Development of District Energy Supply System for CHP Implementation

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ABSTRACT

Advancement in the Combined Heat and Power (CHP) technology and the liberalization of the electricity market could contribute to realize various types of energy systems in a district. Thus, innovative energy efficient systems can be designed thorough comparison among available alternatives. However, most communities have no long term plan to improve the energy efficiency of existing districts. As a result, the potential energy saving that can be achieved by installing advanced district scale energy systems is abandoned due to difficulties to set up district scale heat delivery systems.

This paper suggests a process to install district scale CHP systems (District CHP) that could overcome the installation obstacles. In this process, combination of buildings starts within a few buildings. Thus, a number of small district CHP systems for two or three buildings are placed in a district. Finally, a large district CHP system integrates these subsystems.

This paper compares CHP implementation strategies to install District CHP and CHP for individual buildings (Individual CHP) by applying a bottom-up type district energy system simulation model for the Yodoyabashi district in Osaka, Japan. In this district, the District CHP strategy can achieve two times energy saving compared with the Individual CHP strategy. However, districts have to be carefully selected to implement the District CHP strategy, as the economical feasibility is heavily dependent on the arrangement and sizes of buildings. For densely developed existing districts, the District CHP strategy can be a promising plan to improve the overall community energy efficiency.

Introduction

Urban areas are heavily contributing to the burden on environment due to the high density of human activities. This situation provides opportunities to reduce per-capita energy consumption by implementing advanced building and district energy systems (Burer et al. 2003). The advancement of the Combined Heat and Power (CHP) technology and the liberalization of the electricity market can be seen as aid to realize a highly energy efficient community. At this moment, the net energy consumption at city/district level is still increasing. Also, there are a lot of communities that have no long term plan to improve the present situation. In order to curb this trend and to reduce energy consumption, strategies comprehensively improving energy efficiency with a holistic community view should be imposed.

Conventionally, the performance of the application of the CHP technology was dependent on the heat demand due to its low power-to-heat ratio. Thus, the implementation of this technology was limited on large-scale applications such as those in industries and large district heating and cooling (DHC) systems. On the contrary, with its current advancement, the power-to-heat ratio has been considerably raised. As a result, marketing of this technology has been gradually shifting to include small scale applications (Bourgeois at el. 2003). Thus, this technology can exist on a variety of scales (Grohnheit et al. 2003). For example, according to the simulation results of Burer at el. (2003), a DHC plant integrating a solid oxide fuel cell (SOFC) and gas turbine (GT) combined cycle with an output more than 1 MW could potentially reduce CO_2 emission up to 50% compared to a conventional system. Besides large scale applications, due to the cost reduction efforts of small systems (i.e. George 2000), CHP for individual buildings can also be attractive. However, the flexibility of this technology brings new challenge: what is the optimum scale of application, could it really contribute to the community economically and environmentally?

Thus, a thorough study and comparison among available alternatives is essential to design efficient urban energy systems. However, there are obstacles to install district scale energy systems. Most urban communities that have no long term plan to improve energy efficiency are already densely developed. Thus, according to the following causes the payback of initial investment needs a few decades:

1) Installation of a heat delivery system for buildings is difficult.
2) Participation of buildings to a district energy system is projected with the renewal of building itself or the facility.

As a result, installation of district scale energy systems is cured from the possible alternatives. The potential energy saving that can be realized by installing the advanced district energy systems is abandoned.

This paper suggests a process to install district scale CHP systems (District CHP) that overcomes the obstacles. In this process, combination of buildings starts among a few buildings. Thus, small district CHP systems for two or three buildings are placed in a district. Then, a large district CHP system integrates these systems. This paper compares CHP implementation strategies to install District CHP and CHP for individual buildings (Individual CHP) in an existing urban community.

For thorough comparison, various factors have to be taken into account, as the installation process of the District CHP systems takes some decades. The future efficiency and practicability of the CHP technology will be one of the most important factors. Besides, the arrangement of buildings, long term heat and electricity demand profile (Rolfsman 2004), and difficulties to set up heat delivery systems would affect the energy and economic performance of these strategies. To include these factors, we developed a bottom-up type district energy system simulation model. In this model, the total energy flow of a district is modeled as the sum of energy flow of each building based on a building heat and electricity demand prediction model. By applying this model for the Yodoyabashi district, in Osaka, Japan, the energy and economic performance of two strategies were evaluated under a realistic condition.

In this paper, a description of the installation strategy of the District CHP is given. Then, we illustrate the structure of the simulation model. Finally, the simulation results of the Yodoyabashi case study are presented.

Strategy to Develop a District Scale CHP

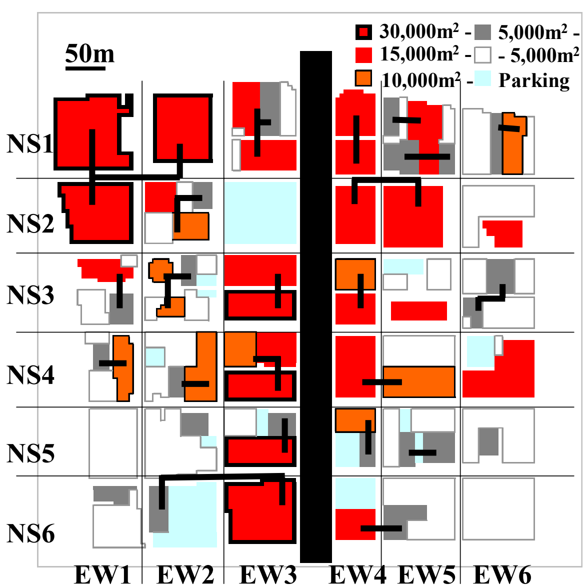
In an existing community, gradual extension of heat delivery systems is the only way to install district scale energy systems due to the obstacles mentioned above. The main feature of the installation process of the District CHP is the gradual installation of CHP and heat delivery systems with the renewal of buildings or facilities. The process is divided into two stages. In the first stage, a CHP system is installed and delivers cooling and heating energy and electricity for two or three neighboring buildings. In the second stage, after payback of the initial investment, a large CHP system will be installed by integrating these small CHP systems.

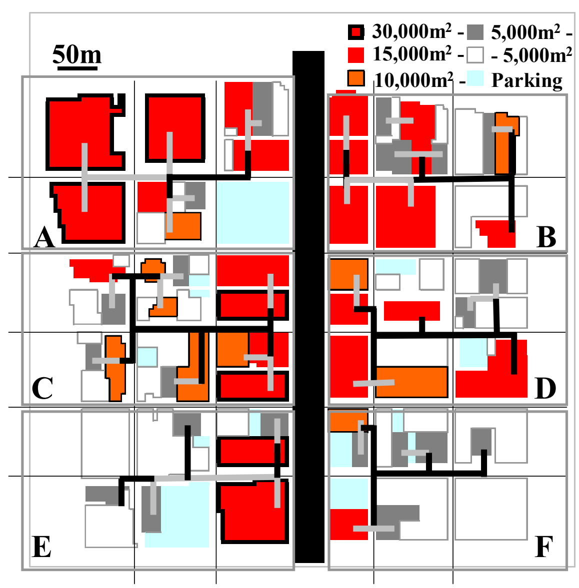
As an example, we chose the Yodoyabashi district, in Osaka, Japan for the case study. This district is a matured office area consists of 55 office buildings larger than 5,000 m^2 and about 200 smaller buildings in its 250,000m^2 area. During the first stage, a few neighboring buildings are integrated by a CHP system as shown in Figure 1. During the second stage, neighboring networks are connected as shown in Figure 2. In this stage, we assumed 6 CHP plants in the district A to F as illustrated in Figure 2.

This strategy can gain economical advantages by adopting the gradual extension process. In Figure 1, buildings are shown as boxes and divided by arterial roads on which the vertical and horizontal axes are placed. There are two types of combinations based on the building arrangement. First, if arterial roads surround a few buildings, its combination is limited within the area as the integration of buildings across the road is impractical and relatively expensive. This combination consists of relatively small buildings. The other type is a combination that crosses the roads if each area is occupied by a single building. This combination consists of relatively large buildings. As a result, in both combinations, the increment of the initial investment for the heat delivery system can be balanced with the operational cost reduction as well as the initial investment reduction given by absent of heat source systems in each building. During the second stage, the economical burden for combining each CHP systems is moderate, as some parts of a district heat delivery system has already developed in the first stage.

Figure 1. (Left) Buildings and Heat Delivery Systems Installed During the First Stage of the District CHP (Bold Lines Show the Heat Delivery Pipelines)

Figure 2. (Right) A to F Districts and These Heat Delivery Systems (Black Bold Lines Show the New Heat Delivery Pipelines Installed During the Second Stage While the Grey Bold Lines Are Pipelines Installed During the First Stage)





District Energy System Simulation Model

Figure 3 illustrates the calculation procedure of the district energy system simulation model. This model consists of three basic components, namely an occupant behavior model, a building energy demand model and district energy supply system model. Firstly, based on occupant behavior, schedules of occupant and lighting and patterns of the heat and electrical loads of appliances are predicted in the occupant behavior model. Then, heat and electricity demand profile of each building are calculated. Finally, the total energy flow of a district is quantified.

The remaining part of this section presents descriptions of each sub-model.

Occupant Behavior Model

The purpose of this model is to reflect the practical operational conditions of a building and energy consuming appliances in the energy demand profile. So far, the operational conditions of many prototypical buildings have been modeled as fixed conditions. In reality, however, these conditions vary through long term operation of buildings. Particularly, appliances differ in specification. These conditions could change the energy demand profile. Then, it could further affect the performance of energy systems. Thus, to account for these influences, we developed the occupant behavior model as a calculation module of occupant and lighting schedules and heat and electrical load patterns of appliances. These data are led by stochastically simulating occupant behavior and linked with the use of lighting and appliances.

Figure 3. Flow Chart of the District Energy System Simulation Model

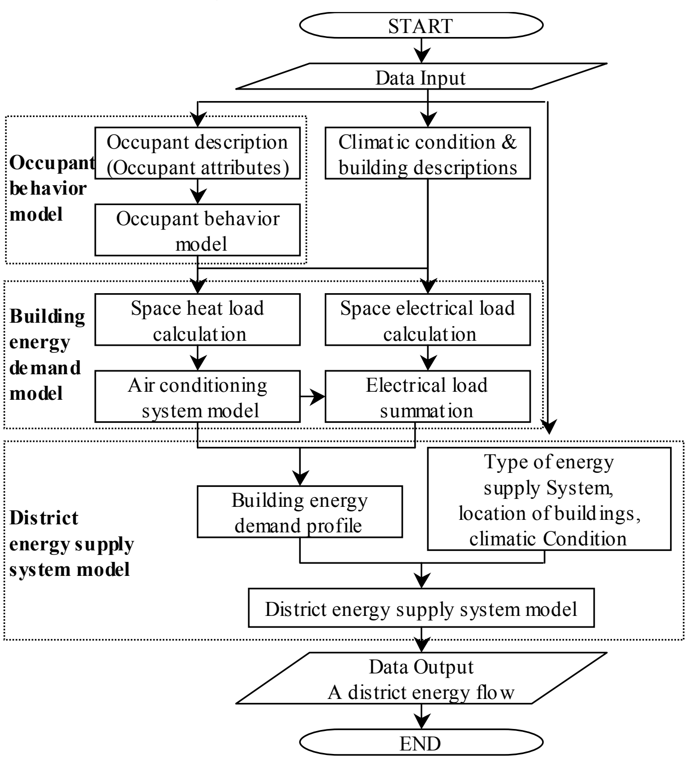


Figure 4. Flow Chart of the Occupant Behavior Model

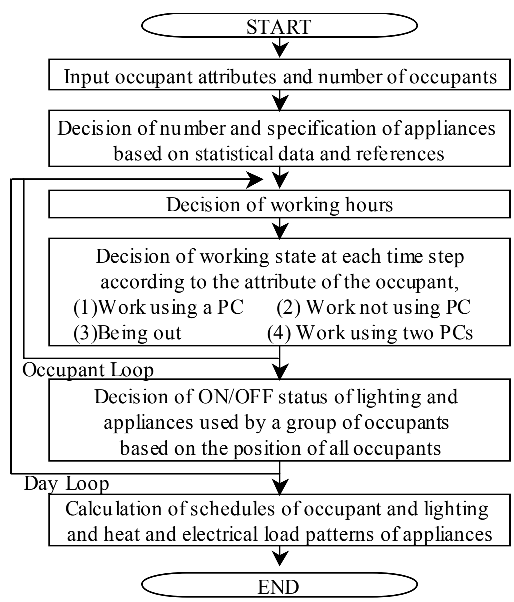


Figure 4 illustrates the flow chart of the occupant behavior model. Detail descriptions of the modeling approach of occupant behavior are given elsewhere (Yamaguchi at el. 2003). Based on the simulated occupant behavior, the load pattern of appliances used by individual occupants is calculated. Also, based on the position of each occupant, lighting and appliances used by group of occupants are given.

Building Energy Demand Model

The building energy demand model simultaneously calculates hourly heat and electricity demand profile of each building. The space heat load is calculated using the transfer function method (ASHRAE 1997). Then, the air conditioning system model translates the space heat loads into the cold and hot water coil loads. It is assumed that an air conditioning system is installed in each story. The load of the heat source system is then defined as the sum of all cold and hot water coil loads.

The electricity demand of a building is calculated by summing the electrical loads shown in Table 1. Table 1 also shows the calculation method of each load. Electrical load for conveyance, emergency, sanitary, security and etc. are also calculated by the total capacity of 31.2W/m^2 and the schedule shown in Figure 5. The value of total capacity is taken from statistical data (Japan Building Mechanical and Electrical Engineers Association 1994). The schedule pattern is decided by referring to reference (Japan Institute of Energy 2002).

District Energy Supply System Model

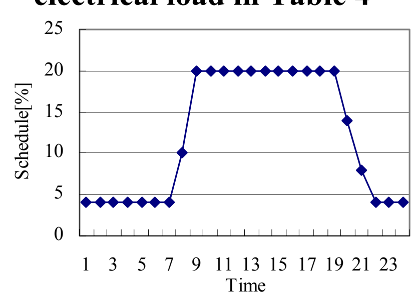
The district energy supply system model calculates the total energy flow of a targeted district. The input information is the energy demand profiles of all buildings, climatic conditions, types of energy supply system, and arrangement of the buildings, which is required for the design of heat delivery systems.

The district energy supply system model is able to deal with systems for a single building and for a number of buildings. The inner and outer diameters of heat delivery pipelines and its insulator are designed from the peak heating or cooling demand of each building. The part-load characteristic is assumed in the calculation for all components of the facilities. For refrigerators, in addition to the part-load characteristics, the COP modeled from its rated COP and its regression with chilled water temperature as well as condenser water temperature.

Table 1. Electrical Load and Calculation Method

Term	examples	Load calculation method
Lighting	-	Capacity * schedule (calculated by occupant behavior model)
Appliances controlled by a single occupant	PC, monitor	Input from occupant behavior model
Appliances controlled by a group of occupants	Copy machines	Input from occupant behavior model
Fan for air conditioning	-	Input from air conditioning system model
Other electrical loads	Conveyance	Capacity (31.2W/m^2) * Schedule Schedule is shown in Figure 5
	Emergency	
	Sanitary	
	Security	

Figure 5. Schedule for other electrical load in Table 4



Case Study

This case study quantitatively compares the energy and economic performances of the District and Individual CHP strategies for the Yodoyabashi district.

First, schematic diagrams of District and Individual CHP systems and simulation conditions are explained. Second, the energy demand prediction results of all 55 office buildings with a floor area over 5,000m^2 are illustrated. This case study focuses on the energy saving of the 55 buildings. Finally, the CHP implementation strategies are discussed based on two sets of energy system simulation results. Finally, based on results of energy system simulation, the energy saving and economic aspects of the CHP implementation strategies are discussed.

Schematic Diagrams of District and Individual CHP Systems

Three types of energy supply systems will be discussed in this case study. Figure 6 illustrates the basic energy system in calculating energy saving ratio and simple payback period of District and Individual CHP systems.

Figure 7 and Figure 8 illustrate the Individual and District CHP systems. In the Individual CHP, all generated electricity and exhaust-heat are used only in the building itself. On the contrary, in the District CHP, all buildings in a system are received the generated electricity and chilled and hot water supply from a CHP plant installed in one of the buildings. Note that electricity exportation to the grid is not permitted in both systems.

The configurations of both systems are basically common. The exhaust-heat of the distributed generator is recovered as hot water. It is converted into heating energy using heat exchangers, then to cooling energy using exhaust-heat gas absorption chiller/heaters (EGAR) (COP = 1.3 at rated condition for cooling base on the higher heating value of natural gas). Finally, surplus of the recovered hot water is discharged from cooling towers. However, it should be noted that there is an upper limit of the exhaust-heat utilization. A maximum of 45% of EGAR cooling capacity could be supplied by exhaust-heat utilization.

Figure 6. Schematic of Base System

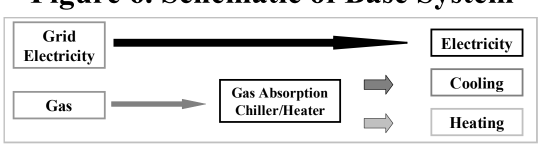


Figure 7. Schematic of Individual CHP System

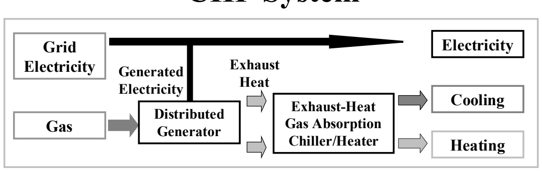
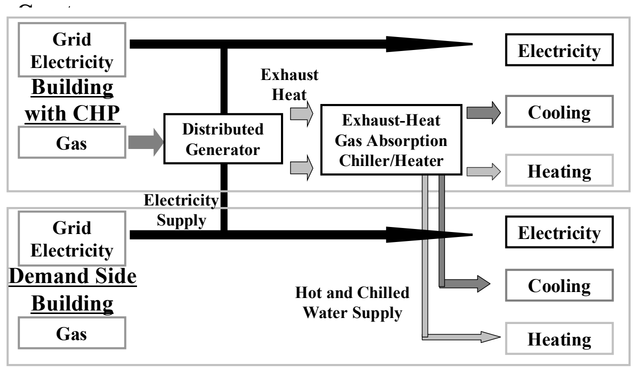


Figure 8. Schematic of District CHP



Simulation Conditions

This case study assumes 4 sets of electricity generation and heat recovery efficiencies of distributed generators. All generator efficiencies are assumed to have a common overall efficiency of 74% (based on the higher heating value of natural gas). These 4 sets are shown in Table 2.

Only with the 20%up case, the integration of compression chillers (COP = 6.0) is examined. This case will be indicated as “20%up/MIX” case. In this case, a mix use of an EGAR, compression chillers and an auxiliary boiler is assumed in the Individual CHP system and the District CHP system during the first stage while the District CHP system during the second stage utilizes a single effect absorption chiller, compression chillers and an auxiliary boiler.

Table 3 shows the initial costs of distributed generators, heat source components, and installation of heat delivery pipelines. The running cost includes the standing and unit commodity charges for the electricity and gas utilities, which are referred from the utility rates respectively, and the maintenance cost of a CHP system shown in Figure 10.

Table 3 also indicates items that are counted in the initial cost with ○ marks on the last 3 rows. As can be seen from Figure 8, all demand side buildings in a District CHP system have no initial costs of heat source components. Instead, the initial cost includes costs for the heat delivery system. The initial cost and maintenance cost of distributed generators are assumed as independent on the 4 sets of generator efficiency mentioned above. It should also be noted that the initial and running costs exclude costs for electricity transportation between buildings.

We assumed 2 times of renewal of heat source components until completion of District CHP systems in the A to F districts in this case study. The total amount of initial cost via the 2

Table 2. 4 sets of Generation Efficiency

Case	Generation Efficiency	Supposed Technology
Base	Figure 9	Top runner Gas Engine
5%up	Base case + 5%	Gas Turbine/Steam Turbine combined cycle or Fuel Cell
10%up	Base case + 10%	
20%up	Base case + 20%	Fuel Cell + Gas Turbine Combined Cycle

Figure 9. Generation Efficiency of the Base Case (Hishinuma 2003)

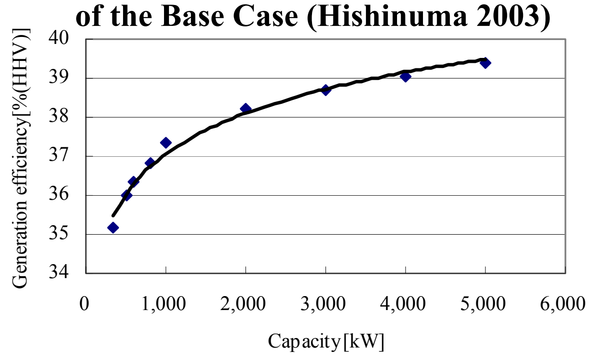


Table 3. Initial Cost of Machines and Heat Delivery System

Items	x[unit]	regression[10^3yen]	Base case	Individual CHP	District CHP
Distributed generator	capacity[kW]	150.0x+20,000		○	○
GEAR	capacity[kW]	20.4x+6,000	○	○	○
Single effect absorption chiller	capacity[kW]	7.0x+10,000			*
Comresssion chiller	capacity[kW]	12.0x+10,000		*	*
Boiler	capacity[kW]	3.5x+318		*	*
Cooling tower	capacity[kW]	2.5x+40	○	○	○
Materials of heat delivery pipeline	weight[kg]	3,000x			○
Civil engineering for pipeline	length[m]	400x			○
Facility for receiving heat delivery	number of buildings[-]	10,000x			○

Items indicated by * are counted in case of 20%up/MIX case. In this case, GEAR is not used in a District CHP system.

times of renewal for each case is shown in Figure 11.

Figure 10. Maintenance Cost of a CHP System

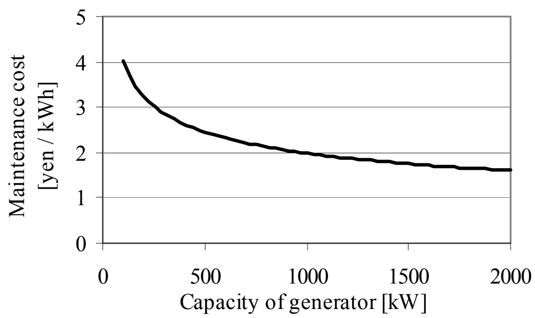
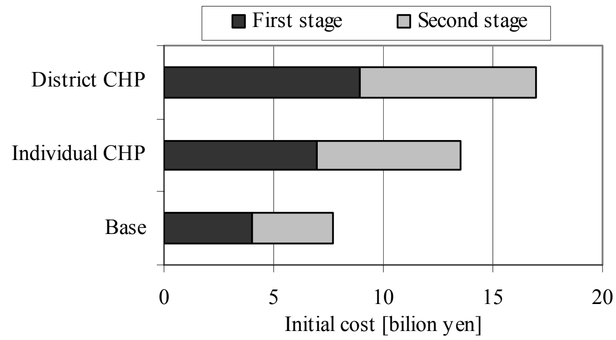


Figure 11. Total amount of initial cost via 2 times of renewal



Capacity of generators is decided through optimization to minimize the simple payback period of the CHP plant (and heat delivery pipelines). There is an economical restriction of simple payback periods that is basically supposed as 10 years. Note that the District CHP strategy regards the A to F districts as a unit of optimization while optimization of the Individual CHP strategy is executed in each building individually. Thus, during the first stage of the District CHP system, a simple payback period of a building combination more than 10 years is permitted when the district satisfies the economical restriction.

Building Heat and Electricity Demand Prediction Results

To take into account features of heat and electricity demand profiles of buildings, information gathering through maps and field surveys were carried out. The main items of survey in each building were as follows:

1) Area of floors and number of the floors
2) Zoning of conditioned and unconditioned area (Those of 7 buildings were unknown. Those of the others were assumed as the most frequent zoning)
3) Ratio of windows on the façade
4) Quantity of outdoor air intake (Those of 12 buildings were known. Those of the others were assumed as $5m^3$ per conditioned floor area.)

As the installation of District CHP systems takes decades due to the gradual extension process for completion, penetration of the energy saving measures for reducing heat and electricity demand of buildings can be predicted within the period. Decrease of energy demand could change energy and economic performance of CHP implementation (Rolfsman 2004). Thus, to include this effect, the case study assumes two sets of heat and electricity demand profiles, the Baseline and Saving Demand. The results of the demand prediction are shown from Figure 12 to Figure 14 while the calculation conditions of each case are shown in Table 4. Note that in the following analysis, the Baseline Demand is assumed during the first stage of the installation process of the District CHP while the Saving Demand is assumed during the second stage for more practical analysis.

Figure 12. Cooling and Heating Demand of the Baseline Demand

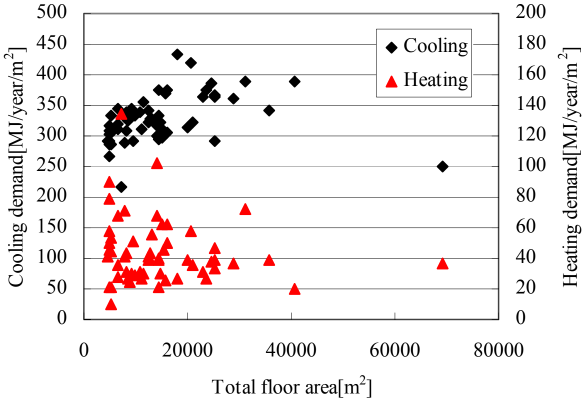


Figure 13. Cooling and Heating Demand of the Saving Demand

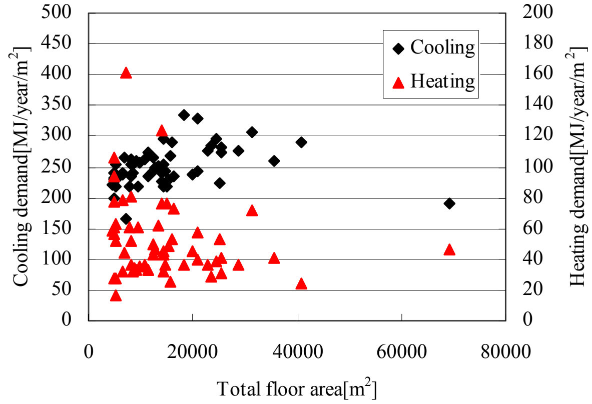


Figure 14. Electricity Demand

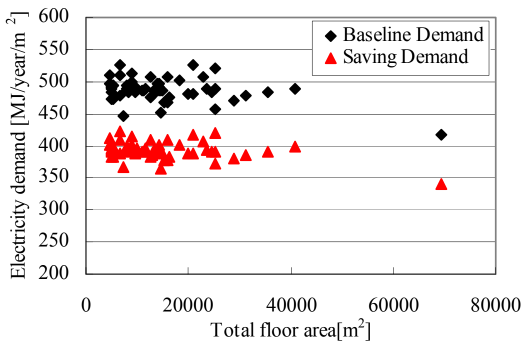


Table 4. Conditions of Baseline and Saving Demand

Energy saving measures	Related item	Baseline Demand	Saving Demand
Adoption of efficient lighting system	Lighting	$20W/m^2$	$14W/m^2$
Replacement of monitors accompanied to PC	Portion of monitors (CRT:LCD)	(84:16)	(0:100)
Control of outdoor air intake	Quantity of outdoor air intake	Maximum intake	$25m^3$ per occupant

Energy and Economic Performance of District and Individual CHP Strategies

Figure 15 to Figure 18 give the sets of energy saving ratios and simple payback periods, obtained when the Individual and District CHP strategies were applied to the A to F districts. Plots represent the performance of the two strategies in the A to F districts respectively.

As can be seen in the figures, the energy saving ratios of the District CHP systems are higher compared to those of the Individual CHP systems with each generator efficiency during both the first and second stage. This difference can be attributed to larger penetration ratio of CHP systems as shown in Table 5 and merit of scale of generator efficiencies shown in Figure 9. Due to relatively large initial investment, installation of Individual CHP systems for small buildings is economically infeasible. On the contrary, combination of buildings results in larger heat and electricity demand enough to realize lower simple payback period under its restriction due to the economical advantages of gradual extension process of the District CHP stated above. As a result, the District CHP strategy could achieve higher penetration ratio of CHP systems compared to the Individual CHP strategy; thus higher energy efficiency.

From a comparison between Figure 15 and Figure 17, we can recognize that the heat and electricity demand of buildings affect the energy saving and economic performance of Individual CHP systems. District CHP systems are also influenced by the demand of buildings. Thus, to what extent the performance is dependent on the size of demands should be made clear, as a trend towards even greater efficiency than we simulated could occur and it could result in difficulty to install CHP systems.

Figure 15. Performance of Individual CHP Systems (First stage: Baseline Demand)

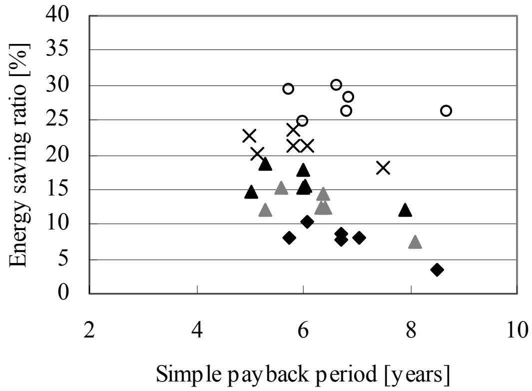


Figure 16. Performance of District CHP Systems (First stage: Baseline Demand)

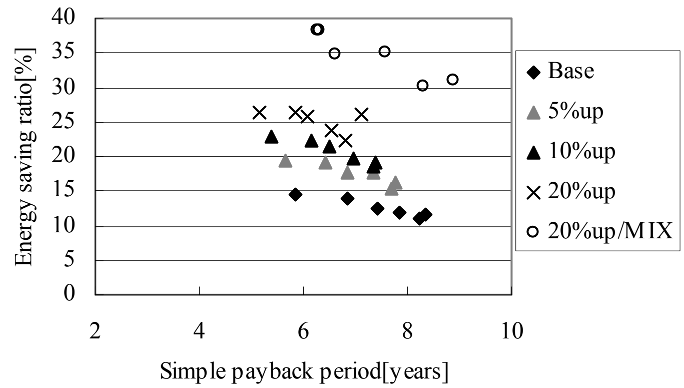


Figure 17. Performance of Individual CHP Systems (Second stage: Saving Demand)

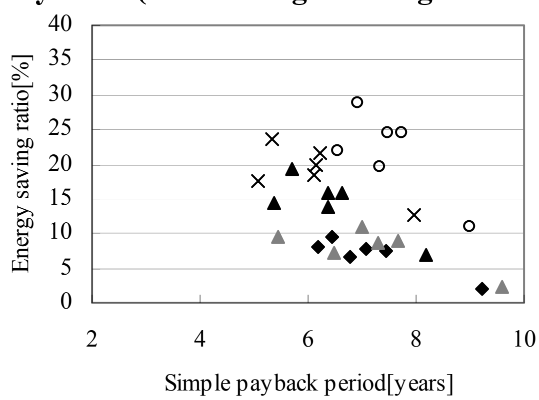


Figure 18. Performance of District CHP Systems (Second stage: Saving Demand)

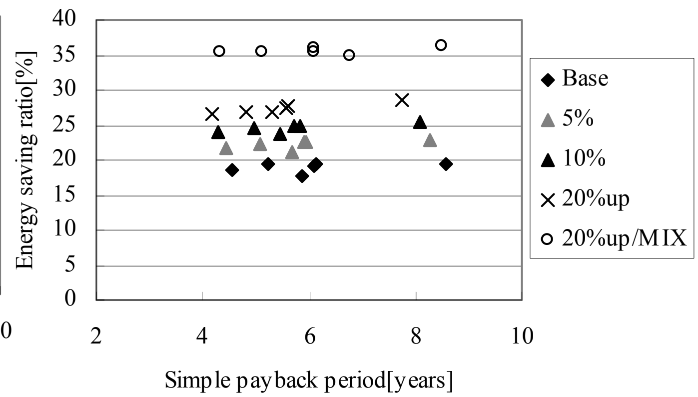


Table 5. Penetration Ratio of CHP Systems of A to F Districts[1]

District	Total floor area[m^2]	Length of heat delivery pipelines[m]	Peak electricity demand[kW]	Penetration ratio of CHP[%]			
				Individual CHP		District CHP	
				First stage	Second stage	First stage	Second stage
A	198,416	320	9,652	97	97	100	100
B	142,059	415	7,326	81	81	100	100
C	217,979	390	10,219	69	64	100	100
D	121,534	450	6,494	89	79	100	100
E	85,790	335	4,387	71	71	86	100
F	74,659	375	3,910	51	36	93	100

[1] The base and 20%up cases of generator efficiency are assumed during the first and second stage of the District CHP respectively.

Influence of Economical Restriction on Share of Energy Systems

In the former section, performance of the CHP implementation strategies has discussed with the restriction of simple payback period under 10 years. In this section, economic aspect of the CHP implementation strategies is investigated by sensitivity analysis of the simple payback period restriction.

Figure 19 and Figure 20 show the share of floor area occupied by each energy system with restriction of simple payback period of 6, 8, and 10 years where the base and 20%up cases of generator efficiency are assumed during the first and second stage of the District CHP respectively. Additionally, Figure 21 shows the total primary energy consumption of the Yodoyabashi district at the same conditions where the restriction of simple payback period is applied as 6 and 10 years. Figure 21 also shows the annual primary energy consumption of the Individual CHP strategy as a reference where the simple payback period restriction is given as 6 years.

As can be seen in Figure 20, with the simple payback period restriction of 8 and 10 years, all buildings were combined into District CHP systems. On the contrary, with the restriction of 6 years, District CHP systems could not occupy B, D, E and F districts. For these districts, the restriction is too severe to install building combination during the first stage. Thus, as the projected heat delivery pipeline installation was deferred to the second stage, the District CHP strategy became infeasible.

This result implies that districts have to be carefully selected to install a District CHP system if there is a stringent economical restriction. A value given by dividing the total floor area of buildings in a district by the total length of heat delivery pipelines can be seen as a reference data that indicates feasibility of the District CHP system. As seen in Table 5, the value must be

Figure 19. Share of Energy Systems During the First Stage of District CHP

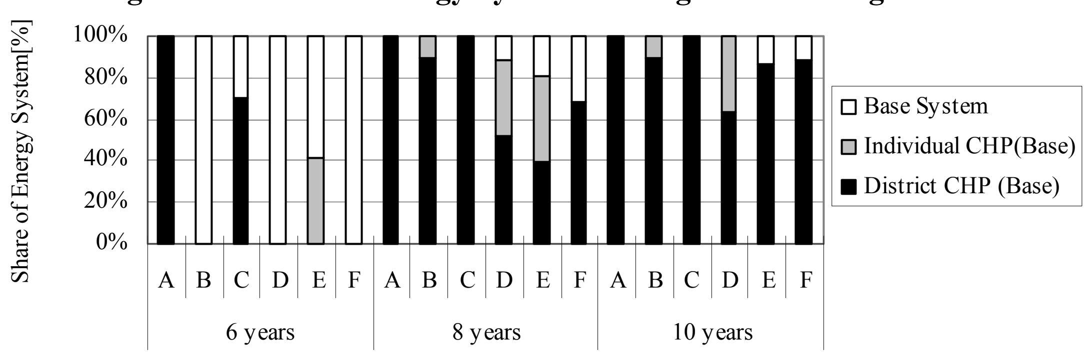
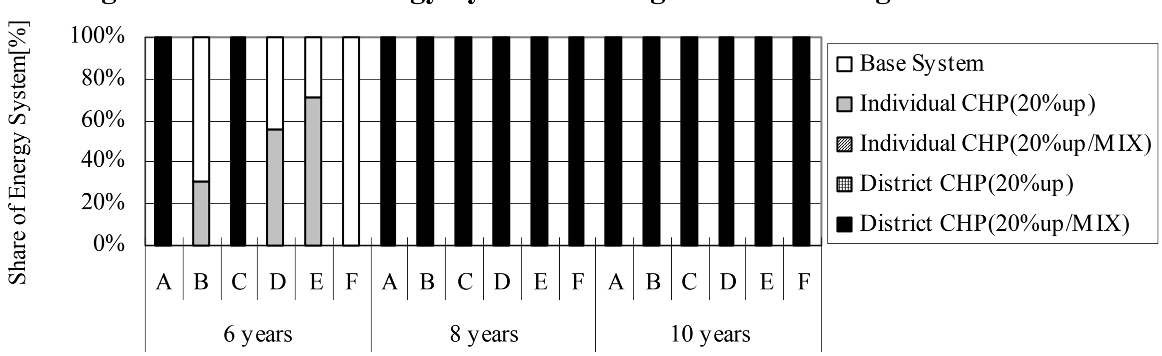
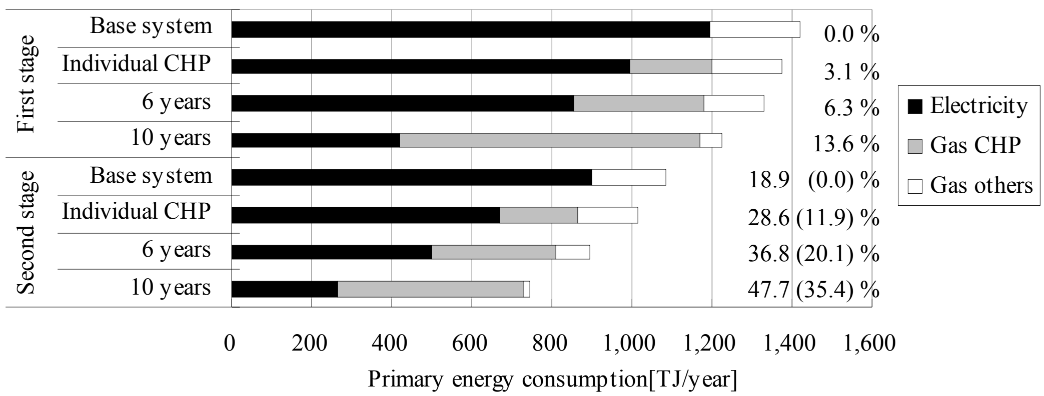


Figure 20. Share of Energy Systems During the Second Stage of District CHP



larger than 400 to 500 m^2/m. Thus, a scheme to replace small buildings with a large building could contribute to realize potential energy efficiency of District CHP systems. Without such a scheme, economical support to install building combination during the first stage could lead to large amount of primary energy saving. Totally, as can be seen in the Figure 21, almost half of the total primary energy consumption of the Yodoyabashi district can be reduced by adopting energy saving measures to reduce energy demand of buildings and installing advanced District CHP systems.

Figure 21. Primary Energy Consumption and Energy Saving Ratio [%] With Different Simple Payback Period Restrictions[2]



Conclusion

A CHP implementation strategy to install district scale energy systems (District CHP) was suggested and compared with a strategy to install CHP systems in individual buildings (Individual CHP) by applying a bottom-up type district energy system simulation model to the Yodoyabashi district. In this district, the District CHP strategy is able to achieve two times energy saving compared with the Individual CHP strategy. However, districts have to be carefully selected to install a District CHP system, as the economical feasibility is heavily dependent on the arrangement and sizes of buildings. For densely developed existing district, the District CHP strategy could provide a long term plan to improve the overall community energy efficiency.

The most important finding of this paper is that a combination of buildings based on the CHP technology could contribute to increase the energy efficiency of an existing district. Although the case study in this paper discussed a certain procedure to develop a district scale energy system, community energy system development plans do not necessarily follow the procedure strictly. A combination of buildings has to be planed flexibly according to the situation of districts.

In order to enhance the feasibility, a further analysis will be carried out. First, we ignored the cost for electricity transportation between buildings in a District CHP system. The technical and economical aspects of this problem should be clearly addressed. Second, our simulation results showed that the performance of a system using distributed generators is dependent on heat and electricity demand profile of buildings. Thus, to what extent the heat and electricity demand profile can vary and to what extent the performance is dependent on the demand profile

[2] Percentages at the end of bar graph show energy saving ratios from the base case during the first stage. Percentages in parentheses show energy saving ratios from the base case during the second stage.

will be analyzed. Finally, a more detail case study assuming practical conditions of a district will be carried out with considering various uncertain factors in, for example, timing of renewal of buildings, energy demand profile, available technologies, and tariff systems of the gas and electricity utilities.

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References

Burer, M., Tanaka, K., Favrat, D., and Yamada, K. "Multi-criteria Optimization of a District Cogeneration Plant Integrating a Solid Oxide Fuel Cell-Gas Turbine Combined Cycle, Heat Pumps and Chillers." *Energy* 28: 497-518.

Bourgeois, T.G., Hedman, B., and Zalcman, F. 2002. "Creating Market for Combined Heat and Power and Clean Distributed Generation in New York State." *Environmental Pollution* 123: 451-462.

Grohnheit, P.E., and Mortensen, B.O.G. 2003. "Competition in the Market for Space Heating. District Heating as the Infrastructure for competition among Fuels and Technologies." *Energy policy* 31: 817-826.

George, R.A. 2000. "Status of Tubular SOFC Field Unit Demonstrations." *Journal of Power Sources* 86: 134-139.

Rolfsman, B. 2004. "Optimal Supply and Demand Investment in Municipal Energy Systems." *Energy Conversion and Management* 45: 595-611.

Yamaguchi, Y., Shimoda, Y., and Mizuno, M. 2003. "Development of District Energy System Simulation Model Base on Detailed Energy Demand Model." *Proceedings of the Building Simulation* 8: 1443-1450.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) 1997. *ASHRAE Handbook Fundamentals*.

Japan Building Mechanical and Electrical Engineers Association. 1994. "Data of completion building equipment." In Japanese.

The Japan Institute of Energy. 2002. "*Natural Gas Cogeneration Plan/Design Manual 2002*." 33-56. In Japanese.

Hishinuma, Y. 2003. "Shift of Circumstances Surrounding Cogenerations and the Present Condition of the Development Race of Gas Engine". *Clean Energy* 8: 19-22. In Japanese.