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APPLICATION MULTI-OBJECTIVE GENETIC ALGORITHM FOR OPTIMAL DESIGN METHOD OF DISTRIBUTED ENERGY SYSTEM

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ABSTRACT

Distributed energy system based on cogeneration system has high potential of energy saving due to utilizing waste heat from power generator effectively. However, unless the appropriate combination of machinery and operation are conducted, the expected performance is not achieved, it is quite difficult to determine the optimal combination of machinery and operation. Authors had already developed and proposed new optimal design method for building energy systems or distributed energy systems using Genetic Algorithm (GA) in some previous studies (e.g. Ooka R et al, 2008). GA could deal with nonlinear optimization problems. The proposed method designs the most efficient energy system by optimizing operation of available systems in consideration of optimal machinery capacity in the systems. However, it can intend just only optimization of primary energy consumption. For practical use, it is necessary that the method is able to search optimal energy systems with various kinds of objectives, such as environmental impact factors, economical factors, building structural factors, and so on. Therefore, the method was improved to be able to exam the energy systems with various kinds of objectives using Multi-Objective Genetic Algorithm (MOGA) in this study. This study has developed the optimal design method for energy system of single building for the first step aiming at establishing optimal design method for distributed energy system. A case study of hospital building was carried out to examine application possibility of the method as an optimal design tool.

INTRODUCTION

Distributed Energy System

Distributed energy system is expected to enlarge usage of renewable energy or unused energy effectively, or to raise energy efficiency higher working as local energy network. Distributed energy system based on cogeneration system has high potential of energy saving due to utilizing waste heat from power generator effectively. However, unless the appropriate combination of machinery and operation are conducted, the expected performance is not achieved. Thus, it is quite difficult to determine the optimal combination of machinery and operation. To promote application of distributed energy system widely, optimal design method for it is needed. In practical design process of energy systems, there are many draft plans that may be candidate of optimal plan. However, it is hard to evaluate it as exclusive optimal plan, because there are various kinds of aspects among stakeholders (such as building designers, building owners, energy providers, and energy system engineers), for example, minimization of cost, energy consumption, number of machineries, and so on. For practical use, it is necessary that the method is able to search optimal energy systems with various kinds of objectives, such as environmental impact factors, economical factors, building structural factors.

Optimal Design Method

About optimal design method for energy system, some researchers have developed and proposed the method applying some optimization techniques. Some researchers (e.g. Sundberg G et al, 1997) established it based on linear Programming (LP), but LP has difficulty to examine application for the recent machinery, which has nonlinear characteristics. Description machinery characteristic with nonlinear equation is needed. In consideration of the problem, Huang or Fong applied GA to the optimization of the control parameters of HVAC (e.g. Huang W et al, 1997), Ohara used GA to operation optimization of complex energy system (Ohara S et al, 2003), and D.A. Manolas proposed using GA (Manolas D. A. et al, 2007). However, their methods are established for specific energy system, which has its own machinery combination, and its capacities are already known. Authors had already developed and proposed new optimal design method for building energy systems or distributed energy systems using Genetic Algorithm (GA) in some previous studies (e.g. Ooka R et al, 2008). This method designs the most efficient energy system by optimizing operation of available systems with consideration of optimal capacity size of machinery in the systems. GA could deal with nonlinear optimization problems. The proposed method designs the most efficient energy system by optimizing operation of available systems in consideration of optimal machinery capacity in the systems. However, it can intend just only optimization of primary energy consumption.

Therefore, the method is improved to be able to exam the energy systems with various kinds of objectives using Multi-Objective Genetic Algorithm (MOGA) in this study.

METHODOLOGY

Energy System Modeling

To calculate energy consumption of system, system model is composed of three elements, fuel resource, system machinery, and energy demand. Figure.1 shows the correlation among elements. There are three types of fuel resources, city gas, electricity, and solar energy. There are four types of energy demands, CD as cooling demand, HD as heating demand, WD as hot water demand, and ED as electricity demand. Table.1 shows fundamental machinery line up and its abbreviation of this energy system model. Machinery has its own characteristics, fuel resource and possible supply.

Chromosome Coding

Figure.2 indicates chromosome information in this study. When machinery combination is made with GA operators, machinery capacity is selected as chromosome information. Chromosome has sixteen cells relating to output form. To exam machinery division, each machinery has two cells. 5th, 9th, and 13th information is about fuel type of HP, electricity or gas. Information of Photovoltaic Power System (PV) is set by square scale [m^2] to place it.

Demand Data

In the analysis, demand data is referred to default data of "Computer Aided Simulation for Cogeneration Assessment & Design III" (CASCADEIII) provided by the Society of Heating, Air-Conditioning and Sanitary Engineers of JAPAN (SHASE). Each demand data are classified [kW/m^2] or [kWh/m^2], which were investigated existing building. To use the value in the calculation, representative data of each season is selected. August day as summer demand, April day as middle season demand, and January day as winter demand. 24 hours on a representative day of each month is set as input data of calculation.

Machinery Database

Database has information about machinery capacity, fuel consumption, initial cost, running cost, weight, and necessary space to place included maintenance space. The database is built to be able to calculate with chromosome information. The necessary data is searched and assembled from manufacturer's catalogue, or published documents.

Machinery Performance

Figure.3 shows the performance curve of machinery such as Absorption Refrigeration Machine (AR), Heat Pump System (HP), Gas Boiler (GB) and Co-Generation System (CGS). The performance curves become non-linear function of the machine load rate

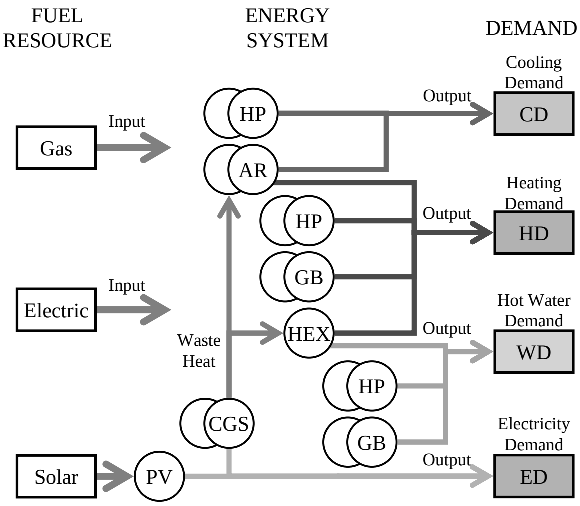

Figure.1 Fundamental Flow Form of Energy System

Table.1 Machinery Line up

		COP		Input		Output			
		C	H	Gas	Elec	C	H	W	E
AR	Absorption Refrigeration Machine	1.1	0.8	●		●	●		
HP	Electrical Heat Pump System	1.4	1.4		●	●	●	●	
GB	Gas Boiler	---	0.9	●			●	●	
CGS	Co-Generation System	0.36*1		●		○	○	○	●
PV	Photovoltaic Power System	---							●

C: Cool Heat H: Hot Heat W: Hot Water E: Electricity

○ : output as waste heat

COP: Coefficient of Performance (=Output/Input)

※COP value of this study is based on catalogue information.

*1 : COP of generation only (not include waste heat efficiency)

	1	2	3	4	5	6	7	8	9
source	Cool Heat Supplier					Hot Heat Supplier			
name	AR1	AR2	HPc1	HPc2	eneHP	GBh1	HPh1	HPh2	eneHP
unit	USRT	USRT	HP	HP	G/E	kw	HP	HP	G/E

	10	11	12	13	14	15	16
• • •	Hot Water Supplier				Electricity Supplier		
	GBw1	HPw1	HPw2	eneHP	CGS1	CGS2	PV
	kw	HP	HP	G/E	kw	kw	m^2

Figure.2 Coding of Chromosome

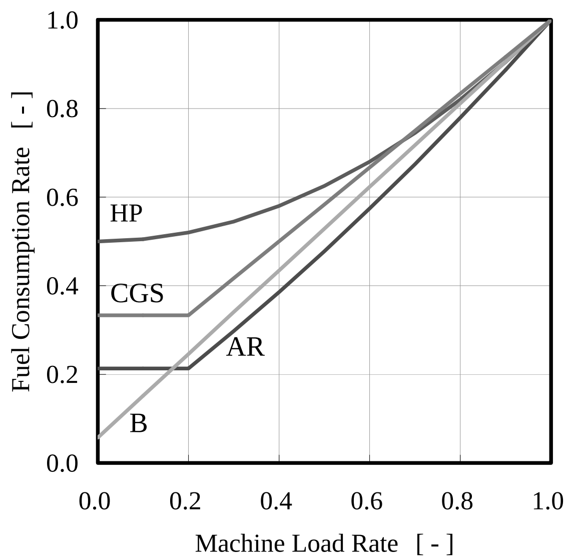

Figure.3 Machinery Performance

except GB. Machinery efficiency is defined as performance fuel consumption rate. Because high driving control technology with the inverter developed, the machinery characteristic has a non-linear energy input and output power characteristic. It is said that optimization technique using GA can beeffective by the non-linear machinery chalacterstic to change by machinery capacity or load factor greatly. The machinery data referred to a manufacturer catalogue value and the value of the machinery of the CEC/AC calculation program "BECS/CEC/AC for Windows" published by Institute for Building Environment and Energy Conservation (IBEC) based on energy saving method. The machinery capacity in CGS adopted a manufacturer catalogue value, but assumed the facility of the calculation a fixed value of generation efficiency 45.6%, exhaust heat efficiency 31.4% about the machinery efficiency to plan becoming it. The fuel consumption efficiency referred to information of AR and calculated. The generation efficiency of the commercial electricity adopted 52.8% (efficiency of generator edge) of the 1,500 degree combined cycle generator (MACC).

Cost Calculation

In this study, both initial cost and running cost are examined as cost parameters. Energy price of commercial electricity is 28.28 [JPY/kWh] and that of city gas is 131.85 [JPY/m^3(N)], and both of them are constant value in this study. Initial cost of each machinery is calculated with the following formula (1). Basic formula form is made in order to enable to calculate with the variables based on chromosome information.

$$F_{cst} = \mathrm{a}x_{capa}^{2} + \mathrm{b}x_{capa} + \mathrm{c} \qquad \text{-(1)}$$

F_{cst} is the initial cost of machinery and x_{capa} is the capacity of machinery (chromosome information). The coefficients of each formula are shown in Table. 2 and Table.3.

Table. 2 Coefficients for Cost to Install

Cost to Install		a	b	c
AR	10^3 JPY/USRT	0.00002	-0.0113	4.6348
HP	10^3 JPY/kw	0.4874	-8.2716	110.51
GB	10^3 JPY/kw	0.0000001	-0.0002	0.2826

Table. 3 Coefficients for Price of Machinery

Price of Machinery		a	b	c
AR	10^3 JPY/USRT	0.0002	-0.231	104.43
HP	10^3 JPY/kw	0.0331	-0.859	8.4988
GB	10^3 JPY/kw	0.0001	-0.0451	7.1259

Objectives

The objectives are mainly minimization of primary energy consumption and cost. Objective energy consumption does not include initial energy to construct energy system, but objective cost includes both initial cost and running cost. Objectives about cost consist of initial cost that includes machinery price and installing cost, and running cost that is based on energy prices. In addition, objectives about total machinery weight and volume are set as building structural factors.

SIMULATION

Object Building

In this study, case study was calculated to exam its validation of the model. Hospital was selected as a case study, which is 6,000m^2 located in Tokyo, Japan. About the seasonal demand of hostpital buildings, there are high heating demand (HD) in winter and high cooling demand (CD) in summer, but these demands are not required in other season. Hot water demand (WD) and electricity demand (ED) are required constantly through the year. To see the daily change, CD and HD have big gap between daytime and nighttime. Optimum energy system adapting these demand properties is inquired by examining the system combination and operations.

Design Variable

Table.4 shows the selection range of each variables. The variables are not continuous, but step change machinery lineup. Basically [kw] is used as an unit in the calculation model. The machinery which can provide both cool heat and hot heat, are used other unit, [USRT] such as AR, or [HP] such as HP. In the calculation, [USRT] or [HP] is converted to [kw] of necessary supply.

Table.4 Design Variables

Cool Heat Supply				Hot Heat Supply			Hot Water Supply			Electricity Supply		
AR1 [USRT]	AR2 [USRT]	HP1 [HP]	HP2 [HP]	GB1 [kw]	HP1 [HP]	HP2 [HP]	GB1 [kw]	HP1 [HP]	HP2 [HP]	CGS1 [kw]	CGS2 [kw]	PV1 [m^2]
0	0	0	0	0	0	0	0	0	0	0	0	0
30	30	10	10	58	10	10	58	10	10	115	115	50
40	40	16	16	87	16	16	87	16	16	200	200	100
50	50	20	20	116	20	20	116	20	20	230	230	150
100	100	25	25	151	25	25	151	25	25	300	300	200
120	120	32	32	186	32	32	186	32	32	350	350	500

MOGA Parameter

In this case study, there were 100 individuals in each generation, and number of generations was set 100. So the estimated number of runs were 10,000. The mutation rate was 0.05 regarding the experiences in previous calculations done by authors (e.g. Ooka R et al, 2008).

DISCUSSION AND RESULT ANALYSIS

Pareto Optimal Solutions

Figure.4 shows the distribution of pareto optimal solutions. Its horizontal axis indicates primary energy consumption of three days and vertical axis indicates initial and running cost. All of dots are runs in 100th generation which was last generation in this calculation. Black dots indicate the pareto optimal solutions of this case study. Between these two objectives, there was the relationship of trade-off. On the other hand, there was directly proportional relationship among other objectives. In order to investment scale for energy system or regulation by government, acceptable bound is able to be determined in this figure. It is expected that the method can provide various objective views to make decisions among stakeholders in practical design process.

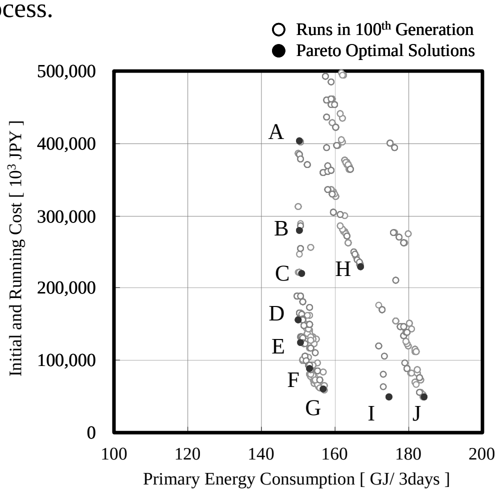

Figure.4 Result of Pareto Optimal Solutions

Machinery Combination Comparison

Table.5 shows the result of ten energy system combinations selected from pareto optimal solutions. System candidate "D" is minimum energy consumption, and system candidate "J" is minimum cost consumption among these 10 candidates. Regarding primary energy consumption, system candidate "D" requires approximately 81.5% of system candidate "J" requires in this case study,. On the other hand, regarding initial and running cost, system candidate "J" requires approximately 30.8% of system candidate "D" requires. This result shows the cost effectiveness of each candidate when planning energy system.

Optimal Operation Comparison

Figure.5 shows the optimal operation of two systems, system candidate "D" and system candidate "J". In system candidate "D", waste heat from two CGSs operates for fundamental loads through all day, and in some daytime peak load, other machineries work. In middle season, waste heat are supplied for WD, therefore other machineries for WD is not needed in middle season. On the other hand, there is no CGSs in system candidate "J". Two ARs operates through all the day in winter and summer season. Sinse two ARs have the little difference about capacity, there are priority to operate ARs relating to demand situation. This results show that there is optimal operation patterns depending on machinery combination of the system. This design method provides the optimal operation guideline for energy system engineers.

Calculation Time

In this case study, it took four hours and half to complete all 10,000 runs. This calculation was perfomed on the computer with POWER 5+ 1.5GHz and 2GB RAM. Regarding current progress of PCs, it is evident that the application of this method requires no special hardware. Therefore the calculation time is adaptable enough for practical use.

CONCLUSION

(1) In this study, the previous model was improved to be able to exam the energy systems with various kinds of objectives using Multi-Objective Genetic Algorithm (MOGA), and case study was calculated to exam its validation of the model.

(2) The case study results showed the result distribution of pareto optimal solutions. Since acceptable bound is determined in the result distribution in order to investment scale for energy system or regulation by government, it is expected that the method can provide various objective views to make decisions among stakeholders in practical design process.

(3) The result of ten energy system combinations selected from pareto optimal solutions showed the cost effectiveness when planning energy system.

(4) The case study results also showed that there is optimal operation patterns depending on machinery combination of the system. It means that there is possibility for this model to provide the optimal operation guideline for energy system engineers.

(5) This case study showed it is evident that the application of this method requires no special hardware, therefore the calculation time is adaptable enough for practical use.

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OPERATION OF SYSTEM "D" — ENERGY CONSCIOUS PLAN

OPERATION OF SYSTEM "J" — COST CONSCIOUS PLAN

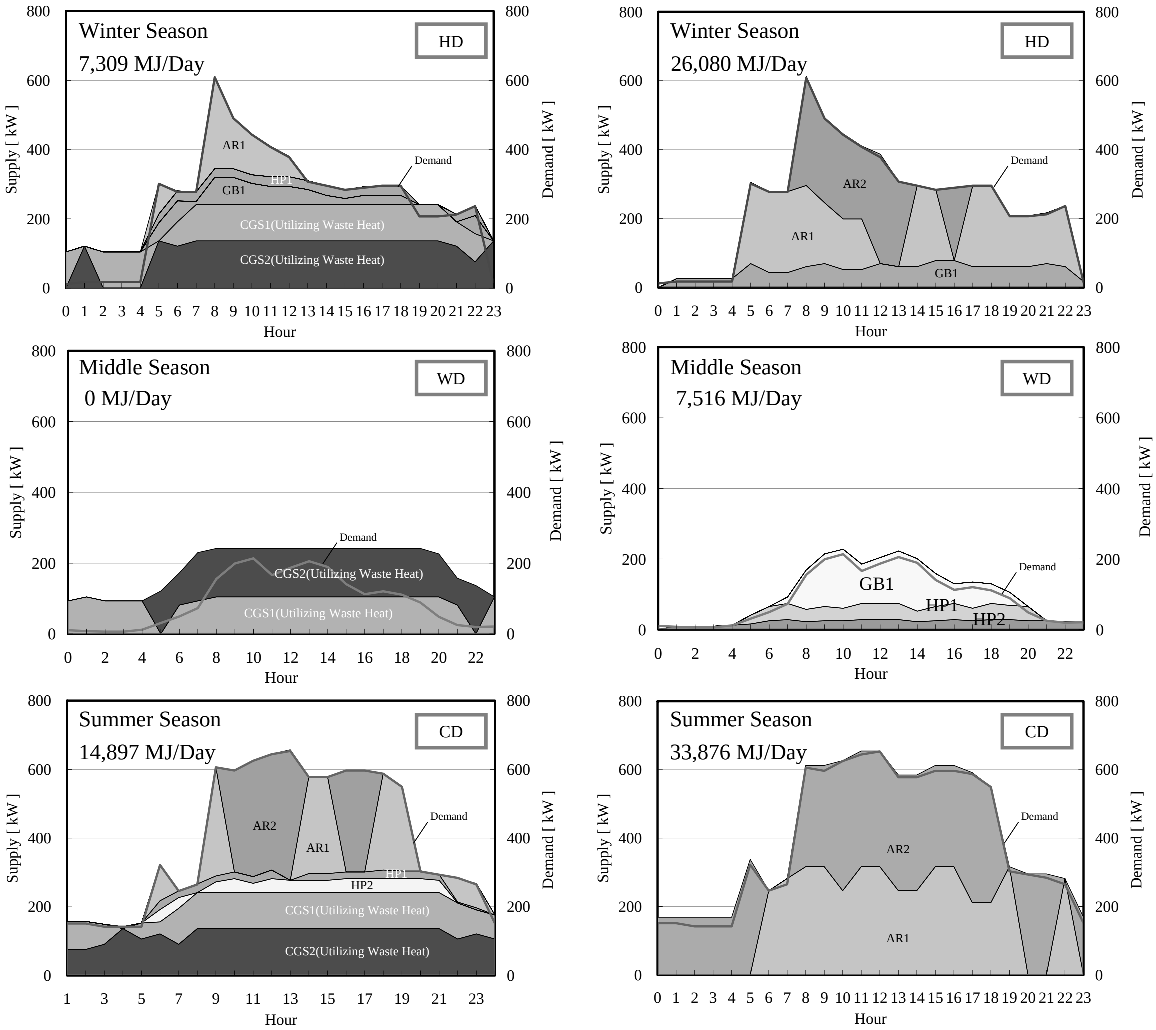

Figure.5 Optimal Operation of System Candidate "D" and System Candidate "J"

Table.5 Candidate of Pareto Optimal Solutions

SYSTEM CANDIDATE	Cool Heat Supply				Hot Heat Supply			Hot Water Supply			Electricity Supply			RESULT of OBJECTIVES			
	AR1	AR2	HP1	HP2	GB1	HP1	HP2	GB1	HP1	HP2	CGS1	CGS2	PV1	ENERGY	COST	WEIGHT	VOLUME
	[USRT]	[USRT]	[HP]	[HP]	[kw]	[HP]	[HP]	[kw]	[HP]	[HP]	[kw]	[kw]	[m^2]	[MJ/3days]	[10^3JPY]	[t]	[m^3]
A	100	120	0	16	116	10	0	186	10	32	200	300	500	150,463	402,476	43.05	115.16
B	100	120	10	16	116	10	0	151	25	16	200	300	500	150,430	278,365	43.55	116.09
C	100	100	10	10	116	10	0	151	20	20	200	300	500	150,984	219,439	42.23	112.22
D	100	120	10	16	87	10	0	186	16	10	230	300	500	**150,072**	155,385	44.29	116.51
E	100	120	10	0	87	10	0	186	16	10	230	300	500	150,704	124,269	43.50	112.71
F	100	120	10	10	87	10	0	186	10	10	230	300	200	153,189	87,024	43.96	114.74
G	100	120	0	0	116	10	0	186	10	10	200	300	0	157,076	59,213	41.68	106.23
H	100	120	0	0	151	0	0	116	20	25	200	0	0	167,065	228,982	27.51	71.04
I	100	120	0	0	151	0	0	186	10	10	0	115	0	174,831	48,659	23.25	57.70
J	100	120	0	0	87	0	0	186	10	10	0	0	0	184,208	**47,908**	**16.03**	**39.68**

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