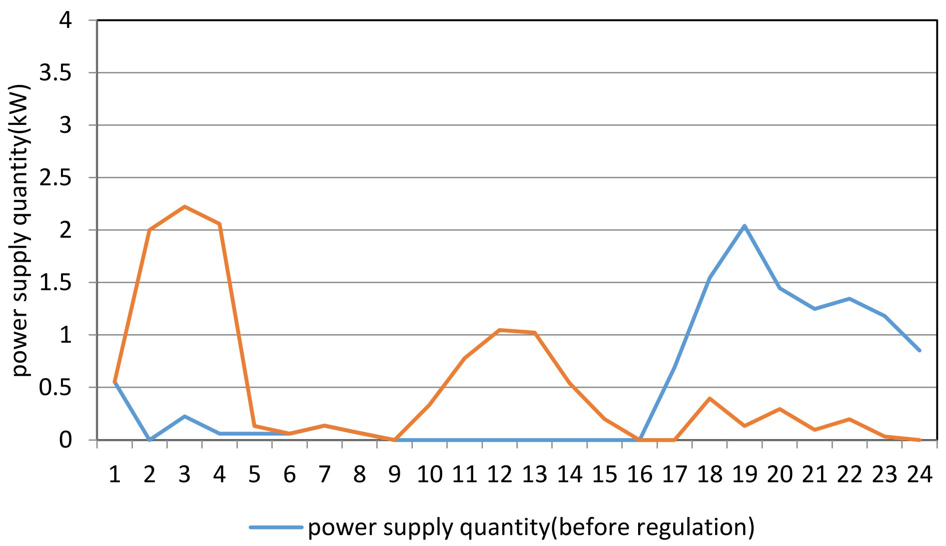


Figure 3-4-23 Change of storage batteries in a day (electricity tracking mode in interim period)

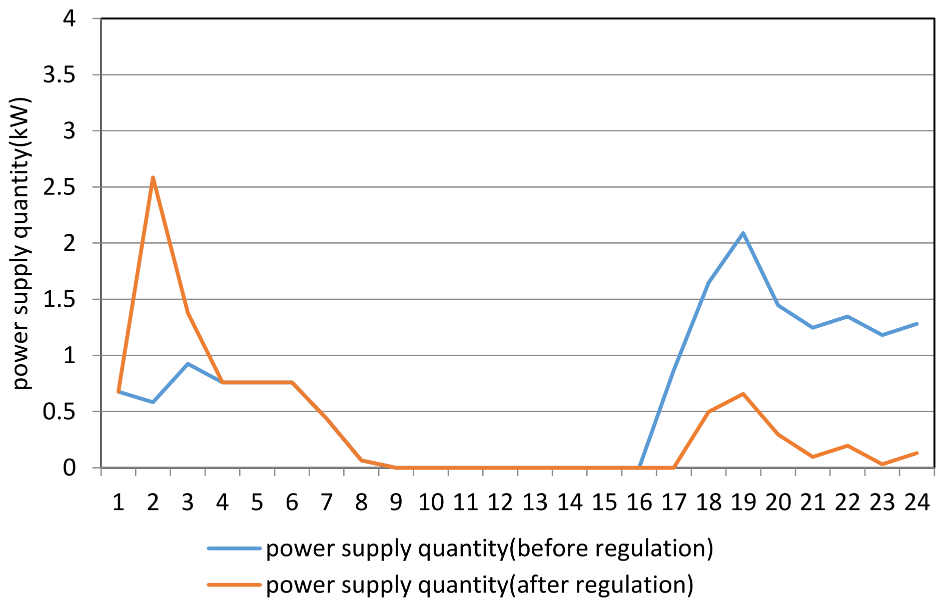


Figure 3-4-24 Change of storage batteries in a day (heat tracking mode in interim period)

From figure 3-4-19 to figure 3-4-24 show the change of storage batteries in one day. Both of electricity tracking mode and heat tracking mode can shave peak very well. Consider about the power supply quantity by regulation. In case 6, we should choose the heat tracking mode. It can make energy conservation, also can make peak cut.

CHAPTER FOUR

SENSITIVITY ANALYSIS OF POWER GENERATION CAPACITY IN THE RESIDENTIAL HOUSE

4.1 Introduction of method

The sensitivity analysis is that how to change index to reveal the effect of the final result. By sensitivity analysis can be used to quantify if the index changed, or unexpected benefits happened when the environment is changed. We can do specific preparation for the uncertain events.

We introduce photovoltaic (PV), gas fuel cell (FC) and hydrogen fuel cell (FH) in this house, analyze the annual cost and optimal introduction capacity of each power generation equipment by simulation. Also annual cost and optimal introduction capacity of each power generation equipment will be discussed by sensitivity analysis. Sensitivity analysis is a method to examine the influence trend of the annual cost, electricity price for optimal introduction capacity of each power generation equipment, electricity sales price, carbon tax, gas price and fluctuation of hydrogen price. Use sensitivity analysis to introduce photovoltaic (PV), gas fuel cell (FC), hydrogen fuel cell (FH) to make charts. In the figure, vertical axis is the annual cost, and horizontal axis is the introduction capacity of each power generation equipment. In addition, the optimal introduction capacity of each power generation equipment is the optimal introduction capacity on the vertical axis, and initial investment have a significant change on the horizontal axis. We assumed the case has economics that the value of optimal introduction capacity is greater than zero when the power generation equipment is introduced. We need to verify the economic impact of electricity price, electricity sales price, carbon tax, gas price and hydrogen price in each power generation equipment.

4.2 Calculation

Figure 4-2-1 shows the demand side (hourly heat, electricity load), fuel cost of this house (gas, electricity, hydrogen), distributed energy and heat source technology such as capacity, efficiency, investment cost, etc. are necessary to investigate and improve. We input investigate and improve data to analysis. Then we decide to carry out the analysis of any case. We consider about the balance and the constraints conditions of energy supply and demand, like power generation capacity, waste heat, and technology import quantity. We use modeling tool to optimize calculations to satisfy the condition of the determined model, minimize the annual cost in the programming. And the determined information to output, optimal capacity, optimum operation pattern and get the results of energy conservation, economic and the environment.

Objective function in running costs of power generation facilities lead to increase the initial cost of the power generation facilities. The formula is represented as following.

Annual cost min =power generation*heat source equipment running cost + power generation*heat source equipment annual recurring fee.

Annual recurring fee is the most convenient index to evaluate the effects of long-term economic effect. Initial costs convert include per year expense to compare with traditional systems. In other words, we also need to consider about the useful life and

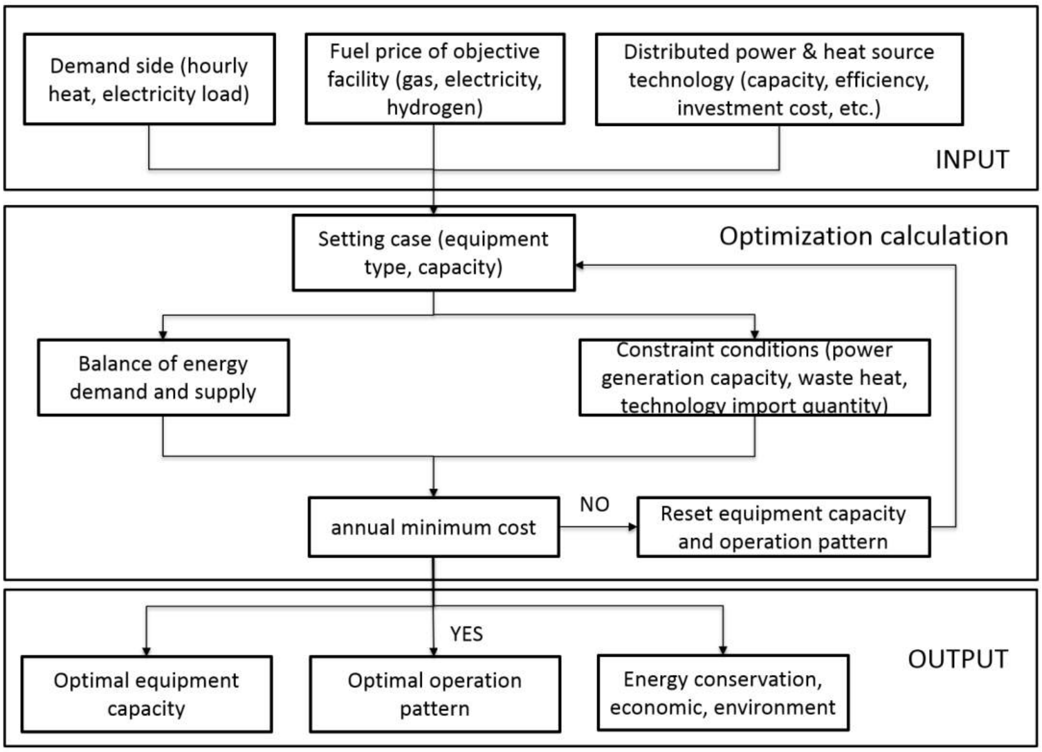


Figure 4-2-1 Model calculation flows

interest rates of initial cost. Fixed costs as converted to the amount each year and increase the variable costs (running cost), represented as following equation.

Annual recurring fee = variable cost + fixed cost

Fixed cost= equipment cost + fixed ratio

Fixed ratio= {interest (1+interest) $^{\text{useful life}}$ / (1+interest) $^{\text{useful life}}$-1}

As following are the constraint conditions 1~4

(1) Power demand balance in each time

Electricity demand is gross power facility output plus purchase electricity power subtract sold electricity power. The formula is represented as following.

Electricity demand = gross power facility output + purchase electricity power - sold electricity power

(2) Heat demand balance in each time

Heat demand less than or equal to gross heat facility output plus heat source equipment output. The formula is represented as following.

Heat demand ≤ gross heat facility output + heat source equipment output

(3) Limitation of contract power

Contract power greater than or equal to purchase electricity power. The formula is represented as following.

Contract power ≥ purchase electricity power

(4) Limitation of contract gas

Contract gas greater than or equal to gas consumption of power generation・heat resource equipment. The formula is represented as following.

Contract gas ≥ gas consumption of power generation・heat resource equipment

(5) Limitation of power generation amount of power generation facility

Heat rejection in each time less than or equal to capacity of power generation equipment times heat recovery efficiency. The formula is represented as following.

Heat rejection ≤ capacity of power generation equipment × heat recovery efficiency

4.3 Setting cases and load calculation

We use the detached house as the model, it is analyzed as an object in Fukuoka, Kitakyushu Yahata higashi-ku, higashida 2-2-6. The floor area of this building is 183.42 m^2.

The model of energy system is shown in figure 3-1. Electricity (EL), air conditioner (AC) purchase the electricity from the power grid (UG), and the solar photovoltaic will be sold to UG. Gas fuel cell (FC), gas boiler (GB) purchase the gas from the city gas (CG), FC or hydrogen fuel cell (FH) will be sold to UG. Cooling load (CL) and heating load (HL) is supplied by the AC. FC and FH through the heat exchanger (HE) to be used by water heating load (WL). In addition, the maximum capacity of PV, FC and FH is 3kW. Set up models for each case are shown as following.

Case 1: introduce PV to conventional system

Case 2: introduce FC to conventional system

Case 3: introduce FH to conventional system

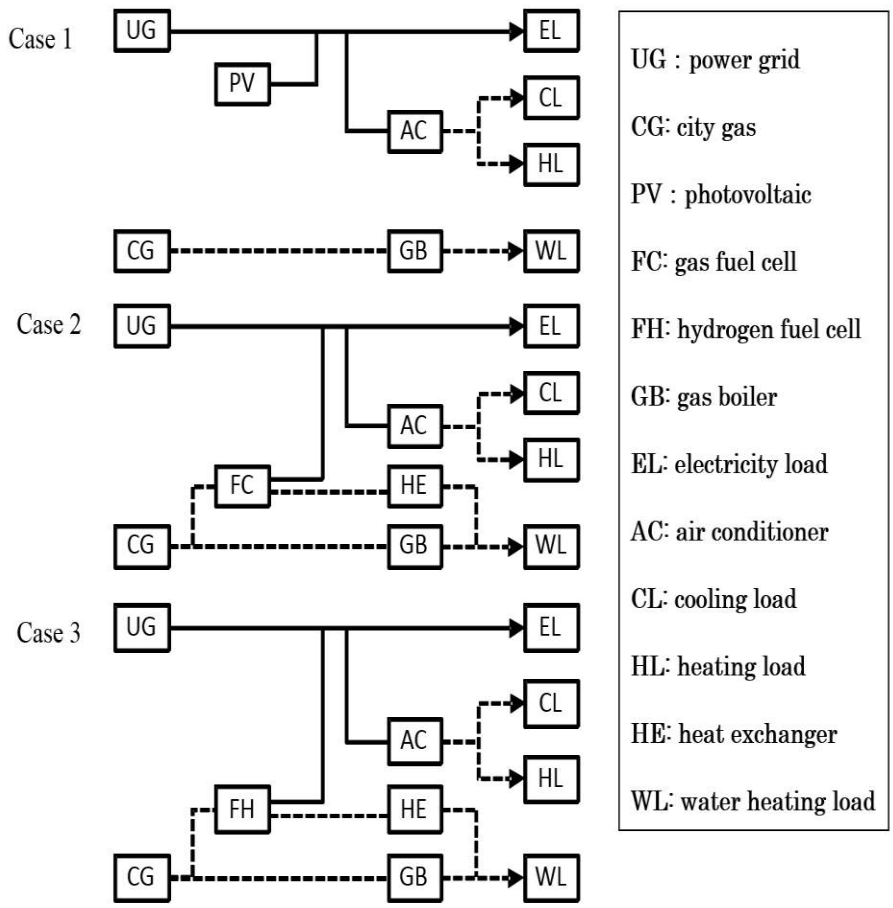


Figure 4-3-1 Energy system configuration

4.3.1 Energy load and equipment selection

We analyze heating, cooling, hot water and electricity load of the research objective house in seasonal each moment. Heating, cooling, hot water and electricity load in each moment is calculated by original unit. Figure 4-3-2 shows hourly load of month weekday time in winter (February), figure 4-3-3 shows hourly load of month weekday time in summer (August), figure 4-3-4 shows hourly load of month weekday time in interim period (October). From the figure shows that the fluctuation of heating load and water heating load is greater than general electricity load in each hour. We can know that the peak of heat load and electricity load are occurred at different time. And peak generation of heat load and electricity load is from 18 to 23. Compare with summer and interim period, the energy load in winter is much larger than them.

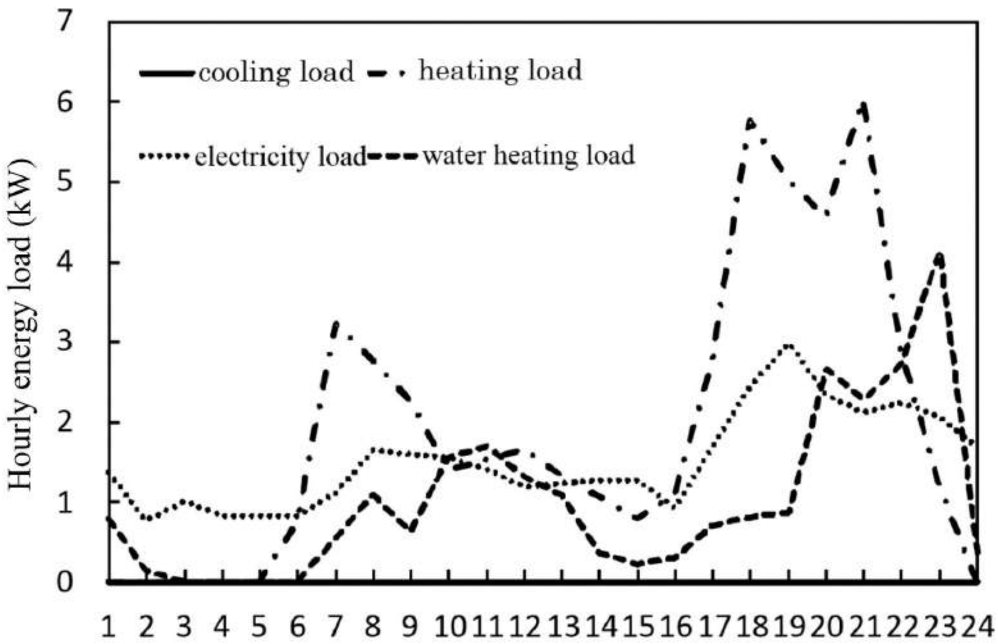


Figure 4-3-2 Hourly load curve in weekday of February

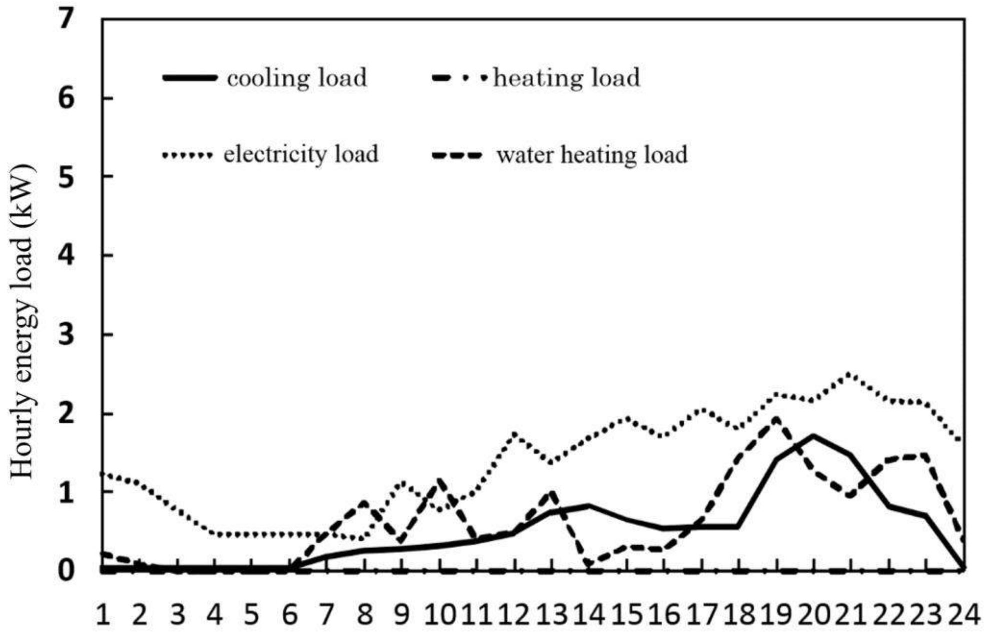


Figure 4-3-3 Hourly load curve in weekday of August

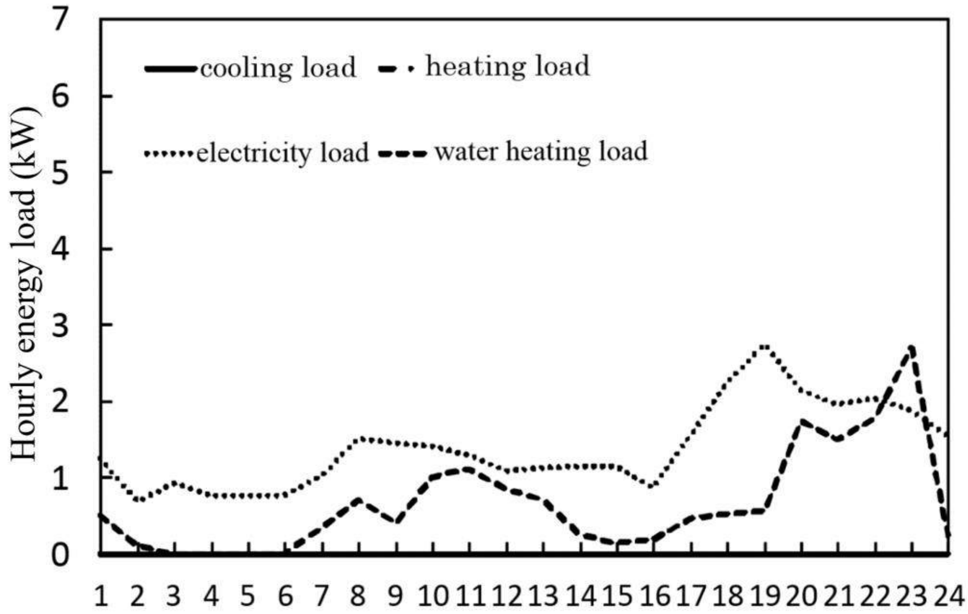


Figure 4-3-4 Hourly load curve in weekday of October

Table 4-3-1 shows the capacity of power generation facilities, power generation efficiency, heat recovery rate and initial investment of research object. Table 4-3-2 shows the heat supply capacity, COP, initial investment of heat source equipment. Introduce PV, FC and FH in the power generation equipment respectively. Introduce air conditioner, gas boiler and heat exchanger in heat resource equipment.

Table 4-3-1 Data of power generation equipment

power generation equipment	capacity(kW)	power generation efficiency(%)	heat recovery rate(%)	initial investment(10T/kW)	lifetime(year)
PV	0～3	14	/	60	20
FC	0～3	36	50	260	15
FH	0～3	48	42	260	15

Table 4-3-2 Data of heat resource equipment

heat resource equipment	supply capacity(kW)		COP		initial investment(10T/kW)
	cooling	heating	cooling	heating	
AC	7	7	4.5	4.5	1.8
GB	/	4.5	/	0.9	1.5
HE	/	5	/	0.9	1

Table 4-3-3, 4-3-4, 4-3-5 shows the energy charge in the research object of residence, electricity sales price, the conversion factor between calorific value and CO_2 emissions in Kitakyushu area.

Table 4-3-3 Energy charge

	Cost structure	price
Electricity	Basic charge	1134 yen/M
	Usage-based charge	20 nen/kWh
Gas	Basic charge	1501.5 yen /M
	Usage-based charge	198.52 yen /m^3
Hydrogen	Usage-based charge	80 yen /m^3

Table 4-3-4 Electricity sales price

Electricity sales price of PV	Ordinary	Purchase price
		42 nen/kWh
Electricity sales price of FC,FH	Season classification・time interval	Purchase price
	Summer daytime	7.5 yen /kWh
	Other season daytime	6.6 nen/kWh
	Night	3.6 nen/kWh

Table 4-3-5 Conversion factor between calorific value and CO_2 emissions in Kitakyushu area

	conversion factor of calorific value	conversion factor of CO_2 emissions
Electricity	9.97MJ/kWh	0.69kg/kWh
Gas	45MJ/m^3	2.26kg/m^3
Hydrogen	12.79MJ/ m^3	/

4.4 Influence factor

Figure 4-4-1 shows the annual cost of PV when the electricity price fluctuate. From this figure we can know when the electricity price of PV fluctuate, the way of annual cost change like a straight line, all lines form almost same trend shape graph. From this graph, introduction capacity of PV become large, we can see the annual cost will decrease by degrees of electricity charge.

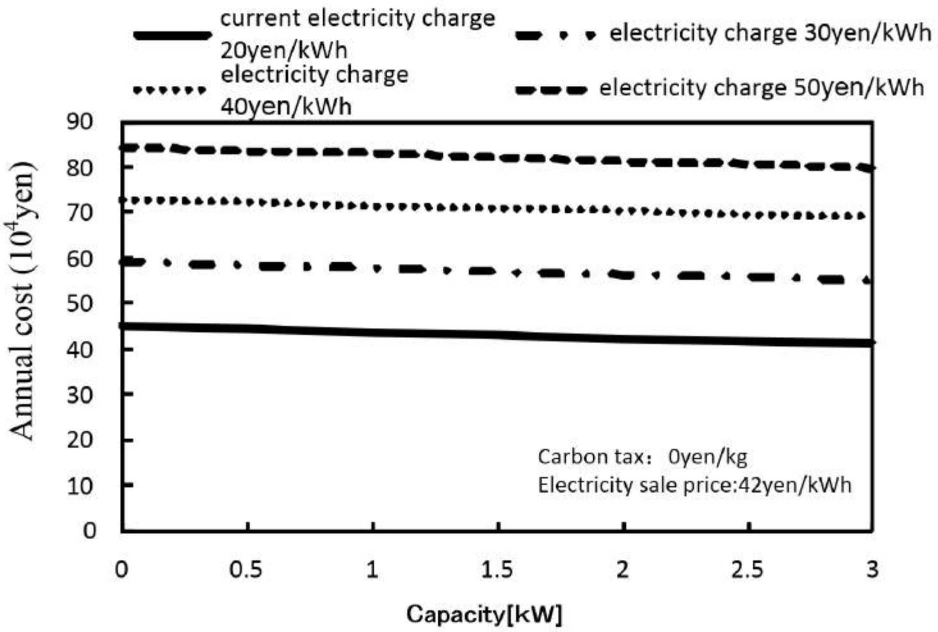


Figure 4-4-1 Annual cost of PV with capacity at the different electricity charge

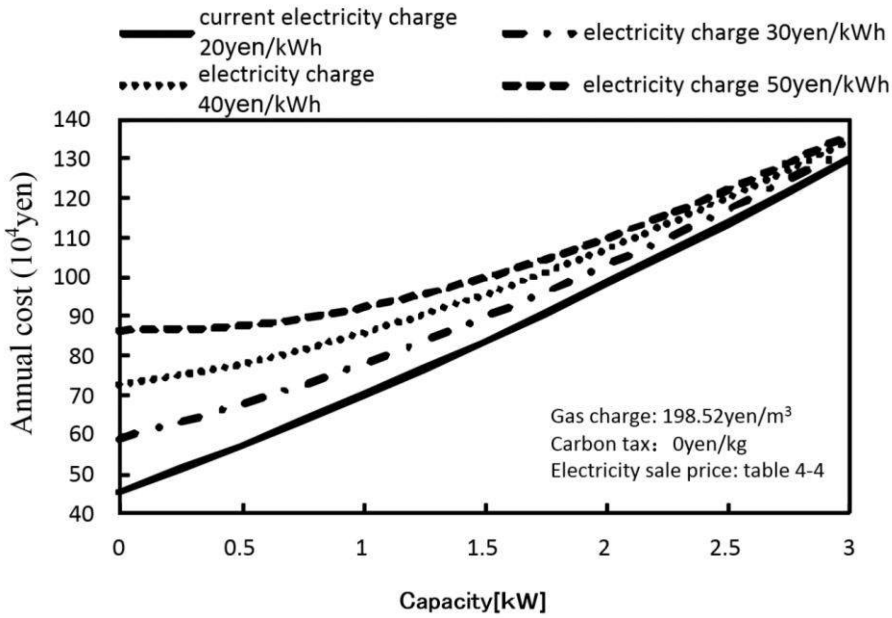


Figure 4-4-2 Annual cost of FC with capacity at the different electricity charge

Figure 4-4-2 shows the annual cost of FC when the electricity price fluctuate. From figure 4-4-2 we can know when the electricity price of FC fluctuate, the annual cost of PV is not like a straight line but the initial curve gradually approaching the straight line. From this graph, when introduction capacity of FC become large, we can see the annual cost will increase by degrees of electricity charge.

Figure 4-4-3 shows the annual cost of FH when the electricity price fluctuate. From this figure, the shape is almost like FC's graph.

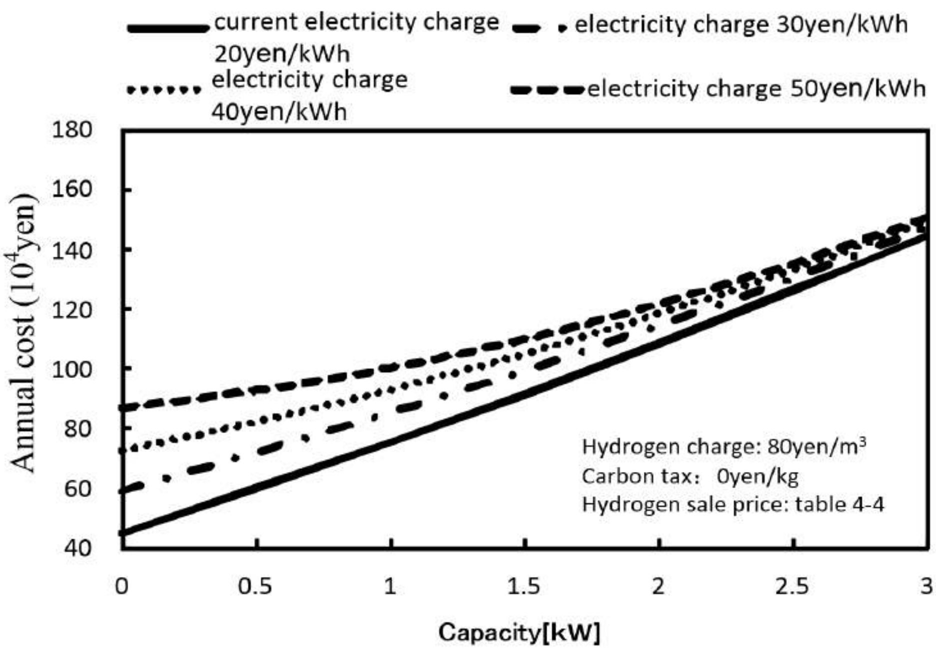


Figure 4-4-3 Annual cost of FH with capacity at the different electricity charge

Figure 4-4-4 shows the annual cost of PV when the electricity sales price fluctuate. From this figure we can know the situation of the electricity price of PV fluctuate. When the electricity sales price become 0 yen/kg and 20 yen/kg, the introduction capacity also become large and annual cost will rise up, almost become as annual cost.

Figure 4-4-5 shows the annual cost of FC when the electricity sales price fluctuate. From figure 4-4-5 we can know when the electricity sales price increase, the growth rate of annual cost will go down. However, when the introduction capacity become large, annual cost will rise up.

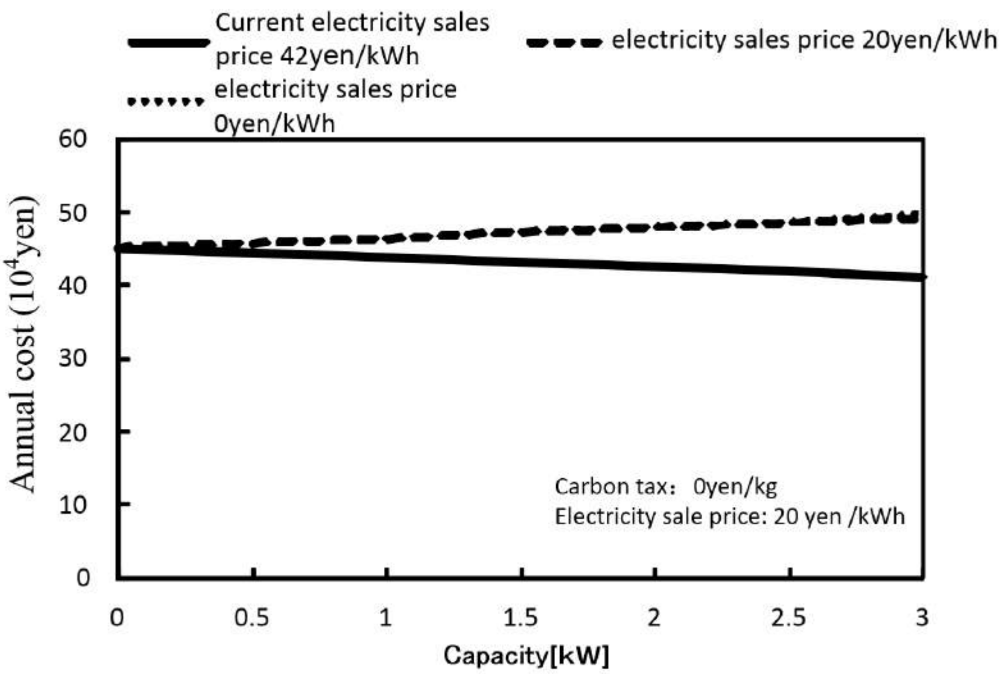


Figure 4-4-4 Annual cost of PV with capacity at the different electricity sales price

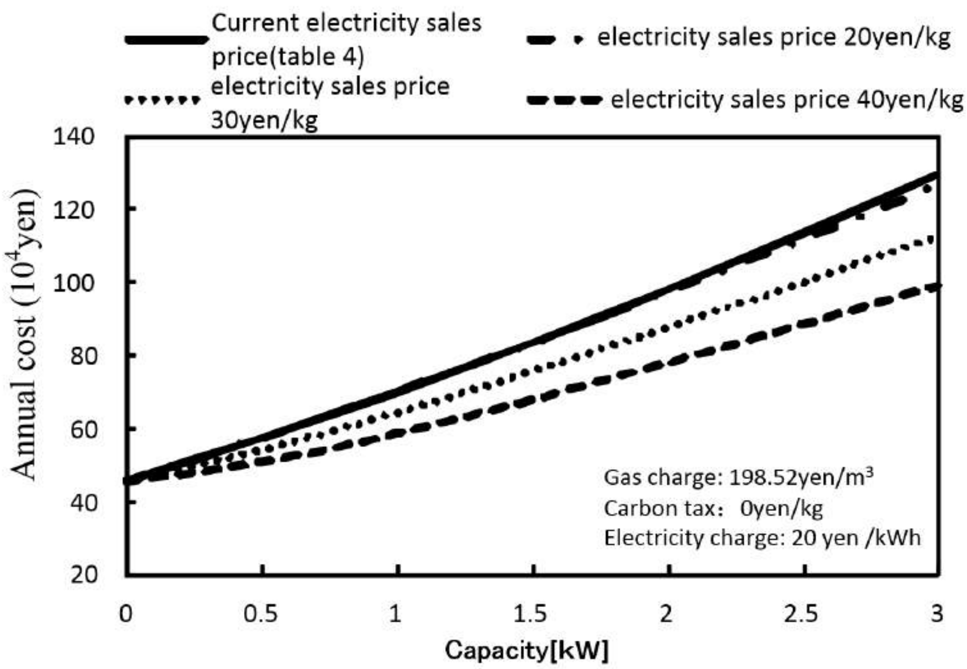


Figure 4-4-5 Annual cost of FC with capacity at the different electricity sales price

Figure 4-4-6 shows the annual cost of FH when the electricity sales price fluctuate. From figure 4-4-6, FH is almost the same shape with the figure of FC.

Figure 4-4-7 shows the annual cost of PV when the carbon tax fluctuate. From figure 4-4-7, we can know when the carbon tax increase, the annual cost will rise up too. Also, the annual cost will go down when the introduction capacity become large.

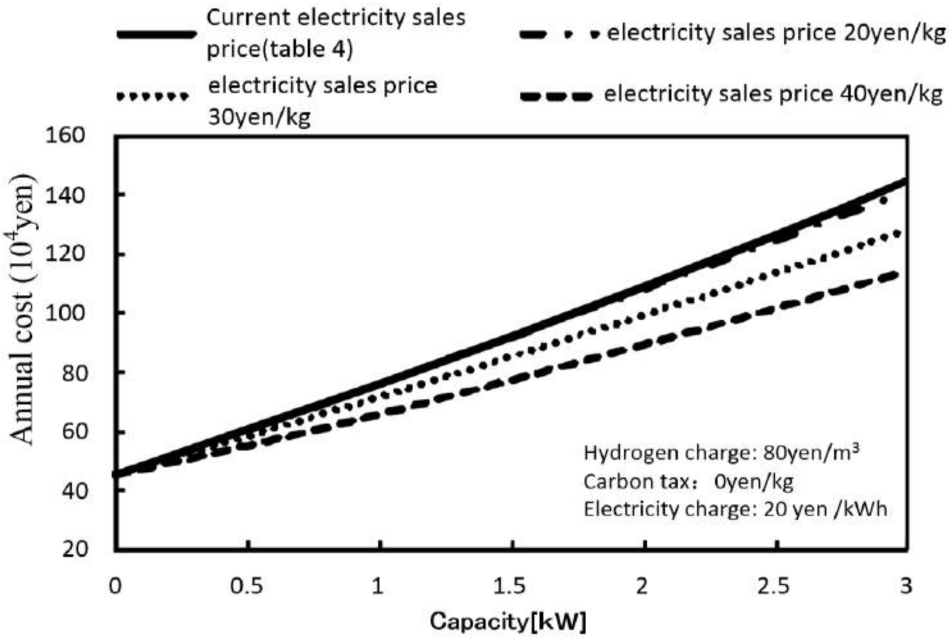


Figure 4-4-6 Annual cost of FH with capacity at the different electricity sales price

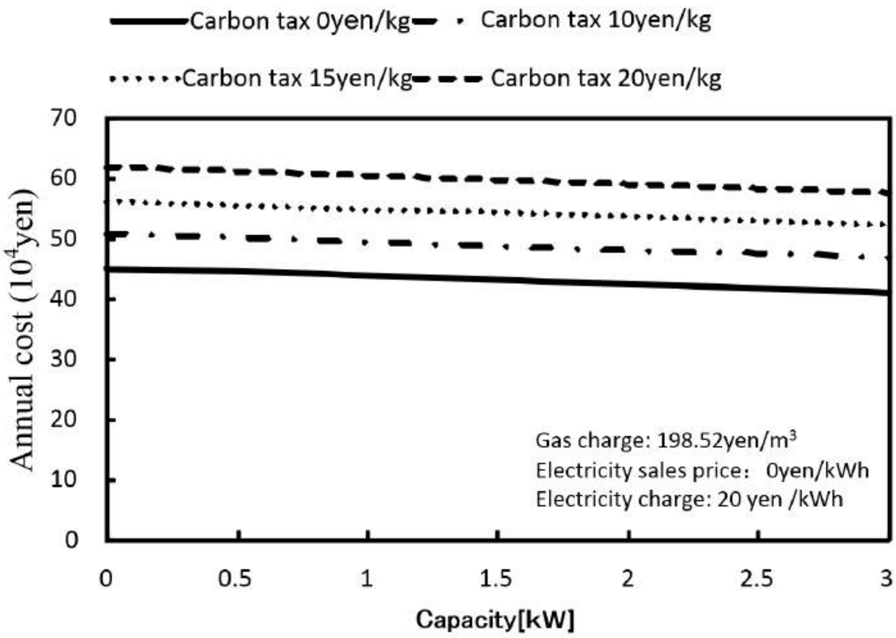


Figure 4-4-7 Annual cost of PV with capacity at the different carbon tax

Figure 4-4-8 shows the annual cost of FC when the carbon tax fluctuate. From figure 4-4-8 we can know when the carbon tax as PV increase, the annual cost will rise up. In addition, the annual cost will rise up when the introduction capacity become large.

Figure 4-4-9 shows the annual cost of FH when the carbon tax fluctuate. From figure 4-4-9, the graph of FH is almost similar shape with FC.

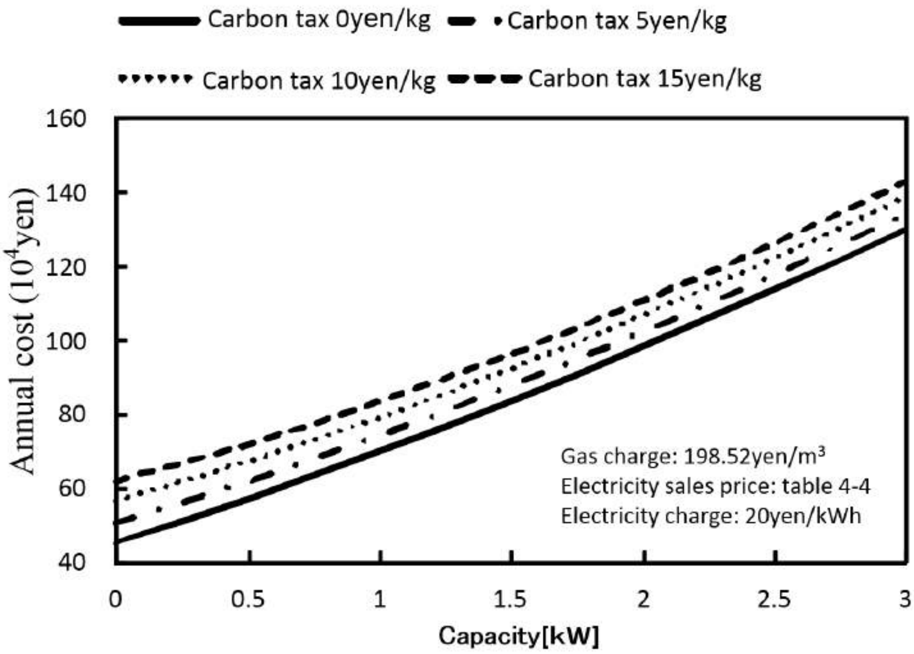


Figure 4-4-8 Annual cost of FC with capacity at the different carbon tax

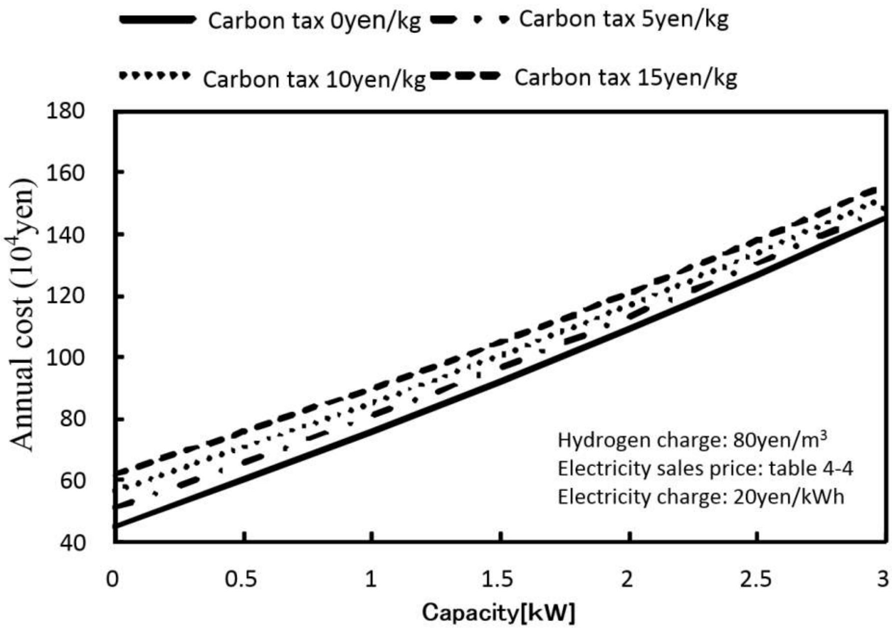


Figure 4-4-9 Annual cost of FH with capacity at the different carbon tax

Figure 4-4-10 shows the annual cost graph of FC when the carbon tax fluctuate. From figure 4-4-10, the annual cost will descend when the gas charge of FC goes down. In addition, the annual cost will increase when the introduction capacity rise up.

Figure 4-4-11 shows the annual cost graph of FH when the hydrogen price fluctuates. From this figure we can know the annual cost will descend when the hydrogen price of FH goes down. In addition, the annual cost will increase when the introduction capacity rise up.

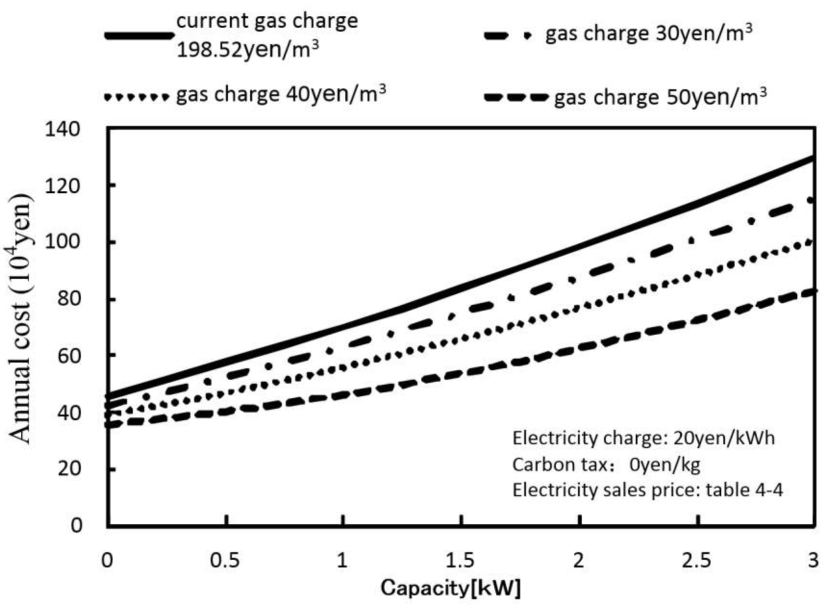


Figure 4-4-10 Annual cost of FC with capacity at the different gas charge

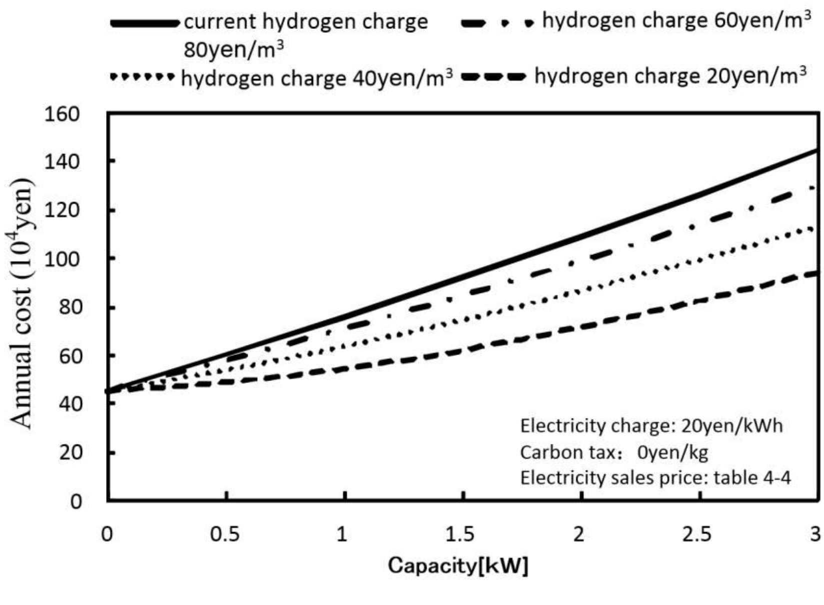


Figure 4-4-11 Annual cost of FH with capacity at the different hydrogen charge

From figure 4-4-12 of annual cost graph, if we introduce the PV which current electricity sales price is 42 yen/kWh. We analyze the prediction economic, we can know the optimal introduction capacity of PV when the electricity sales price reaches 0 yen /kWh.

Figure 4-4-12 shows the economic impact of PV when the electricity charge fluctuate. From the graph of figure 4-4-12, when the current electricity charge of PV reaches 20 yen/kWh, PV have introduction effect when the initial investment reaches 350000 yen/kW. If the electricity charge reaches 30 yen/kWh, PV have introduction effect when the initial investment reaches 550000 yen/kW. If the electricity charge reaches 40 yen/kWh, PV have introduction effect when the initial investment reaches 60 0000 yen/kW.

Figure 4-4-13 shows the economic impact of FC when the electricity charge fluctuate. From the graph of figure 4-2-13, when the electricity charge of FC reaches 30 yen/kWh, FC have introduction effect when the initial investment reaches 400000 yen/kW. If the electricity charge reaches 40 yen/kWh, FC have introduction effect when the initial investment reaches 1600000 yen/kW. If the electricity charge reaches 50 yen/kWh, FC have introduction effect when the initial investment reaches 2600000 yen/kW.

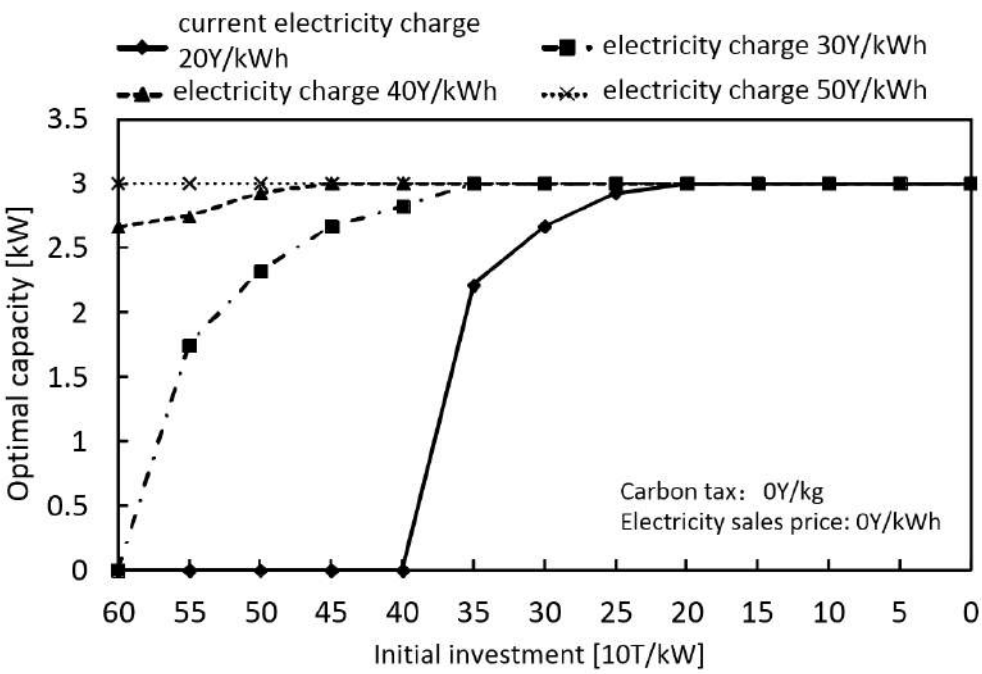


Figure 4-4-12 Optimal introduction capacity of PV at the different electricity charge

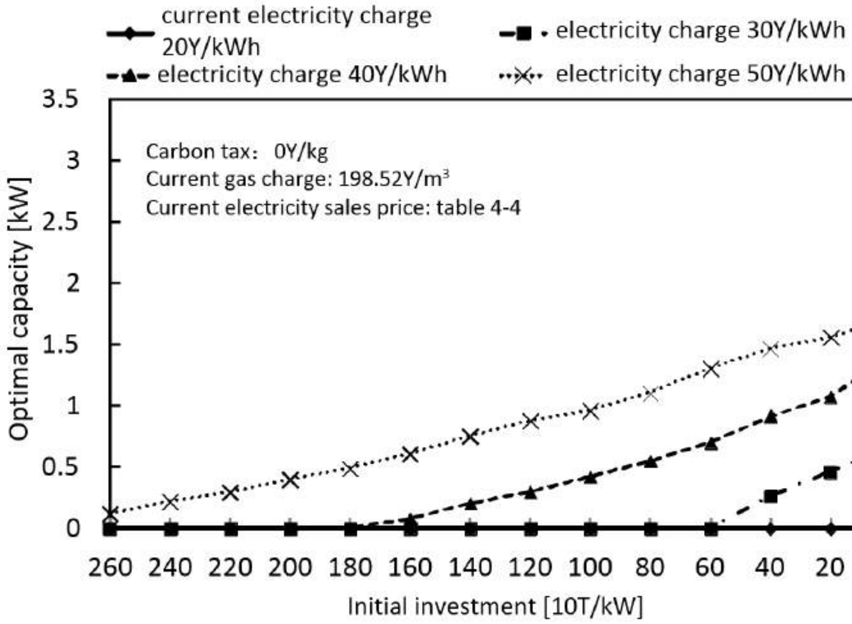


Figure 4-4-13 Optimal introduction capacity of FC at the different electricity charge

Figure 4-4-14 shows the economic impact of FH when the electricity sales price fluctuate. From the graph of figure 4-4-14, when the electricity charge of FH reaches 40 yen/kWh, FH have introduction effect when the initial investment reaches 400000 yen/kW. If the electricity charge reaches 50 yen/kWh, FH have introduction effect when the initial investment reaches 1800000 yen/kW.

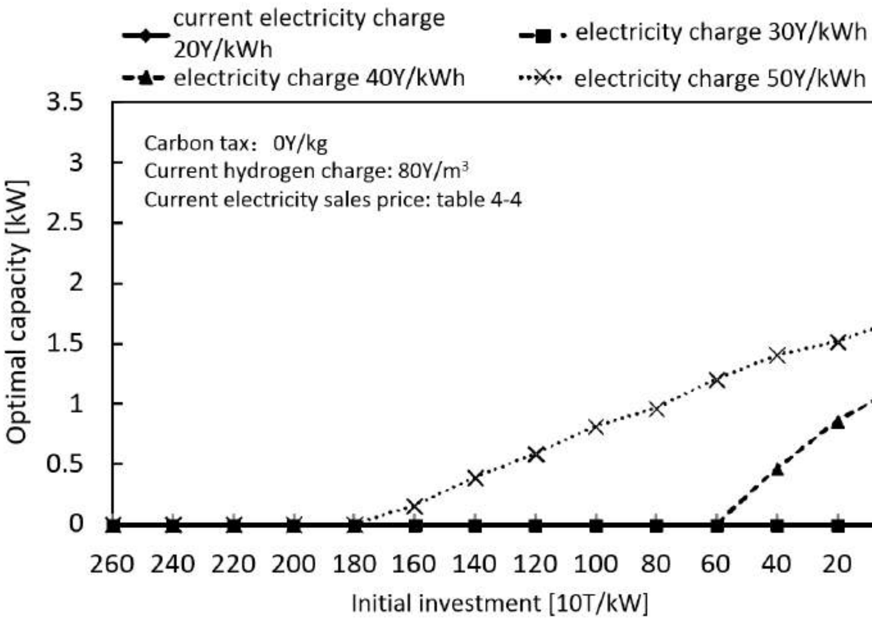


Figure 4-4-14 Optimal introduction capacity of FH at the different electricity charge

Figure 4-4-15 shows the economic impact of PV when the electricity sales price fluctuate. From the graph of figure 5-15, when the electricity sales price of PV reaches 0 yen/kWh, PV have introduction effect when the initial investment reaches 350000 yen/kW.

Figure 4-4-16 shows the economic impact of FC when the electricity sales price fluctuate. From the graph of figure 5-16, when the electricity sales price of FC reaches 40 yen/kWh, FC have introduction effect when the initial investment reaches 1600000 yen/kW. If the electricity charge reaches 60 yen/kWh, FC have introduction effect when the initial investment reaches 2600000 yen/kW.

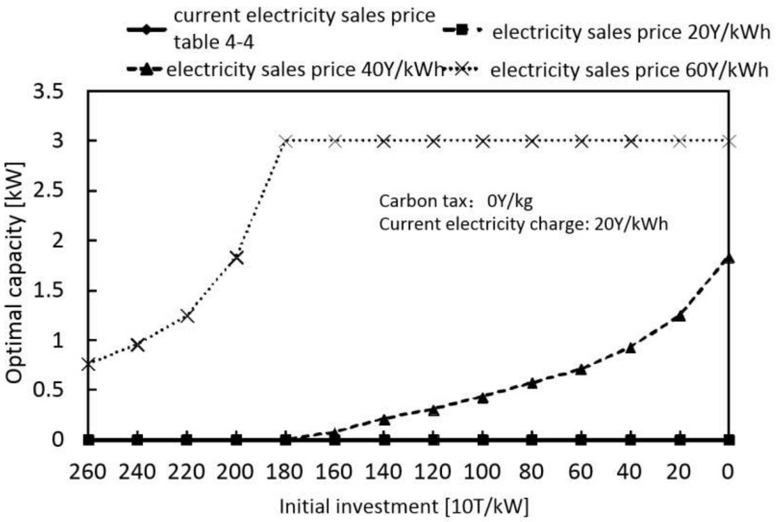


Figure 4-4-15 Optimal introduction capacity of PV at the different electricity sales price

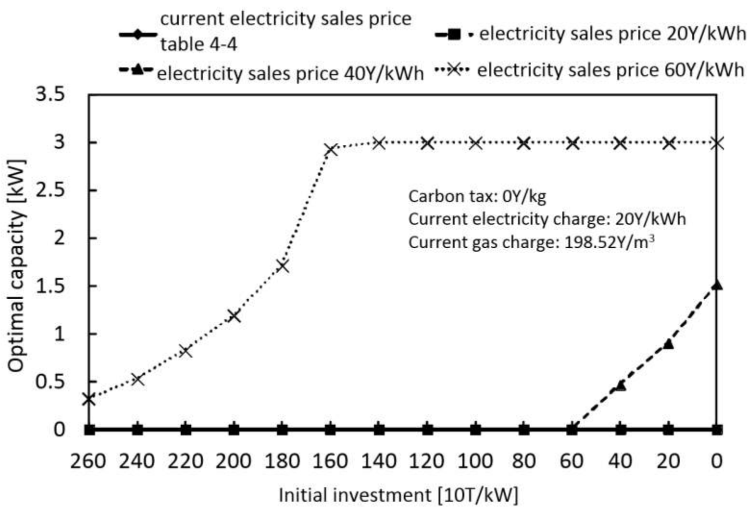


Figure 4-4-16 Optimal introduction capacity of FC at the different electricity sales price

Figure 4-4-17 shows the economic impact of FH when the electricity sales price fluctuate. From the graph of figure 4-4-17, when the electricity sales price of FH reaches 40 yen/kWh, FH have introduction effect when the initial investment reaches 400000 yen/kW. If the electricity charge reaches 60 yen/kWh, FH have introduction effect when the initial investment reaches 2600000 yen/kW.

Figure 4-4-18 shows the economic impact of PV when the carbon tax fluctuate. From the graph of figure 4-4-18, when the carbon tax of PV reaches 0 yen/kg, PV have introduction effect when the initial investment reaches 350000 yen/kW. If the carbon tax reaches 10 yen/kg, PV have introduction effect when the initial investment reaches 500000 yen/kW. If the carbon tax reaches 20 yen/kg, PV have introduction effect when the initial investment reaches 600000 yen/kW.

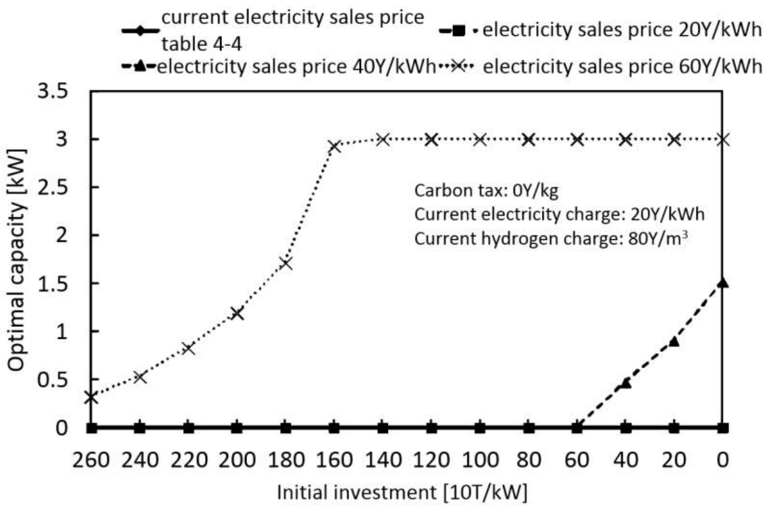


Figure 4-4-17 Optimal introduction capacity of FH at the different electricity sales price

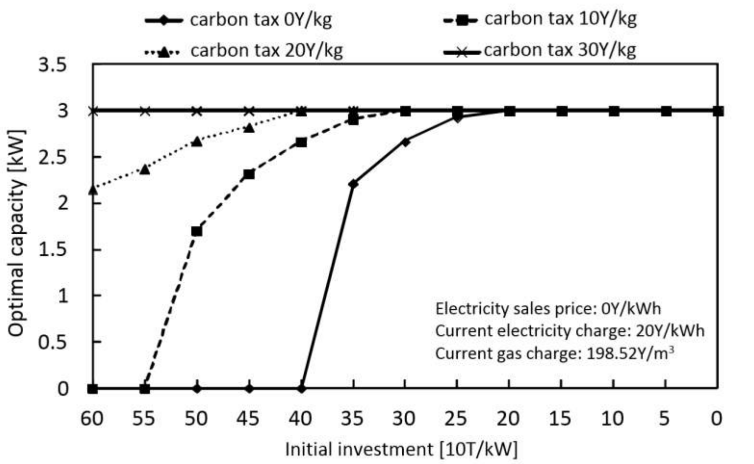


Figure 4-4-18 Optimal introduction capacity of PV at the different carbon tax

Figure 4-4-19 shows the economic impact of FC when the carbon tax fluctuate. From the graph of figure 4-4-19, when the carbon tax of FC reaches 50 yen/kg, FC have introduction effect when the initial investment reaches 1800000 yen/kW. If the carbon tax reaches 100 yen/kg, FC have introduction effect when the initial investment reaches 2600000 yen/kW.

Figure 4-4-20 shows the economic impact of FH when the carbon tax fluctuate. From the graph of figure 4-4-20, when the carbon tax of FH reaches 50 yen/kg, FH have introduction effect when the initial investment reaches 1000000 yen/kW. If the carbon tax reaches 100 yen/kg, FH have introduction effect when the initial investment reaches 2600000 yen/kW.

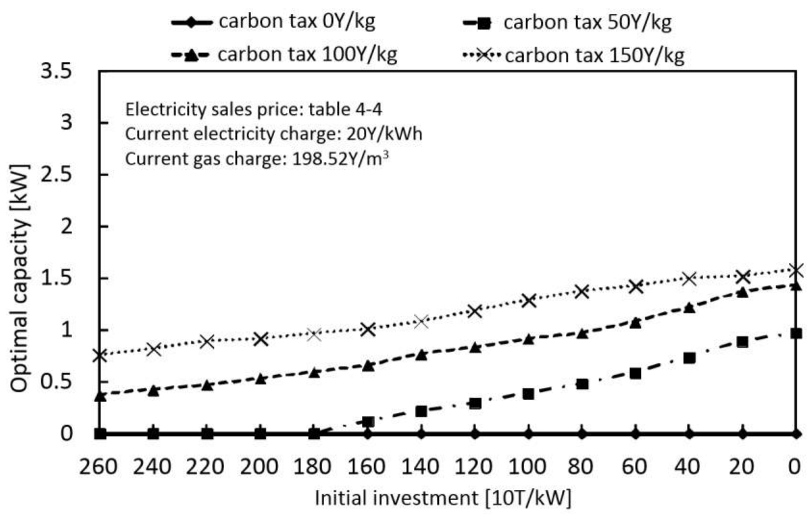


Figure 4-4-19 Optimal introduction capacity of FC at the different carbon tax

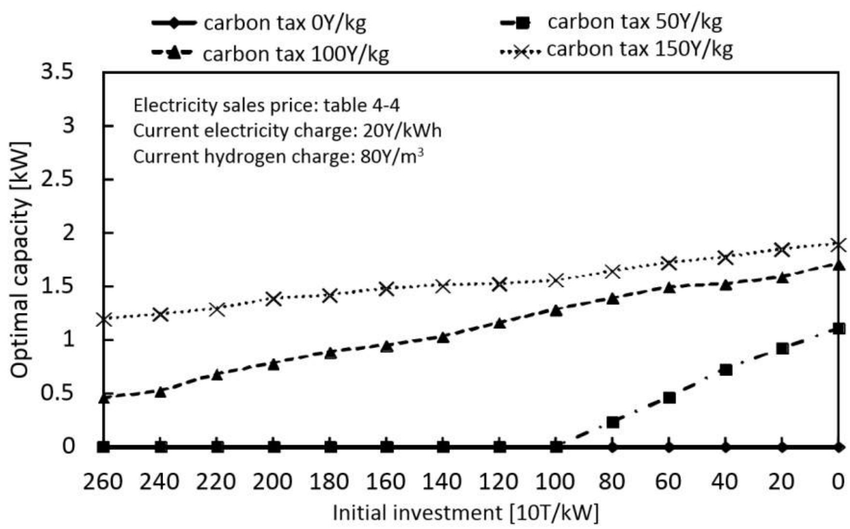


Figure 4-4-20 Optimal introduction capacity of FH at the different carbon tax

Figure 4-4-21 shows the economic impact of FC when the gas charge fluctuate. From the graph of figure 4-4-21, when the gas charge of FC reaches 150 yen/m^3, FC have introduction effect when the initial investment reaches 0 yen/kW. If the gas charge reaches 100 yen/m^3, FC have introduction effect when the initial investment reaches 600000 yen/kW. If the gas charge reaches 50 yen/m^3, FC have introduction effect when the initial investment reaches 1400000 yen/kW.

Figure 4-4-22 shows the economic impact of FH when the hydrogen charge fluctuate. From the graph of figure 4-4-22, when the hydrogen charge of FH reaches 40 yen/m^3, FH have introduction effect when the initial investment reaches 800000yen/kW. If the hydrogen charge reaches 20 yen/m^3, FH have introduction effect when the initial investment reaches 2200000 yen/kW.

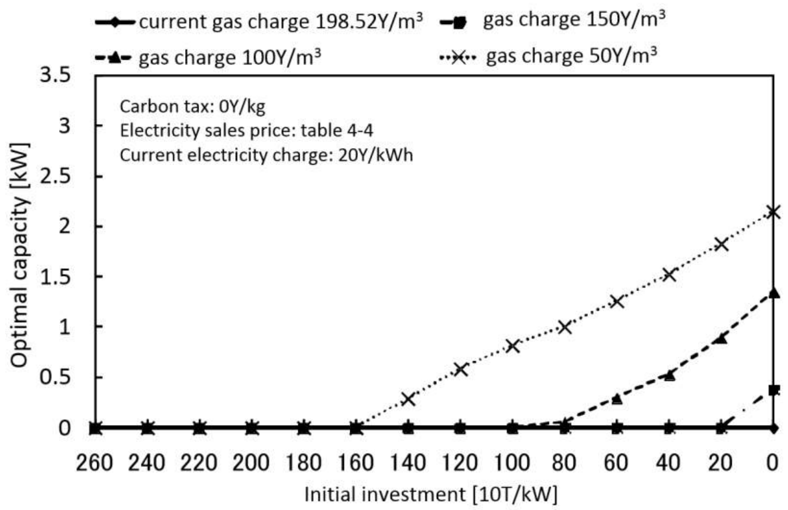


Figure 4-4-21 Optimal introduction capacity of FC at the different gas charge

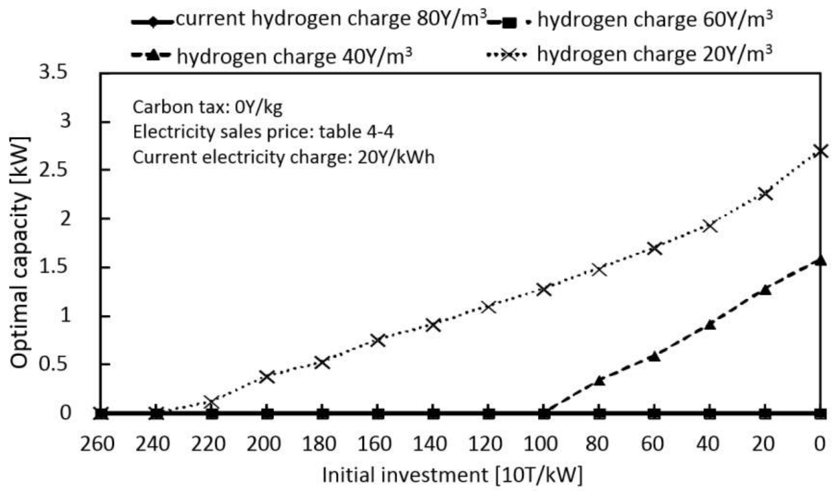


Figure 4-4-22 Optimal introduction capacity of FH at the different hydrogen charge

4.5 Influence analysis

In this study, we introduce power generation equipment include photovoltaic cell, gas fuel cell and hydrogen fuel cell to analyze the different economic relationship. As factors related to the economy, we adopt electricity charge, gas charge, electricity sales price, initial investment, carbon tax and hydrogen charge. As analysis results, the shape of graph between FC and FH are similar, and FH has high environmental and economics. The summary of analysis results is shown as following.

1) Electricity charge summary

If the electricity charge of PV reaches 40 yen/kWh, the electricity charge of FC goes up to 50 yen/kWh, and we can forecast that current initial investment also has economics. When the electricity charge goes up to 50 yen/kWh, we cannot forecast that current initial investment has economics. If the initial investment goes down to 1600000 yen/kW, we can forecast the economics.

2) Electricity sales price summary

If the current electricity sales price reaches 42 yen/kWh, we can forecast that current initial investment has sufficiently economics. However, the electricity sales price of FC and FH are too cheap, if the electricity sales price goes up to 60 yen/kWh, current initial investment do not has economic.

3) Carbon tax summary

Carbon tax of PV is 20 yen/kg, if the carbon tax of FC and FH go up to 100 yen/kg, we can forecast that current initial investment has economics.

4) Gas charge summary

Gas charge can only affect FC, gas charge reaches 50 yen/m^3, and we can forecast that current initial investment has economics. It also has economics if the initial investment goes down to 1400000 yen/kW.

5) Hydrogen charge summary

Hydrogen charge can only affect FC, Hydrogen charge reaches 20 yen/m^3, and we can forecast that current initial investment has economics. It also has economics if the initial investment goes down to 220 yen/kW.

According to summary, we can find that as following

If we introduce the PV, we can forecast that it has economics.

If we introduce the FC, we can forecast that it almost do not have economics.

FH can have highly effective environmental and energy conservation, the economics figure of FH is harder to understand than FC.

CHAPTER FIVE

DEVELOPING AN ENERGY INFRASTRUCTURE WITH THE DISTRIBUTED ENERGY RESOURCE IN JONO AREA

5.1 Structure of the plan objective and database

5.1.1 Plan objective

The construction plan area is "Low carbon advanced model block", and the area of this block is 18 ha.

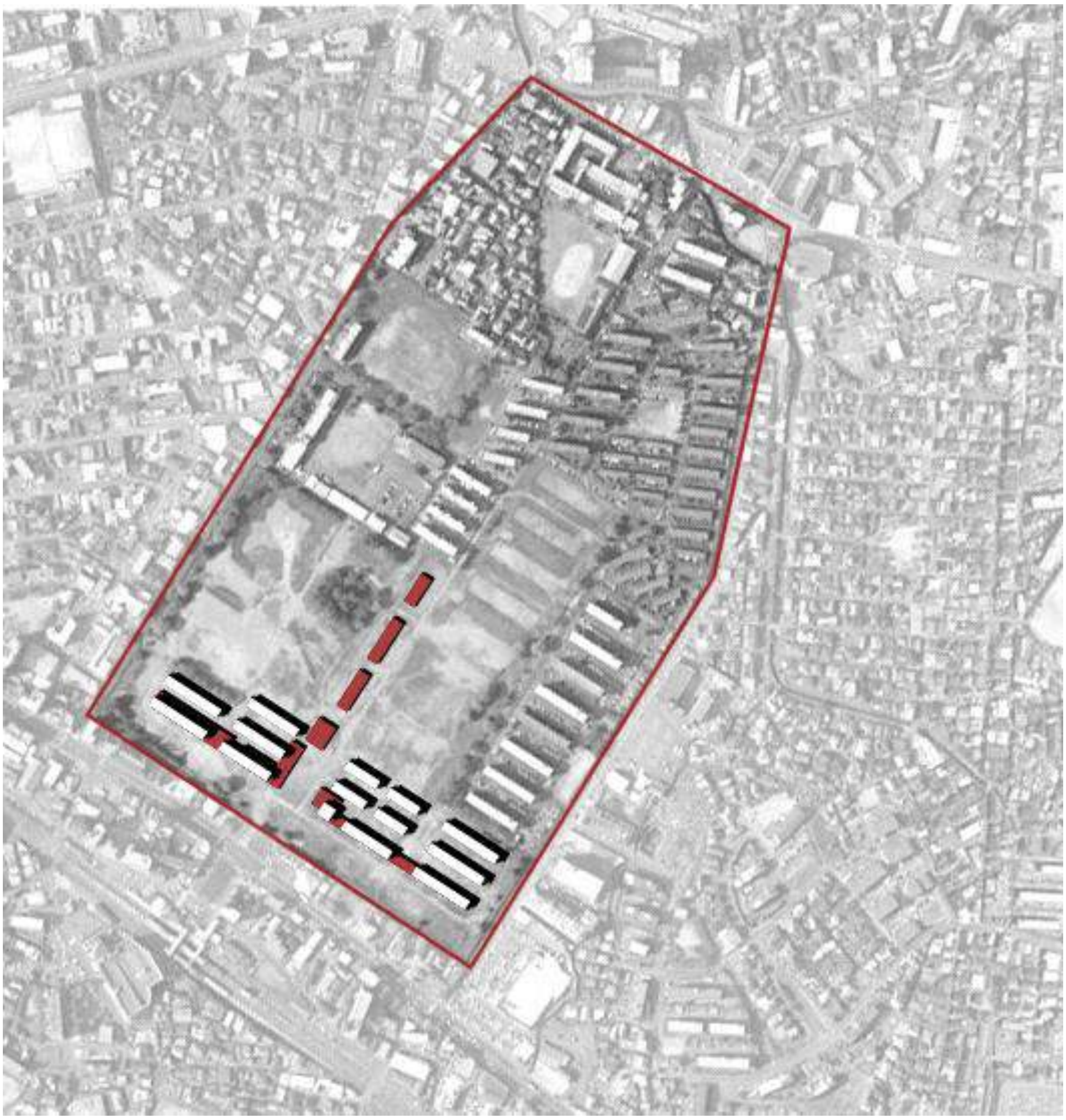


Figure 5-1-1 The image of construction plan

JONO area is decrepit and was built in 1955, rebuilding project such as a concrete policy is not out yet. In order to aggregating the rebuilding policy, promote the conversion of significant land use such as the effective use of the remaining land.

Table 5-1-1 Specification of life convenience facility

Facility	Facility example	Floor area (㎥)	Remarks
General medical facility	Clinic	1,500 ㎡	Internal medicine, dentistry, pediatrics, etc.
	Hospitalization facility		
Energy center	Energy-related facility room		
	Control room	200 ㎡	Include data center
	Energy management office	100 ㎡	
Elderly welfare facility	Day service center	500 ㎡	
	Living salon	200 ㎡	
Sports and health facility	Fitness gym	500 ㎡	Pool, bath facilities, sauna …
	Gymnasium	600 ㎡	
	Health promotion guidance room	200 ㎡	
child welfare, nursery and education facility	child welfare, nursery	200 ㎡	
	Parenting salon	200 ㎡	
	Tutoring room	500 ㎡	
commercial and dining facility	Supermarket	1,000 ㎡	
	Small tenant	500 ㎡	Cleaning, bookstore, pharmacy ...
	Cafe, snack	300 ㎡	
	Restaurant		
	Food court		
Community center	Town management office	300 ㎡	
	Conference room, lecture room, classroom	500 ㎡	
	Cooking class	200 ㎡	
	Studio	100 ㎡	
	Information dissemination center	100 ㎡	
total		7,700 ㎡	

Use land to create a pedestrian road to walk in the north and south of the center in the block of JONO station. North area of the station is the medium and high-rise residence and living service zone. We utilize remaining land around the low and medium-rise residence and ponds to become park zone.

The concept of “Low carbon advanced model block” along with the infrastructure of good urban development, about 400 units of detached houses, 800 units of amalgamated dwelling total about 1200 units are planning. We introduce energy conservation houses and long term high-quality houses.

In this study, the “eco front of life convenience facility” as the object to been proposed in this research, and we introduce the district energy system in this plan.

5.1.2 Setting energy load

The district energy system such as co-generation system (CGS), generally in order to drive the generator by the engine, to predict accurately the electricity load of the building, also plan and design a suitable energy system is important, not only calculate the annual peak value of the electricity load, but also predict the hourly, weekly, monthly electricity load to reflect the features. Depend on the electricity load pattern of hourly, weekly, monthly electricity load to choose the main specifications of CGS (power generator capacity, number, operation time period, control method). Also, consider about the effective utilization of heat energy recover from the CGS, it is necessary to grasp the heat load such as cooling demand, heating demand, hot water demand, and other heat demand etc. which is the actual situation of buildings.

In this study, in order to calculate the energy load of the life convenience facilities, use energy consumption per floor area of different buildings (original unit) to multiply the floor area of different buildings.

From chart 5-1-2 to chart 5-1-5 shows the monthly energy consumption original unit in different uses buildings.

Business facility	Cooling	Heating	Water heating	Electricity	Total
Jan.	0.00	15.52	0.74	14.90	31.16
Feb.	0.00	13.33	0.74	14.90	28.97
Mar.	0.00	9.60	0.74	14.90	25.24
Apr.	0.21	1.17	0.77	16.07	18.22
May.	2.88	0.00	0.75	16.18	19.81
Jun.	10.65	0.00	0.75	14.90	26.30
Jul.	17.13	0.00	0.75	14.90	32.78
Aug.	16.74	0.00	0.74	14.90	32.38
Sep.	10.74	0.00	0.75	14.90	26.39
Oct.	4.03	0.00	0.75	15.87	20.65
Nov.	0.03	3.08	0.74	15.54	19.39
Dec.	0.00	13.66	0.74	14.88	29.28
Annual total	62.41	56.36	8.96	182.84	310.57

M cal/m²·mo

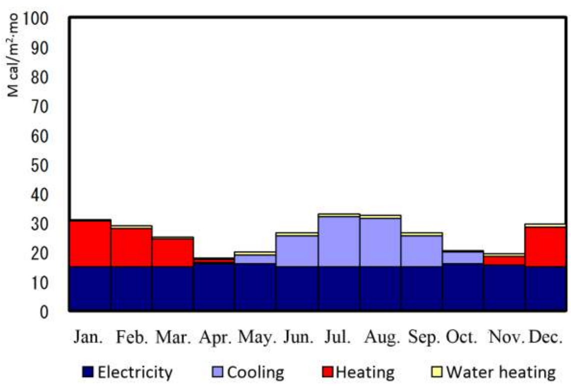


Figure 5-1-2 Energy consummation original unit of business facilities

Commercial facility	Cooling	Heating	Water heating	Electricity	Total
Jan.	0.00	10.20	2.50	37.49	50.19
Feb.	0.00	9.50	2.40	36.02	47.92
Mar.	0.20	6.20	2.40	36.02	44.82
Apr.	1.20	1.17	2.20	37.73	42.30
May.	5.70	0.00	2.50	39.45	47.65
Jun.	10.30	0.00	1.90	41.65	53.85
Jul.	17.00	0.00	2.10	46.31	65.41
Aug.	17.80	0.00	1.80	48.75	68.35
Sep.	14.20	0.00	1.60	47.53	63.33
Oct.	5.70	0.00	1.80	42.88	50.38
Nov.	0.90	0.00	2.20	40.18	43.28
Dec.	0.00	7.60	2.40	42.88	52.88
Annual total	73.00	34.67	25.80	496.89	630.36

M cal/m²·mo

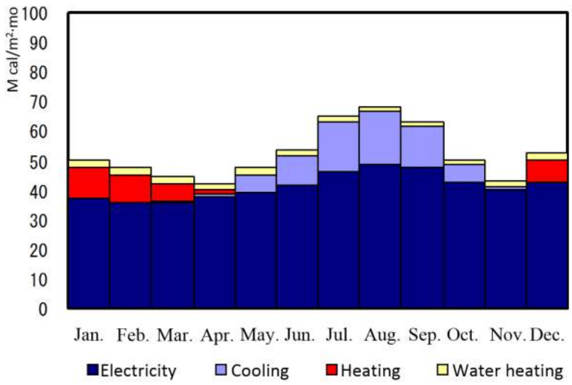


Figure 5-1-3 Energy consummation original unit of commercial facilities

Medical facility	Cooling	Heating	Water heating	Electricity	Total
Jan.	0.00	28.60	22.50	19.11	70.21
Feb.	0.00	24.20	21.50	17.64	63.34
Mar.	0.00	19.80	19.60	18.62	58.02
Apr.	0.00	10.40	18.30	17.39	46.09
May.	0.00	0.00	20.90	21.32	42.22
Jun.	8.00	0.00	18.40	18.87	45.27
Jul.	15.50	0.00	19.10	18.87	53.47
Aug.	16.30	0.00	18.10	19.84	54.24
Sep.	7.10	0.00	17.40	18.62	43.12
Oct.	0.00	0.00	19.80	18.37	38.17
Nov.	0.00	11.30	19.20	17.64	48.14
Dec.	0.00	19.40	25.90	19.35	64.65
Annual total	46.90	113.70	240.70	225.64	626.94

M cal/m²·mo

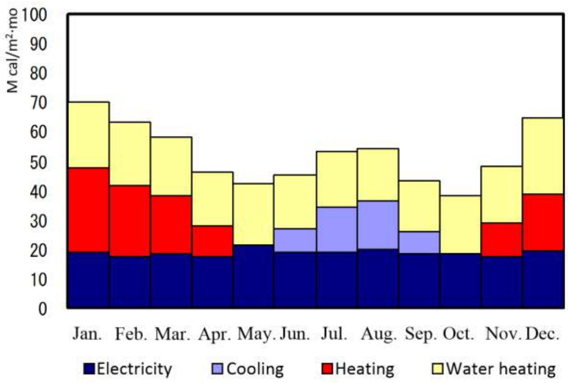


Figure 5-1-4 Energy consummation original unit of medical facilities

Accommodation	Cooling	Heating	Water heating	Electricity	Total
Jan.	0.00	30.90	29.60	26.46	86.96
Feb.	0.00	22.50	32.00	25.73	80.23
Mar.	0.00	19.00	27.50	25.97	72.47
Apr.	0.50	10.30	26.40	24.99	62.19
May.	2.50	0.00	25.30	25.73	53.53
Jun.	6.80	0.00	25.30	25.48	57.58
Jul.	16.60	0.00	22.10	26.22	64.92
Aug.	19.80	0.00	20.80	31.85	72.45
Sep.	14.60	0.00	21.80	29.40	65.80
Oct.	3.70	0.00	24.60	30.14	58.44
Nov.	0.30	8.40	26.60	25.97	61.27
Dec.	0.00	27.30	27.50	26.46	81.26
Annual total	64.80	118.40	309.50	324.40	817.10

M cal/m²·mo

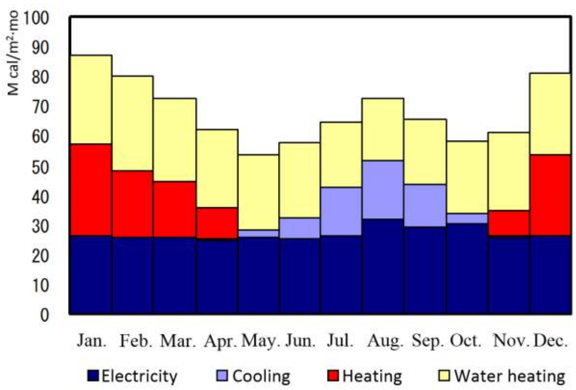


Figure 5-1-5 Energy consummation original unit of accommodation

5.1.3 Energy demand

We use the following formula to calculate the energy demand.

Energy demand = floor area of different buildings × energy consumption original unit

The value of floor area in different uses building is described in table 5-1-1, and original energy consumption unit is used in 5.1.2. Calculate the energy demand of each facilities are shown from figure 5-1-6 to figure 5-1-12. Based on this, from figure 5-1-13 to figure 5-1-16 shows the load fluctuation in each month (weekdays) of life convenience facility.

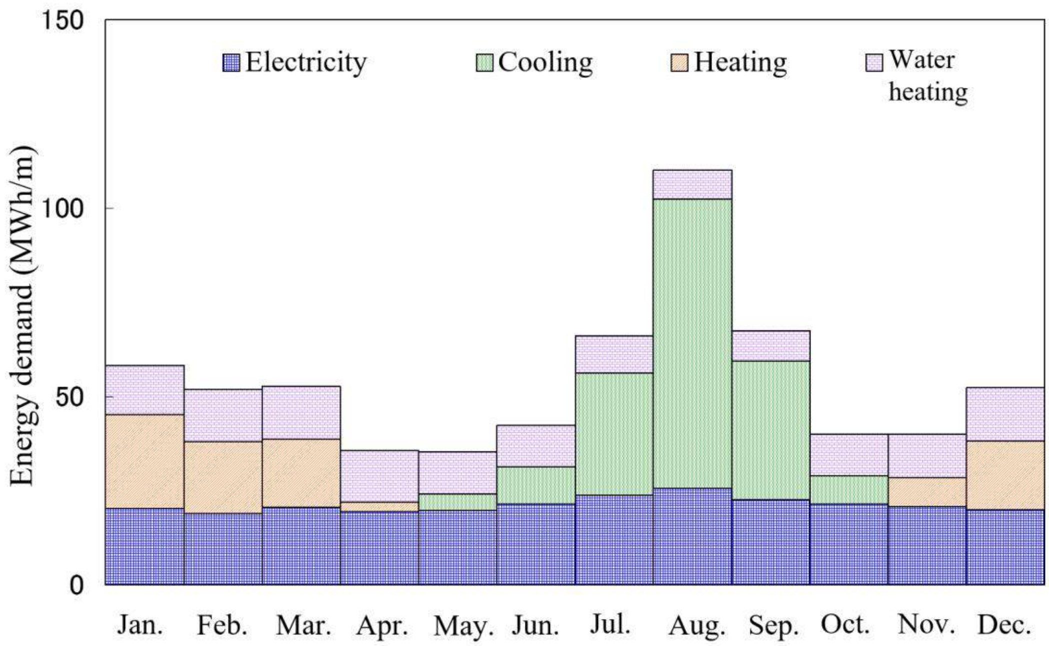


Figure 5-1-6 Energy load of general medical facility

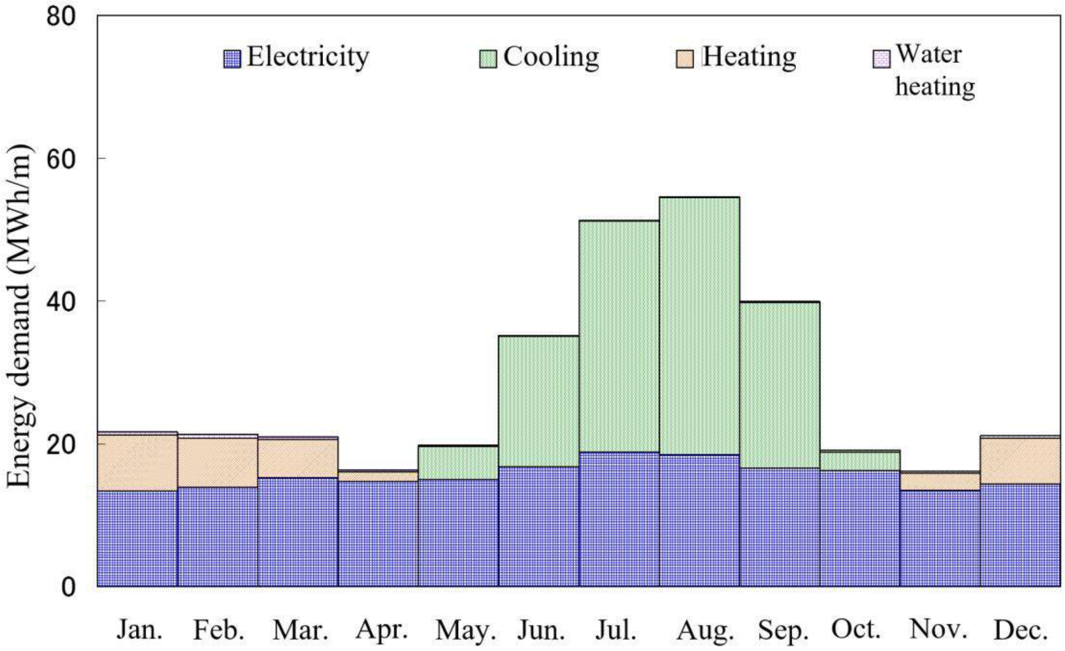


Figure 5-1-7 Energy load of energy center

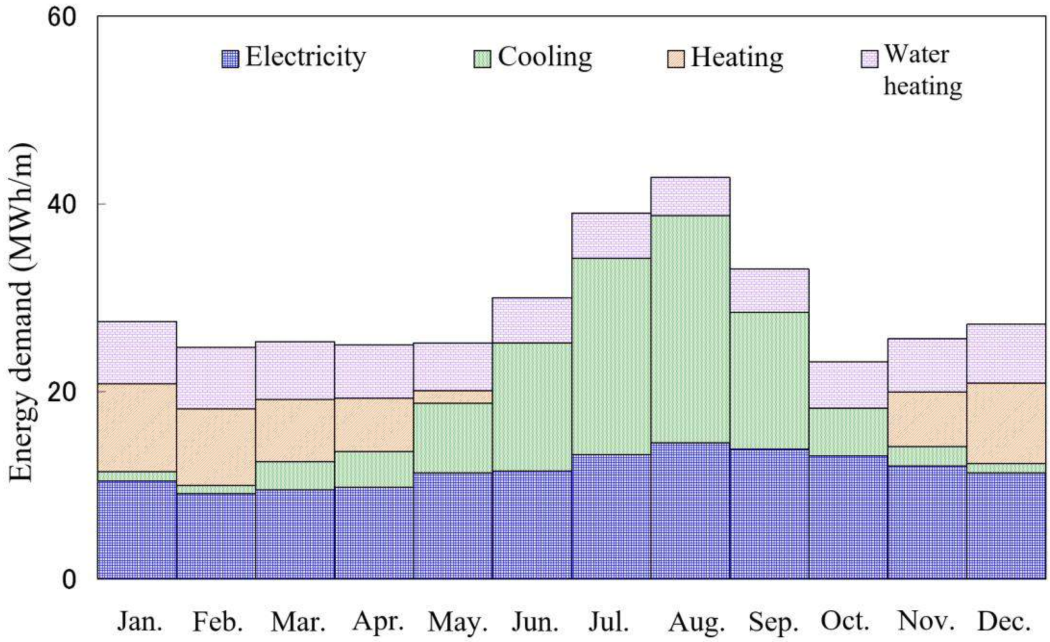


Figure 5-1-8 Energy load of elderly welfare facility

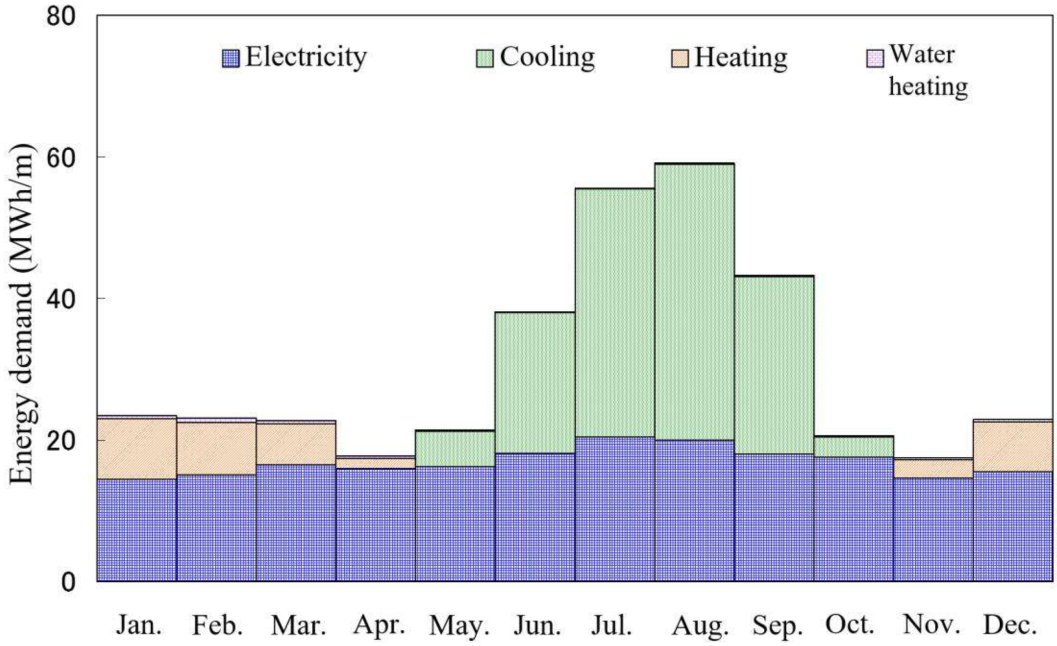


Figure 5-1-9 Energy load of sports and health facility

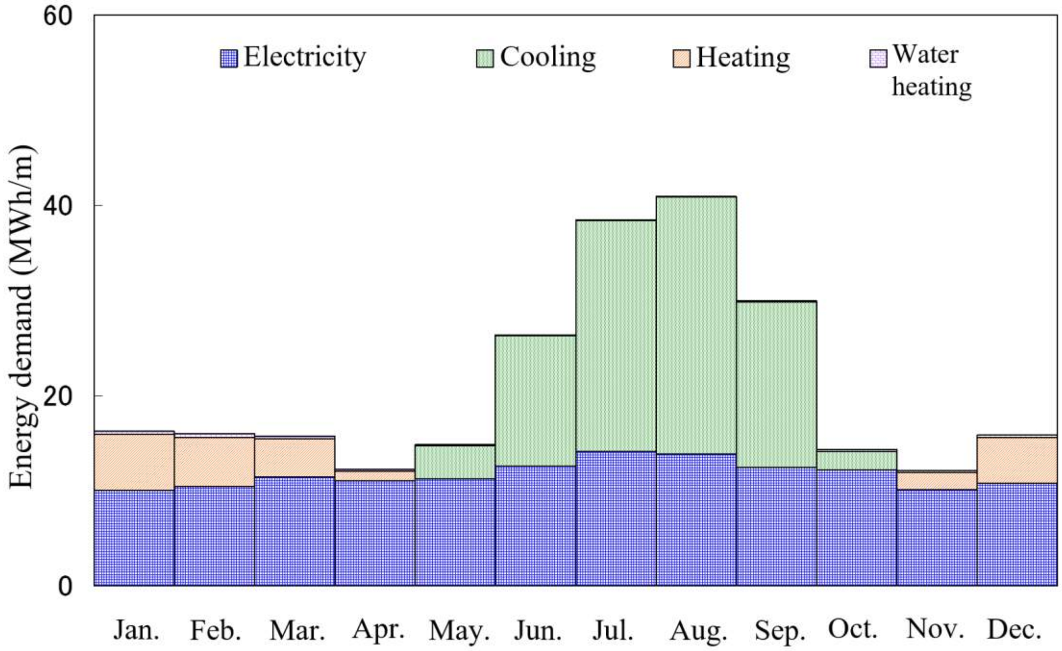


Figure 5-1-10 Energy load of child welfare, nursery, education facility

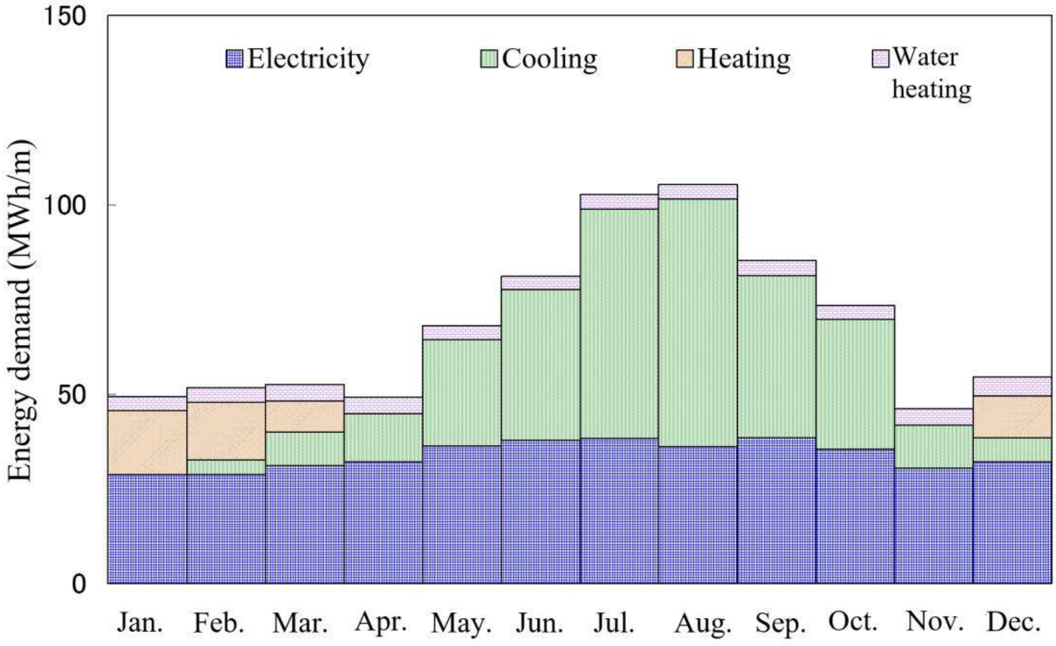


Figure 5-1-11 Energy load of commercial and dining facility

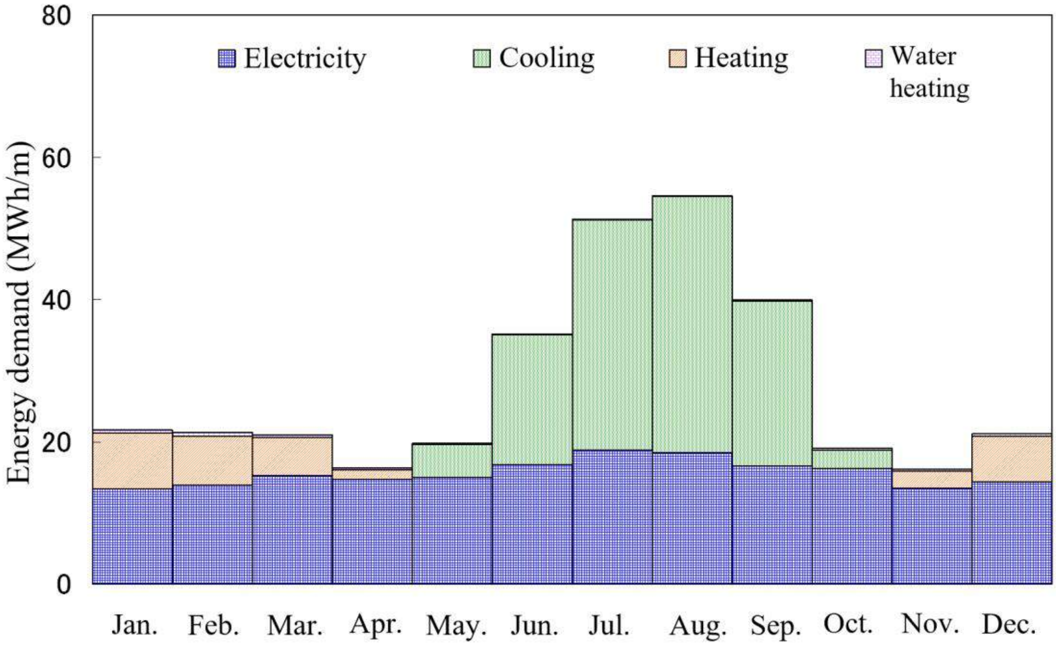


Figure 5-1-12 Energy load of community center

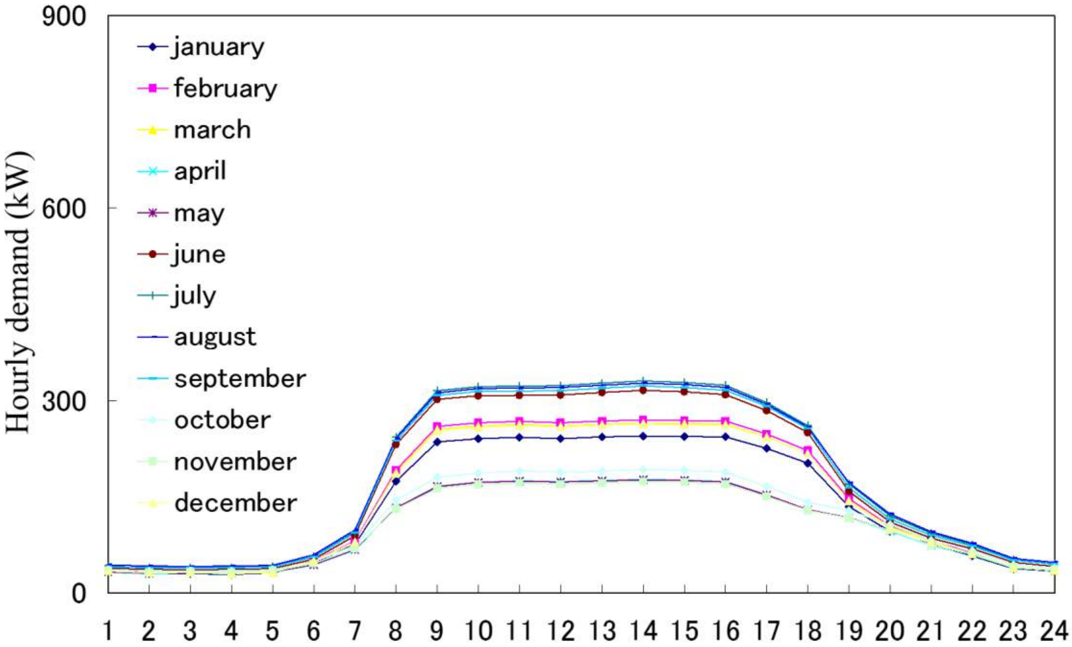


Figure 5-1-13 Hourly electricity load in each month of life convenience facility

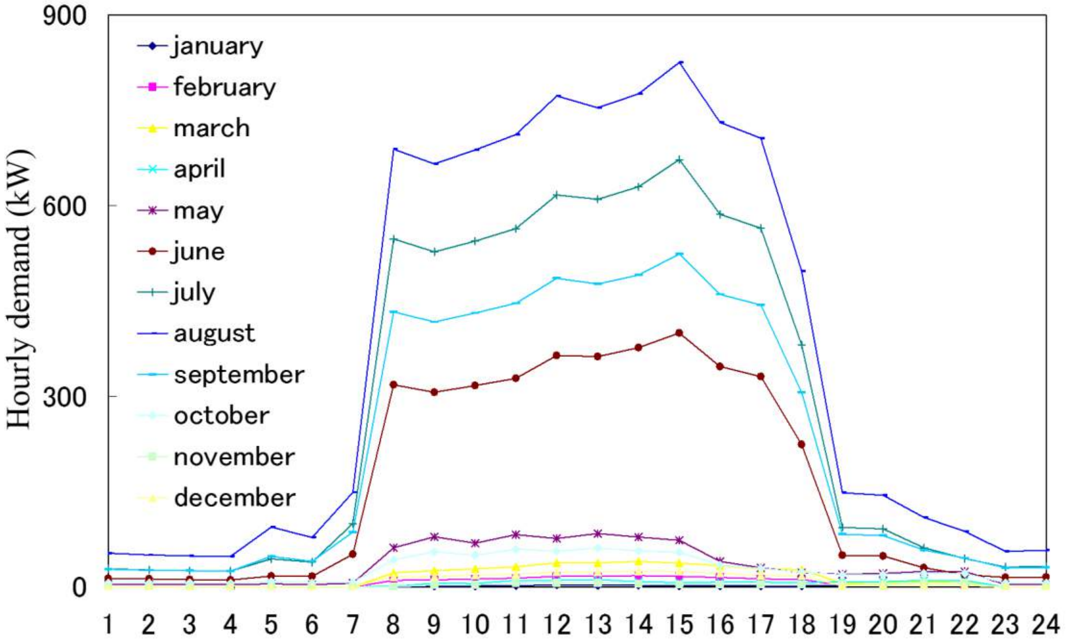


Figure 5-1-14 Hourly cooling load in each month of life convenience facility

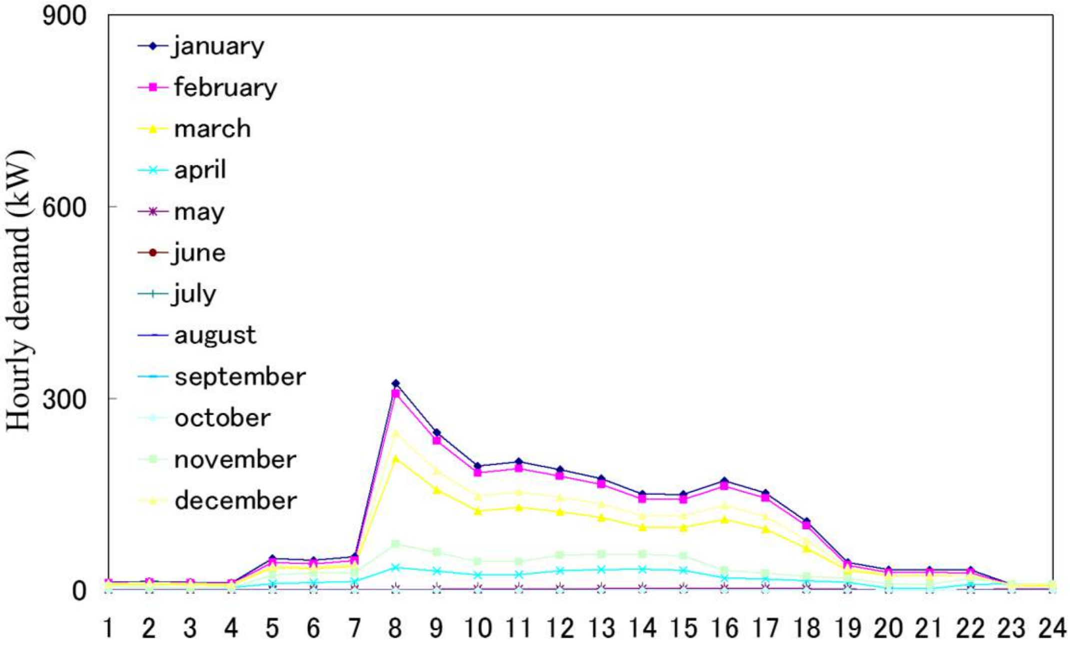


Figure 5-1-15 Hourly heating load in each month of life convenience facility

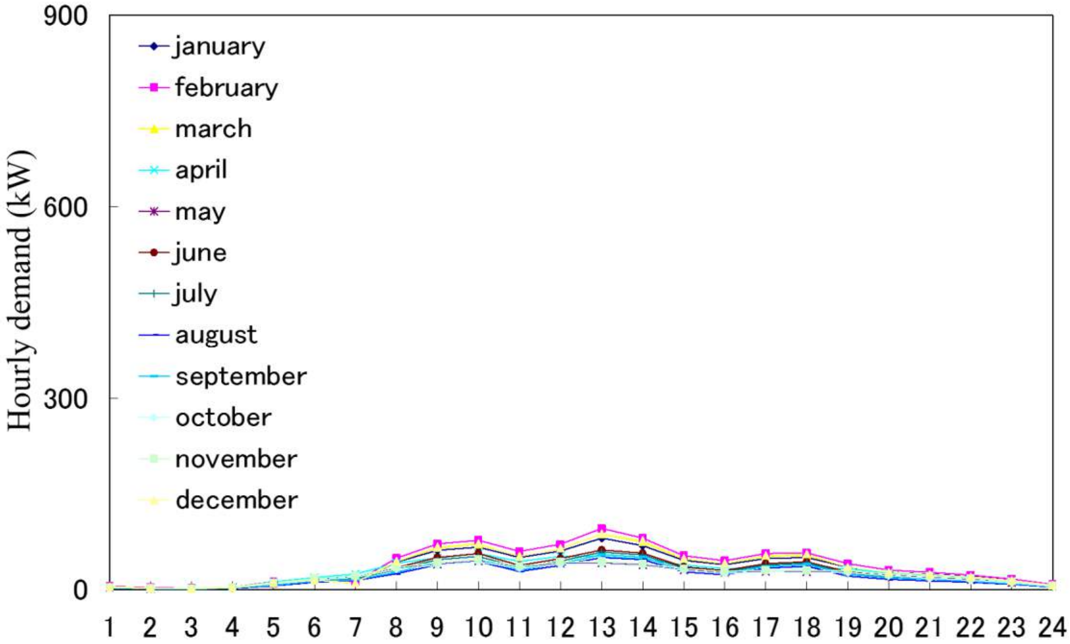


Figure 5-1-16 Hourly hot water load in each month of life convenience facility

5.2 Climate data

We take advantage of solar energy, adopt the measured value of the solar radiation data in Kitakyushu. From figure 5-1-17 to figure 5-1-18 shows the monthly and hourly solar radiation data.

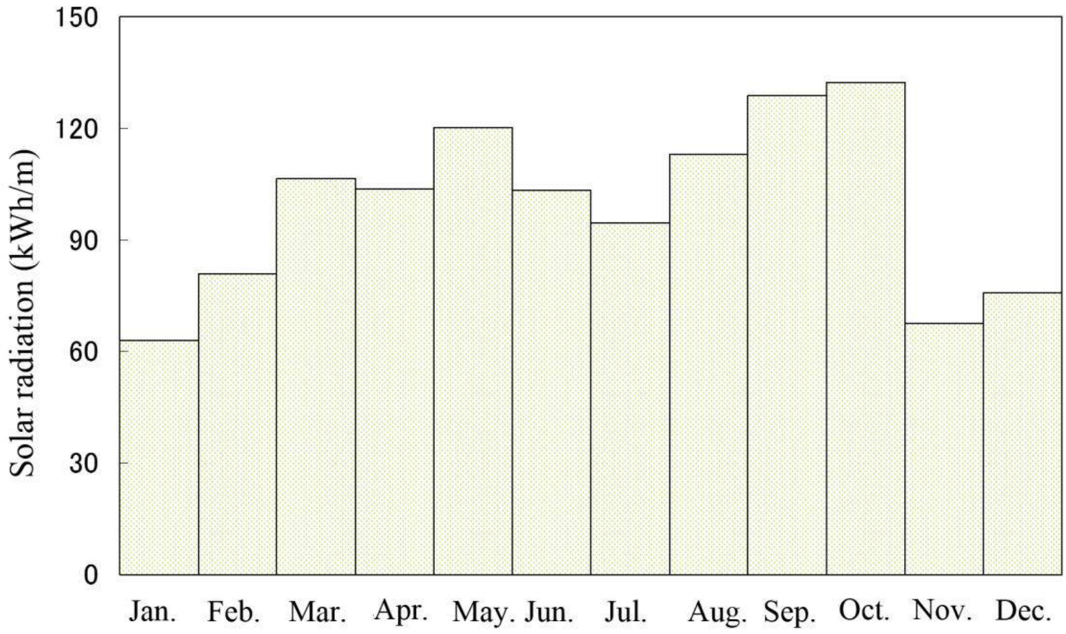


Figure 5-1-17 Monthly solar radiation data

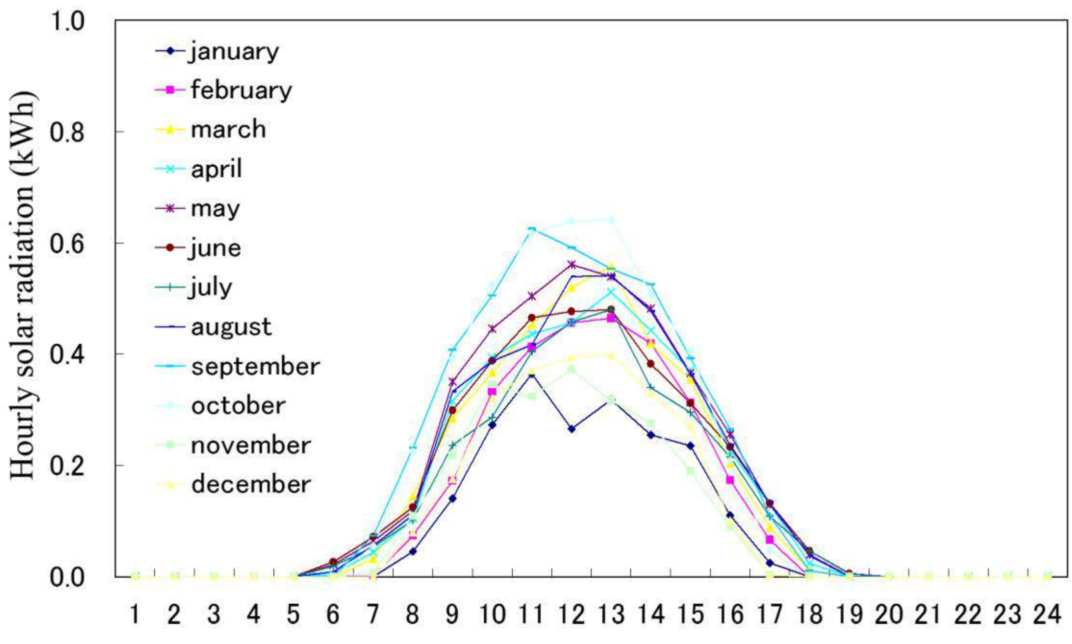


Figure 5-1-18 Hourly solar radiation data

5.3 Select energy equipment

As part of "low carbon advanced model block", when we select energy equipment of life convenience facility, based on four criteria as following:

1) In order to build zero carbon community, we need to use renewable energy.
2) Such as co-generation that combine high efficiency equipment, and high overall efficiency system need to be designed.
3) Ensure the safety of people when in the disaster, we need to enhance the "blackout" and "backup".
4) Combine with new equipment, the block become a model for future urban development design.

Based on the above criteria, we select 3 kinds of energy equipment (5-1-2~5-1-4) for standby equipment (5-1-19).

Table 5-1-2 Renewable energy system

Equipment name	Classification	Application facility	Remarks
Solar cooling	Central air conditioner	Gymnasium, energy center, studio, etc.	Combination solar water heater
Solar link excel （GHP）	Individual air conditioner	Hospital private room, day service, cram school, nursery, supermarket, tenants, restaurants, etc.	Combination with solar to make steady generation
Solar power generation	Power generation	All facility	
Solar water heater	Water heater	Hospital, day services, restaurants, etc.	

Table 5-1-3 High efficiency equipment

Equipment name	Classification	Application facility	Remarks
Gas co-generation	Generator	Gymnasium, energy center, studio, etc.	Waste heat can be used by air conditioner in gene link
GHP XAIR	Individual air conditioner	Hospital private room, day service, cram school, nursery, supermarket, tenants, restaurants, etc.	

Table 5-1-4 Disaster response equipment

Equipment name	Classification	Application facility	Remarks
BOS micro co-generation	Generator	General Hospital, Energy Center, etc.	Start using battery in the time of blackout
Blackout independence type GHP	Individual air conditioner	Hospital private room, day service, cram school, nursery, supermarket, tenants, restaurants, etc.	Even no heat demand, power generation + air conditioning is possible

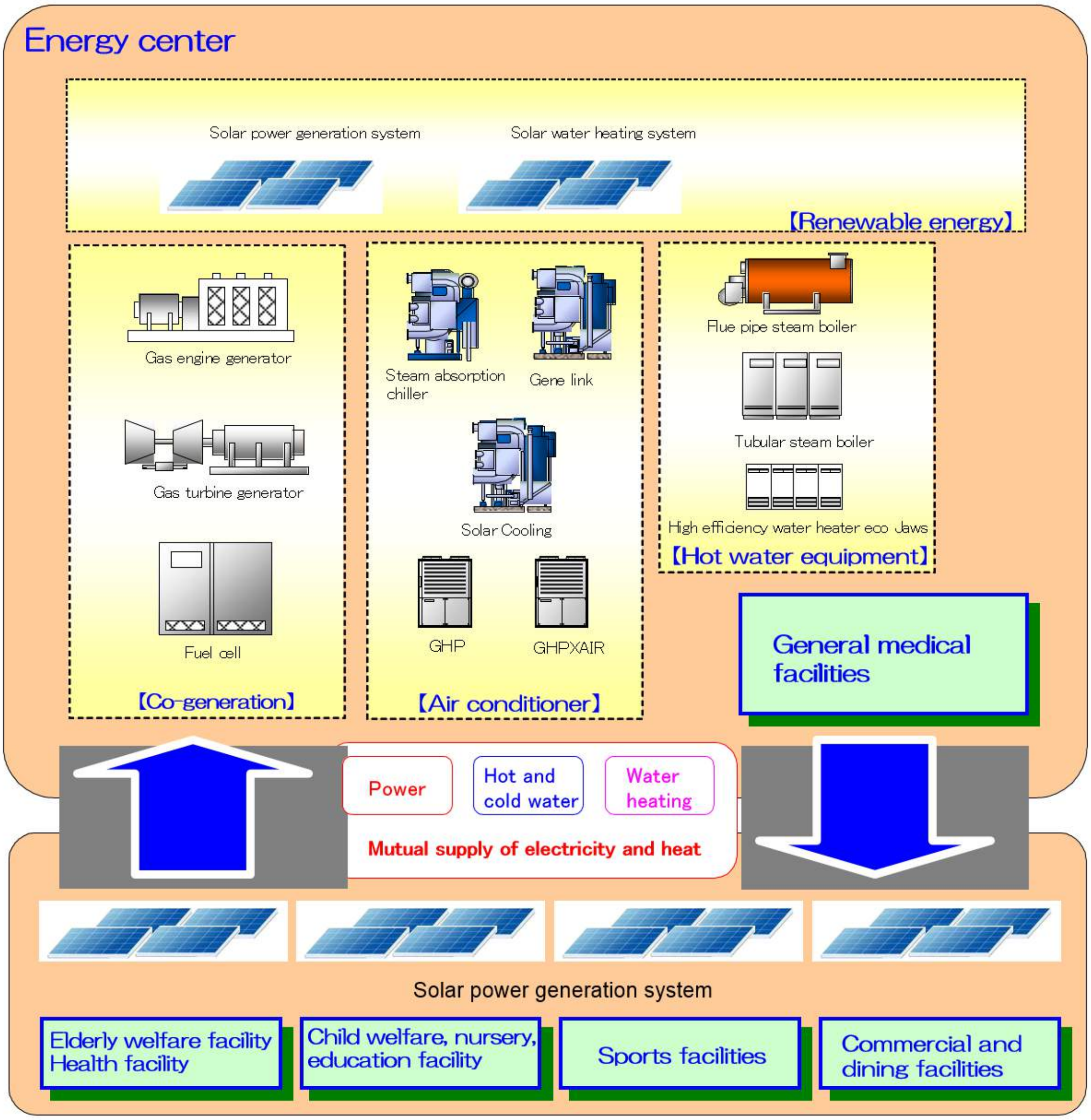


Figure 5-1-19 Standby energy facilities

We grasp the information of various types of energy equipment by the research from manufacturer and distributor.

(1) Specification of solar cell

A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. Figure 5-1-20 and table 5-1-5 is the image and specification of high efficiency single-crystal solar cell module.

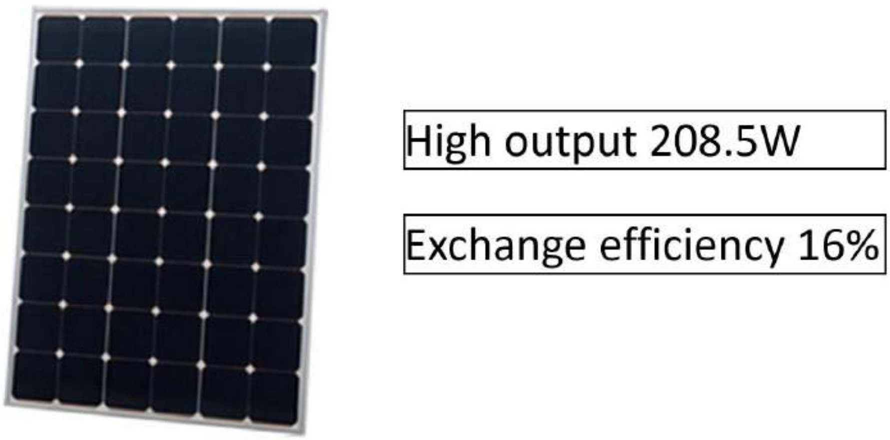


Figure 5-1-20 Image of high efficiency single-crystal solar cell module

Table 5-1-5 Specification of high efficiency single-crystal solar cell module

Model name	High output type
Cell type	Single crystal
The maximum output	208.5 W
Dimensions (width × depth × height)	1,318×990×46 mm
weight	17.0 kg

(2) Specification of solar thermal collector

The solar heat collector is a device to utilize heat from infrared rays contained in sunlight for warming water. There are three types of heat collector, include plate heat collector, vacuum tube heat collector (Figure 5-1-21), condenser heat collector, and the average heat collection efficiency can reach 40%.

Figure 6-1-21 Image of vacuum tube heat collector

(3) Specification of fuel cell

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent. Fuel cells are different from batteries that they require a continuous source of fuel and oxygen or air to sustain the chemical reaction, whereas in a battery the chemicals present in the battery react with each other to generate an electromotive force. Figure 5-1-22 and table 5-1-6 shows the image and specification of 100kW phosphoric acid fuel cell.

Figure 5-1-22 Image of 100kW phosphoric acid fuel cell

(Source: http://www.fujielectric.co.jp/products/fuelcell/pafc/spec.html)

Table 5-1-6 Specification of 100kW phosphoric acid fuel cell

Item	Specification
Type	Phosphoric acid fuel cell
Structure	Package
Size and mass	2.2m*5.6m*3.4m, 15t
Type of fuel	City gas
Rated output	105kW
Rated voltage	AC210V/220V
Heat output	High temperature type: 50kW (90℃/80℃) Medium temperature type: 123kW (60℃
Efficiency	Power generation: 42% Heat recovery rate (High temperature type): 20%

(4) Specification of gas engine

The gas engine co-generation system, gas is friendly for the environment and provide steady power by driving the engine. Also it is an equipment that can be effectively utilize waste heat for air conditioning, hot water and steam. Figure 5-1-23 shows the image and specification of gas engine co-generation system development.

Standard equipment	13A specification 	13A specification 	13A specification 	13A specification 	13A LPG specification 
Output	55kW	9.9kW	25kW	31kW	35kW
Power generation	29%	31.5%	33.5%	33%	34%
Overall efficiency	85%	85%	85%	84%	85%
Operation decibel	51dB	54dB	62dB	62dB	62dB

Figure 5-1-23 Image and specification of gas engine co-generation system

(Source: http://www.yanmar.co.jp/energy/)

(5) Specification of solar link excel

Solar link excel is a power generation system that linked solar power generation and high power excel system. Supply steady power by the solar cell and the power generator with gas heat pump linkage system. In addition, compare with solar power generation, combine the gas heat pump air conditioner which can provide invariant electricity power. Figure 5-1-24 and Table 5-1-7 shows the image and specification of solar link excel.

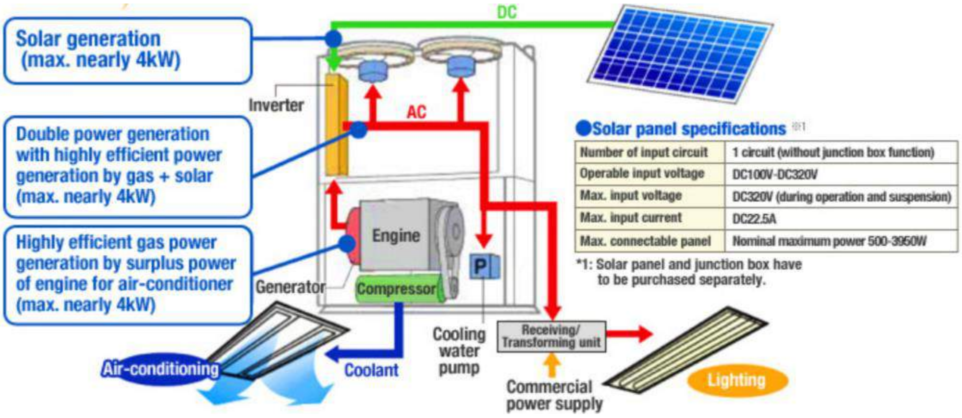


Figure 5-1-24 Image of solar link excel

(Source: https://www.osakagas.co.jp/en/rd/technical/1198834_6995.html)

Table 5-1-7 Specification of solar link excel

Model lineup	16~20HP
Cooling capacity	56kW
Heating capacity	63kW
Operation electricity current	Cooling 7.4/7.2A heating 6.0/6.0A
Electricity consumption	Cooling 1.36/1.36kW heating 1.12/1.12kW
Fuel consumption (cooling)	44.0kW
Fuel consumption (heating)	48.7kW
Power	200V
Size	L: 1000 W: 1800 H:2280mm
Product quality	890kg

(6) Specification of solar cooling

Solar cooling system put hot water (70 ~ 90℃) from the solar thermal collectors in the waste heat input gas absorption chiller to make cold water for cooling. During heating period that utilize hot water (around 60℃) from the solar thermal collectors for heating. We operate gas backup if the solar heat is not enough. Figure 5-1-25 is the mechanism of solar cooling, and table 5-1-8 shows the specifications of the solar cooling.

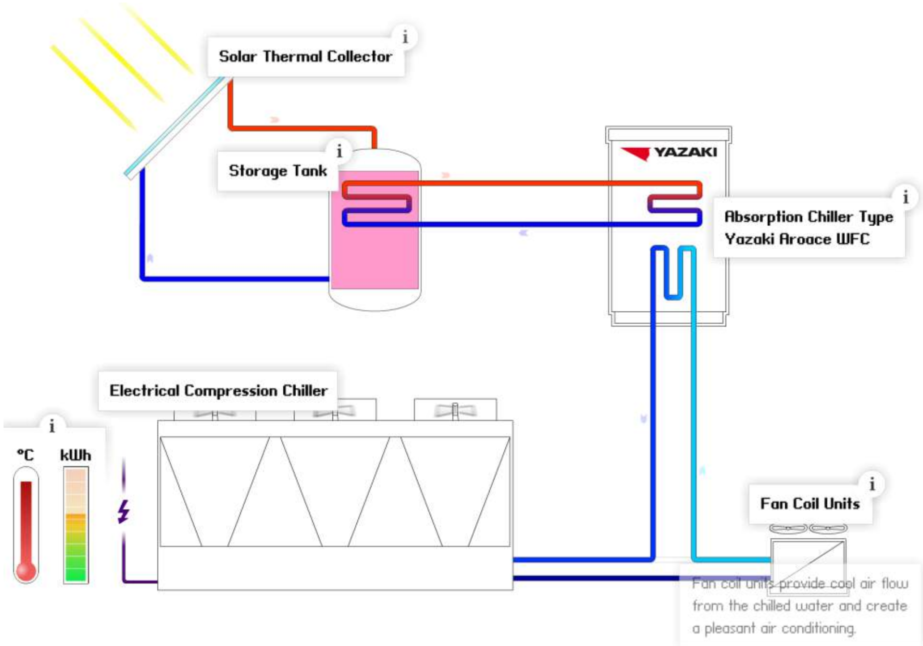


Figure 5-1-25 Mechanism of solar cooling system

(Source: http://www.yazaki-airconditioning.com/applications/solar_thermal_assisted.html)

Table 5-1-8 Specification of solar cooling

Different equipment of solar cooling system			
Cooling capacity	281~1055kW	352~700kW	422~3516kW
Rated cooling water temperature	31℃	31℃	31℃
Temperature of cold water	15~7℃	15~7℃	15~7℃
Temperature of hot water	75~98℃	75~98℃	75~98℃
Solar hot water rated temperature	1.66 (kW/RT) 90℃	2.14 (kW/RT) 90℃	1.77 (kW/RT) 90℃
Solar hot water minimum temperature	2.33 (kW/RT) 75℃	2.32 (kW/RT) 75℃	2.44 (kW/RT) 75℃

(7) Specification of gene link

Gene link is waste heat input type absorption chiller that effectively utilizes waste heat, hot water from a co-generation system such as gas engine to supply cold and hot water. Figure 5-1-26 is the mechanism of gene link, table 5-1-9 shows the specifications of gene link.

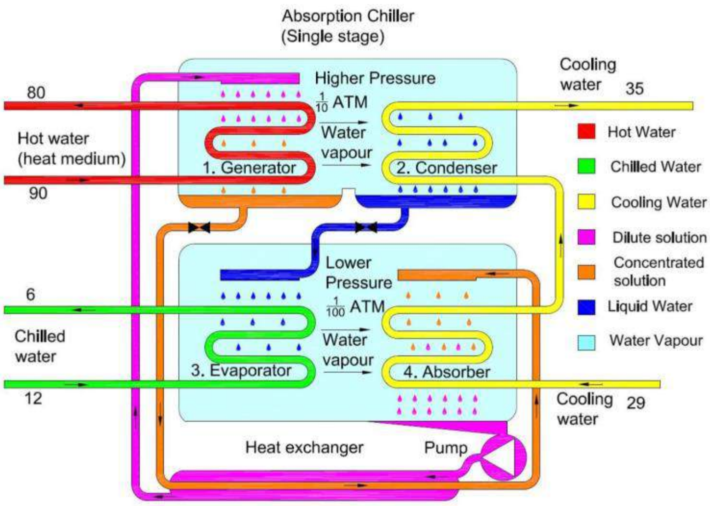


Figure 5-1-26 Mechanism of gene link

(Source: http://simonsboiler.com.au/product/shuangliang-absorption-chillers-trigeneration/)

Table 5-1-9 Specification of gene link

Model lineup	100~800RT
Cooling capacity	1055kW
Cooling capacity (only waste heat)	422kW
Heating capacity	703kW
Temperature of cold water	15~7℃
Temperature of hot water	49.7~55℃
Temperature of cooling water	32~37.5℃
Temperature of heating water	90~80℃
Power	200V 50/60HZ
Size	L: 4250 W: 2670 H:3410
Operation quality	17.5ton
Fuel consumption	800/600kW

(8) Specification of gas heat pump (GHP)

Gas heat pump is a heat pump air conditioner for driving the outdoor unit compressor with gas engine. In addition, ordinary electric heat pump air conditioner also use fluorocarbons as refrigerants.

Fuel gas is a power source of the outdoor unit compressor, and use its waste heat as heat source during the heat pump operation, it is possible to have powerful and high efficiency operation. Figure 5-1-27 shows the mechanism of the GHP. Table 5-1-10 shows the specifications of the GHP.

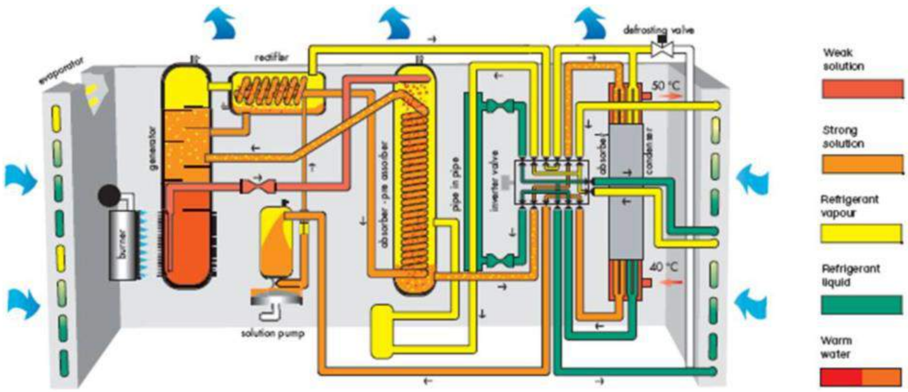


Figure 5-1-27 Mechanism of GHP

(Source: http://www.gasairconditioning.org/heatpump_how_it_works.htm)

Table 5-1-10 Specification of GHP

Model lineup	16~25HP
Cooling capacity	56kW
Heating capacity	63kW
Operation electricity current	Cooling 3.2/3.1A heating 2.0/2.0A
Electricity consumption	Cooling 1.02/1.02kW heating 0.64/0.64kW
Fuel consumption (cooling)	39.1kW
Fuel consumption (heating)	42.5kW
Power	200V
Size	L: 1000 W: 1650 H:2280
Product quality	775kg

5.4 Setting cases

Combine with energy equipment which are mentioned above, construct a district energy supply system as shown in Figure 5-1-28.

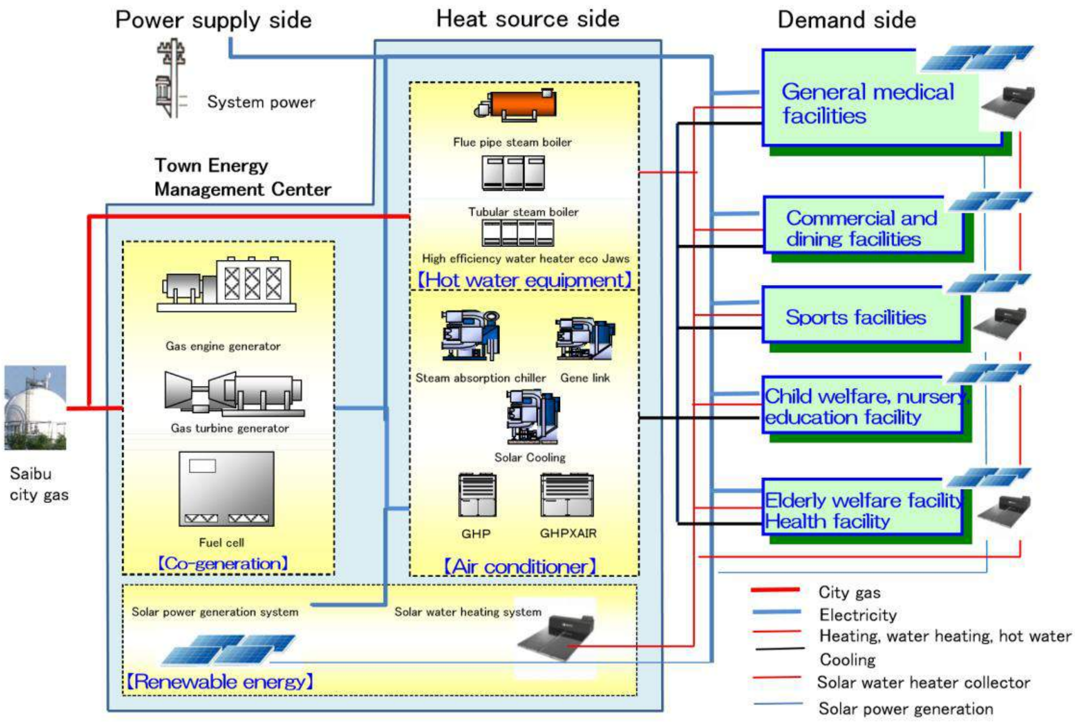


Figure 5-1-28 Image of the regional energy supply system

In this study, in order to plan a district energy supply system to take advantage of city gas. We need to consider the impact of different type technology and placement (distributed and centralized), and operation strategy (electricity tracking mode and heat tracking mode). We set up six cases to discuss.

(1) Case 0: conventional system

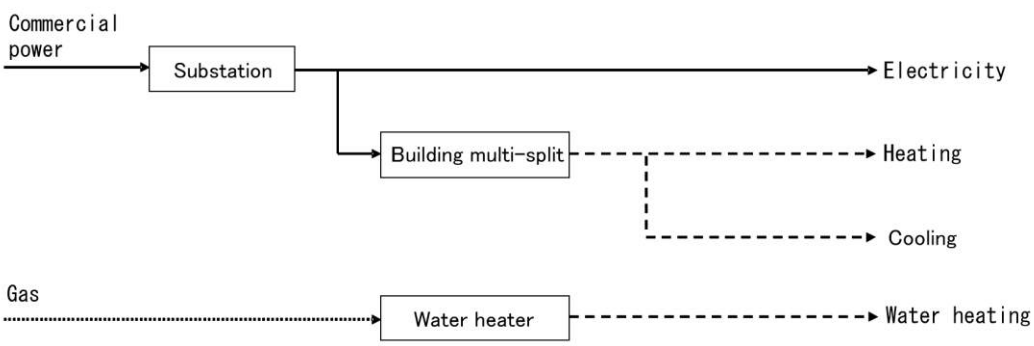


Figure 5-1-29 Conventional system

Case 0 is the conventional energy supply system (figure 5-1-29). Purchase electricity from power grid for electricity load, cooling and heating load from multi-split air conditioner, and hot water load from water heater.

(2) Case 1: distributed equipment + gas engine + electricity tracking mode

Case 1 is a distributed equipment case, each facility provide electricity and heat load by its own energy system. Specifically, the general medical facility and sports and health facilities are shown in Figure 5-1-30, and introduce solar power, gas engine and solar thermal collectors. Elderly welfare facility is shown in Figure 5-1-31, and introduce solar power generation and freestanding GHP. In addition, child welfare, nursery and education facility, commercial and dining facility and the community center are shown in Figure 5-1-32, and we introduce a solar power generation and solar link excel.

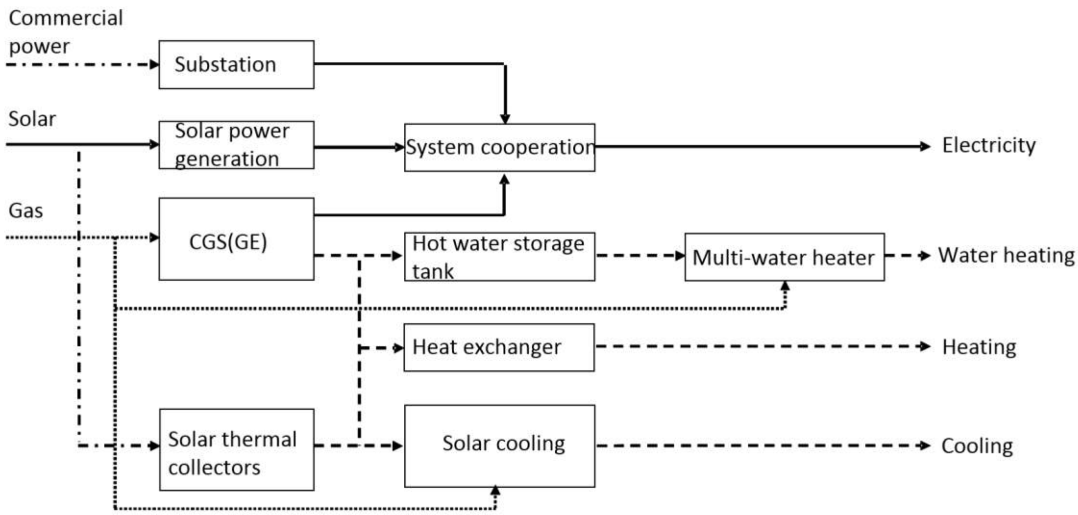


Figure 5-1-30 Distributed equipment case (general medical facility, sports and health facility)

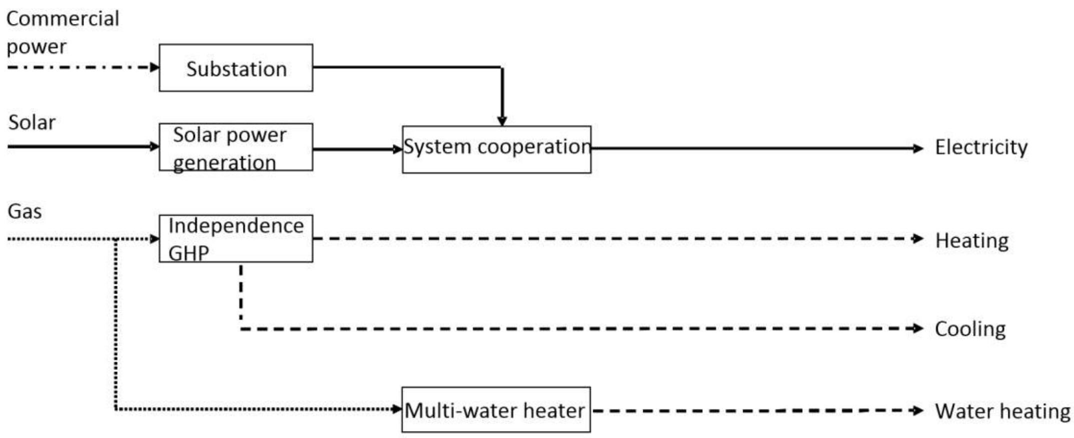


Figure 5-1-31 Distributed equipment case (elderly welfare facility)

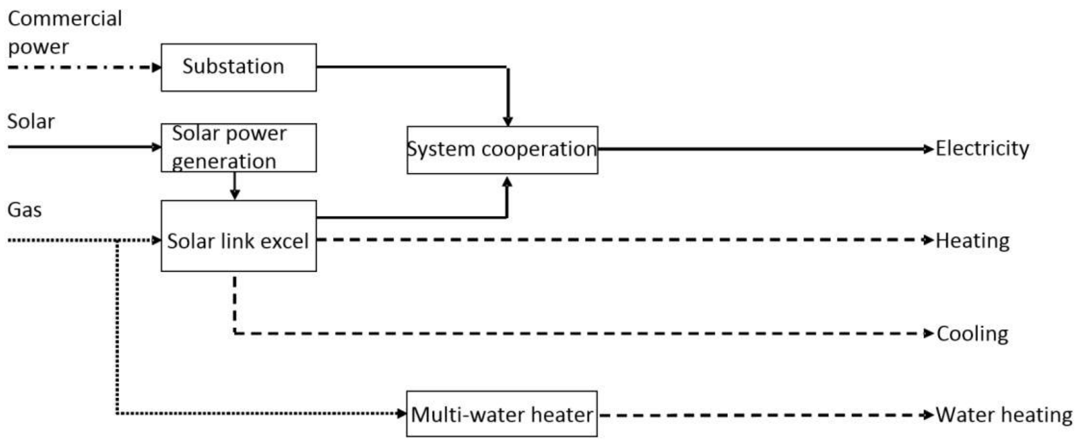


Figure 5-1-32 Distributed equipment case (child welfare, nursery and education facility, commercial and dining facility and the community center)

(3) Case 2: part of distributed equipment + gas engine + electricity tracking mode

Case 2 has a part of distributed equipment case. In other words, district energy center provide the overall electricity demand and the most heat demand of life convenience facility, and GHP chiller meets the cooling and heating load of elderly welfare facility,

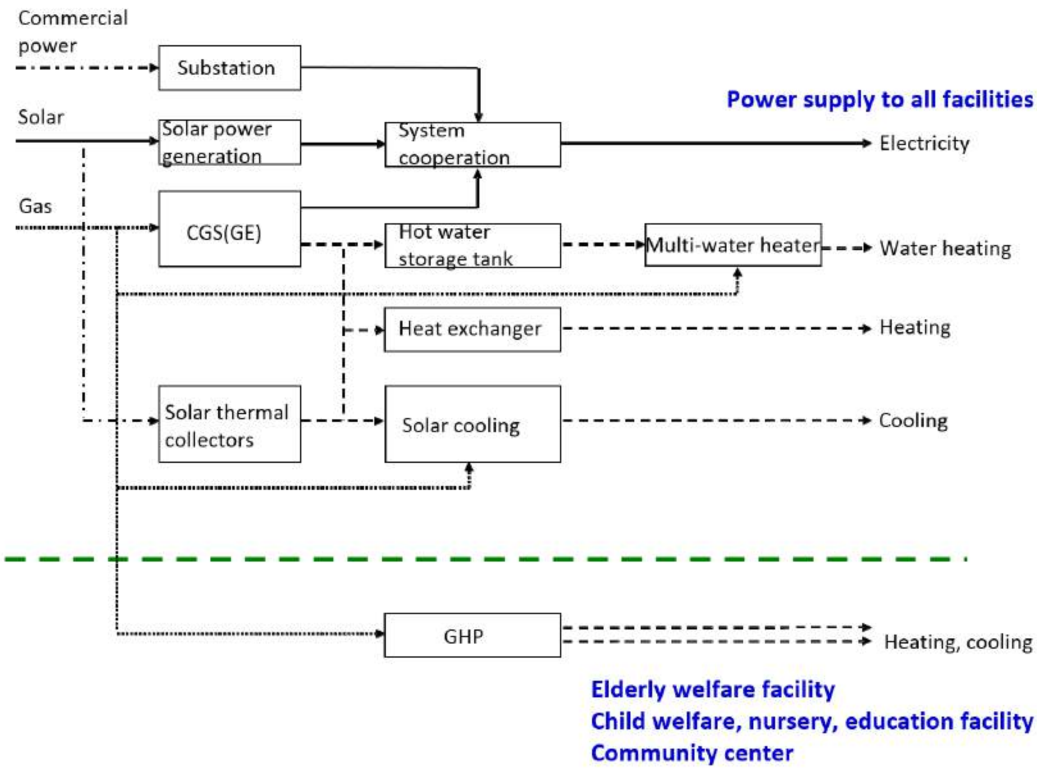


Figure 5-1-33 Part of distributed equipment case

child welfare, nursery and education facility, and the community center. In this case, considering the operation characteristics of these three facilities can be set up own thermal environment.

(4) Case 3: centralized facility + gas engine + electricity tracking mode

Case 3 is a centralized facility case, entire heat and electricity load of the life convenience facility is supplied from district energy center. Specifically, electricity load of distributed energy system is provided by power generation output (solar power generation+ gas engine), if it cannot provide the full electricity load from power generation, purchase electricity shortage from the power grid. Furthermore, considering the operation strategy, set up the operation method of "electricity tracking mode", so there are no residual electricity. In other words, the power generation need to match the electricity load, and utilize the waste heat as much as possible.

For heating demand, use the recovered waste heat from solar thermal collectors CGS as heating resource of hot water load and heating load. Heat shortage compensate by city gas directly burned, and utilize solar cooling and gene link to meet the cooling load.

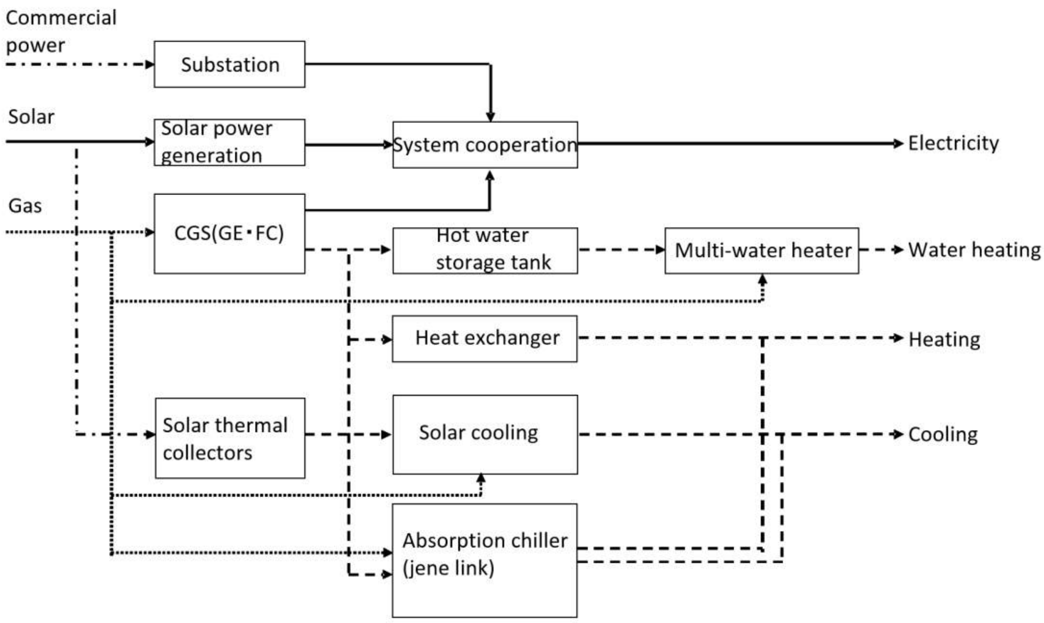


Figure 5-1-34 Centralized facility case

(5) Case 4: centralized facility + fuel cell + gas engine + electricity tracking mode

Case 4 is a centralized facility case, CGS is not only gas engine, and fuel cell has been introduced. Heat and electricity supply mode is same as case 3.

(6) Case 5: centralized facility + gas engine + heat tracking mode

Case 5 is based on case 3, and adopts operation mode "heat tracking mode", quantity of power generation changes by heat load.

Table 5-1-11 Cost information of energy equipment

Equipment	Capacity（kW）	Owner delivery price	ratio of retail price
Gas engine	25	6,240,000	80%
	35	7,840,000	80%
Fuel cell	100	80,000,000	←Include construction cost
Jene link	352	17,000,000	←Include accessories
GHP	45	1,764,000	35%
	56	1,999,200	35%
	71	2,260,125	35%
Solar cooling	281	13,000,000	Estimate
	422	18,500,000	
	528	23,000,000	
Solar link excel	45	3,312,000	45%
	56	3,420,000	45%

Table 5-1-12 Commercial electricity charge

Basic charge（yen/kW）	Electricity charge（nen/kWh）	
	Summer	Other seasons
1953	10.6	9.7

Table 5-1-13 Commercial electricity charge

Contract type	Basic charge			Unit Rates（yen /m3）
	Fixed（yen/m）	Flow（yen/m3）	Other basic（yen /m3）	
Small business air conditioner	4200	Air conditioner 1470	-	74.7
		Other　2940	-	
Total energy system	78750	793.8	Maximum demand period 1.03	62.7

In order to discuss the economics of district energy system, we need to investigate the cost information of each energy equipment, this study is set based on surveys of conventional research (table 5-1-11). In addition, energy charge is investigated from the home page of the local electricity and gas company to make a charge database (table 5-1-12 and table 5-1-13)

On the other hand, in order to evaluate the energy conservation of the district energy system, and setting the power generation efficiency of the electricity system at 39.2%. In addition, in order to discuss the environment of the system, CO_2 emission factor of the system power is 0.369 Kg/kWh (power factor) and 0.69 Kg/kWh (thermal coefficient), CO_2 emission factor of city gas is 0.0134 t/GJ.

CHAPTER SIX

ANALYSIS OF THE ENERGY INFRASTRUCTURE WITH THE DISTRIBUTED ENERGY RESOURCE IN JONO AREA

6.1 Capacity of the equipment

We decide the introduction capacity of energy equipment is an important part of the district energy supply system plan, and it also can affect the operation effect of the system (energy conservation and environment and economics). In this study, introduction capacity of CGS used a method that calculate the maximum area to select the CGS capacity of each case. Specifically, electrical load is based on the accumulation curve (heat tracking mode follow heating load), based on the criteria that maximize annual amount of power generation with fixed capacity (heat tracking mode follow the waste heat) to decide the capacity of facility. The concept of this method is not satisfied with the peak value of the local energy (electricity and heat) load from CGS, and supply the average value of the energy load, the shortage is supplied by commercial electric power and backup boiler.

As shown in Figure 6-1-1, optimal CGS capacity of general medical facility and sports and health facility of the case 1 is 32 kW and 35 kW. Optimal CGS capacity of case 2 to 4 is 166 kW, the optimal capacity of case 5 is 213 kW

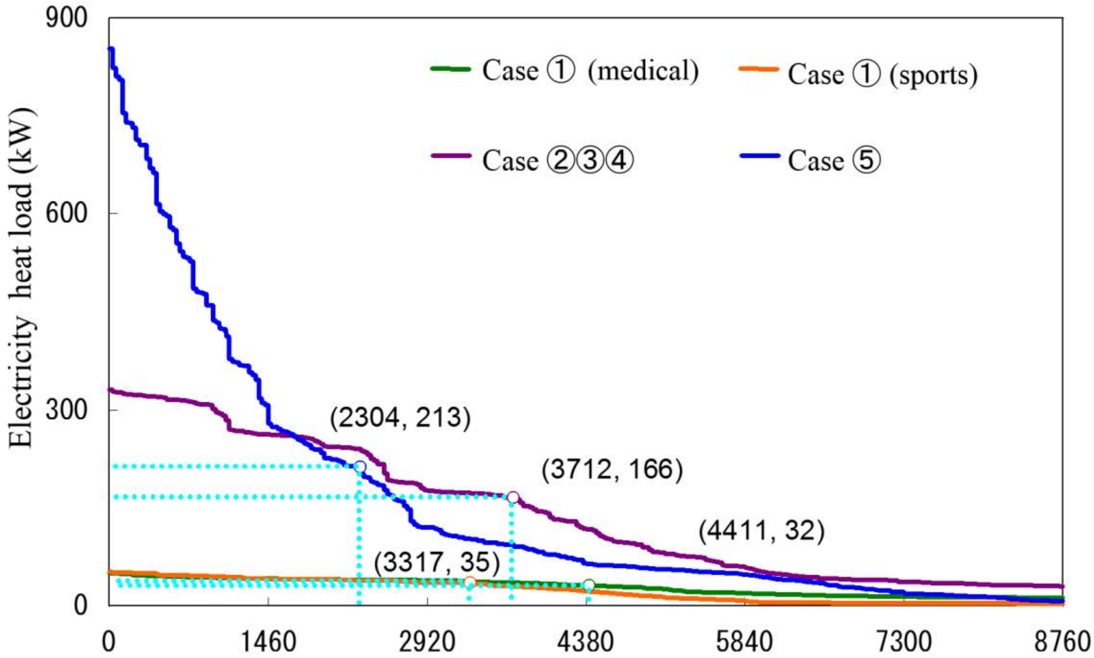


Figure 6-1-1 Selection of CGS capacity

Photovoltaic power generation and solar heat collector and capacity will be set by the roof area of the facility. In this study, we assume that solar photovoltaic utilize 1/2 of roof area, solar heat collector utilize 1/3 of roof area. Table 6-1-1 shows the floor area of each facility, the roof area, the area that can be installed solar photovoltaic and solar thermal collectors.

Table 6-1-1 Set up the capacity of solar power generation and solar heat collector

Examination facility	Floor area （m²）	stairs	Roof area (m²)	PV establish area （m²）	PV capacity* （kW）	Solar heat collector area（m²）	Solar heat collector capacity ** （peak kW）
General medical facilities	1500	3	500	250	40	167	83
Energy center	300	2	150	75	12	50	25
Elderly welfare facility	700	1	700	350	56	233	117
Sports and health facility	1300	2	650	325	52	217	108
Child welfare, nursery and education facility	900	2	450	225	36	150	75
Commercial and dining facility	1800	2	900	450	72	300	150
Community center	1200	2	600	300	48	200	100
Total	7700	-	3950	1975	316	1317	658

*assume the fixed capacity of solar photovoltaic at 0.16kW / m2

**assume the fixed capacity of solar water heater at 0.50kW / m2

In addition, the capacity of absorption chiller, gene link, GHP, solar cooling, solar link excel will be set up by the peak value of cooling and heating load.

Based on the above setting method, table 6-1-2 shows the capacity of power generation equipment and heat source equipment of each case. Also table 6-1-3 is a list of the specifications of each equipment.

Table 6-1-2 Capacity of equipment

<table>
<tr><th colspan="2" rowspan="2">Case</th><th colspan="8">Equipment capacity （kW）</th></tr>
<tr><th>Gas engine</th><th>Fuel cell</th><th>PV</th><th>Jene link （cooling）</th><th>GHP (cooling)</th><th>Solar heat collector</th><th>Solar cooling (cooling)</th><th>Solar link excel （cooling）</th></tr>
<tr><td rowspan="6">Case ①</td><td>General medical facility</td><td>35</td><td>-</td><td>40</td><td>-</td><td>-</td><td>83</td><td>281</td><td>-</td></tr>
<tr><td>Energy center</td><td>-</td><td>-</td><td>56</td><td>-</td><td>90 (45×2)</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Elderly welfare facility</td><td>35</td><td>-</td><td>52</td><td>-</td><td>-</td><td>108</td><td>281</td><td>-</td></tr>
<tr><td>Sports and health facility</td><td>-</td><td>-</td><td>8*+52</td><td>-</td><td>-</td><td>-</td><td>-</td><td>112 （56×2）</td></tr>
<tr><td>Child welfare, nursery and education facility</td><td>-</td><td>-</td><td>20*+100</td><td>-</td><td>-</td><td>-</td><td>-</td><td>280 （56×5）</td></tr>
<tr><td>Commercial and dining facility</td><td>-</td><td>-</td><td>12*+68</td><td>-</td><td>-</td><td>-</td><td>-</td><td>135 （45×3）</td></tr>
<tr><td rowspan="4">Case ②</td><td>Energy center</td><td>165 (35×4+25)</td><td>-</td><td rowspan="4">316</td><td>-</td><td>-</td><td rowspan="4">658</td><td>422</td><td>-</td></tr>
<tr><td>Elderly welfare facility</td><td>-</td><td>-</td><td>-</td><td>71</td><td>-</td><td>-</td></tr>
<tr><td>Child welfare, nursery and education facility</td><td>-</td><td>-</td><td>-</td><td>101 （45+56）</td><td>-</td><td>-</td></tr>
<tr><td>Community center</td><td>-</td><td>-</td><td>-</td><td>127 （56+71）</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">Case ③</td><td>165 (35×4+25)</td><td>-</td><td>316</td><td>352</td><td>-</td><td>658</td><td>528</td><td>-</td></tr>
<tr><td colspan="2">Case ④</td><td>70 (35×2)</td><td>100</td><td>316</td><td>352</td><td>-</td><td>658</td><td>528</td><td>-</td></tr>
<tr><td colspan="2">Case ⑤</td><td>140 (35×4)</td><td>-</td><td>316</td><td>352</td><td>-</td><td>658</td><td>528</td><td>-</td></tr>
</table>

Set up according to the capacity of the solar link excel

Table 6-1-3 Specification of equipment

Equipment	model	Generation efficiency (%)	General efficiency (%)	Cooling COP
Gas engine	CP35VC-TN	33.5	85.0	-
	CP25VB3	34.0	85.0	-
Fuel cell	FP-100i	42.0	92.0	-
Solar cell	NQ-209LW	16.0	-	-
Jene link	BUWL-WE100FG	-	-	1.5
GHP	SGP-H450S1GD	-	-	1.5
	SGP-H560S1GD	-	-	1.4
	SGP-H710S1GD	-	-	1.2
Solar cooling	TZU80	-	-	1.3
	TZU120	-	-	1.3
	TZU150	-	-	1.3
Solar link excel	SGP-GP450M4G2DR	29.0	-	1.5
	SGP-GP560M4G2DR	29.0	-	1.5

6.2 Operation pattern of system

Operation characteristics of system also have significant impact on the operation effect of district energy system (energy conservation and environmental and economic). We analyze the operation pattern of system from electricity consumption and heat consumption as following.

(1) Composition of electricity consumption

Figure 6-2-2 shows the composition of annual electricity consumption. Viewed from whole cases, cooling and heating load of case 0 (conventional system) are supplied by electricity, so it has the most annual electricity consumption. On the other hand, since Case 1 is the distributed equipment case, district energy center is not necessary, annual electricity consumption is lower than centralized case.

According to the viewpoint of electricity composition, distributed energy (solar power generation + gas engine + fuel cell) meet the most of the electricity demand of case 1-5, shortage part is provided by power grid. Specifically, the percentage of distributed occupied the total power consumption in case 1 is 76.4% (distributed equipment), Case 2 has 93.8% (part distributed), Case 3 has 93.8% (centralized + gas engine), Case 4 has 94.5% (centralized + fuel cell), case 5 has 50.8% (centralized + heat tracking). In Case 1, the elderly welfare facility, child welfare, nursery and education facility, commercial and dining facility and the community center have not set up solar heat collector, utilize the area for introducing solar cells, solar power generation can meet the approximately 43.9% of the total power demand. In addition, general medical facility and sports and health facility are introduced the gas engine, the power generation of CGS accounts for 32.5% of the total power load. In cases 2 and 3, supplying 63.6% of the total power load when introduced the 165 kW gas engine, solar power generation accounts for 30.2%. For case 4, because introduces 100 kW fuel cell and 70 kW gas engine, the power generation of fuel cell and gas engine respectively occupy 49.3% and 15.0% of total power load. Case 5 use the operation method of "heat tracking mode", so power generation amount of gas engine is the lowest, approximately accounts for 20.6% of total power load.

Viewed from the above analysis, compare the utilization of district energy system, most of the power load of the life convenience facility can be made on site. Particularly, it is planned centralized case of installing district energy centers, when utilizing the operation method of "electricity tracking mode", more than 90% electricity can be supplied from district energy system. In addition, it was found that utilize the roof of each facilities lead to the introduction effect of solar cell is excellent.

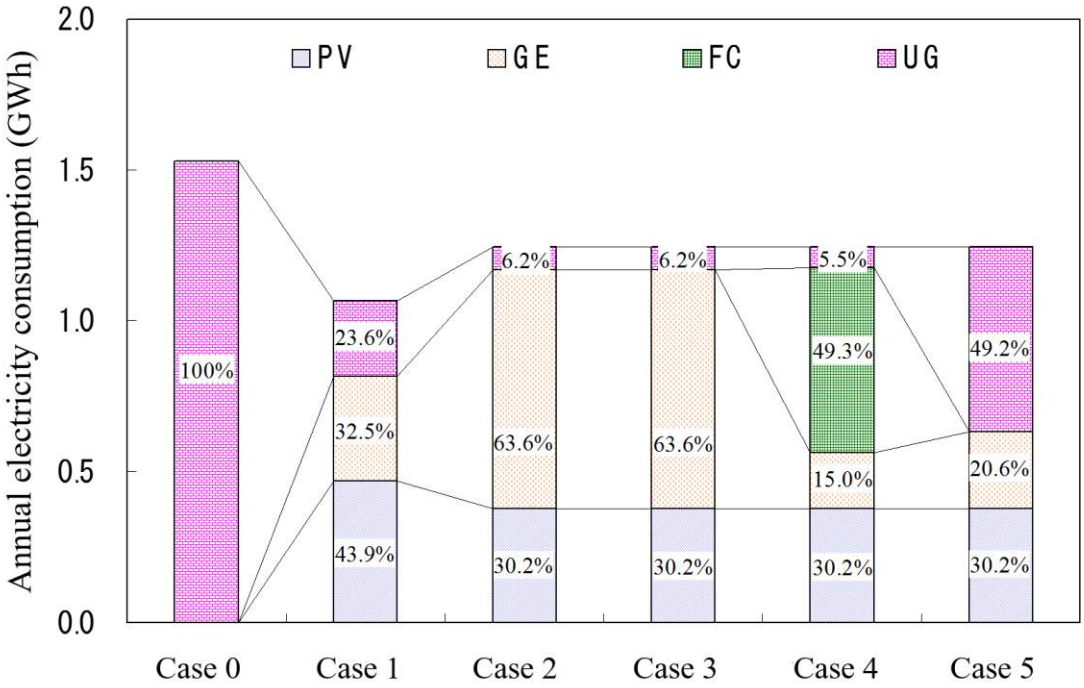


Figure 6-2-2 Composition of annual electricity consumption

Figure 6-2-3 ~ 6-2-6 shows the composition of a monthly electricity consumption of case 1, case 2 and 3, case 4 and case 5.Viewed from whole figures, electricity load of the interim period (April, May, October and November) is less than heating period and cooling period, total power load is provided by district energy system (Case 1-4). Since the electricity load of cooling period is the maximum value, also power purchase amount from the power grid system is more than other seasons.

Specifically, since the capacity of case 2-4 of the district energy system is large, most of the monthly electricity demand of life convenience facility is provided by the distributed energy sources. Consider about the amount of power generation by the solar cells, winter power generation is less than other seasons in all cases.

Also in case 4, solar power, fuel cell, gas engine, power grid is utilized in this sequence, the power generation amount of the gas engine in the interim period is limited. In case 5, utilize the operation method of "heat tracking mode", so the heat demand of the interim period is less, the amount of power generation from gas engine is also limited.

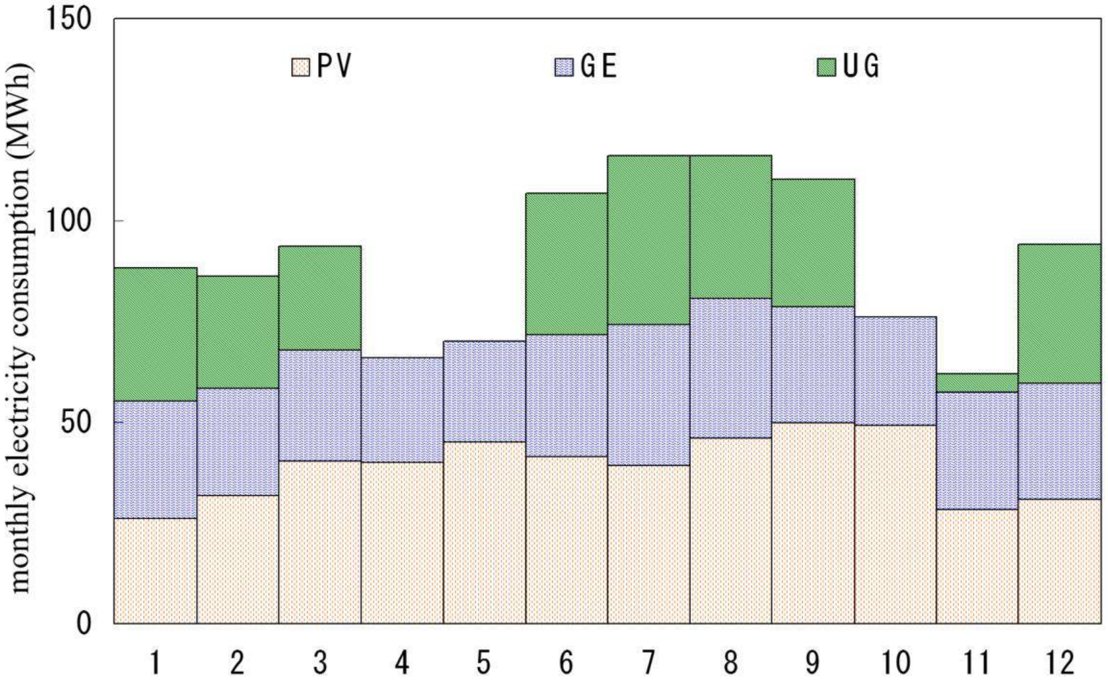


Figure 6-2-3 Composition of monthly electricity consumption (Case 1)

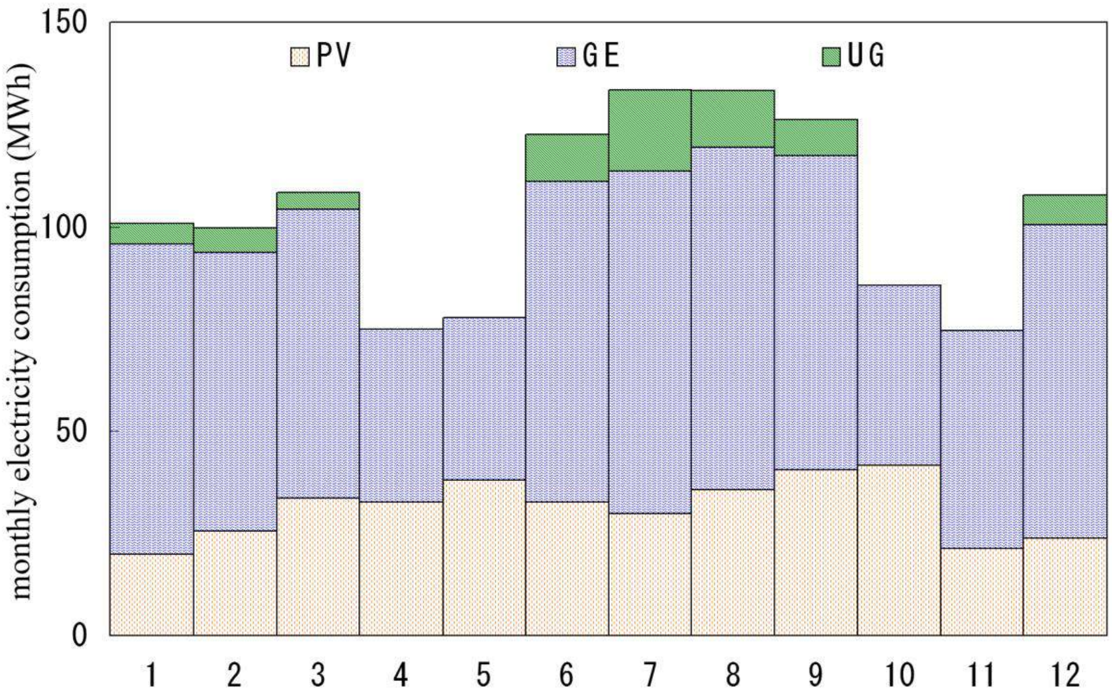


Figure 6-2-4 Composition of monthly electricity consumption (Case 2 and 3)

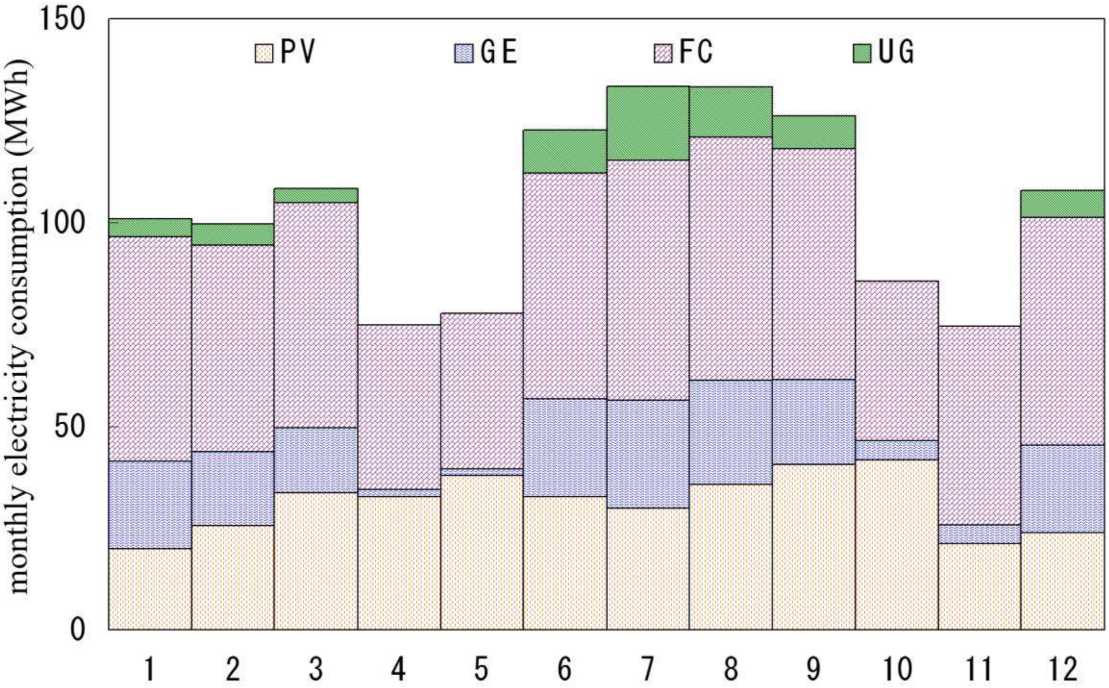


Figure 6-2-5 Composition of monthly electricity consumption (Case 4)

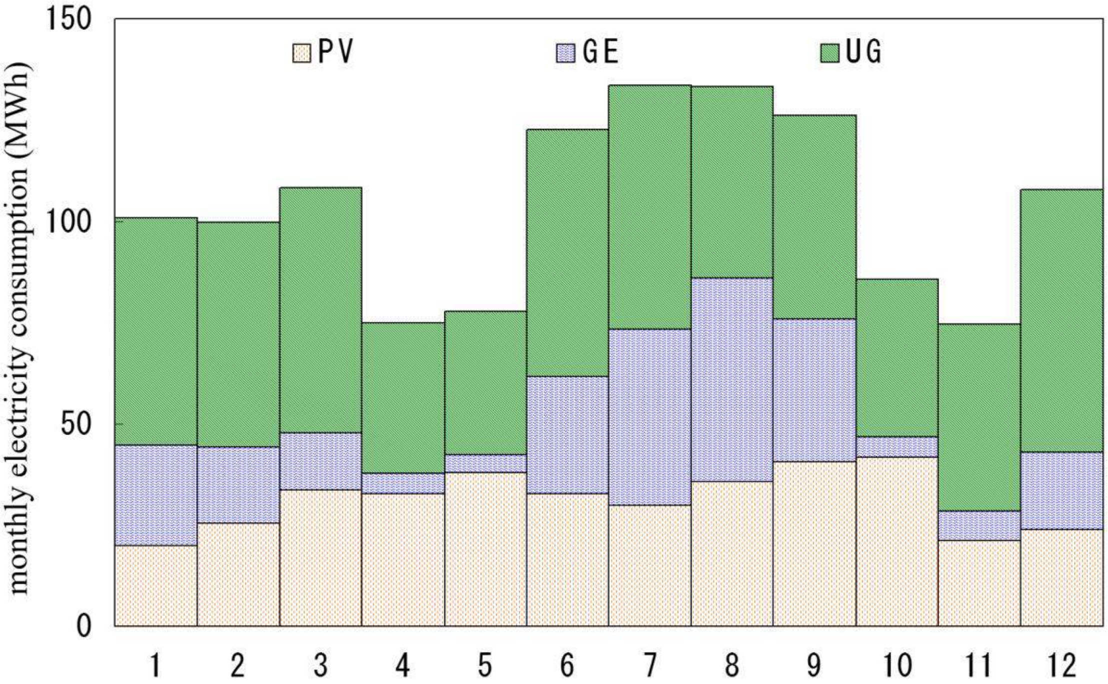


Figure 6-2-6 Composition of monthly electricity consumption (Case 5)

Taking January as example, we analyze the composition of hourly electricity consumption in each case as following. Figure 6-2-7~6-2-10 shows the composition of hourly electricity consumption in the case 1, case 2 and 3, case 4 and case 5. In this study, because aim at “zero carbon city block”, we need to use the maximum of natural energy. Solar power generation, fuel cell, gas engine, power grid is utilized in this sequence to supply district electricity demand. From the figure to know that power generation amount of solar power generation during the daytime (particularly 10:00 to 15:00) is large, it is not generate electricity at night. In case 1, because the capacity of CGS is relatively small, we need to purchase the electricity from power grid even the electricity demand is small at night. On the other hand, in cases 2 and 3, the gas engine operate one day can meet most electricity demand of life convenience facility. But it’s necessary to purchase electricity from power grid between A.M. 8:00 to 10:00 and P.M. 14:00 to 7:00.

Also, in case 4, we introduce the fuel cell to operate fixed load in daytime, operate partial load in nighttime to meet the total electricity demand. On the other hand, gas engine is operated only during the daytime. Case 5 utilize “heat tracking mode”, the operation level of gas engine is smaller than the other cases. The most district electricity demand is supplied by power grid.

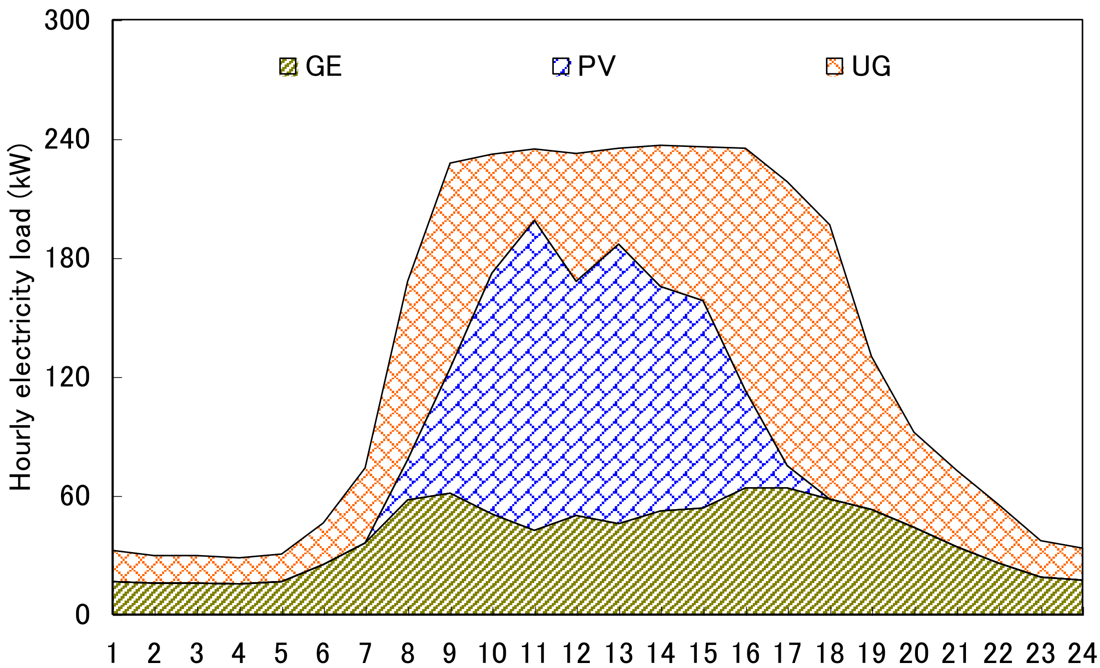


Figure 6-2-7 Composition of hourly electricity consumption (Case 1)

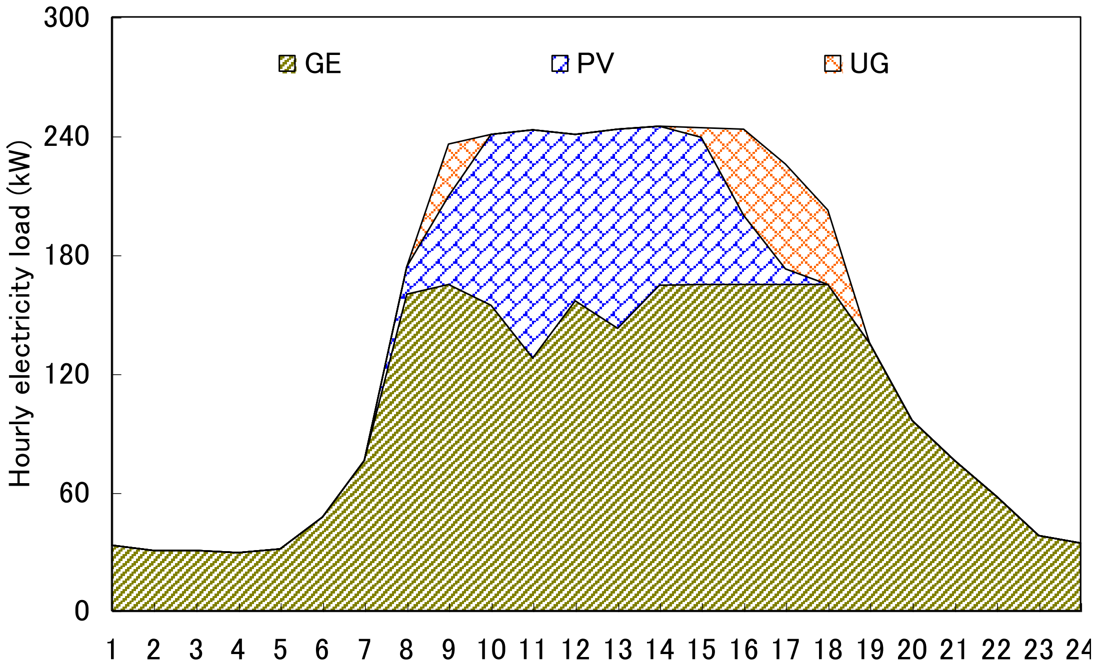


Figure 6-2-8 Composition of hourly electricity consumption (Case 2 and 3)

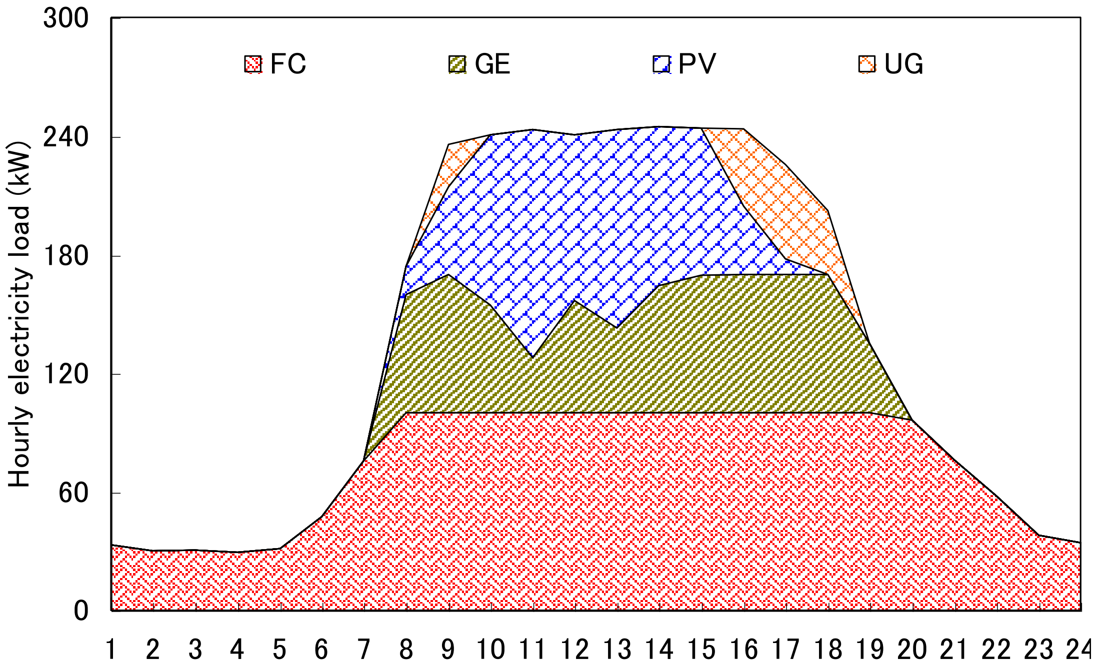


Figure 6-2-9 Composition of hourly electricity consumption (Case 4)

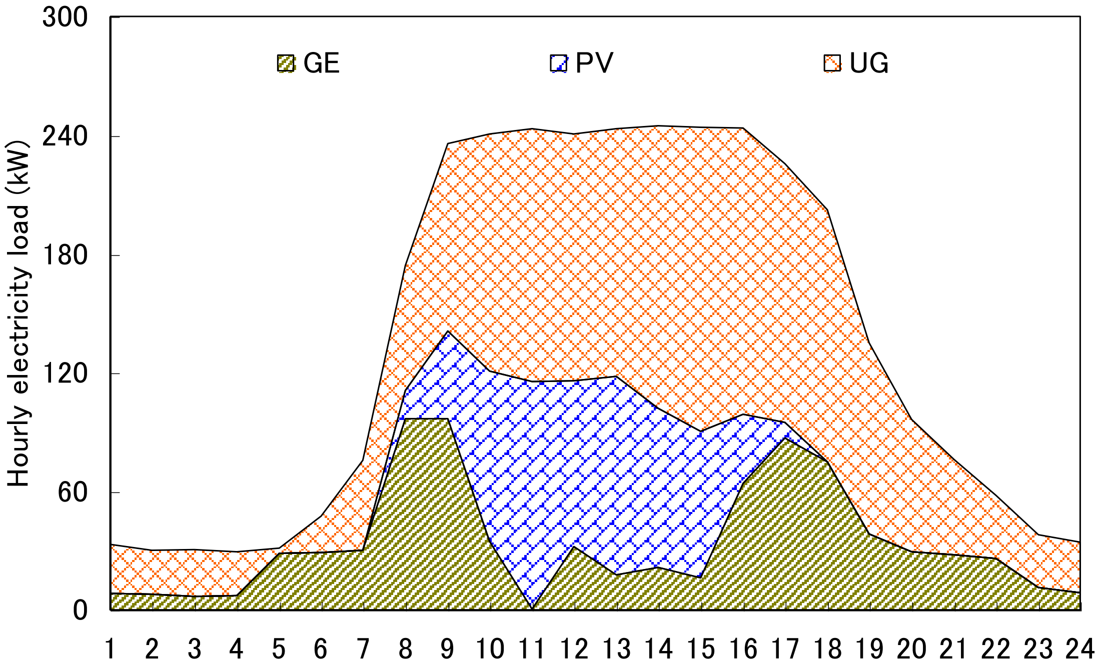


Figure 6-2-10 Composition of hourly electricity consumption (Case 5)

(2) Composition of heat consumption

For important merit of district energy system including CGS is the utilization of waste heat, so it is necessary to analyze the composition of district heat consumption. Because aim at "zero carbon city block", give priority to utilize natural energy to supply heat demand. In other words, we use solar thermal, CGS waste heat, city gas to meet heat demand in this order. As shown in Figure 6-2-11, introduce building multi-split air conditioner in case 0, so use electricity to meet the cooling and heating load. Case 1 is a distributed facility case, and the capacity of solar thermal collectors and CGS is small, solar heat, CGS waste heat and city gas respectively accounts for 15.4%, 21.7% and 62.9% of total heat load. On the other hand, since the heat load pattern of solar heat and CGS waste heat are not match, unused amount of annual solar heat and CGS waste heat has reaches 52 MWh and 243 MWh.

In case 2, part of the facility is distributed equipment to supply heating and cooling load, so it has the maximum unused amount of waste heat. Specifically, solar heat, CGS waste heat and city gas respectively accounts for 39.4%, 31.2% and 29.4% in total heat load. Also the case 3 is a centralized facility case, solar heat and CGS waste heat supply approximately 93.6% of total heat load, and city gas meets the remaining part of total heat load. Case 4 introduce the fuel cell (high power generation efficiency, low heat-power ratio), the proportion of CGS waste heat is less than Case 2. In addition, because case 5 utilize “heat tracking mode”, all of the CGS waste heat is utilized to supply about 40% of total heat load.

About the concrete utilization situation of waste heat, figure 6-2-12 shows the utilization ratio of solar heat and CGS waste heat in each case. Viewed from whole cases, except case 5 which adopt “heat tracking mode”, it was found that the utilization ratio of solar heat is higher than utilization ratio of CGS waste heat. About utilization ratio of solar heat, case 1-5 respectively accounts for 78.5%, 65.8%, 74.9%, 74.9% and 74.9%, utilization ratio of CGS waste heat respectively accounts for 52.4%, 25.5%, 39.9%, 45.2% and 100%. In other words, when using the operation pattern of “electricity tracking mode”, it was found that utilization ratio of waste heat is limited. So when using “heat tracking mode”, all of the waste heat can be utilized.

Viewed from above analysis, when introducing of district distributed energy system, solar heat and CGS waste heat can supply more than 90% of total heat load of all the facilities (case 3 and case 4). However, because it does not take the balance of demand side and supply side, effective utilization of waste heat in the future become an important point of the district energy system plan.

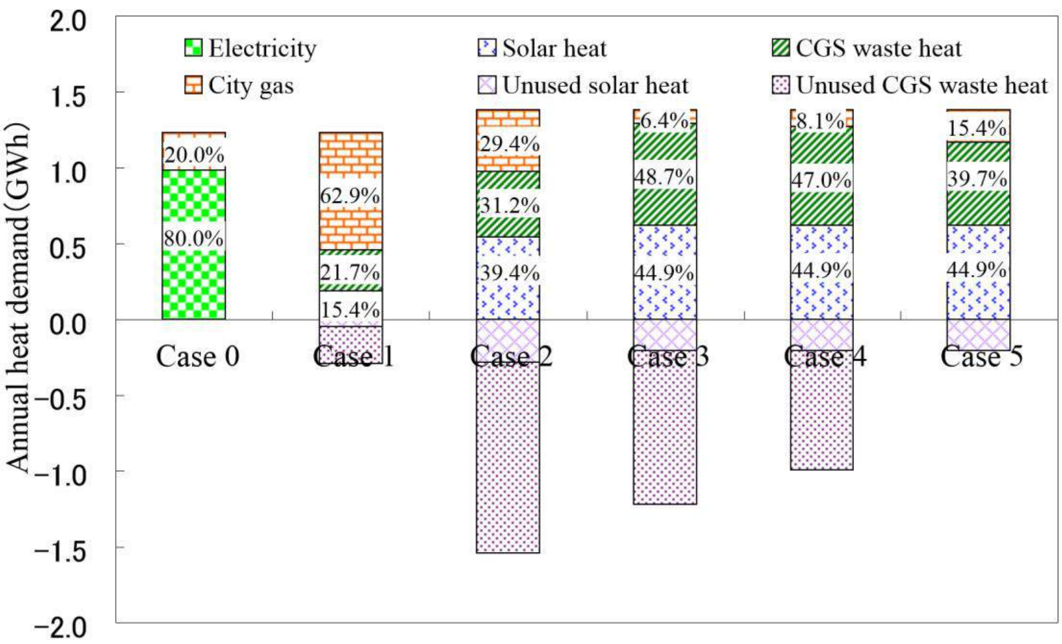


Figure 6-2-11 Composition of annual heat consumption

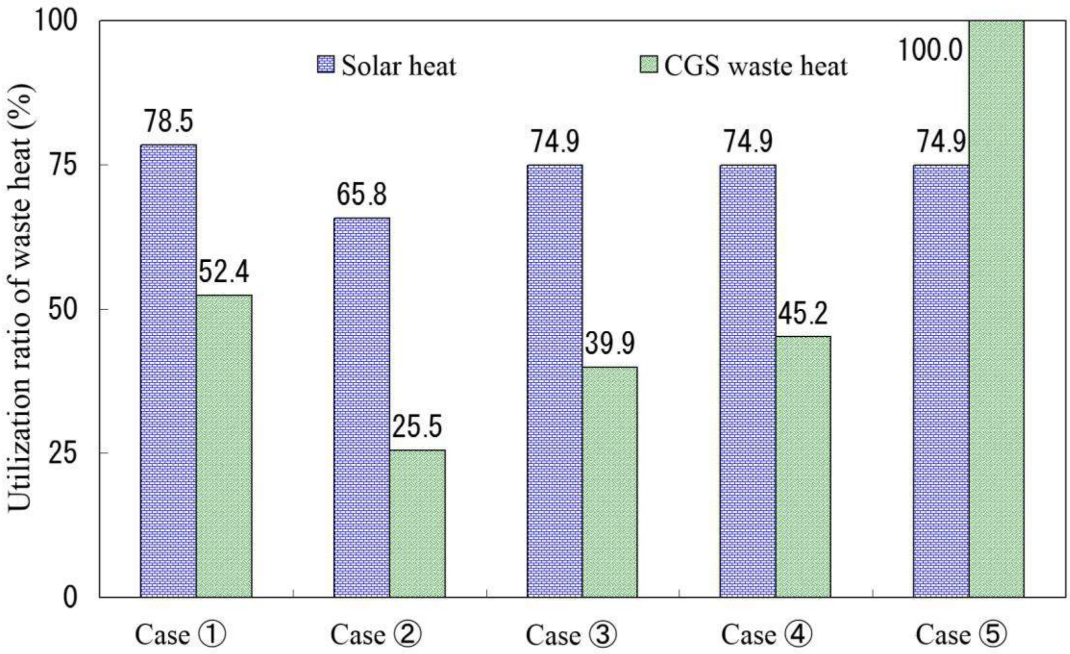


Figure 6-2-12 Utilization ratio of waste heat

In order to understand the features of monthly heat supply, Figure 6-2-13 to Figure 6-2-18 shows the composition of monthly heat demand in case 0 to case 5. Viewed from whole cases, because the heat demand of summer is large (especially cooling demand), solar heat and CGS waste heat can meet part of heat demand, remaining part is supplied by city gas. On the other hand, heat demand of centralized equipment case is supplied by all of solar heat and CGS waste heat in winter and interim period. About the usage situation of solar heat, all of the solar heat is utilized in summer, and the unused quantity has a lot in interim period. In addition, the usage situation of CGS waste heat is very bad in interim period and winter, unused quantity is greater than usage quantity.

Viewed from above analysis, usage situation of waste heat has changed according to season. Use ratio of summer is relatively high, usage situation in interim period and winter is not good. In the future, utilize the heat storage need to take into account the seasonal movement. It is a direction of effective utilization of waste heat.

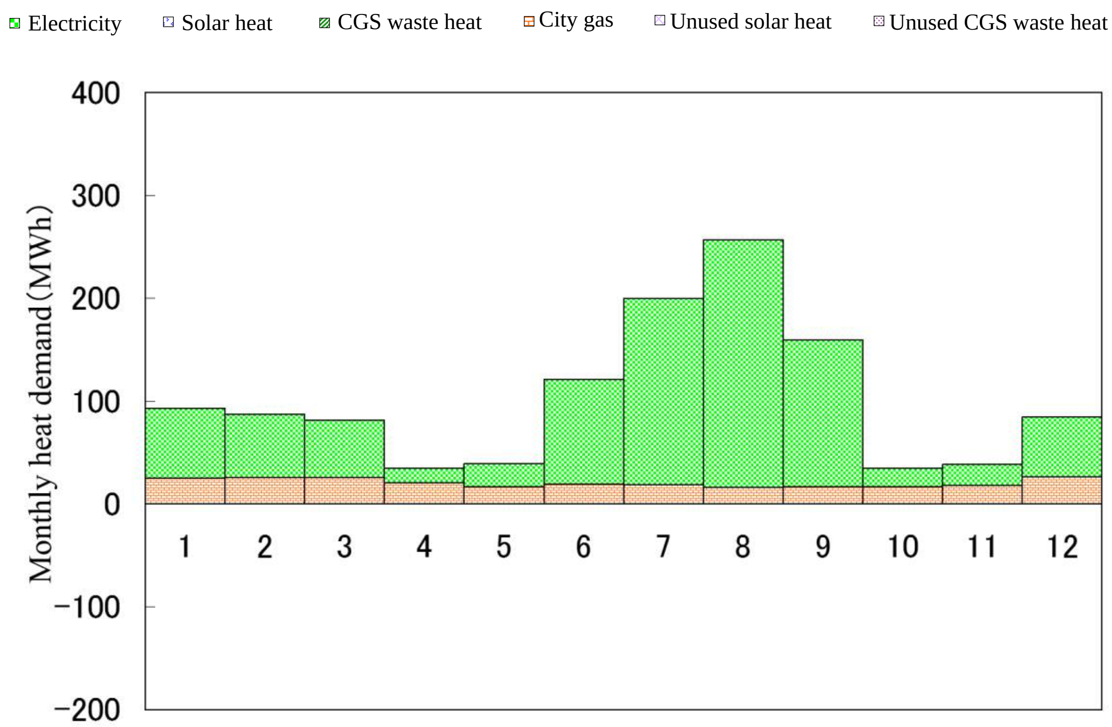


Figure 6-2-13 Composition of monthly heat demand (Case 0)

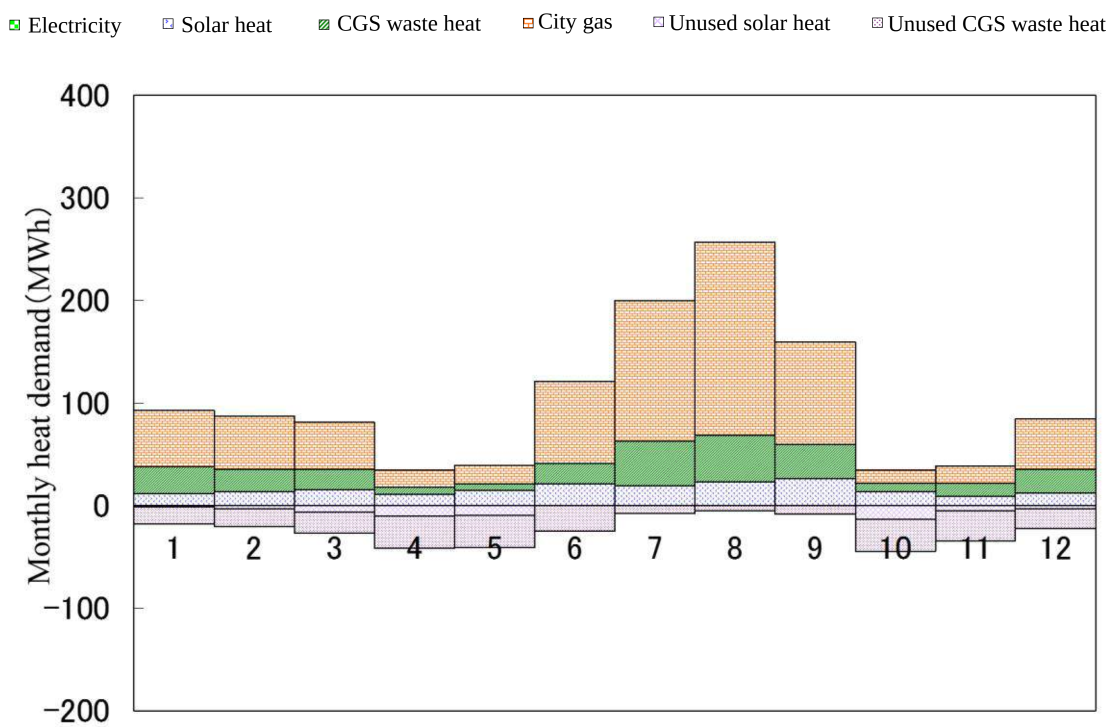


Figure 6-2-14 Composition of monthly heat demand (Case 1)

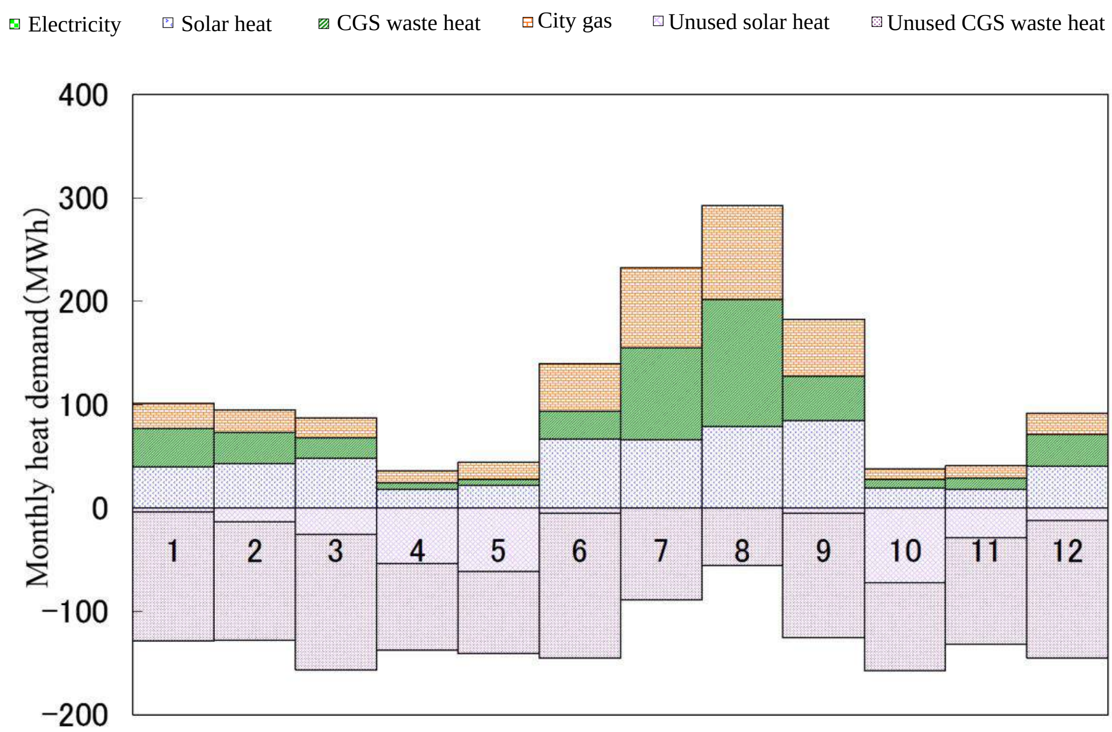


Figure 6-2-15 Composition of monthly heat demand (Case 2)

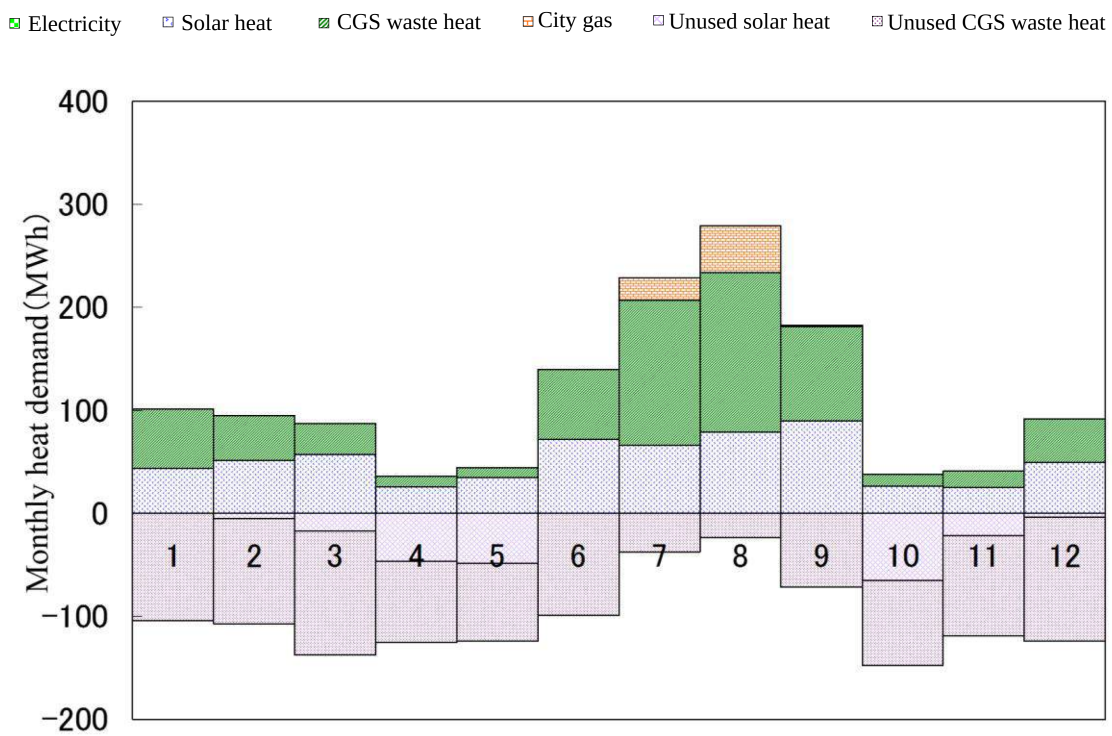


Figure 6-2-16 Composition of monthly heat demand (Case 3)

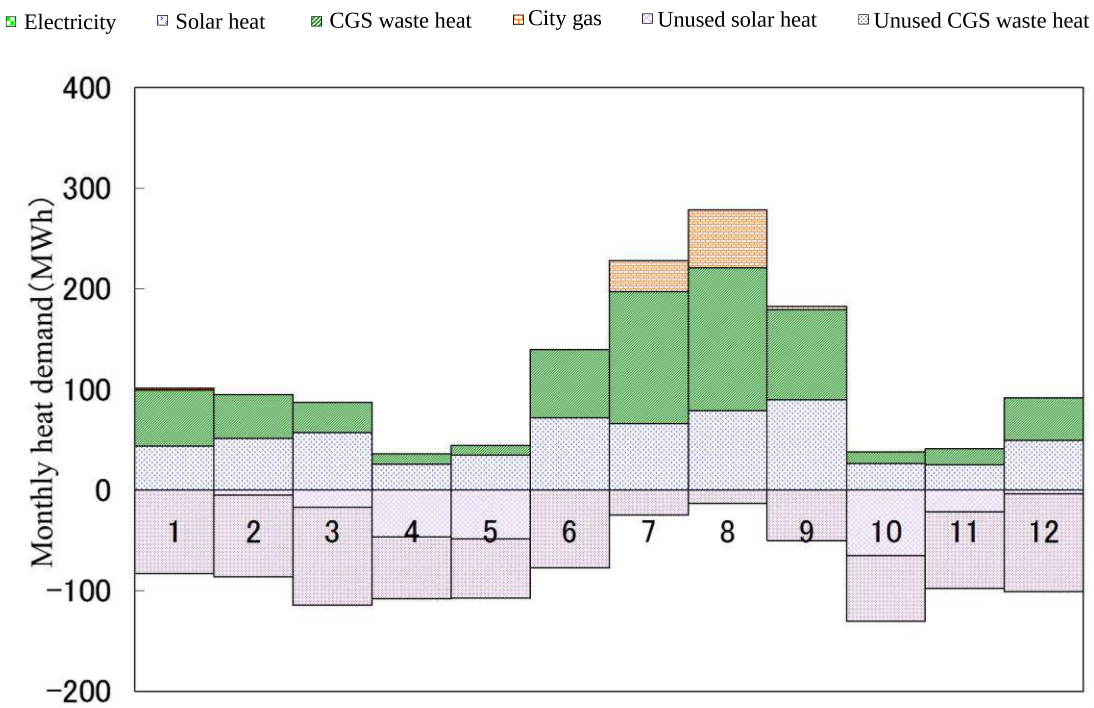


Figure 6-2-17 Composition of monthly heat demand (Case 4)

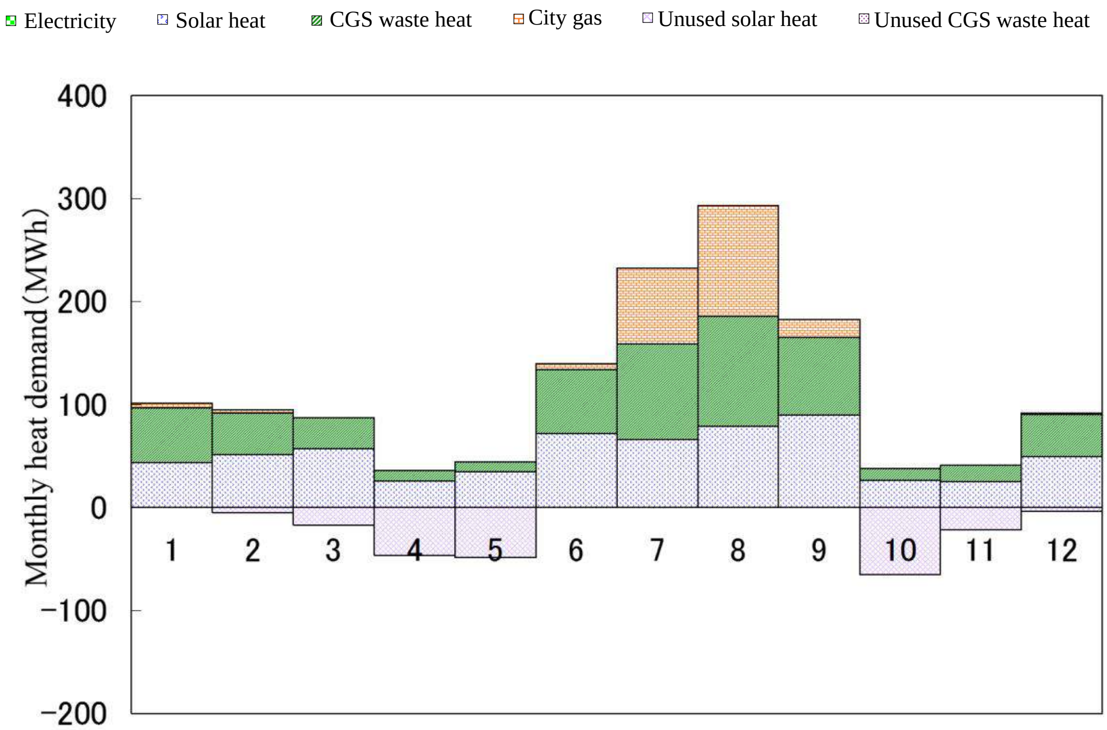


Figure 6-2-18 Composition of monthly heat demand (Case 5)

When we understand the features of monthly heat demand, we also need to utilize the waste heat more effectively, it is necessary to analyze the composition of hourly heat demand. Figure 6-2-19 to figure 6-2-24 shows the composition of hourly heat load in January in each case. Viewed from whole cases, in part of distributed case and centralized case, solar heat can meet most of the heat load during daytime, main heat load during nighttime is supplied by CGS waste heat. Analyze the usage situation of waste heat, the heat load in January is quite large, solar heat has been used around in all cases. However, except case 5 which adopt "heat tracking mode", utilization ratio of CGS waste heat is very low in daytime from case 1 to case 4, and most of waste heat is lost. In addition, case 3 as an exception, all heat demand is supplied by waste heat, and the city gas is not used at all.

From above analysis, in order to use heat effectively, it is necessary to consider about the balance of solar heat and CGS waste heat. In addition, according to the viewpoint of effective utilization of waste heat, operation method "electricity tracking mode" is found to be not very effective. In fact, the capacity of the equipment also can affect the situation of heat utilization, and it is necessary to consider the operation pattern at the same time.

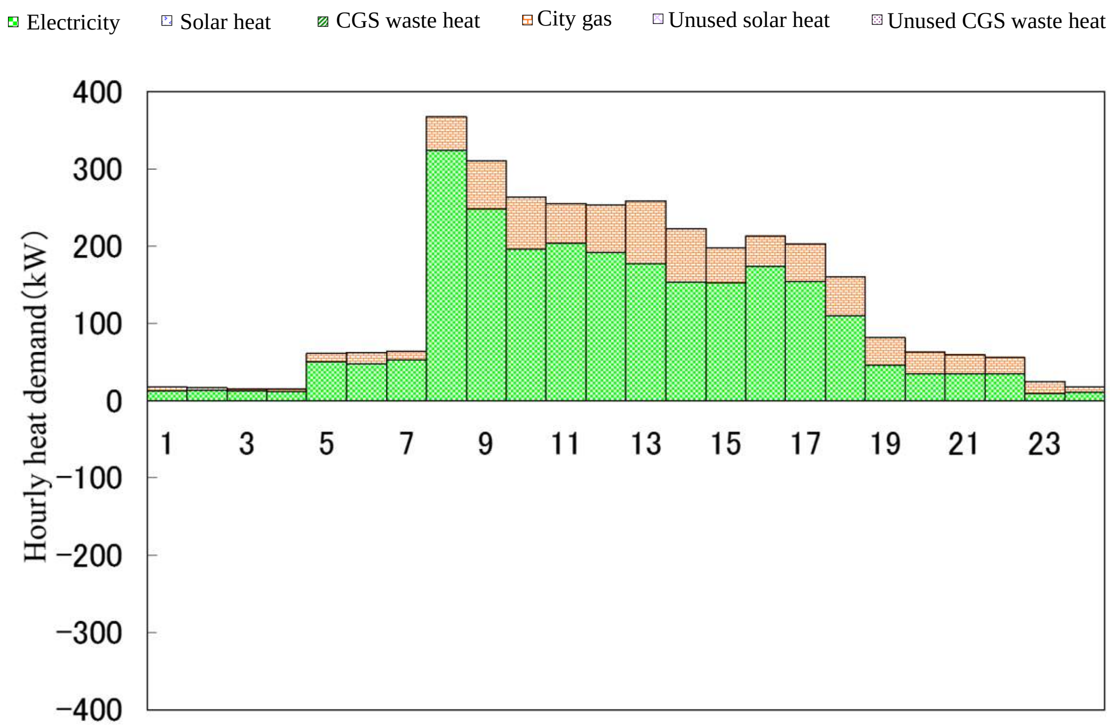


Figure 6-2-19 Composition of hourly heat demand (Case 0)

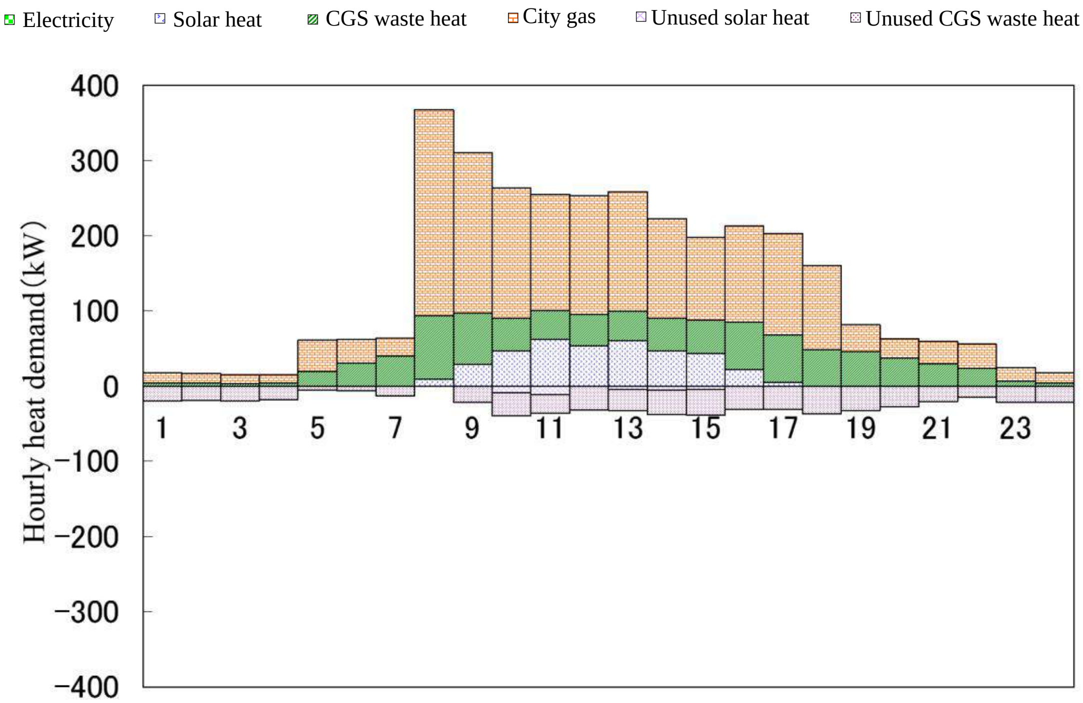


Figure 6-2-20 Composition of hourly heat demand (Case 1)

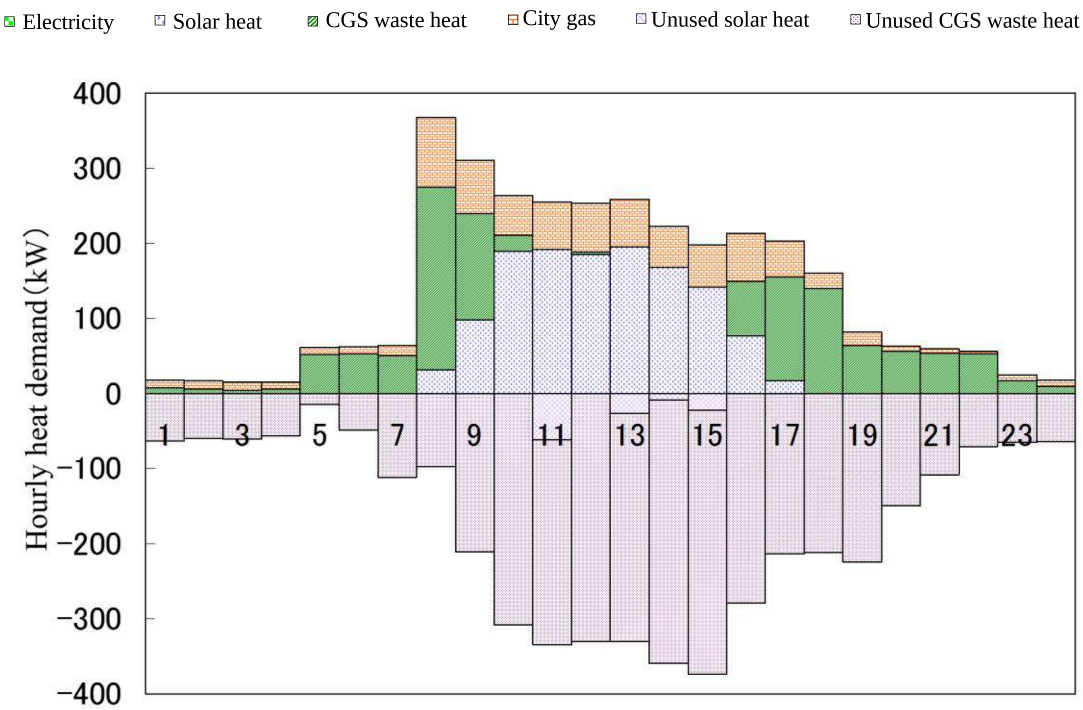


Figure 6-2-21 Composition of hourly heat demand (Case 2)

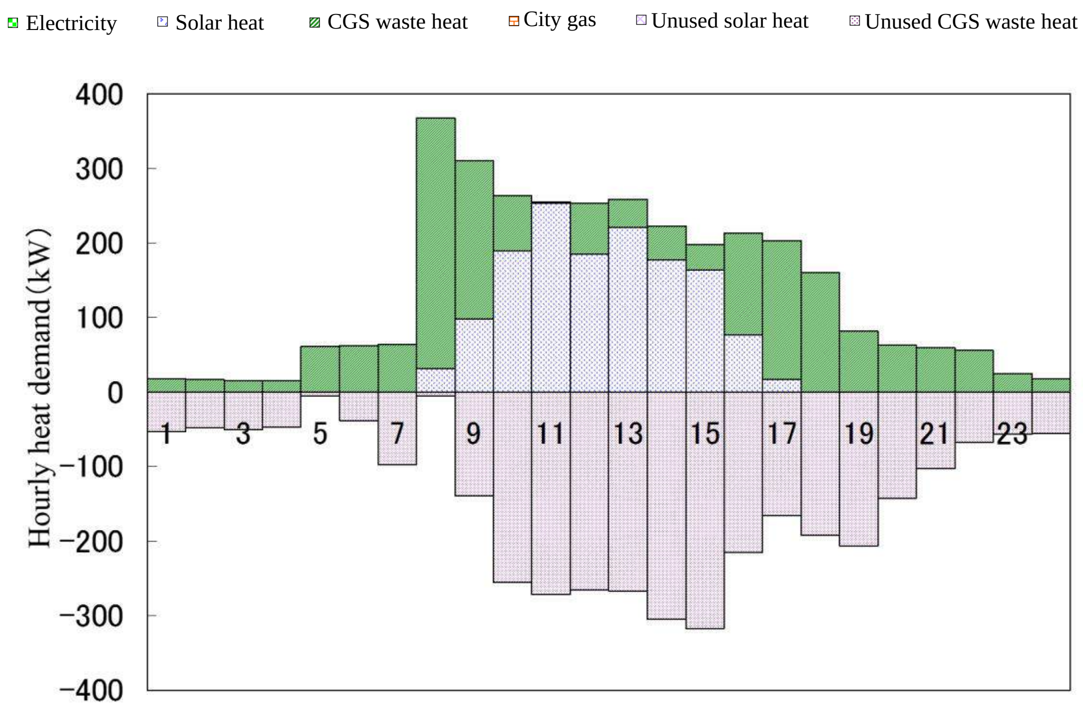


Figure 6-2-22 Composition of hourly heat demand (Case 3)

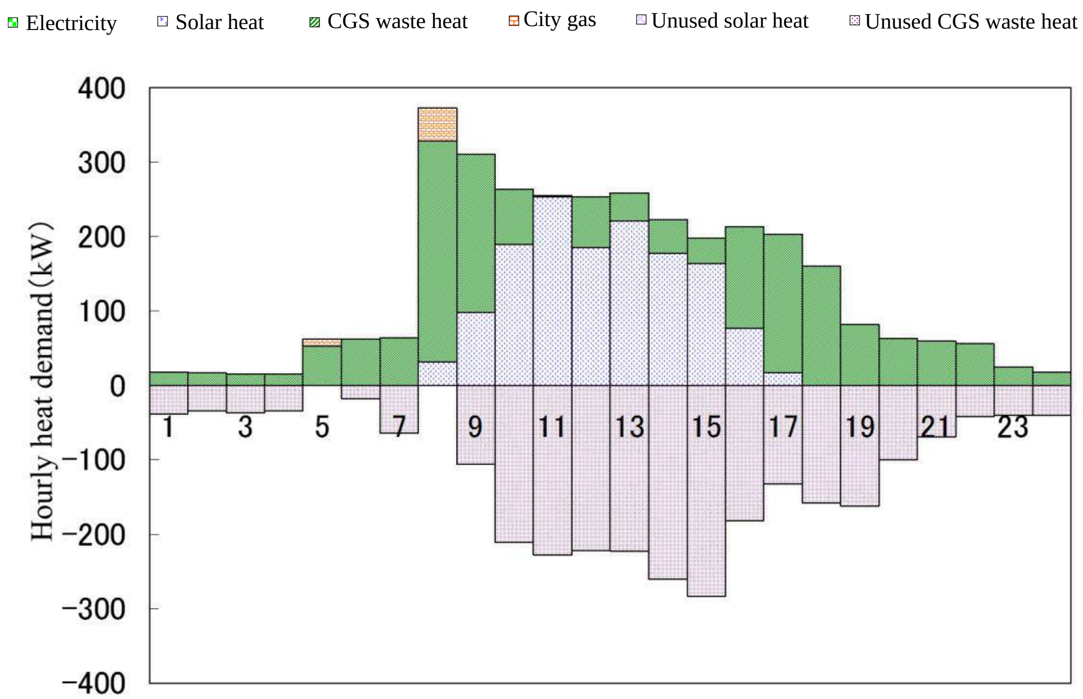


Figure 6-2-23 Composition of hourly heat demand (Case 4)

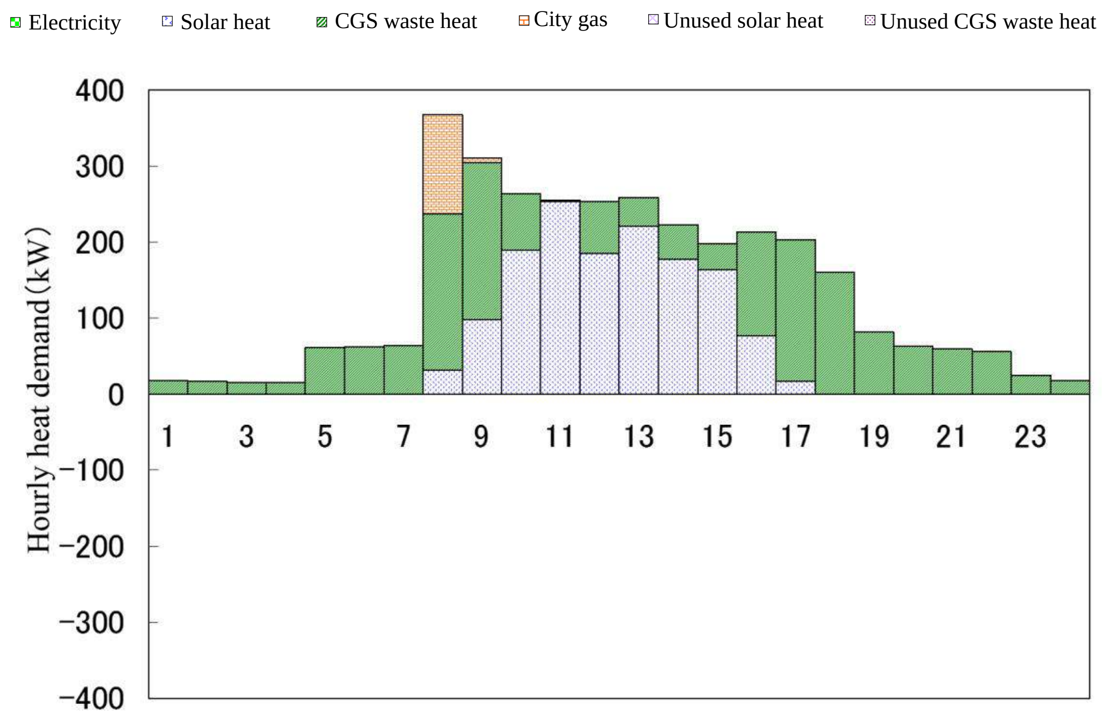


Figure 6-2-24 Composition of hourly heat demand (Case 5)

6.3 Energy conservation assessment

In this study, we consider CGS as "co-generation", not only generate "electricity" also it is a system that attempt to effectively utilize "waste heat" with power generation. It can effectively utilize electricity and heat, there is a potential to become a powerful energy saving equipment, But if cannot balance electricity and heat demand will become increasing energy usage rather than energy saving.

In other words, it is expected to achieve a high energy efficiency in district energy system when utilizing CGS and solar energy. Therefore, energy conservation has become a most important evaluation index in district energy system planning. In general, energy conservation is an index for energy evaluation of entire building, relatively evaluate the adoption of the conventional system and district energy system to compare the annual primary energy consumption. In this study, formula of energy conservation is shown as following.

Various energy Consumption of conventional system is the sum of gas consumption and power system.

Energy consumption of conventional system:

$$Q_E^{Conv} = G^{Conv} + P_{Utility}^{Conv} / \eta_E^{Utility} \quad (1)$$

And,

Q_E^{Conv} = energy consumption of conventional system

G^{Conv} = gas consumption of conventional system

$P_{Utility}^{Conv}$ = power consumption of conventional system

$\eta_E^{Utility}$ = power generation efficiency of power system

Various energy Consumption of district energy system is the sum of gas consumption and power of district energy system.

Energy consumption of district energy system:

$$Q_E^{DES} = G^{DES} + P_{Utility}^{DES} / \eta_E^{Utility} \quad (2)$$

And,

Q_E^{DES} = energy consumption of district energy system

G^{DES} = gas consumption of district energy system

$P_{Utility}^{DES}$ = power consumption of district energy system

The reduction rate of annual primary energy consumption:

$$PERR = \frac{Q_E^{Conv} - Q_E^{DES}}{Q_E^{Conv}} = \frac{(G^{Conv} + P_{Utility}^{Conv} / \eta_E^{Utility}) - (G^{DES} + P_{Utility}^{DES} / \eta_E^{Utility})}{G^{Conv} + P_{Utility}^{Conv} / \eta_E^{Utility}} \quad (3)$$

And,

$PERR$ = reduction rate of annual primary energy consumption

Based on the above formulas, Figure 6-3-25 shows the annual primary energy consumption and reduction rate in each case. Compare with conventional system (case 0), reduction rate of annual primary energy consumption from case 1 to case 5 is 26.1%, 32.4%, 37.6%, 45.2% and 39.1%. Viewed from total consumption, each case adopt “electricity tracking mode”, and the main emission source is city gas, next is power system. On the other hand, when adopting “heat tracking mode” (case 5), power system has become the main emission source.

Also, all of facilities are introduced distributed equipment, it is found that there have significant energy saving effect. case 4 introduce fuel cell that has the excellent energy saving effect, and next is case 5 adopt “heat tracking mode” and case 3 adopt “electricity tracking mode”. In other words, introduce the district energy system can obtain excellent energy saving effect.

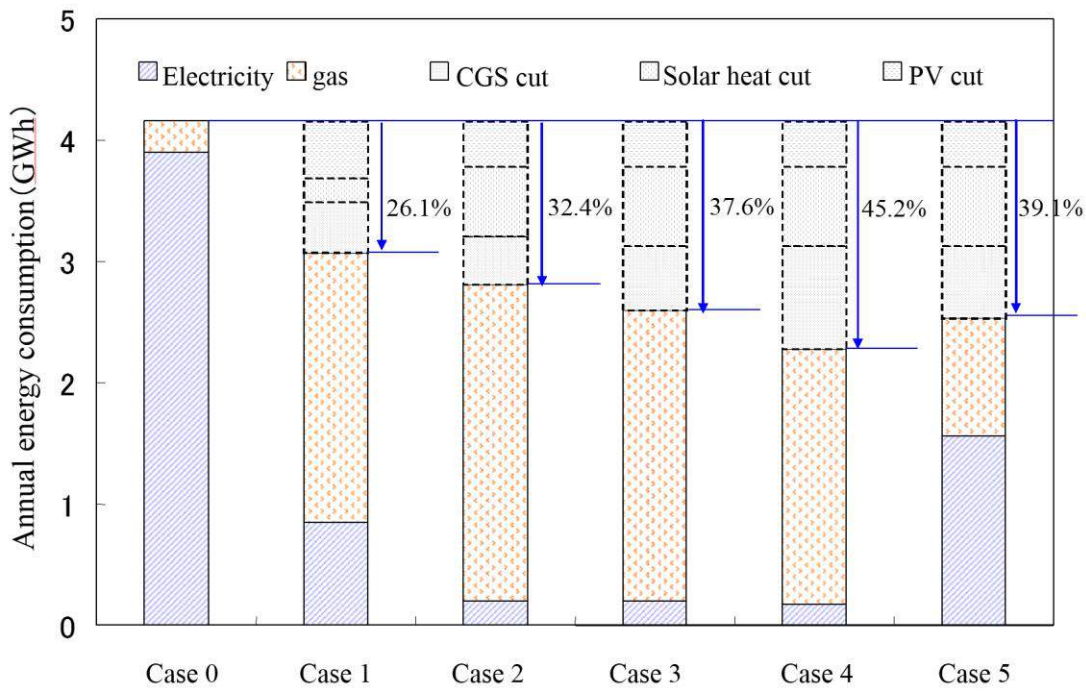


Figure 6-3-25 Annual primary energy consumption

6.4 Environmental assessment

Energy conservation of district energy system can be expected that CO_2 has a large reduction effect. Therefore, consider that he global level of environmental issues is closed up, the social significance of the district energy system as an important evaluation indication of CO_2 reduction.

In this study, evaluation of environment is that evaluate CO_2 emissions reduction rate of annual district energy system for conventional system. Evaluation objective is not just the buildings that generate CO_2 by CGS and cold/warm water generator, also consume the electricity that generate the CO_2 of commercial electricity in power plant. In the latter case, the commercial electricity is composed of variety power source, and its operation is complicated, utilize the mean value of total power when calculating the absolute value of emissions, calculate reduction need to use emissions original unit of thermal power plant.

Specifically, the CO_2 emissions of conventional system is the sum of gas CO_2 emissions and power CO_2 emissions. And CO_2 emissions of the district energy system is the sum of gas CO_2 and power CO_2 emissions, the gas consumption is the sum of CGS gas usage quantity and gas direct combustion quantity. In addition, the reduction rate is a difference value between the CO_2 emissions of conventional system and the CO_2 emissions of district energy system, and it obtain the proportion of CO_2 emissions of conventional system.

CO_2 emissions of conventional system:

$$EX_{CO2}^{Conv} = ex_{CO2}^{Gas} \times G^{Conv} + ex_{CO2}^{Pow} \times P_{Utility}^{Conv} \quad (4)$$

And,

EX_{CO2}^{Conv} = CO_2 emissions of conventional system

ex_{CO2}^{Gas} = CO_2 emissions unit of city gas

ex_{CO2}^{Pow} = CO_2 emissions unit of power system

CO_2 emissions of district energy system:

$$EX_{CO2}^{DES} = ex_{CO2}^{Gas} \times G^{DES} + ex_{CO2}^{Pow} \times P_{Utility}^{DES} \quad (5)$$

And,

EX_{CO2}^{DES} = CO_2 emissions of district energy system

Reduction rate of CO_2 emissions:

$$CERR = \frac{EX_{CO2}^{Conv} - EX_{CO2}^{DES}}{EX_{CO2}^{Conv}}$$

$$= \frac{(ex_{CO2}^{Gas} \times G^{Conv} + ex_{CO2}^{Pow} \times P_{Utility}^{Conv}) - (ex_{CO2}^{Gas} \times G^{DES} + ex_{CO2}^{Pow} \times P_{Utility}^{DES})}{ex_{CO2}^{Gas} \times G^{Conv} + ex_{CO2}^{Pow} \times P_{Utility}^{Conv}} \quad (6)$$

Based on the above calculation formulas, Figure 6-4-26 shows utilization situation of full power coefficient, and the annual CO_2 emissions in each case. Compared with conventional system (Case 0), annual CO_2 emissions from case 1 to 5 has been reduced in each case. In other words, the introduction of district energy system is obtained excellent environmental effect.

Figure 6-4-27 shows the annual CO_2 emissions and the reduction rate in each case when adopt the thermal coefficient. Compare with conventional system (Case 0), reduction rate of the annual CO_2 emissions from case 1 to case 5 respectively increase 43.4%, 53.2%, 56.6%, 61.9% and 46.0%. When using thermal coefficient, reduction rate of the annual CO_2 emissions of each case that adopt "electricity tracking mode" can increase more than 20%.

When introducing the district energy system, effective utilization of waste heat is an important point. Unused solar heat and CGS waste heat that assume to cascade use low-

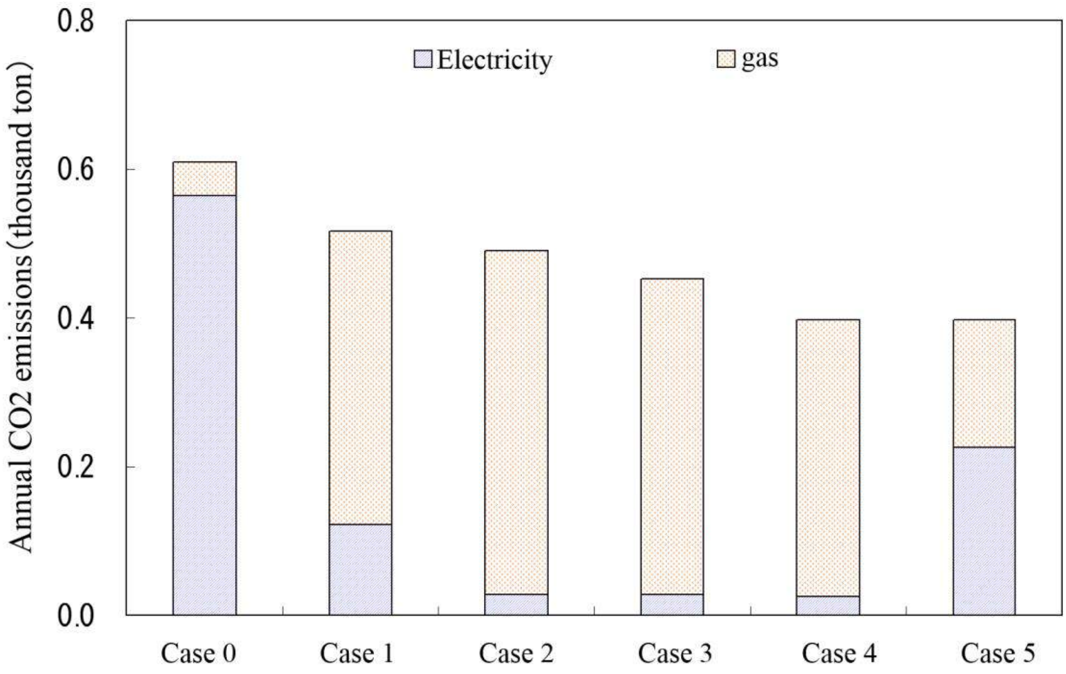


Figure 7-4-26 Annual CO_2 emissions (power coefficient)

temperature water binary power generation, analyze the reduction rate of annual CO_2 emissions. As shown in Figure 6-4-28, annual CO_2 emissions can be reduced almost more than half. In particular, the centralized case adopt the "electricity tracking mode" can obtain more than 66% reduction rate.

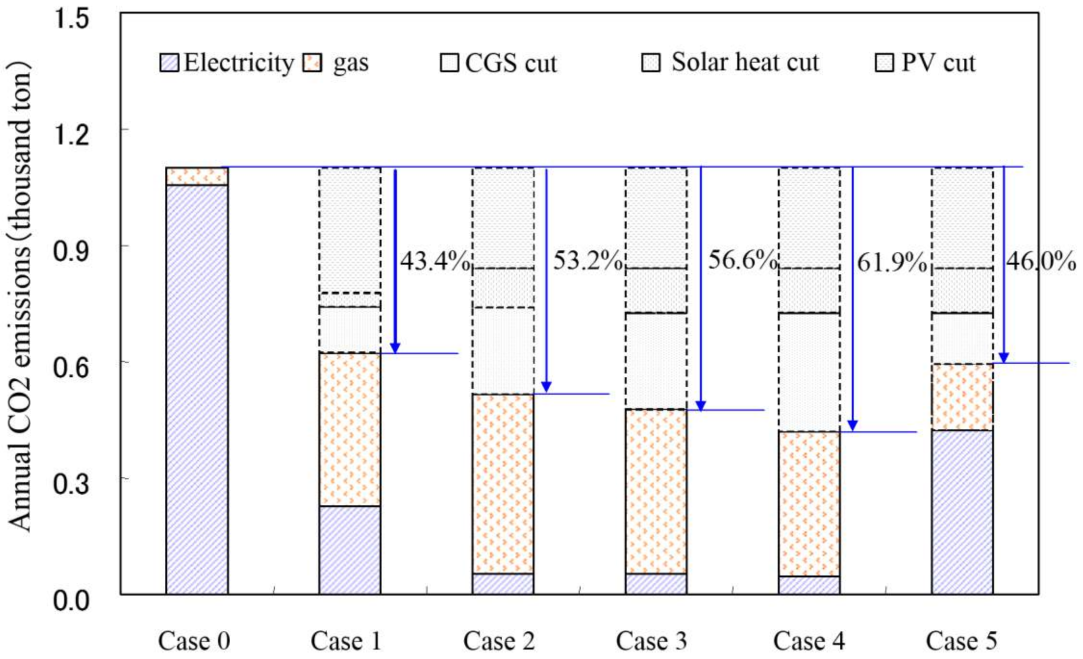


Figure 7-4-27 Annual CO_2 emissions (thermal coefficient)

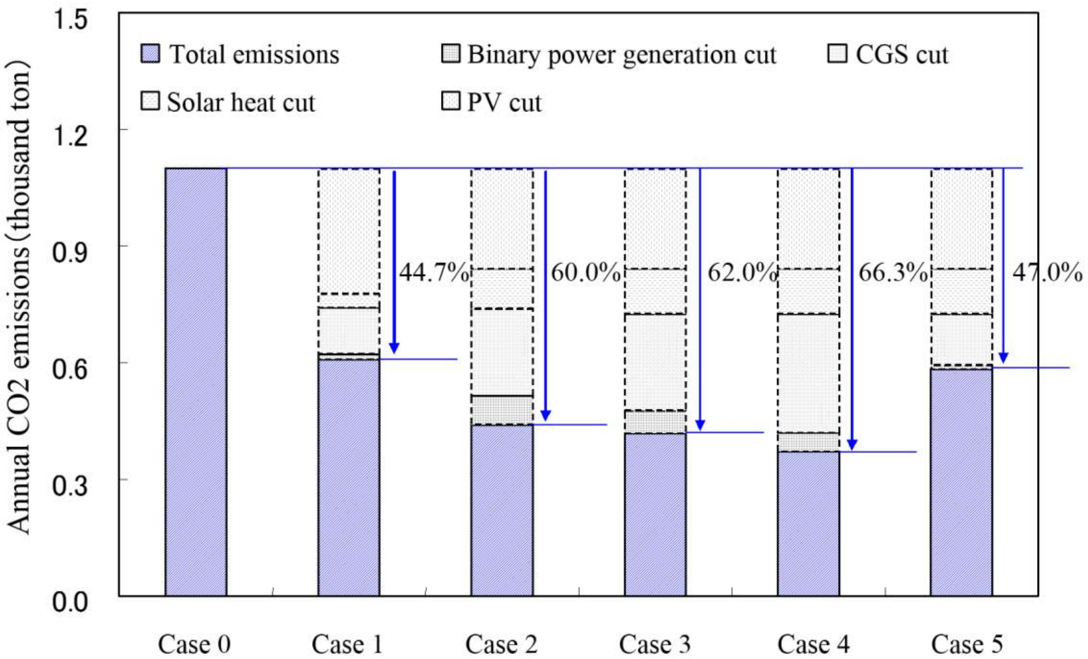


Figure 7-4-28 Annual CO_2 emissions with effective utilization waste heat (thermal coefficient)

6.5 Economical assessment and results

Purpose of introducing the district energy system, it can be said that the economy is great concern from the user side and the point is energy saving. Although energy conservation and economy is closely related, system relate maximum energy saving does not necessarily become the maximum economy system.

Also evaluation of economy and energy conservation are also discussed in the relative evaluation compare with conventional system. In addition to calculating the conventional system and the initial cost of district energy system, after energy simulation to calculate the annual running cost. Then based on these costs, comprehensively judgment the gains or loss of cost by economic evaluation.

Annual cost of conventional system:

$$C^{Conv} = C_{Ini}^{Conv} + C_{Run}^{Conv} \quad (7)$$

And,

C^{Conv} = Annual cost of conventional system

C_{Ini}^{Conv} = Initial cost of conventional system

C_{Run}^{Conv} = Running cost of conventional system

Annual cost of district energy system:

$$C^{DES} = C_{Ini}^{DES} + C_{Run}^{DES} \quad (8)$$

And,

C^{DES} = Annual cost of district energy system

C_{Ini}^{DES} = Initial cost of district energy system

C_{Run}^{DES} = Running cost of district energy system

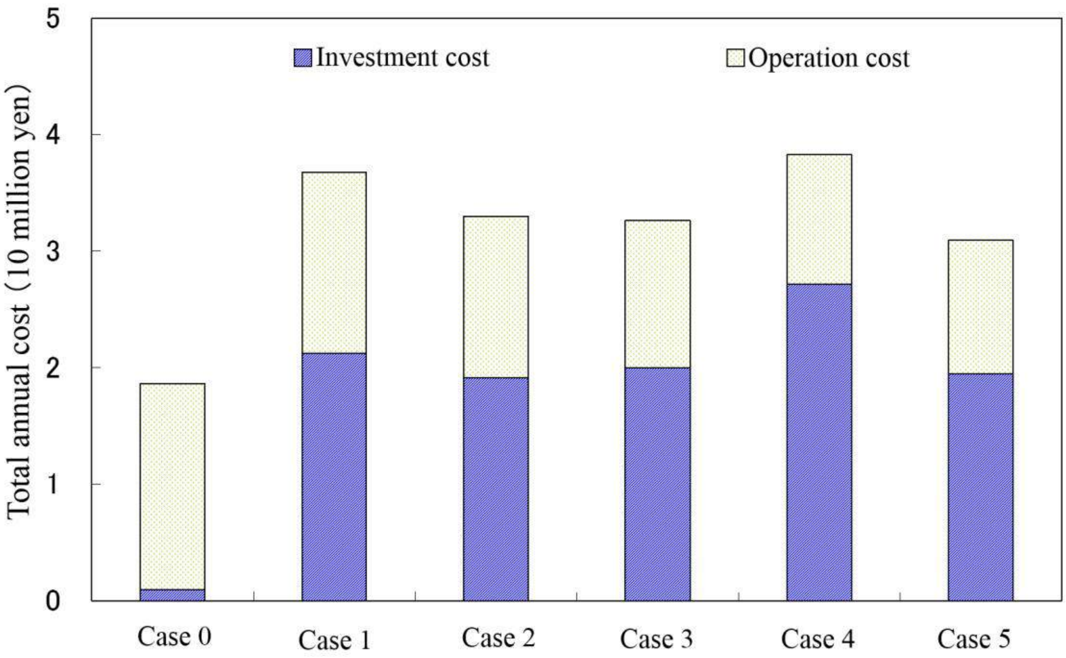


Figure 6-5-29 Total annual cost comparison

At last, we can know the effect result as following:

(1) As reasonable system planning, high efficiency district energy supply by utilizing natural energy and city gas that can supply more than 90% of the total energy load (electricity and heat) of life convenience facility. In centralized equipment case that adopt district energy center, solar power generation can meet 30% total power load, and 45% total heat load.

(2) Introduction the district energy system that has excellent energy saving and environment. In particular, introduce fuel cell in case 4 that the primary energy consumption and annual CO_2 emissions can be respectively reduced by about 45.2% and 61.9%.

(3) Effective utilization of waste heat has become an important point to influence the effect of district energy system. We propose a cascade use as power by the low temperature water binary power generation, the annual CO_2 emissions can be reduced more than 65%.

(4) Since the initial investment of distributed energy technology is high, district energy system do not have the economic benefits at this stage, it becomes an important problem to realize zero carbon.

CHAPTER SEVEN

CONCLUSION AND PROSPECT

7.1 Conclusion

Base on each chapter, we can know the conclusion as following:

1. The distributed energy resources system can improve the operation efficiency more than 30%.
2. When we set up the PV system in the detached house, the energy reduction rate can reach more than 15% and also have residual energy.
3. From case 3 to case 6, use hydrogen fuel cell, can cut down more than 30% CO_2 emissions.
4. If we introduce the PV, we can forecast that it has economics. If we introduce the FC, we can forecast that it almost do not have economics. FH can have highly effective environmental and energy conservation.
5. As reasonable system planning, high efficiency district energy supply by utilizing natural energy and city gas that can supply more than 90% of the total energy load (electricity and heat) of life convenience facility. In centralized equipment case that adopt district energy center, solar power generation can meet 30% total power load, and 45% total heat load.
6. Introduction the district energy system that has an excellent energy saving and environment. In particular, introduce fuel cell in case 4 that the primary energy consumption and annual CO_2 emissions can be respectively reduced by about 45.2% and 61.9%.
7. Effective utilization of waste heat has become an important point to influence the effect of district energy system. We propose a cascade use as power from the low temperature water binary power generation, the annual CO_2 emissions can be reduced more than 65%.
8. Since the initial investment of distributed energy technology is high, district energy system does not have the economic benefits at this stage, it becomes an important problem to realize zero carbon.

7.2 Prospect

In the future we will further improve the system in the buildings. Make full use of the energy consumption, enhance the operation efficiency. We need to efforts to improve buildings to break the current situation, circulate the energy and regional resource of district area and cooperate between buildings. Suggest an optimal district energy system to “zero carbon block”. Will use other buildings as the objective, multipurpose project for distributed resource and heat technology and to discuss. Expand its database of equipment, combine the distributed resource technology and heat source technology to extend scope, and continue to improve the calculation method.

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