博士論文

INTEGRATED PLAN AND EVALUATION OF DISTRIBUTED ENERGY SYSTEMS BY AREA ENERGY NETWORK IN LOW CARBON COMMUNITY

低炭素街区におけるエネルギーの面的利用による分散型エネルギーシステムの総合計画と評価に関する研究

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2013 年 9 月

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ABSTRACT

The increasing density of people and buildings in the urban area results in an increasing in energy consumption and brings with it environmental challenges such as global warming and atmospheric pollution. Japan, as one of the leading environmental country in Asia, has improved its energy using efficiency and got a remarkable reward but still cannot control the increasing energy consumption and carbon emission in the commercial and residential sector. Under this situation, in the post-Kyoto Protocol period, the new energy using concept should be considered, like the area energy network, which stress on the distributed energy resource, renewable and untapped energy using. For a long time the researches on distributed energy generation always focused on individual, the ‘green field site’ buildings, or addressed climate issues, transport infrastructure in the city scale. Additional benefit and solution to the weakness may be gained by the collaborative energy using between clusters distributed energy plants in the neighborhood community, which termed as area energy network in Japan.

In this thesis, firstly, the method and related policies for the planning and evaluating area energy network is analyzed theoretically. By study the necessities of the paradigm shift at the community level, a new plan method for the area energy network are developed. Focusing on a residential area, the research chose the neighborhood community as a basic level. It stressed on the using of Geographic information system (GIS), by which the building information, the renewable energy resource information and the untapped energy can be gathered and visualized in a map. The spatial analysis function can also make sense in the area energy network planning. Furthermore, the method proposed in this research also explored some new technologies and suggested the intelligent control. In addition, the method has been employed to examine the feasibility.

Chapter1, **PREVIOUS STUDY AND PURPOSE OF THE STUDY**, investigated the present situation of the distributed energy generation technologies including their characteristics, benefits and weakness. As a solution to the weakness, the concept of area energy network and the low carbon community demonstration projects, as case studies of area energy network, are introduced. In addition, the previous studies about this research are reviewed.

Chapter2, **INVESTIGATION ON PRESENT CONDITION OF AREA ENERGY NETWORK,** the recently developed technologies and policies of area energy network are investigated in detail. Firstly, the definition of area energy network and its categories in Japan are introduced. Secondly, the characteristics of area energy network and its contributions to the environment are analyzed. Finally, some previews researches and related policies are sited to assume the conditions as the basic criterions for area energy network.

Chapter3, **CONCEPT AND INVESTIGATION ON THE PLAN OF AREA ENERGY NETWORK,** introduced the concept of the area energy network plan. By analyzing the general structure, the paradigm

shift for the distributed system at the community level is analyzed. In addition, the research proposed the methodology and procedure for the area energy network planning.

Chapter4, **SPATIAL ANALYSIS OF RENEWABLE ENERGY AND UNUSED ENERGY IN KITAKYUSHU WITH GIS**, proposed a method to explore the renewable energy and unused energy. Making use of the on-site renewable energy and unused energy is one of the important features of the distributed energy system. Therefore, the investigation on the on-site energy recourse should be put forward before energy system plan. Further, it set up and data base of factory exhaust heat resource. A questionnaire was taken out in all the factories and industries in Kitakyushu. Secondly, it suggested a method to estimate the exhaust heat and mapped out by GIS. Finally, based on the existing research, the optimal using areas are displayed out. Compared with the energy consumption mesh map in Kitakyushu, it is suggested that most of the areas with high energy consumption belonged to this district. Finally, the case study in Yahata Higashida explored a way to select the energy resource and estimated the energy that can derive.

Chapter five, **INTEGRATED ASSESSMENT OF COMBINED HEAT AND POWER SYSTEM FOR LOW CARBON COOPERATIVE HOUSING BLOCKS,** proposed a model for the residential communities in downtown area. Based on the discussion in chapter two, the research here firstly proposed the urban pattern with the introduction of CHP system, which can develop in grid model and shared in a collaborative way. It can prove that the isolated CHP system can only save 20% primary energy while the interchanging using in the new urban unit can save 30% and around 30% CO_2 emission. The urban pattern can be introduced with commercial area and developed into a compact residential block. This paper took the commercial area, which is common in residential block, as an example, analyzed the relationship between mixed function and environmental efficiency. The result can suggest that with the introduction of the commercial area, the energy saving ratio and the carbon reduction ratio are increased, and the optimal point is come out when the residential block mixed with 10% commercial area. Furthermore, this kind of urban block also have potential to accommodate people in different age groups. The different life styles can also make sense to the energy system design and its environmental performance. In this research, under the aging society in Japan, the lifestyle of elderly people is taken into consideration. It was proved that the area energy system planning with well designed age structure can improved the system performance. As the result suggest, the block with 40% elderly people is the optimal structure.

Chapter six, **POTENTIAL ANALYSIS ON THE AREA-WIDE FACTORY EXHAUST THERMAL ENERGY UTILIZATION BY PCM TRANSPORTATION SYSTEM IN A RECYCLING-ORIENTED COMMUNITY**, investigated the PCM system. By analyzing the technical characteristics of PCM system, this chapter proposed the utilization of PCM heat transport system into the collaboration between the CHP plants instead of the conventional pipe system. Secondly it takes the apartment in the low carbon demonstration area in Kitakyushu as case study and suggested that the system to some extent a better way for the utilization of factory waste heat, thus contributed to the energy saving and carbon reduction.

Chapter seven, **A MODEL FOR AREA ENERGY NETWORK BY OFFLINE HEAT TRANSPORT SYSTEM AND DISTRIBUTED ENERGY SYSTEMS,** proposed an energy system model for smart community in Japan, with industry, commercial buildings, public service buildings and residential area. The model not only has a smart grid but also has a smart heat energy supply chain by offline heat transport system (PCM). The PCM system controlled by community energy management system, conducted the heat sharing between buildings. In that way, it can maximize onsite use of CHP recovery heat. Further, this model promoted a collaborative energy utilization mode between the industrial sector and the civil sector. The introduced PCM system will also collected the exhaust heat from the nearby factory. It not only made use of the untapped energy but also cut off the CO_2 on the factory side (the exhaust heat) as well. In addition, the research chose the smart community in Kitakyushu as case study and executed the model. The simulation and the analysis of the model is embodied by temporal perspective of the low carbon techniques in Japan, including nature and untapped resource, CHP plants and the PCM system. The result not only suggests the environmental effect of different technologies but also the potential of its overall performance.

In Chapter8, **CONCLUSIONS,** the whole summary of each chapter has been presented

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CHAPTER2 INVESTIGATION ON PRESENT CONDITION OF AREA ENERGY NETWORK

RECYCLING-ORIENTED COMMUNITY

CHAPTER SEVEN: A MODEL FOR AREA ENERGY NETWORK BY OFFLINE HEAT TRANSPORT SYSTEM AND DISTRIBUTED ENERGY SYSTEMS

CHAPTER ONE: PREVIOUS STUDY AND PURPOSE OF THE STUDY

1-1 INTRODUCTION

The definition of cities, at the simplest level, is that they are the focal point of human activity and of buildings that accommodate such activity. This density of people and buildings results in an increasing energy consumption and brings with it environmental challenges such as atmospheric pollution, beat build-up, traffic, noise, drainage and waste disposal, reduced areas of vegetation and open water. These environmental challenges need to be resolved to provide improved conditions for living and working.

Energy use is another central issue and relatively straightforward metric of environmental performance of urban design. The largest sources of air pollution are associated with energy use in buildings, transport and industry, of which buildings typically account for the largest fraction.

Beside energy shortage, Global warming also becomes major challenge of the world environment. The global land and marine surface temperature record from 1856 to 2010[1] suggests that the world surface temperature in 2012 is 0.9 ℃ higher than that of the end of 19th century. Most of the observed warming over the last 50 years is likely to have been due to the increase in green house gas concentration. The green house gas emission has a potential that fiercely effects world nature environment as well as human societies and economies.

Kyoto Protocol was widely known as an international act to restrict the greenhouse gas (GHG) emission and 2012 is the fiscal year of the first period. However, the statistic suggested that, even engaged nations greatly improved its energy using efficiency and got a remarkable reward, the targets set in Kyoto Protocol cannot be easily realized. Japan, who should be cut 6% CO2 emission compared with 1990 still need to reduce 1.6% until 2012. AS the energy consumption and CO2 emission controlled in industrial section, the consumption in commercial and residential sector increased, owning to the increase of changed life style and living requirements [2]. It is suggested that until the year 2009, the carbon emission from the civil sector increased 30% compared with 1990 and occupied for 1/3 of the total carbon emission. Japan has decided against join the second commitment period through extension of the Kyoto Protocol [3], instead, set its own target and low carbon policy from the year 2013. For the policies after 2013, the distributed energy resource, renewable energy resource, untapped energy using as well as area energy network become important aspects. The demonstration projects are focused on the introduction of the renewable energy system, heat transport system based on the regional characteristics [4]. The construction of the low carbon demonstration area is one of these demonstration projects, shedding light on the residential community. It is an indication on a shift in the emphasis towards energy saving and green gas emission with regional cooperation in civil using. The energy system for the next generation, the demonstration project for the smart communities that carried out presently is a development for the area energy network with the intelligent control.

The object of this research is to explore the environmental implications of the intermediate scale of urban blocks, and how energy and environmental issues related to the individual buildings on the on hand and the urban or city region on the other. In the past, much of the researches have focused on individual, often ‘green field site’ buildings. Similarly, at the regional scale, researches have addressed climate issues, transport infrastructure.

This research establishes the missing link and proposed an energy supply as well as demand pattern in the neighborhood community level, with the resent concept of area energy network and smart grid. Firstly, the method and related policies for the planning and evaluating area energy network is analyzed theoretically. By study the necessities of the paradigm shift at the community level, a new plan method for the area energy network are developed. The research chose the neighborhood community as a basic level and focused on the energy system modeling for the residential area. Secondly, as one of the merits for area energy network, the utilization of the unutilized energy will be stressed in the model. The research will construct a database for the area energy network plan and analysis. It adopts Geographic information system (GIS), by which the building information, the renewable energy resource and the unutilized energy information can be gathered and visualized in a map. The spatial analysis function can also make sense in the area energy network planning. Furthermore, the method proposed in this research will be applied into several case studies which can represent the normal residential block. By these case studies, the thesis will also explore some new technologies and suggested the intelligent control.

1-2 RESEARCH BACKGROUND AND SIGNIFICANT

1-2-1PRESENT SITUATION OF GHG EMISSION

During the past hundred years, the weather and climate were getting warm. It is projected that in the next century the global temperature will rise 1 to 6℃. The little changes in the average temperature can cause large and potentially dangerous shift in climate and weather--oceans are warming and becoming more acidic, ice caps are melting, and sea levels are rising. The human activities are largely responsible for this climate change. The majority of greenhouse gases come from burning fossil fuels to produce energy, although deforestation, industrial processes, and some agricultural practices also emit gases into the atmosphere [5]. The green gas not only change Earth's climate but also result in dangerous effects to human health and to ecosystems. Figure 1-1 displayed the global greenhouse gas emissions (GHG) between 1965 and 2011. It can suggest that the emissions are increasing fierily. Even the problem had been called attention in the last 10 year, cannot reversed increasing trend. The energy supply account for 26% of the total GHG emission, ranking at the top. The other sectors account for the GHG emission are transport (13%), residential & commercial buildings (8%), industry (19%), agriculture (14%), forestry (17%) and waste& waste water (3%) [6].

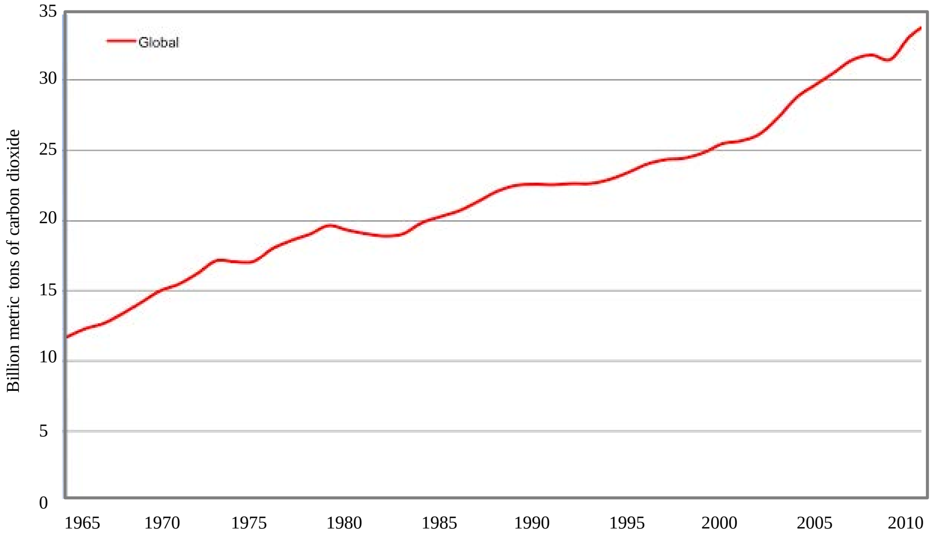


Figure1-1 Global greenhouse gas emissions in 1965--2011

(Source: 2012 BP statistical Review of World Energy)

The Kyoto Protocol is an international agreement, which commits the countries in this community by setting internationally binding emission reduction targets.

As a result of more than 150 years of industrial activity, Kyoto Protocol recognized that developed countries should be principally responsible for the current high levels of GHG emissions. Therefore, the Protocol places set strict burden on developed countries.

The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh, Morocco, in 2001, and are referred to as the "Marrakesh Accords." Its first commitment period started in 2008 and ended in 2012 [7]. Figure 1-2 displayed the CO_2 emission from 1990 to 2011, one year before the first fiscal year. Among all the countries, the Europe countries such as German, France and United Kingdom finished GHG emission cut target. However, Japan still increased 2.9%.

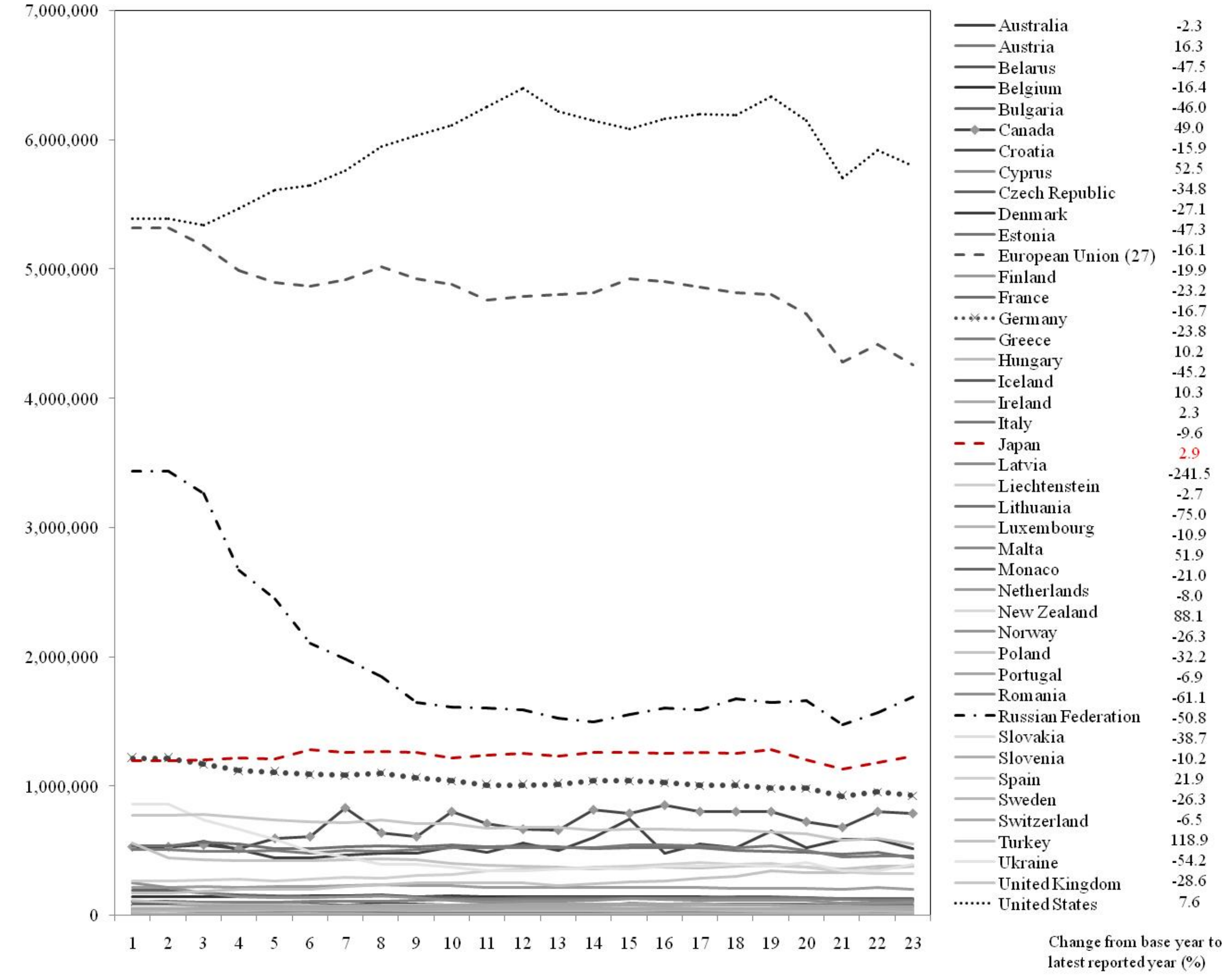


Figure1-2 CO_2 Emissions by nations (1990—2011)

(Source: United Nation Framework Convention on Climate Change (UNFCCC))

Figure 1-3 is the CO_2 emission, which account for most of the GHG in Japan, listed by sectors. The figure can suggest that the CO_2 emission in the industry sector and industry processes is well controlled, cut 13% and 34% of the total emission compared with 1990. However, the CO_2 emission in the commercial buildings and residential buildings are increased 50.9% and 48.1%.

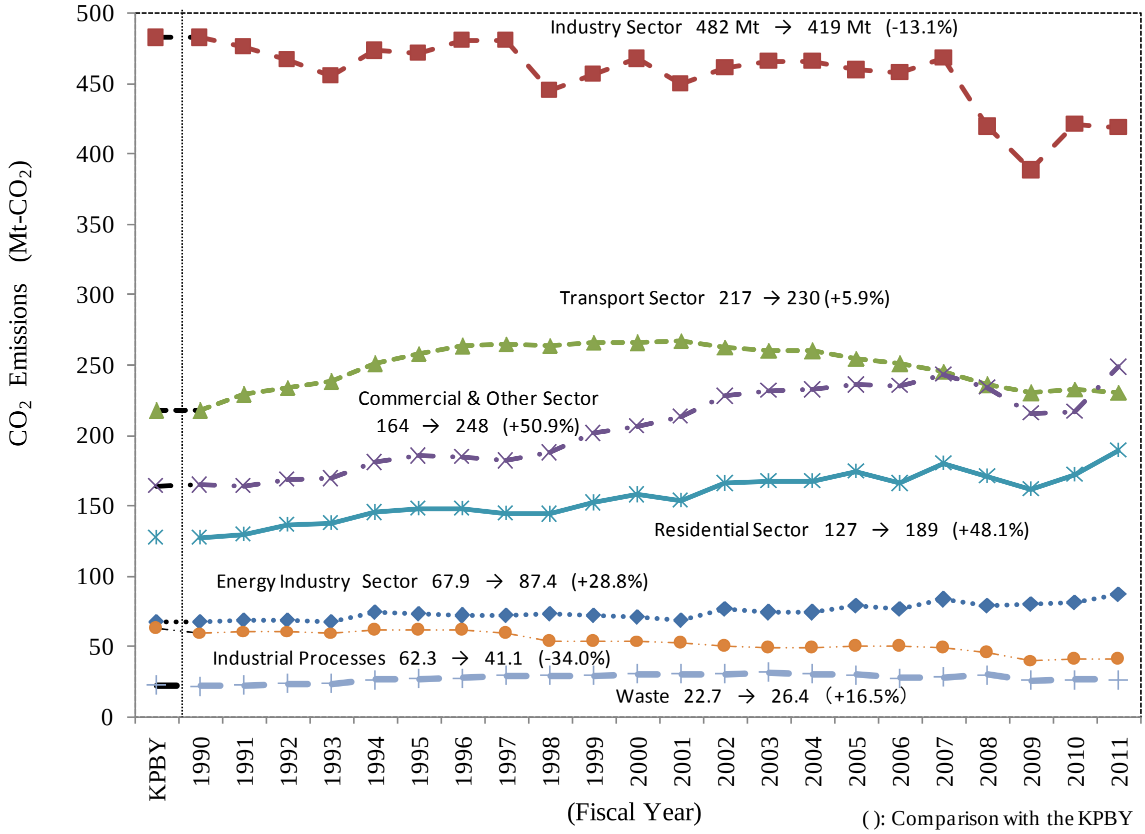


Figure 1-3 Indirect CO2 emissions by sector (1990-2011)

(Source: Greenhouse Gas Inventory Office of Japan, National Institute for Environmental Studies)

1-2-2 THE CONCEPT AND DEVELOPMENT OF THE DISTRIBUTED ENERGY SYSTEM

Sustainability in global energy terms is a major challenge, under constant pressure from continual growth in the energy demand. Although it helps to moderate demand growth and provides more time in order to develop new energy production technologies, energy conservation alone is unlikely to be able to meet the increasing energy demand. Among the discussion of sustainable energy use, the question of how energy is most efficiently supplied to the consumer is crucial. Basically speaking, there are two approaches: centralized ('top down') and dispersed ('bottom up'). The centralized approach typically entails massive power station, which are usually located away from population centers, where economies of scale are exploited to generate large quantities of electricity which are then distributed by grid. The dispersed approach generates energy in much smaller amounts, typically close to the population being served. Centralized energy production generally achieves an efficiency of about 40%, but lost largely as waste heat. Since the power station located in remote location, the waste heat cannot easily be utilized. Figure1-4 displayed the energy flow of this two energy generation approaches.

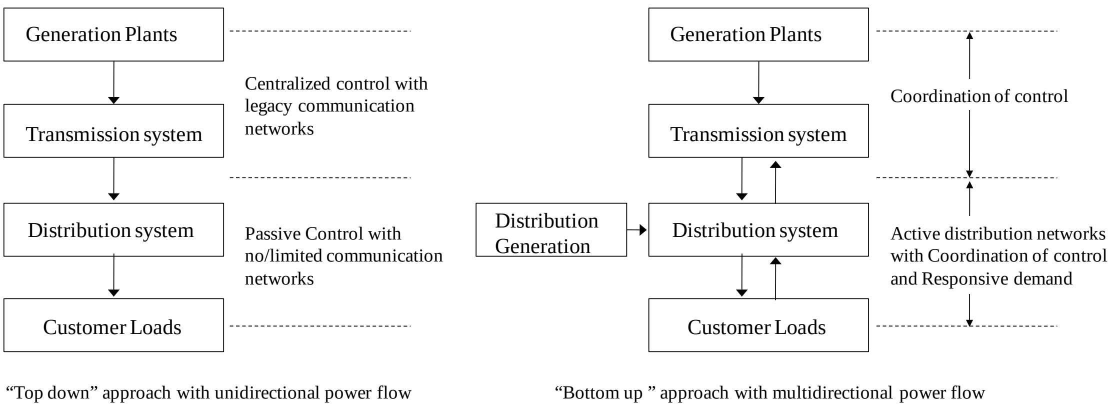


Figure1-4 The power flow of centralized (Top down) and dispersed (Bottom up) energy generation

The increasing concern regarding the depletion of fossil energy resource and the pollution of the environment, as well as the on-site power generation has increased the interest on the dispersed approach, usually termed as distributed energy resource (DER) [8]. DER means small scale electric generation units located within the electric distribution system at or near the end-users. Small local power stations are less efficient but being close to the population they serve. Their waste heat can be used to provide district heating in Combined Heat and Power (CHP) system. It is usually considered to be constructed aiming at utilizing local energy resource and establishing local energy storage. Beside the CHP system, the DER can employ a wide range of technologies as photovoltaic system (PV), small scale wind turbines and other renewable energy resource.

The terms that have been used by the electric industry include distributed generation (DG), distributed power (DP) and distributed energy resource (DER). DG is defined as anything outside of the conventional utility grid that produces electricity. DG technologies include internal combustion engines, fuel cells, gas turbines and micro-turbines, hydro and micro-hydro applications, photovoltaic, wind energy, solar energy, and waste/biomass fuel sources. DG also includes non-utility combined heat and power plants. DP encompasses all of the technologies included in distributed generation as well as electrical storage technologies. DP includes batteries, flywheels, modular pumped hydro-electric power, regenerative fuel cells, superconducting magnetic energy storage, etc. DER includes all technologies in DG and DP and also includes demand-side measures. DER is an electric generation units (typically in the range of 3 kW to 50 MW) located within the electric distribution system at or near the end user. It paralleled to the electric utility or stand-alone units. It is noted combined heating and power (CHP) technologies represent a special area within the realm of distributed generation. CHP systems that are installed at or near the point of use for off-grid applications are considered to be distributed generation systems. However, large central station CHP units are not included in DG. That is to say, it is not included in DER in this paper. The size of this type of unit is typically between 50–400 megawatts (MW) [8-12].

The point of using DG can be categorized into two mean aspects, the liberalization of electricity markets and environmental concerns [13].

At present, environmental policies or concerns are probably the major driving force for the demand for distributed generation

◆Combined generation of heat and electricity

Especially on sites where there is a considerable and relatively constant demand for heat, it makes sense to consider the combined generation of heat and electricity instead of generating the heat in a separate boiler and buying electricity from the grid. These so-called cogeneration units form a large segment of the distributed generation market.

◆Efficient use of cheap fuel opportunities

There is the increased interest by electricity suppliers in distributed generation because they see it as a tool that can help them to fill in niches in a liberalized market. In such a market, customers will look for the electricity service best suited for them.

◆Standby capacity or peak use capacity (peak shaving)

Many distributed generation technologies are indeed flexible in several respects: operation, size and expandability. For example, making use of distributed generation allows a flexible reaction to electricity price evolutions. Distributed generation then serves as a hedge against these price fluctuations. Apparently, this is the major driver for the US demand for distributed generation, i.e. using distributed generation for continuous use or for peaking use (peak shaving). In Europe, market demand for distributed generation is, for the moment, driven by heat applications, the introduction of renewable and by potential efficiency improvements.

◆Reliability and power quality

The second major driver for distributed generation (especially in US) is quality of supply or reliability considerations. Reliability problems refer to sustained interruptions, which are voltage drops to near zero (usually called outages), in electricity supply. The liberalization of energy markets makes customers more aware of the value of reliable electricity supply.

◆Alternative to expansion or use of the local network

Distributed generation could serve as a substitute for investments in transmission and distribution capacity as a bypass for transmission and distribution costs. This is possible only to the extent that alternative primary fuels are locally available in sufficient quantities. For example, increased use of distributed generation could result in new congestion problems in other networks, such as the gas transport network.

◆Grid support

Distributed generation can also contribute in the provision of ancillary services. These include services necessary to maintain a sustained and stable operation of the grid, but not directly supplying customers. This may be the capability to generate on demand of the grid operator, for instance to stabilize a dropping frequency due to a sudden under capacity or excess demand.

1-2-3 DIFFERENT DG TECHNOLOGIES AND THEIR CHARACTERISTIC

Different DG technologies are implemented to fulfill the requirements of a wide range of applications. These applications and technologies differ according to the load requirements.

The widely used DG technologies are:

- Reciprocating engines (internal combustion engines)
- Gas turbines
- Micro turbines
- Fuel cells
- Photovoltaic systems
- Thermoelectric solar plants
- Wind energy conversion systems (WECSs)
- Biomass to energy power plants
- Hydroelectric power plants

These technologies can be divided into two categories, the cogeneration technologies and the renewable technology utilization. Reciprocating engines, Gas turbines, Micro turbines, Fuel cells belong to the cogeneration technologies. Photovoltaic systems, thermoelectric solar plants, wind energy conversion systems, biomass to energy power plants, hydroelectric power plants are renewable energy utilization technologies.

Cogeneration, also known as combined heat and power (CHP), is the simultaneous production of electricity, heat and/or cooling at or near to the point of consumption. CHP provides many benefits compared to separate heat and power production. They include increased energy efficiency, operating cost savings, and reduced air pollution and global warming. There are additional benefits for industry including increased reliability, power quality, and higher productivity. The electric power industry and its customers can also benefit when industrial CHP capacity is used to support and optimize the overall power grid [14].

Reciprocating engines, Gas turbines, Micro turbines, Fuel cells are different prime mover technologies.

○Reciprocating engines

Also known as internal combustion engines, reciprocating engines are a widespread and well-known technology. A variety of stationary engine products are available for a range of power generation market applications and duty cycles including standby and emergency power, peaking service, intermediate and base load power, and combined heat and power (CHP).

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

Diesel engines have historically been the most popular type of reciprocating engine for both small and large power generation applications. Current generation natural gas engines offer low first cost, fast start-up, proven reliability when properly maintained, excellent load-following characteristics, and significant heat recovery potential.

○**Gas turbines**

Gas turbines are an established technology available in sizes ranging from several hundred kilowatts to over several hundred megawatts. Gas turbines produce high quality heat that can be used for industrial or district heating steam requirements. Alternatively, this high temperature heat can be recuperated to improve the efficiency of power generation or used to generate steam and drive a steam turbine in a combined-cycle plant.

○**Micro-turbines**

Micro-turbines are small electricity generators that burn gaseous and liquid fuels to create high-speed rotation that turns an electrical generator. Today's micro-turbine technology is the result of development work in small stationary and automotive gas turbines, auxiliary power equipment and turbochargers

○**Fuel cells**

Fuel cells are an entirely different approach to the production of electricity than traditional prime mover technologies, and are currently in the early stages of development. Fuel cell stacks available and under development are silent, produce no pollutants, have no moving parts, and have potential fuel efficiencies far beyond the most advanced reciprocating engine or gas turbine power generation systems. Fuel cell systems with their support ancillary pumps, blowers, and reformers maintain most of these advantages.

Fuel cells produce power electrochemically from hydrogen delivered to the negative pole (anode) of the cell and oxygen delivered to the positive pole (cathode). The hydrogen can come from a variety of sources, but the most economic method is by reforming of natural gas or liquid fuels. There are several different liquid and solid media that support these electrochemical reactions - phosphoric acid (PAFC), molten carbonate (MCFC), solid oxide (SOFC), and proton exchange membrane (PEMFC) are the most common systems.

Photovoltaic systems, thermoelectric solar plants, wind energy conversion systems, biomass to energy power plants, hydroelectric power plants is the renewable energy utilization technology.

○**Biomass energy**

Biomass is regarded as a renewable fuel and has considerable potential for use in distributed energy cogeneration systems, including those discussed above. For electricity generation, the potential energy stored in biomass is typically extracted in one of the following ways:

Direct combustion of the biomass within a boiler can produce steam to drive a steam turbine. In this case, only certain biomass materials are used in order to avoid ash buildup, which decreases efficiency and

Table 1-1 Distributed generation technologies and characteristic

	General information	Application range	Electric conversion efficiency	Application	Fuel
Reciprocating engine	Diesel engine	20kW–10+MW	36%–43%	Emergency or standby services	Diesel, heavy fuel oil, biodiesel
	Gas engine	5kW–5+MW	28%–42%	CHP	Gas (natural gas, biogas, landfill gas)
Gas turbine	Simple cycle	1–20MW	21–40%	CHP	Gas, kerosene
	Recuperated cycle			Peak power supply units	
Micro turbine	Combined cycle	30kW–200kW	25–30%	Power generation (CHP)	Natural gas, flare,landfill, biogas
	Cheng cycle	35kW–1MW			
	Brayton-fuel cell cycle	<1kW			
	Brayton-diesel cycle				
Fuel cells	MCFC	250kW–2MW	50–55%		Methanol
	DMFC				
	PAFC	200kW–2MW	35%	CHP, UPS	
	SOFC	1 kW–5MW	50–55%	High temperatures, Power generation is the most likely application	Hydrogen or natural gas
	PEMFC	1 kW–250kW	35%	Low temperature applications in transport and stationary use	
	PAFC	200kW–2MW	<25%		
Photovoltaic	Generates no heat	1+kW		Household and small commercial	
		20+kW		Off-grid applications	
Wind	On shore and in-land	200W–3MW			

increases costs.

Processing the biomass through a gasifier, which converts the liquids and solids into a combustible gas. This gas can then be used as a fuel for a gas turbine.

○**Photovoltaic systems**

Photovoltaic systems are commonly known as solar panels. Photovoltaic (PV) solar panels are made up of discrete cells connected together that convert light radiation into electricity. The PV cells produce direct-current (DC) electricity, which must then be inverted for use in an AC system.

Photovoltaic systems produce no emissions, are reliable, and require minimal maintenance to operate. They are currently available from a number of manufacturers for both residential and commercial applications, and manufacturers continue to reduce installed costs and increase efficiency. Applications for remote power are quite common.

○**Wind turbines**

Wind turbines convert the kinetic energy of wind into electricity. Windmills have been used for many years to harness wind energy for mechanical work like pumping water. Wind turbines, basically windmills dedicated to producing electricity, were considered the most economically viable choice within the renewable energy portfolio.

Table1 listed the different technologies that can be used for small-scale electricity generation [13].

As the points of using DG that stated in the last part, the DG technologies and their potential benefits can be summarized in the following Table2.

Table2 DG technologies and their potential benefits

	Standby	Peak shaving	Reliability	Power quality	Avoiding grid expansion	Grid support	co-generation
Reciprocating engine	□	□	⊠	⊠	⊠	⊠	□
Gas turbine	□	□	⊠	⊠	⊠	⊠	□
Micro turbine	□	□	⊠	⊠	⊠	⊠	□
Fuel cells	□	×	⊠	⊠	⊠	⊠	□
Photovoltaic	×	×	×	×	△	△	×
Wind	×	×	×	×	△	△	×
Hydrogen	×	×	□	□	△	△	×
Boimas	×	×	×	×	△	△	□
□	Technology contributes to						
⊠	Technology can contributes to, if dispatchable						
×	Technology not contributes to						
△	Requires significant additional technologies, like extra energy storage						

1-2-4 TECHNICAL CHALLENGES OF DG AND DEVELOPMENT OF DISTRIBUTION NETWORK

1-2-4-1 TECHNICAL CHALLENGES OF DG

As discussed in the last section, in the distribution system, DG technologies can provide benefits for the consumers as well as for the unities. However, DG can also give some technical problems.

There are related concerns with voltage fluctuations and their potential impact on neighboring consumers. The voltage of the local line system is likely to fluctuate if the output of DG changes over a short time, and this fluctuation would cause over- or under voltage at the customer's receiving point. There is particular concern when generating systems that depend on natural conditions, such as wind power or solar photovoltaic generators, are interconnected to the local system. The phenomenon of flicker is the result of rapid fluctuations in active power or reactive power, causing rapid fluctuations in voltage, sufficient to cause perceptible ‘‘flicker’’ of lighting.

Some DG technologies (PV, fuel cells) produce direct current. Thus, these units must be connected to the grid via a DC–AC interface. Special technologies are also required for systems producing a variable frequency AC voltage. Such power electronic interfaces can be regarded as a small energy buffer capable of matching fast changes in the power balance.

Some problems will occur [15]:

- Responding to reverse power flow in the distribution system and transmission system. Such a negative impact on the system security occurs when the share of non-dispatchable generation capacity increases, such as wind turbines, photo- voltaic systems, and co-generation units that are closely tied to heat demand. The latter units cannot be centrally controlled because of the natural variability of their power supply. As a consequence, there is an increased need for regulating (back-up) power. DG units can have a positive impact on distribution system reliability if they are correctly coordinated with the rest of the network.
- Need of initial network investments to accommodate the injection of power produced by DG.
- The problems of small scale and decentralization

The main challenge lies in connecting distributed generators in remote areas with weak grids. In these grids, power quality and reliability can be improved by an integrated approach, i.e. by intelligent management of generators.

1-2-4-2 DEVELOPMENT OF DISTRIBUTION NETWORK

The electricity system is an integrated system that has a sensitive interaction between generators, the grid systems and the users. In the existing "top down" grid, the consumers are passive receivers without further participation in the operational management. In that case, each end user node is only a "sink" for the electricity.

In the long term, the distributed generation should be considered as the final form for the electricity supply system. Thus in the future, a large proportion of the electricity generated by the large conventional plants will be displaced by DG (RES). In the new system the consumers have more possibilities including flexible and competitive tariffs; local generation; supporting schemes for renewable energies; cost-effective energy-saving programs; demand-side management; and communication and billing services.

The conventional grid will not be adequate for these functions. The integrated DG functions need the changes in transmission, distribution network structure, planning, and operation procedures. The distribution grid will become active and will have to accommodate bi-directional power flows.

◎Active distribution networks

The future networks with DG are an active distribution network with total coordinate. The active distribution network efficiently links power sources with consumers' demand (connectivity), allowing both to decide how best to operate in real time. The network is interactive with the generator and consumer. Information, communication, and control infrastructures will be needed with increased complexity of system management.

◎Micro grids

In order to reduce distribution costs (and losses), DG systems tend to work best in urban areas of relative high density, where there is a concentration of demand. However, as buildings become better insulated, or in warm climates, the demand per customer tends to drop and infrastructure cost thus rise. To overcome this drawback, there has been a trend for 'micro- grids', where one unit serves an urban block or neighborhood. Total system fuel efficiency can become high where there is a reasonably constant and appropriate mix of heating and electrical demand that matches CHP system. An individual household will have a wide variation of electricity demand during a 24-hour period, but such peaks and troughs are smoothed out when many consumers are served.

Micro grids are generally defined as low-voltage networks with DG sources, together with local storage devices and controllable loads. They connect multiple customers to multiple DG sources and storage devices.

Although they operate mostly connected to the distribution network, they can be automatically transferred to the islanded mode (working in an autonomous way disconnected from the main grid, providing continuity of supply in cases of upstream faults, and they can be resynchronized after restoration of the upstream network voltage.

Within the main grid, a micro grid can be regarded as a controlled entity that can be operated as a single aggregated load or generator. Given attractive remuneration, it can support the network, providing services such as a small source of power or ancillary services, when required or when market conditions favors it. From the customer’s point of view, micro grids provide both thermal and electricity needs and, in addition, have the potential to enhance local reliability. They can improve power quality by supporting voltage and reducing voltage dips, and can lower the costs of energy supply, when compared to spot peak market prices.

At medium level, the coordination of several micro-grids and the operation of virtual power plants, i.e. coordination of several distributed energy resources so that the full functionalities of central power plants are obtained, allows DER to take the responsibility for delivery of security services in co-operation with, and occasionally taking over the role of central generation [15].

◎Virtual utilities

Virtual utility can be defined as a new model of energy infrastructure that consists of different kinds of DG utilities in an energy generation network controlled by a district energy management system (DEMS). Every DEMS is a cluster of energy users, connected with the active distribution networks. DEMS receives information from the users, analysis and send information to DG. It can set the run or standby of the utilities of its cluster. The DEMS can give priority to the better resource instead of the use of fossil fuels. Different from the grid, the electricity production in the network is subordinated to the heat demand. The thermal energy is consumed on site, while the electricity is generated and distributed in the entire network.

The benefits of the virtual utility are optimization of utilization yield of the whole network, high reliability of electricity production, complete control of the network for achieving the main aim of the EMS, the high speed needed to follow quick changes in the demand of the system, and high integration of RESs, plus the advantages of DG. For a grid operator or energy trader, purchasing energy or ancillary services from a virtual power station is equivalent to purchasing from a conventional station. The concept of a virtual power station is not by itself a new technology but a method of organizing decentralized generation and storage in a way that maximizes the value of the generated electricity to the utility. Virtual power stations using DG, regional energy storage (RES), and energy storage have the potential to replace conventional power stations step by step.

The system is like figure1-5, Demand-side management techniques allow customers to take an active role in the supply of electricity. These systems allow customers to shift their power consumption towards off-peak periods and to reduce their total or peak demand, taking advantage of the real-time energy price and network status information, developing strategies for local demand modulation and load control by electronic metering and automatic meter management systems.

Energy storage has a very important strategic value in future electricity networks. It can allow the reduction of spinning reserves to meet peak power demands, by storing electricity, heat, and cold, which is produced at times of low demand and low generation, and released when energy is most needed and expensive. Energy storage consists of an intermediate stage between energy production and its consumption. It reduces the generation export into the distribution system by diverting part of the output into a storage device.

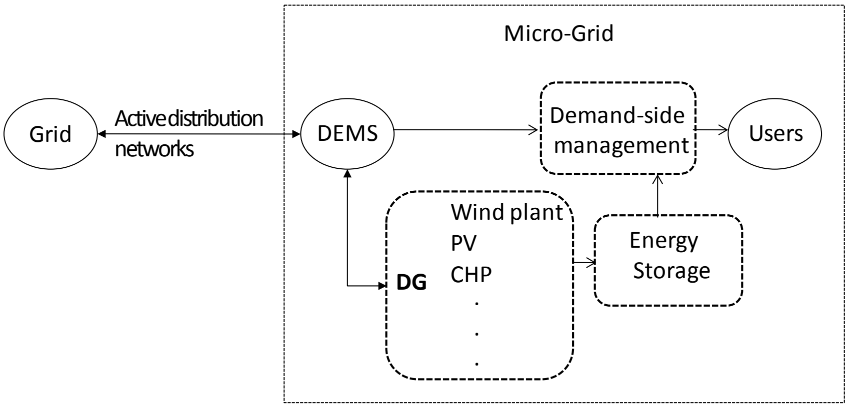


Figure1-5 Diagram of DG in an active network

1-2-5 THE DEVELOPMENT OF SMART GRID

1-2-5-1THE CONSTRUCTION OF SMART GRID CITY IN USA

In the USA, the utility grid is not so reliable that the outages always happen in a lot of cities. Therefore, the smart grid mostly means smart meters (the country is ahead of the rest of the world in metering) and features to improve the reliability of aging transmission and distribution infrastructures.

Xcel Energy's SmartGridCity^{TM}, the world first smart community project in Boulder, Colo., has completed construction of the infrastructure and launched the remaining software to enable all SmartGridCity operational functions in Sep, 2009. This step makes it the first fully functioning smart grid enabled city in the world that increases reliability, provides customers with greater energy use information, and allows participating customers and Xcel Energy to control in-home energy management devices remotely when demand calls for it [16]. There are four main components :

Smart grid infrastructure creates the "backbone" of the entire smart system. Xcel Energy has layered digital capabilities across the grid, including two-way, high-speed communications. This has added new automation capabilities and, because the utility can now sense and predict grid conditions, it can proactively monitor the grid's health and detect outages before they occur.

Smart meters are an essential link between the user and the smart grid. Smart meters collect home's electricity use data in 15-minute increments. This gives you much more visibility into your energy use compared to a traditional meter, which is only read once a month. Smart meters also act as sensors that help the utility gauge what's happening on the system at any time. And when outages do occur, smart meters allow Xcel Energy to pinpoint specific problems and get them fixed faster.

MyAccount **website** provides customers with detailed information about their energy usage so they can have more choice and control over how and when they use electricity. When coupled with a smart meter, MyAccount generates an in-depth snapshot of energy use, identifying times when consumption is highest. The site also gives easy access to energy efficiency information that fits lifestyle.

In-home smart devices like wireless, two-way thermostats and smart plugs, will be available in the future

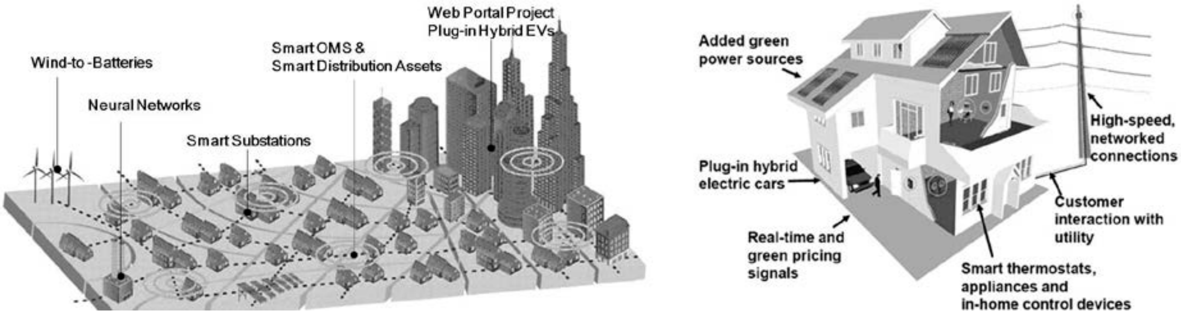


Figure1-6 The smart grid concept and in-home device of Xcel Energy's SmartGridCity^{TM}

to connect customer homes to the smart grid. This will allow customer systems and electrical outlets to "talk" to the MyAccount website and provide customers with advanced capabilities to monitor and adjust energy usage.

1-2-5-2 THE SMART COMMUNITIES IN EUROPE

Compared with the USA, the European grids don't have any major reliability problems but they are rapidly integrating renewable, which poses a different set of smart-grid challenges [17]. Father, the Europe pay more attention to the local district, promoting the construction of smart community.

The eco-friendly construction of smart community in Dutch is an indication to hook for electric cars, solar panels, and household wind turbines. In Amsterdam, the 17th century town houses and meandering canals will under big changes [17]. The major shopping avenue in the center of the Dutch capital, street trash will be collected by nonpolluting electric trucks, while the electronic displays in local bus stops will be powered by small solar panels. Elsewhere, 500 households will pilot an energy-saving system from IBM and Cisco aimed at cutting electricity costs. An additional 728 homes will have access to financing from Dutch banks ING and Rabobank to buy everything from energy-saving light bulbs to ultra-efficient roof insulation. The governments set aside billions of dollars to create so-called "smart cities," or towns that mix renewable projects, next-generation energy efficiency, and government support to cut overall CO2 emission.

Beside the technology characteristics, the Europe has more historic feature as sustainable monuments. Therefore, the Amsterdam Smart City is a universal approach for design and development of a sustainable, economically viable program that will reduce the city's carbon footprint [18].The canals and historic buildings tell us a part of the rich history of Amsterdam. In their different functions, the monumental buildings attract a lot of visitors each day. In this project, different technologies and working methods are tested to find out what works best to realize sustainability at the canals and change behavior of the visitors.

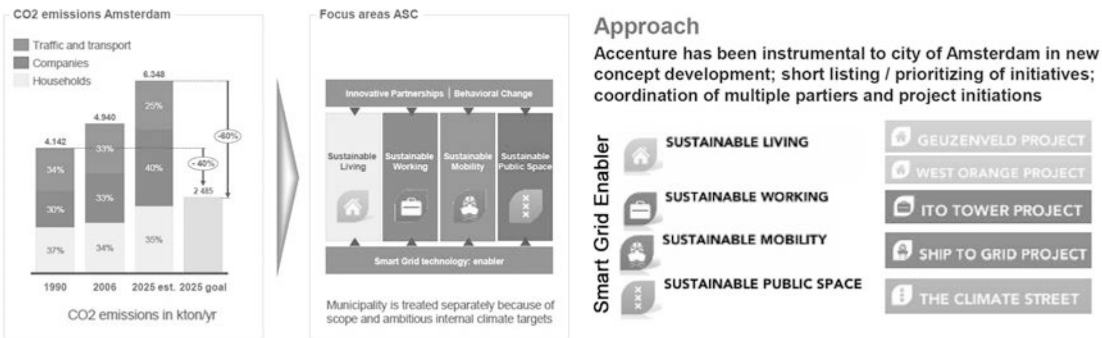


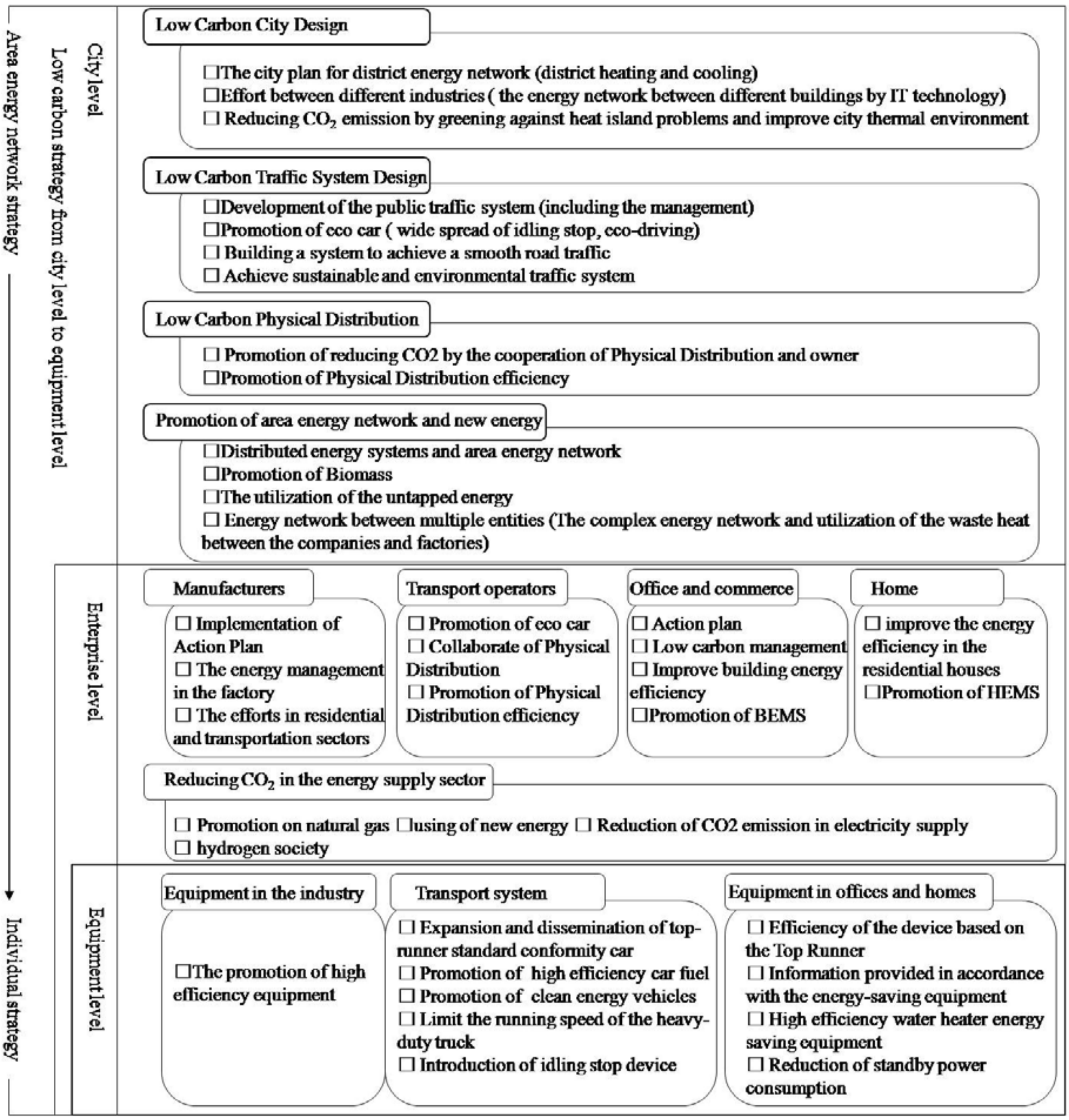
Figure 1-7 Reduces emissions by collaborative approach [15]

1-3 THE CONCEPT AND PROMOTION OF AREA ENERGY NETWORK IN JAPAN

1-3-1 THE CONCEPT OF AREA ENERGY NETWORK IN JAPAN

In these years, the carbon emission in the residential and commercial section is getting serious. Therefore in the future, beside the development of the low carbon technology, the governments need to make more policies in environment protecting, energy using and city development for the low carbon movement. In 2005, the government set the "Kyoto Protocol Target Achievement Plan", which mentioned that Japan will make a

Table 1-3 Overall description of the low carbon measures related to energy using
(Source: Kyoto Protocol Target Achievement Plan)



progress for cutting carbon emission in the view of area energy network by adjusting the structure of energy supply and demanding. It is taught, in order to get better CO_2 reduction effect, the government should improve the energy using efficiency especially in the downtown area where posse high energy density. For the high density area, the energy technologies and polices should not be limited in the single building scale, but pay more attention on the area energy network, improving the city energy environment, constructing low carbon district.

The construction of these low carbon district will cover from city plan, as well as energy system design and optimization.

1-3-2 THE DEMONSTRATION PROJECT OF LOW CARBON COMMUNITY AND SMART COMMUNITY

The low carbon communities in Japan is firstly put forward in the low carbon model cities that designated by government in 2008. There are 13 model cities and more than 30 low carbon demonstration areas. 30% of the projects are related to the reconstruction of public transportation system. The others are for the residential and commercial section, which also suggests the growing concern.

The projects for the reconstruction of the public transportation include: promotion of public transportation and the efficiency of parking area; the development and the plan for LRT public transportation; the promotion of pedestrian system and the bicycle using.

The projects for the residential and commercial area are much more complicate, including:

(1) The regeneration of the urban area is aim to promote untapped energy using and the renewable energy using in the reconstruction of the urban district, leading to the low carbon society.

(2) Area collaboration means the optimization of the environmental urban structure and the energy collaborative using in the district.

(3) The new technologies introduction on the individual building, including the promotion of PV system on public service area and the low carbon housing.

(4) The land use adjustment is transition of the building function for the environmental developing.

☐The Japanese model of “smart community”

In Japan, the “smart community” is defined as an efficient control of electricity flow with fully utilizing IT technology and enables various new services for power suppliers and demand side users. It is a new social system with a net work among energy resource, vehicles, homes, buildings, industries and infrastructures. The technologies cover the effective use of electricity and renewable energy resource, the traffic system and life style. The goal of such communities is more than the mere improvement of the living quality. Rather it is to meet the challenges of global environment and sustainable development [19][20]. Monitoring and operating under the ITC, the renewable energy such as solar energy, wind turbine can offer to the families and buildings reliably corresponding to the timely demand. The visual management can promptly optimize the network between the energy generation and consumption.

The Japanese model of the smart community can be described as four parts: New information network (the second internet), New energy system, New transportation system and New urban development. Among them, the new energy system, different with the normal system, has two level systems, described in figure1-8 [21]. The system in community scale, community energy management system (CEMS), run and monitor the facilities in the community, control the service, received energy demand and consumption information from the secondary energy system. The secondary systems are the energy systems in the building scale, including the energy system for smart house (HEMS), smart building (BEMS) and smart factory (FEMS). They directly face to the users, offer the energy to the families, offices and even electric vehicles (EV), receive and send energy information to the CEMS.

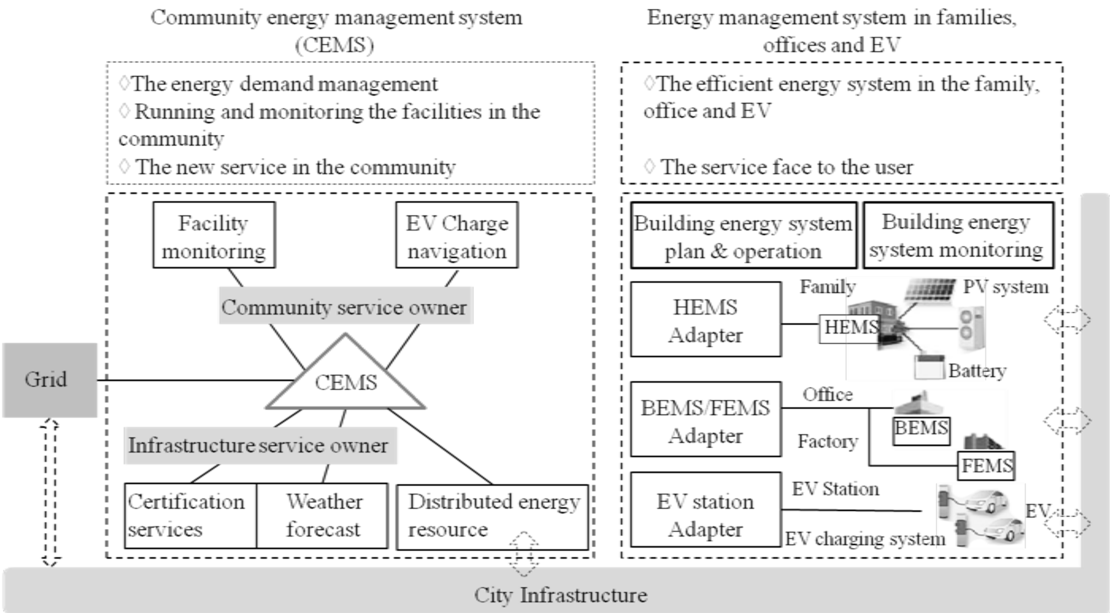


Figure1-8 Distributed energy system for smart community（CEMS）

(Source: http://www.hitachi.co.jp/products/smartcity/solution/cems/index.html)

☐ The promotion of smart community in Japan

In Japan, the government established the related policy and the organization to promote the development of smart community.

(1) The Japan Smart Community Alliance (JSCA)

The Japan Smart Community Alliance (JSCA) was established on April 6, 2010 with the aim to promote the concept of Smart Community through government-private cooperation [22]. The smart community was incorporation of varied technologies, thus the cooperation is necessary. JSCA was the organization, to promote the smart communities by tackling various common issues such as deployment and research on smart grid standardization.

(2)The demonstration areas for the smart community were carried out in 2009;

There were four unique large-scale demonstration projects for the smart community in Japan, Kyoto Keihanna District, Yokohama City, Kitakyushu City and Toyota City.

1) Kyoto Keihanna District was the co-project developed by Kyoto Prefecture, Kansai Electric Power, Osaka Gas Kansai Science City and Kyoto University. It aimed to cut the 20% of the CO2 emission in the residential sector and 30% of the of the CO2 emission in the transportation sector. The real practices including: installing PV on 1000 homes, EV car-sharing system; management of the coexist electricity supply between grid, PV and the fuel cell in the houses and buildings (visualization of demand); grant “Kyoto

eco-points" for green energy usage.

2) Yokohama City was sponsored by Yokohama city, Toshiba, Panasonic, Meidensha, Nissan, Accenture. It set the target to cut down the 30% of CO2 emission by 2025, compared with 2004. The project included: the energy management system that integrated HEMS, BEMS, EV; PV system (27000kW); Use of heat and unused energy; 4000 smart houses and 2000 EVs.

3) Kitakyushu City was developed together by the Fuji Electric System, GE, IBM and Nippon Steel. It aimed to cut down 50% CO2 emission (compared with 2005). The projects included: real-time management of 70 companies and 200houses; energy management using HEMS and BEMS; energy system that coordinate demand side management with overall power system.

4) The Toyota city project was supported by the Toyota city, Toyota monitor, Chubu Electric Power, Toho Gas, Toshiba, Mitsubishi heavy Industries, Denso, Sharp, Fujitsu, Dream Incubator, etc. Its object was to cut 20% CO2 emission in residential sector and 40% in transportation sector. The whole project included: Use of heat and unused energy in addition to electricity; demand response at more than 70 homes, the promotion of 3100 EV and the system of V to H (vehicle to house), V to G (vehicle to grid).

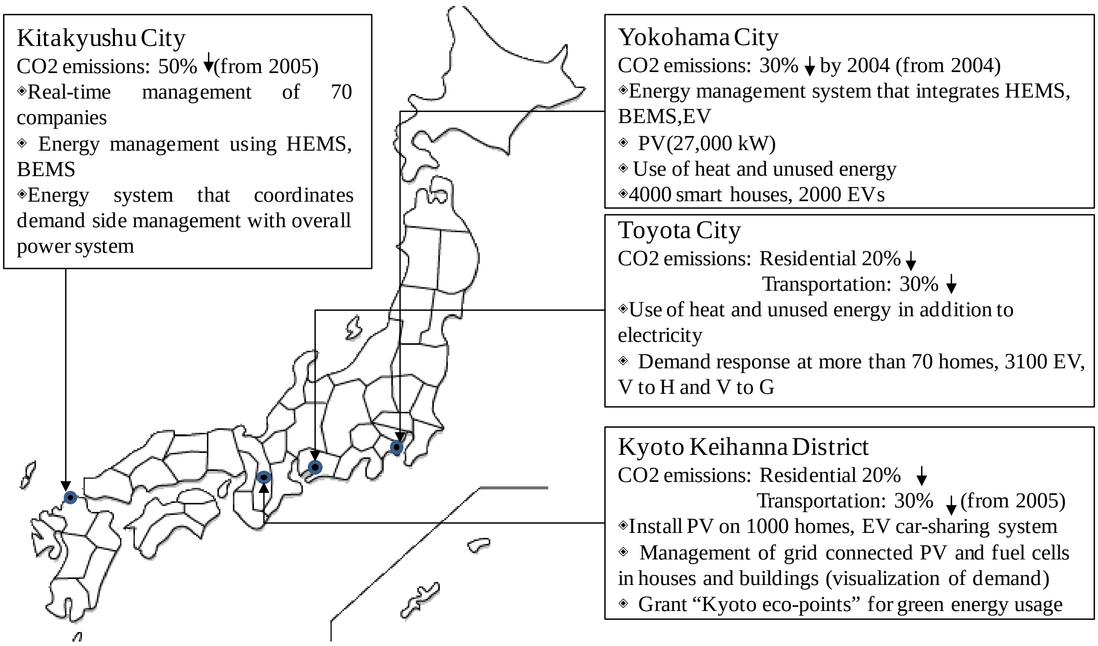


Figure1-9 The demonstration areas for the smart community in Japan

(Source: Japan smart community alliance)

☐The road map of "smart community"

The mean policies and targets for the Japanese smart community and the oversea development can be described in the road map of "smart community", displayed in figure1-10 [21]. The road map set the road in three stages, covering from the building level to the district level. The policies at the district level focused on pushing forward the renewable energy, which including the two-way energy supply between the grid and the CEMS, the technologies of battery and smart censers. For the housing, the policies shed light on the developing on the smart meters and the EV (electric vehicles).   Other office and commercial buildings aimed to the ZEB (Zero emission building).

	Today--	2020--	2030----------------------------------
Grid ↕ CEMS	◈The popularization of PV panel leads to the price decrease ◈ Measures to maintain power quality. ◈ Energy storage system will be installed. ◈ The technologies for CEMS ◈ The cost of the battery decreased because of the technology	◈Decreased PV price stimulate the installation ◈CEMS contribute to Regional energy(RE) generate ◈ Declining battery price increase installation ◈The distribution and transmission that enable two way communication (the distributed energy supply &grid)	◈The cost of using RE will be less than fissile price. ◈EMS that can provide an optimized balance in terms of economy and security between CEMS and grid ◈EMS will charge EVs and can supply back to the grid as regional cooperation
House	◈ Installation of smart meters ◈ The development of HEMS; ◈ Demonstration of EVs	◈The integration of HEMS&CEMS ◈The home service developing ◈EVs used for power storage	◈A fully-automated HEMS will be realized
Build -ings	◈ Demonstration of ZEB (Zero emission building)	◈New public buildings realize the ZEB	◈ZEB will realize a great reduction of CO_2 emission

Figure1-10 Road map of “smart community”

(Source: Ministry of Economy, Trade and Industry , Japan)

1-4 PREVIOUS STUDY

Many technologies and approaches have been used for the distributed energy system plan as well as onsite renewable and unutilized energy using. In the following, some previous studies are reviewed.

1-4-1PREVIOUS STUDY ON DISTRIBUTED ENERGY SYSTEM

Distributed energy systems (DES) have been drawing increasing attention as a substitute for grid in the low-carbon society development, especially for the buildings with high energy consumption. It was firstly developed in the commercial and public buildings but now recently become popular in the residential buildings.

There were many researches about distributed energy system in the commercial and public buildings. H. Ren developed a multi-objective optimization model, analyzing the optimal operating strategy of a DER system while combining the minimization of energy cost with the minimization of environmental impact. An eco-campus in Japan has been selected for case study. It demonstrated the operation of the DER system is more sensitive when environmental objective is paid more attention. The consideration of electricity buy-back, carbon tax, as well as fuel switching to biogas, has more or less effect on the operation of DER systems [23]. S.Naderi presented a novel frequency-independent control method suitable for distributed generation [24]. Nowadays, there are some researches that discussed the introduction of DES in the residential area. Ruan [25] studied on the introduction and optimization of systems in residential area. The research use the software HEATMAP to simulate the distribute energy system. It discussed the system efficiency under different running patter of CHP system and the scale. The integration evaluation covers from energy saving, CO2 emission reduction and the economic efficiency.

From the long-term viewpoint, the utilization of renewable energy in DES should be a final solution for sustainable development and low-carbon society.

A. Knoll[26] researched on residential and commercial scale distributed wind energy in North Dakota, USA. The result showed that a residential-scale turbine could provide between 90% and 165% of annual net per-person electricity usage in these 14 counties, depending on the wind speed. The introduction of the renewable energy in the DES will cause the revers low to the converntinal grid. There are some researches use the intellegigent control which can solve the problem. S.Lin proposed a DPOPF (distributed and parallel OPF) algorithm for the smart grid transmission system with renewable energy sources to account for the fast variation of the power generated by renewable energy sources. The proposed DPOPF algorithm is a combination of the recursive quadratic programming method and the Lagrange projected gradient method; it can achieve the complete decomposition and can be executed in the smart grid transmission system to make distributed and parallel computation possible. We also propose Petri nets to control the computational synchronization of the DPOPF algorithm under the asynchronous data arrival in the smart grid transmission system [27].

1-4-2 STUDY ON DISTRIBUTE SYSTEM NETWORK

The individual DES will have a lot of problems. Thus nowadays the developments of distributed energy network in the city level draw more and more attention.

S. Obara considered the construction of a Syowa Base small-scale energy network (Syowa Base Micro-Grid: SBMG) for the purposes of reducing fuel consumption and increasing green energy utilization. The relationship between the amount of green energy (photovoltaic and wind power generation) connected to the proposed power supply distribution and the amount of fuel consumed by the engine generators and backup boiler was clarified. Moreover, the outside temperatures, insulation levels, and wind velocity at the Syowa Base change seasonally, resulting in large changes in the SBMG operation method [28].

M. Manfren provided an approach while attempting to calculate such effects for a large complex system like a city, to overcome difficulties in modeling correctly real phenomena while maintaining computational transparency, reliability, interoperability and efficiency across different levels of analysis. A selection of currently available models for distributed generation planning and design is presented and analyzed in the perspective of gathering their capabilities in an optimization framework to support a paradigm shift in urban energy systems [29].

E. Mehleri presented a mixed-integer linear programming (MILP) super-structure model for the optimal design of distributed energy generation systems that satisfy the heating and power demand at the level of a small neighborhood [30].

Yamagugi [32] investigated alternative prospects for an urban energy systems network from a long-term perspective in order to achieve a reduction in CO_2 emission by more than 50% of the current emission in Japanese commercial sector. The simulation model based on the bottom-up approach, which optimized system according to the energy demand. The variety of scenarios provided insights into the changes required in all the components of urban energy systems from the equipment level to the entire building and system levels. Finally the model will be put forward to the neighborhood and the city level. The case study applied the simulation model to the Yodoyabashi district, a central business district in Osaka, Japan. The result predicts the end-use energy consumption and CO_2 emission. It can suggest the possibility to achieve a reduction of 60%-90% of current CO2 emission by the middle of the 21st century.

H. Chen elaborated a future vision for the year 2030 in the Sancha Area (SANCHA VISION 2030), a typical densely built-up area in Tokyo, including a simulation to estimate benefits from the application of distributed energy systems in terms of reduced energy consumption and CO2 emissions as well as mitigation of the heat-island phenomenon. it demonstrated that a “distributed local energy system”, which provides a district with both electrical power and heat through an integrated distribution system, may contribute to a considerable improvement in energy efficiency for those areas. It also provided other benefits, including enhancement of living amenity and urban security in times of emergency [33].

1-4-3 STUDY ON OFFLINE HEAT TRANSPORT SYSTEM

Usually, the heat transport system in the area energy network is consisted of pipe system, which needs a large initial cost. The pipe system is limited by the heat resource and the heat loss. Recently, some of the researches proposed an offline heat transport system instead of the conventional pipe system. H. Kiyoto investigated and promoted an offline system for the energy storage, transport and recycling. The model of offline system was developed to collect the energy from the factory. It estimated the heat loss, cost during the transport and the exchange. Further, the heat that collected from the factory was utilized as heat supply in an apartment, evaluating its possibilities by several cases [34].

The research proposed way on the calculation of heat loss in the system and get the optimal distance for this system. It also estimated that the system loss is around 95%, which is much more efficient than the pipe system.

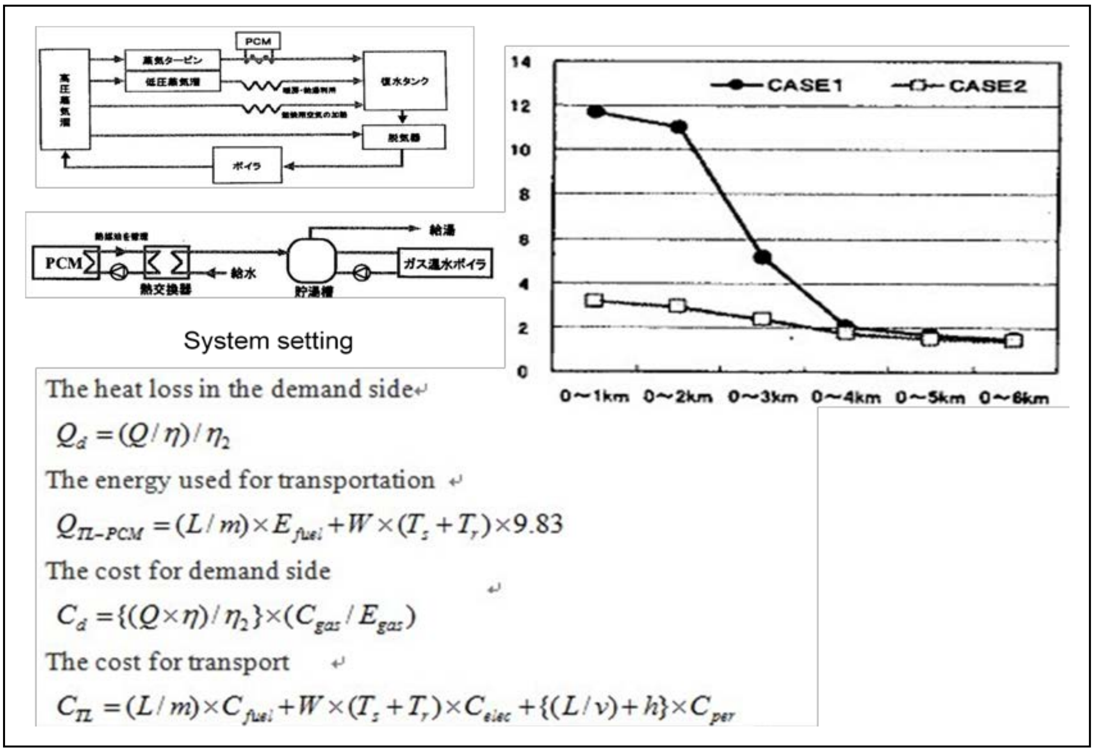


Figure 1-11 The content of the research on offline heat transport system

1-5 PURPOSE OF THIS STUDY

The review of the existing studies can suggest the tendency of area energy network development. These researches always focused on the performance of the energy system but ignored it relationship with the factors in city plan. Furthermore, the distributed energy system rarely considered the widely renewable energy using and the unutilized energy using. This study proposed a model for area energy network in the community level with the heat transport system, under the concept of intelligent monitoring. It will also employ the model to some of the communities and analysis the effect of city function. Figure1-12 is the research flow.

◇Previous study

Chapter 1 investigated the present situation of the distributed energy generation technologies including their characteristics, benefits and weakness. As a solution to the weakness, the concept of area energy network and the low carbon community demonstration projects, as case studies of area energy network, are introduced. In addition, the previous studies about this research.

In Chapter2, the recently developed technologies and policies of area energy network are investigated in detail. Firstly, the definition of area energy network and its categories in Japan are introduced. Secondly, the characteristics of area energy network and its contributions to the environment are analyzed. Finally, some previews researches and related policies are sited to assume the conditions as the basic criterions for area energy network.

◇Concept

Chapter 3 investigated on the existing technologies that related to the CHP system and systems network. By analyzing the general structure, the paradigm shift for the distributed system at the community level is analyzed. In addition, the research proposed the methodology and procedure for the area energy network planning.

◇Database construction

Chapter4 proposed a method to explore the renewable energy and unused energy. Making use of the on-site renewable energy and unused energy is one of the important features of the distributed energy system. Therefore, the investigation on the on-site energy recourse should be put forward before energy system plan. Further, it set up and data base of factory exhaust heat resource. A questionnaire was taken out in all the factories and industries in Kitakyushu. Secondly, it suggested a method to estimate the exhaust heat and mapped out by GIS. Finally, based on the existing research, the optimal using areas are displayed out. Compared with the energy consumption mesh map in Kitakyushu, it is suggested that most of the areas with high energy consumption belonged to this district. Finally, the case study in Yahata Higashida explored a way to select the energy resource and estimated the energy that can derive.

◇Case study

Chapter5, proposed a model for the residential communities in downtown area. Based on the discussion in chapter two, the research here firstly proposed the urban pattern with the introduction of CHP systems, which can develop in grid model and shared in a collaborative way. It will analyze the effect of area energy utilization in the residential block under this urban pattern. Further, this kind of urban pattern can is tend to introduced commercial or other functions and develop compact residential block. This paper took the commercial area, as an example, analyzed the relationship between mixed function and environmental efficiency of the energy system. In addition, this kind of urban block also have potential to accommodate people in different age groups. Under the aging society in Japan, the lifestyle of elderly people is taken into consideration. It was proved that the area energy system planning with well designed age structure can improved the system performance. This kind of mixed residential block not only has social meanings but also improved the efficiency of the energy system.

Chapter6 proposed a method for utilizing the factory waste heat by offline heat transport system. Based on the investigation of offline heat transport system, this chapter proposed a district heat utilization system between the CHP plants instead of the conventional pipe. Secondly it takes the apartment in the low carbon demonstration area in Kitakyushu as case study and suggested that the system to some extent a better way for the utilization of factory waste heat, thus contributed to the energy saving and carbon reduction.

Chapter7 proposed an energy system model for smart community in Japan, with industry, commercial buildings, public service buildings and residential area. The model not only has a smart grid but also has a smart heat energy supply chain by offline heat transport system (PCM). The PCM system controlled by community energy management system, conducted the heat sharing between buildings. In that way, it can maximize onsite use of CHP recovery heat. Further, this model promoted a collaborative energy utilization mode between the industrial sector and the civil sector. The introduced PCM system will also collected the exhaust heat from the nearby factory. It not only made use of the untapped energy but also cut off the CO_2 on the factory side (the exhaust heat) as well. In addition, the research chose the smart community in Kitakyushu as case study and executed the model. The simulation and the analysis of the model is embodied by temporal perspective of the low carbon techniques in Japan, including nature and untapped resource, CHP plants and the PCM system. The result not only suggests the environmental effect of different technologies but also the potential of its overall performance.

◇Conclusion

In Chapter8, all the works has been summarized and the future study about the energy system for low carbon community has been discussed.

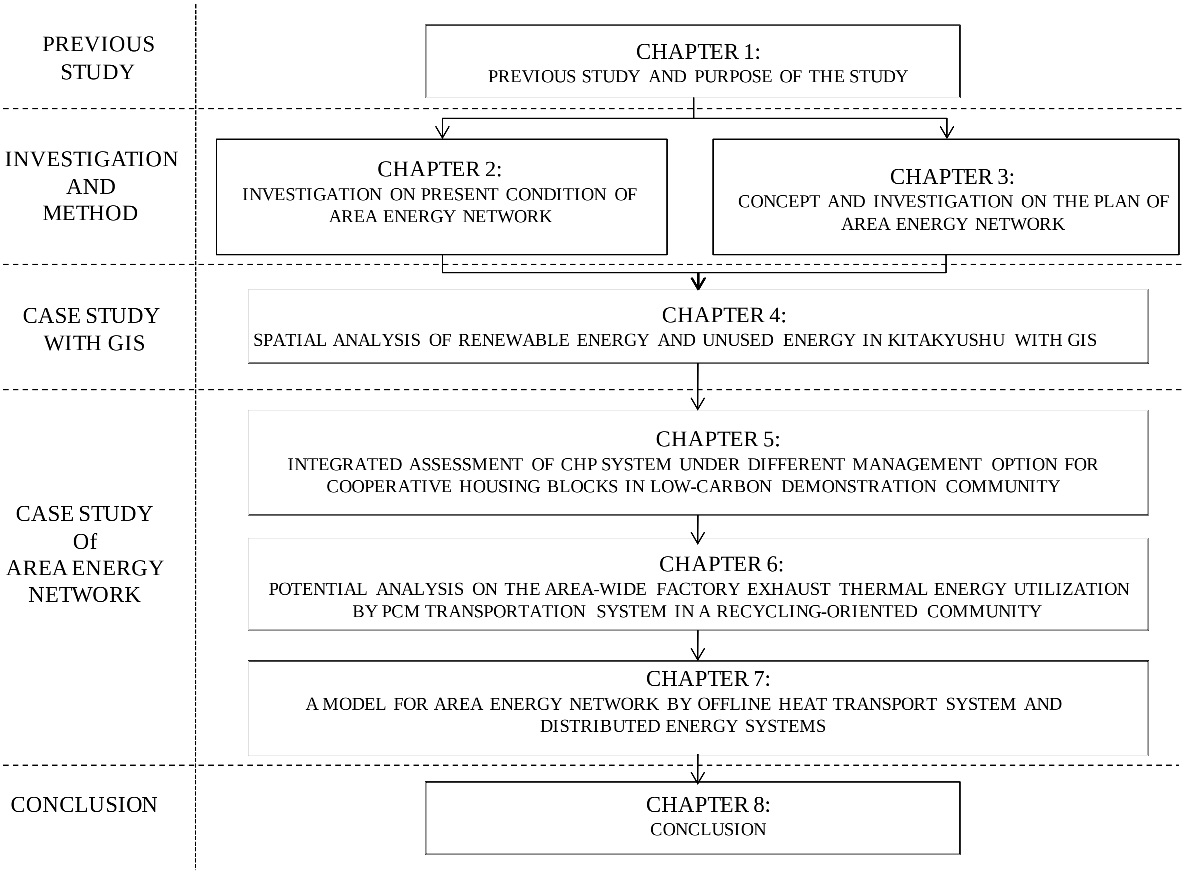


Figure1-12 Research flow

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CHAPTER2 INVESTIGATION ON PRESENT CONDITION OF AREA ENERGY NETWORK

2-1INTRODUCTION

Climate change, environmental pollution and resource depletion are issues that have to be addressed in global sustainability. Especially, for the contemporary cities, this is a challenging task, where the rapidly changing lifestyles and habits result an increasing energy demand. For a long time, the path towards energy sustainability is commonly referred to the incremental adoption of available technologies, practices and policies that may help to decrease the environmental impact of energy sector.

Distributed generation paradigm should be recognized as the future power paradigm because of economic, technical and environmental benefits. By acting in the electricity sector renovation, DG can help in the reduction of transmission losses and problems related to congestion in electricity distribution system, while providing appropriate power quality for different types of end-users and fostering the penetration of diffuse renewable energy sources. Additionally, the potential to sell surplus power to the grid can yield significant income during the periods of peak demand. Further, combined heat and power technologies can enable the rational use of thermal energy that would normally be wasted and thus can determine a reduction in primary energy use and carbon emission. This is fundamental especially for users who have a large heating demand with respect to electricity demand, both in civil and industrial sector. However, the current DG technologies still have some limits. For example, the efficiency for the small scale DG technologies still not high and the price is not so competent in the liberalized market. This postpones the development of DG technologies in residential using. Furthermore, the energy saving performance and the environmental performance of single DG plant is subject to the energy demand curve. These problems can be improved in the current concept of area energy network. Beside these, the increase requirements for the utilization of untapped energy also need a paradigm shift for the existing urban energy system [1].

The advanced pattern of distributed generations network (DGs) under the concept of area energy network needs a paradigm shift both in demand and supply sides with a transition towards distributed generation and smart grids paradigm. However, the paradigm shift in energy systems has to be supported, by mandatory regulations, technological infrastructures, etc. Local energy policy involves necessarily the planning and the design of efficient solutions at the community level.

With the rapid development of the computing process, it is possible to think about a smarter use of available resources and technologies at the community level, for example with the help of expert systems, to reduce the environmental impact of energy services while maintaining competitiveness in a liberalized market.

In this chapter, the concept and definition of area energy network will be introduced. The resent categories and development of area energy network is also investigated. In addition, this chapter also investigated the related technologies and policies that supported the area energy network.

2-2 DEFINITION AND CLASSIFICATION OF AREA ENERGY NETWORK IN JAPAN

2-2-1 THE DEFINITION OF THE AREA ENERGY NETWORK

Area energy network refers to the idea of mutually accommodating electricity and heat among multiple buildings. As figure2-1 displayed, in conventional system, buildings use electricity and heat individually. However, in an energy system based on area energy network, electricity and heat are distributed among multiple buildings in order to level out usage patterns of electric energy and thermal energy. The conventional, vertically integrated system (mono-energy) will be converted to a horizontally integrated system (multi-utility) [2].

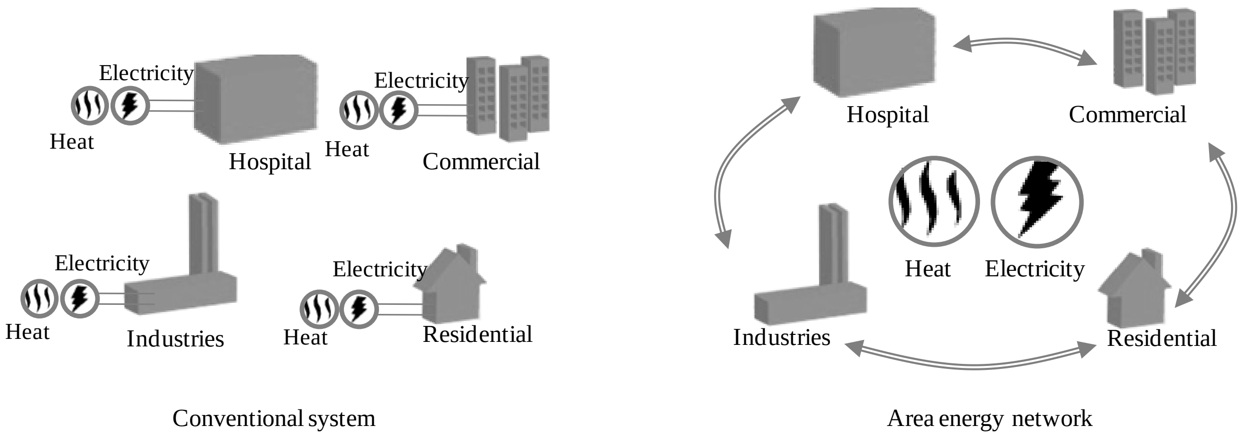


Figure2-1 the conventional system and area energy network

The Area energy network practice until now is limited in heat demand is to some extent same as district energy. It is a generic term for district heating and district cooling. The concept of district energy is opposite to individual heating and cooling in the sense that heat or cold is produced centrally and distributed through pipes to several individual consumers.

Making use of the local fuel or heat resource instead of discarding it into the environment is the fundamental idea of district energy today. Otherwise, the waste heats that discarded will cause environment problems. This is all possible by utilizing an efficient local distribution network of insulated pipes, which provide for a cheap and reliable heat or cooling source once established.

The district heating and cooling system is basically working as below: Water is circulating from the plant to the consumer in a district energy network. In the case of district heating water is heated at the plant, distributed to the consumer where the heat is delivered, and returned to the plant to be re-heated. District cooling systems work in the same way except the fact that the circulating water is chilled instead of heated at the plant [3].

2-2-2 THE CLASSIFICATION OF AREA ENERGY NETWORK IN JAPAN

The area energy network practices until now in Japan have a lot of different classifications. It varies according to the fertilities, energy supply objectives, and the characteristic of the district. It can basically categorize into three kinds according to the scale: the district heating, centralized plant and the interchanging energy system. Table2-1 displayed the

Table2-1 Types of area energy network

	Scale	Contract	Energy provider	Supply form
① District heating （A large energy plant supplying energy to a broad district）	Large	The supply regulations based on the heat supply business law	Heat supply companies that set by the law	supply obligation based on the heat supply business law (Defining the supply conditions by the supply rules)
② Centralized plant type (Supplied centralized plant energy plant to a small specific area)	middle	The contract between the energy provider and the customer	Energy supply companies under the contract	Supply obligation under the contract (less constraints compared to district heating)
③ The interchanging system between the buildings (the collaborative energy using between the)	Small scale	Mutual agreement between building owners	The owners of more than one buildings	The arrangements by mutual agreement

☐ The first type-- district heating (cooling)

District energy systems (DES), displayed in figure2-2 centralize the production of heating or cooling for a neighborhood or community. Now, district systems are one of the potential solutions to our energy and emissions challenges

◆District heating

District heating is a technical system for heating a town or a part of a city. Water is normally used for transporting the heat in a piping system, the district heating network. The heat is supplied by one or more large centralized plants.

District heating is used mostly in places where the demand for heat is high and consumers are located fairly closely. This means district heating networks can be found in towns in countries with chilly climates. Tradition and the history of technological evolution mean the greatest relative use of district heating is in northern, eastern and western Europe, in Russia, and in China. However, recently is also found in the USA, Korea, and Japan, where the heat demand is large.

District heating plants can provide higher efficiencies and better pollution control than localized boilers. The heat is often obtained from a cogeneration plant burning fossil fuels but increasingly biomass, although heat-only boiler stations, geothermal heating and central solar heating are also used, as well as nuclear power.

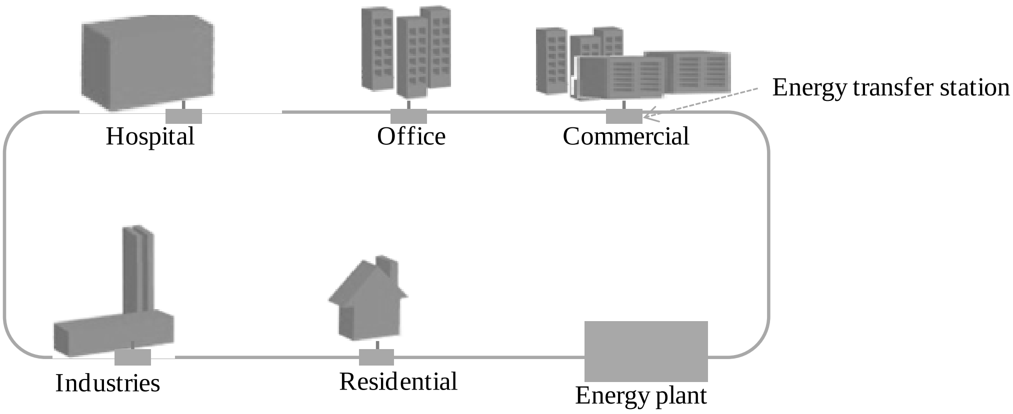


Figure 2-2 The concept of district heating (cooling) system

◆District cooling

The district cooling has almost the same principle as district heating. Just as it is possible to distribute heat in district heating networks, it is also becoming more interesting to make similar use of district cooling in large distribution systems. District cooling usually refers to the central production of cooling energy, which is distributed to customers as cold water in a closed circuit. District cooling is most common in buildings where the cooling demand is high, such as office buildings, factories, hospitals, etc.

District cooling has a number of advantages compared with locally produced cooling energy:

◈It is better for the environment because it reduces the use of Freon. The energy utilization is also higher compared with conventional ways of cooling.

◈The using of the district cooling system instead of local refrigeration plants is more convenient. Because the maintenance work in the centralized system is much easier without handling of Freon, no future fees or legal regulations.

◈There are also financial reasons for using district cooling. Energy costs can be reduced, maintenance costs can be kept to a minimum, the investment cost to the customer is low, and finally the security of delivery is increased.

☐ The second type -- centralized plant

Centralized plant, displayed in figure 2-3 is almost same with district heating and cooling. It uses centralized heat generation as heat supply system for the particular customers in same site. Compared with district heating, centralized plant is in small scale and excluded from the heat supply law. This type usually called regional heat and cooling, widely used in the residential area, universities, hospitals and commercial areas.

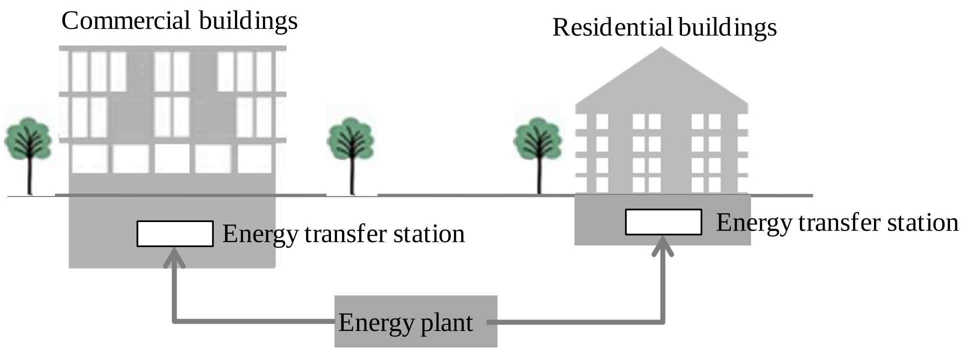


Figure 2-3 The concept of centralized plant

□The third type-- interchanging energy system between buildings

Compared with other two types before, the interchanging energy system between buildings (displayed in figure 2-4) is the area energy network in small scale, with the energy interchanging between buildings. In this kind of project, the nearby buildings are connected together with pipes and share the heat. The characteristic of this type is that the buildings in this area network have their own heat generation system as the base heat supply. In another word, the buildings in this type can also work individually.

Till now, this type is rarely used. However, it is expected that the energy interchanging between buildings will have opportunities in the renewal of the individual buildings and redevelopment projects in the urban area. The efficiency of the heat supply system in the existing buildings can be improved by high efficient equipment introduction in the new constructions and the energy interchanging management. If this kind of energy interchanging can be explored to the scale as the district energy supply, the area-wide use of energy with a large-scale energy infrastructure in the entire city as some exiting cases in Western countries can be expected.

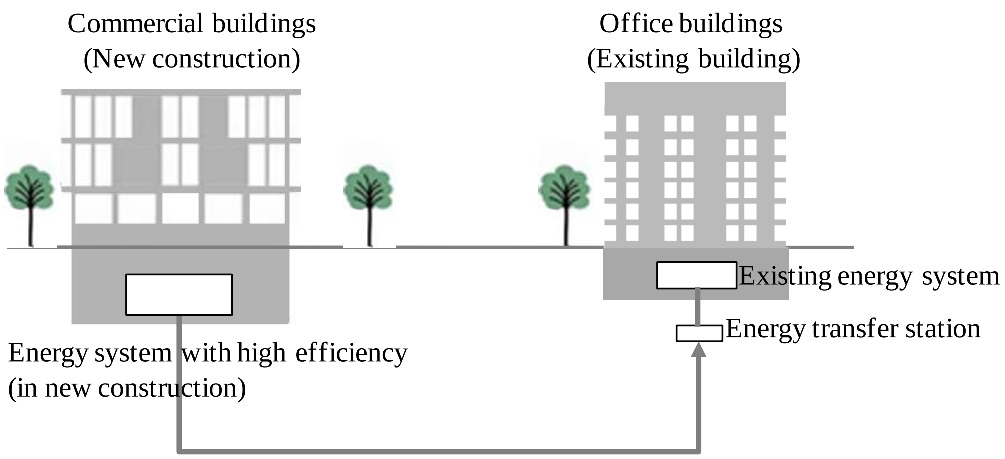


Figure 2-4 Interchanging energy system between buildings

2-3 SIGNIFICANCE OF AREA ENERGY NETWORK

2-3-1 THE ENERGY SAVING EFFECT

The area energy network aggregates the energy load in the region. In that case, it can adopt more efficient energy generation plant and can manage the system in a more efficient to support part load by appropriate equipment division. The optimization of the system construction and controlling can improved the energy saving effect.

The survey in the year 2002, displayed in figure2-5, suggested that the district heat supply system can save 12% primary energy compared with the individually heat supply system.

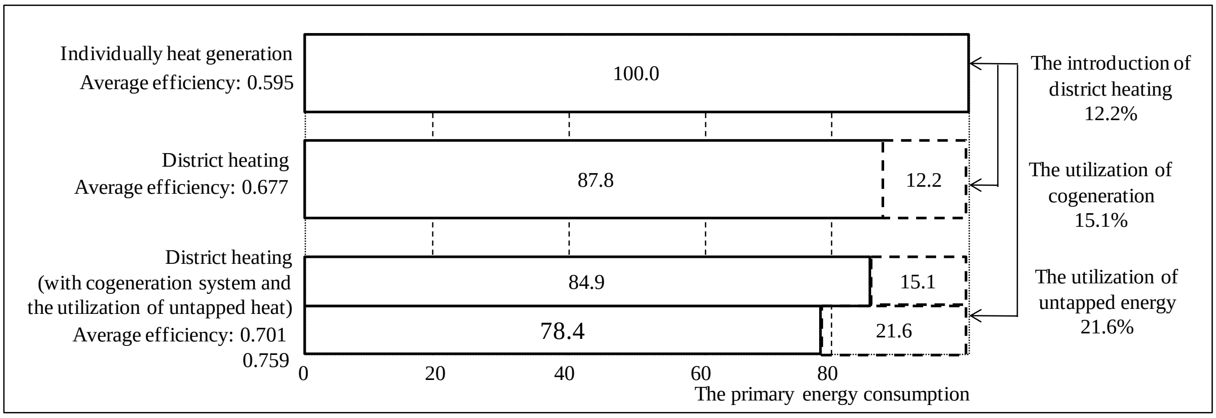


Figure2-5 The energy saving effect of area energy network[4)]

The effect of energy saving can be realized in the following way:

☐Load leveling of the electricity and heat by the aggregation of multiple customers

The intensive electricity and heat consumption differ among buildings depending on the time of day. Area energy network allow the pattern of energy use to be leveled by mutually accommodating energy sources.

◈Compact facility

The capacity of the facility for air conditioning or electricity is designed to match the maximum demand. Load leveling by the aggregation of multiple customers decreased the maximum load, which makes the facility compact.

◈Efficient operation at high load

Load leveling by the aggregation of customers increases the minimum demand and enables a high load factor. In other words, the facility installed is likely to be operated at high efficiency due to the high load factor compared to a system that does not use aggregation.

This increase in minimum demand also increase the capacity of the system installed.

Generally, the efficiency of CHP is improved with an increase in capacity, especially in CHP utilizing a gas engine. This means an additional efficiency improvement can be expected.

□Independency of energy source

Once a district energy network has been established, it is compatible with any kind of energy source. The effect of this is visible in many modern district energy networks: Where fossil fuels have been the primary energy source in the past, renewable such as biomass, solar or geothermal heating are gradually replacing or complementing the previously used sources of energy.

The conversion to a more environmentally friendly supply of energy takes place without any changes of equipment for the consumer and without them even noticing it.

□Economic efficiency

One of the primary barriers to the expansion of district heating and cooling systems is the financial climate favoring fast returns on investment. District heating and cooling infrastructure however provides a long-term, secure investment opportunity in real value:

District heating and district cooling reduce primary energy demand. This frees financial resources for redistribution into other spheres of the economy. It also reduces the need for investment in more generation capacity.

As a system using local heat and cold resources and infrastructure, local economic opportunities are improved. Investment in networks and customer connections is local investment. The supply of renewable sources is also mainly local, providing value and promoting the sustainable management of regional resources. The system's ability to integrate a wide variety of energy sources also boosts competition between the various sources on the market. Avoidance of consumer investment in new systems parallels to the continuous substitution of energy sources.

The principles for energy savings and their effect are classified and calculated as Table2-2

Table2-2 The principles for energy savings and their effect

Principles	Effect	
	← Energy increasing	Energy saving →
□Energy aggregation ◈ Load leveling ◈ Appropriate equipment division ◈Energy generation system with high efficiency		16%
□ Control and maintains ◈The management and operation in detail ◈ Proper maintains		9%
□Heat loss of pipes ◈ The heat loss because of the pipe extension	10%	
□Transport power increase ◈ The transport power increase because of the pipe extension ◈ Cooling (or heating) pump	3%	
Total		12%

2-3-2 OTHER EFFECT TO THE CITY ENVIRONMENTS BESIDE ENERGY SAVING

☐The improvement of the city environment

Besides the energy saving, the area energy network can also improved the city environment from other aspects (displayed in table 2-3). The aggregation of the heat generation plant can reduced the cooling tower and chimney where can use green roof instead. The green roof can mitigate the heat island effect.

Table 2-3 the significant of area energy network

Prevention of global warming	CO2 emission load reduction	The CO2 emission reduction because of energy saving
Contribution to the city environment	Heat island measures	The centralization of the cooling tower and chimney
	Prevention of air pollution	No_x and SO_x reduction associated with appropriate exhaust gas treatment
Enhancement of urban functions	Improvement of urban disaster prevention function	Reduction of fire disaster source Use of heat storage tank and water receiving tank in an fire disaster and earthquake Use as emergency power generator
	Improvement of the urban landscape	The consolidation of chimney and cooling tower, improving the rooftop landscape and appearance of the building
Contribution to the energy system of the city	Load leveling	Peak cut by introduction of the large-scale heat pump and cogeneration system
	Construction of a flexible and stable energy system	a more appropriate energy system by the combination of the on-site generation and grid
Improved stability and reliability of energy supply		Improvement of energy security by diversifying the operation and maintenance with professional operators
Space-saving, labor-saving		The aggregation of the energy plants can saving the equipment on the demand side so that saves the space for equipment and qualified persons

☐The utilization of the untapped energy

The utilization of untapped energy is not easy for the individual energy generation system because of the difficult in matching with the demand and large capital investment. These problems can be solved with the aggregation of energy generation, the area energy network.

There is still lot of untapped energy utilization potential in the urban area as the waste heat from factories, subway stations, waste treatment plants, sewage treatment plants. (suggested in figure2-6)

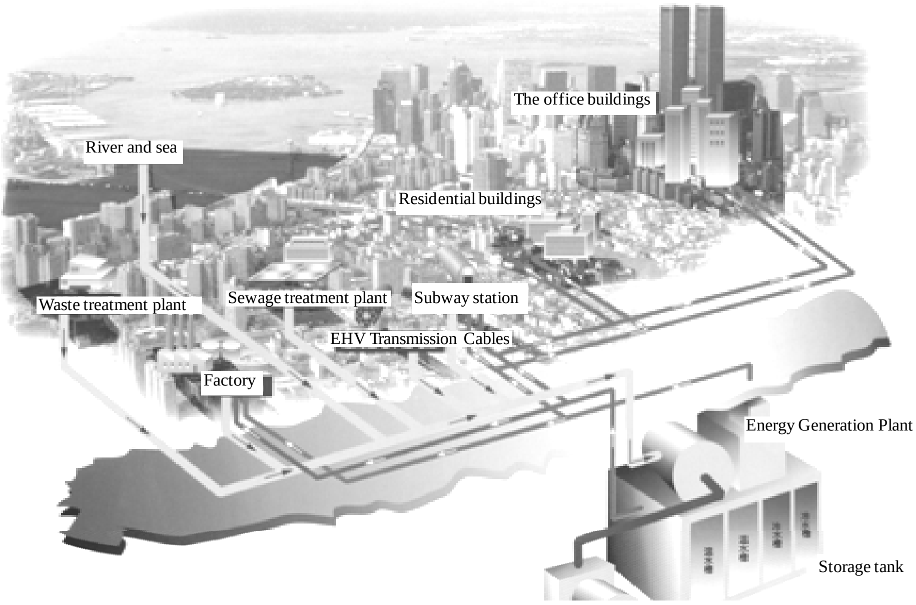


Figure2-6 Untapped energy resource in the urban area.

2-4 THE TECHNICAL REQUIREMENTS FOR AREA ENERGY NETWORK

2-4-1THE REQUIREMENT FOR THE AREA ENERGY NETWORK

The district energy system introduction is the area energy network in a large scale, which involves numerous buildings like commercial buildings, office, factories and residential areas. The project need a large capital investments and qualified infrastructure. Therefore, the previous plan and feasibility research are vital to make the project succeed. From the existing projects, some experiences, summarized in table2-4 can be pulled out to support the district energy plan in the pre-stage

Table 2-4 The key points and the outline of the area heat network [6]

	Key Point	Outline
Characteristic of the district	The maximum or yearly heat demand density is high	Heat demand density is high so that the introduction of high efficient energy generation system possible Heat demand density (GJ) (Cooling demand) Above 8GJ/h・ha Possible Above 2GJ/h・ha ↓ Below 2GJ/h・ha Impossible (Heating demand) Above 6GJ/h・ha Possible Above 2GJ/h・ha ↓ Below 2GJ/h・ha Impossible
	Control the development of fertilities	If the load demand spots are increased stepwise, it is expected that the investment of the fertility and instruments also developed step by step. The heat load is better to developed from the heat resource.
	Construct the facilities and start the service in plan	Construct the district as the plan and then make the heat resources service follow the district construct.
	A short construction period	If the heat demand place developed in stages, it is desirable that the demand can fix in a short period
	A proper energy source	The energy resource using cheap fuel
Characteristics of the business	Appropriate business entity	Business can be expanded by the business entity that meets the business characteristics and regional characteristics
	Obtain the understanding and cooperation of local governments	Coordination and guidance of the participants operators and get the support of local governments
	Meet the demands of home heat demand	Set the price system and the service which can be accepted by the customers
	Properly the funding	Financing the investment not excessive
	Proper plan for the pipes and heat service	Make the plan as accurate as possible

2-4-2 DISTRICT EXTRACTION CRITERIA FOR AREA ENERGY NETWORK

☐There still lack of criteria for setting the place where is properly to be introduced with the area energy network. The basic concept for the area energy network is high heat demand density or closely located buildings with large heat demand. Three key points are set for extracting the district in the first stage:

The district expected for area energy network—stage I

◈ The district with the heat density higher than 4.2TJ/ha per year and the district area is more than 5.0ha

◈ Gross floor area ratio is higher than 94.1% and the district area is more than 5.0ha

◈ Capacity ratio is more than 500% and the district area is more than 5.0ha

The district expected for area energy network—stage II

Compared with stage I, the district extraction in this stage pays more attention on the practical possibility

It is set that: the buildings with more than 3000m^2 building area also have high heat demand density (more than 4.2TJ/ha per year)

In this stage, the potential of untapped energy utilization is also taken into consideration. The place for the untapped energy utilization is set by limit the heat transport distance:

The untapped energy with high temperature: within 2km

The untapped energy with low temperature: within 0.5km

2-4-3 THE POTENTIAL DISTRICT FOR AREA ENERGY NETWORK

Based on the conditions that described in the last part, the city of Kitakyushu will be analyzes to pick out the district appropriate for area energy network.

The research use the energy consumption unit [7] [8] to calculate the heat demand which includes hot water, heating and cooling. The Geographic Information System (GIS) was adopted in this calculation. The characteristics of GIS and its application will be introduced in chapter 4.

The building heat amount is displayed in the mesh map (100m mesh). Figure2-7 is the mesh map of the yearly heat demand. Figure 2-8 is the district that picked out with the heat demand density above 4.2 TJ/ha・year. It suggested that the area with heat demand above 4.2 TJ/ha・ year is not so common in the city. The area around Yahata Higashida and Kokura station have more meshed that the heat density above 4.2 TJ/ha・ year. Therefore, these two districts are probably suitable for the area energy network.

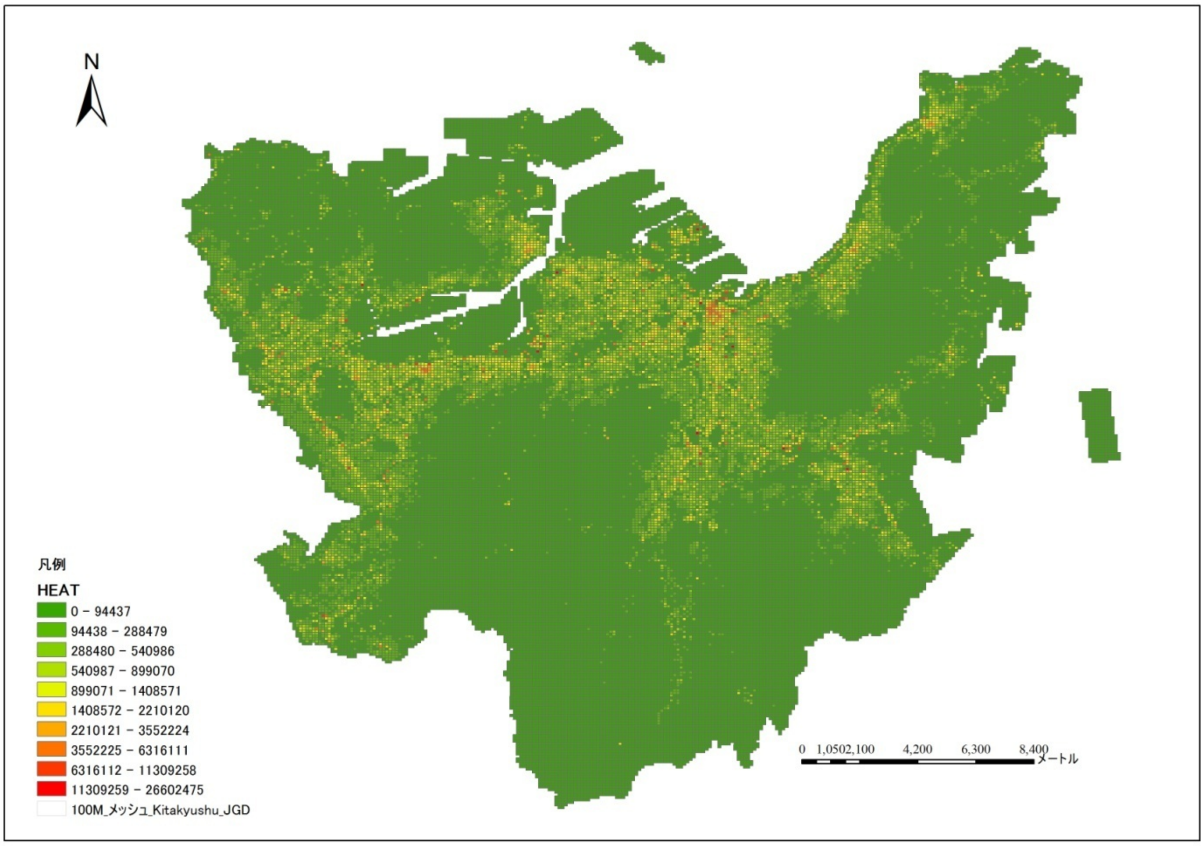
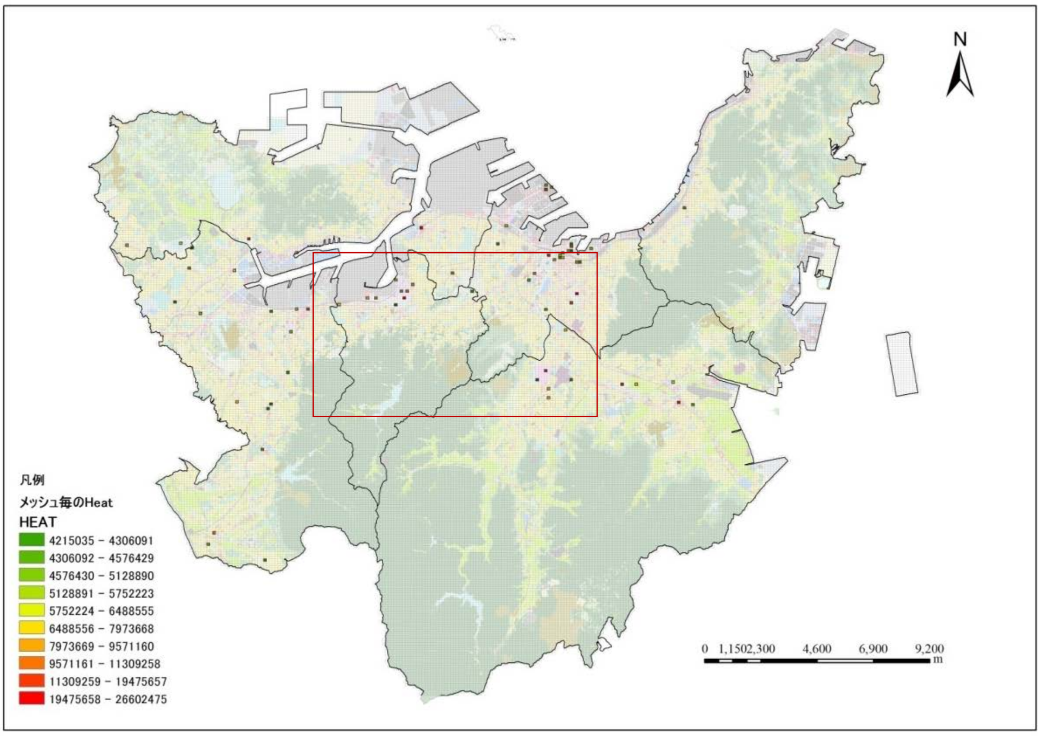


Figure2-7 Mesh map of the heat demand



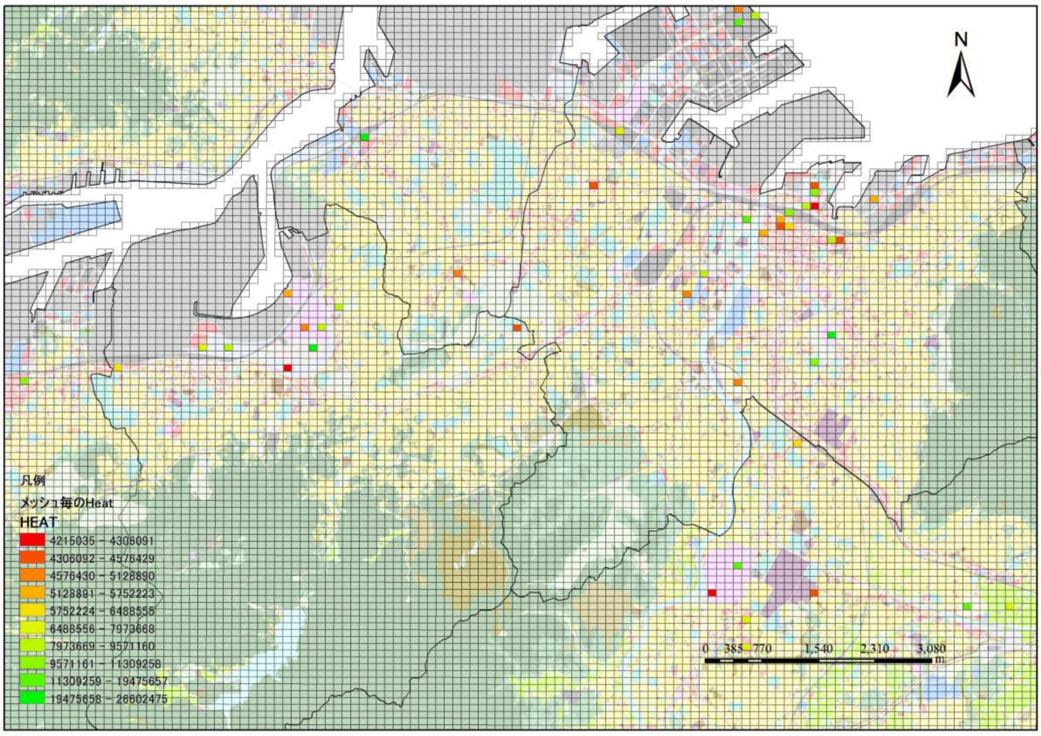


Figure2-8 The area with heat demand density above 4.2 TJ/ha・year

2-5 SUMMARIES

In this chapter, the recently developed technologies and policies of area energy network are investigated in detail. Firstly, the definition of area energy network and its categories in Japan are introduced. Secondly, the characteristics of area energy network and its contributions to the environment are analyzed. Finally, some previews researches and related policies are sited to assume the conditions as the basic criterions for area energy network.

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CHAPTER3 CONCEPT AND INVESTIGATION ON THE PLAN OF AREA ENERGY NETWORK

3-1INTRODUCTION

Increasing concern on the depletion of fossil energy resources and the pollution of the environment has increased the importance of developing high efficiency energy generation techniques, known as distributed energy resources (DER). The area energy network concept developed in Japan, has the same concept as the district energy system but weigh more on the collaborative energy using between buildings as well as the utilization of the untapped energy. In the near future, with the development of smart control, the smart use of electricity that balanced between grid and local generation will also be realized.

In order to increase the efficiency of such systems and ensure their operation near their optimal load, it is important to examine possible extensions to end-applications comprised of more than just one building. By doing so, one can take advantage of the various load profiles of the buildings, compensate the fluctuations and achieve a smoother operation. It is therefore much more advantageous to implement them in a small plant that serves several buildings, and that is managed for instance by an energy service company.

Although, DER technologies are growing fast, there are many open questions regarding the optimal design, scheduling and control of such systems. This is mainly due to the complexity imposed by the availability of many different technologies and the special requirements of each specific installation, such as the location of the DER system around the globe, heat and power demand profiles, electricity pricing policies etc. In particular, the design of a DER system that is optimized to address both power and heating requirements is a very challenging problem. The complexity is further increased when the DER systems are designed for covering the demands of multiple end-users in the neighborhood level, which often involves the design of a heating pipeline network [1].

The role of the planning is to reveal the best (under certain criteria and constraints) design and the best optional point of the system. Currently, a number of plan and evaluation models are available, including Distributed Energy Resources Customer Adoption Model (DER-CAM)[2], which has been developed by the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) and HEATMAP which has been developed by Washington State University[3].

The majority of the literature on district heating systems focuses on the optimization of the energy conversion technologies and their operational strategies [4-6]. The simultaneous consideration of heating and power demand has not been studied to the same extent.

Some of existing researches deal with the design of the heating networks within the micro grid. However, most of the existing models refer to either single non-residential sites or focus on the design of the heating pipeline network, in a more detailed aspect [7-9]. The overall design and operation of DER system within a micro grid in a residential scale with the incorporation of a heating pipeline network, has rarely been mentioned.

In this chapter, the model of the district energy and area energy network within the micro grid will be investigated. By analyzing the structural level of the area energy system plan, this chapter will propose a model of area energy network with in micro grid in the community level, for residential area. The neighborhood where several options for satisfying its electricity and heat demands is considered. The adoption of DER technologies combined with a heating pipeline network and electricity transmission lines is examined. In addition, the evaluation methods for the area energy network model are discussed.

3-2 PARADIGMS SHIFT AT THE COMMUNITY LEVEL

3-2-1 GENERAL STRUCTURE OF AREA ENERGY NETWOTRK

The area energy network within micro grid and distributed generation paradigm should be recognized as the future power paradigm. The model discussed in this thesis is not an isolated system but connected with the conventional system. The system can both import and export surplus electricity at times of low local demand. This helps to further smooth out the demand profile, and allows suitably sized power units to match import with exports (to achieve an overall energy neutral result). The interconnected infrastructure with several energy carriers: electricity, heat, gas is also produced by on-site resource, such as from PV cells or wind turbines. Such integrated energy network can supply consumers with different types of end-use energy-based products and service. The area energy network in this thesis is a model in the neighborhood community level that with the energy distribution system supplies several energy carriers to various buildings. That is to say, the energy consumers will have diversified consumption pattern, as industrial, commercial, residential and office.

Understanding the dynamic interaction among energy demand, energy distribution systems (national electric grid, natural gas distribution grid, electric active grids, district heating and district cooling networks) and distributed generation technologies is essential for the area energy network planning in order to determine correct technical solutions.

For this purpose, it is meaningful to identify the physical components of a area energy network. :

As an advanced type of distributed energy system, area energy network is also a network of energy chains, starting from the primary energy supply and end in the end-use sectors

The main parts of area energy network are primary energy supply sector, energy transformation sector, energy distribution sector and end-user sector.

◈Primary energy supply sector

Primary supply sector includes the non-renewable energy (fossil fuel, etc), renewable energy (solar, biomass, etc) and unutilized energy (industrial by-pass, water energy, etc), displayed in figure 3-1.

◈Energy transformation sector

The small-scale distributed technologies will be dominated in the area energy network model with distributed energy generation. As described before, the area energy network is connected with the conventional centralized generation system. That means the users can also adopt centralized electricity generation and total generation capacity installed may take into account the possibility to export energy into the grid.

Various technologies, as CHP plant, renewable technology, will be adopted in the energy transformation sector. The technology selection considering the energy saving, environmental and economic the objective is one of the energy planning process.

◈Energy distribution sector

The energy distribution sector is an essential part in the area energy network. It connected the distributed energy generations to form a network with the electricity and heat sharing. Normally, pipe system and local grid are used for energy interchange, now the offline system is under development for the heat storage as well as transport. The pipe plan with less heat loss, the selection between the heat distribution and heat storage are also vital to the energy system plan. The optimization of the distribution sector with the intelligent control can level out the load fluctuation, cut the capital investment, rewarding both in environmental aspect and economic aspect.

◈End-user sector

The integrated energy system can supply customers with different kind of end-use services. In area energy network, the end-users usually formed with more than one building. Load profiles represent the basis for generation and distribution systems sizing and economic dispatch optimization [10]. The most common way to calculate loads for buildings is the use of simulation programs, which can be employed as whole building energy simulation tools. Loads for industrial and other types of use (public lighting, ancillary services, electric vehicles, etc.) can be derived from activity types, working schedules and other available statistics. The area energy network as distributed energy system is a bottoms up energy type. Therefore, design and the plan in the end-user sector is the base for the area energy network.

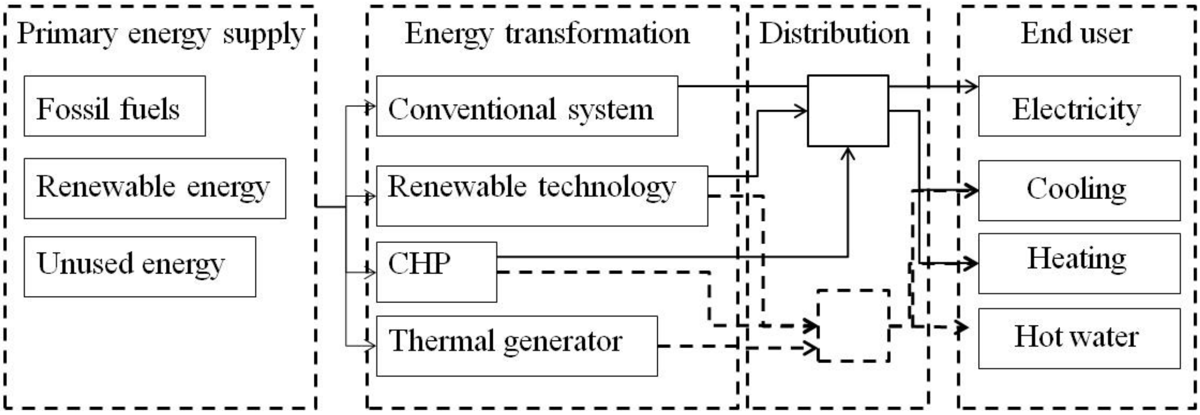


Figure3-1 Main parts of area energy network

3-2-2 PARADIGM SHIFT AT THE COMMUNITY LEVEL

The paradigm shift in energy systems, from the centralized system to the area energy system network, has to be supported, at local and global level, by mandatory regulations, technological infrastructures, business strategies, etc.

□ Demand side and demand response management

The demand management involves actions that affect the pattern and quantity of energy demand by the end-user. By introducing more efficient electric appliances and better strategy, the electricity, heating and cooling demand can be reduced. Further, in the larger scale, increasing land-use mixes and densities reduce commuting and travel requirements, minimizing infrastructures and optimizing their operation to reduce embodied energy and life-cycle energy consumption. The emerging energy patterns with DG technologies, renewable energy create a stronger connection between energy demand and supply, especially with respect to load dispatch and control strategies. It can cut the load peak with response to the real-time market prices and can be successfully interpreted as a more wide and general concept, involving other types of load, when transferred to local energy systems.

□ Distributed generation

The evolution of electric infrastructures towards area energy network in smart grid will lead to a more effective integration of stochastic energy resources into power system, due to the possibility of adjusting the dispatch strategy of on-site capacity in response to varying demand and renewable energy production. Further, standard communication protocols over the grid will also enable load curtailment and rescheduling strategies.

Under the existing system, customers have only a little incentive to reduce their demand in peak hours unless real-time pricing is adopted. On the other hand, the synergetic interaction of integrated distributed energy systems (with a mix of local renewable energy system and conventional fossil fuels) and present large centralized power plants could result in a balanced economic and environmental benefits [11,12]. Furthermore, small scale generation technologies can adapt better and faster to load curve variation than large ones [13] and can ensure the possibility of finding solutions tailored to meet specific needs because of their scalability. Finally, DG will result in reduced investments in operation reserve, improved reliability, (by controlling extreme conditions) and better rates of return due to an improved capacity factor of the whole electric generation and distribution system.

□ Paradigm shift in policies for synergies and conflicts among actors

From a theoretical point of view, policy transfer can be soft, involving ideas, concepts and attitudes, or hard, with the transfer of programs and implementation. The construction of a best practice at the community level embodies political rationalities for both local sustainable development and technological progress [14].

In this sense, the policies for the practice in the paradigm shift to community level should not be recognized as a source of general technical expertise, but rather as a type of intervention that can identify problems and provide useful insights. A strategic approach consists in identifying first the specific institutions and actors affecting and being affected by different processes of change and then proceeding incrementally, gradually covering more issues and involving more stakeholders. Community level processes should involve awareness raising, mobilization, capacity building, action planning and small-scale actions to improve the efficacy and the confidence of actors. Naturally, it is difficult to cope with these processes in a coherent and pragmatic way.

Economists generally interpret social processes in terms of a market with separate, but interlinked, domains of knowledge and action. The technical, organizational and economic complexity of energy-related decision making is neglected by an image of autonomous rational actors projected towards a more sustainable future. Therefore, the role of government in this vision is clear: setting background conditions such that investors will take decisions in both their own and general interest. This is clearly a distorting view that, as a matter of facts, cannot support a paradigm shift in an effective way.

☐ Transformation through shared visions

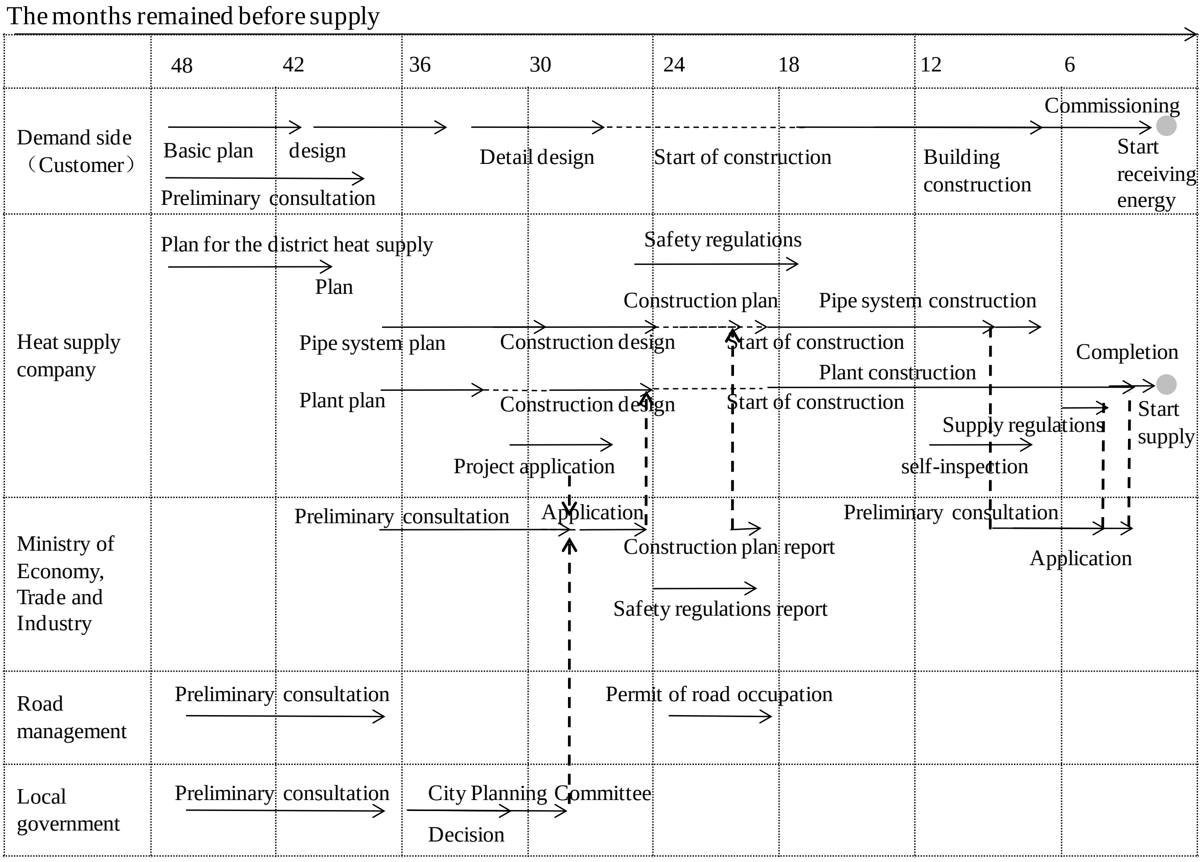
Planning at the community level is more about process than methodology and the focus should be placed on communication and participation of stakeholders. Therefore, it may be possible to reach correct decisions in energy planning starting from a participatory approach and on relatively simple tools, for example by discussing certain aspects of the local energy system with respect to national and international environmental quality objectives. Additionally, actively inviting different stakeholders in the information gathering process can be an efficient way to enhance a broader participation.

3-3 PROCEDURES FOR THE INTRODUCTION OF AREA ENERGY NETWORK

Procedures for the introduction of area energy network are different according to its type, district characteristic and system form. Usually, the procedure is from the basic concept and the plan of the business, the system design, construction, operation and maintenance, evaluation and system renovation.

The area energy network will be proposed firstly based on the city development, as the construction or renew of the urban blocks. Then the developers will analysis the surrounding heat resource and the situation of the heat supply, deciding the type of the project. Table 3-1 displayed the flow and time schedule for area energy network construction.

Table 3-1 Time schedule for area energy network construction.



The area energy network need detailed planning during every stage for the survey on the untapped energy using, energy demand side prediction, plant system setting. Further, it needs more information about the characteristic of the district and the urban plan information to make the project more practicable. Figure 3-2 displayed the considerations in the area energy network planning decisions.

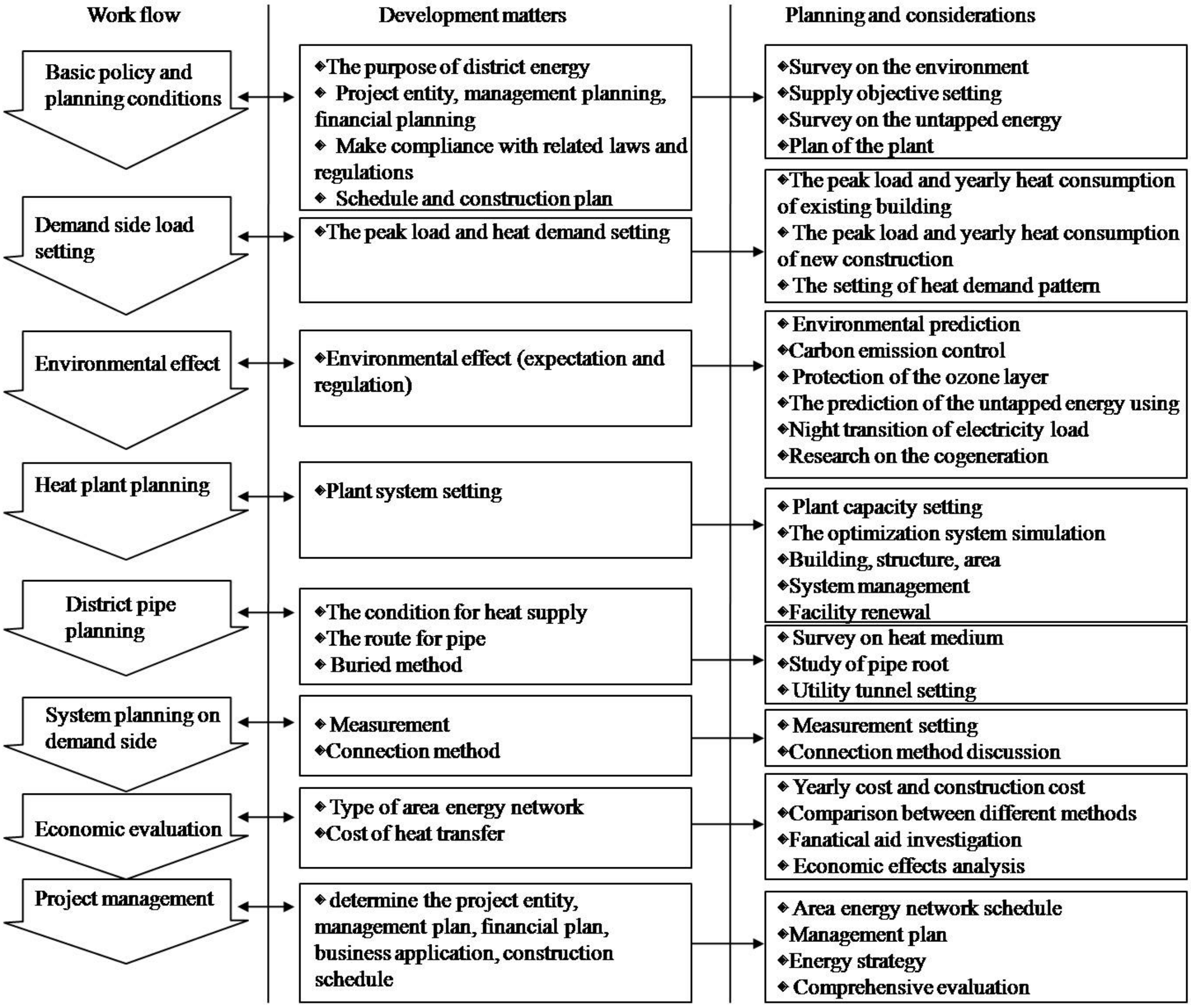


Figure 3-2 Considerations in the area energy network planning decisions

3-4 METHODOLOGY AND FRAMEWORK FOR COMMUNITY SCALE AREA ENERGY NETWORK

The methodologies and design process are currently being developed with the scope of identifying optimal solutions for district scale energy systems, the area energy network. Energy, environmental and economic analysis criteria are simultaneously considered in the optimization.

The processes for the area energy network need many special tools to manage large data in the district scale. The methodology proposed in this thesis will firstly stress the utilization of Geographical Information Systems (GIS). GIS is essential for storing, organizing and visualizing spatial data and for performing spatial calculation. Further, different simulation and calculation model will be proposed according to the characteristic of the building and district. Finally, the environmental and economic impact will be evaluated

The process for the area energy network plan should address pre-processing phase, design phase and post-processing phase.

3-4 -1 PRELIMINARY PHASE

The area energy network design involves several issues: energy services market competitiveness, maximization of on-site renewable energy resources use, minimization of local and global emissions, etc. In this stage, GIS will be employed. Data related to the district have to be collected, organized and stored in datasets and connected within GIS to enable fast and accurate spatial calculation in the preliminary phase. Usually, for the area energy network, a large amount of disaggregated data needs to be present and processing techniques are fundamental to extract useful information and statistics. The data include:

－Building data (general dimension, heated ground area, heated gross volume, number of dwellings, windows to wall ratio, exposed end area, construction technology, envelope features etc.);

－Building function types (residential, commercial, offices, industrial, etc.);

－Energy consumption data (natural gas and electricity consumption from utility);

－Electric load profiles data;

－Energy tariffs and fuel costs (market and trading data);

－Climatic data (one hour resolution)

The data are used to identify potential sites, analyze existing customers’ distribution and characteristics and formulate preliminary hypotheses that are necessary to enter the pre-processing phase, where data analysis is performed. In the real world applications, energy flows monitoring is necessary for both demand and supply side. The information from different layers has to be organized to be interoperable.

☐Pre-processing phase

The Pre-processing phase is the data preparing for the energy system plan. It need the forecasting techniques to be employed to simulate the hourly and yearly energy consumption, such as using the history data analysis though statistical regression. Some of time can also be available by the simulation soft like energy plus. In Japan, the energy consumption unit is widely accepted data resource for assuming the energy consumption patter. It is a value that summarized though statistical regression including the yearly energy consumption for every building type as well as the dispatch pattern in each hour [15-20].

Loads are basic inputs for the sizing and dispatch optimization procedure. Even the load can be calculated also with simulation models the use of real metered data is necessary for existing districts. The simultaneous presence in the design process of real metered and simulation data is particularly critical, because of the uncertainty connected with modeling assumptions. Finally, realistic load profiles are essential also for assessing load rescheduling and curtailment strategies, in order to exploit the possibility for end users to positively interact with changing market conditions and local generation systems.

3-4-2 DESIGN PHASE

The design phase comprises the optimization of energy services supply system from economic, energy and environmental point of view. The analysis is performed in two steps, plant sizing and economic dispatch optimization.

☐Setting of individual CHP plant

For the plant sizing optimization, many studies have been reported on the optimization methods for the size design [21–24]. Different from those difficult optimization models, a common practice called maximum rectangle method, which the capacity of a plant is based on the maximum amount of energy annually supplied at full load, may be simply implemented in the load duration curve. The idea of this method is based on sizing the plant unit to cover an average instead maximal energy demand while the back-up facilities can meet the peak demand. In other words, it is a size design method based on the concept of maximizing energy consumption amount supplied at full load. It can be simply determined based on finding the 'maximum rectangle', where the 8760 hourly energy demand values are sorted in descending order and placed in a load duration diagram (figure3-3). The method prevents dramatic undersize or oversize of the plant unit, providing a good compromise between the requirements for a good part of the annual energy demand from the system and for a sufficient annual operation at high load levels[25-27]. For example, the combined heat and power

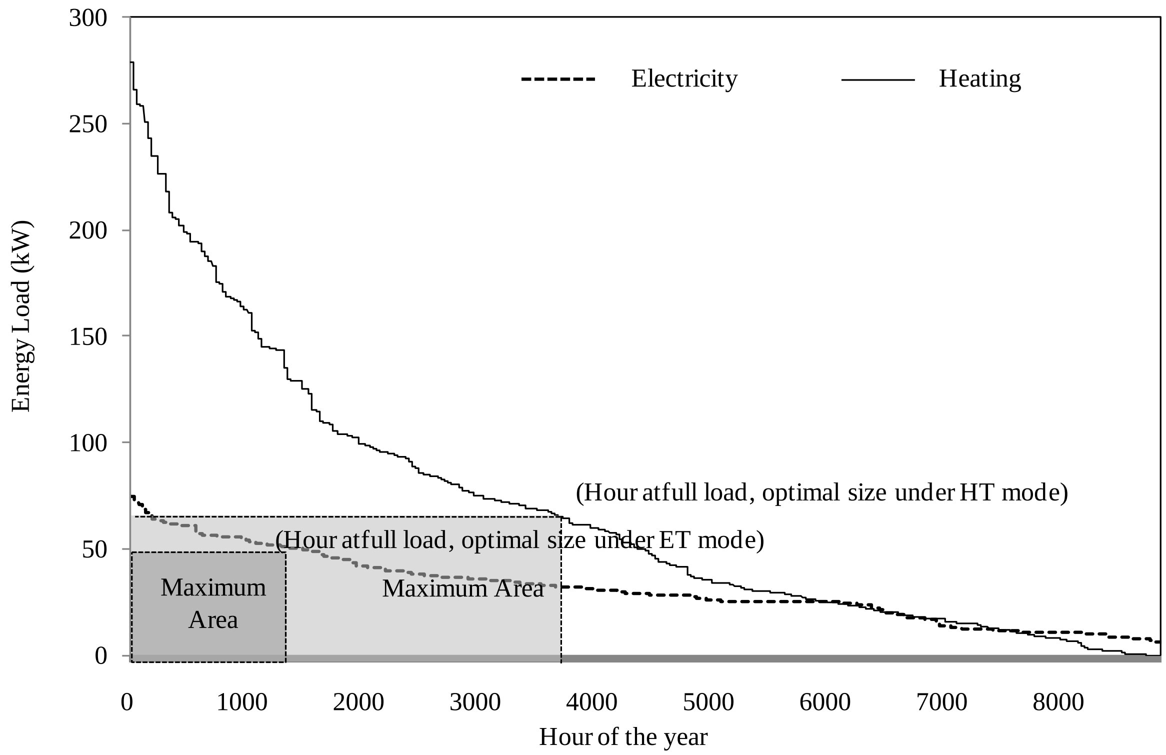


Figure 3-3 Rule of 'maximum rectangle' for plant size setting

(CHP) system, a widely used distributed energy plant, is usually managed in two modes, the heat tracking mode and the electricity tracking mode. Under the heat tracking mode, the plant size will be by finding the 'maximum rectangle' of the descending heat load, while the plant size will be by finding the 'maximum rectangle' of the descending electricity load under the electricity tracking mode.

The second step of the design is the optimization of the dispatch. The procedure is also multi-objective with consideration of the economic and environmental performance. Further, energy tariffs and energy demand variability, technologies performance degradation and pollutant emission increment factors have also to be taken into consideration for the optimization analysis in costs, energy use and pollutant emissions.

The result of the first step will be put into the second step. Therefore, this step has to treat with large amount of district data that stored in the GIS. Besides the spatial analysis that can be finished in GIS, The developments in mathematical programming methods highlight the possibility of solving large scale optimization problems.

Area energy network in smart grid still need communication technologies beyond the physical connected distributed energy system. In recent years many new numerical techniques have emerged and existing ones have been improved [28]. The IEEE 2030-2011 standard, which is being widely accepted as the industry's first guideline regarding its architecture and interoperability provides the smart grid interoperability reference model. It uses a systems-level approach to provide guidance on interoperability among various component of communications, power systems, and information technology platforms in the smart grid [29].

3-4-3 POST-PROCESSING PHASE

3-4-3-1THE COMPREHENSIVE EVALUATION OF AREA ENERGY NETWORK

The purpose of this phase is the comprehensive assessment of the area energy network. In this work phase a large amount of data (outputs from the design phase) have to be organized and analyzed to enable the calculation of useful indicators.

The evaluations of the area energy system network include its effect on every stage, for different entities, customers as well as government that engaged in the project. Figure 3-4 displayed the evaluation of the area energy network from different aspects.

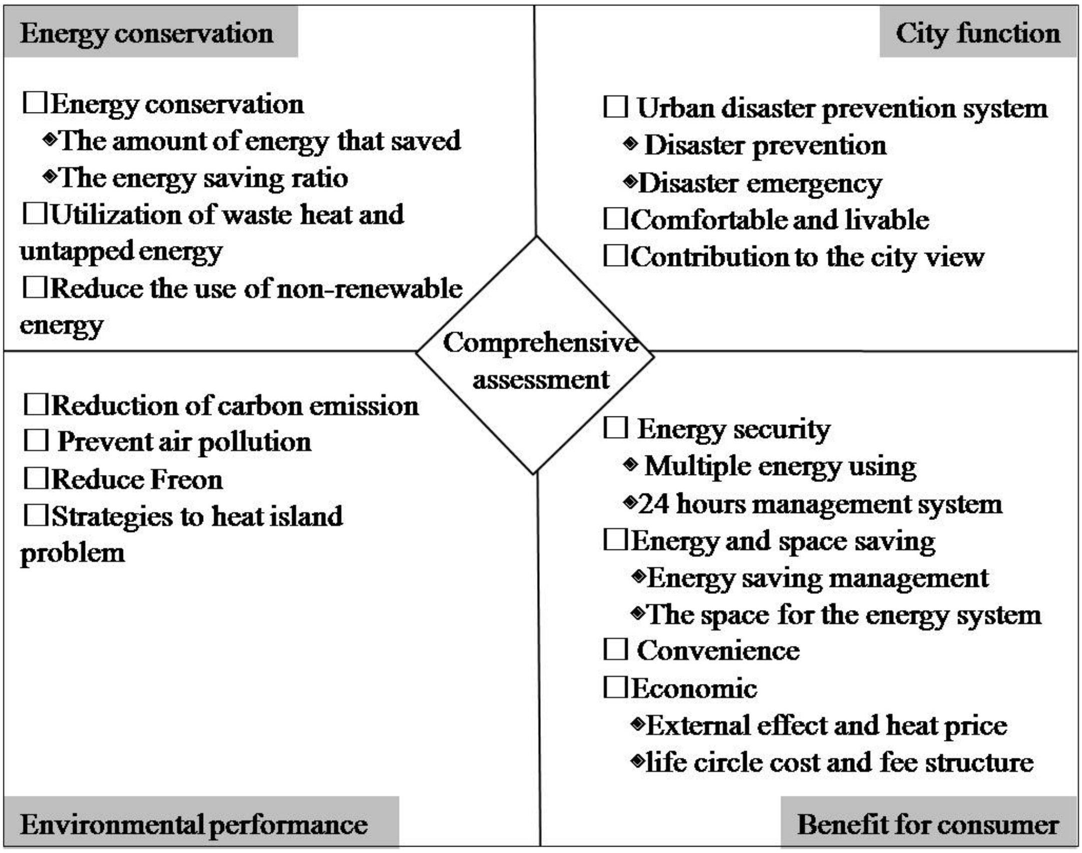


Figure 3-4 Comprehensive evaluation of the area energy network from different aspects.

☐ Energy saving aspect

◈Energy saving effect

The energy saving effect should be considered as the most important aspect for area energy network. The evaluations on the energy saving effect usually include the reduction on total energy consumption and energy saving ratio.

The utilization of waste heat and untapped heat

The effect on waste heat utilization and the untapped energy using will be analyzed, considering the district energy load pattern.

Reduce the use of non-renewable energy

Based on the energy saving effect and onsite utilization of untapped energy resource, the area energy network can cut the total utilization of the traditional non-renewable energy.

Contribution to the load leveling

□ Environmental aspect

◈ Low carbon effect

The comparison of carbon emission (as well as Freon emission) between the individual systems and the area energy network can be a factor to evaluate the low carbon effect of the system.

Contribution to heat island problem

The centralized plant can promote using of green roof can weaken the heat island problem.

□ The urban function aspect

Urban disaster prevention system

The area energy network is the centralized energy system, which can improve the urban disaster prevention. The evaluation on its effectiveness during the emergency time is an important aspect.

The contribution to the urban view

The area energy network can promote the green roof, which is help to the building design and urban landscape.

Contribution to improving urban infrastructure

□ The economic consideration for customer

Convenience and comfort

Compared with the individual system, the evaluation should analysis on the improvement by the centralized management, maintains and the facility renewal. Further, the centralized heating and cooling can using less energy consumption and offers more comfortable living environment.

Energy security

The 24hours centralized controlling system can improve the system security compared.

Laborsaving

The centralized system need less person for system management and tectonic engineer.

Space saving

□ Economic for the entity

The assessment in this thesis will focused on the environmental effect of the area energy network and the factors will be selected according to the cases in the following chapter.

3-4-3-2 EVALUATION FACTORS DEFINED IN THIS PAPER

The evaluation for the area energy system is consisted with various factors that described in the last section. In this thesis, the area energy network system model is discussed aiming for the construction of low carbon communities. Therefore, the evaluation factors defined in this paper are limited in energy saving performance and environmental performance.

Three main factors are mentioned in the thesis:

□Assessment of energy performance

▪ Primary energy saving ratio

The CHP system provided higher utilization of the primary energy, thus the evaluation of the energy saving performance is one of the most important aspects of the CHP system. This research used the primary energy saving (ESR) ratio as the key factor to determine the energy saving performance, which is defined as the rate of the energy savings of the CHP system (the difference between the conventional system and the CHP system) to that of conventional energy system. ESR is defined as (3-1):

$$\mathrm{ESR} = \frac{Q_{input}^{Conv} - Q_{input}^{CHP}}{Q_{input}^{Conv}} \qquad \text{……(3-1)}$$

Q_{input}^{CHP} is primary energy input to the CHP system; Q_{input}^{Conv} is the primary energy used by conventional system;

The annual primary energy consumption for CHP system included the energy consumption for utility, and the gas consumption for on-site power generation, the CHP unit. The primary energy used in CHP unit also included the primary energy consumption for absorption chiller and the heat recovery boiler to satisfy the cooling, heating and hot water.

▪ Net-zero energy ratio

The concept of Zero Energy Building (ZEB) has gained wide international attention during last few years and is now seen as the future target for the design of buildings [30]. It has become a new important evaluation criterion for the reduction of energy use. The definition of ZEB varies according to the situation in different countries. Basically speaking, there were two kinds of ZEB: the off-grid ZEB, unconnected to any utility grid, can autonomously supply energy, and has the capacity to store energy for night-time or wintertime use[31]. The on-grid ZEB, named as ‘net zero energy’, is connected with grid or other energy supply infrastructure. Therefore, it can get energy or feedback energy to the grid, avoiding on-site electricity storage [30]. Actually, the net-zero ZEB received more attention, which was considered as the final solution while the off-grid is regarded as an intermediate step [31].

In this research, the ZEB referred to the net-zero system, a system connected to the energy networks that can obtain electricity from the utility provider and send back surplus electricity. The physical boundary of ZEB can encompass a single building or a group of buildings. This research defined that “net-zero energy” as “a building or a district, whose annual energy input can be entirely offset by the energy output”.

Figure3-4 displayed the concept for “net-zero energy balance” in this research. The physical boundary encompassed the whole district, while the energy input to the district mainly referred to electricity and gas. The distributed energy system means all the CHP systems in CHB and the on-site renewable energy generation. The energy output is the timely surplus energy that sends back to the grid.

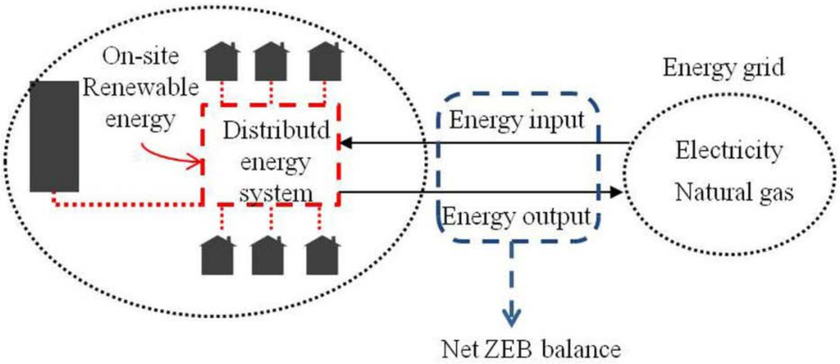


Figure3-4 Concept for “net-zero energy balance”

The factor to evaluate the net-zero balance is named as net-zero balance ratio (RNZ), defined as below:

$$R_{NZ} = \frac{E_{Input}}{E_{Output}} \quad \text{...... (3-2)}$$

E_{Input} is the energy input from the grid, including the electricity and the gas;; E_{output} is the energy output of the community.

Whether the community or buildings realized “net-zero” or not is evaluated by the comparison between Rnz and 1. $R_{NZ} \geq 1$ means the community realized “net- zero”. $R_{NZ} < 1$ means the community can not realize “net- zero” or only near “net- zero”.

▪ **Recovery heat utilization efficiency**

Recovery heat utilization efficiency (*RHUE*) is defined as the rate of thermal energy utilized to primary energy input as (3-3)

$$RHUE = \frac{U_{RH}}{Q_{input}} \qquad \text{…… (3-3)}$$

U_{RH} is the thermal energy be used from the recovery heat. Q_{input} is the primary energy input to the CHP system.

▪ Primary energy utilization efficiency

Primary energy utilization efficiency (*PEUE*) is defined as the rate of energy utilized to the overall primary energy input. It is a sum of electricity generation efficiency and recovery heat utilization efficiency and expresses that the overall energy utilization efficiency in the distributed energy system. It is defined as (3-4)

$$PEUE = \frac{E_{elec} + U_{RH}}{Q_{input}} \qquad \text{…… (3-4)}$$

E_{elec} refers to the electricity generated by the distributed energy system;

▪Fraction of self-sufficient electricity generation

Fraction of self-sufficient electricity generation (SEG) is defined as the rate of electricity produced by distributed energy system to the electricity demand. It is a factor to suggest the independence of the conventional utility. In this case, the electricity in the distributed energy system is produced by CHP system and PV system. It is calculated as (3-5)

$$SEG = \frac{E_{elec}^{CHP} + E_{elec}^{PV}}{E_{elec}^{demand}} \qquad \text{…… (3-5)}$$

E_{elec}^{CHP} refers to the electricity generated by CHP plant.

E_{elec}^{PV} refers to the electricity generated by PV system

E_{elec}^{demand} refers to the electricity demand.

☐Assessment of environmental performance

▪ CO_2 emissions reduction ratio

Environmental benefit is another concern for the introduction of the CHP system. This study used CO2 emissions reduction ratio (CERR) to assess the environmental performance (the difference between CO2 emissions in the conventional system and the CHP system).

The CERR is defined as (3-6):

$$CERR = \frac{EX_{CO_2}^{Conv} - EX_{CO_2}^{CHP}}{EX_{CO_2}^{Conv}} \qquad \text{…… (3-6)}$$

Where $EX_{CO_2}^{Conv}$ and $EX_{CO_2}^{CHP}$ denoted annual CO2 emissions of the conventional energy system and the CHP system, respectively.

▪Zero carbon ratio

The factor to evaluate the net-zero balance is named as zero carbon ratio (R_{ZC}), similar as the "net-zero energy ratio" as described in chapter3. It is being understood to refer to achieving net aero carbon emission by balancing a certain measured amount of carbon released with an amount of carbon offset, calculated as (3-7):

$$R_{ZC} = \frac{C_{emission}}{C_{Offset}} \qquad \text{…… (3-7)}$$

$C_{emission}$ is the carbon emission to the environment because of using energy, including the electricity and the gas; C_{offset} is the carbon offset of the community by sending back energy to the surrounding area.

☐Economy assessment

▪Payback year

Economy is a decisive factor in the introduction of distributed energy resource. The distributed energy system has usually the higher initial investment and lower running cost compared with the conventional energy supply system. In economy evaluation, an important index, payback year ($Y_{payback}$), has been adopted to evaluate the distributed energy system. It expresses the profitability of the distributed energy system and is defined as the rate of the initial investment gap to the running cost gap between the distributed energy system and the conventional energy system. It is calculated as (5-18)

$$Y_{payback} = \frac{CO_{initial}^{CHP} - CO_{initial}^{conv}}{CO_{running}^{conv} - CO_{running}^{CHP}} \qquad \text{…….(3-8)}$$

$CO_{initial}^{conv}$ is the initial investment of conventional system;

$CO_{initial}^{CHP}$ is the initial investment of CHP system;

$CO_{Running}^{conv}$, $CO_{Running}^{CHP}$ are the running cost for conventional system;

3-5 SUMMARIES

This chapter firstly investigated structural level and design process of the area energy system plan. Based on this, it developed an model for the area energy network in community level and analyzed the necessary paradigm shift at the community level. At last it proposed a procedure of area energy network design within micro grid in the community level, for residential area. This model included a database that can convey the comprehensive information, such as city plan and building information, renewable energy resources and unutilized energy resources as well as the demand side energy consumption. It also proposed the method to set the capacity of the individual energy plant with the sharing distribution view. Further, it described the energy distribution section and set the evaluation factors.

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CHAPTER FOUR: SPATIAL ANALYSIS OF RENEWABLE ENERGY AND UNUTILIZED ENERGY IN KITAKYUSHU WITH GIS

4-1 INTRODUCTION

The environment problem is getting more and more serious so that the construction of low carbon needs much broader concepts and technologies. The efforts on the development and implementation of the renewable energy have been promoted worldwide. Europe established a target for 20% share of energy consumption from renewable energy by 2010, and the Unites states pledged that 25% of electricity should come from renewable sources by 2025 [1].

In Japan, renewable energy is finally beginning to gain attention as a key element in energy, climate change and industrial policy with renewable energy such as wind power and solar photovoltaic (PV) emerging as an attractive new industry and market. This is attributed to the “Green New Deal” policy, which has been undertaken in countries around the world, as well as other effective policies such as Feed-in Tariff, which was initiated in Europe and expanded to the rest of the world [1].

Energy companies such as electric power, gas or oil companies are also pursing renewable energy. Power utilities are planning solar power generation as well as integrating solar heating technologies in the development of hot-water heat pump mechanisms. In addition, gas companies are developing solar heating for apartment balconies, and oil companies are entering full-scale into the solar PV market. As shown in figure4-1, the existing capacity of renewable power generation reached over 10,000MW at the end of fiscal year 2008, 60% of which consisted of small hydro under 10,000kW and biomass (including waste power generation). Solar PV and wind power accounted for an estimated 37% at the end of 2008. Increases in waste-power generation, especially those using general wastes, have led to an overall increase in biomass power capacity resulting in biomass providing just fewer than 30% of total capacity at the end of 2008.

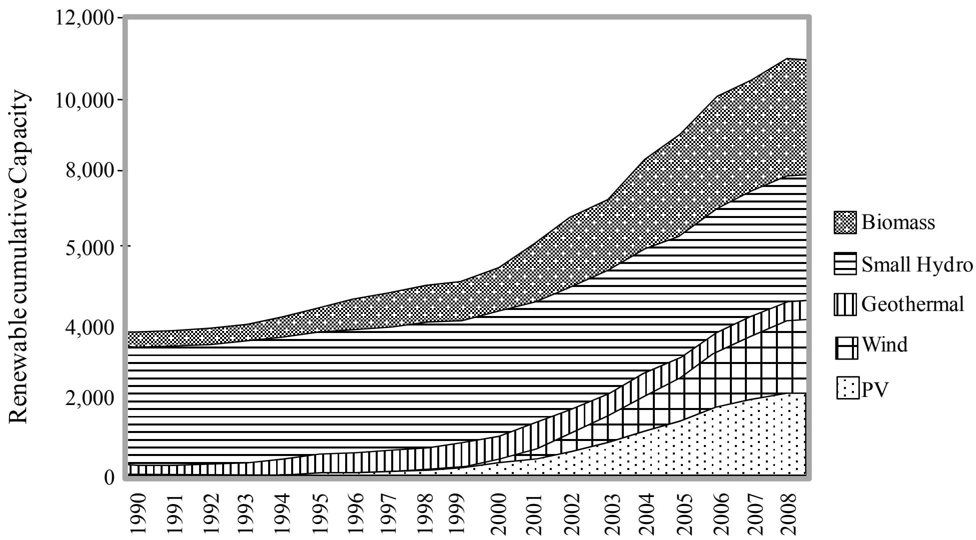


Figure4-1 Cumulative Renewable Power Capacity in Japan (Data from Institute for Sustainable Energy Policies)

The "renewable energy vision in 2050", displayed in figure4-2, set a goal of 75% reduction in CO_2 emissions originating from energy use (based on 2000 levels). It also suggests that there is a potential that the renewable energy can afford for 67% of domestic electric demand and more than 50% of the primary energy supply.

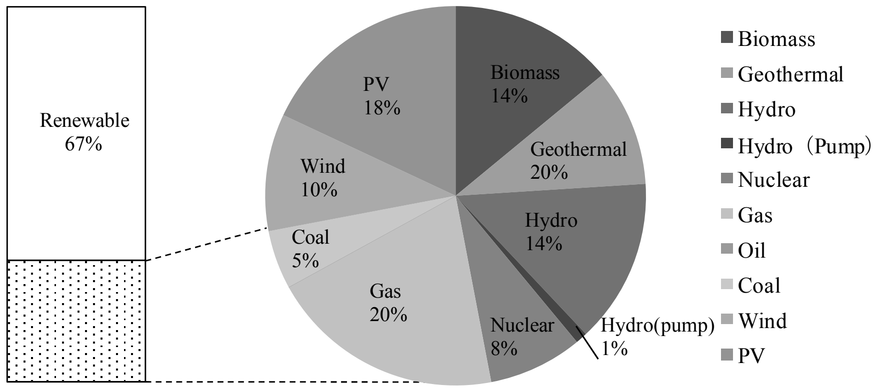


Figure4-2 Share of Power Generation by Technologies in 2050(Data from ISEP)

Japan has established "environmental model-city" system in 2008 to hold its leading position in the worldwide tendency towards low carbon society. As one of the big cities, Kitakyushu "low-carbon city" as an environmental model city were approved in July 2008.

Being an industrial city, in consideration of the low birth rate and aging population, the city of Kitakyushu aims to construct a low carbon society with the establishment of a society that combines industry, school, government and residential environment together. However, until now, waste power generation, factory exhaust heat and wind generation are not yet efficiently utilized.

In this chapter, GIS technology is employed mapping the complex existing energy condition. It can contribute to deal with the large quantity of the data. The research will first promote a method for the estimation of the reserved renewable and the unutilized energy. Further, with GIS, the spatial analysis will be put forward displaying the areas that appropriate for using these resources.

4-2 BASIC THEORY OF GEOGRAPHIC INFORMATION SYSTEM

A geographic information system (GIS), or geographical information system, captures, stores, analyzes, manages, and presents data that is linked to location. Technically, GIS is geographic information systems which includes mapping software and its application with remote sensing, land surveying, aerial photography, mathematics, photogrammetric, geography, and tools that can be implemented with GIS software.

In a more generic sense, GIS applications are tools that allow users to create interactive queries (user created searches), analyze spatial information, edit data, maps, and present the results of all these operations. Geographic Information Science is the science underlying the geographic concepts, applications and systems, taught in degree and GIS Certificate programs at many universities [2].

4-2-1 GIS MODELING

A data model in GIS is a mathematical construct for representing geographic objects or surfaces as data [3]. There are two types of GIS model, Cartographic and Spatial.

Cartographic Model — automation of manual techniques which traditionally use drafting aids and transparent overlays, such as a map identifying locations of productive soils and gentle slopes using binary logic expressed as a geo-query [4].

Spatial Model — expression of mathematical relationships among mapped variables, such as a map of crop yield throughout a field based on relative amounts of phosphorous, potassium, nitrogen and ph levels using multi-value logic expressed as variables, parameters and relationships [4].

GIS is driven by various spatial data. The characteristics of GIS, separating from other kinds of environmental mapping are rooted in the spatially explicit nature of the data. Spatial data are often referred to as layers or coverage [5]. There are two basic kinds of spatial data, the vector data and raster data.

The data was represented as discrete points, lines, and polygons termed as vector data. Vector data are composed of points, lines and polygons. The vector data can render the geographic features with great precision but cost greater complexity in data structures. Points represent discrete locations on the ground. Lines represent linear features, such as rivers, roads and transmission cables. Polygons form bounded areas. In the point and line datasets shown above, the land masses, islands, and water features are represented as polygons. Polygons are formed by bounding arcs, which keep track of the location of each polygon.

Raster data represent the landscape as a rectangular matrix of square cells. Each cell has a value, representing a property or attribute of interest. While any type of geographic data can be stored in raster format, raster datasets are especially suited to the representation of continuous, rather than discrete, data.

Figure4-3 is the diagrammatic model of how raster datasets represent real-world features. As it displayed, cells are assigned a single numeric value, but with GRID (a proprietary Arc Info data format) layers. Cell values can also contain additional text and numeric attributes. In this figure, each feature type on the landscape (buildings, elevation, roads, vegetation) is represented in its own raster layer.

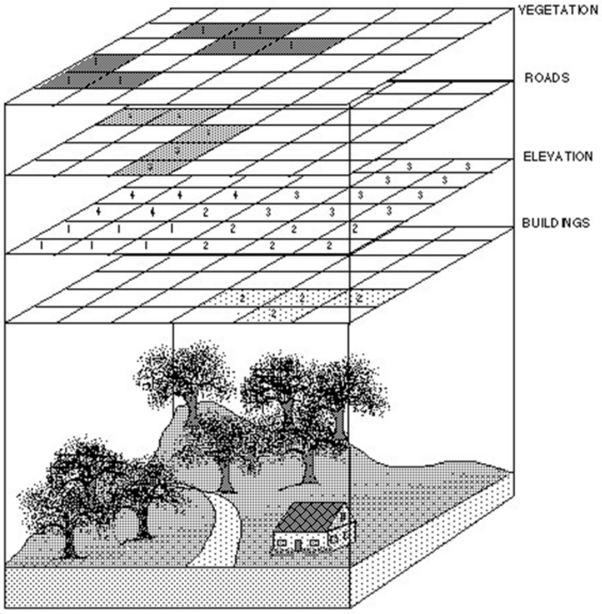


Figure4-3 Diagrammatic model of how raster datasets represent real-world features

(Source: http://courses.washington.edu/gis250/lessons/introduction_gis/spatial_data_model.html#raster)

4-2-2 GIS DATABASE IN KITAKYUSHU

The city of Kitakyushu began to develop its GIS database from the year 1990. Until now the data can cover from the population, industry, residential development, land use, building information, green space, urban facilities to transportation system. These systems have already been used to help the city development and policy decision.

For the utilization of the unutilized energy, such as solar energy, wind energy, and sea energy, the facilities as solar panel, wind turbine and the heat pump should be put into effect into the field first.

The plan of area energy network needs draft information about the energy demand, existing energy plants and all kinds of onsite energy resources. Therefore, the database that can gather all these information is very important. Furthermore, the area energy network plan is firmly related to the location because their energy saving potential as well as economical efficiency is influenced by their location.

In this chapter, the research will explore the theory for constructed such kind of database for the area energy network. As a base, the methodologies for mapping out the unutilized resources and display the possible utilizing distance will be discussed first.

There are different kinds of data modeling in GIS as described in the last part. According to the characteristic of the resources, polygon, point and mesh data are employed in this chapter.

The data resource and their format are listed out in table 4-1

Table4-1 the data information for the unutilized energy resource

The energy resource	The category of data	The GIS data resource
River energy	Polygon	Land use
Factory discharged thermal energy	Point	From the factory information
Garbage energy	Point	The city fertility information
Solar energy	Mesh	The exiting utilized data
Sewage energy	Point	The city fertility information
Sewage process center	Point	The city fertility information

4-3 CURRENT SITUATION OF RENEWABLE AND UNUTILIZED ENERGY RECOURSE

4-3-1 DEFINITION OF UNUTILIZED ENERGY

A large portion of the energy disappears without using into the air via waste heat. Unutilized energy is referred to this part of surplus energy that from the city life and industry, not recycled and directly discharged into the environment. Supposed that the discharged energy in the form of heat with different temperature and other kind of nature energy can be recycled and utilized, it can make great efforts on the urban environment, by cutting both the energy consumption and waste emission.

The waste thermal energy is usually utilized in the district heating and cooling system, including the following recourses [6].

◇Cogeneration systems

The co-generation system, generate electricity by powering engines or turbines using gas or oil, serve as an efficient energy source for buildings. However, it also discarded a part of waste heat depend on its running pattern or management.

◇Energy generated from wastewater temperature differential

The temperature differential between the air and intermediate water, wastewater from households as well as the water from treated sewage can also be utilized for energy supply.

◇Energy derived from solid waste

The waste heat generated when trash and other waste materials are incinerated can be effectively has been defectively used throughout the world for many years. It is an excellent energy resource in terms of both quality and quantity and supply to buildings.

◇Energy derived from waste (Refuse Derived Fuel)

The use of thermal energy obtained by burning refuse derived fuel (RDF) is made from discarded wood, paper, plastic and other materials is the basis of a heating and cooling system.

◇Heat energy from seawater

Seawater is an excellent source of thermal energy because it freezes at a lower temperature than fresh water. Another advantage of this energy source is its virtually inexhaustible supply.

◇Heat energy from river water and groundwater

River water and groundwater provide a stable source of thermal energy because of their relative lack of fluctuation in temperature throughout the year and at different times of the day.

◇Waste heat from subways, underground shopping arcades, electrical transformers, and other heat sources (waste heat from urban space)

◇Waste heat from factories

4-3-2 DEFINITION OF RENEWABLE ENERGY RESOURCE

Renewable energy is energy that comes from resources which are continually replenished such as sunlight, wind, rain, tides, waves and geothermal heat. Table 4-2 is classification of the new energy. The mainstream of renewable technologies includes wind power, hydropower, solar energy, biomass, biofuel, geothermal energy and Oceanogenic power. Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuel and rural (off-grid) energy services [7].

Table 4-2 the new energy classified by use type

The categories of new energy	The new energy classified by use type	
Nature rescource	Wind power	Renewable Energy Resource
	Hydropower	
	Solar energy	
	Oceanogenic power	
	Geothermal energy	
	Biofuel	
	Biomass	
	Temperature differential	Unutilized Energy Resource
Recycled energy	Waste heat from Cogeneration plants (unused part)	
	Waste heat from Solid waste	
	Waste heat from Refuse derived fuel	
	Waste heat from Sewage exhaust heat	
	Waste heat from Seawater	
	Waste heat from River water and groundwater	
	Waste heat from Urban space	
	Waste heat from factories	
High efficient energy using	Cogeneration (used part)	
	Feul cell	
Other new techonolegies	Green bicycle	

4-3-3 RELATED DATA FOR THE AREA ENERGY NETWORK WITH UNUTILIZED AND RENEWABLE ENERGY

The database that related to the area energy network needs a wind range of information, including the information for the energy supply side, demand side and other related information. These types of information are compassed by GIS. Table 4-3 listed out the related information.

Table 4-3 Database information for area energy network

(Resource: regional new energy introduction guide book)

Categories	Type of data		Database
Energy supply	① Unutilized energy	▪Temperature differential ▪Waste heat ▪Solid waste	▪Location of potential energy ▪Potential energy reserve ▪Available energy reserves ▪The temperature and variation of ▪Waste heat amount
	② Energy ③ Infrastructure	▪City gas supply range ▪Common duct	▪Range ▪Location
Demand side	④ City development plan ⑤ Public service	▪Redevelopment district ▪Main public service with high heat demand	▪The area of building ▪Location ▪Building function ▪Heat demand (density)
	⑥ District heating and cooling ⑦ Existing city area	▪The district information ▪Heat demand of the existing area	
Other related information	⑧ City redevelopment	▪City redevelopment plan ▪City zoning	▪City redevelopment district ▪District function ▪Legal capacity rate
	⑨ Heat island inhibition	▪District that promoted heat island inhibition	
	⑩ Regional Disaster Prevention	▪Regional Disaster Prevention plan	▪The area of the facility (location and heat demand) ▪Important base facility during disaster

There are some applications for using this database in the city development, unutilized energy usage and city environmental design [7].

◇Used as basic data for unutilized energy usage in area energy network plan (①②③④⑤⑥⑦)

◇Used as basic data for global warming prohibit (①④⑤⑥⑦)

◇Used as basic data for heat island prohibit (①③④⑤⑥⑦⑨)

◇Used as basic data for the energy saving plan in the existing city district (①③④⑤⑥⑧⑩)

◇Used as basic data for public service renew(①③⑤)

◇Used as basic data for new energy usage (①④⑤⑥⑦)

4-4 SPATIAL DISTRIBUTION OF THE RENEWABLE AND UNUTILIZED ENERGY

4-4-1 DISTRIBUTION OF SOLAR ENERGY

Solar energy, refer to the radiant light and heat from the sun, offers a clean, climate-friendly, very abundant and inexhaustible energy resource to mankind, relatively well-spread over the globe. The costs of solar energy have been falling rapidly and are entering new areas of competitiveness [8].

For estimating the solar energy, the GIS mesh data will be employed in to the calculation.

The estimation of horizontal solar radiation energy density (H) can be get from the local data

The **potential solar energy (Q_f MJ/year)** in a certain district can be estimated as formula 4-1 [9] (4-1)

$$Q_f = k \times \sum(H_i \times A_i) \times day \times 3.6 \quad (4\text{-}1)$$

k is the correction factor between the slop and the horizontal solar radiation density(if the solar cell is set in the optimal installation angle, the k can be set as 1.1-1,2);

H_i is the horizontal solar radiation density for the mesh i (kWh/㎡･day);

A_i is the area for the mesh i (㎡);

day is the day for calculation (for the yearly amount calculation, day is 365).

The **maximum utilizable amount (Q_m MJ/year)** can be calculated as (4-2)

$$Q_m = Q_f \times \eta \times 3.6 \quad (4\text{-}2)$$

η is the efficiency of the solar technology (usually set 0.125 for solar electricity and 0.7 for solar hot water system).

If the solar energy used both for heating and electricity, the **expected utilizable amount (Q_e MJ/year)** can be calculated as (4-3)

$$Q_e = k \times \sum(H_i \times A_{0i}) \times \eta \times K_t \times day \times 3.6 \quad (4\text{-}3)$$

A_{0i} is the area of solar cell in the mesh i (㎡);

K_t is correction factor

For the electricity only, the yearly electricity that produced by PV system (**Q_{e1}**) can be calculated as (4-4) [10] MJ/year

$$\mathbf{Q_{e1}} = H \times K \times P \times day \div 1 \times 3.6 \quad (4\text{-}4)$$

H: Hourly solar resource (kWh/m^2/day);

K: Average loss co-efficiency (the average value is set as 27%)

P: Capacity of the PV system (kW);

365: The days of year

1: Hourly solar resource at the standard state (kWh/m^2);

In this research, the estimation use the formula (4-4).Supposing that solar power was introduced and the introduction scale of buildings was determined by type.

(1)For every detached houses and apartment house, the introduction scale was 3kW (the PV panel is about 24 ㎡);

(2)Enterprise owning more than 30 persons and school were set to be 10kW (the PV panel is about 80 ㎡);

Figure4-4 shows the result of a 100m photovoltaic mesh map. According to the type of building's scale, the amount of solar power was estimated: the mesh's minimum supply is 10.92GJ, and the maximum supply is 815.20GJ.

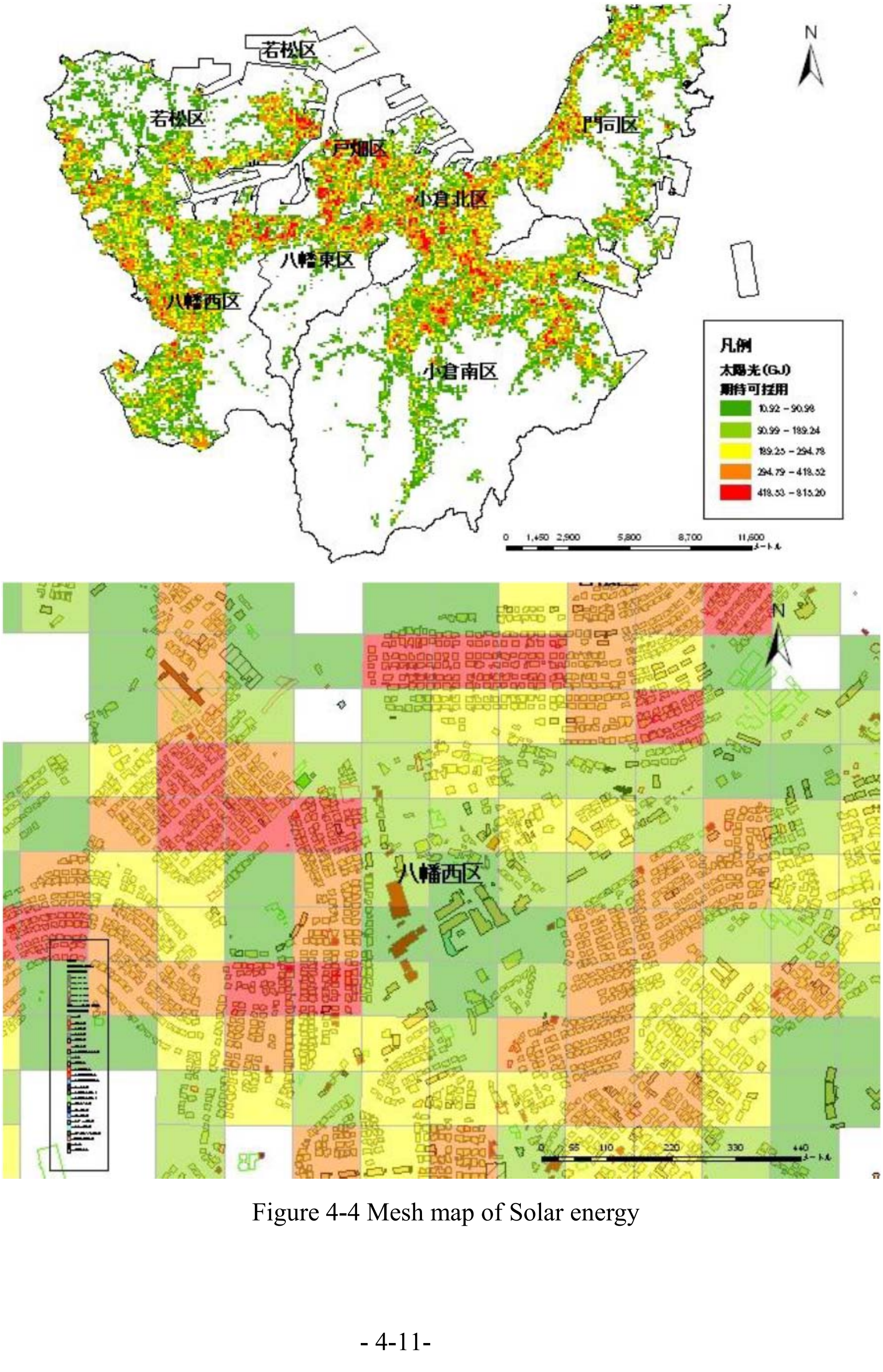


Figure 4-4 Mesh map of Solar energy

4-4-2 DISTRIBUTION OF RIVER RESOURCE

The utilization of the river energy should consider the regulation, getting the permission of possesses the river. Further, it should consider the effect to the river. If the river resource used for cooling, the temperature of the water will getting higher. When it used for heating, the temperature of the water will getting lower. This will disturb the river environment and the living creature inside.

It is calculated as below

$$Q_r = \Delta t \times V \times c_r \qquad (4\text{-}2)$$

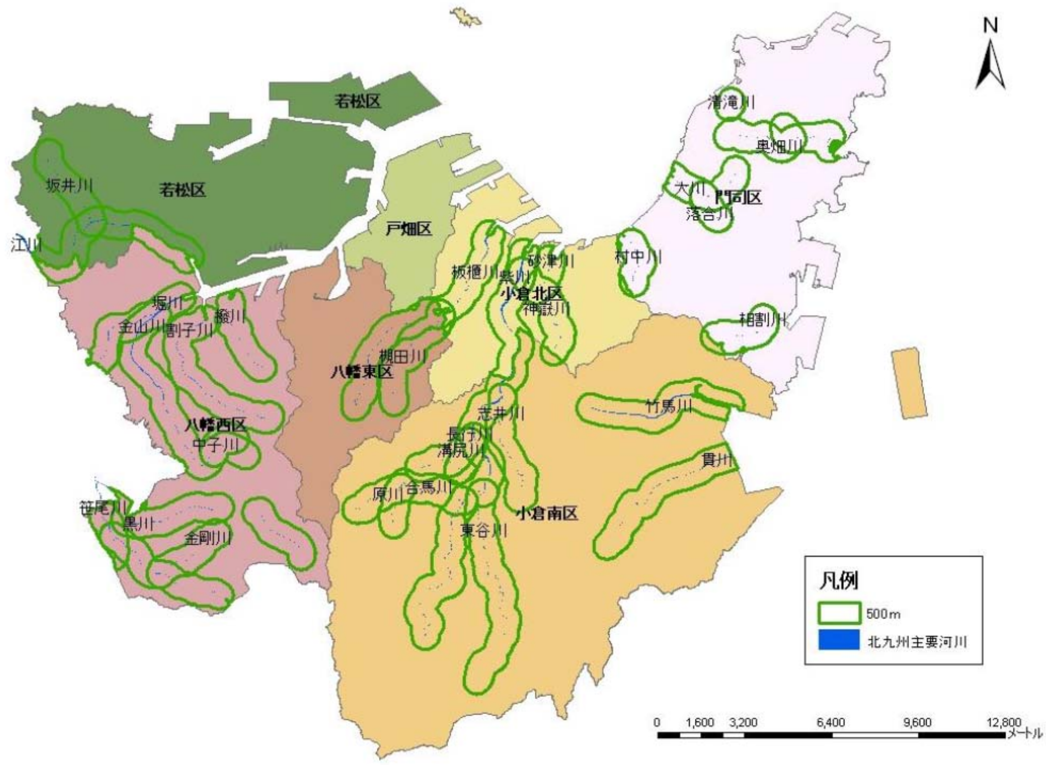
Q_r is the energy reserves of the river (MJ/H);

Δt is the temperature difference for utilizing the river energy (5℃);

V is the flow of the river;

c_r is the special heat (MJ/m^3·℃)

Take the energy contained in the 1 meter-wide river as unit (velocity of flow is 0.35 m^3/s), the energy reserves every year is 233GJ/m. Figure 4-5 can suggest the area for using the river energy and calculated the reserves by GIS. Ketabakawa in Kokuraminami District have the maximum annual amount of endowment with 12706TJ.



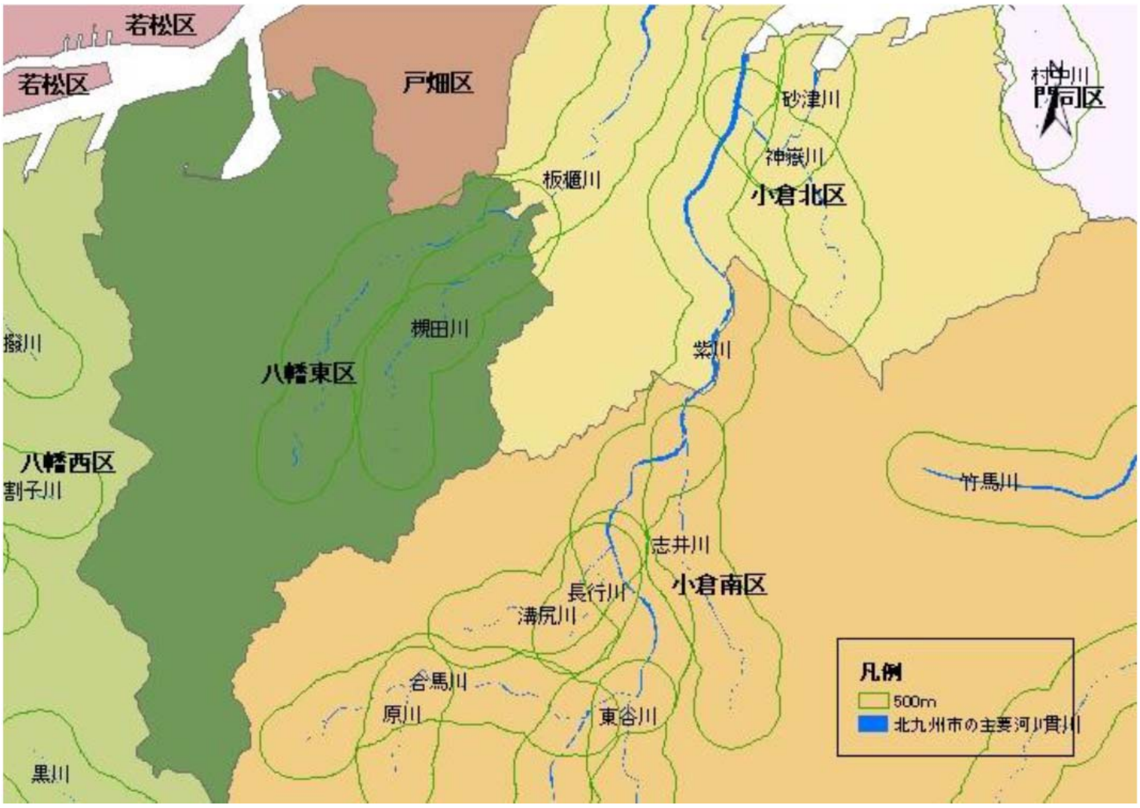


Figure4-5 Buffer map of river energy

4-4-3 DISTRIBUTION OF SEWAGE PUMP STATIONS

In the whole country, the discharged water from the sewage is around 9.5 billion m^3.The temperature is too low for reutilization. However, there still has possibility to make use of it when the technologies of heat pump getting better.

Assumed the temperature between the heat pump and the sewage is 5℃, the yearly energy reserves for one pump station every area (ha) can be estimated as below:

$$Q_S = \Delta t \times V \times c_S \qquad (4\text{-}3)$$

Q_s is the energy reserves of the sewage pump station (MJ/H);

Δt is the temperature difference between the heat pump and the sewages (5℃);

V is the water discharge of the sewages;

c_s is the special heat (4.2 MJ/m^3·℃)

Figure 4-6 displayed all the sewage pump plants in Kitakyushu and their utilization area. The annual amount of heat reserves is 21544.9TJ / year. The highest area is Minatomati, Otemachi and Yahatanishi Fujita, the value is 3197.26TJ / year, 2730.14TJ / year and 3396.85 TJ / year.

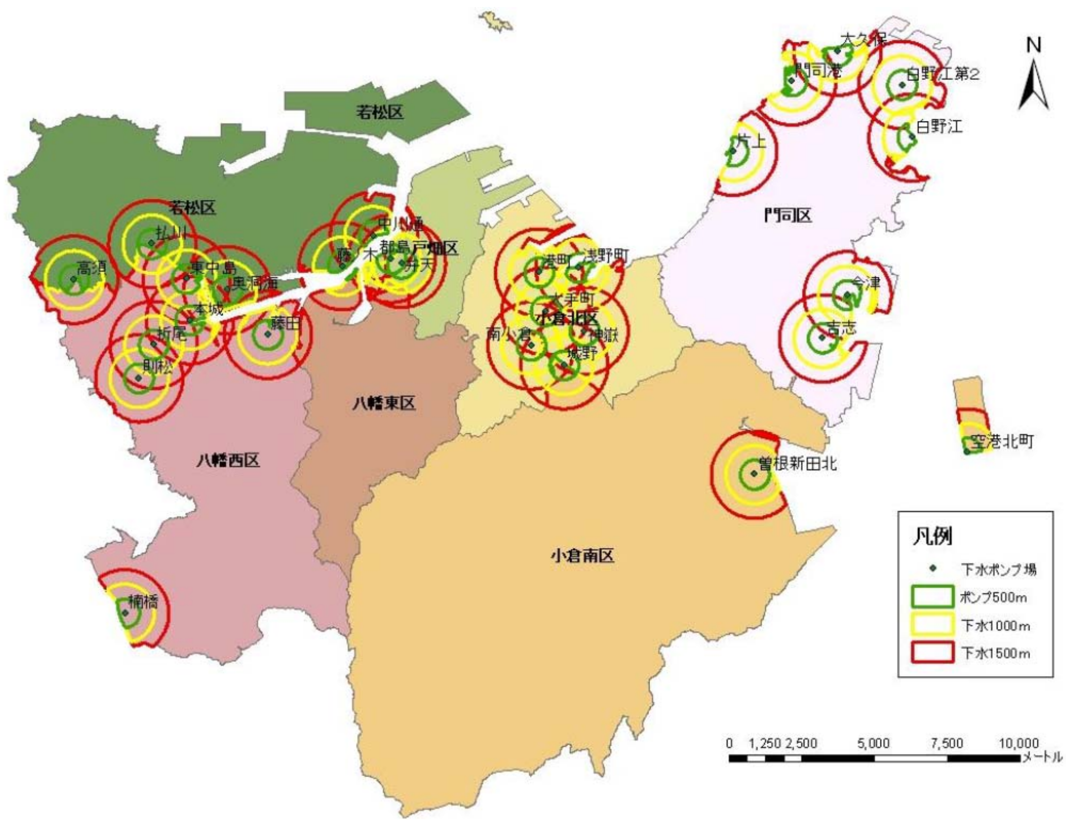


Figure 4-6 Buffer map of sewage pump station

4-4-4 DISTRIBUTION OF SEWAGE PURIFICATION CENTER

The calculation is same as Sewage pump stations. There are five purification centers in Kitakyushu City. The annual reserves and available reserves are listed as below.

Table 4-4 The annual reserves of the sewage purification center

Name	Annual reserves (TJ/year)	Available reserves (TJ/year)	α(%)
Center 1	1200.36	2009.56	0.60
Center2	566.22	489.02	1.16
Center 3	860.14	557.79	1.54
Center4	1582.86	1352.44	1.17
Center 5	739.60	336.20	2.20

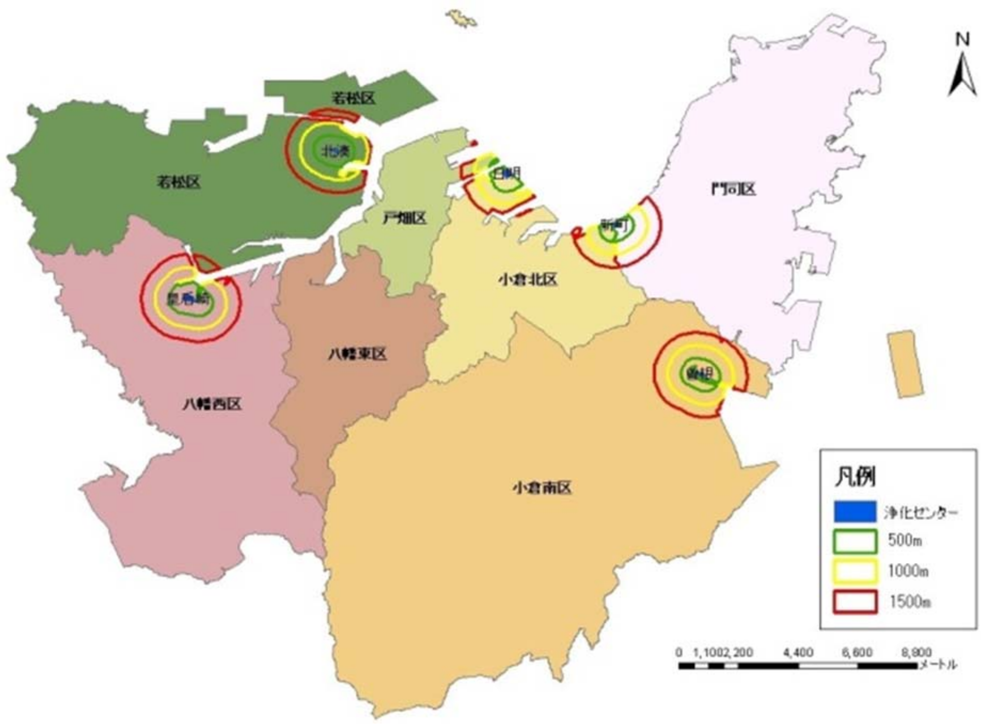


Figure 4-7 Buffer map of sewage purification center

4-4-5 DISTRIBUTION OF WASTE PLANT

The waste plant will discharge a large quantity during its process. It can be used for produce electricity and the heat load. The existing cases used the heat for residential buildings and office buildings. Still some other cases used it for the pool

It can be estimated as below:

$$Q_w = V_w \times c_w \times \varepsilon \qquad (4\text{-}4)$$

Q_w is the yearly heat reserves (MJ/Y);

V_w is the waste processed (t/Y);

c_w is the special heat (8.4MJ/kg);

ε is heat efficiency (0.8)

The total annual amount of heat coming from endowment garbage incineration plant is 3796.07 TJ / year, and the most heat energy is from KOGASAKI cleaning plant whose amount is 1689.38TJ / year, the second one is from the Hiagari cleaning plant whose amount is 1072.79TJ / year, and Shinmoji plant whose amount is 1033.9TJ / year

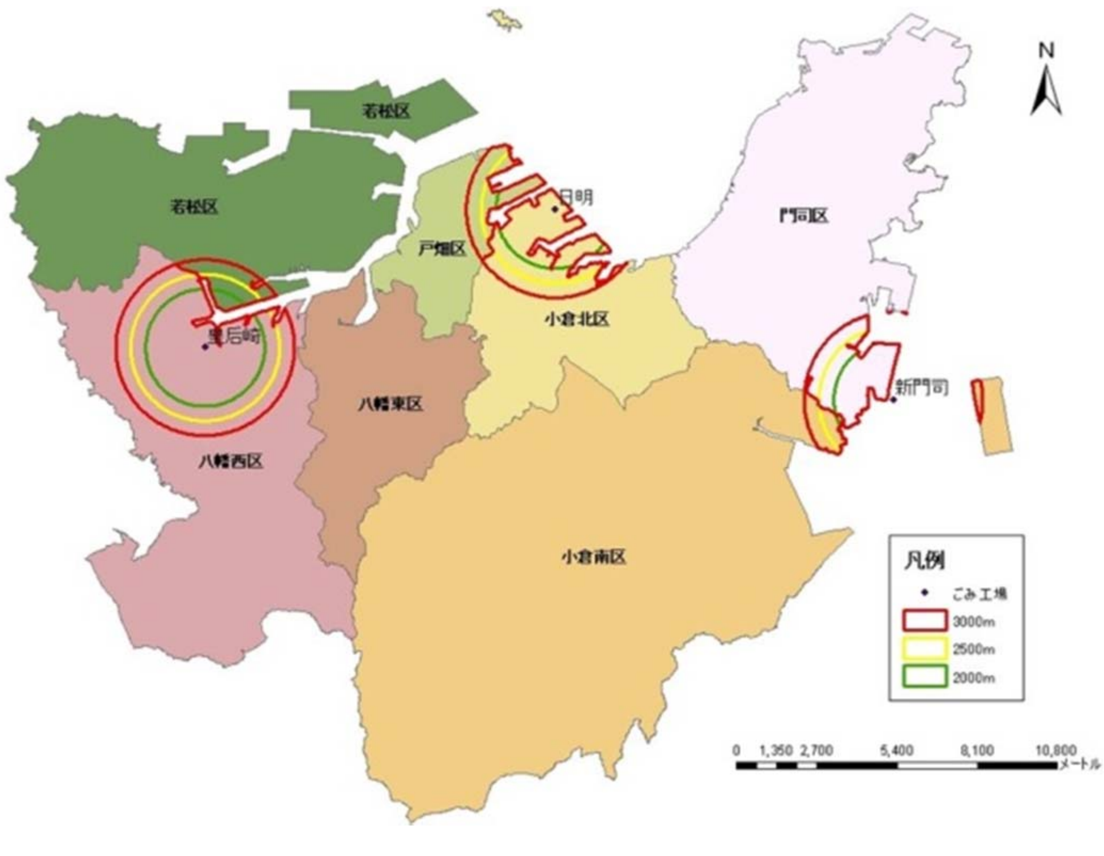


Figure 4-8 Buffer map of waste plant

4-4-6 DISTRIBUTION OF POWER SUBSTATIONS

The electricity generation efficiencies are different, but almost around 40%. The efficiency of the discharged gas is 14% and hot water is 46%.

$$\varphi = \frac{\varphi_w}{\varphi_e} = \frac{46\%}{40\%} = 1.15$$

$$Q = 1.15 \times 3.6MJ/Kwh = 4.14MJ/Kwh \qquad (4\text{-}5)$$

φ_w is the efficiency of discharge hot water(0.46);

φ_e is the heat recovery efficiency (0.4)

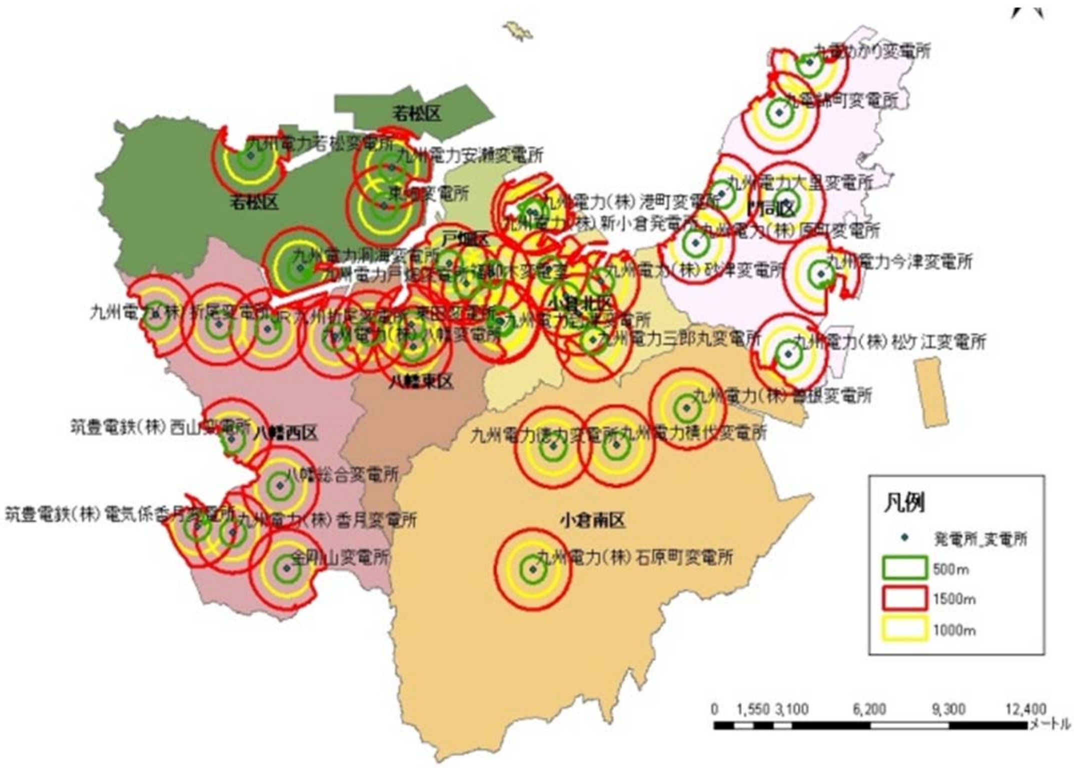


Figure 4-9. Buffer map of power substation

4-5 INVESTIGATION AND ESTIMATION OF THE FACTORY EXHAUST HEAT

Kitakyushu is one of the most important industrial cities and having a large area of industry. Thus, the CO2 emission from the factories is more serious than the average level of the whole country. In that case, the city will try to reuse the potential energy from the factory exhaust heat, aiming to construct a low carbon society combines industry, school, government and residential environment together.

In order to estimate the exhaust heat of the whole city, the research put forward a questionnaire to all the factories and industries in Kitakyushu. The investigation includes 170 factories and 213 industries. It covers from the equipments, the temperature, working hours and so on. All the factories that been reported by the Kitakyushu were included in the estimation in this research

4-5-1 METHODS

In Japan, around 90% of the exhaust heat is discharged as gas. Therefore, in this research, the estimation of the exhaust thermal reserves is estimated by gas.

(1) Maximum exhaust heat

From the result of the questionnaire, the factory measured values can offer the maximum gas discharge amount and the discharge temperature. The maximum exhaust heat energy can be calculated as below:

$$E_{\max}^{RH} = V_{\max}^{RG} \times T_{\max}^{RG} \times C_g \qquad (4\text{-}6)$$

$E_{\max}^{RH}$ (KJ/h) is maximum hourly exhausted thermal energy;

$V_{\max}^{RG}$ (Nm^3/h) is maximum hourly gas discharge amount;

$T_{\max}^{RG}$ (℃) is gas discharge temperature;

Cg (KJ/N m^3·℃) is the specific heat capacity of gas (1.356 KJ/N m^3 [12]).

(2)The ratio between the maximum exhaust heat and the normal exhaust heat

The facilities with exhaust heat will measure the hourly exhaust gas including the discharge amount and the temperature. It takes out two or six years a time depend on the scale of the facility. This research use the last record measured value, and set the mean value as the normal value.

Conversion coefficient between the maximum value and the normal value can be defined like

$$\alpha_V = \frac{V_{\max}^{RG}}{\overline{V}_{real}} \qquad (4\text{-}7)$$

$$\alpha_T = \frac{T_{\max\ x}^{RG}}{\overline{T}_{real}} \qquad (4\text{-}8)$$

α_V is the Conversion coefficient between the maximum exhaust gas amount and the normal exhaust gas amount;

$\overline{V}_{real}$ is the mean value of the last measured data of discharged gas amount per hour ;

α_T is the Conversion coefficient between the maximum exhaust gas temperature and the normal exhaust gas temperature;

$\overline{T}_{real}$ is the mean value of the last measured data of discharged gas temperature;

The result of α_V and α_T are listed out in figure 4-10 and figure 4-11. The mean value are set as the conversion coefficient.

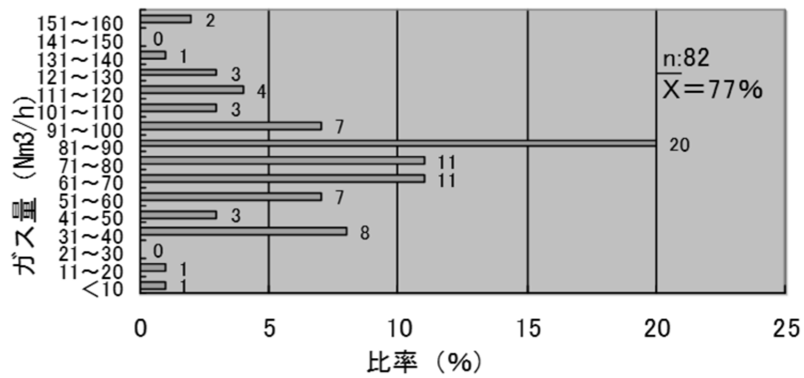


Figure 4-10 α_V plot ($\overline{\alpha}_V = 0.77$)

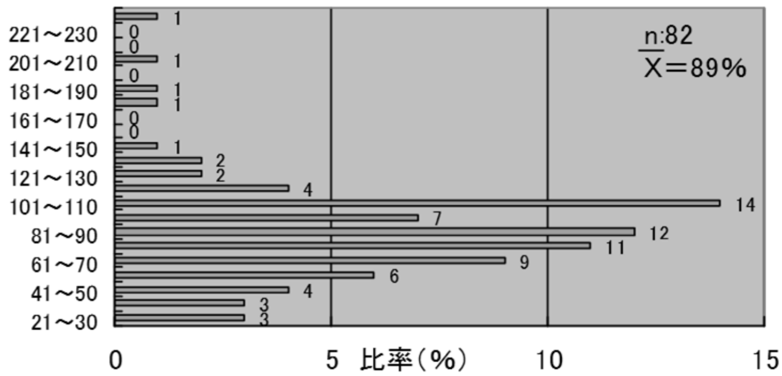


Figure 4-11 α_T plot ($\overline{\alpha}_T = 0.89$)

Therefore, the exhaust heat energy can be estimated as follow:

$$
\begin{aligned}
E^{RH} &= V_{\max}^{RH} \times \overline{\alpha}_V \times T_{\max}^{RG} \times \overline{\alpha}_T \\
&= V_{\max}^{RH} \times 0.77 \times T_{\max}^{RG} \times 0.89
\end{aligned} \tag{4-9}
$$

E^{RH} (KJ/h) is estimated exhaust heat per hour.

(3) The setting for working hours

The working hours will be estimated according to the questionnaire among the factories. The investigation includes 170 factories and 213 industries and the questionnaire recovery rate is 37.6% for factories and 20.3% for industries.

According to the result, the working hours can be set as Table4-5. The average working ratio can set as 0.7.

Table 4-5 The setting for working hours

Building category		Working hours(h)
Factory	the factory above 500cal/h	24
	Others	8
Industry	Hospital, hotel	24
	Public Waste disposal facilities	24
	Nursing homes for elders	24
	Shopping centers	12
	School	12
	Others	8

(4) The estimation for yearly rejected heat energy

The yearly rejected heat energy for every factory can be calculated as below:

$$E_{yearly}^{RH} = E_{\max}^{RH} \times 0.77 \times T_{\max}^{RG} \times 0.89 \times C_g \times 24h \times 356d \times 0.7 \qquad (4\text{-}10)$$

E_{yearly}^{RH} (KJ/h) is yearly gas discharge amount.

4-5-2ESTIMATION RESULT OF THE EXHAUST HEAT

In this survey covered 1552 facilities that have exhausted heat in Kitakyushu, among which 1412 were used for the estimation.

There are 7 districts in the city, and the 1412 factories are located in the whole city. As the result of estimation, the yearly rejected heat energy is about 18,000TJ. Figure4-12 shows yearly rejected heat energy of every district.

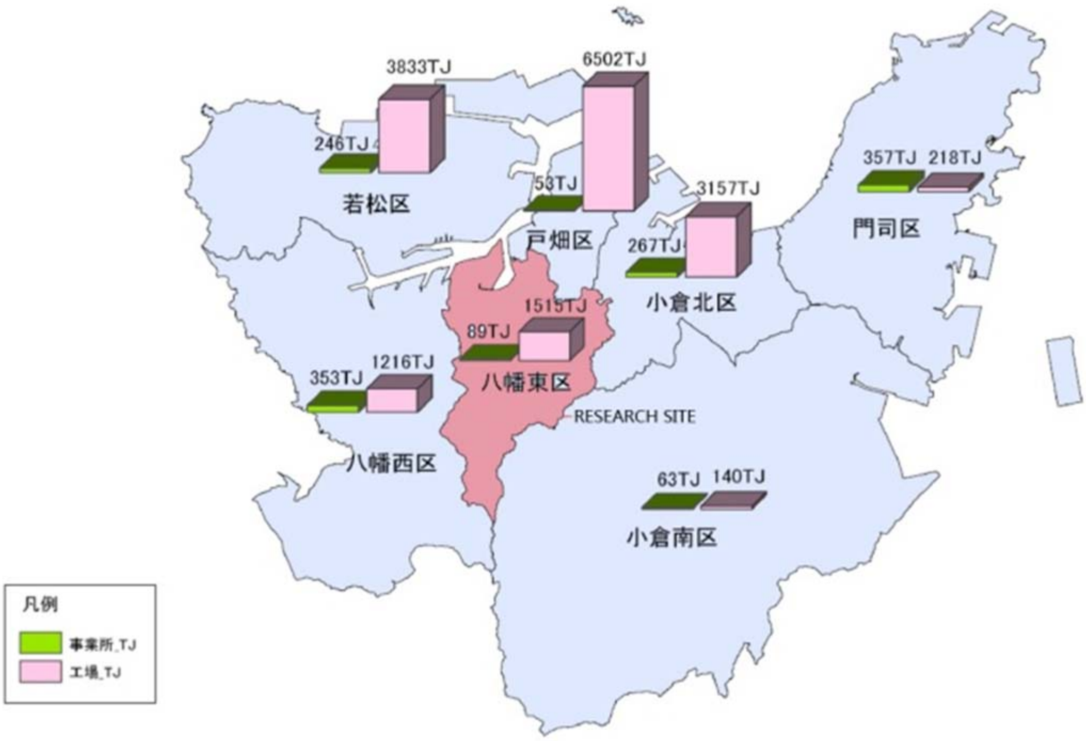
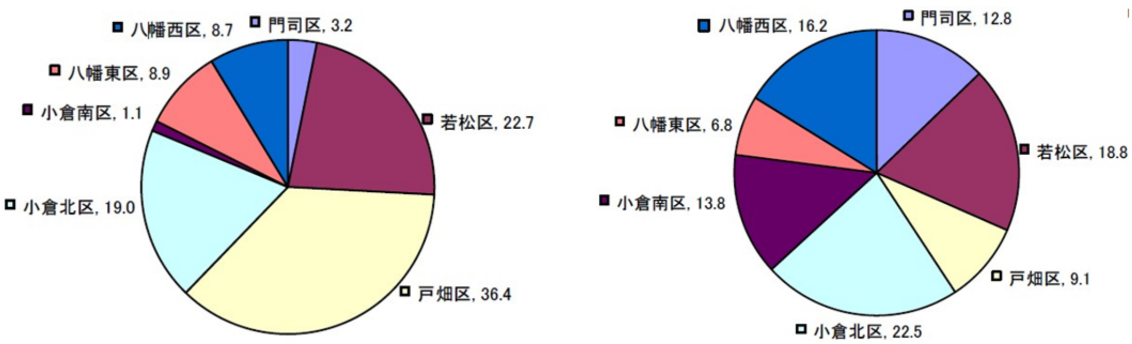


Figure 4-12 Yearly rejected heat energy of every district



(a) The exhaust heat reserves Proportion (b) The exhaust heat facilities Proportion

Figure 4-13 The distribution of exhaust heat reserves and facilities by district

4-5-3 DICTRIBUTION OF EXHAUST HEAT RESERVES

In consideration of the efficiency of using the exhaust heat, the research categorized the heat resource into:

□ T^{RG}>150℃ : has possibility to be reused

□ T^{RG}>300℃: has high potential to be reused

In Considering the efficiency of heat recovery equipments, the research divided the factories into 3 groups by their exhaust heat reserves. The three groups are the hourly reserves above 420MJ, 1260MJ and 2100MJ.

Table 4-6 the discharged temperature above 150℃

	Above 420MJ/h	Above 1260MJ/h	Above 2100MJ/h
Number of factory	118	55	33
Number of facilities	472	272	170
Exhaust heat (TJ/Y)	11879	11201	10390
Proportion (%)	66.0	62.2	57.7

Table 4-7 the discharged temperature above 300℃

	Above 420MJ/h	Above 1260MJ/h	Above 2100MJ/h
Number of factory	53	35	25
Number of facilities	241	143	74
Exhaust heat (TJ/Y)	4914	4518	3964
Proportion (%)	27.3	25.1	22.0

(1)The factory with the exhaust heat tempreture above 150℃

Figure 4-14 displayed the distribution of exthuast heat resource with the exhaust tempreture above 150℃. The research classified them by their hourly exthust amount, more than 420MJ/h, more than 1260MJ/h and more than 2100MJ/h. The figure also suggest their yearly exhaust heat amount. There are 77 factories in this group, and most of them gathered along the sea.

Table 4-8 factory with the discharged temperature above 150℃

	Above 420MJ/h	Above 1260MJ/h	Above 2100MJ/h
Number of factory	77	47	28
Number of facilities	399	256	157
Exhaust heat (TJ/Y)	10,942	10,406	9,607

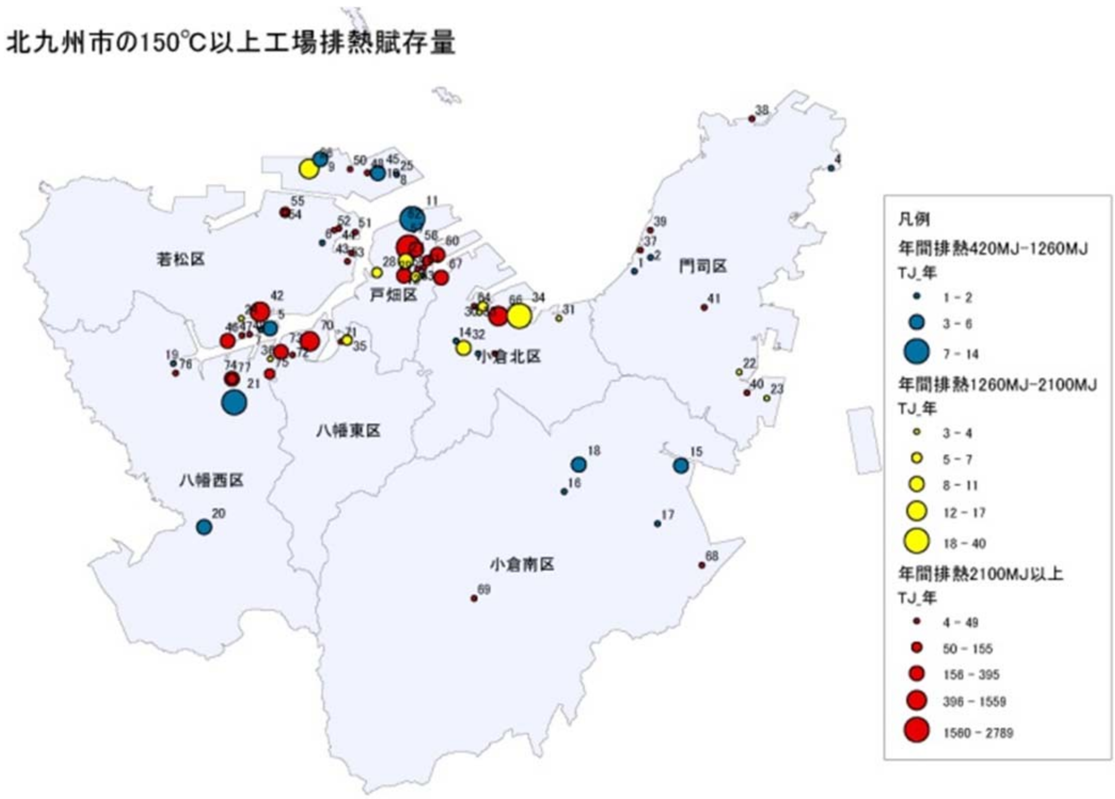


Figure 4-14 The exhaust heat resource (factory, above 150℃)

(2) The factory with the exhaust heat tempreture above 300℃

Figure 4-15displayed the distribution of exthuast heat resource with the exhaust tempreture above 150℃. The research classified them by their hourly exthust amount, more than 420MJ/h, more than 1260MJ/h and more than 2100MJ/h. The figure also suggest their yearly exhaust heat amount. It can also suggest that the have more factory.

Table 4-9 Factory with the discharged temperature above 300℃

	Above 420MJ/h	Above 1260MJ/h	Above 2100MJ/h
Number of factory	43	34	25
Number of facilities	226	142	74
Exhaust heat (TJ/Y)	4,872	4,516	3,964

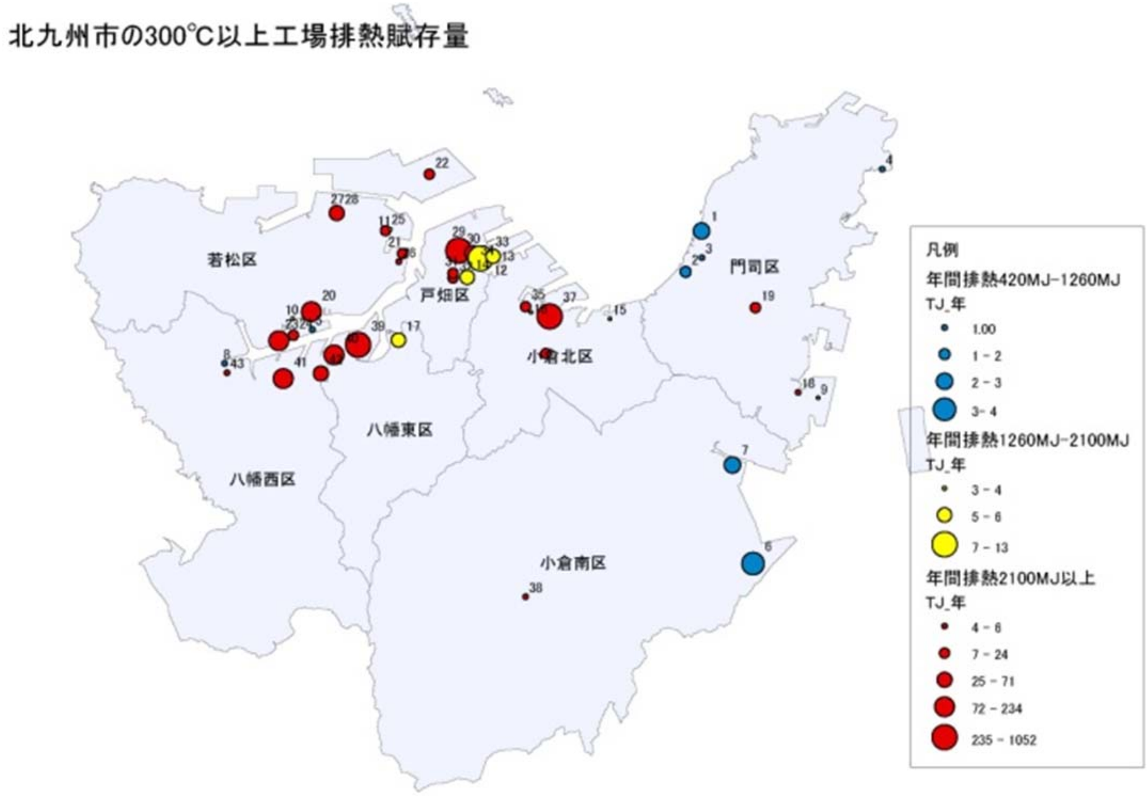


Figure 4-15 The exhaust heat resource (factory, above 300℃)

(3) The industry with the exhaust heat tempreture above 150℃

Figure 4-16 displayed the distribution of exthuast heat resource with the exhaust tempreture above 150℃. The research classified them by their hourly exthust amount, more than 420MJ/h, more than 1260MJ/h and more than 2100MJ/h. The figure also suggest their yearly exhaust heat amount. The indudtris in the city only occuppied 5% of the the total amount and the small scale are almost in Kokura.

Table 4-10 Industry with the discharged temperature above 300℃

	Above 420MJ/h	Above 1260MJ/h	Above 2100MJ/h
Number of factory	41	8	5
Number of facilities	73	16	13
Exhaust heat (TJ/Y)	937	795	783

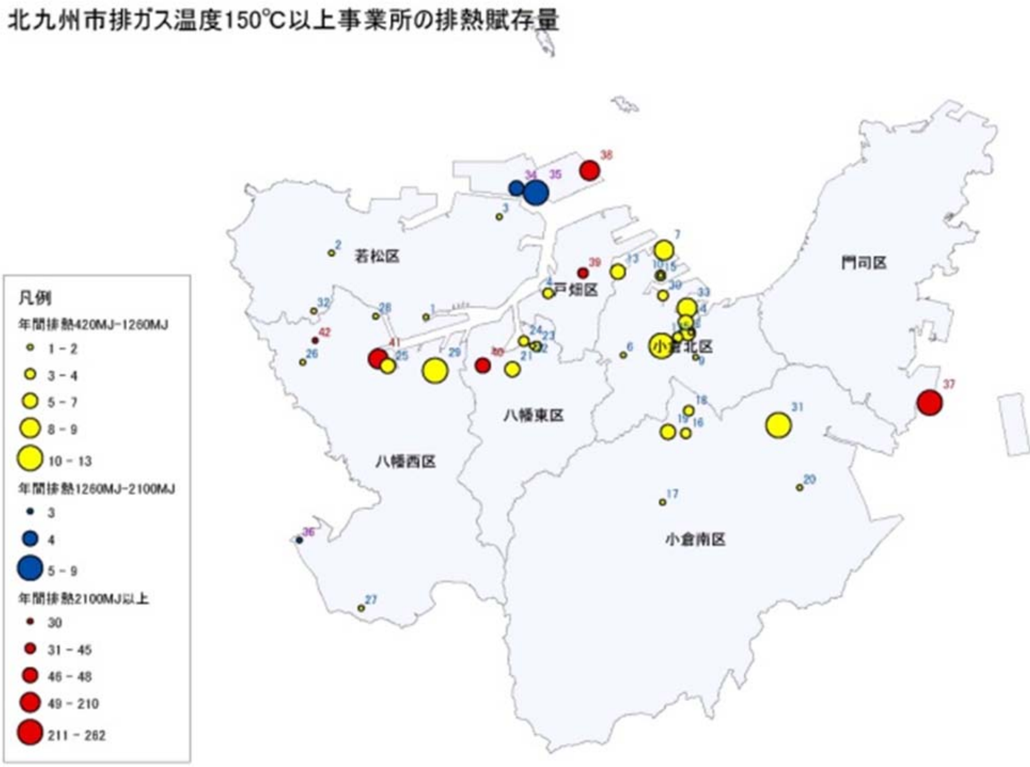


Figure 4-16 The exhaust heat resource (industry, above 150℃)

(4) The industry with the exhaust heat tempreture above 300℃

Figure 4-17 displayed the distribution of exthuast heat resource with the exhaust tempreture above 300℃. The research classified them by their hourly exthust amount, more than 420MJ/h, more than 1260MJ/h and more than 2100MJ/h. The figure also suggest their yearly exhaust heat amount. It can suggest that only a few of the industries can have the exhaust heat above 300℃.

Table 4-11 Industry with the discharged temperature above 300℃

	Above 420MJ/h	Above 1260MJ/h	Above 2100MJ/h
Number of factory	10	1	—
Number of facilities	15	1	—
Exhaust heat (TJ/Y)	42	2.5	—

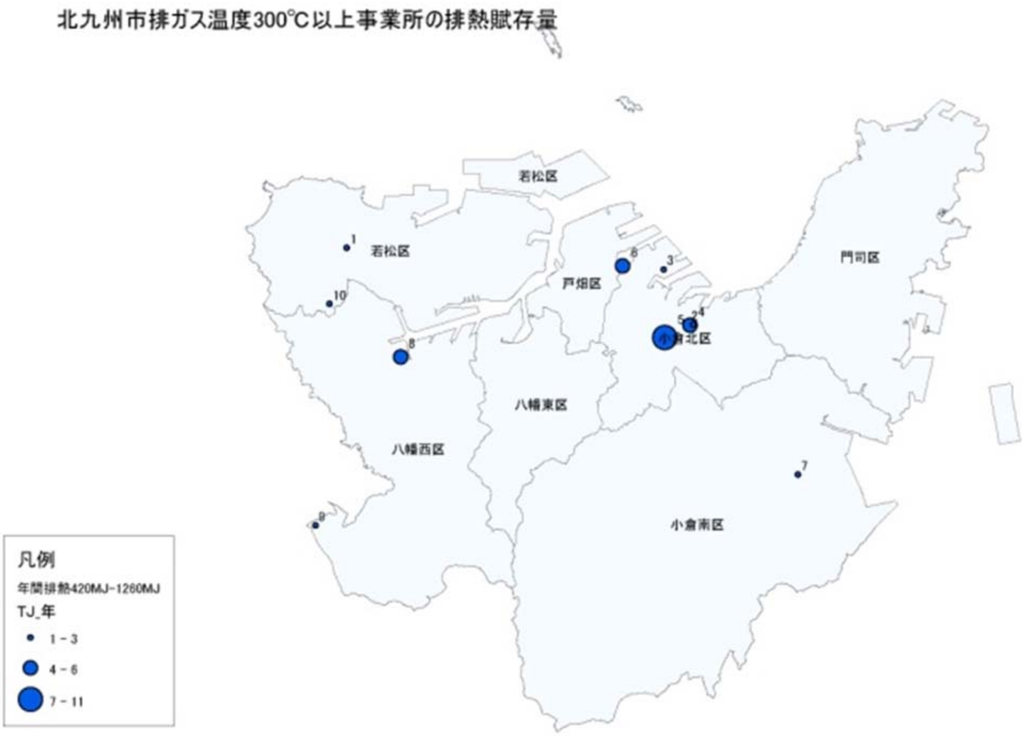


Figure 4-17　The exhaust heat resource (industry, above 300℃)

4-6 UTILIZATION OF THE EXHAUST HEAT

4-6-1 ANALYSIS OF ENERGY DEMAND

In order to calculate the demand of energy, the research use the classification offered by Kitakyushu City Environment in figure4-18. In all the categories, the pointed 9 in the following graph are excluded, for the reason that the energy calculation for these fertilities is unavailable and only occupied a small amount.

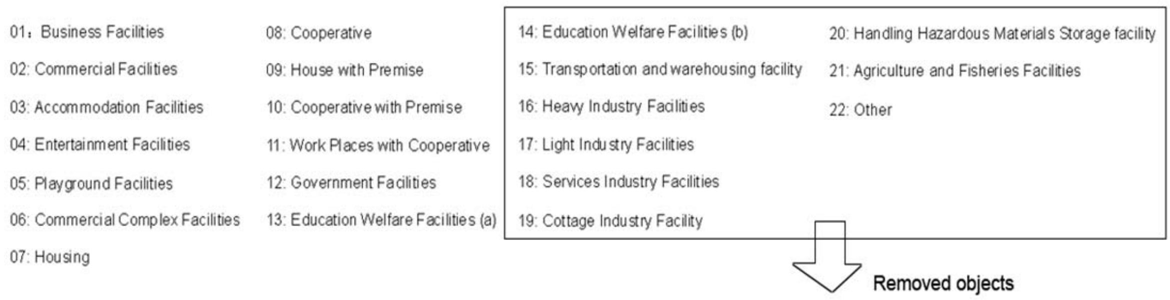


Figure4-18 Building category

The energy consumption of the demanding side is estimated by the energy consumption unit (listed in table) and the building area.

Table 4-12． Annual building energy demand by using

Classification	Cooling	Heating	Hot water	General Power	Total
Detached houses	14.03	114.59	143.40	240.2	512.22
Apartment	20.39	124.26	224.20	342.69	711.54
Commercial Facilities	261.3	235.97	37.51	765.51	1300.29
Business Facilities	305.64	145.16	108.02	2080.38	2639.2
Educational Facilities	261.3	259.2	37.51	371.75	929.76
Hotel	271.3	495.72	1295.81	1358.2	3421.03

MJ/ m^2 ・ year

4-6-2 OPTIMAL AREA FOR UTILIZING THE EXHAUST HEAT

For using the factory exhaust heat reserves, there is always a long distance between the energy resource and the demand side. In consideration of the energy loss, the optimal distance is always limited in the 1000m. Figure4-19 displayed the spatial distribution of the energy consumption and the optimal using area.

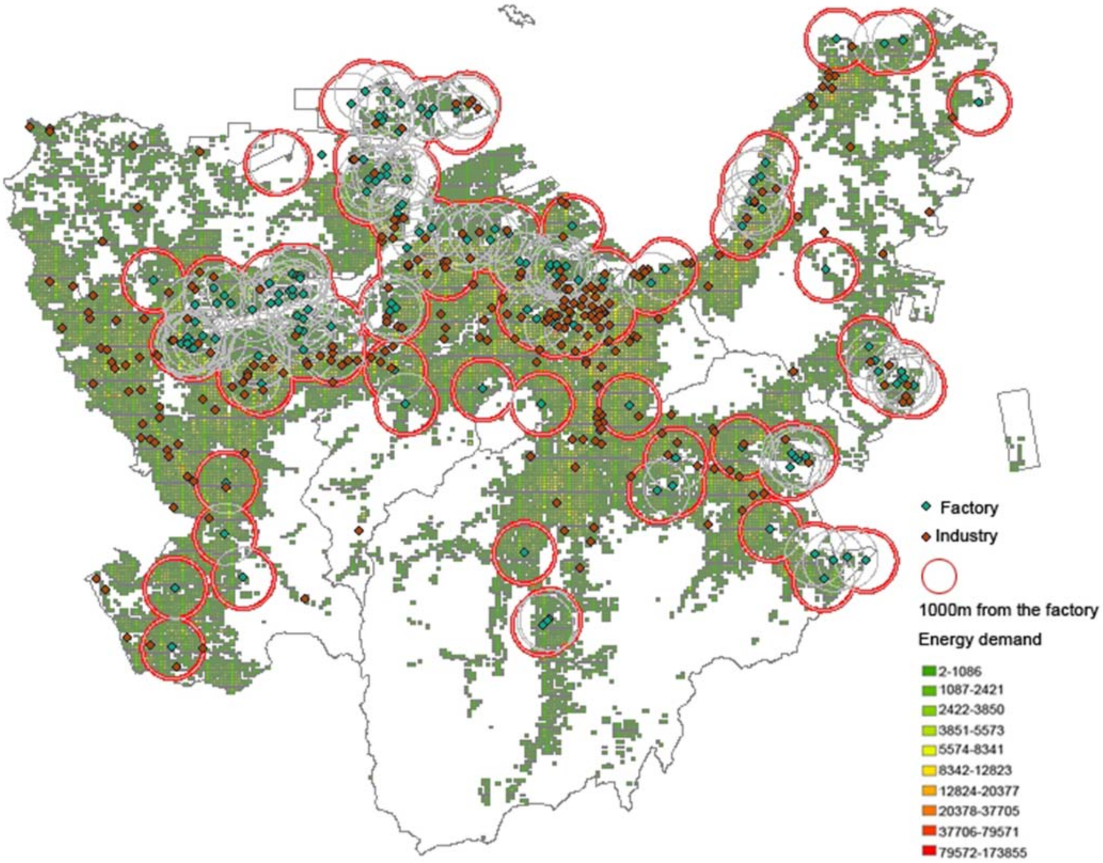


Figure4-19 optimal utilization area.

4-6-3 THE CASE STUDY IN YAHATA HIGASHIDA

Yahata higashida is a “green village” in Kitakyushu. The research will take here as an example to calculate the exhaust heat reserves. The buildings and their function are suggested figure 4-20.

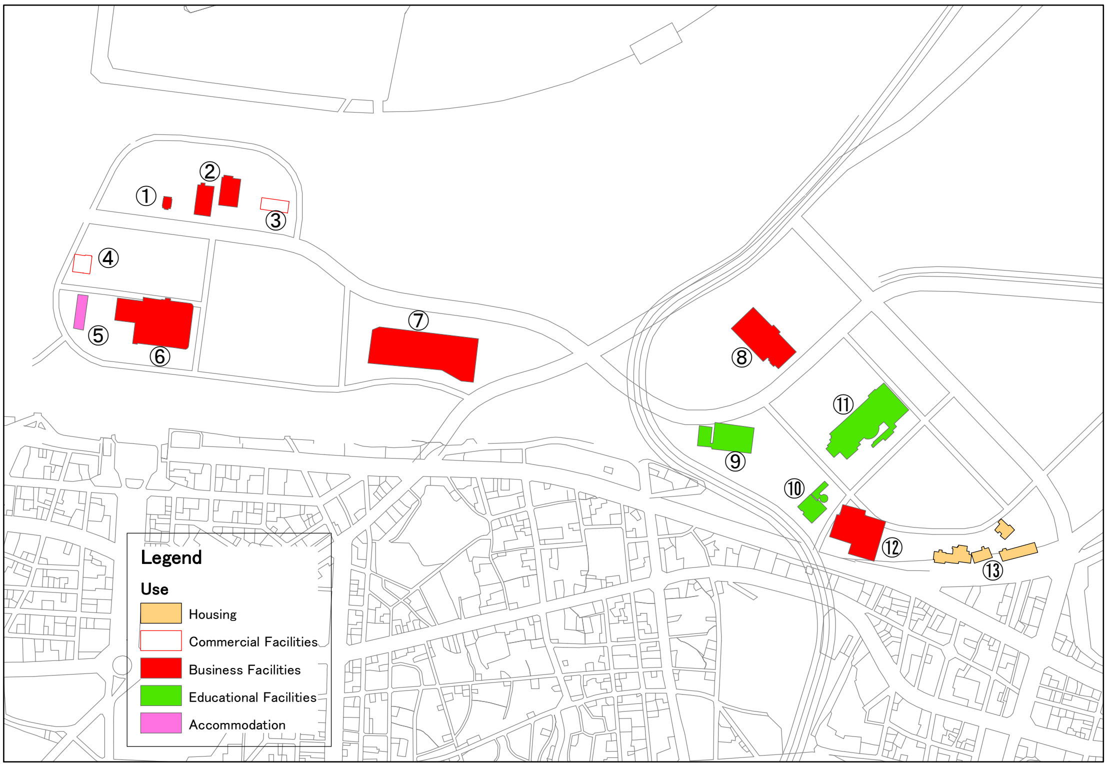


Figure 4-20 buildings in Yahata Higashida green village

Used for the district heating and cooling with the exhaust heat of the factories, a high temperature (above300□) is assumed to supply 5,000m and the low temperature (150□~300□) is assumed to supply 2,000m. This simulation supposed that the energy within the 2km is attenuate with the distance.

The energy form the heat resource for one certain building can be calculated as below:

$$E_O = E_R \times \left(1 - \frac{d}{D}\right); \qquad (4\text{-}11)$$

$$E = \sum Eo$$

E_O : the energy that the calculated building get from this heat resource ;

E_R : The total energy of this heat resource;

E: The total energy that can get from the surrounding building and industries

d: The distance from the calculated building to recourse

D: The possible energy supply distance (2km for low temperature and 5km for high temperature)

(1) The possible resource analysis

Firstly, the study will take the recourses as the core making buffer may with GIS. The low temperature resources are with the radius of 2000m, and the high temperature resources are 5000m. The factories can be selected out by the buffer map.

In the calculation, the possible resource to a certain place will be selected according to the practical situation. The ones across the sea or mountains will be eliminated out.

(2) The distance calculation

The distance between the energy resources and the demand building will be calculated by the GIS. The result can be displayed by GIS like the following graph (Figure4-21)

Figure 4-21 (a) Low temperature for factory

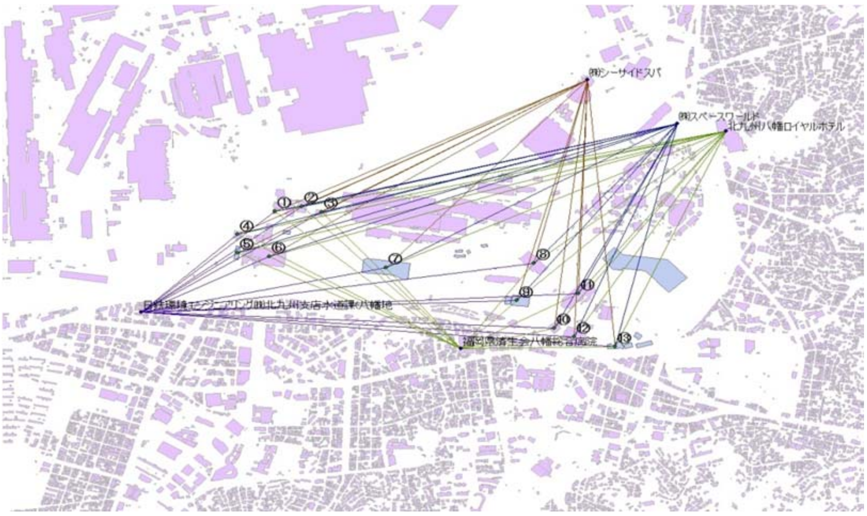


Figure4-21 (b) High temperature for factory

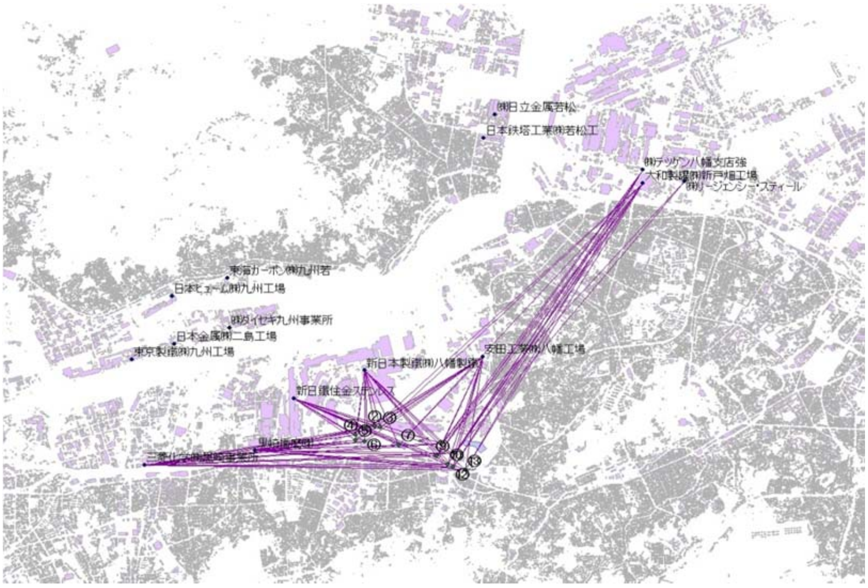


Figure 4-21(c)Low temperature for industry

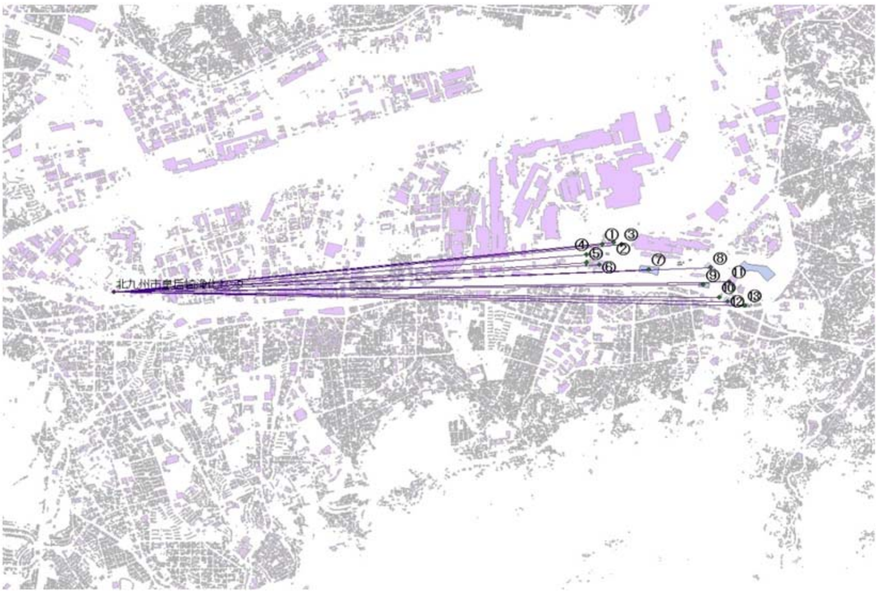


Figure 4-21 (d)High temperature for industry

One factor was defined to evaluate the potential of using the surrounding energy resource. It can be expressed like below:

$$P = \frac{E_S}{E_D} \qquad (4\text{-}12)$$

(P is the reliability of the thermal energy from the surrounding factories and industries; E_S is Energy the building can get, E_D is the energy demand for the certain building)

The calculation result can be displayed in table 4-13

Table 4-13 the comparison of energy supply and demand (TJ/year)

Demand District	Factory		Industry		Total	Hot water demand	Reliability	Total demand	Reliability
	150℃	300℃	150℃	300℃					
Kyushu Human Media Creation Center	684.06	989.11	34.71	0.41833632	1708.30	5003.95332	34.1%	122257.3151	1.4%
Kitakyusyu Telecomcenter	692.98	993.90	36.38	0.55	1723.81	20075.88515	8.6%	490496.9453	0.4%
Advantest	653.13	981.92	39.76	0.73	1675.54	978.2753045	171.3%	33909.79571	4.9%
Kitakyushu J-com	581.77	956.31	39.45	0.59	1578.12	294.7361344	535.4%	10216.39007	15.4%
Kamenoi Hotel	652.39	976.80	34.01	0.33	1663.53	90111.38573	1.8%	237898.9529	0.7%
Kojima Electric Shop	147.14	751.17	15.95	0	914.26	16076.42011	5.7%	392781.4338	0.2%
Nafuko Home Center	256.24	805.21	20.10	0	1081.55	47091.06359	2.3%	1150535.713	0.1%
Sports Depot	75.69	724.95	15.82	0	816.46	21578.49899	3.8%	527209.0251	0.2%
Kitakyushu Industry Technology Succession	10.98	687.61	11.43	0	710.02	13101.52196	5.4%	320098.2896	0.2%
Environmental Museum	207.01	791.78	21.82	0	1020.61	1091.512307	93.5%	27044.61731	3.8%
Inotinotabi Museum	440.47	899.78	32.10	0.05	1372.40	15291.22085	9.0%	378873.6174	0.4%
Best Electric Shop	606.44	966.06	41.02	0.74	1614.26	22155.42532	7.3%	541304.5732	0.3%
Ribio Higashida Apartment	114.18	745.35	17.94	0	877.47	186901.578	0.5%	593169.9279	0.1%

.

From the result, it can suggest that the exhaust heat that can be reused is not a large amount. It can hardly afford the heat demand.

4-7 SUMMARIES

This chapter proposed a method to explore the renewable energy and unused energy. Making use of the on-site renewable energy and unused energy is one of the important features of the distributed energy system. Therefore, the investigation on the on-site energy recourse should be put forward before energy system plan. Further, it set up and data base of factory exhaust heat resource. A questionnaire was taken out in all the factories and industries in Kitakyushu. Secondly, it suggested a method to estimate the exhaust heat and mapped out by GIS. Finally, based on the existing research, the optimal using areas are displayed out. Compared with the energy consumption mesh map in Kitakyushu, it is suggested that most of the areas with high energy consumption belonged to this district. Finally, the case study in Yahata Higashida explored a way to select the energy resource and estimated the energy that can derive.

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CHAPTER FIVE: INTEGRATED ASSESSMENT OF COMBINED HEAT AND POWER SYSTEM FOR LOW CARBON COOPERATIVE HOUSING BLOCKS

5-1 INTRODUCTION

Kyoto Protocol was widely known as an international act to restrict the greenhouse gas (GHG) emission and 2012 was the fiscal year of the first period. Under its restriction, Japan was supposed to reduce six percent of the GHG emission, compared with 1990[1]. However, the statistic suggested that, its yearly GHG emission increased 4.2% until the year 2010[2]. Even worse, after Fukushima crisis, Japan cut down the nuclear energy. The Ministry of Environment reported that the greenhouse gas emissions increased 13 percent compared with 2010[3]. Therefore, Japan has to rely on other more efficient and independent electricity productions, preferential based on the renewable and untapped resource.

Distributed energy systems (DES) have been drawing increasing attention as a substitute for grid in the low-carbon society development [4,5]. Compared with the traditional centralized energy supply system, the distributed energy generations can reduce the loss in energy delivery to minimum and are easy for renewable energy using as well [6-9]. From the long-term viewpoint, the utilization of renewable energy in DES should be a final solution for sustainable development and low-carbon society. However, most of the current renewable energy technologies, such as solar energy, have low energy utilization efficiency and high expense, thus cannot compete with conventional fossil fuels with respect to the economic performance. Therefore, from the short-term viewpoint, such as economic efficiency approach, the CHP plant is considered to be one of the feasible and effective solutions. In Japan, the CHP system was firstly used in industry area, but now it has also become popular in commercial area and residential area [10]. It can recover the waste heat which came from the electricity generation process. Instead of discharging into the environment, it is used for cooling, heating and hot water supply. In that case, the CHP system can realize a primary energy efficiency around 60%-90% [11]. The higher energy using efficiency also contributed to the low carbon society. In Japan, many studies have reported on the introduction of the CHP systems in civil use. Y. Yang analyzed the distribution system at a university site and optimized the system from the economic aspect [12]. Y. Ruan researched on the introduction of CHP systems in residential areas and analyzed how operating pattern and housing scale affect the system performance [13]. Some studies began to combine CHP with renewable energy technologies such as a PV system or biological energy. H. Ren introduced PV into the energy system and discussed its economic efficiency [14].

Besides economic feasibility, there are still many barriers for the introduction of CHP systems into residential area. As to the residential area, the electricity load and heat load varies with the season and fluctuates hourly during the day. In another word, operation of residential CHP system is subject to the variation of load demands. Many researches were reported on how to design the optimal size of the CHP to get a higher efficiency [15]. However, from the intermediate scale side, the cooperative energy use and the interactions between buildings, has been more or less ignored. For example, the introduction of small commercial area or other function in the residential area can smooth out the electricity and heat load.

Furthermore, if, during the design process, the life style of the residents can be considered, it can also take edge off the variation of load demands.

In fact, the mixed residential development with varies function and age groups, have already been proposed by the city planners and stressed on its social meaning [16-17]. The cooperative housing development, a participatory design and construction process which has been popularized in Japan, is one of the housing strategies that can deliver the mixed residential concept. In this process, developers would, given the different lifestyles and needs of the residents, design and assemble them into community [18]. This kind of housing usually has a common space that can be introduced with different building function and gathering residents in different age groups [19-20]. It is expected that the energy system can also work in the cooperative way, managed by one energy center.

In order to understand the feasible benefits of the cooperative using of CHP system, the environmental evaluation on the effect of mixed function and lifestyle is most important. There have been some studies on this subject. Y. Yamaguchi developed a model to set up an urban energy system, and applied it into a central commercial district which was formed with various building function [21-22]. However, these researches were in commercial areas and public areas. The mixed residential area is paid little attention in the previous studies. Actually, the energy consumption in a residential building will be much more complicated. P.J. Boait set up a simple computer model of the time distribution and use of the electricity output for micro CHP, based on trials with a real installation in a UK dwelling. There were six household scenarios comprising three different types of house [23]. However, the studies only stress on the importance of marketing and the use of half-hourly metering, not emphasize on the environmental aspect.

In this chapter, the performances of typical CHP systems are investigated for a cooperative housing block (CHB), a mixed residential development pattern that recently popularized in Japan. Based on the building's energy consumption, CHP technologies have been assumed and assessed following two design and management modes, namely heat tracking mode and electricity tracking mode. In order to have a comprehensive understanding of the performance of the assumed CHP systems in CHB, the system was assessed under different area functional proportion (AFP) and area social age structure (ASAS, the proportion of housing styles for different age groups). It can prove that the cooperative using of CHP system in CHB is better than individual using in the conventional housing development. In addition, the CHP system can perform better if the urban planner properly design the function formation and consider the lifestyle of residents in different ages.

5-2 METHODOLOGY

Based on the theory of CHB develop pattern and the DSE system, the research proposed a CCHP model. The following discussions were based on the data collection, including the technical data and demand side information. It assumed CHP system into the CHB and assessed the potential of the cooperative energy using, which is then followed by the discussion on the optimization of the mixed function and age structure (see Figure 5-1).

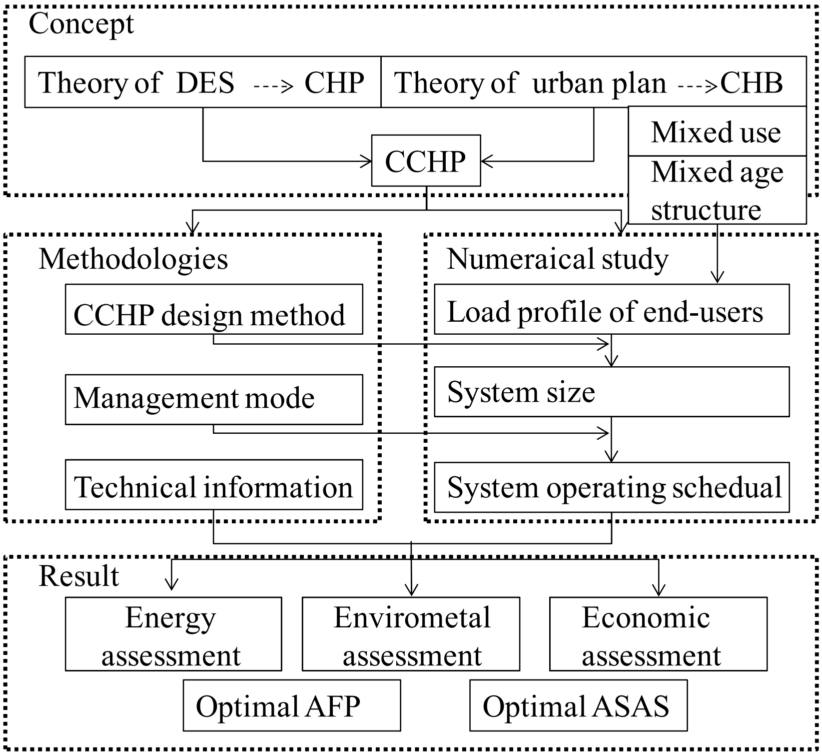


Figure5-1 Research flow

5-2-1 CONCEPT FOR CHB DEVELOPMENT AND THE CHP SYSTEM

The CHB is a distinctive form of housing development that recently becomes popular in Japan. The members in one CHB bought their own real estate and granted by way of a share management and development in the cooperative way. A primary advantage of the cooperative housing is the pooling of the members' resources so that they can build a common area as their common interest. They can design the house or apartment according to their own requirement and life style. Therefore, this kind of housing block can gather the people in different ages into one block, making a safe and comfortable living environment for aging people [19-20]. Another key element is that they can manage and design the common area in cooperation to make some revenue, developing it into commercial, office or other kind of function they like.

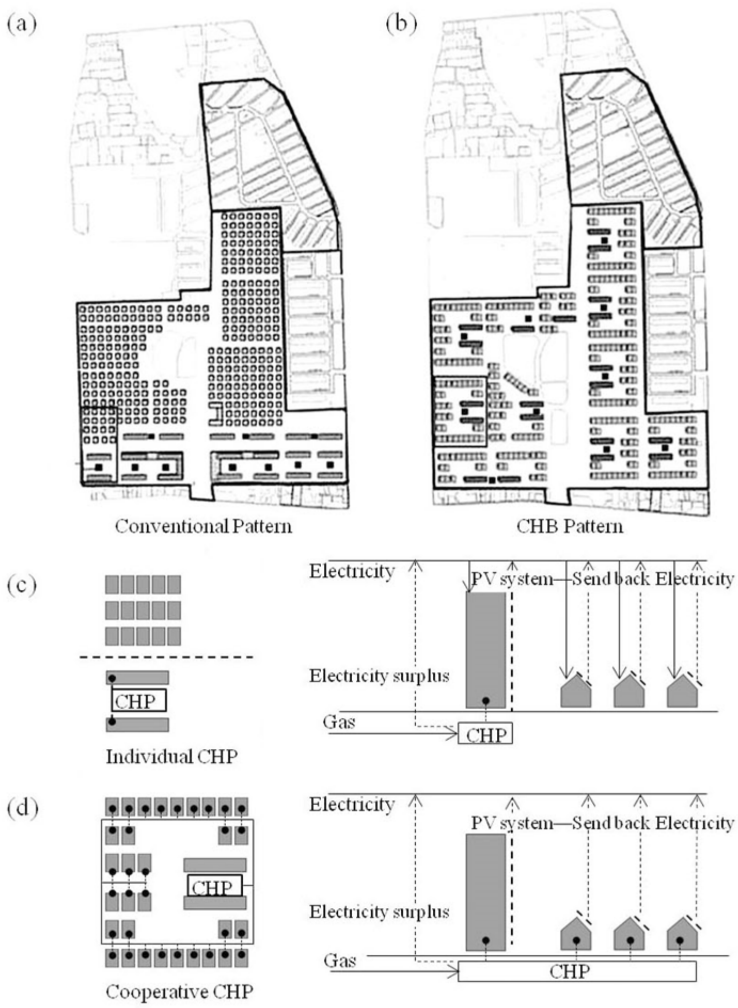


Figure 5-2: The concept for urban pattern and the energy system

The figure2 (a) is the conventional plan for residential area. The apartments and detached houses are constructed individually. This kind of plan is much easier and faster for construction, with less housing styles. Therefore, in the communities with conventional pattern, the role of the environment is less immediate in the human-interaction group, which causes the issues of less social interaction, citizen participation in the design process, and less community identity [24]. Under this kind of plan, usually the energy systems are also introduced and managed individually. Figure2 (c) is the conventional community pattern with CHP system. The CHP systems are designed, introduced and managed individually in apartment, taking a single building as one unit. The detached houses are not introduced with the CHP system, because the small scale CHP for one household are still not so efficient under the existing tectonic condition [25].

This research proposed a plan with the CHB development concept, displayed in figure2 (b). In this plan, the apartment and the detached houses were developed together by blocks, surrounding a common open space. Under this pattern, the CHP system can also be used in a cooperative way (suggested in figure2d). Every CHB will be introduced with one CHP plant under the common area, offering electricity, heating, cooling and hot water for both apartments and detached houses. The system assumed in this research is not an isolated system. It was connected to the energy networks, can obtain electricity from the utility provider and send the surplus electricity back to the grid, which will be supplied to some other existing apartments.

5-2-2 DESCRIPTION OF THE CHP SYSTEM

For a comparative study, this research assumed a conventional system as a baseline. The energy flows of the conventional system and the CHP system are illustrated in Figure5-3. The left side is the conventional system and the right side is the CHP system. Direct electrical consumption for lights and equipments, heating and cooling demands, as well as hot water load have been considered in this research.

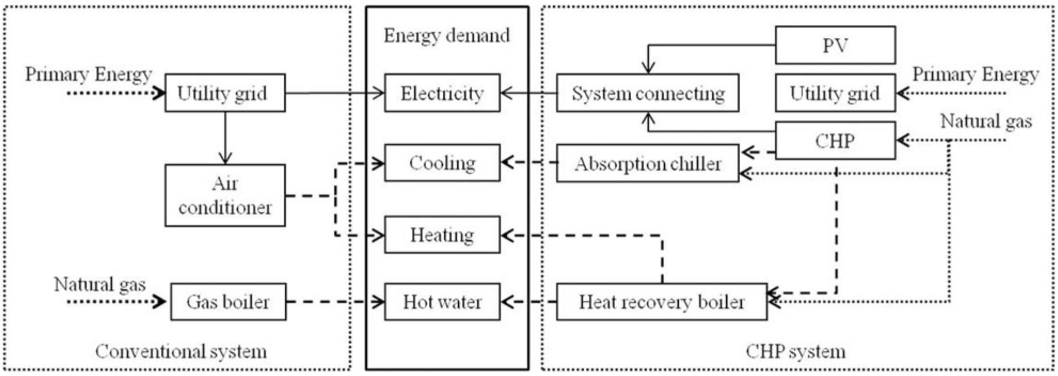


Figure 5-3 The description of conventional system and the CHP system

In the conventional system, the electricity demand is served all by utility grid, not only for the direct power consumption, but also for the space heating and cooling as well by using the air conditioner. Gas boiler, fueled by natural gas, served hot water demand.

In the CHP system, the electricity demand referred to the power consumption. It could be met by either the utility grid, or the on-site generators, such as solar electricity system (PV) and CHP. The recovery heat from the CHP is used for meeting the cooling, heating and hot water demand through the absorption chiller and heat recovery boiler respectively. When the recovery heat is not enough, the auxiliary boiler can also be fired by the natural gas to satisfy the heat demand. On the contrary, if the recovery heat exceeded the local heat demand, the surplus thermal energy would be exhausted directly into the atmosphere. Similarly, according to the current electrical standard in Japan, the electricity produced by PV system can be sold back to the grid, but the electricity produced by CHP system is not allowed to sell. Only the surplus part can be send back to the grid for other existing buildings.

In this research, gas engine is employed as the prime mover. As a widely used technology in Japan, gas engine is attractive for various scale CHP systems for its low first cost, fast startup, reliability, load-following characteristics, and heat recovery potential. The main technical and financial specifications of above four prime movers are given in Table5-1.

Table5-1. The Specification for various equipments

Equipment		COP
Utility	Generating Electricity	0.35
	Transport and distribution	0.9
Gas Engine	Electric generation efficiency	0.3
	Exhaust heat recovery efficiency	0.45
Gas Boiler		0.85
Air Conditioner	Cooling	3.22
	Heating	2.83
Gas Hot Water Heater		0.85

5-2-3 DESIGN AND MANAGEMENT OPTIONS OF THE CHP SYSTEM

According to the demand features, the CHP designer may design its size and employ operation strategies which affected its performance. In the following, two typical design and management options are discussed in a detailed way.

☐ **Heat tracking (HT) mode**

The HT mode weighed on the heat production. It is assumed that all the recovery heat from the CHP system can be efficiently reused. Under this mode, the electricity production of the CHP system will follow the variation of the thermal demand. The CHP system managed in this mode had possibility to produce excess electricity beyond local demand. As mentioned before, it would be used in the nearby community but cannot be sold back. In another words, this part of surplus electric energy cannot get extra economic benefit but still had environmental benefit.

Deciding on the system size is the first obstacle to execute the HT mode. If the system is oversized, the CHP would waste too much electric energy. Many studies have been reported on how to optimize the size of the CHP system [26-28]. This research executed a common method called maximum rectangle method which can be easily applied. This method can prevent the oversize or undersize of the CHP system. The idea is to size the CHP unit to cover the average heat demand instead of the maximum. It is determined by the load duration curve and with the concept of maximizing heat amount supplied at full load [29-31]. It can be simply(easily) determined based on finding the 'maximum rectangle', where the 8760 hourly heat demand values are sorted in descending order and placed in a load duration diagram.

The operation of the CHP will be controlled as below:

$$\begin{cases} Q_{elec}^{CHP} = 0 & \forall 0 \le \mu_{heat} < \theta \\ Q_{elec}^{CHP} = \eta_e \cdot Q_{heat}^{Load} / \eta_{rec} & \forall \theta \le \mu_{heat} < 1 \\ Q_{elec}^{CHP} = R_{cap}^{CHP} & \forall 1 \le \mu_{heat} \end{cases} \quad \text{…….. (5-1)}$$

Q_{elec}^{CHP} and R_{cap}^{CHP} denoted the electricity generation and rated capacity of the CHP system; Q_{heat}^{Load} denoted the heat demand; η_e denoted the electricity generation efficiency of CHP plant; η_{rec} denoted the heat recovery efficiency of the CHP plant.

μ_{heat} was the instantaneous fraction of the CHP system for recovery heat, calculated as (2)

$$\mu_{heat} = \frac{Q_{heat}^{Load} \cdot \eta_e}{R_{cap}^{CHP} \cdot \eta_{rec}} \quad \text{…….. (5-2)}$$

θ is the critical fraction determining to control the working status of the CHP plant. If $\mu_{heat} < \theta$, it means the CHP should turn off because the output is too low.

□Electricity tracking (ET) mode

The ET mode weighed on the electricity generation. The CHP system is operated following the electricity fluctuation so that the recovery heat is also based on the electricity generation. Therefore, in the ET mode, there would be no surplus electric energy, but thermal energy instead. This part of surplus thermal energy will be discarded into the environment.

The direct electricity consumption in residential area does not fluctuate as its thermal demand, thus different from the HT mode. The size of the ET mode, determined by maximum rectangle method is similar with the maximum value. Therefore, the CHP system in ET mode is dimensioned to cover the maximum electricity and operated according to the real-time electricity load.

This design and management mode also means an option for isolated energy system that serves all types of energy demand through on-site generation. It is an independent option for electrification in remote areas where grid extension is not feasible or economical.

The CHP system is operated as below:

$$\begin{cases} Q_{elec}^{CHP} = 0 & \forall 0 \le \mu_{elec} < \theta \\ Q_{elec}^{CHP} = Q_{elec}^{Load} & \forall \theta \le \mu_{elec} < 1 \end{cases} \quad \text{……(5-3)}$$

Q_{elec}^{Load} denoted the electricity demand;

μ_{elec} was the instantaneous fraction of the CHP system for electricity generation, calculated as (2)

$$\mu_{\text{elec}} = \frac{Q_{elec}^{Load}}{R_{cap}^{CHP}} \quad \text{…….. (5-4)}$$

In this mode, rated capacity of the CHP system is the maximum value of the electricity load. Similar with HT mode, θ is the critical fraction determining to control the working status of the CHP plant. If $\mu_{elec} < \theta$, it means the CHP should turn off because the output is too low.

5-3ASSESSMENT CRITERIA

5-3-1ASSESSMENT OF ENERGY PERFORMANCE

◇Energy saving ratio

The CHP system provided higher utilization of the primary energy, thus the evaluation of the energy saving performance is one of the most important aspects of the CHP system. This research used the primary energy saving (ESR) ratio as the key factor to determine the energy saving performance, which is defined as the rate of the energy savings of the CHP system (the difference between the conventional system and the CHP system) to that of conventional energy system. ESR is defined as (5-5):

$$\mathrm{ESR} = \frac{Q_{input}^{Conv} - Q_{input}^{CHP}}{Q_{input}^{Conv}} \quad \text{……(5-5)}$$

The annual primary energy consumption for CHP system included the energy consumption for utility, and the gas consumption for on-site power generation, the CHP unit. The primary energy used in CHP unit also included the primary energy consumption for absorption chiller and the heat recovery boiler to satisfy the cooling, heating and hot water.

The primary energy consumption in CHP system is as (5-6)

$$Q_{input}^{CHP} = E_{Pow}^{CHP} \cdot \varepsilon_{pow} + (V^{CHP} + V^{Boiler}) \cdot \varepsilon_{gas} \quad \text{……(5-6)}$$

Q_{input}^{CHP} is primary energy input to the CHP system; E_{Pow}^{CHP} is the electricity input to the CHP system; V^{CHP} is the gas used by CHP unit; V^{Boiler} is the gas used for boiler.

On the other hand, the annual primary energy consumption for the conventional system is composed of the energy consumption of boiler and electricity consumption, for direct power consumption, cooling and heating,

The primary energy consumption in CHP system is as (5-7):

$$Q_{input}^{Conv} = E_{Pow}^{Conv} \cdot \varepsilon_{grid} + V^{boiler} \cdot \varepsilon_{gas} \quad \text{……(5-7)}$$

Q_{input}^{Conv} is the primary energy used by conventional system; E_{Pow}^{Conv} is the electricity input in conventional system;

ε_{pow} is the primary energy consumption unit of grid in Japan, a value indicating the electricity generation efficiency of grid (10.3MJ/kWh)

ε_{gas} is the primary energy consumption unit of gas in Japan (45MJ/m^3).

◇Recovery heat utilization efficiency

Recovery heat utilization efficiency (*RHUE*) is defined as the rate of thermal energy utilized to primary energy input as (5-8)

$$RHUE = \frac{U_{RH}}{Q_{input}} \quad \text{...... (5-8)}$$

U_{RH} is the thermal energy be used from the recovery heat. Q_{input} is the primary energy input to the CHP system.

◇Primary energy utilization efficiency

Primary energy utilization efficiency (*PEUE*) is defined as the rate of energy utilized to the overall primary energy input. It is a sum of electricity generation efficiency and recovery heat utilization efficiency and expresses that the overall energy utilization efficiency in the distributed energy system. It is defined as (5-9)

$$PEUE = \frac{E_{elec} + U_{RH}}{Q_{input}} \quad \text{...... (5-9)}$$

E_{elec} refers to the electricity generated by the distributed energy system;

◇Fraction of self-sufficient electricity generation

Fraction of self-sufficient electricity generation (SEG) is defined as the rate of electricity produced by distributed energy system to the electricity demand. It is a factor to suggest the independence of the conventional utility. In this case, the electricity in the distributed energy system is produced by CHP system and PV system. It is calculated as (5-10)

$$SEG = \frac{E_{elec}^{CHP} + E_{elec}^{PV}}{E_{elec}^{demand}} \quad \text{...... (5-10)}$$

E_{elec}^{CHP} refers to the electricity generated by CHP plant.

E_{elec}^{PV} refers to the electricity generated by PV system

E_{elec}^{demand} refers to the electricity demand.

5-3-2 ASSESSMENT OF ENVIRONMENTAL PERFORMANCE

◇CO_2 emissions reduction ratio

Environmental benefit is another concern for the introduction of the CHP system. This study used CO2 emissions reduction ratio (CERR) to assess the environmental performance (the difference between CO2 emissions in the conventional system and the CHP system).

The CERR is defined as (5-11):

$$CERR = \frac{EX_{CO_2}^{Conv} - EX_{CO_2}^{CHP}}{EX_{CO_2}^{Conv}} \quad \text{...... (5-11)}$$

Where $EX_{CO_2}^{Conv}$ and $EX_{CO_2}^{CHP}$ denoted annual CO2 emissions of the conventional energy system and the CHP system, respectively.

CO2 emissions from the conventional system included the CO2 emissions from the natural gas and grid electricity for both electricity and heat consumption, and they can be calculated according to (5-12).

$$EX_{CO_2}^{conv} = ex_{CO_2}^{gas} \times V^{Boiler} \times \varepsilon_{gas} + ex_{CO_2}^{Pow} \times E_{pow}^{Conv} \times \varepsilon_{pow} \quad \text{...... (5-12)}$$

$ex_{CO_2}^{gas}$ is the CO2 emission unit of the gas（13.8 g-C/MJ）;

$ex_{CO_2}^{Pow}$ is the CO2 emission unit of the grid（153 g-C/kWh) .

Annual CO2 emissions from the CHP system are composed of the emissions of grid electricity and natural gas consumption, as shown in (5-13).

$$EX_{CO_2}^{CHP} = ex_{CO_2}^{gas} \times (V^{CHP} + V^{Boiler}) \times \varepsilon_{gas} + ex_{CO_2}^{pow} \times E_{pow}^{CHP} \times \varepsilon_{Grid} \quad \text{...... (5-13)}$$

◇Zero carbon ratio

The factor to evaluate the net-zero balance is named as zero carbon ratio (R_{ZC}), similar as the “net-zero energy ratio” as described in chapter3. It is being understood to refer to achieving net aero carbon emission by balancing a certain measured amount of carbon released with an amount of carbon offset, calculated as (5-14):

$$R_{ZC} = \frac{C_{emission}}{C_{Offset}} \quad \text{...... (5-14)}$$

$$C_{emission} = C_{emission}^{grid} + C_{emission}^{gas} \quad \text{...... (5-15)}$$

$$C_{\text{offset}} = C_{sur-elec}^{CHP} + C_{elec}^{PV} \quad \text{…… (5-16)}$$

$C_{emission}$ is the carbon emission to the environment because of using energy, including the electricity and the gas; $C_{emission}^{grid}$ is the carbon emission from electricity consumption; $C_{emission}^{gas}$ is the carbon emission from gas consumption; C_{offset} is the carbon offset of the community by sending back energy to the surrounding area. It is assumed that the electricity produced by PV system will be used in the community but the surplus part will be send back to the grid. The carbon offset in this chapter is referred to the electrical energy, including the electricity that produced by PV and the surplus electricity produced by CHP. $C_{sur-elec}^{CHP}$ means the carbon offset surplus electricity that produced by CHP system while C_{elec}^{PV} means the electricity produced by PV system, calculated as (5-17):

$$C_{elec}^{PV} = S \times \alpha \times \eta \times \varepsilon \quad \text{… … (5-17)}$$

S is the area for PV penal in a group (n);

α is the hourly sun radiation rate [34];

η is the efficiency of the PV penal [35].

ε is the CO_2 emission unit of grid.

Whether the community or buildings realized “net-zero carbon” or not is evaluated by the comparison between Rzc and 1. $R_{NZ} \geq 1$ means the community realized “net- zero carbon”. $R_{NZ} < 1$ means the community can not realize “net- zero” or only near “net- zero”.

5-3-3 ECONOMY ASSESSMENT

◇Payback year

Economy is a decisive factor in the introduction of distributed energy resource. Usually, a project includes initial investment and running cost. The initial investment is defined as the total fee of project construction, including of all kinds of equipment. The initial investment in this chapter is shown in table5-2.

Table5-2 Initial investment in distributed energy system

Equipment	Initial Investment
Boiler	15000 yen／kW
Absorption chiller	450000 yen／kW
Gas Engine	200000 yen／kW
Fan coil	400000 yen/unit
Main-pipeline	400000 yen/m
Branch-pipeline	100000 yen/m
PV	100000 yen/m^2
Gas heater	150000 yen/unit

Scource：Ojima lab, Waseda university

The distributed energy system has usually the higher initial investment and lower running cost compared with the conventional energy supply system. In economy evaluation, an important index, payback year ($Y_{payback}$), has been adopted to evaluate the distributed energy system. It expresses the profitability of the distributed energy system and is defined as the rate of the initial investment gap to the running cost gap between the distributed energy system and the conventional energy system. It is calculated as (5-18)

$$Y_{payback} = \frac{CO_{initial}^{CHP} - CO_{initial}^{conv}}{CO_{running}^{conv} - CO_{running}^{CHP}} \quad \text{…….(5-18)}$$

$CO_{initial}^{conv}$ is the initial investment of conventional system, including air-condition ($CO_{initial}^{RC}$) and gas heater ($CO_{initial}^{Heater}$). It can be expressed as (5-19)

$$CO_{initial}^{conv} = CO_{initial}^{RC} + CO_{initial}^{Heater} \quad \text{…….(5-19)}$$

$CO_{initial}^{CHP}$ is the initial investment of CHP system including CHP plant ($CO_{initial}^{unit}$), boiler ($CO_{initial}^{boiler}$), absorption chiller ($CO_{initial}^{ABS}$), Fan coil ($CO_{initial}^{FC}$) and pipe ($CO_{initial}^{pipe}$), as described in (5-20):

$$CO_{initial}^{CHP} = CO_{initial}^{unit} + CO_{initial}^{boiler} + CO_{initial}^{ABS} + CO_{initial}^{FC} + CO_{initial}^{pipe} \quad \text{……. (5-20)}$$

Running cost for conventional system ($CO_{Running}^{conv}$) includes gas consumption ($CO_{Running}^{convgas}$) and electricity consumption ($CO_{Running}^{convelec}$), as described in (5-21)

$$CO_{Running}^{conv} = CO_{Running}^{convgas} + CO_{Running}^{convelec} \quad \text{……. (5-21)}$$

Same as conventional system, the running cost for CHP system can also described as (5-22)

$$CO_{Running}^{CHP} = CO_{Running}^{CHPgas} + CO_{Running}^{CHPutility} \quad \text{……. (5-22)}$$

◇Gas tariffs

In economy evaluation, it is need to calculate the running cost for the distributed energy system and the conventional energy system. In this thesis, the natural gas is selected as the primary fuel. Therefore, natural gas tariffs at the located must be grasped. There are lots of Gas companies, which can supply the certain district gas. The site of the case study is located in Kyushu area and the gas tariffs in Saibu Gas Company have been introduced. The tariffs related in this study are listed as Table5-2.

Table5-2 Gas tariffs for residence

Rank	Gas consumption per month	Basic charge (yen/month)	Volume charge (yen/m^3)
A	0m^3--15m^3	871.5	234.99
B	15m^3--30m^3	1092	220.29
C	30m^3--100m^3	1501.5	206.64
D	>100m^3	2047.5	201.18

Scource：Saibu gas
(http://www.saibugas.co.jp/home/rates/structure/calculation.htm)

The gas tariffs for distributed energy system are different from the conventional system. In this case study, the tariffs system for as described in 5-3

Table5-3 Gas tariffs for distributed energy system

Rank	Gas consumption per month	Basic charge (yen/month)	Volume charge (yen/m^3)
A	0m^3--15m^3	871.5	212.37
B	15m^3--30m^3	2866.5	79.81

Scource：Saibu gas
(http://www.saibugas.co.jp/home/rates/menu/discount.htm#myhome_merit)

◇Electricity tariffs

Similarly, in economy evaluation, electricity energy cost must be calculated for the distributed energy system and the conventional energy supply system. The electricity tariffs in Kyushu Electric Power Company have been introduced, as table5-4.

Table5-4 Electricity tariffs for residence in conventional energy supply system

Rank	Electricity consumption per month	Charge (yen/kWh)
Basic charge (yen/kVA)		270
Quality charge	0kWh--120kWh	15.45
	120kWh--300kWh	20
	>300kWh	21.65

Scource：Kyushu electric power (http://www.kyuden.co.jp/rate_mein-menu_4_2.html)

Table5-5 Electricity tariffs for residence in distributed energy supply system

5-4 NUMERICAL STUDIES

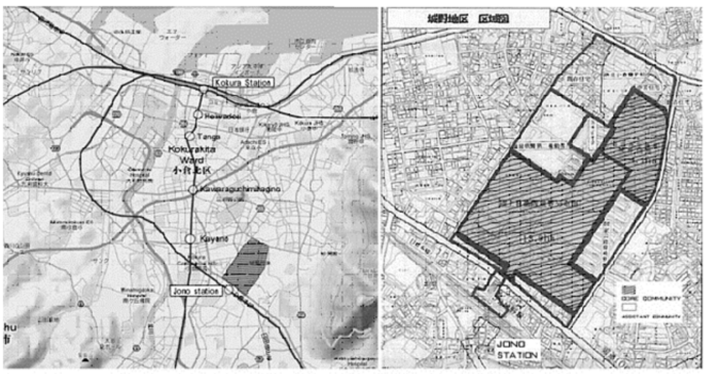
To analyze the application performances of the CCHP systems for low carbon community with the CHB development, a numerical study is presented below. Different CHP solutions are evaluated and compared by using the proposed general and systematic procedure described in Section 5-2. In particular, different function formation and the houses for different age groups are considered, to highlight the importance of residential impact of the mixed-use and mixed-age, as well as the different technical and management options on the CHP system performances.

5-4-1 EXISTING CONDITION

The Jono area is located in the northern part of Kokura, Kitakyushu, directly opposite the Jono station (Figure5-4). Under the concept of setting up a longevity block, the low-carbon demonstration area aims to accommodate 860 families in the form of apartments and 320 families as detached houses（Table5-5）. The whole area is divided into core community and assistant community. All the newly increased households will be arranged in the core area, and the surrounding parts of the community will be renewed. The new efficient technologies will also be introduced into the core community and will incorporate new, efficient energy technologies. The energy using in surrounding community (Assistant community) can also be renewed by the cooperation with the system in core community.

Table 5-5. The research area and building area

Residential area	33Ha= 330，000 ㎡	
	18Ha=180，000 ㎡	
Core community	Apartment	72 ㎡×860 h
	Detached House	120 ㎡×320 h
Assistant community	15 Ha=150，000 ㎡	



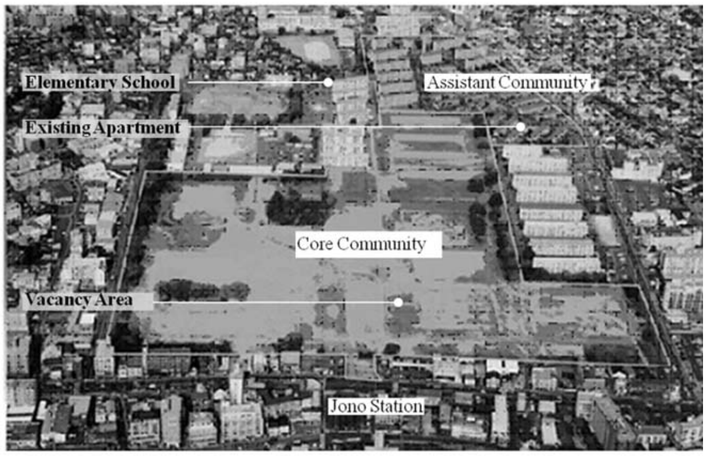


Figure 5-4 The location of the Jono area

5-4-2 PROPOSAL PLAN

This district is used as an army station in the history but now becomes derelict. The land for core community is a vacant lot and the assistant community is covered with residence including apartments and detached house. As most of the residence in downtown area, the surroundings is homogeneous high density houses with little open space, lack of connectivity and communication. The communities in this pattern are efficient at providing urban housing, but creating many negative consequences as well. The lack of open space and connectivity destroy the walk-ability and bike-ability of neighborhoods, increasing car dependence as primary mode of transit, increasing traffic congestion and pollution in the arterial corridors.

The sustainable development of the "longevity block" is based on existing site remnants, reuse, rehabilitate, and rediscover existing pattern.

◇Existing research—the new development of the district, streets, open space based on the existing site research. Reuse, rediscover and regenerate the existing pattern. The existing green land are linked together to provide continual green park, connecting the subway station to the bus stop, forming the axis and also providing a continual walking and cycling route.

◇Transit supported community—the "longevity community" concentrate higher density and mixed-use neighborhoods along the central axis. In that case, the commercial zones are growing along the axis combined with the residence.

◇Promote connectivity—induce a secondary system of public pedestrian and bike only green shortcuts through the blocks connecting to the central park system.

◇Neighborhood construction—provides the core community and the assistant community with office, commercial and school, constructing a compound using community.

◇Sustainable living block—induced proper energy system and technology to build a "self-sufficient & zero-waste" neighborhoods.

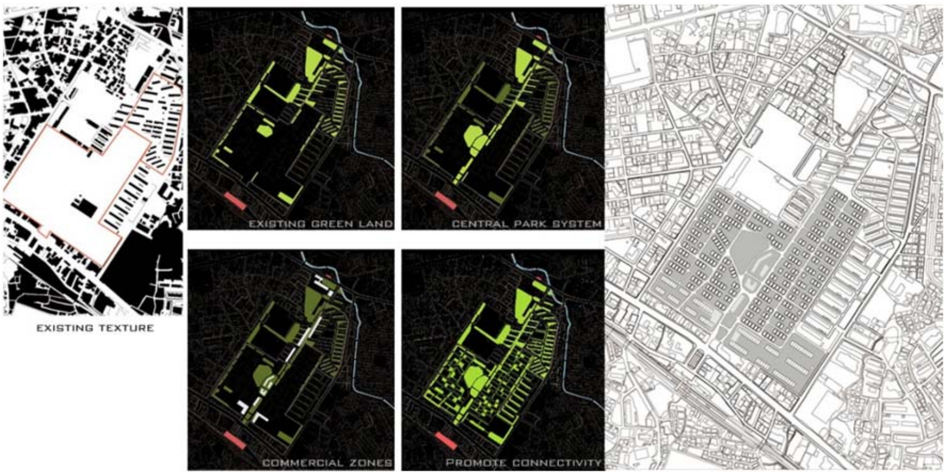


Figure 5-5 Sustainable proposal plan

5-4-3 LOAD ASSESSMENT

Detailed knowledge of energy end use loads is important for selecting an appropriate residential CHP system. Figure5-6 can tell the characteristic of yearly energy consumption fluctuate for residential building [4].

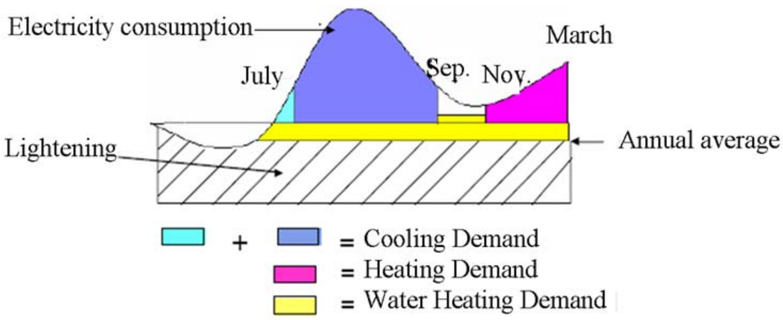


Figure5-6 The estimation of energy use in residential

(Wellington, New Zealand Ms. Momoko Aoshima EDMC/IEEJ Energy Consumption Survey in Japan's residential sector 2010.3)

•Japan's electricity demand generally peak during summer time because of increase of cooling use. Increase from annual average from July to September and small increase from May to June are considered as electricity demand for cooling.

•Heating demand is also considered as an increase from annual average from November to March.

•Demand for water heating is defined as energy consumption of household having electricity water heating system. Electricity company sends receipt of expenditure and consumption to every household who has electricity water heating system

•Demand for lighting is calculated by total electricity demand minus cooling minus heating minus water heating.

In Japan, energy consumption in buildings was always obtained through direct on-site measurement. Some researchers also set up the database, named as energy consumption unit, which can represent the average energy consumption per area for various buildings with different function and in different areas. In that case, the energy consumption can be estimated by multiplying the energy consumption unit by its building area.

In this research, the energy loads were set according to the building area and the energy consumption unit in Kyushu area [38]. The energy consumption pattern for detached house and apartment for per unit has been simulated in 8760 hours. The energy consumption patterns for apartment are displayed in figure 5-7～figure 5-14

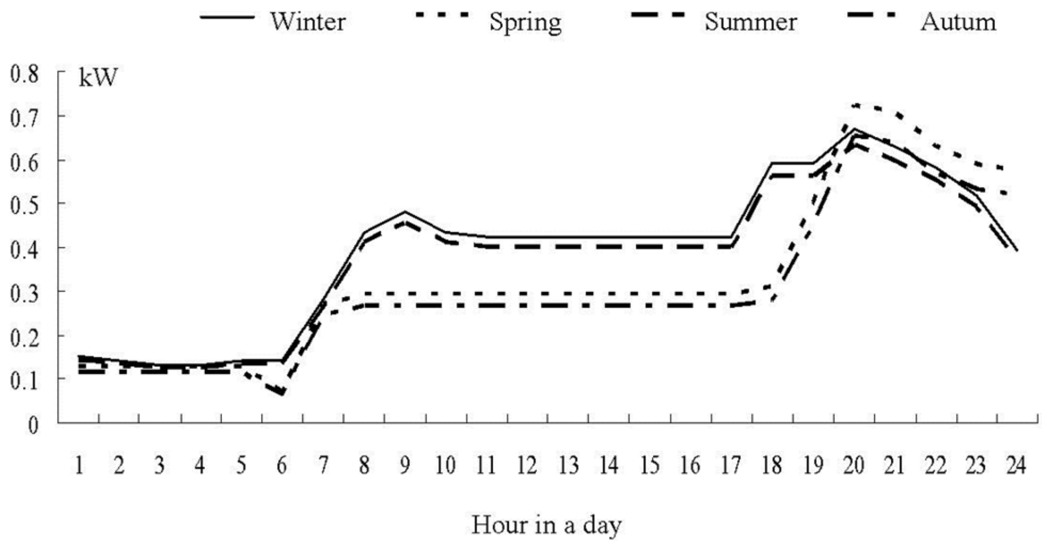


Figure5-7 Hourly mean electricity load in detached house

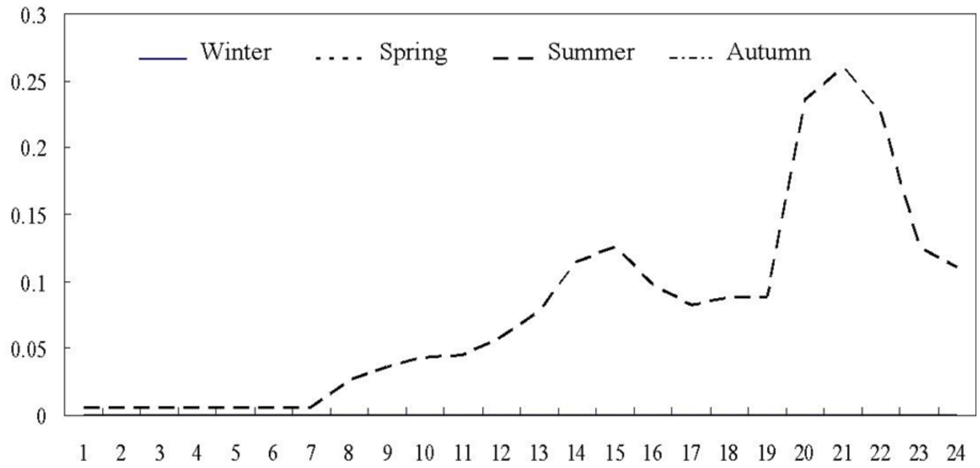


Figure5- 8 Hourly mean cooling load in detached house

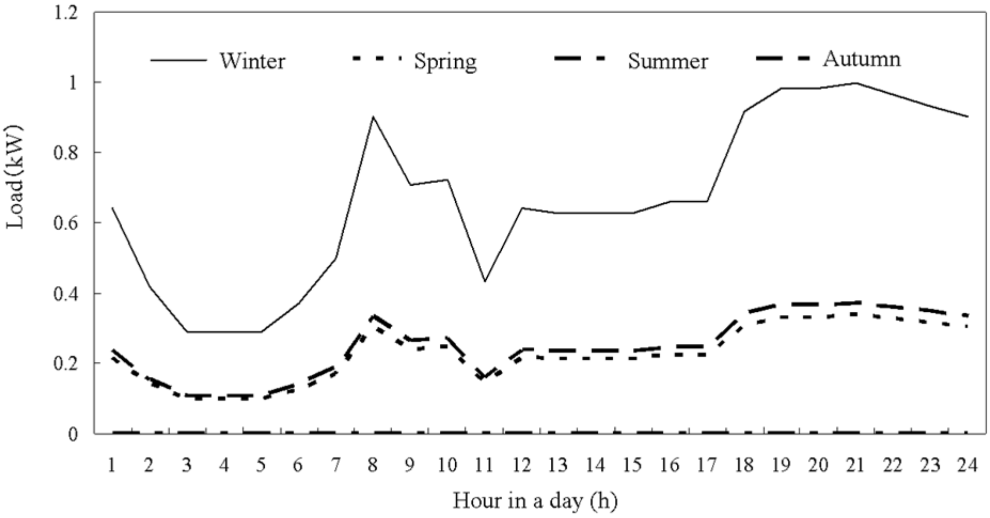


Figure5-9Hourly mean heating load in detached house

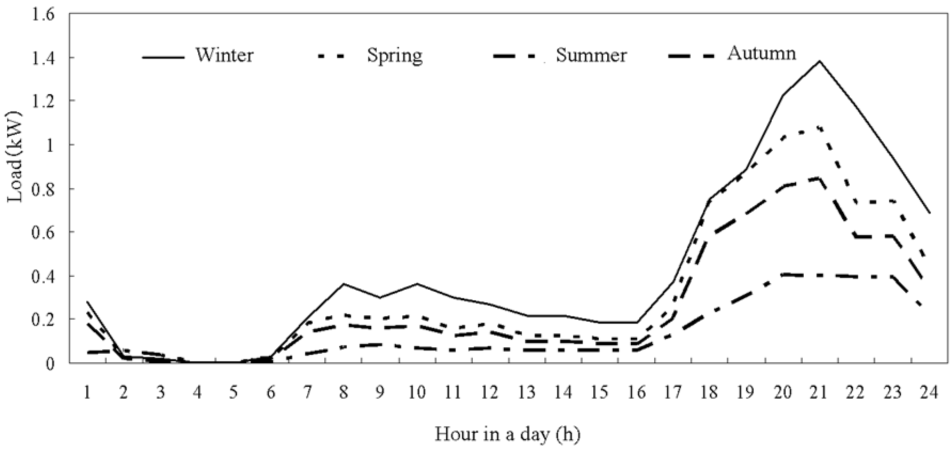


Figure5-10 Hourly mean hot water load in detached house

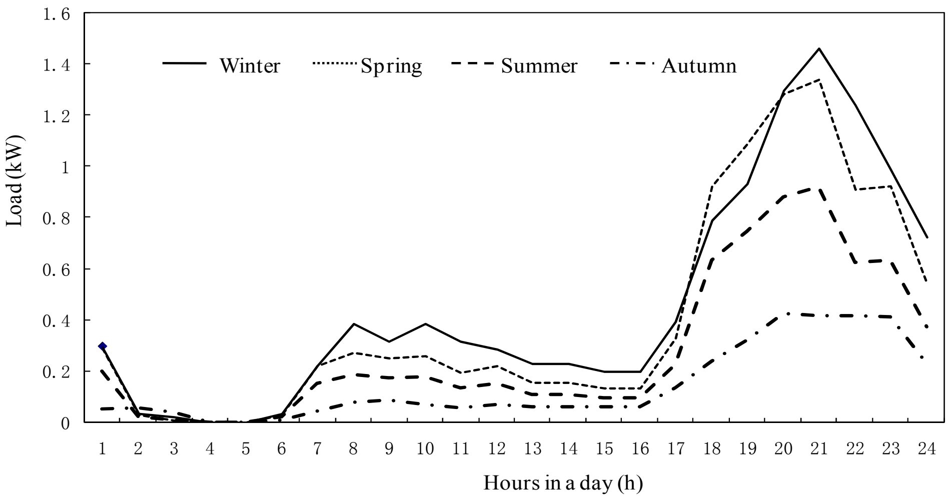


Figure5-11 Hourly mean electricity load in apartment

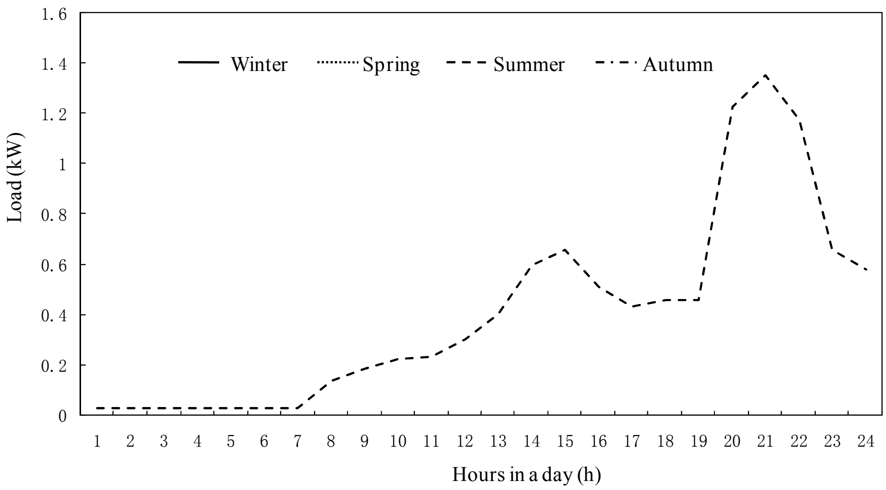


Figure5-12 Hourly mean cooling load in apartment

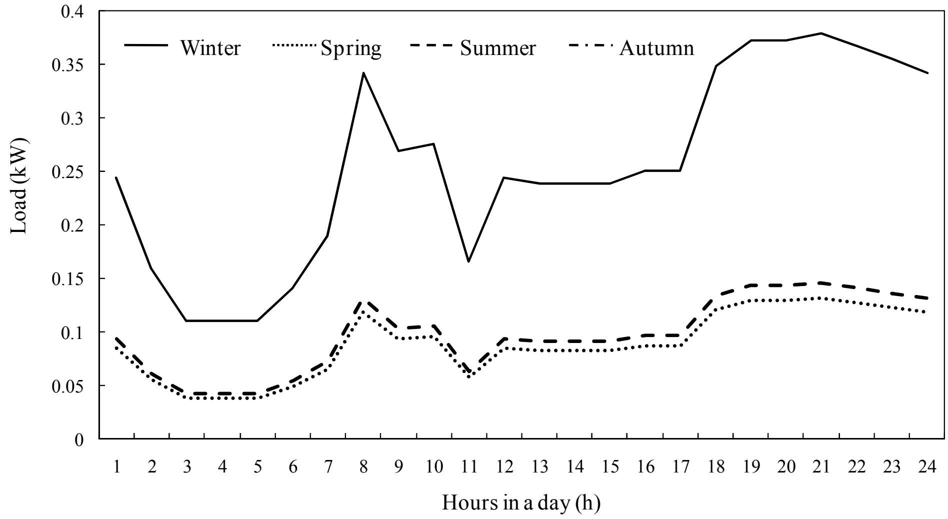


Figure5-9Hourly mean heating load in apartment

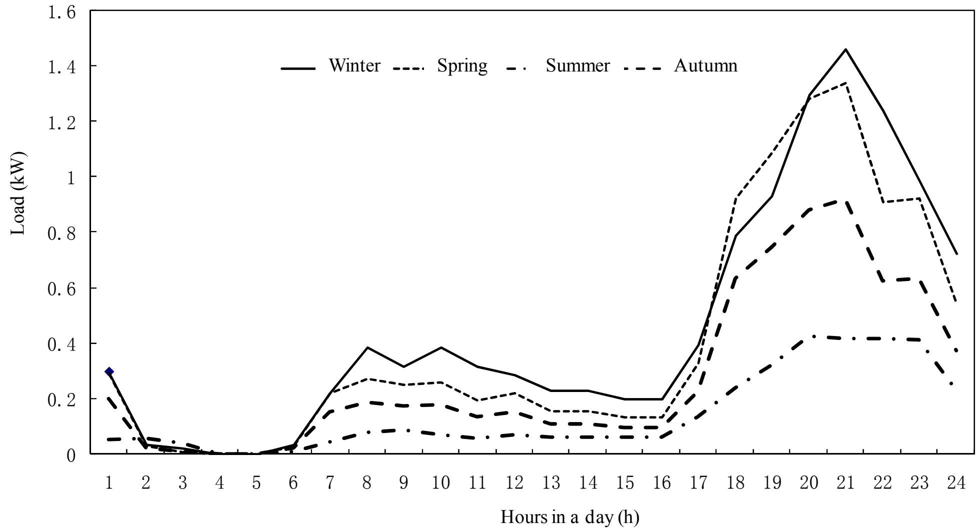


Figure5-14 Hourly mean hot water load in apartment

From these profiles, the following characteristics can be derived:

 The hourly heat and hot water load fluctuates more than the hourly electricity demand.

The cooling load is relative low because of the cool climate of Kitakyushu.

The heat and electricity load peaks generally occur at different times. Correspondingly, the ratio of heat to electricity load fluctuates with time.

 The peak period for heat and electricity load starts at about 18:00 hours and continues until 23:00.

Fig. 5-15 shows the load demand duration curve, which reveals the characteristics of CHB's energy consumption. It illustrates the peak load demand and each demand level range with annual number of hours, which is important information in determining CHP capacity. As mentioned in Section 2, for ET mode, the capacity of the prime mover can be easily determined as the peak electrical load (75 kW). In the HT mode, the capacity is determined based on the thermal duration curve. As shown in Fig. 5-15, based on maximizing the area below heat duration curve, the maximum heat (68 kW) from the power generation unit, and the duration time (3549h) are determined.

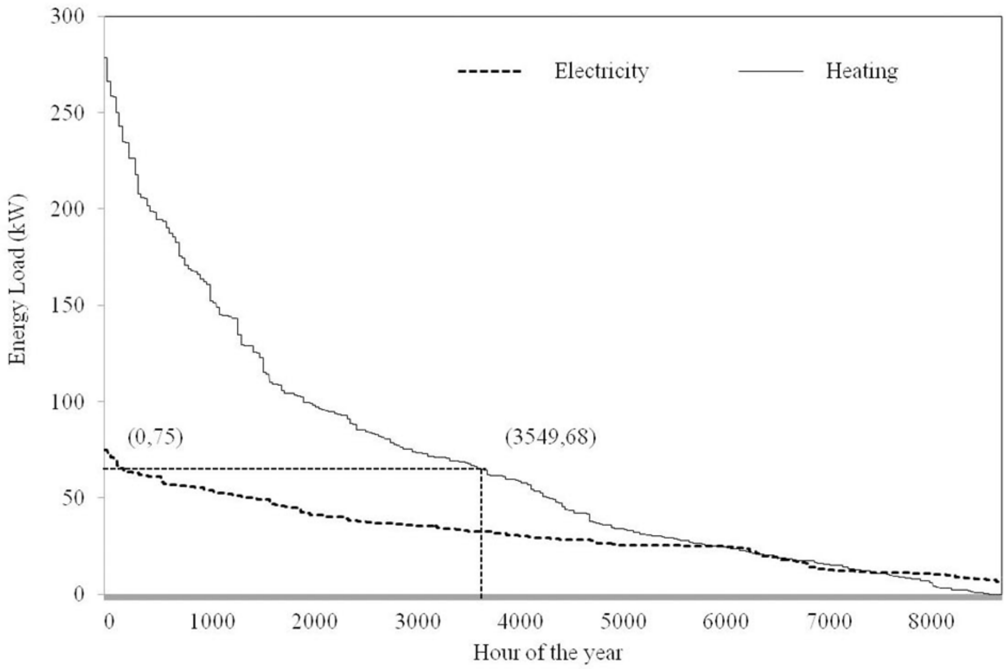
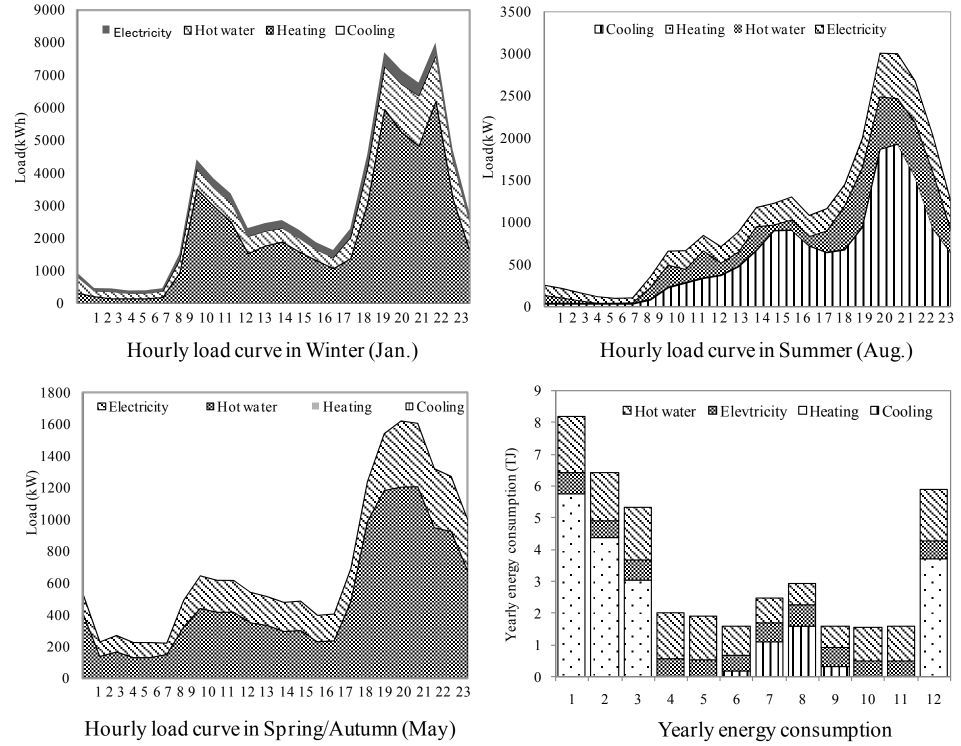
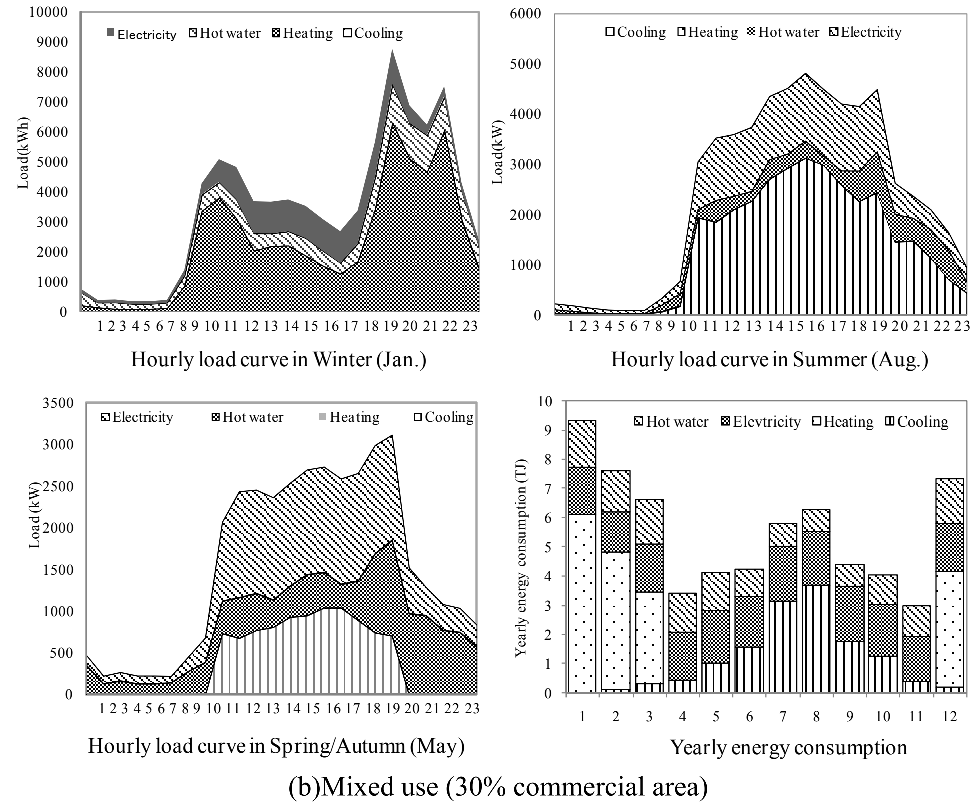


Figure5-15 Load demand and duration curves for one CHB

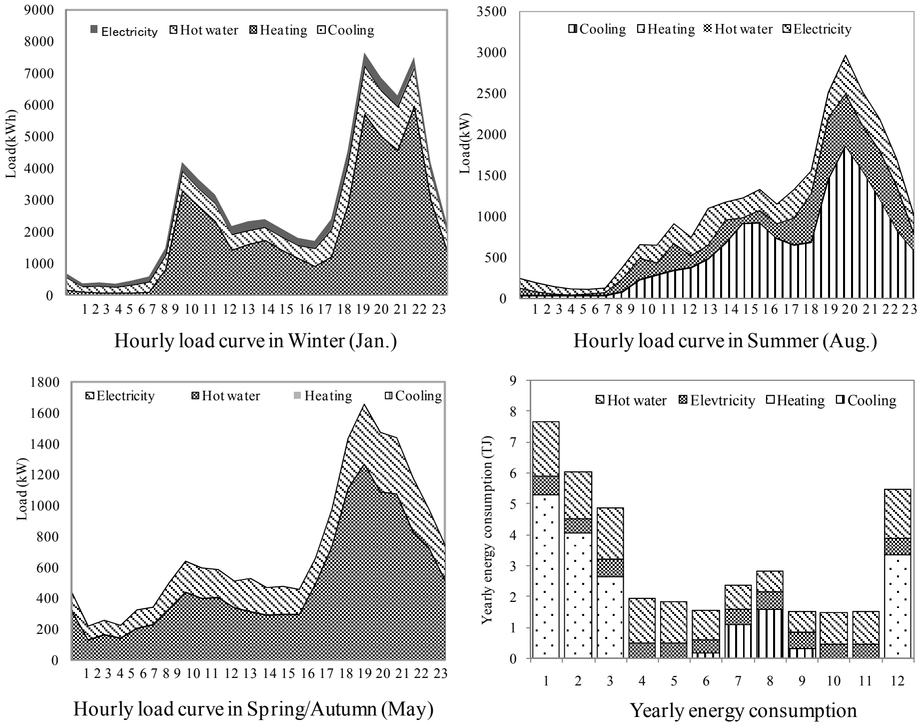
In addition, this research will discuss the CHP performance with mixed-use and the mixed residents in different ages. Therefore, the understanding of the relationship of the energy load and the CHB pattern is vital for the analysis. Figure 5-16 shows the typical daily energy consumption during the summer period (August), winter period (January) and the temperate season (May). Figure 5-16-a represents the residential-only case; Figure 5-16-b shows an example of mixed use including 30% commercial area; Figure 5-16-c shows an example for mixed demographic structure, including 50% elderly residents.



(a)Residential only



(b)Mixed use (30% commercial area)



(c)Mixed demographic structure (50%)

Figure5-16 Monthly and yearly energy consumption

From Figure 5-16, the characteristics of energy consumption can be described as follows:

(1) For a residential apartment (a), electricity and hot water always comprise the main energy requirements, so consumption is always higher than for heating and cooling. They are relatively constant, with low fluctuation, compared with the heating and cooling load.

(2) The variations in cooling load during summer, and heating load during winter, suggest that heat load fluctuates less than cooling load. Moreover, the electricity and hot water loads are slightly more consistent during winter, but have a similar peak load during summer.

(3) The peak heat and electricity load generally occur at different times. Correspondingly, the ratio of heat-to-electricity demand fluctuates with time. The peak period for heat and electricity load starts at about 18:00 h and continues until 23:00.

(4) Figure 5-16-b includes an assumption that 30% of the apartments are converted to commercial functions. This result in higher overall energy consumption, but the daily energy consumption is equalized. Otherwise, the energy used in hot water for commercial units is relatively low and electricity usage is higher. Thus, by adding a proportion of commercial floor space, the ratio of hot water to total energy consumption is reduced.

(5) Figure 5-16-c assumes that 50% of the families in the apartments are aging families. With the mixed

age structure, the energy consumption is lower and slightly stabilized.

5-4-4 CASE SETTING

Case 1–Case3: Residence-only CHB

Case 1: (conventional urban pattern with individually using CHP). The energy systems for department and the detached houses are separate systems. A CHP system is introduced into the apartment part and the detached houses retain as the conventional system.

Case 2: (CHB urban pattern with CCHP, cooperative using only for hot water). Hot water pipes connect the energy systems for department and the detached houses. In this case, the CHP systems are only introduced into the apartment, while detached houses remaining in conventional system. However, the interchanging system can transfer the surplus hot water to the detached houses.

Case 3: (CHB urban pattern with CCHP) In this case, all the apartments and houses in every CHB are connected, sharing a CHP system, which offers electricity, hot water, cooling and heating load to the housing in the block.

Case 4–Case 5: mixed pattern (with mixed function and mixed residents in different ages).

Case 4: Based on case3, the commercial areas are introduced into the CHB. In order to understand the effect of mixed function and get an optimal AFP, the research introduced the commercial area into the CHB. As the total building area is a constant value, when the commercial area increased, the residential area reduced.

Case 5: Based on case3, the CHB is introduced with mixed residents in different ages. The energy consumption unit can suggest that the people in different age groups usually had a different life style, which can smooth out the energy fluctuation and help to improve the environmental performance of the CHP system. In these cases, various proportions of elderly residents are suggested to display the effect of the mixed residents and system performance deriving an optimal ASAS.

5-5 THE EFFECT OF URBAN PATTERN

Beside the social benefit, an important and indisputable aspect of CHB development is its cooperative energy using. In this study, different energy using pattern will be introduced into the residential only community (case1-case3) to suggest the environmental and energy saving potential of CCHP.

5-5-1 COMPREHENSIVE ASSESSMENT OF CHP SYSTEM

(I)Energy performance

□Energy saving ratio

The energy saving aspect of a CHP system is always motioned first. In this study, the primary energy saving ratios for various options with different urban pattern, energy system design and management modes are calculated and illustrated in Figure5-17 (a). The results suggested that CCHP system can achieve higher ESR.

On the other hand, from the viewpoint of design and management, all examined CHP systems at HT mode result in higher ESR than that at ET mode.

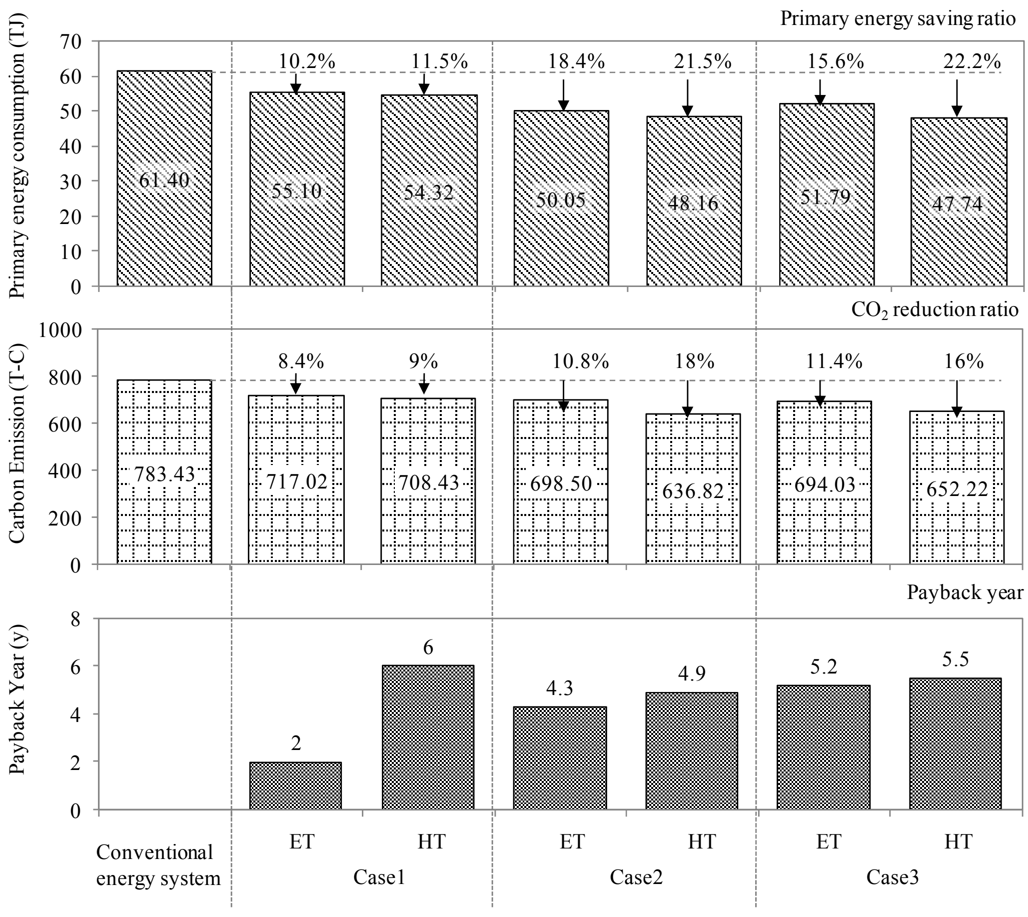


Figure5-17 Comprehensive evaluation for Case1-3

□Fraction of self-sufficient electricity generation

Beyond primary energy saving effect, the energy share pattern can also improve the electricity independency. As figure5-18 displayed, Case1 and case2 can produce 35% of the electricity by the distributed energy system. In case3 almost all the electricity can be produced by the distributed energy system. The improvement of the electricity independency can cut the fuel resource consumption and enhance the stability of the district electricity supply.

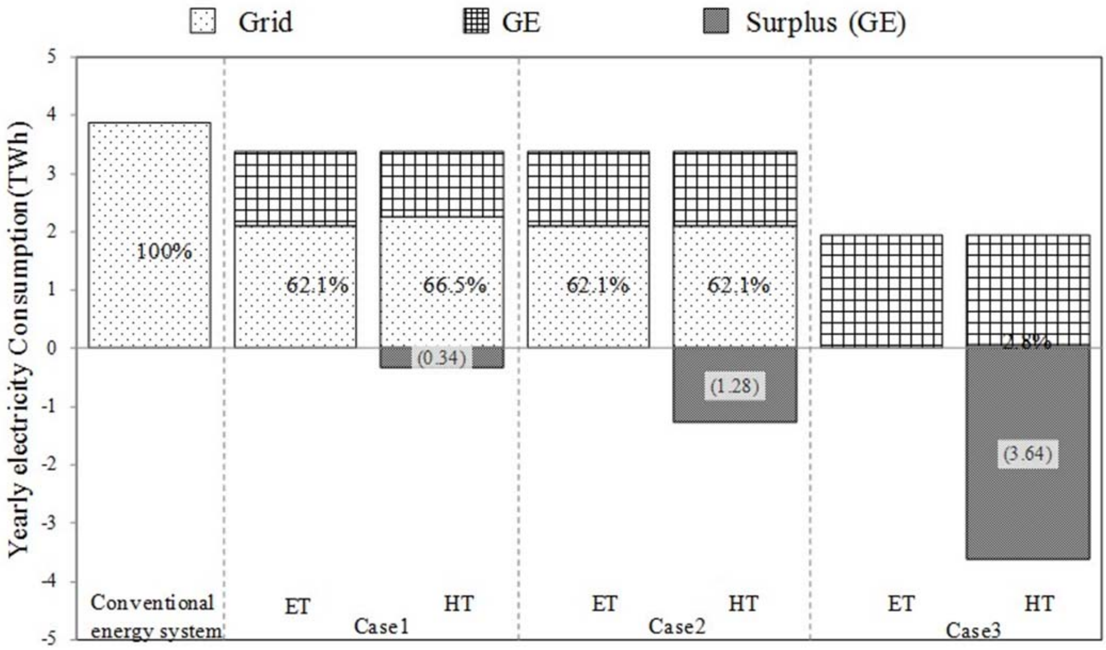


Figure5-18 Yearly electricity consumption structure

□Primary energy utilization efficiency and recovery heat utilization efficiency

The CHP systems in the residential area have higher heat recovery efficiency. Under the HT mode, the CHP systems produce more electricity and recovery heat. Especially in case2 and case 3, recovery heat utilization can reach to 45%. In those cases, the primary energy utilization efficiency of the CHP system can reach to 75%.

Above all, from the viewpoint of energy performance, for the gas engine based CHP energy system, the CCHP in the CHB development is a suitable option for the residential block. Among the examined design and management options, the HT mode achieves better energy performance.

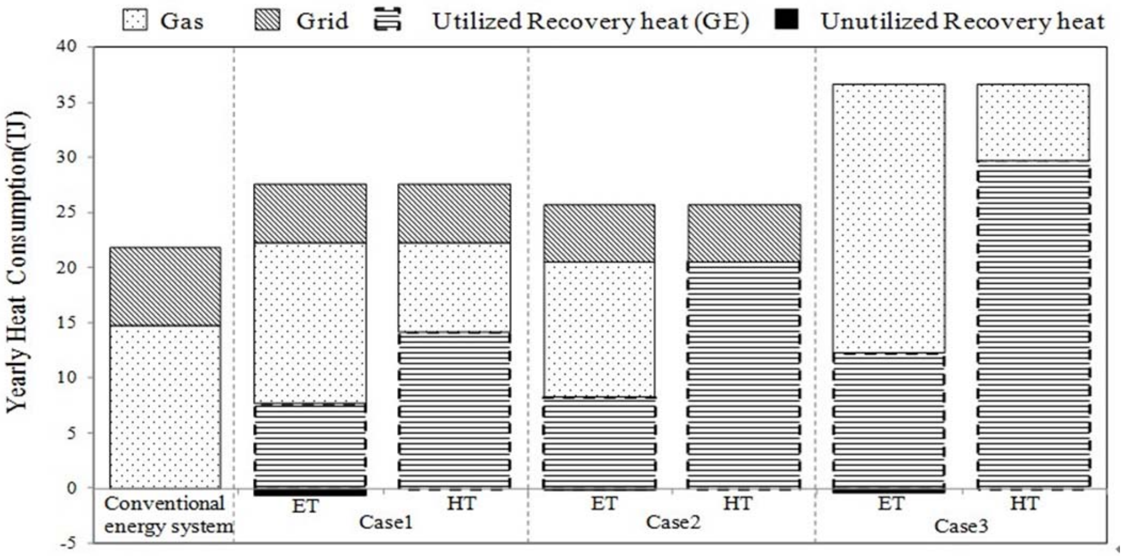


Figure5-19Yearly heat consumption structure

(II) **Assessment of environmental performance**

Environmental impact is an important factor that cannot be neglected in any energy related projects. Figure5-17 shows the CERR values for various options. Generally, the application of the CCHP system in the CHB had almost same environmental performance as the energy saving performance examined in previous sub-sections. To the same management mode, cooperative using of hot water (case2) enjoys the best environmental performance with a CERR around 18%, followed case2 and the individual CHP using in conventional urban pattern. In addition, the comparison between the two running modes can tell that the HT mode results in higher CERR.

(III)Assessment of economic performance

In order to obtain a complete and accurate picture of the advantages of a CCHP system implementation, its economic performance should be assessed in a quantitative way. The payback year for various options are calculated and illustrated in Figure5-17.

Generally, the payback years for all the cases are around 5 years, which means the CHP systems are feasible for residential areas from the economic point of view. As to the relative comparison, the ET mode is better than HT mode. This is mainly due to the oversized CCHP system especially at HT mode, the unbalanced heat-to-power ratio between the demand side and the prime movers, the relatively high capital cost of the CCHP devices.

5-5-2 COMPREHENSIVE ASSESSMENT OF INTEGRATED CHP AND PV SYSTEM

The CHP system in the residential area can only save 20% of the primary energy consumption. That is mainly due to the unbalanced heat-to-power ratio between the demand side and prime mover. Therefore, other kind of renewable energy resource should be introduced into the site. Solar energy is one of the widely used renewable energy resource. In this case, it is set that 1/3 of the roof area all the apartments and detached houses are introduced with PV panel. The comprehensive evaluation results are displayed in figure5-20.

From the energy saving aspect, the result can suggest that the using of renewable energy can greatly improved the primary energy saving efficiency and the fraction of self-sufficient electricity generation. Similar with the energy saving effect, the renewable energy can also improved the environmental efficiency of the system, cutting down 49% carbon emission.

However, the price of the PV panel is still al little high. Therefore, the introduction of the PV panel is not feasible from the economic aspect. The payback year increased to 9 years in case1, the individual CHP system. However, in case2 and case3, the energy sharing between the apartments and detached houses can

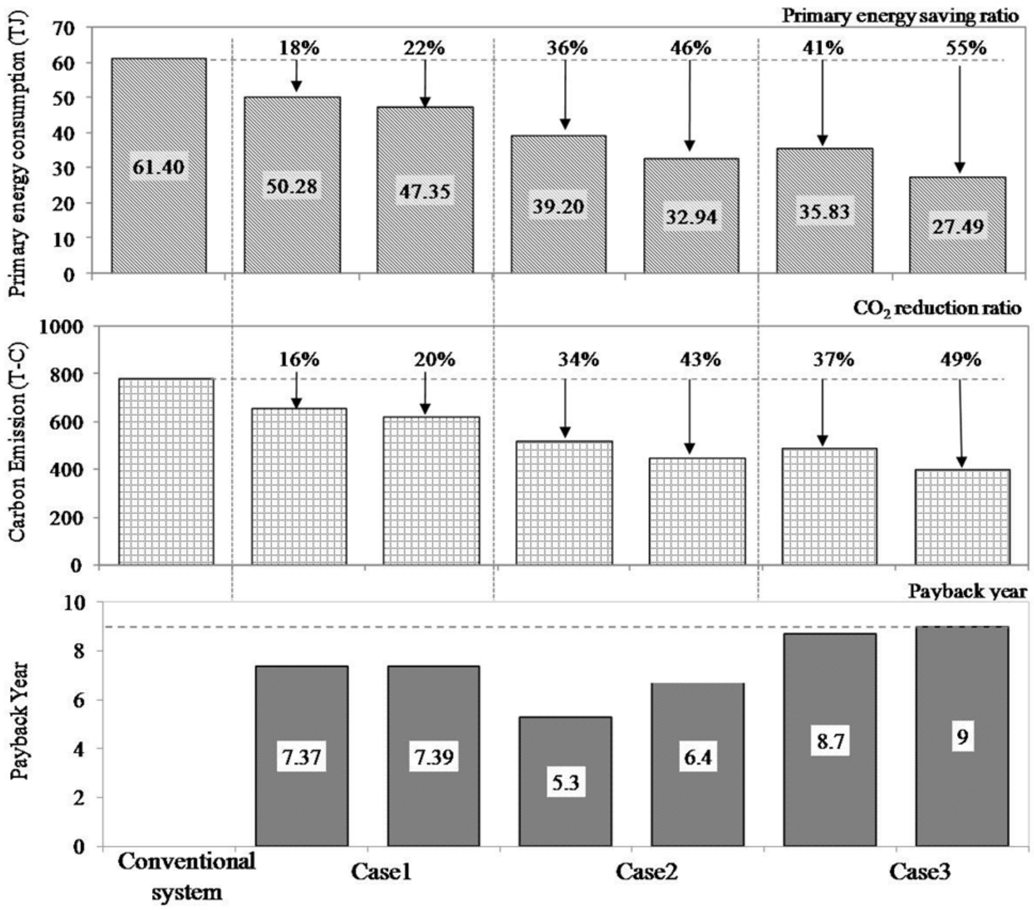


Figure 5-20 Comprehensive evaluation for integrated PV and CHP system (Case1-3)

cut the electricity consumption. In that case, the systems had more surplus electricity produced by PV system, selling back to the grid. The electricity sell back to the grid has higher price than the electricity buy from the grid. This recede the negative effect of the system from economic aspect.

Figure5-20 displayed the relationship between the price of selling electricity that generated by PV system and economic effect. The current price is 38yen/kWh. As the PV system become popularize, the promotion policy for the PV system is getting weak. Therefore, the price is assumed getting down in the future. Generally speaking, the payback year increased when the price is getting down. Comparatively speaking, the case2 under the ET mode has less payback year and less effected by price.

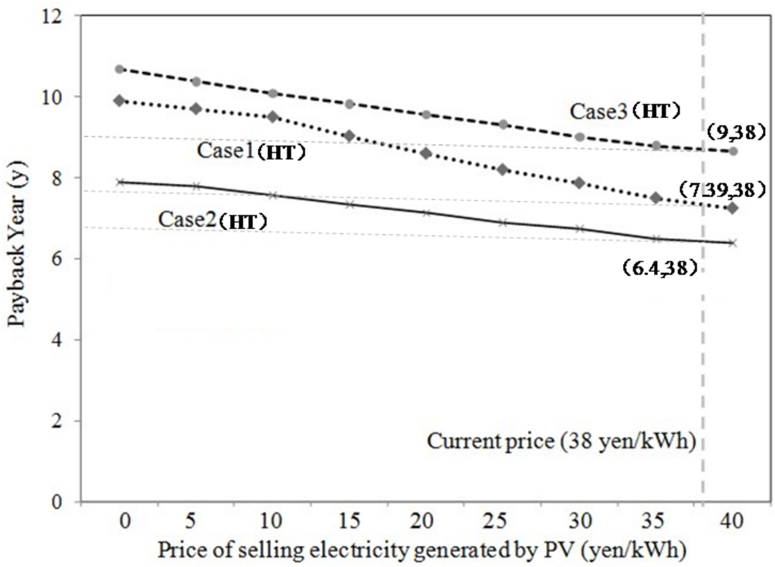


Figure 5-20 The price of selling electricity generated by PV and economic effect

5-5-3 INTEGRATED ASSESSMENT

A well designed distributed energy system should balance economical, energy saving, and environmental consideration. In the sustainability assessment of the distributed energy system, it is often necessary to take into account all above aspects of sustainability at the same time. However, the above criteria are usually contradictory objectives; for example, it is often expensive to utilize environmentally friendly systems. Therefore, in order to achieve a system determination that would be the most appropriate distributed energy system with the most suitable operation mode for particular buildings, an integrated assessment is necessary.

Since index is corresponded to special physical implication, the original data need be standardized by a dimensionless number to eliminate the effects of dimension and order of magnitude. We standardized the data by difference standardization law. Provided that m evaluated units are evolved in a system and each unit has n indicators, difference standardization towards every indicator are depicted as follows:

$$\bar{x}_{ij} = \frac{x_{ij} - \min_i(x_{ij})}{\max_i\left(x_{ij}\right) - \min(x_{ij})} \qquad \begin{pmatrix} i = 1,2,...,m \\ j = 1,2,...,m \end{pmatrix} \tag{5-23}$$

Where, $\bar{x}_{ij}$ is the standardized value of *i*th assessment index in *j*th selected assessment case, $x_{i,j} \in$ [0，1]; Min{$x_{i,j}$} is the minimum assessment index value; Max{$x_{i,j}$} is the maximum assessment index value. These standardized data are excavated mutual information and then are conversed into single indicator.

The second step in this procedure is the definition of the synthesizing function, which can represent the general index. The integrated evaluation factor (IG) comprises the formation of an aggregative function with the weighted arithmetic mean as the synthesizing function shown in the following equation:

$$IG = \sum_j w_j \bar{x}_{ij} \tag{5-24}$$

In this case study, the energy saving, environmental and economic aspects are same important for the low carbon community. The weigh and the assessment result are displayed in table5-6

Table5-6 The integrated assessment of cases

	Energy saving (1/3)				Environment (1/3)		Economic (1/3)		
	ESR (0.25)	SEG (025)	RHUE (0.25)	PEUE (0.25)	CERR (0.5)	R_{ZC} (0.5)	$Y_{payback}$ 1	IG	Ranking
Case1(ET)	0.18	0.38	0.43	0.71	0.16	0.15	7.37	0.18898	6
Case1(HT)	0.22	0.335	0.45	0.75	0.2	0.22	7.39	0.391337	4
Case2(ET)	0.36	0.38	0.45	0.75	0.34	0.16	5.3	0.301025	5
Case2(HT)	0.46	0.38	0.45	0.75	0.43	0.46	6.4	0.499166	3
Case3(ET)	0.41	1	0.43	0.73	0.37	0.16	8.7	0.543205	2
Case3(HT)	0.55	1	0.45	0.75	0.49	0.96	9	0.870185	1

Result of the integrated evaluation can suggested that the CCHP system is better for the low carbon community. Compared with electricity tracking mode the heat tracking mode is better.

5-6THE EFFECT OF MIXED USE

In CHB, the residents can design their housing at their personal will. In other words, they can develop the common open space into the commercial or other functions that they like to make some revenue. In that case, the CHB tend to develop into a residential block mixed with other functions. For example, in the commercial area, its energy consumption peak comes during the daytime. For the residential area, it comes during the evening time. Further, the heat to electricity ratio of the commercial buildings is not as high as in residential buildings. Therefore, as Figure5-16 (b) suggested, the replacement of the commercial area can smooth out the energy fluctuation, and slightly cut the peak. On the other hand, the pattern of the function formation can affect the performance of the CHP system, which is of vital importance to determine the ratio for the mixed function. This section took the commercial as an example, to suggest the performance of the CCHP system with mixed building function and get the optimized ratio of commercial area.

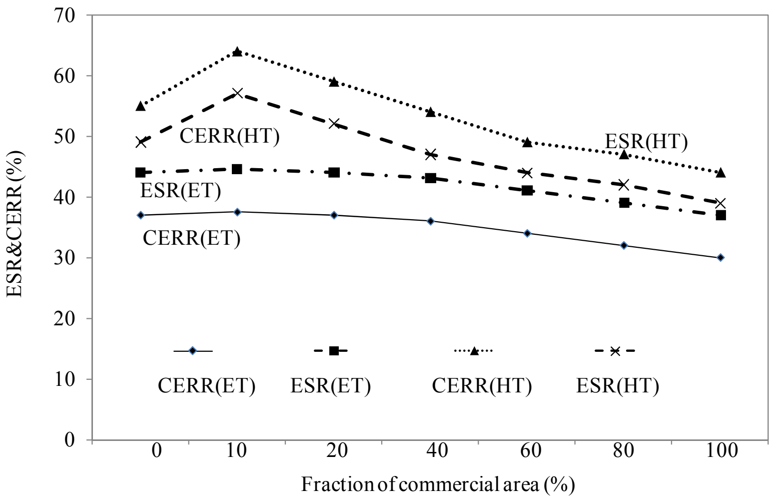


Figure5-21 Energy saving ratio and CO2 emission reduction ratio for Case4

Fig. 5-21 shows the ESR and CERR of Case 4. In this case, the residential area is replaced with the commercial area. Generally speaking, with the replacement of the commercial function, both the ERS and CERR increased as the increasing commercial share. When 10% of the residential area is replaced with the commercial area, the CHP system achieved the optimal performance. However, when the commercial sharing is more than 10%, the efficiency of the system will come down.

On the other hand, from the viewpoint of management, the HT mode is better than the ET mode. When the commercial area accounted for 10% of the total area, the HT mode can realize 55% ERS and 49% CERR. The ET mode can only get 41% ERS and 37% CERR. However, when the commercial area increased, the difference between the HT and ET mode reduced.

In general, as the replacement of the commercial areas, the efficiency of the CHP system increased, but too much commercial area effect reversely. That means the mixed use of residential area can help to increase the energy saving and environmental performance of CHP system, but the area of other function such as commercial should remain in a low share. For gas engine CHP system (taking the mixed residential-commercial area as example), the optimal ratio is around 10%. In other word, the designer should encourage the mixed use in CHB, but better control it near the optimal AFP.

5-7 THE EFFECT FOR MIXED HOUSING STYLE FOR DIFFERENT AGE

In the CHB block, even the unit in the apartment can be designed according to the lifestyle of the residents. In that case, the housing styles can be varied to meet the demand of young couple, elderly people and the family of four. From the social aspect, these kinds of mixed communities are safe to live in and have intimate neighborhood relationship. It created a suitable living condition especially for elderly people. As Japan has now become a serious aging society, it is vitally important to discuss the CHP performance under the mixed housing style for the elderly people. In this section, the CHP system in the CHB will be tested under the different share for elderly housing to suggest its effect to the system performance.

From the view of energy using, the different housing styles have different kinds of energy consumption pattern. Some existing researches are reported on the energy consumption for aging people in Japan [39]. The energy consumption of the housing for elderly people can be described like this: Peak load occurs 2 h earlier than a standard family; the electricity and hot water demand is 10% lower while the energy for heating and cooling is 5% higher. Figure5-16 (c) is an example for the energy consumption curve under the mixed housing. It suggested that a mixed age structure reduces energy consumption, especially cut the peak. As the mixed use, it can also smooth the energy consumption fluctuation, but less effective than mixed use.

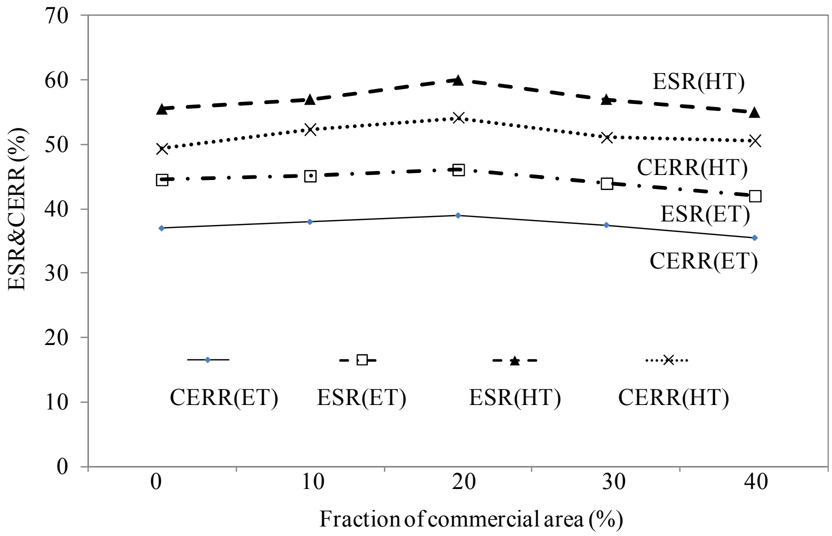


Figure5-22 Energy saving ratio and CO2 emission reduction ratio for Case5

Figure5-22 shows the comprehensive evaluation for case5:

In all, it suggested that the CHP system in CHB with the mixed housing for different age can affect the energy saving performance and the environmental performance. With the replacement of the housing for aging people, the efficiency of the CHP system improved and reached the optimal efficiency when the housing for aging people possessed 20% of the whole building area. However, if the share keeps growing, the

CHP efficiency will come down. The optimal value of the ESR is 60% and CERR is 54%

Compared with the ET mode, the HT mode is better. However, the ET mode performed with more stability, less affected by the increasing aging housing.

Generally speaking, if the designers construct the CHB as mixed housing for different age, it can benefit the performance of CHP system. In addition, it is of vital importance for the designers to balance the share of the housing for age people in one CHB according to the optimal ASAS.

5-8 EVALUATION OF NET-ZERO RATIOS FOR VARIOUS CASES

"Net-zero" energy consumption is one of the target for this demonstration area. The ZEB concept is already perceived as a realistic solution for the mitigation of CO2 emissions and the reduction of energy use in the building sector. The R_{nz} is an index that determines whether the community can achieve energy self-sufficiency in a dynamic view. Following the calculation method assumed in sector2, the research listed out the R_{nz} for cases in Figure5-22. The results suggest that:

Generally speaking, almost all the R_{nz} are under 1. This means the net-zero community is difficult to realize under the current technology situation. From the view point of urban pattern, for the residential-only community, the CCHB has greater potential to achieve "net-zero", especially under the HT mode.

The CHB is common for the mixed use. However, the introduced function such as the commercial and the office usually have higher energy consumption. Therefore, although the replacement of other function in CHB can contribute to the ESR and the CERR, but it also adds to the energy consumption. As a result, the mixed use design pattern in CHB is difficult to achieve a "net-zero" outcome either in HT mode or in ET mode.

The scenario with a proportion of elderly residents not only improves the environmental performance, but also lowers the energy consumption of the total area. The Rnz for the CHB that has mixed housing style (taking the housing for elderly people for example) is near one, which suggested a near "net-zero" community. Especially, when 40% of the housing is substituted for elderly housing, the community can realize the "net-zero" energy consumption under the HT mode. In another word, the mixed housing design pattern in CHB, in consideration of the lifestyle, not only can contribute to the ESR and CERR, but also to "net-zero". In addition, in this pattern, the HT mode is better than ET mode in consideration of "net-zero".

Generally, under the current technologies, the "net-zero" community is not easy to realize. The CHB design pattern, which encourages the cooperative energy using between the buildings, can contribute to the "net-zero", especially in the HT mode. From the view of the "net-zero", the CHB with the mixed housing style by considering the life style is more efficient then the mixed use.

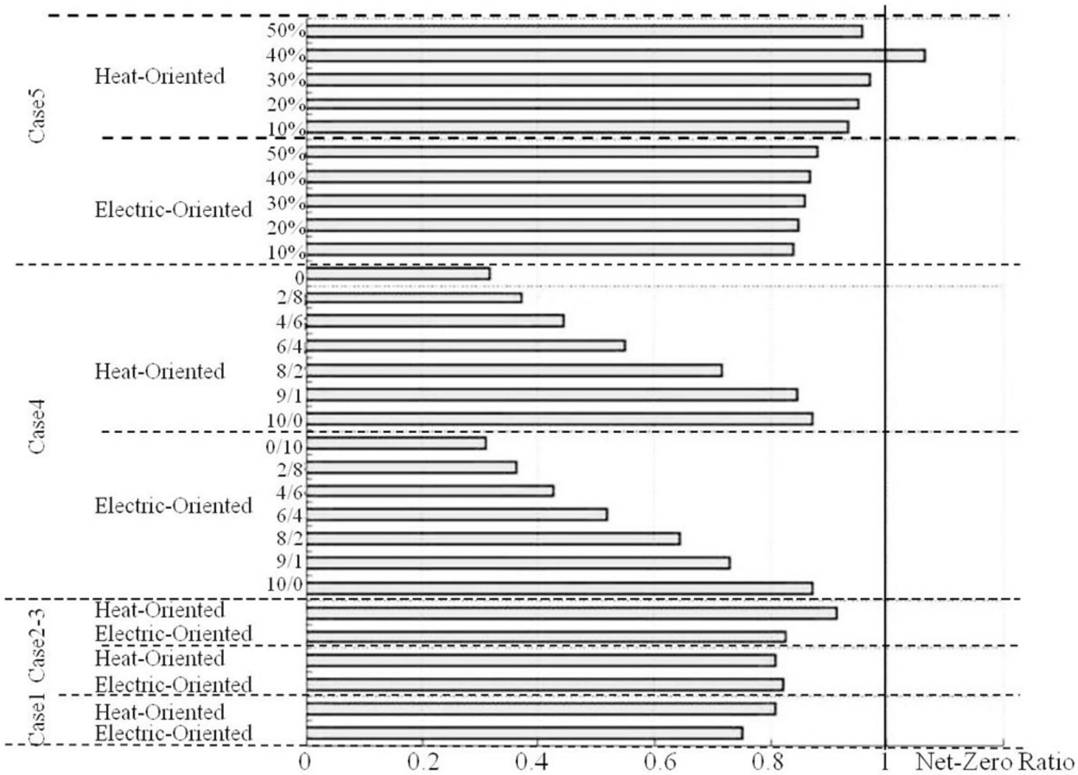


Figure5-22 Net-zero potential evaluation for cases

5-9 SUMMARIES

The chapter proposed a CCHP model within CHB pattern, the housing development pattern that has become popular in Japan recently. One innovation is that the study shed light on the relationship of the urban design pattern and the energy using effect, proposed general and systematic procedure suitable for the energy, environmental and net-zero assessment of the CHP system, and considered various design and management modes. Further, the research discussed two features in the CHB：the mixed use for buildings with various functions and mixed housing styles for people in different age groups. Their effects to the CCHP system were also assessed. The chapter chose the low carbon demonstration community in Kitakyushu as case study, executing the urban design pattern and the energy using model. Various scenarios were examined as a means to optimize a proposed CHP system by variations in the urban pattern, operating mode, AFP and ASAS in consideration of the lifestyle. According to the results, the following conclusions can be deduced:

(1) In the residential-only community, from the viewpoint of energy performance and environmental performance, the CCHP system in the CHB development has better energy saving performance and environmental performance, especially under the HT mode.

(2) The CHB block can be designed into a mixed use residential community, according to the composition of residents. This characteristic can help to increase the energy and environmental performance of the CCHP system, but should remain in a limited commercial share (the optimal share is around 10%). In another word, the urban planner should consider the mixed use in CHB, but follow the optimal AFP.

(3) From the social aspect, the CHB constructed a comfortable living environment for aging people, sharing the life with other people with different ages. This kind of mixed age structure can also make benefit to the energy and environmental performance of CCHP system, the optimal share is around 40%. That means both the urban planner and engineers should consider the life style of the residents in different ages to construct a CHB with optimal ASAS, offering a better living environment for aging society.

(4) Even with the CCHP system, under the current technologies, the “net-zero” community is not easy to realize. The CHB design pattern, which encourages the cooperative energy using between the buildings, can contribute to the “net-zero”, especially in the HT mode. From the view of the “net-zero”, the CHB with the mixed housing style by considering the life style is more efficient than the mixed use.

Of course, the numerical results obtained in the case study cannot be generalized to other CHP systems. However, the conceptual exploration of the results has provided a useful indication of the type of CCHP solution relevant to urban pattern, AFR, ASAS design and management strategies. In the following studies, the assessment procedure presented in this study is expected to be used to other CHP prime movers, so that the feasibility of CCHP system penetration can be examined in a more comprehensive way. In addition, the CCHP system will be assessed from the economic aspect, which is also important for the application of CHP system. In this way, an integrated assessment of the CCHP system can be realized from energy, environmental and economic performance.

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CHAPTER SIX: POTENTIAL ANALYSIS ON THE AREA-WIDE FACTORY EXHAUST THERMAL ENERGY UTILIZATION BY PCM TRANSPORTATION SYSTEM IN A RECYCLING-ORIENTED COMMUNITY

6-1 INTRODUCTION

Accompanied by the global economic development and industrialization, the energy crisis is the issue that has been discussed by many years. The increasing reject heat from factories, industries and cars make the environment problems even worse, air pollution heat pollution and especially the green house effect. The statistic shows yearly amount of the rejection heat from factories can cover the energy of all houses in Japan for five years. Therefore, the promotion of using the reject heat is a great contribution to the energy conservation and greenhouse gas reduction.

The Japanese steelmaking industry consumes as much as 11% of total primary energy, and then releases 5% in the form of waste heat [1]. Beside energy shortage, utilization of waste heat from industry – which occurs in very large volumes and in a wide temperature distribution – has a great potential to reduce energy consumption and reduce CO2 emissions. However, it is not very easy to recover and use waste heat generated in a local process; the “when” and “where” of its availability does not always match the “when” and “where” of its reuse. Therefore, heat transportation system using technology of thermal energy storage (TES) has recently attracted considerable attention [2].

Latent heat storage (LHS) using phase change material (PCM) offers many benefits of (1) large density of thermal storage, (2) change from periodically emitted heat to constant-temperature heat source, and (3) repeatable utilization without degradation. The promise of a latent heat transportation (LHT) system using PCM for recovery of waste heat is particularly attractive

In the system, a mobile latent heat accumulator would recover industrial waste heat at low temperature (below 200℃) and distribute it over a wide area situated at distances of up to 35 km from the heat source. It would store industrial waste heat in the form of latent heat by melting PCM, and then it would be transported via container tank car to the city. This facilitates the availability of hot water for municipal uses, without the combustion of fossil fuels.

Used to be an industrial city with heavy pollution, the city of Kitakyushu is devoted a lot to recovery the environment and till now have already occupied the leading position. In 2008, Kitakyushu is identified as one of environmental model cities in Japan. As one of the most important industrial cities and having a large area of industry, thus the CO_2 emission from the factories is more serious than the average level of the whole country. In that case, city of Kitakyushu will try to reuse the potential energy from the factory reject gas, aiming to construct a low carbon society with the establishment of a stock-society that combines industry, school, government and residential environment together.

This study proposed a way of reusing exhausted thermal energy by PCM (phase change material) transportation system and collecting it from district scale. It firstly introduced the system and reviewed on previous study. Third, the study took Yahata Higashida, one of the Green villages as case study, analyzed the possibility and efficiency of using rejected thermal energy by PCM Transportation System.

6-2 PCM'S IN THERMAL ENERGY STORAGE APPLICATIONS

(1)Heat storage capacity

The advantage of a PCM is the use of the latent heat, which is available during the phase change process. A smaller amount of the heat storage capacity (depending on the temperature difference) consists of sensible heat.

The specific heat capacity of PCM´s is about 2.1 kJ/(kg·K). Their melt enthalpy lies between 120 and 160 kJ/kg, which are very high for organic materials. The combination of these two values results in an excellent energy storage density. Consequently, PCM offer four to five times higher heat capacity by volume or mass, than water at low operating temperature differences

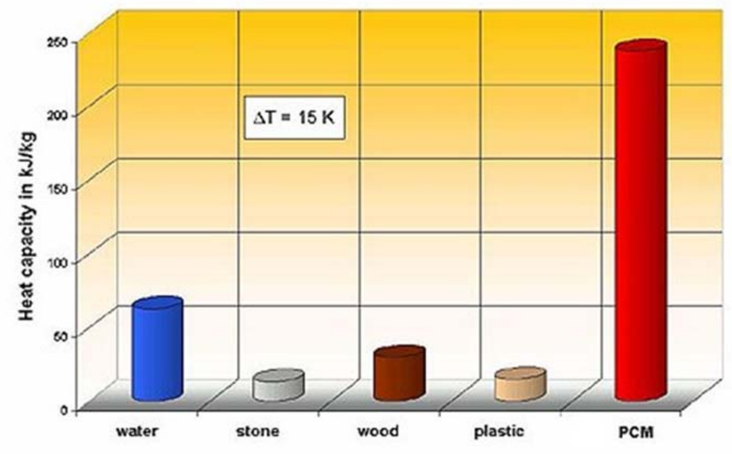


Figure 6-1 the heat capacity of PCM and other materials[4]

(2) Heat conductivity

An efficient input and output of heat energy, for example into a latent heat storage unit, requires a high thermal conductivity coefficient. Other applications, such as food transport, have no such requirement.

Like nearly all other organic materials, PCM´s have a low heat conductivity. Although this is seemingly a disadvantage (in food transport systems for example, this is an advantage), it can be compensated for by large heat transfer surface areas of the heat storage material. This is achieved in the case of many of our bound PCM forms, where a large surface area of thin layers of PCM is created.

(3)Volume expansion

Every material changes its density and thus its volume when it goes through phase change from solid to liquid. This can be problematic in certain applications. Consequently, if used in a closed container, provision must be made for the volume expansion of pure PCM's, in order to avoid excess pressure.

(4)Super cooling

If the melting point of a material is found well above it's solidification point, supercooling is observed. During phase change the entire heat transported should be available at the same temperature for both, melting and solidification. In contrast to many other known PCM's, RUBITHERM PCM's show little to none supercooling.

(5)Stability

During the "lifespan" of a PCM, it is submitted to an immense number of thermal energy charging and discharging cycles. Ideally, the thermodynamic properties of the PCM should not be affected, i.e. neither the heat storage capacity nor the melting and congealing temperatures should change over the product's life time.

Unlike many other latent heat storage materials, RUBITHERM PCM's are long-lasting and stable throughout phase change cycles. This is because there is no chemical reaction during the thermal energy storage process, not within the material itself, nor with the heat transport medium, nor with the construction materials used in the application construction. Melting and solidification are purely physical processes, which is the reason why the heat storage capacity, remains at a high level throughout the unit's working life.

(6)Overheating

If the temperature within a system is higher than foreseen, overheating of the PCM could occur. Over short periods, the result is simply that additional sensible heat is stored within the system. If overheating takes place over a longer time period, there could also be a negative effect on the PCM itself.

(7)Corrosion

Another important feature of a PCM is its lack of reactivity to other materials. The PCM should ideally cause neither corrosion nor other negative effects within a storage unit.

PCM are chemically inert to nearly all materials. Consequently, no corrosion problems occur within containers.

6-3 THE OFFLINE HEAT TRANSPORTATION SYSTEM WITH PCM

The offline heat transport system is the reject heat transport system without pipeline that can utilize the reject heat at less than 200℃. It is a track with a PCM container that can collect storage exhausted thermal energy from the factories, storage and then transport to the heat demand area.

The system is firstly developed by the aviators and introduced in Japan from the year 2003, and then became widely used these years. Compared with the traditional pipe system, the offline system can collect heat from all the factories in possible distance rather than one. Furthermore, it can avoid of the large initiate cost of pipes.

The concept of the PCM container is displayed in figure6-2[5]. The oil and PCM material exchanged the heat. This circulation storage and release heat.

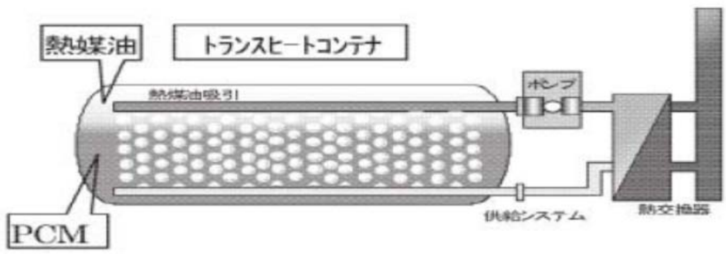


Figure 6-2The concept of the PCM container

The system can be described as figure6-3

(1) Reliable and sufficiently heat storage and release.

When the heat used for heating or cooling, the system has 3 times heat capacity then water, thus the this system can offer an reliable heat supply. In the container, the oil can make a good contact with the PCM material that the heat can transit fast and efficiently to PCM. When the surface enlarged, the speed becomes much faster. The maximum can reach to 0.6MW.

(2) Heat transport

①The offline system can avoid the infrastructure and the initial cost is not affected by distance.

② It is possible to supply heat to more than one demand place.

③ The system is not limited by the pipe, and can chose the demand place freely.

(3) Reliable heat supply

The system firstly collected heat from the supply side, storage and then transported to the demand side. Even the heat demanding and discharging of the demand side always fluctuate, the PCM container has an buffer tank which can promise an stable supply. There are two energy supply patterns as figure6-4

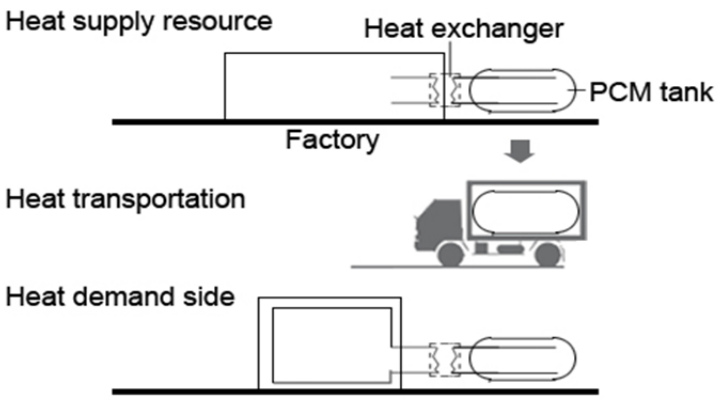


Figure6-3-3 the offline heat transport system

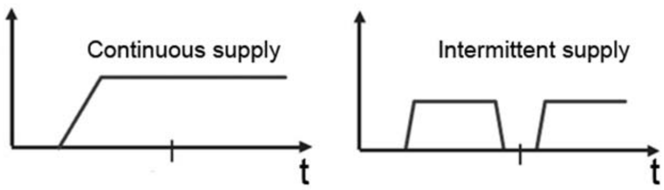


Figure6-3-4 the energy supply pattern of demand side

6-4 THE PREVIOUS RESEARCH ON OFFLINE HEAR TRANSPORT SYSTEM

Hiromitsu [6] introduced the offline heat transport system, collecting the exhaust heat from the Garbage dump and used in the heat density area, described in figure 6-5.

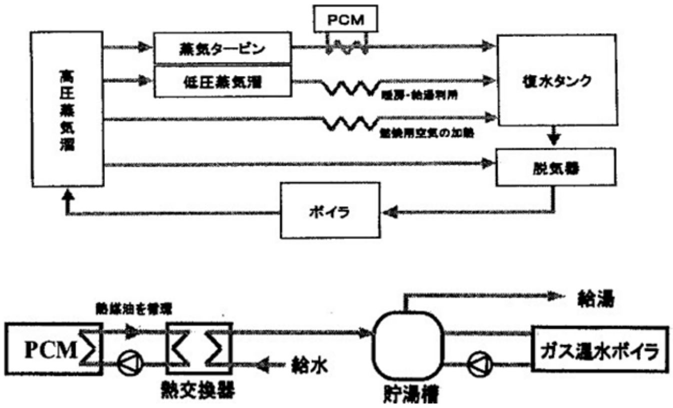


Figure 6-5 the system concept

It promoted the calculation of the efficiency, cost and heat loss. It can described as below:

The heat loss in the demand side

$$Q_d = (Q/\eta)/\eta_2 \qquad (6\text{-}1)$$

The energy used for transportation

$$Q_{TL-PCM} = (L/m)\times E_{fuel} + W\times(T_s + T_r)\times 9.83 \qquad (6\text{-}2)$$

The cost for demand side

$$C_d = \{(Q\times\eta)/\eta_2\}\times(C_{gas}/E_{gas}) \qquad (6\text{-}3)$$

The cost for transport

$$C_{TL} = (L/m)\times C_{fuel} + W\times(T_s + T_r)\times C_{elec} + \{(L/v)+h\}\times C_{per} \qquad (6\text{-}4)$$

The research can suggest that the heat loss during the whole process from one place is around 5% and 95% of the heat can supply to the demand side.

The result of the research can also suggest that the most efficient using area is within 2km.

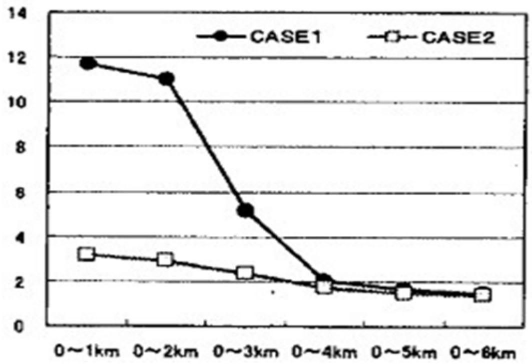


Figure 6-6 the system efficiency

6-5 CASE STUDIES IN THE "RIBIO HIGASHIDA APARTMENT", KITAKYUSHU

6-5-1 ENERGY SUPPLY OBJECT AND ENERGY DEMAND ANALYSIS

Ribio apartment is located in Yahada Higashida, the smart community of Kitakyushu. This place used to be one of the most important industry areas in Japan, and until now still has large factories. Therefore there are great potential to utilize the rejected thermal energy The Ribio apartment is the only residential building in this community, introduced with the latest energy saving and low carbon technologies, which is the demonstration model for the residential apartment.

There are four buildings and the total area is 36106㎡. The energy demand is estimated by the total area and the energy consumption unit (figure6-7—figure6-9).

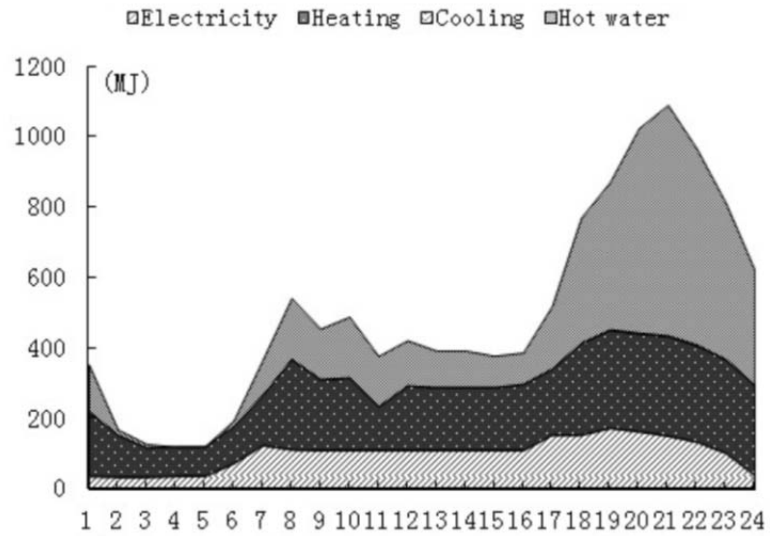


Figure 6-7 Hourly energy consumption in winter

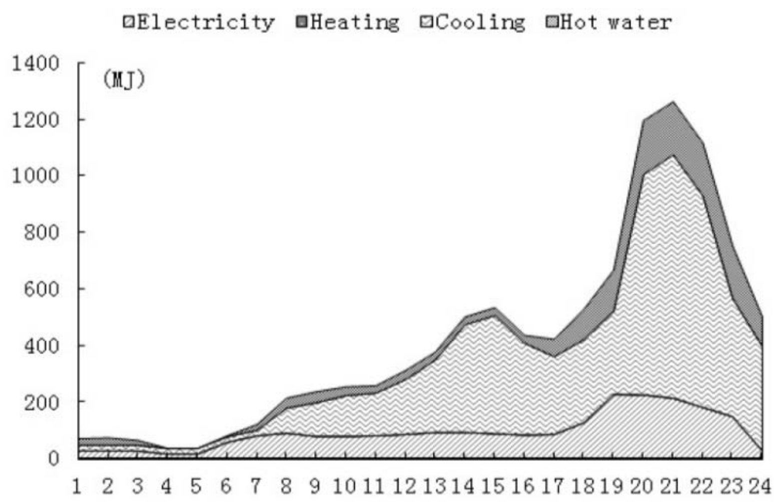


Figure 6-8 Hourly energy consumption in summer

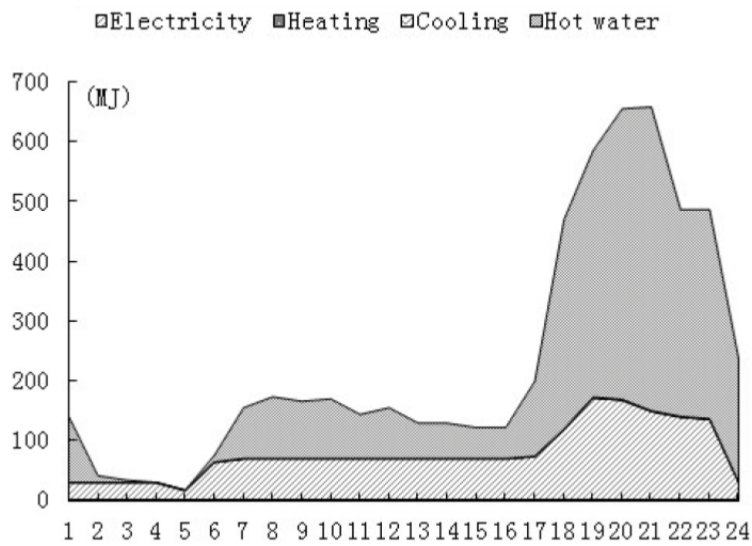


Figure 6-9 Hourly energy consumption in Spring (autumn)

6-5-2 ANALYSIS OF POTENTIAL RESOURCE AND EXHAUSTED THERMAL ENERGY

In this research, the offline heat transportation system is introduced for collecting the exhausted thermal energy from the potential heat resources and transport to the apartment.

The energy loss for transport is

The energy consumption used for transportation (Q_{TL-PCM}):

$$Q_{TL-PCM} = (L/m) \times E_{fuel}$$

E_{fuel}: Calorific value of diesel (2MJ/liter);

L: the transport distance

m: the diesel consumption for truck(2km/liter)

L:the distance between the thermal recourse and demand side (62.5 the total distance of 25 factories, calculated by GIS)

The heat capacity for the container Q: 3600MJ [7]

In this research, the energy consumption used for transportation is offset in the efficiency of the system. Beside the heat loss in heat charging and storage, the research set that only 80% of the total heat can be reused.

Therefore the potential economical heat resource is the factories less than 2000m away from the apartment. The research use GIS to do the buffer map, and selected out the potential resources (figure6-10).

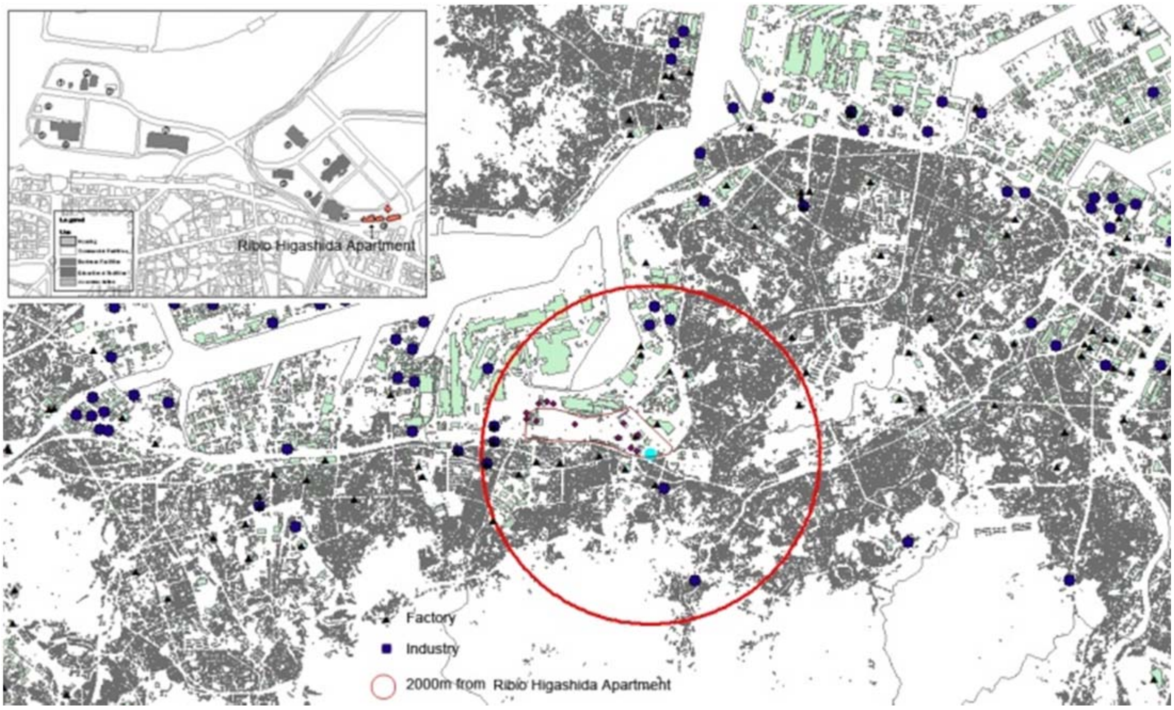


Figure6-10 potential economical heat resource

GIS date can also calculate and offer the total heat amount of these resources.

The total exhausted thermal energy from these factories is 3401TJ every year. This research assumed that the factories offered same amount every day. Therefore the daily energy that can supply to the apartment is

$$E = 3400 \times 0.95 \times 0.8 / 365 = 7(TJ) \qquad (6\text{-}5)$$

6-5-3 CASE SETTING

Base case: the existing system is described in figure6-11. The electricity is supplied by the utility. Room air conditioner is used for cooling and heating. Hot water is supplied by boiler.

Case1: systemI, based on the existing system, continuously using exhausted thermal energy in 24 hours for hot water supply

Case2: systemI, the same system as case1,but use potential economical heat resource only in peak time(7:00-9:00,16:00-0:00)

Case3: systemII, introduce a CHP system according to the electricity peak load, and running in electric-track mode.

Case4:systemIII, based on the system in case3, continuously use the potential economical heat resource for cooling, heating and hot water supply.

Case5: system III, the same system with case4, but use potential economical heat resource only in peak hours (7:00-9:00, 16:00-0:00).

In consideration of the transportation condition, finally only 1/10 of the total potential heat was introduced into this area.

For continuous supply pattern in 24h, the PCM system offers 295 MJ/h. For the intermittent supply pattern, it offered 590 MJ/h.

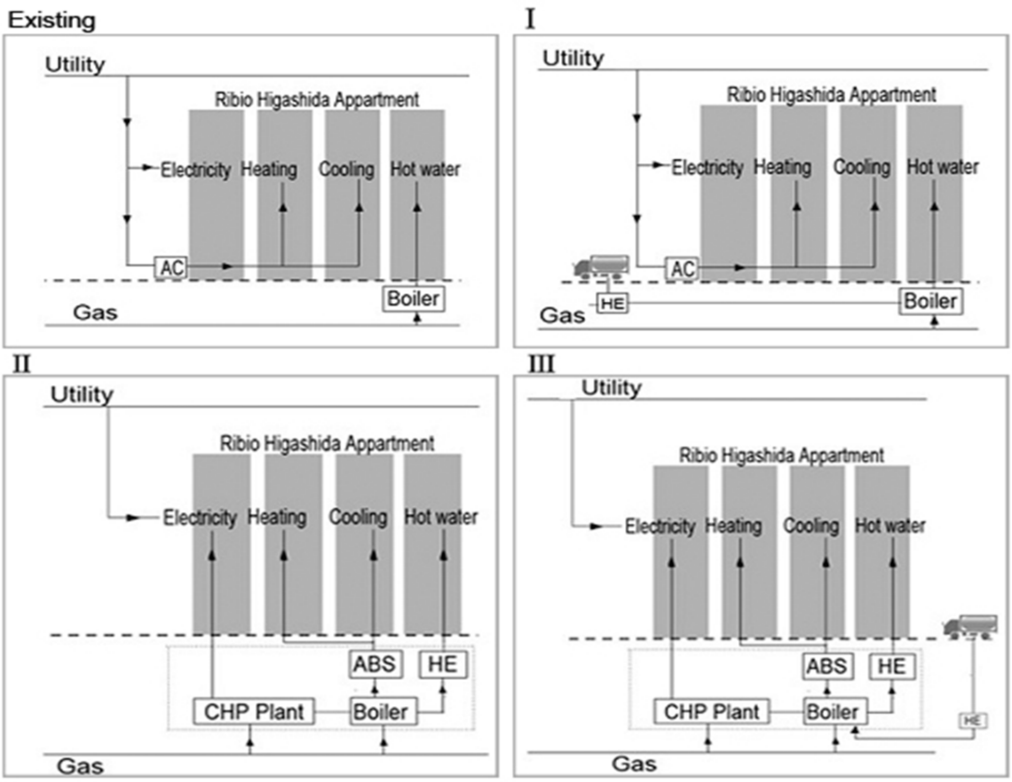
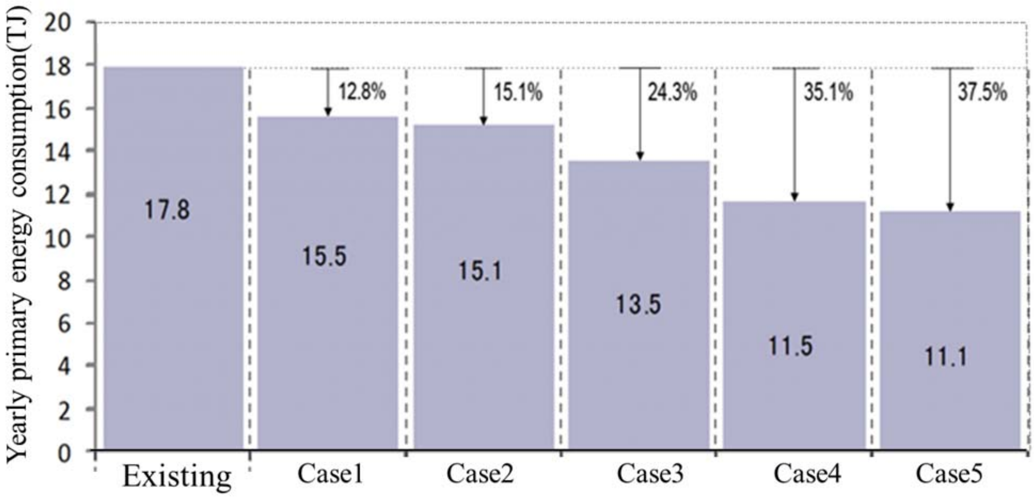


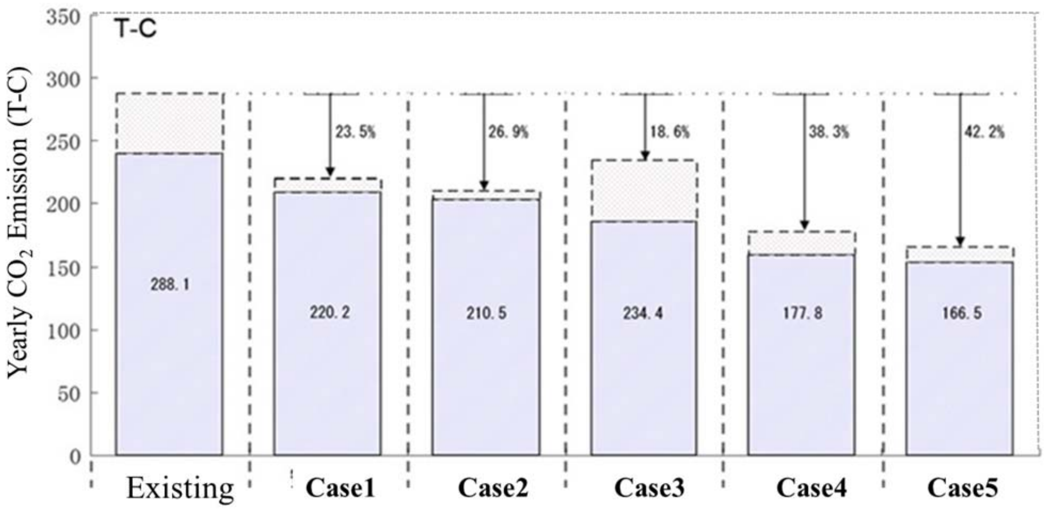
Figure6-11 Case setting

6-6RESULT AND DISCUSSION

Figure 6-12 is the energy saving ratio and low carbon ratio for case1, 2. The energy saving ratio for case1 is 12.8% while for case 2 is 15.1%, which means the intermittent pattern is better at energy saving. Case1 can cut off 13.0% CO2 emission and case2 can cut 15.3% by saving the primary energy. Furthermore, they can also cut off the CO2 emission by cutting off the factory reject heat, thus the total low carbon ration can reach to 23.5% and 26.7%.



Energy saving ratio



Low carbon ratio

Figure 6-12 energy saving ratio and low carbon ratio for case 1,2

The figure 6-13 and figure6-14 is the relationship between the heat demand, auxiliary boiler, CHP reject heat. The use of the factory rejected thermal energy can cut off the working hour of boiler and save energy. For case3, around the 8760 hours of one year, the boiler worked 6895 hours. However, with the exhausted thermal energy the gas boiler only worked 4405 hours in case4, 62.4% exhausted thermal energy from the factories are reused(figure 6-16). For case5 the boiler only worked for 3239 hours, 73.6% exhausted thermal energy from the factories is reused.

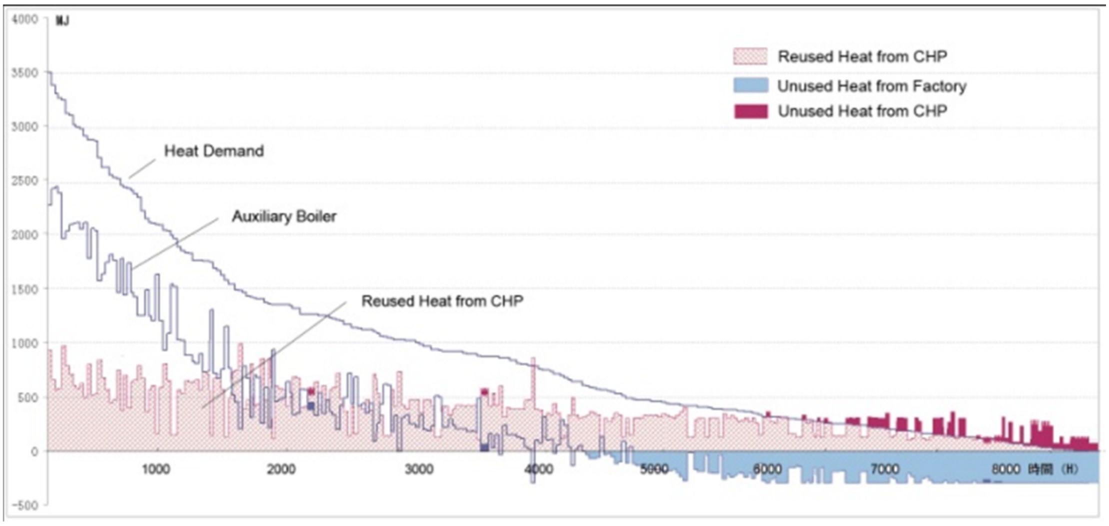


Figure 6-13 Heat demand, auxiliary boiler and CHP reject heat for case4

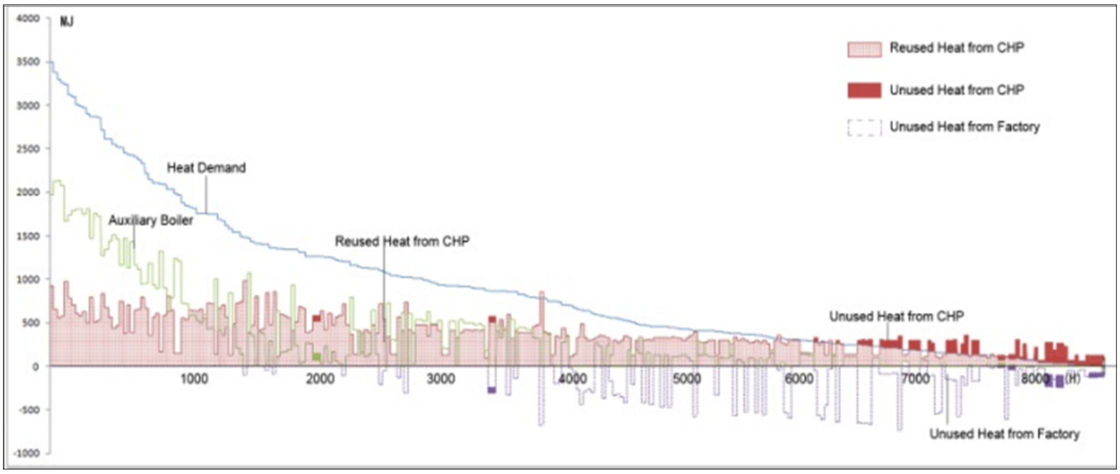


Figure 6-14 Heat demand, auxiliary boiler and CHP reject heat for case5

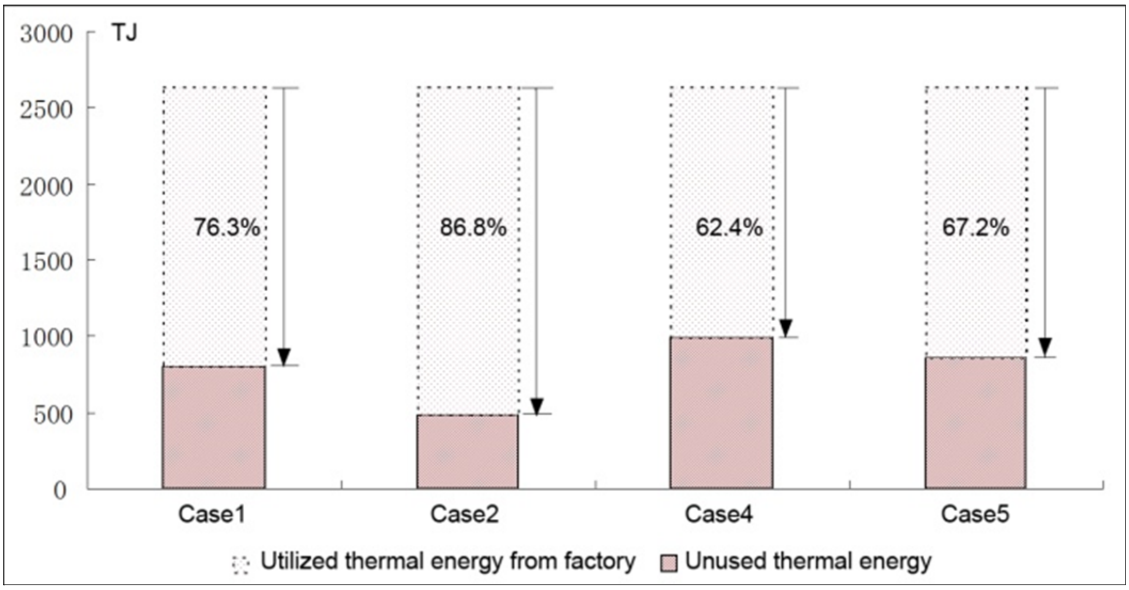


Figure 6-16 Utilization ratio of exhausted thermal energy for every case

6-7 SUMMARIES

The offline heat transportation system can collect the exhausted thermal energy from the factories in a district view, therefore made a contribution to the energy saving and low carbon society.

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CHAPTER SEVEN: A MODEL FOR AREA ENERGY NETWORK BY OFFLINE HEAT TRANSPORT SYSTEM AND DISTRIBUTED ENERGY SYSTEMS

7-1 INTRODUCTION

Kyoto Protocol was widely known as an international act to restrict the greenhouse gas (GHG) emission and 2012 is the fiscal year of the first period. Under its restriction, Japan was supposed to reduce six percent of the GHG emission, compared with 1990[1]. However, the statistic suggested that, even Japan has greatly improved its energy using efficiency and got a remarkable reward in the year 2009. Its yearly GHG emission still increased 4.2% until the year 2010[2]. Even worse, after Fukushima crisis, Japan cut down the nuclear energy. The Ministry of Environment estimated that with the loss of nuclear energy, Japan would produce about 15 percent more greenhouse gas emissions than 1990 [3]. That means Japan has to rely on other more efficient electricity productions, preferential based on the renewable and untapped resource.

Beside the low carbon effect of renewable resource, its domestic using characteristic, such as onsite using of solar and wind resource can greatly reduced the energy loss in transportation and hence reduce the energy price [4-6]. Compared with the traditional centralized energy supply system, the distributed energy generations are easy for renewable energy using and can avoid the loss in energy delivery as well. However, as the integration of distributed energy generation become major concerns, one problem occurred that the conventional energy supply model, the unidirectional top-down grid could hardly be multipurpose to it [7]. It can only support the energy flow from the energy station to static users. A much smarter energy supply system will be desirable to support multi-direction energy flows that can dynamically switch between the user and local energy providers [8]. It need for more observable, accessible, and controllable network infrastructures. The future energy system, termed as smart grid, is the system emerging as these requires. It can intelligently and automatically control and optimize operations. Further, the smart system will have to manage the rapid dynamic reconfiguration of system parameters to handle such distributed and volatile energy as well as load dispatches [9-11].

The Japanese motivation toward “smart grid” can be suggested in its new energy strategies (decided on Dec.30th, 2009). Four areas are conducted to be the demonstration trial sites, known as “smart community”. In its concept, smart community is the basic unit in the smart evolution for the country [12]. More than merely concentrate on the electricity supply chain (the mean concern of smart grid [13]), Japan paid more attention on the collaborative regional energy using. The three main aspects of the smart community were distributed energy generation (DEG), distributed energy storage (DES), and demand side response (DSR) [11,14].

The DEG referred to the energy generation in the smart community, which is distributed into the power grid, including PV systems, micro-turbines and combined heat and power (CHP) plants. The prevailing of the distributed renewable resource was the focus for the Europe smart grid development. By review of “New Energy Strategy for Europe 2011–2020”, Karoly Nagy et al. explored the impact of the implementation of renewable energy sources. The research also discussed how a global network could promote the development and implementation of an energy policy ensuring the appropriate utilization of renewable energy sources [15].In some sense, the DEG can be the fundamental element that the energy generation and consumption can be carried out in an islanded manner. In another words, it is expected that the smart community only import a small amount of electricity from the outside, or even export their energy surplus to the neighborhood. Mathiesen et al. presented the analysis and results of a 100% renewable energy system by the year 2050 including transport. It revealed that 100% renewable energy systems would be technically possible in the future, and may even be economically beneficial compared to the business-as-usual energy system [16].

The DES under the DSR control is a key underpinning of smart grid [11]. The intelligently controlled DES can serve to shift the electricity demand away from the peak periods, making the energy supply system more efficiently. Elma et al. developed model for stand-alone house that only supported by the renewable resource such as PV and wind system [17]. It proved that when load and source dynamics are considered, approximately 10% less backup size is required compared to backup size found with hourly averaged values. Matallanas et al. developed a control system for demand-side management in the residential sector with distributed generation. The system consisted of the electricity supply system and the control system. The electricity supply system incorporated local PV energy generation, electricity storage system, connection to the grid and a home automation system. The control system composed of a scheduler and a coordinator. Its result suggested that how demand-side management enhances the local energy performance [18].

The energy system model for the smart community (grid) should convey the concept of DEG, DES and DSR. R.S. Adhikari et al. employed a multi-commodity network flow models for dynamic energy management for smart community, aiming to a compromise between practicality, accuracy, flexibility, solvability and scalability with smart grid applications [19]. M. Welsch et al. demonstrated the flexibility and ease-of-use of open source energy modeling System with regard to modifications of its code. It may therefore serve as a useful test-bed for new functionality in tools with widespread use and larger applications, such as MESSAGE, TIMES, MARKAL, or LEAP. [20]. B.B. Alagoz et al. draw a framework for the future digital power grid concept and assess its viability in relation to volatile, diverse generation and consumption possibilities [11].

It can be found that the models mentioned above are mostly focused on electricity supply chain, among which the heat supply system hardly be mentioned. The DEG, DES and the DSR are almost around electricity. However, for Japanese smart community, rather than the merely smart grid in Europe and the USA, the energy system not only has a distributed electricity supply chain but also a distributed heat supply chain as well. The heat supply should also convey the concept of DEG, DES and DSR. It can make use of onsite exhaust heat, such as recovery heat of CHP plant and nearby factory exhaust heat (FEH) [21]. It should be a dynamic controllable as well, which can smooth out the heat fluctuation.

In this paper, the research introduced a smarter heat supply infrastructure into the smart community, paralleled with the electricity supply system. The proposed district energy system network response to the smart community concept including the use of diverse renewable and untapped energy resource, demand-responsive intelligent management, and efficient energy delivery. It not constructed an intelligent distributed electricity supply chain system with PV and CHP plants, but also promoted DEG, DES and DSR concept on heat supply chain system.

An intelligent heat supply chain system should have efficient heat storage, delivering system for the heat sharing between buildings. Not like the electricity, the heat delivering always faced to two mean problems. With the traditional pipe system, it will be limited by the delivering distance because of the high infrastructure fee and heat lost during the way. Further, the traditional pipe system can hardly use the temperature lower than 90□. To come over these two problems, in this research, the model introduced the offline heat supply system (PCM) to realize the DEG, DES and DSR concept of heat.

Offline heat transport (PCM) system is a truck with a container that full of phase change material (PCM). It was firstly developed by the German National Aerospace Laboratory in 1980, and put into practical use in the year 2001 by a chemical company in Frankfurt [22]. There were many researches that use the PCM material as a heat storage component in the buildings or other area [23-25]. Japan introduced this technology in 2003, and creatively used it as heat supply system [22]. In Aomori, the PCM heat transport system was firstly put into trial in the year 2008. It collected the exhaust heat from a sewage factory, transported and supplied to a fishing center. Now it becomes a business for the SANKI Company, termed as "Heat home delivery". Okumiya proposed the PCM system for exhaust thermal energy utilization [26]. As the smart system expect, this system can intelligently response to the demand side, switching between the energy provider and energy storage. It can collect the heat from the buildings where have surplus heat, store and then transport to the buildings where have heat demand.

This chapter presented a model of a controllable, demand-responsive and balanced distributed energy systems network under the concept of smart community in Japan. Various technologies such as PV, CHP plant and PCM system were considered in the model. As a case study, the model was conducted into one demonstration smart community in Kitakyushu, Japan. Through the execution of the model, the research evaluated the environmental effect of every technology and estimated the potential of the smart community that whether the place can finally cut off 50% CO_2 emission as it set.

7-2 CONCEPT, DEFINITION AND MODELING

7-2 -1THE DEMAND-RESPONSE NETWORK MODEL

The demand-response network (DRN) model for smart community is a tree-like hierarchical model that comprises the community energy management system (CEMS), energy station (ES) and building energy management system (BEMS).

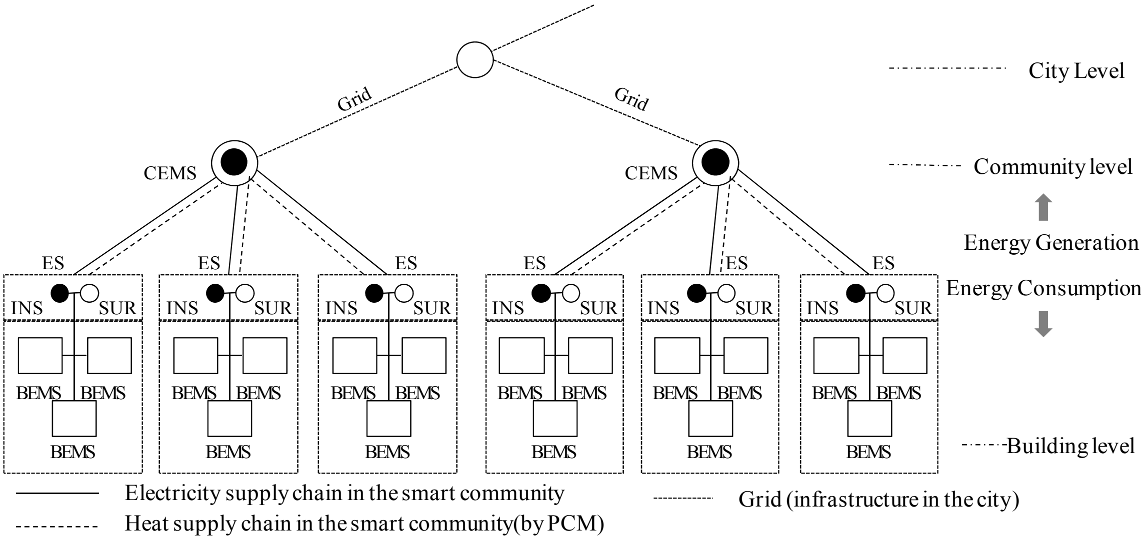
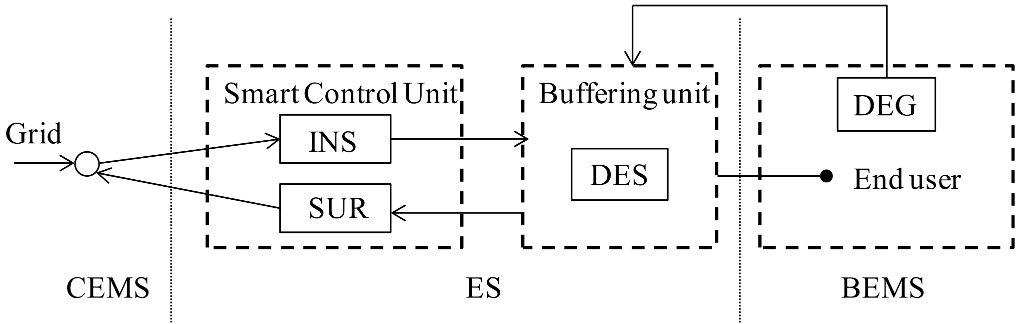
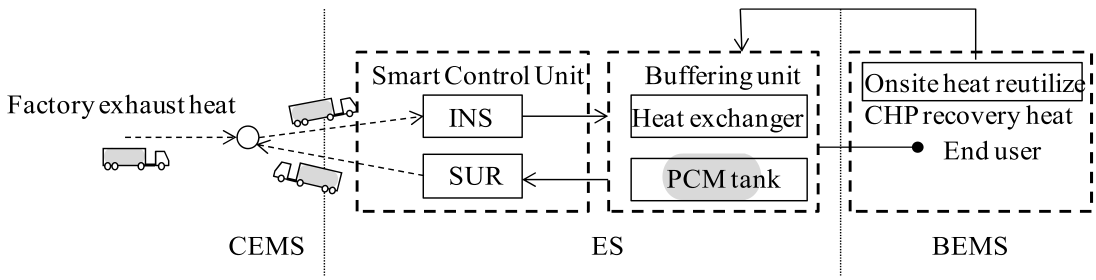


Figure 7-1 The tree-like hierarchy of DRS

Figure 7-1 demonstrated the hierarchical model. The end users (managed by BEMS) reside at the bottom of the hierarchy. They will be prioritized and organized into groups. Every group is managed by one ES. The ES is at the lowest rank unit for the energy strategies decision that controls the introduction of DEG, DES and DSR. The ES collect information of the energy generation and consumption in the group and send signals to the CEMS. The CEMS connected with each other and formed city energy net work, which organized in a topological structure. ES is assumed to have two modes, the energy surplus mode (SUR) and the energy insufficient mode (INS). The ES can dynamically switching its mode depending on the energy generation and consumption in the group. There mode signal will send to CEMS who collected and distribute the energy.



(a) Electricity supply chain



(b) Heat supply chain

Figure 7-2 DRN system energy supply chain

The proposed DRN system in this research is different from the smart grid that it not only has electricity supply chain but also has heat supply chain as well. Figure 7-2(a) illustrated the electricity supply chain. The DES in DRN system only acts as a back up and the buffer unit. The energy produced by DEG is supplied to the end users from the buffer unit. When the energy generated by DEG is more than the energy consumption in the group, the ES will in SUR mode and become an energy supplier to other ES. Oppositely, the ES will in INS mode when the energy generated by DEG is less than the energy consumption, and become an energy consumer. Figure 7-2 (b) illustrated the heat supply chain. Similar with the electricity supply chain, it has a buffering unit that comprises the PCM tank and the heat exchanger. Under the INS mode, the CEMS will transport heat to the ES by trucks that with PCM tank. Under the SUR mode, the tank in the buffer unit will collect the surplus heat and be transported to other ES when it received the order from the CEMS. The mode signals in the heat supply and that in the electricity supply are self-governed.

7-2 -2DISTRICT ENERGY USING CONCEPT AND OPERATION HYPOTHESIS

As the DRN system illustrated before, the building in the community will be divided into Groups. Every group is managed by ES, the basic unit to make energy strategies. Figure 7-3 described the district energy using concept.

1)Introduction of the renewable energy: all the buildings will be introduced with PV system. The electricity generated by PV system will be preferentially used by the building themselves and the left electricity will be sent back to the grid.

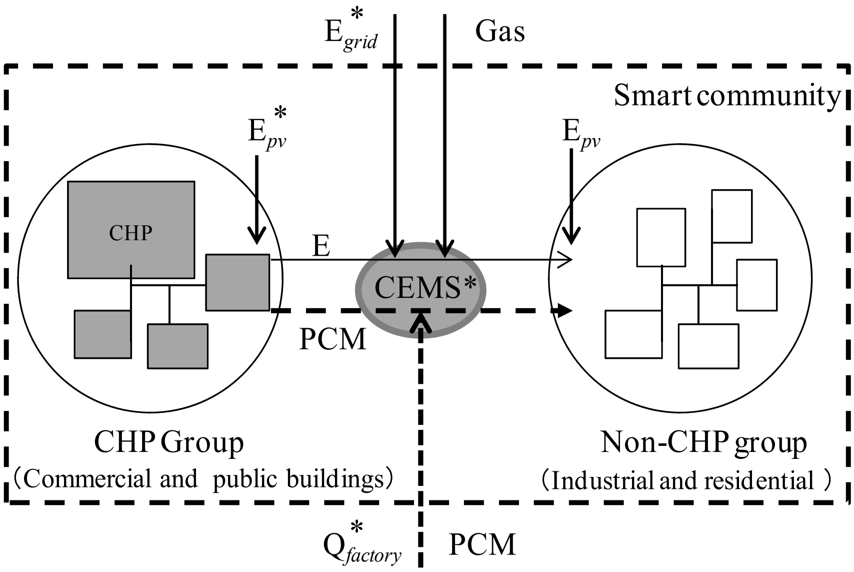
2) Introduction of the CHP system : The CEMS will characterize buildings by their demand types. The buildings have both high electricity consumption and heat consumption (such like commercial buildings and public buildings) will be introduced with the CHP system, named as CHP group. The capacity of the CHP system is set as electricity peak load of the group. The buildings without CHP system is considered as Non-CHP (NCHP) group. The electricity produced by CHP plant will satisfy themselves first and then send the left electricity to NCHP system. The CHP group will generate all their own demand beside PV. Therefore, as the DRN described before, the electricity of these groups are only in SUR mode. The NCHP group will be in INS mode if PV cannot afford their electricity consumption.

The CEMS will manage the model signal, control and dispatch the electricity. It will preferentially use the DEG, thus maximum the output of CHP plant. The electricity produced by PV can sell back to grid but the electricity produced by CHP plant cannot. In that case, when the electricity generated by CHP more than the district electricity demand, the CEMS will restrict the CHP output. It will preferentially chose the CHP plant with higher efficiency and lower down the CHP plant with low efficiency. If the efficiencies of the CHP plants are the same, CEMS will cut down the CHP plants in same rate.

3) Reutilization of the onsite exhaust heat and the FEH: the recovery heat of the CHP system will be preferentially used by the group first. However, if the recovery heat is more than the heat demand, the heat supply mode of the ES will turn to SUR. This part of heat surplus will be collected by CEMS.

Further, the CEMS will select out the FEH resource based on the characteristic of the PCM system, which collects the FEH and utilizes it in the community.

The onsite CHP exhaust heat and the FEH stored in the PCM system will be preferentially used. The CEMS will distribute the heat according to the SUR signal from the ES. It will be sent to the ES which have the higher heat insufficient amount.



E_{grid}: Electricity from Grid $Q_{factory}$: Exhausted heat from factory
E_{pv}: Electricity by PV
CEMS : Community Energy Management System

Figure7-3 District energy using concept

7-3 ENERGY BALANCE MANAGEMENT AND SIMULATION MODELING

The energy balance management and the simulation flow are conducted as Figure 7-4. The simulation of the DRN system is also a bottom-up model. Firstly, based on the district zoning, the research will estimate the building energy consumption and described profiles by groups. As the tree-like hierarchy described in the second part, buildings in one group will be managed by one ES. Secondly, the CEMS will characterize the groups by its energy consumption character and introduce proper DEG in every ES, some are with CHP system but some are not. The simulation separated them into CHP group and the NCHP group. Thirdly, the research executed the simulation. During the simulation, ES will dynamically switch between the INS mode and the SUR mode by estimating the energy consumption and the generation. Finally, the research will calculate the primary energy consumption and evaluate the environmental effect of the every technology as well as the whole community.

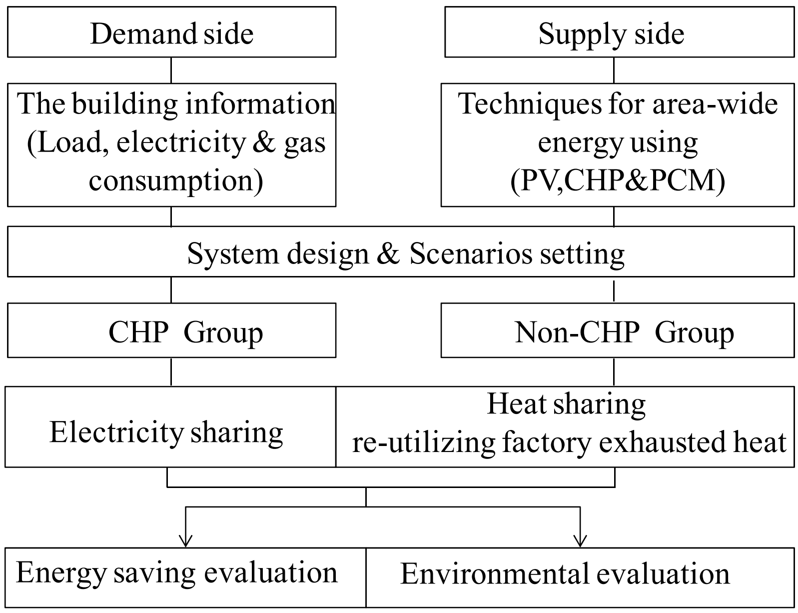


Figure 7-4 The simulation flow

7-3-1 ESTIMATION OF DISTRICT ENERGY CONSUMPTION

The energy consumption of the whole community ($E_{demand}^{community}$) is calculated as (7-1)

$$E_{demand}^{community} = E^1 + E^2 ...... + E^n = \sum_n \sum_m \sum_d \sum_i (ELEC_{mdh}^n + HEAT_{mdh}^n) \qquad ......(7\text{-}1)$$

$ELEC_{mdh}^n$ is hourly electricity load, calculated as (7-2)

$$ELEC_{mdh}^n = \sum_k e_{mdh}^n \times s_k \qquad ... ... (7\text{-}2)$$

$HEAT_{mdh}^n$ is hourly heat load, calculated as (3)

$$HEAT_{mdh}^n = \sum_k h_{mdh}^n \times s_k \qquad ... ... (3)$$

n is the group number;
m is month; *d* is date、*h* is hour;
$E^1 ... E^n$ is the energy consumption of every group;
e_{mdh}^n and h_{mdh}^h is the energy consumption unit in Kyushu area, Japan[27];
k is the building function;
s_k is the building area for one function(k)

7-3-2 THE ELECTRICITY BALANCED MANAGEMENT

Figure 7-5 illustrated the simulation model for the electricity balance.

The buildings will preferentially use the electricity produced by PV.

The electricity produced by PV system in one group (PV^n_{mdh}) is calculated as (7-4):

$$PV^n_{mdh} = S_n \times \alpha_{mdh} \times \eta \qquad \ldots\ldots (7\text{-}4)$$

s_n is the area for PV penal in a group (n);

α_{mdh} is the hourly sun radiation rate [28] ;

η is the efficiency of the PV penal [29]。

The CHP capacity (C^n_{CHP}) is decided as (7-5):

$$C^n_{CHP} = \begin{cases} MAX(ELEC^n_{mdh} - PV^n_{mdh}) & (CHPgroup) \\ 0 & (NCHPgroup) \end{cases} \qquad \ldots\ldots (7\text{-}5)$$

The ES will decide the mode by the prediction of electricity load profile of the CHP system, PV system and electricity demand.

When $C^n_{CHP} + PV^n_{mdh} - E^n_{mdh} \geq 0$, the group is in SUR mode. The expected surplus electricity ($ElecPLUS^n_{mdh}$) is calculated as (7-6)

$$ElecPLUS^n_{mdh} = C^n_{mdh} + PV^n_{mdh} - E^n_{mdh} \qquad \ldots\ldots (7\text{-}6)$$

On the contrary, when the group is in INS model, the expected electricity insufficiency ($ElecINS^n_{mdh}$) is calculated as (7-7)

$$ElecINS^n_{mdh} = E^n_{mdh} - PV^n_{mdh} - C^n_{mdh} \qquad \ldots\ldots (7\text{-}7)$$

If $\sum_n ElecPLUS^n_{mdh} \leq \sum_n ElecINS^n_{mdh}$, CEMS would lower down the total CHP output (prior use the equipment with higher efficiency). Under this situation, there was no electricity supplement from the grid. The electricity generated by CHP plant ($CHPElec^n_{mdh}$) is calculated as (7-8):

$$\sum CHPElec^n_{mdh} = \sum ELEC^n_{mdh} - \sum PV^n_{mdh} \qquad \ldots\ldots (7\text{-}8)$$

If $\sum_n ElecPLUS^n_{mdh} > \sum_n ElecINS^n_{mdh}$, the surplus electricity from CHP group will be offered to the NCHP group. Under this situation, the electricity from the grid ($GRIDElec^n_{mdh}$) is calculated as (7-9):

$$\sum GRIDElec^n_{mdh} = \sum ElecPLUS^n_{mdh} - \sum ElecINS^n_{mdh} \qquad \ldots\ldots (7\text{-}9)$$

Electricity offered by CHP is calculated as (7-10):

$$\sum CHPElec_{mdh}^{n} = \sum C_{CHP}^{n} \qquad \ldots \ldots (7\text{-}10)$$

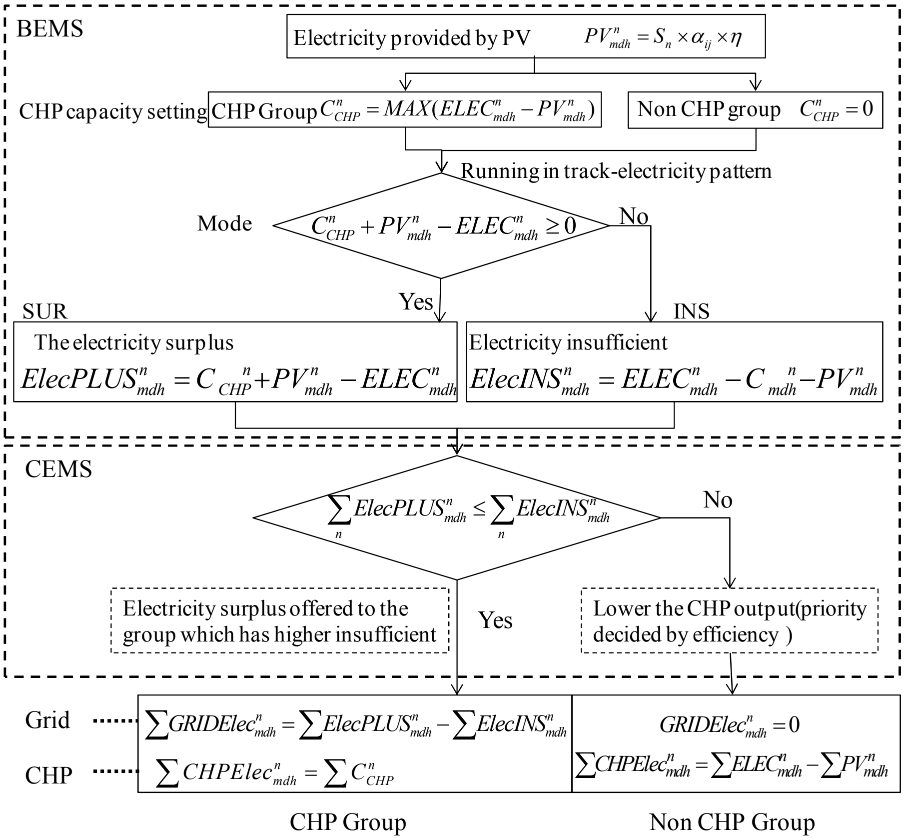


Figure7-5 the electricity balanced model

7-3-3THE DESIGN AND MODELING FOR THE PCM SYSTEM

◈PCM for collecting the FEH

According to the system parameter, economically the system can utilize heat with in 135km and 20km round trip [26]. The CEMS will economically select out the possible utilized rescource, and make a plan for the PCM system. The collecting schedule of the PCM trucks should match with the factory working hour. It will become more complecate as the factory heat resource increase. Considering the various factors for making the plan, the research assumed that the FEH that collected would be transport to the demand side and use in the following day.

The number of the tanks for collecting FEH used in one day (x) is desided by the capacity (listed in table7-1 [31]). It should satisty (7-11):

$$Q_{pcm} \cdot x \geq \sum Q_{fac} \qquad x \in (1, p) \qquad \text{………(7-11)}$$

Q_{pcm} is the capacity for the PCM tank;

Q_{fac} is the daily factory exhaust of the selected resources;

The exhaust heat that can be used in the demand side is limited by the energy lost during the heat storage, transport and heat exchange. CEMS will estimate it can select out the proper resource. The amount of the heat ($HEAT_{recFAC}$) that can use in the demand side is as (7-12)

$$HEAT_{recFAC} = \mu \cdot Q_{fac} \qquad \text{…..(7-12)}$$

μ is the overall efficiency of the PCM system, set as 0.91 in this research[32]

Table7-1 The type and parameters of the PCM tank

Type	Melting Point/℃	Heat temperature/℃	Tank capacity /MWh	Usage		
				Hot Water	Heating	Cooling
Type1	58	85(70)	0.8～1.1	○	○	—
Type2	78	100(90)	—※	○	○	—
Type3	116	150(130)	—※	○	○	○
Type4	118	150(130)	1.1～1.4	○	○	○

※Type2 and Type3 are used outside Japanese　○ The function it has　— The function it doesn't has

◈PCM for the heat delivery between the groups

ES will use the estimated consumption pattern for the consistent prediction and send the mode signal to CEMS.

For every group, CHP recovery heat ($CHPREC^{n}_{mdh}$) is as (7-13):

$$CHPREC^{n}_{mdh} = \begin{cases} \frac{\eta_h}{\eta_e} ElecCHP^{n}_{mdh} & (CHPgroup) \\ 0 & (NCHPgroup) \end{cases} \qquad \text{… … (7-13)}$$

η_e is the electricity generating efficiency of CHP plant;

η_h is the heat recovery efficiency of CHP plant;

If $CHPREC_{mdh}^{n} - HEAT_{mdh}^{n} \geq 0$, the ES is in SUR mode and the expected value of heat surplus ($Heat_0SUR_{mdh}^{n}$) is as (7-14):

$$Heat_0SUR_{mdh}^{n} = CHPREC_{mdh}^{n} - HEAT_{mdh}^{n} \qquad \ldots\ldots (7\text{-}14)$$

If $CHPREC_{mdh}^{n} - HEAT_{mdh}^{n} < 0$, the ES is in INS mode and the expected value heat insufficient ($Heat_0INS_{mdh}^{n}$) is as (7-15):

$$Heat_0INS_{mdh}^{n} = HEAT_{mdh}^{n} - CHPREC_{mdh}^{n} \qquad \ldots\ldots (7\text{-}15)$$

Every day, the PCM system will carry the FEH and input into the community from the first peak time in the morning, set as h_0. During the day, the system will preferentially use the heat stored in the PCM and release it before the next day. Therefore, every day at the time h_0, the heat amount stored in the PCM system is reset.

The amount of stored heat energy in the PCM that can be supplied to the ES in SUR mode at h time in one group ($PCMREC_{mdh}^{n}$) is as (7-16)

$$\sum^{n} PCMREC_{mdh}^{n} = \begin{cases} \sum^{n} PCMREC_{md(h-1)}^{n} + \sum^{n} Heat_0SUR_{mdh}^{n} - \sum^{n} Heat_0INS_{mdh}^{n} & (h \neq h_0) \\ HEAT_{recFAC} & (h = h_0) \end{cases} \qquad \ldots(7\text{-}16)$$

The total amount of PCM truck (p) should satisfy condition (7-17)

$$MAX(\sum^{n} PCMREC_{mdh}^{n}) \leq Q_{pcm} \cdot p \qquad (7\text{-}17)$$

$MAX(\cdot)$ is an function to determine the maximum value of the stored heat in PCM system by the expected value.

7-3-4THE HEAT BALANCED MANAGEMENT

Figure7-6 illustrated the heat balanced management. The collected heat in the PCM system including the recovery heat of CHP system and FEH are used for heating, cooling and hot water in the community. It is also managed by CEMS following total quantity priority that supplied to the group, which had lager amount of heat insufficient, MAX($Heat_0 INS^n_{mdh}$).

With the use of the waste heat that collected by the PCM system, The heat insufficient ($Heat_R INS^n_{mdh}$) is as (7-18):

$$\sum_n Heat_R INS^n_{mdh} = \sum^n (HEAT^n_{mdh} - CHPREC^n_{mdh} - PCMREC^n_{md(h-1)}) \quad \dots \dots (7\text{-}18)$$

When $Heat_R INS^n_{mdh} \le 0$, the heat demand can be satisfied with the onsite exhaust heat reutilization that the heat-source equipment ($AUSHEAT^n_{mdh}$) is not required as (7-19)

$$AUSHEAT^n_{mdh} = 0 \quad \dots \dots (7\text{-}19)$$

When $Heat_R INS^n_{mdh} > 0$, the heat-source equipment is used as supplement. The heat offered by the heat-source equipment is as (7-20):

$$AUSHEAT^n_{mdh} = Heat_R INS^n_{mdh} / \eta^n \quad \dots \dots (7\text{-}20)$$

η^n is the efficiency of heat source equipment.

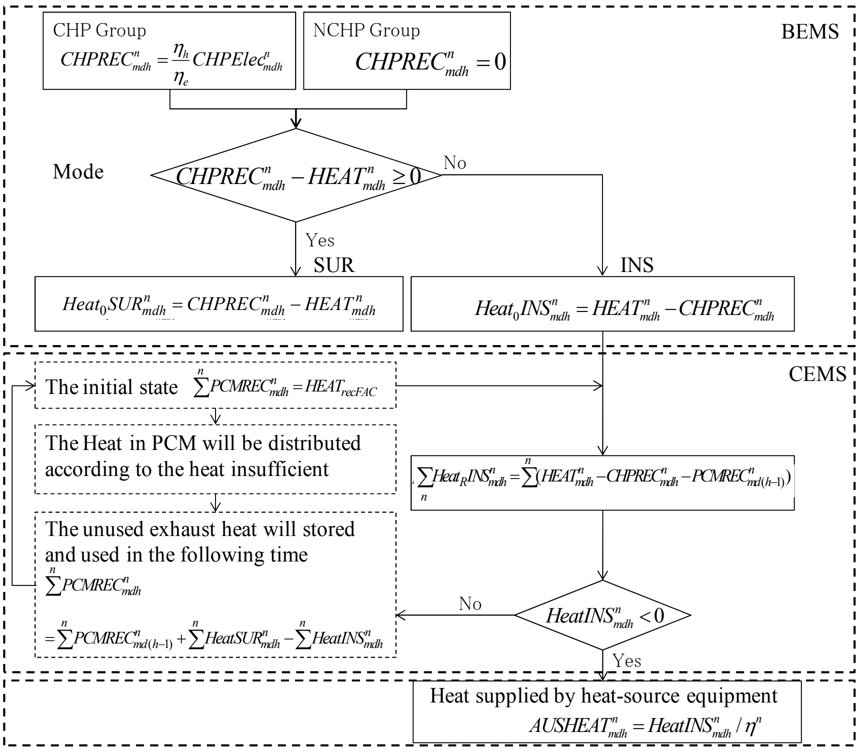


Figure 7-6 heat supply calculation flow

7-3-5ASSESSMENT INDEX SETTING

1) Energy saving ratio

ESR is energy saving ratio, defined as (7-21):

$$\text{ESR} = \frac{Q_{input}^{Conv} - Q_{input}^{CHP}}{Q_{input}^{Conv}} \qquad \text{…….(7-21)}$$

For CHP system, the primary energy input is as (7-22):

$$Q_{input}^{CHP} = E_{Utility}^{CHP} \times \varepsilon_{Grid} + (V^{CHP} + V^{Boiler}) \times \varepsilon_{gas} \qquad \text{…….(7-22)}$$

$E_{Utility}^{CHP}$ is the electricity input in CHP system; V^{CHP}, V^{Boiler} is the gas input to the CHP plant and boiler.

For conventional system, the primary energy input is as (7-23):

$$Q_{input}^{Conv} = E_{Utility}^{Conv} \times \varepsilon_{Grid} + V^{Conv} \times \varepsilon_{gas} \qquad \text{…….(7-23)}$$

$E_{Utility}^{Conv}$ is the electricity input in conventional system;

V^{Conv} is the gas input to conventional system for hot water;

ε_{Grid} is primary energy consumption unit of grid in Japan (11.4MJ/kWh);

ε_{gas} is primary energy consumption unit of city gas in Japan(45MJ);

2) CO2 reduction ratio

$\eta_{\Delta CO_2}$ is CO2 reduction ratio, defined as (7-24):

$$\eta_{\Delta CO_2} = \frac{EX_{CO_2}^{Conv} - EX_{CO_2}^{CHP}}{EX_{CO_2}^{Conv}} \qquad \text{…….(7-24)}$$

$EX_{CO_2}^{CHP}$ is CO2 emission for CHP system, calculated as (7-25);

$$EX_{CO_2}^{CHP} = ex_{CO_2}^{gas} \times (V^{CHP} + V^{Boiler}) \times \varepsilon_{gas} + ex_{CO_2}^{Pow} \times E_{Utility}^{CHP} \times \varepsilon_{Grid} \qquad \text{…….(7-25)}$$

$EX_{CO_2}^{Conv}$ is CO2 emission for conventional system, calculated as (7-26).

$$EX_{CO_2}^{conv} = ex_{CO_2}^{gas} \times V^{conv} \times \varepsilon_{gas} + ex_{CO_2}^{Pow} \times E_{Utility}^{Conv} \times \varepsilon_{Grid} \qquad \text{…….(7-26)}$$

$ex_{CO_2}^{gas}$ is the CO2 emission unit for gas in Japan (13.8 g-C/MJ);

$ex_{CO_2}^{Grid}$ is the CO2 emission unit for grid in Japan (153 g-C/kwh).

7-4 NUMERICAL STUDY

A numerical study of this model is presented in a smart community in Kitakyushu, Japan. In order to provide a smart community model with low carbon concept, the latest DEG technologies, such as gas engine, fuel cell, hydrogen fuel cell, PV, PCM system and untapped FEH etc. are considered in the model. By analysis on varies cases, the study will suggest the environmental effect of every technology as well as the overall potential of the smart community in Japan.

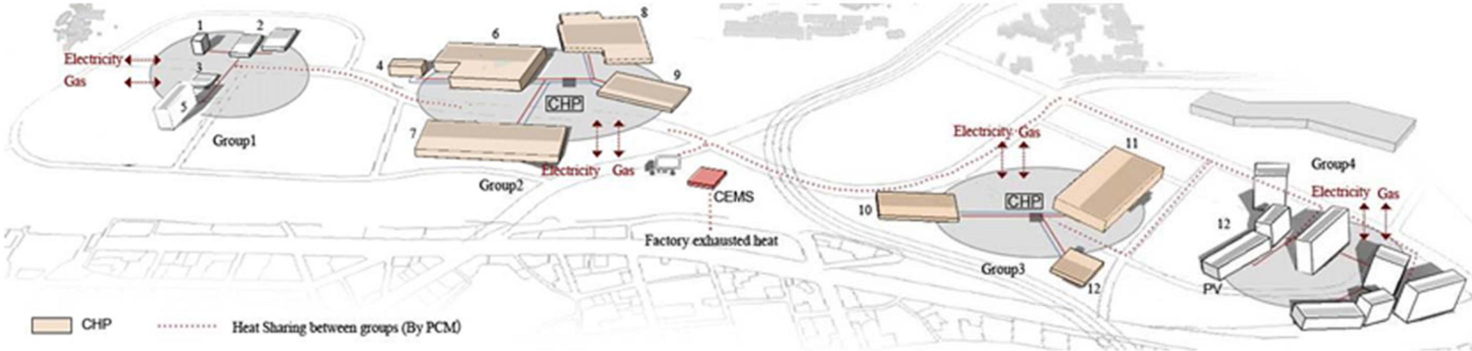
7-4-1 ENERGY LOAD

Kitakyushu lied in the northern part of Kyushu, the westernmost of the four main islands in the Japanese archipelago. It used to be one of Japan's four leading industrial regions and contributed greatly to the rapid economic growth of Japan[33].

The smart community creation project is newly launched in Yahata Higashisa district, where used to be the factory district of the steel company. The government invested 16.3 billion yen over the five-year period from 2010 to 2014. It has already cut 30% of the CO2 emission compared with the other place in the city. However, the target for the smart community was to cut 50% of the existing emission, still 20% need to get.

The urban structure has been changed in the past few years under the concept of “Environmentally Growing Town” and “Creation of a Shared Community.” Commerce, entertainment, museum and residential buildings were introduced into this area, which made a “compact district” with mixed function.

Detailed knowledge about energy end-use loads is important for the energy system design and optimization. In this study, the hourly load demand for electricity, cooling, heating and hot water have been calculated according to the energy consumption unit (the system in Japan that displays energy consumption intensities) of various buildings in Kyushu, Japan [27]. As the method descried in part 2, the whole community is divided into 4 groups. Figure 7-7 displayed the image of community and district zoning. The building information, yearly energy consumption and the peak load of the district are shown in table 7-2.



Group		Group1	Group2	Group3	Group4	Community
Function		Office&hotel	Commerce	Education	Residence	
Building area (m²)		30555	17545	28692.3	72212	149004.3
Roof area (m²)		24358	5420	13342.9	7146	50266.9
Yearly energy consumption	Electricity (GWh)	2.77	7.85	1.50	0.98	13.61
	Electricity* (GWh)	2.51	5.13	0.68	1.49	9.07
	Cooling (TJ)	6.89	24.38	5.05	2.89	39.21
	Heating (TJ)	2.79	3.54	5.75	4.14	16.21
	Hot water (TJ)	3.37	2.85	0.00	8.91	15.13
Peak (kW)	Electricity	598	2260.8	471	1652.4	3313
	Electricity*	532.8	2048.4	344	1634.4	3037
	Cooling	1484.00	5155.50	1920.20	1719.55	9085.60
	Heating	458.76	1808.89	2750.25	566.86	5134.89
	Hot water	275.42	535.85	0.00	1360.87	1622.77

Electricity*: The electricity demand excluded PV

Figure 7-8 Hourly load profiles for every group

Figure 7-8 described the detailed hourly load profiles for every group in summer (Aug.), winter (Jan.), spring and autumn time (May). The energy consumption profile firmly related with the building function.

I) The group4 is the residential area, thus the peak of the energy consumption comes during the night. The group1 also has considerably higher energy consumption compared with group2 and group3, because there is a hotel in the group.

II) The commercial group (group2) has a higher energy consumption during the day, but almost no energy consumption during the night.

III) The hot water load is higher in residential group (group4), but lower in group2 and group3.

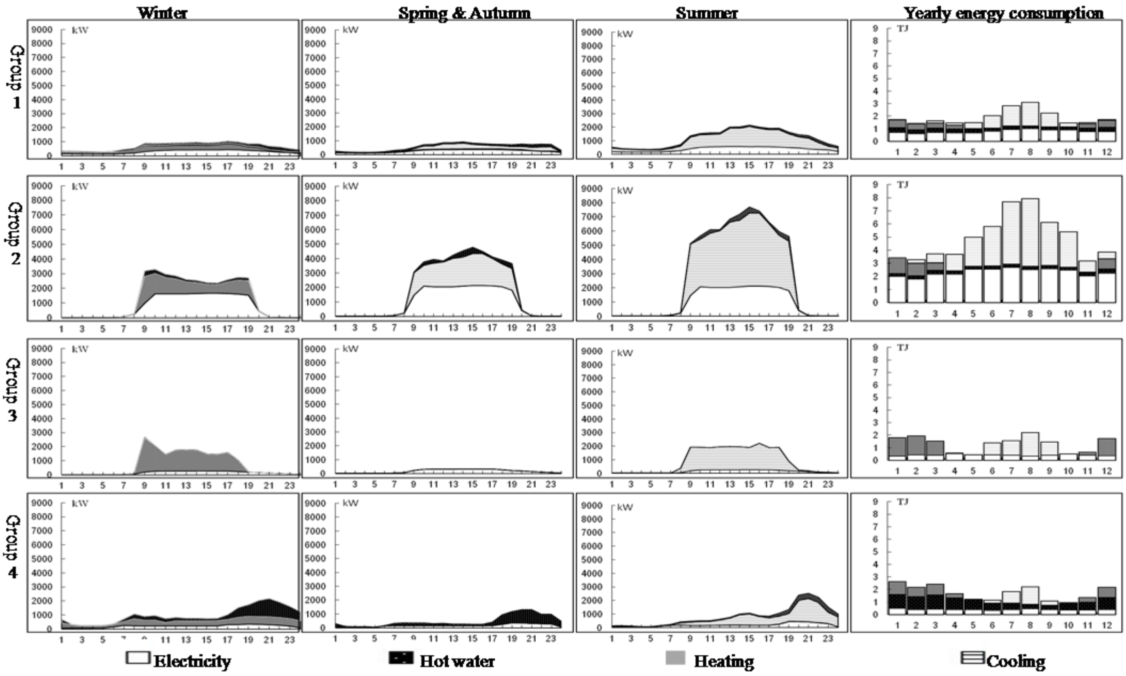


Figure 7-8 The district energy consumption

7-4-2 FEH LOAD

It is reported that the factory exhaust heat in Japan can satisfy the heat consumption of all the residential buildings for five years [34]. In that case, there is a great potential to make use of the factory exhaust heat. It can cut the energy consumption on the civil side as well as the CO2 emission on the factory side.

Another important input to the energy system is the reutilization of the FEH. It collected by PCM system and used in the community for heating, cooling and hot water. The study adopted the database of the FEH based on GIS built in the research before and selected out the four potential factory resources (within 20km) [30]. Usually, the temperature for FEH is higher than 300℃ and daily exhaust heat is around 38.9 GJ. The tank type with the capacity of 1.4 MWh will be introduced into the system. As this research only discussed the enviromental effect of the PCM system, thus it is supposed that there are enough tanks for collecting all the exhaust heat (the heat of the factory and the unused CHP recovery heat).

7-4-3DEG TECHNOLOGIES AND DISTRICT ENERGY SYSTEM

This district is the demonstration area that the latest technologies are expected to introduce into the area. The smart community is also undertaken the Kitakyushu Hydrogen Town project. The project marks as the world-first attempt to use a pipeline recycling the hydrogen generated in the iron manufacturing and operating the fuel cells as an energy supply to the district. The demonstration testing is processed jointly by Fukuoka Prefectural and city gas utilities [33]. The pipeline connected with the hydrogen station and hydrogen fuel cells that installed in buildings in this district. These fuel cells generate electricity by combining hydrogen and oxygen. Table7-2 showed DEG technologies assumed in this study and their properties, including gas engine (GE), fuel cell (FC), Hydrogen fuel cell (HFC) and PV. All equipments are city gas fired.

Table7-3 Technical parameters of system

Facility		Parameter	COP
Grid		η	0.35
CHP Plant			
Gas Engine (GE)	Electricity Generation	η_e	0.3
	Heat Recovery	η_{rec}	0.45
Fuel Cell (FC)	Electricity Generation	η_e	0.4
	Heat Recovery	η_{rec}	0.3
Hydrogen Fuel Cell (HFC)	Electricity Generation	η_e	0.48
	Heat Recovery	η_{rec}	0.42
Absorption Chiller		COP_{ac}	1.1
Heat Exchanger(H-EX)		COP_{he}	1
Boiler		η_{b1}	0.8
Multiple Air-conditioning System	Cooling	COP_1	4
	Heating	COP_2	3.9
Room Air Conditioner	Cooling	COP_1	3.22
	Heating	COP_2	2.83
PCM system		η_{rec2}	0.9

7-4-4 SETTING OF CASES

In order to investigate the effect of technologies in the DRN, the following cases are assumed for analysis.

Base case: conventional system. Base case indicated conventional energy supply system. The electricity load is satisfied by grid. The buildings also used air conditioner for heating and cooling. The commercial buildings, office and public buildings use multiple air-conditioning systems and residential buildings use room air-conditioner. The hot water load is satisfied by gas boiler fired by city gas.

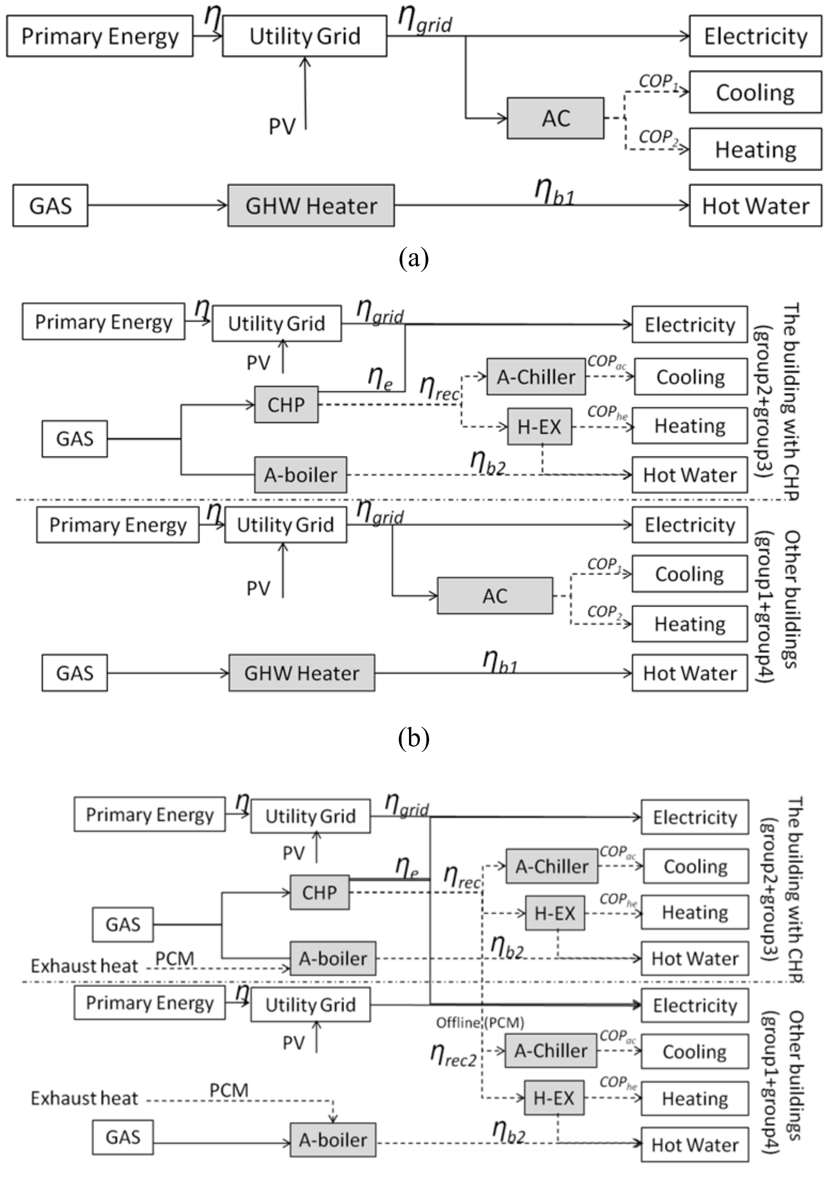
Case 1: The conventional system combined with PV systems. In this case, the community still keep the conventional system, but facilitated with PV. The system is as Figure 7-9(a). The electricity will be supplied by PV system, or by grid, or by combined of both. The electricity from the PV system will be used by the buildings themselves, and left electricity will be send back to the grid.

Case 2: Individually introduced DEG systems, displayed in Figure 7-9 (b). In case2, the CHP plants with GE are introduced in group2 and group3. The CHP plants and PV systems can satisfy the electricity load of these two groups. The thermal load can also be supplied by the recovery heat of the CHP plants and the deficiency supplemented by gas boiler. In this case, the electricity and recovery heat of the CHP plants cannot supply to other groups or return back to the grid. Therefore, the NCHP groups still get electricity from the PV and grid, keep as the conventional system.

Case 3: DRN system without using factory exhaust heat, described in Figure 7-9 (c). In the DRN system, the community uses the same DEG technologies with case2, but controlled and managed by CEMS. Under the CEMS, the electricity produced by the CHP plants not only be used for the CHP group but also supplied to the NCHP group as well. The recovery heat of the CHP group will be used in the CHP group first and then recycled by the PCM system. The CEMS distributed the heat that stored in the PCM system with thermal insufficient and surplus profile of every group.

Case 4: DRN system with the utilization of the FEH, as Figure 7-9 (c). Besides the technologies and DRN system that assumed in case3, case4 also make use of the FEH by PCM system. The PCM system collected the exhaust heat from the factory resource that set in part3 and transport it to the CEMS in the community. Besides the surplus CHP recovery heat, this part of heat will also be distributed by CEMS.

Case 5 and Case 6:the DRN system with the CHP plants of FC and HFC. Beyond the DRN systems that build in case4, case5 introduced the CHP plant of FC and case6 introduced HFC.



(c)

Figure 7-9 case setting

7-5 RESULTS AND DISCUSSIONS

7-5-1 THE EFFECT OF ELECTRICITY SHARING IN DRN SYSTEM

Figure 7-10 is the electricity balance in the community with the individually introduced DEG systems (case2) and the DRN system (case3). Both of the cases use CHP plant with GE and PV. The comparison between the two cases can show the effect of the electricity sharing between them. It can suggest that PV system can provide 35% of the community electricity consumption and the individual CHP plant can produce 41% electricity. By electricity sharing, the CHP group can offer 2GWh electricity to the Non CHP Group, which occupied 52% of their electricity consumption. As a whole, the community can produce 58% of the electricity by CHP, and only 7% from the grid, while the individual system need 24%.

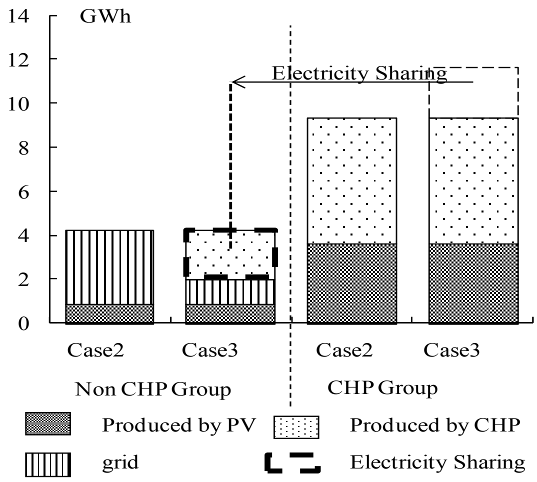


Figure 7-10 Yearly electricity balances of Case2 and Case3

As we know, the electricity produced by DEG has less energy loss during the electricity delivery. Therefore, the system can save more energy as it gets less electricity from the grid. In the DRN system, the CEMS can operate the CHP plants and distribute the electricity to the whole community. Therefore, it will increase the output and working hours of the CHP plant reduce the electricity from the grid.

The electricity sharing under the CEMS can balance the electricity consumption between the different groups, making the system more independent and reliable. Fig.11displayed the daily electricity balance in group1, taking summer as example. The buildings in group1 have small roof areas that the PV can only offer a small part of the electricity. Compared with group4 (the other NCHP group), group1 has higher electricity insufficient, thus preferentially get electricity from the CHP group. CHP can satisfy most of its electricity demand. Especially, during the night, the electricity load is low in commercial buildings that the electricity demand in group1 can be satisfied by CHP only.

The electricity sharing used in DRN system can shift the electricity demand from the peak. Just as Figure7-11 suggested, without CHP plant, the peak hour should come during the noontime, but now it shift to 8 o'clock in the morning and 18 o'clock in the afternoon. Further, from the city level, the less relay on the grid will alleviate electricity shortage especially during the peak hours. That means with the DRN, the city can smooth out the electricity flucuate.

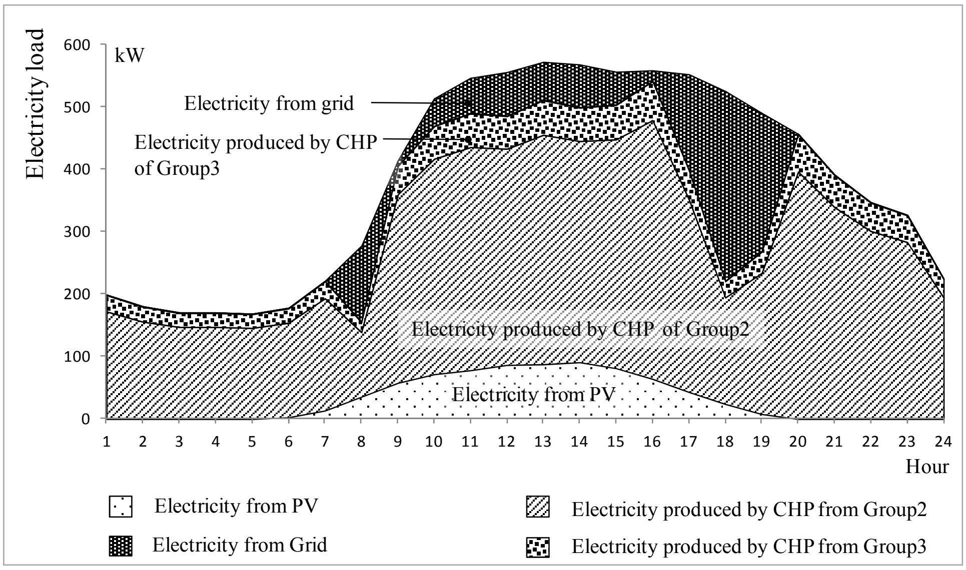


Figure11 Daily electricity balance of Group1 (summer)

7-5-2 THE EFFECT OF HEAT SHARING IN DRN SYSTEM

The DEG with CHP plants not only reduce the energy loss, but can make use of the recovery heat as well. In case2, the individually CHP system can only use the recovery heat by the CHP group itself. However, under the CEMS, in case3, the DRN system can distribute the recovery heat to other group with the PCM system. In that case, it improved the utilization rate of the recovery heat. As Figure 7-12 illustrated, the individual CHP has 37.9GWh recovery heat every year and 31.1GWh is used for thermal consumption in CHP group. In DRN system, the yearly CHP recovery heat is 47.3GWh, among which 6.4GWh heat is offered to the NCHP group. This part of heat occupied 33.8% of heat consumption in NCHP. Under this condition, 85% of the CHP recovery heat can be reused which possessed 68.8% of the community heat demand.

Figure 7-13 illustrates the daily heat balance in the community, taking the wintertime as example. The plus value means the heat surplus of each group. Group2 and group3 are the CHP groups and their heat surplus means the left heat after their own utilization. PCM system can collect this part of heat and used for heat supply in other groups. The minus part means the heat insufficient. For Group2 and group3, it means the heat deficient after utilizing the CHP recovery heat. Fig.13 can suggest that the first peak of the heat insufficient come on 9 o'clock in the morning and the peak of the heat surplus come on 19 o'clock. Group2 and group3 have no heat demand from 19 o'clock to the next 9o'clock, thus during this time all the CHP recovery heat will be supplied to NCHP group. From the 9 o'clock to 19 o'clock, group3 has the largest heat insufficient, thus the stored heat in the PCM system will be preferentially supplied to group3. That means the heat sharing not only between the CHP group and NCHP group, but also between the CHP groups. After the CEMS collect the heat and store in the PCM system, it only distributes the heat according to the heat insufficient volume.

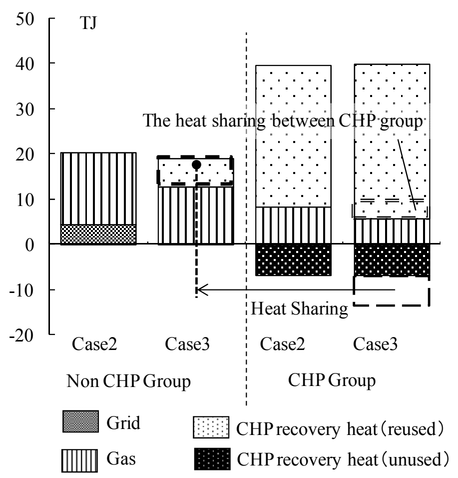


Figure7-12 Yearly heat balances of Case2 and Case3

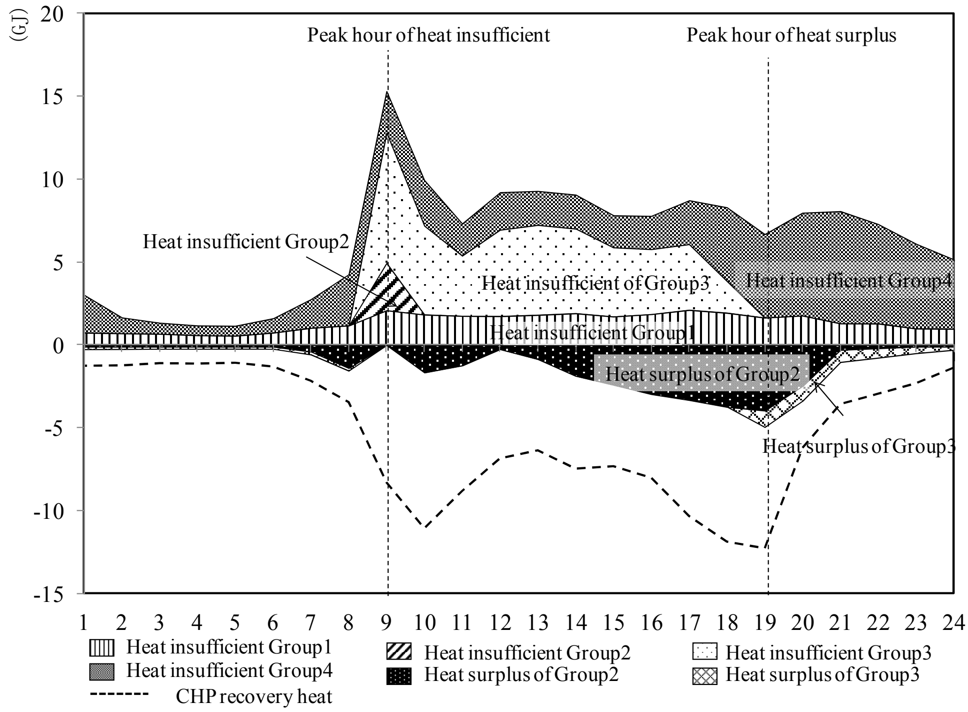


Figure 13 Daily heat balances of the community

7-5-3THE EFFECT OF USING FACTORY EXHAUSTED HEAT

Until now, the city of Kitakyushu still has 1412 factories and industries, which have exhaust heat. The existing research put forward questionnaire to all the factories, estimating and setting up a database by GIS for the yearly exhaust heat. As the result, the yearly exhausted thermal energy is about 18,000TJ.

For this community, four factories were set as the resources and the total yearly heat amount that can offer to the community was 14.2 TJ (38.9GJ per day).

In this research, it is set that exhaust heat will be averagely supplied to the community from the first peak hour in the set time range. Figure 7-14 is the relationship between time range and the heat volume, as well as the energy saving result. It can suggest that in this case, 6 hour is the optimal time range and it can cut 41.4% of primary energy beyond the PV and CHP system.

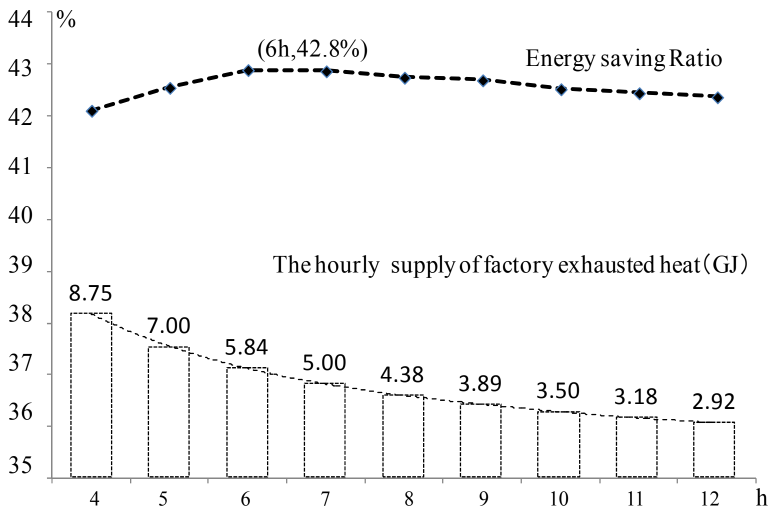


Figure 7-14 Energy saving ratio and the supply span of factory exhaust heat

Figure 7-15 is the daily heat balance with the utilization of the factory exhaust heat, taking group4 in the wintertime as example. During the daytime, the group3 has higher heat load that the factory exhaust heat will firstly be supplied to group3. However, the factory heat can still afford on part of the heat load of group4. During the night, group2 and group3 have no thermal demand that the stored heat will firstly offered to group1, but still another part can afford almost half of the heat demand in group4.

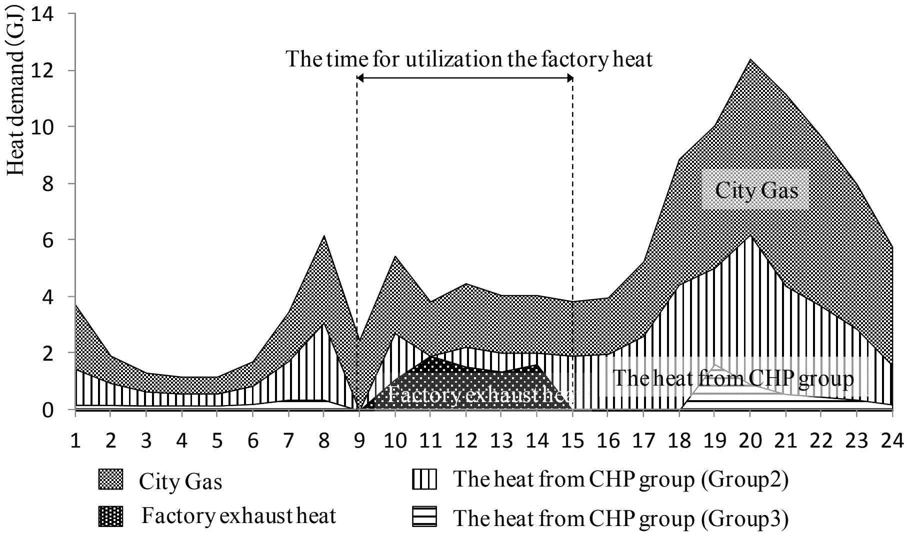


Figure 7-15 Heat balance in considering factory exhaust heat (Group4, winter)

7-5-4 THE EFFECT OF INTRODUCTION OF DIFFERENT CHP PLANT

As the techniques of CHP plant improved, the environmental performance of the system changed as well. The gas engine and the fuel cell have already been widely used in Japan. As a trial project, the community introduced hydrogen fuel cell. Figure 7-16 is the energy saving ratio of these three kinds of CHP plant. The fuel cell and gas engine had similar effect when the capacity is low, but after 1000kW, the fuel cell improved obviously. The hydrogen fuel cell had a higher efficiency on both electricity generating (48%) and heat recovery (42%), thus the system can reach an optimal energy saving ratio around 53%.

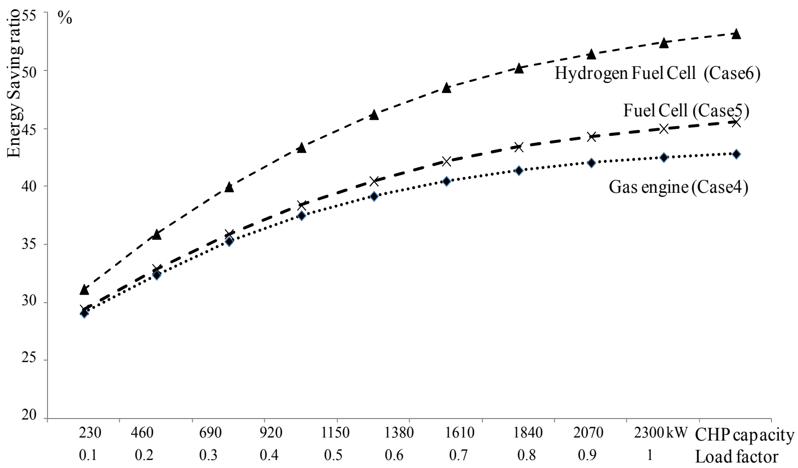


Figure7-16 Energy saving ratio with different kind of CHP plant

7-5-5THE ASSESSMENT OF TOTAL EFFECT OF COMMUNITY

Figure 7-17 is the energy saving ratio for various cases. The PV system can cut off 22.6% primary energy consumption. The individual CHP plants and the PV system can totally cut 30.6% primary energy consumption. Base on this system, the execution of the DRN system can cut off 38.2%. By introduction of hydrogen fuel cell, the community can cut off 53.1% primary energy consumption as its target.

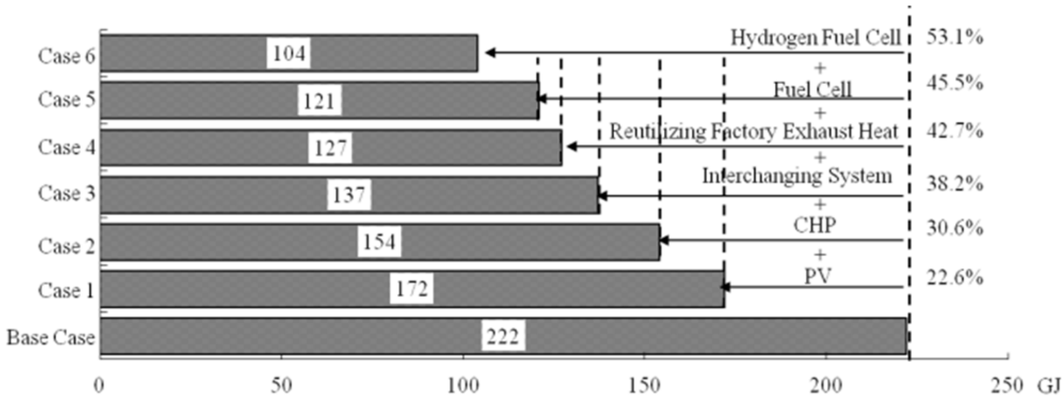


Figure 7-17 The energy saving ratio for various cases

Figure 7-18 is the low carbon ratio for every technology. By introduced the PV system and the CHP plant (gas engine), it can cut off 29.4% of the carbon emission. The networking CHP system can reduce energy consumption and cut off another 7% carbon emission. Beside these, the reusing of factory rejected heat energy can cut off 41.1% CO2 emission. With the introduction of fuel cell and hydrogen fuel cell, it is proved that the community can get 51.8% CO2 emission reduction ratio.

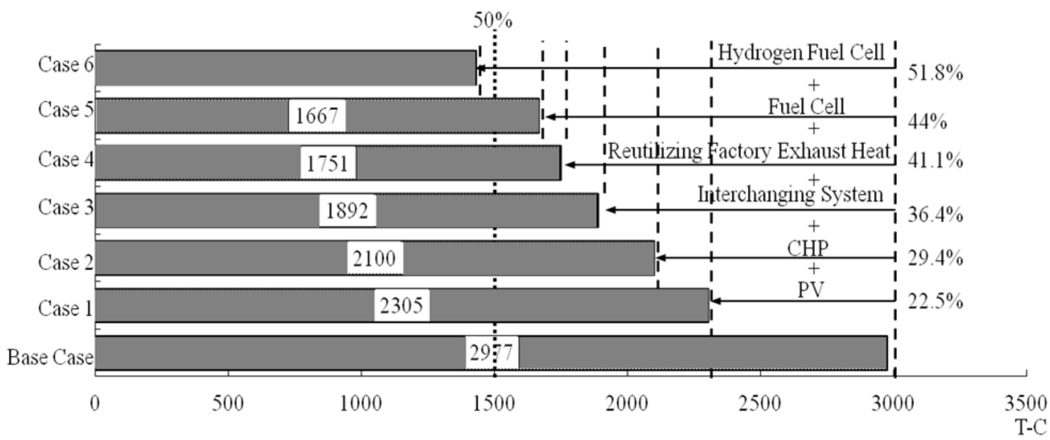


Figure 7-18 Yearly CO2 emissions for cases

7-6 SUMMARIES

The chapter proposed a DRN energy system model for smart community in Japan. One innovation is that the model not only has a smart grid but also has a smart heat energy supply chain by PCM system. The PCM system controlled by CEMS conducted the heat sharing between buildings. In that way, it can maximize onsite use of CHP recovery heat. Further, this model promoted a collaborative energy utilization mode between the industrial sector and the civil sector. The introduced PCM system will also collected the exhaust heat from the nearby factory. It not only made use of the untapped energy but also cut off the CO_2 on the factory side (the exhaust heat) as well. In addition, the research chose the smart community in Kitakyushu as case study and executed the model. The simulation and the analysis of the model is embodied by temporal perspective of the low carbon techniques in Japan, including nature and untapped resource, CHP plants and the PCM system. The result not only suggests the environmental effect of different technologies but also the potential of its overall performance.

(1) The DRN energy system proposed in the study is a tree-like hierarchical model that consists of BEMS, ES and CEMS. The CEMS can dispatch the energy, including heat and electricity in the district, by the information received from the ES. The electricity sharing between the groups can improve the working hour and output of the CHP system. In that case, the distributed energy system can satisfy 95% of electricity consumption by itself. It enhances the reliability and independence of the energy system, shift the energy consumption away from the peak hour as well. The heat sharing can also enhances the independence of the energy system and satisfy the 68.8% of the thermal demand by CHP recovery heat.

(2) The CHP plants is widely used and developed quickly in Japan. There are different kinds of CHP plants, as gas engine and fuel cells. They have different characteristics, different electricity generation efficiency and heat recovery efficiency. The latest HFC, firstly under trail in this district, is the new kind CHP plant that can obviously improved the environmental effect of the system.

(3) In general, the introduction of nature energy resource (PV) can cut 22% of the primary energy consumption and CO_2 emission. The introduction of CHP systems can cut around 30.6% primary energy consumption and CO_2 emission. Beyond that by DRN control, the district energy sharing can cut 38.2% primary energy consumption and 36.4% CO_2 emission. The using of factory exhausted heat and the development of the CHP plant can help the district finally reach the target, that cut more than 50% of the primary energy consumption and the CO_2 emission.

(4) The study analysis the system from the environmental aspect and in the future researches will be carried out to discuss its economic feasibility.

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CHAPTER EIGHT: CONCLUSIONS

The growing concern on the energy shortage and global warming have drove the increasing concern on the development of distributed energy resource. However, the distributed energy system can contribute to the energy saving and carbon reduction on the one hand but also cause problems to the conventional grid on the other hand. Especially for the residential section, the dispersed small scale energy plants and load variation hold up the development of distributed generation technologies in residential sector. For a long time the researches on distributed energy generation always focused on individual, the 'green field site' buildings, or addressed climate issues, transport infrastructure in the city scale. Additional benefit and solution to the weakness may be gained by the collaborative energy using between clusters distributed energy plants in the neighborhood community, which termed as area energy network in Japan.

In this thesis, firstly, the method and related policies for the planning and evaluating area energy network is analyzed theoretically. By study the necessities of the paradigm shift at the community level, a new plan method for the area energy network are developed. Focusing on a residential area, the research chose the neighborhood community as a basic level. It stressed on the using of Geographic information system (GIS), by which the building information, the renewable energy resource and the untapped energy information can be gathered and visualized in a map. The spatial analysis function can also make sense in the area energy network planning. Furthermore, the method proposed in this research also explored some new technologies and suggested the intelligent control.

Chapter1, **PREVIOUS STUDY AND PURPOSE OF THE STUDY**, investigated the present situation of the distributed energy generation technologies including their characteristics, benefits and weakness. As a solution to the weakness, the concept of area energy network and the low carbon community demonstration projects, as case studies of area energy network, are introduced. In addition, the previous studies about this research are reviewed.

Chapter2, **INVESTIGATION ON PRESENT CONDITION OF AREA ENERGY NETWORK,** the recently developed technologies and policies of area energy network are investigated in detail. Firstly, the definition of area energy network and its categories in Japan are introduced. Secondly, the characteristics of area energy network and its contributions to the environment are analyzed. Finally, some previews researches and related policies are sited to assume the conditions as the basic criterions for area energy network.

Chapter3, **CONCEPT AND INVESTIGATION ON THE PLAN OF AREA ENERGY NETWORK,** introduced the concept of the area energy network plan. By analyzing the general structure, the paradigm shift for the distributed system at the community level is analyzed. In addition, the research proposed the methodology and procedure for the area energy network planning.

Chapter4, **SPATIAL ANALYSIS OF RENEWABLE ENERGY AND UNUSED ENERGY IN KITAKYUSHU WITH GIS**, proposed a method to explore the renewable energy and unused energy. Making use of the on-site renewable energy and unused energy is one of the important features of the distributed energy system. Therefore, the investigation on the on-site energy recourse should be put forward before energy system plan. Further, it set up and data base of factory exhaust heat resource. A questionnaire was taken out in all the factories and industries in Kitakyushu. Secondly, it suggested a method to estimate the exhaust heat and mapped out by GIS. Finally, based on the existing research, the optimal using areas are displayed out. Compared with the energy consumption mesh map in Kitakyushu, it is suggested that most of the areas with high energy consumption belonged to this district. Finally, the case study in Yahata Higashida explored a way to select the energy resource and estimated the energy that can derive.

Chapter five, **INTEGRATED ASSESSMENT OF COMBINED HEAT AND POWER SYSTEM FOR LOW CARBON COOPERATIVE HOUSING BLOCKS,** proposed a model for the residential communities in downtown area. Based on the discussion in chapter two, the research here firstly proposed the urban pattern with the introduction of CHP system, which can develop in grid model and shared in a collaborative way. It can prove that the isolated CHP system can only save 20% primary energy while the interchanging using in the new urban unit can save 30% and around 30% CO_2 emission. The urban pattern can be introduced with commercial area and developed into a compact residential block. This paper took the commercial area, which is common in residential block, as an example, analyzed the relationship between mixed function and environmental efficiency. The result can suggest that with the introduction of the commercial area, the energy saving ratio and the carbon reduction ratio are increased, and the optimal point is come out when the residential block mixed with 10% commercial area. Furthermore, this kind of urban block also have potential to accommodate people in different age groups. The different life styles can also make sense to the energy system design and its environmental performance. In this research, under the aging society in Japan, the lifestyle of elderly people is taken into consideration. It was proved that the area energy system planning with well designed age structure can improved the system performance. As the result suggest, the block with 40% elderly people is the optimal structure.

Chapter six, **POTENTIAL ANALYSIS ON THE AREA-WIDE FACTORY EXHAUST THERMAL ENERGY UTILIZATION BY PCM TRANSPORTATION SYSTEM IN A RECYCLING-ORIENTED COMMUNITY**, investigated the PCM system. By analyzing the technical characteristics of PCM system, this chapter proposed the utilization of PCM heat transport system into the collaboration between the CHP plants instead of the conventional pipe system. Secondly it takes the apartment in the low carbon demonstration area in Kitakyushu as case study and suggested that the system to some extent a better way for the utilization of factory waste heat, thus contributed to the energy saving and carbon reduction.

Chapter seven, **A MODEL FOR AREA ENERGY NETWORK BY OFFLINE HEAT TRANSPORT SYSTEM AND DISTRIBUTED ENERGY SYSTEMS,** proposed an energy system model for smart community in Japan, with industry, commercial buildings, public service buildings and residential area. The model not only has a smart grid but also has a smart heat energy supply chain by offline heat transport system (PCM). The PCM system controlled by community energy management system, conducted the heat sharing between buildings. In that way, it can maximize onsite use of CHP recovery heat. Further, this model promoted a collaborative energy utilization mode between the industrial sector and the civil sector. The introduced PCM system will also collected the exhaust heat from the nearby factory. It not only made use of the untapped energy but also cut off the CO_2 on the factory side (the exhaust heat) as well. In addition, the research chose the smart community in Kitakyushu as case study and executed the model. The simulation and the analysis of the model is embodied by temporal perspective of the low carbon techniques in Japan, including nature and untapped resource, CHP plants and the PCM system. The result not only suggests the environmental effect of different technologies but also the potential of its overall performance.

Chapter eight, **CONCLUSIONS** summarized the results in every chapter.