CASE STUDY ON THE EFFECTS OF ENERGY INTERCHANGE AMONG BUILDINGS

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ABSTRACT

The results of a case study are presented focusing on efforts to conserve energy in an existing city block by physically connecting a number of existing buildings with pipes and cables and a Cogeneration System (CGS), and then exchange energy among the buildings using the CGS and existing heat source equipment. Essentially, the proposed system levels-out and reduces variation in the combined inter-building energy load among the buildings with a variety of energy use profiles. Due to significant differences in capacity and degree of deterioration between existing equipment, total energy consumption can be reduced by connecting the energy systems across existing buildings and preferentially operating the equipment with the best performance. Furthermore, CGS systems are often more efficient under higher operating loads but are often sized for the smaller, less efficient operating conditions of an individual building. Therefore, greater efficiency can be achieved by installing a high-capacity CGS sized for multiple buildings. The results of an actual case study in the Kanazawa seaside district of Yokohama city demonstrate the effects of exchanging energy between two different-use buildings with a CGS system.

KEYWORDS

Inter-building energy system, Energy conservation, Co-generation system

INTRODUCTION

District energy systems and the introduction of co-generation systems have attracted much attention as countermeasures for global warming in Japan. Each building has a limit to high-efficiency operation of its energy equipment. A district energy system shares energy equipment among buildings, operating them at high-efficiency, and managing the energy equipment and energy demand for each building. As such, a district energy system can lead to a large reduction in energy consumption. Up to now, district heating and cooling systems (DHC) have fulfilled this role. But DHC has a low diffusion, and in many existing city blocks it is comparatively difficult to introduce DHC because each building owns and operates its own energy equipment individually.

On the other hand, a co-generation system (CGS) is a distributed power production system, and leads to high-efficiency in energy use by using the heat produced during power generation. But CGS requires a small part of the energy demand because the installed capacity is not set to produce surplus electricity and heat for the demand. It is expected that the advantages of installing CGS are much greater in a district energy system than an individual building.

In this study, attention was given to the effects of an inter-building energy system on actual buildings in an actual city block. Buildings with individual energy systems were connected by pipes and cables, and the existing energy equipment owned by each building was shared and inter-operated effectively, and the effects of installing a CGS into an inter-building energy system were simulated.

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TARGET AREA AND BUILDINGS

This study targets two buildings (A and H) in the Kanazawa seaside district of Yokohama city. The kinds of existing heat source equipment, capacity, and the number and performance of this equipment is shown Table 1 and Figure 1.

Table 1 The kinds, capacity, number and performance of existing heat source equipment

	Equipment	The number	Capacity			Co efficiency of Performance (COP)
Bldg. H	GAR	2	Chilled water	[USRT]	400.0	1.11
			Heating water	[MJ/h]	4,653.6	0.95
	EHP	2	Chilled water	[USRT]	32.2	3.88
			Chilled ice	[USRT]	48.6	2.57
	IST	2	Chilled ice	[USRT]	190.0	0.80
	WEHP	2	Hot Water	[MJ/h]	336.0	3.69
Bldg. A	EHP	4	Chilled water	[USRT]	79.4	3.05
			Heating water	[MJ/h]	1,138.2	3.76
	WTST	1	Chilled Water	[USRT]	1,550.0	0.70
			Heating Water	[MJ/h]	19,110.0	0.60
	Bo	2	Hot Water	[MJ/h]	2,520.0	0.63

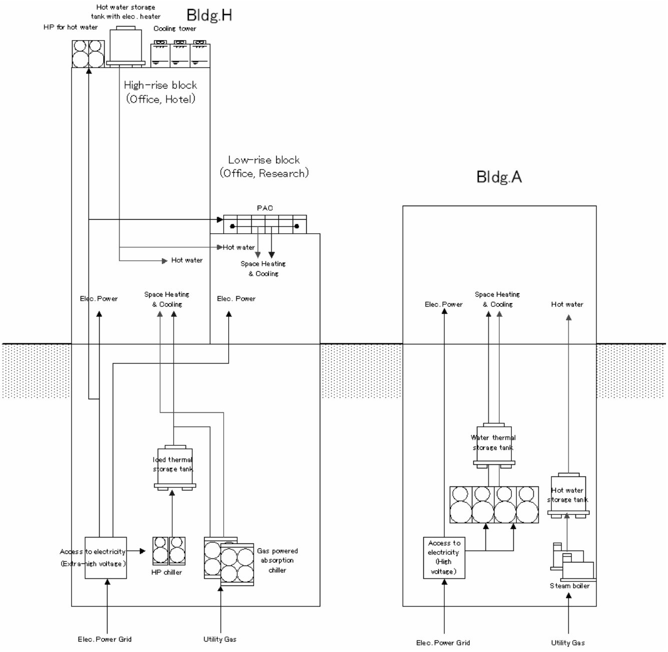

Figure 1 Existing energy system of each building

Building H is large-scale, multi-use building consisting of a high-rise block for office and hotel use, and a low-rise block for office and research use. Total floor space is approximately 50,000 m2. The energy plant is located in the basement. Two gas absorption refrigerating machines (GAR) are installed in the plant and are operated to meet the cooling or heating demand according to the season. Also, electrical heat pump chillers (EHP) and an ice thermal storage tank (IST) are operated for daytime electricity peak reduction during air-conditioning season. The floor managed by the hotel in the high-rise block and all floor space of the low-rise block are individually air-conditioned by multiple package air-conditioners (PAC). Hot water is supplied throughout the building by an electric heat pump (WEHP) installed on the roof. This heat source equipment was installed 12 years ago, but still operated very well. Therefore building H does not need to replace its energy equipment.

Building A is used for accommodations and training foreign engineers. 4 EHPs are installed on the roof and supply chilled water for space cooling or heating water via water thermal storage tanks (WTST) according to cooling or heating demand. An old gas-boiler (Bo) whose COP is 0.63 (HHV) produces hot water. The heat insulator of the water storage tanks and EHP is greatly degraded. Therefore building A urgently needs to replace the energy equipment.

ENERGY DEMAND SIMULATION OF THE TARGET BUILDINGS

Data on electric power consumption per 30 minutes for one year, utility gas consumption per day for one year, and a list of operating equipment were obtained from each building. Equipment specifications were verified from the manufacturer. Based on this information, an interview with operators, and the daily operations reports, the pattern of energy demand and equipment operation were calculated per 24 hours for one year. The pattern of cooling demand (August), heating demand (January), hot water demand (April, August, January), and electric power demand (April, August, January), are shown in Figure 2, Figure 3, Figure 4, Figure 5, respectively. The portion of the heating and cooling demand covered by PAC was calculated as electric power demand because the heating and cooling demand covered by PAC cannot be specified and it is impossible to supply heat for the demand from other heat source equipment.

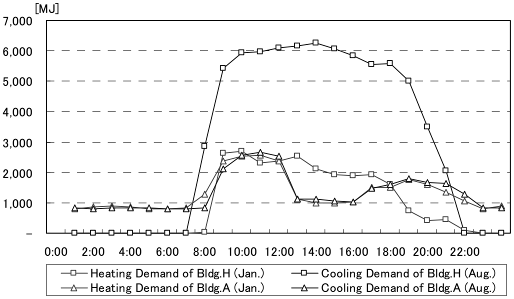

Figure 2 The pattern of heating and cooling demand (January, August)

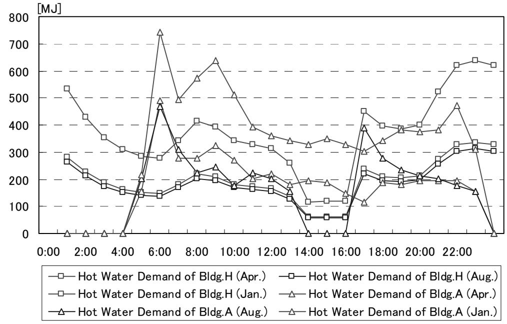

Figure 3 The pattern of hot water demand (January, April, August)

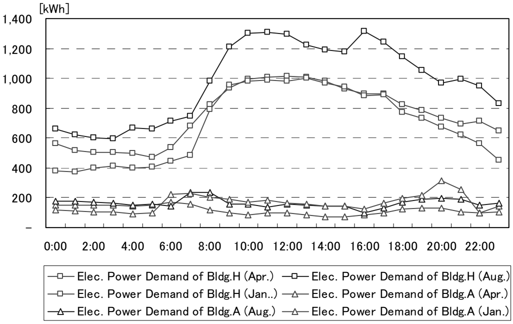

Figure 4 The Pattern of electric power demand (January, April, August)

CASE SETTINGS FOR SIMULATIONS

An inter-building energy system is proposed, based on the calculated pattern of each energy demand and heat source equipment operation, and on the needs for an energy system replacing the current energy equipment of the each building. Case-settings are described in Table 2. This is a stepwise setting for the detailed analysis of the effects of installing an inter-building energy system.

Table 2 Case settings

	Case						
	Base	1	1’-1	1’-2	2-1	2-2	3
Bldg. H	Actual condition	Actual condition	Replacing current energy equipments and installing GE-CGS				
			90kW*4	350kW*1	90kW*4	350kW*1	350kW*2
Bldg. A	Actual condition	Replacing current energy equipments					
					Energy interchange system		

Case 0 shows actual conditions.

In Case 1, the HP and WST of building A are replaced. Building A urgently needs to replace these facilities. The actual condition of building H remains unchanged.

In Case 1’, the heat source of building H is replaced and a new gas engine co-generation (GE-CGS) is installed based on the plan that the heat source equipment of building H will supply heat for building A in the near future, although building H does not need to replace its equipment.

Case 2, is next step of Case1’. Surplus heat of building H’s heat sources is supplied to building A through the inter-building connecting pipes,

Case 1’ and Case 2 have two scenarios where the installed capacity of GE-CGS is two-way. In Case 1’-1 and Case 2-1, four GE-CGS of 90kW are installed, and in Case 1’-2 and Case 2-2, one GE-CGS of 350kW is installed.

In Case 3, two GE-CGS of 350kW are installed, and the GE-CGS in building H supplies surplus heat not only for the hot water demand of building A but also for its heating and cooling demands (Table 3, Table 4).

The GE-CGS electrical capacity produced by gas engines is set so as not to flow out to the power grid when the gas engines operate at capacity, while considering the minimum electric power demand of building H. GE-CGS can be operated exclusively from 8:00 to 22:00 and lower priced midnight power used interim.

GE-CGS generates both electric power and exhaust heat, and the exhaust heat is converted to hot water. This hot water produces chilled water passing the absorption refrigerator (Product name: Genelink). Genelink can be operated only by exhaust heat at 40% load factor, because the reduction rate of gas consumption increases as the load factor decreases. The performance curve of Genelink is shown Figure 5.

The simulation takes into consideration that performance and efficiency change due to fluctuations in the outside temperature and by the load factor of the equipment.

Table 3 Efficiency of GE-CGS in the specification (HHV)

Rated power output	Rated efficiency	
	Power generation	Heat production
350 kW	40.5 %	34.5 %
90 kW	30.5 %	55.5 %

Table 4 Specification of replaced new equipments

	Equipment	The number	Capacity			Co efficiency of Performance (COP)
Bldg. H	Genelink	1	Chilled water	[USRT]	400.0	1.86
			Heating water	[MJ/h]	4,653.6	0.95
	HP for hot water	2	Hot Water	[MJ/h]	336.0	3.69
Bldg. A	HP chiller	4	Chilled water	[USRT]	79.4	4.02
			Heating water	[MJ/h]	1,138.2	3.83
	WTST	1	Chilled Water	[USRT]	1,550.0	0.90
			Heating Water	[MJ/h]	19,110.0	0.90

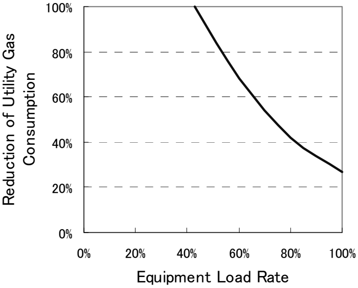

Figure 5 Reduction rate of utility gas consumption by load factor of Genelink

The effects of replacing the heat source and installing GE-CGS can be calculated by a comparison with Case 0. However, to derive the effects of the inter-building energy system, Case 1 is used as the comparison base case. Since the energy source equipment of building H is not in need of replacement, it is assumed that there is no intention to replace the energy system in near future. Therefore, the effect will be differences between Case 1 and Case 2. By providing a detailed description of the differences of Case 1 and Case 1’, the effect resulting from the installation of an inter-building energy system will encourage building H to replace its heat source equipment. The difference between Case 1’ and Case 2 is the effect resulting from surplus heat of building H interchanged to building A. And the difference between Case 2 and Case 3 is the effect resulting from inter-building energy system facilitating the installation of a much larger CGS capacity. Table 5 shows the primary energy equivalencies of utility gas and electric power used in this simulation. The CO_2 emissions rate of purchased electric power is the average CO_2 emissions rate of electric power produced by thermal power plants because GE-CGS is assumed to be operated in the daytime, so the power generated from GE-CGS alternates the power generated from a thermal power plant.

Table 5 Primary energy equivalencies rate and CO_2 emission unit

		Primary energy equivalent rate	CO_2 emission unit
Utility gas (13A)		41.55 [MJ/Nm^3]	2.36 [kg-CO_2/Nm^3]
Purchase electric power	Daytime	9,420 [kJ/kWh]	0.56 [kg-CO_2/Nm^3]
	Night	8,845 [kJ/kWh]	

RESULTS OF THE SIMULATION

System COP = each energy demand / each energy consumption for each energy demand･･･exp1

System COP is described as exp1 and shows the system efficiency for each energy demand (heating, cooling, and hot water). Efficiency of CGS power generation is assumed to be the same as purchased electric power. The primary energy consumption of CGS is divided into power production and heat production. Also, the primary energy consumption of heat production of CGS is the allocated heat for heating, for cooling, and for hot water in proportion to their energy demand (Figure 6).

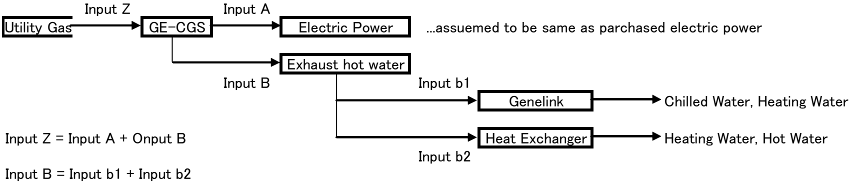

Figure 6 The way to allocate a primary energy for calculation of system COP

Table 6 shows the annual system COPs for heating, cooling and hot water for each case. Installation of GE-CGS leads to improvement in the heating system COP and cooling system COP of building H (Case 1). In spite of using high-efficiency Genelink, no measurable improvement in the cooling system COP could be seen in the case of 90kW*4 GE-CGS because more exhaust heat is created by GE-CGS than can be used. 350kW GE-CGS has higher efficiency than 90kW GE-CGS, and generates less heat than 90 kW GE-CGS. So the cooling system COP is improved in the 350kW GE-CGS case. However, the heating system COP did not improve. The advantages of the installed GE-CGS could not be utilized. This was due to GE-CGS having an unsuitable balance between heat demand and electric power demand. The inter-building energy system encourages effective utilization of surplus heat produced by GE-CGS, and the total system COP improved.

Table 6 Calculated annual system COPs of each energy demand

Simulation Cases			Case0	Case1	Case1'-1	Case1'-2	Case2-1	Case2-2	Case3
	Energy Demand [TJ/year]				**GE90**	**GE350**	**GE90**	**GE350**	**GE350*2**
Bldg.H	Cooling	6.87	0.73	0.73	**0.75**	**0.83**	**0.95**	**1.06**	
	Heating	2.03	0.63	0.63	**0.56**	**0.63**	**0.66**	**0.64**	
	Hot water	2.18	0.50	0.50	**0.83**	**0.83**	0.83	0.83	
Bldg.A	Cooling	2.55	0.71	**0.88**	0.88	0.88	0.88	0.88	
	Heating	3.08	0.62	**0.71**	0.71	0.71	0.71	0.71	
	Hot water	2.06	0.52	0.52	0.52	0.52	**0.67**	**0.64**	
Bldg.A+H	Cooling	9.42	0.72	**0.76**	**0.78**	**0.84**	**0.93**	**1.01**	**0.74**
	Heating	5.11	0.63	**0.68**	**0.64**	**0.68**	**0.69**	**0.68**	**0.72**
	Hot water	4.24	0.51	0.51	**0.64**	**0.64**	**0.75**	**0.73**	**0.67**

Total COP = total energy demand / total energy consumption for total energy demand・・・exp2

Total COP is defined as the total efficiency of all of the buildings. In this study, the Total COP is significantly improved by 2 steps (Figure 7). The first step is when GE-CGS is installed in building H (Case 1'), and the second step is when surplus heat from GE-CGS is supplied, not only to building H, but also to building A by inter-building pipes (Case 2).Also the Total COP for the 350kW GE-CGS case is higher than that for the 90kW GE-CGS case. In Case 3, no improvement in Total COP is seen due to the capacity of 350kW*2 being too large to utilize all the generated heat.

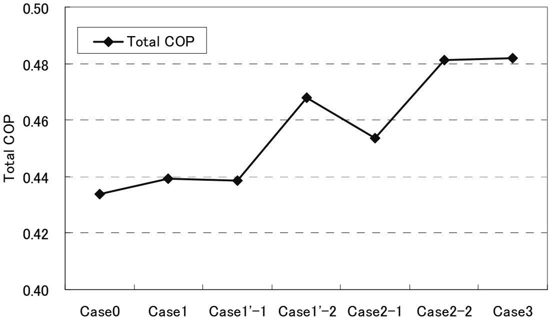

Figure 7 Calculated annual Total COP

EFFECT OF REDUCTION OF THE CO2 EMISSION AND RUNNING ENERGY COSTS

Figure 8 shows purchased electric power consumption and utility gas consumption in each case.

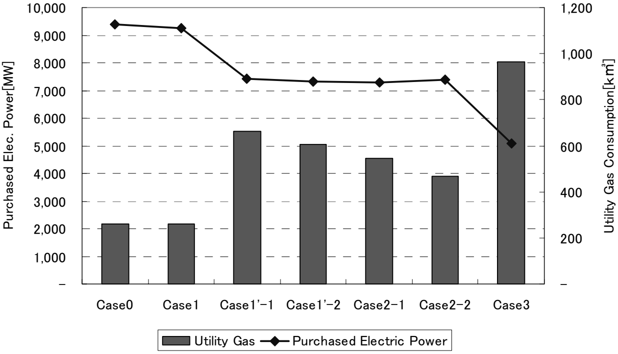

Figure 8 Purchased Electric Power and Utility Gas Consumption of each Case

Figure 9 is compiled Figure8, shows the reduction rate of energy consumption, CO2 emission and running energy cost. The reduction rate of energy consumption is improved by GE-CGS installation. But the case1'-1 is lower value, because the power production efficiency of 90kW GE is lower, utility gas consumption and surplus heat is larger. When Case1 is considered base case, the reduction rate of energy consumption by 350kW GE-CGS installation is about 3.3 % (Case1’-2 – Case1), one by energy interchange among buildings is 5.6 % (Case2-2 – Case1’-2). The reduction of CO2 emission is improved step by step. Because it is considered that the power production by GE-CGS takes thermal power plant in this study. On the reduction of running energy cost, Case2-2 is largest cost in all cases. But actually maintenance of GE-CGS must be considered because Case2-2 has only one GE-CGS.

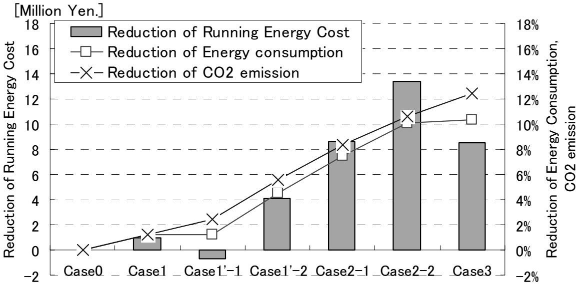

Figure 9 Reduction rate of energy consumption, CO2 emission, and running energy cost

CONCLUSIONS AND PERSPECTIVES

The effects of Inter-building energy system with GE-CGS are simulated in each case by stepwise setting.

- Inter-building energy system encourages effective utilization of heat produced by CGS, and reduces largely energy consumption.

- The reduction rate of energy consumption by 350kW GE-CGS installation is about 3.3 %, one by energy interchange among buildings is 5.6 % in additional.

- Increasing capacity of GE-CGS not always brings improvement of system COP, capacity and numbers of GE-CGS installation and operation is studied enough.

Studying optimal capacity of a GE-CGS installed inter-building energy system was outside the scope of this research. Furthermore, using the thermal storage tank to temporally match the heat generated by CGS with heat demand was not considered.

And it is recommended to address these issues in future research.

REFERENCES

1. Japan District Heating and Cooling Association (1995) “Report of the research on feasibility of DHC introduction in Japan”
2. Japan Energy Association (2005) “Manual for planning and designing of cogeneration systems by natural gas”
3. S. Yoshida, M. Kiyota, et al. (2007) ”Study on the Effects of Introduction of the Energy Flexibility system between Buildings in Yokohama-Kanazawa area” Summaries of technical papers of annual meeting of AIJ (Submitted)