Session 2.10: Transforming SBE Practices – Energy Management (1)

Development of an Integrated Energy Simulation Tool for Buildings and MEP Systems, the BEST: A Pilot Study on Simulation of Demand Response with Cogeneration Systems

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ABSTRACT

Based on the experience of East Japan Earthquake in 2011, demand response is expected to be one of the effective measures to deal with tight supply-demand balance by motivating consumers to contribute peak cutting of electric power demand.

Cogeneration systems are one of the well-known major options for efficient energy use for demand side. Currently cogeneration systems have been adopted in buildings for the purpose of increasing self-sufficiency of power supply. In addition, they are expected to play a role to contribute demand response (DR) in the electric power market to reduce fluctuation within power grid caused by certain amount of renewable energy in the future.

This study is a pilot study of simulation by use of The Building Energy Simulation Tool (BEST). BEST has been developed under the initiative of Ministry of Land, Infrastructure, Transportation and Tourism, which handles housings and facilities in an integrated manner in order to assess the energy performance of buildings as a whole.

Focusing on DR periods and incentives, several DR controller models for the BEST has been developed which operate equipment modules depending on some conditions such as outside temperature, grid power demand, etc. to be considered to determine DR signals. This paper shows some examples of cases of a variety of demand-side options such as cogenerations, heaters and chillers by use of the BEST program. In this study, as a pilot case, assuming automatic demand response (ADR), five-steps of DR signals are available to simulate several situations and evaluation of effectiveness of some incentive options.

Key findings is that the BEST simulation adapting to DR, trade-offs between cases are clarified, such as that DR control using CGS contributing to provide economic incentives by alternating grid power in DR period, keeping the thermal environment for office workers.

Keywords: *demand response, cogeneration system, building energy simulation*

1. INTRODUCTION

Japan experienced serious restrictions on the electric supply capacity after the Great East Japan Earthquake in 2011, which played an important role in changing nation-wide electric power supply systems and influenced the Electricity Business Act to be amended for the first time in 60 years. As part of the amendment, measures are being sought to effectively supply electric power throughout the country. The government expects that by making use of the capabilities of companies and individuals through use of surplus electric power (negawatts) generated by power saving and energy saving, reduction of electric power demand according to the tight balance between supply and demand (Demand Response: DR) and so forth, the supply cost can be reduced while the stable supply of the system power can be secured.

When DR is implemented and power usage is restricted, the need to avoid inconveniences in economic activities and daily life due to excessive power saving would arise on the consumer side. It is considered that effective measures are to use self-supporting power supply systems (cogeneration, solar power generation, and so forth), to use heat-driven chillers and heaters in addition to electrically powered chillers and heaters and to have power storage or heat storage functions on the consumer side.

In this study, on the assumption that DR would be implemented, the BEST (Building Energy Simulation Tool) is proposed to be used as a simulation tool for appropriate system configuration or operation planning in the case of the introduction of a cogeneration systems. The BEST has been developed under the initiative of Ministry of Land, Infrastructure, Transportation and Tourism, which handles building envelops and building facilities in a coupled mode and which calculates load and energy consumption by minutes in order to accurately assess the energy performance of a building as a whole. This study is a pilot study applying BEST simulation to deal with DR on the building facilities and be used in estimation of peak-cut effects brought about by implementation of DR and verification of incentives.

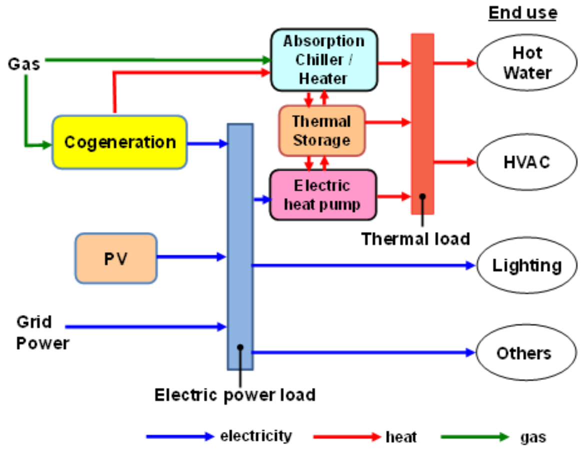


Figure1: Example of demand side energy system adaptable to DR control

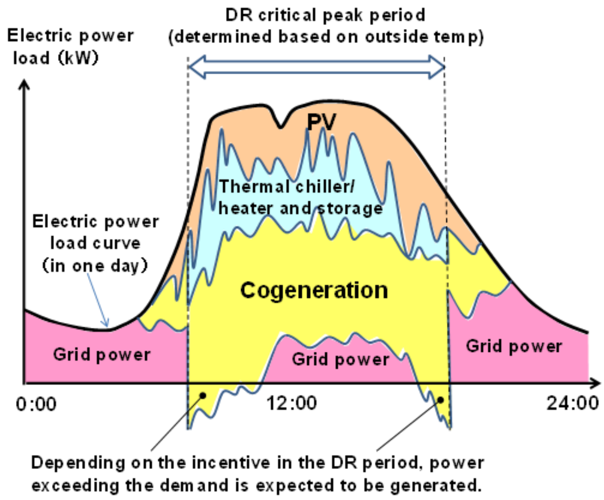


Figure 2: Image of power supply on the demand side in one day

2. BASIC CONCEPT

In the U.S., various methods already exist. Here, the following measures are focused on as the consumers' efforts:

- Change to power supply from the grid power using self-supporting power supply systems (Cogeneration, solar power generation, and so forth) on the consumer side
- Shift from electrically driven chillers and heaters to those of heat-driven for air conditioning system

It is considered that for a building where a cogeneration system is planned to be introduced, it is necessary to select the power source and heat source with an appropriate capacity and to make a plan so that the system can be flexibly operated with consideration given to the following items assuming that DR is implemented in the future:

- Avoidance of restrictions on business operations and daily life while DR request is made
- Continuity of energy saving while DR request is made
- Economic incentives for those who have the DR adaptive equipment

To verify the above requirements in the planning stage, the BSET program which has already developed in consideration of the characteristics of cogeneration system can be used. As a pilot study, operation simulation for some cases including cogeneration is conducted by use of the BEST program assuming that the DR request is effective. Specific case studies are described below.

3. CASE STUDIES

3.1. Case studies

For the case study, a provisional office building located in Tokyo that has 14 stories above ground and one story below and has a gross floor area of 20588.88m^2.is selected. Depending on the presence or absence of a cogeneration system and the presence or absence of DR control, several cases are assumed. The assumptions of the cases are shown in Table 1, in which a cogeneration system (CGS) is comprised of two gas engines (370 kW) and heat source equipment consisting of an exhaust heat input-type absorption water cooling/heating machine and a heat exchanger for heating.

Building type: office Gross floor area : 20588.88m^2 14 stories + 1GL Location: Tokyo

	Equipment		DR control method in demand side
	Power Generation	Chiller / Heater	
Case 1 **CGS + DR control**	Gas engine 370kW x2 Generation efficiency: 41% (LHV)	Waste heat absorption chiller / heater 400kW	When the DR request is issued, the equipped CGS is operated with the maximum power generation output so that it is adapted to the air conditioning/power loads without deteriorating the thermal environment in the office and further, surplus electric power is provided outside of the premises.
Case 2 **CGS** Without DR control			As a comparative case with Case 1, regardless of the presence or absence of the DR request, the operation of CGS following the power load curve in the premises is assumed.
Case 3 Non CGS **DR control**	(non CGS)	Electric Heat Pump (Air cooling) 750kW x2 COP=4.45	When the DR request is issued, the set temperature for the air conditioning equipment is changed to reduce the load of the electricity driven chillers and heaters and the load processing is partially restricted by power saving. To compensate for this, the thermal environment in the office deteriorates, forcing office workers to endure such conditions during DR control.
Case 4 Non CGS Without DR control			Even if the DR request is issued, the set temperature is not changed. The indoor environment is maintained through purchase of expensive peak period electric power. In this case, a trade-off between performance and cost can be evaluated.

Table 1: Overview of the case description

Depending on the outside air temperature, the DR request signal is issued, and the gas engines and the chillers and heaters are controlled. In this study, when the outside air temperature is 30°C, 31°C or 32°C, the DR control level is changed in three stages: Level 1, 2 and 3. When the DR request is issued, the assumed control menus are as follows:

- The gas engine operation are changed to the maximum power generation output.
- The heat source outlet temperature is changed to 7°C, 8°C and 9°C, in that order.
- The set room temperature for the air conditioning equipment is changed to 27°C, 28°C, 29°C, in that order.

3.2. Control methods to deal with DR request

Table 2 shows control methods to deal with DR request issuing conditions assumed in this study. For the outside air temperature exceeding 30°C, three levels are set. The outside air temperature was assumed using data for Nerima Ward in Tokyo in August 1995. In 1995, the average temperature in the same area in August was the highest in 25 years, and the number of days when the daily maximum temperature of 35°C or higher was recorded was relatively large.

For this pilot study, a DR controller for the BEST program has been developed which includes levels 1 to 5. The gap (differential) between operations for making the control stable can also be set arbitrarily.

Category	Devices to be controlled	Control method for DR critical peak period
Power generation	Gas engines	The power generation control is changed to "maximum power generation output".
		The power generation output is changed.
Air conditioning (Secondary side)	Rooms	The set room temperature is moderated.
	Air handling units	The air blowing temperature is moderated.
		The intake amount of outside air is limited.
		Air conditioner is stopped (intermittent operation).
Air conditioning (Primary side)	Heat source units	The heat source outlet temperature is moderated.
		The chilled water supply temperature is moderated.
		The electric heat source is stopped.
	Heat storage tanks	Heat is dissipated during the DR time period.
		Surplus heat is stored.
Lighting	Lighting	Thinned-out lighting
Storage battery	Storage batteries	Electric discharge is operated during the DR time period.

Table 2: DR control methods in the demand side

3.3. Results and considerations

The examples of the results of the simulations for three months (July to September) in the summer season are shown in Figure 3 and Figure 4.

3.3.1 Operation status of the system

Figure 3 describes some of the results in Case 1. In Case 1, for the DR control, CGS was operated at the maximum capacity, and the exhaust heat was used for cooling as much as possible, and the surplus electric power was flowed in reverse to the grid power and contributed as supply capacity to the system

3.3.2 PMV frequency distribution

Figure 4 shows the PMV frequency distribution for three months in summer season in Case 1 (with CGS and absorption chiller) and Case 3 (electric HP). In both cases, the frequencies were counted only in the time frame when air conditioning was operating. In Case 1, PMV was maintained at around 0.5, while in Case 3 where office workers are forced to endure the conditions, PMV became around 1.5 in the time frame when the DR request was issued, which shows that the conditions worsened and people in the room were forced to endure such conditions.

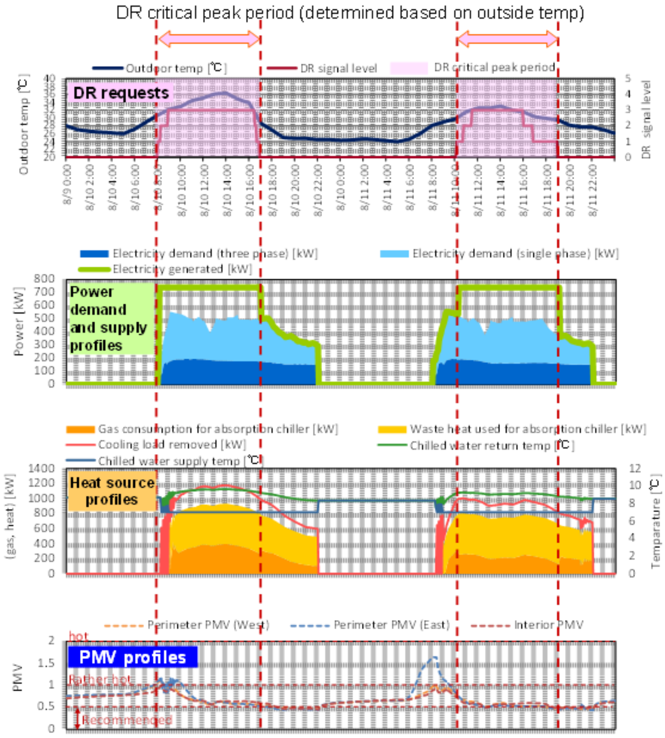


Figure 3: Example of simulation results (Case 1: CGS with DR control; Aug 10–11)

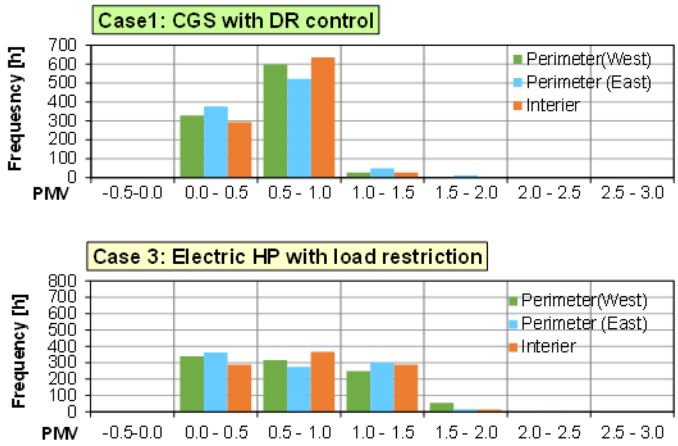
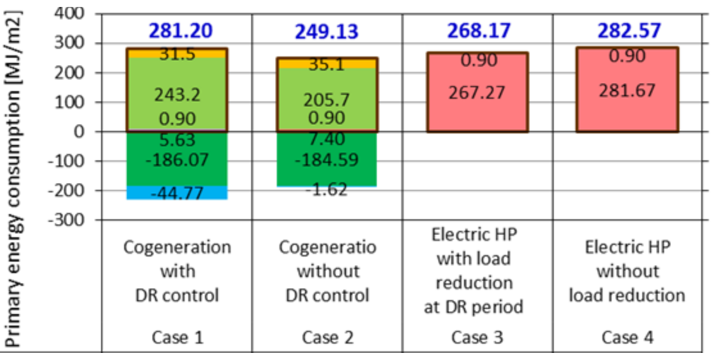


Figure 4: PMV frequency distribution (Case 1 and Case 3)

3.3.3 Primary energy consumption

Figure 5 shows the comparison result of the primary energy consumptions, with the evaluation of the peak time period added, for three months (July to September) in the summer season in the Tokyo area. Some of the generated power is provided to outside of the site, and at the same time, the operating rate of the exhaust heat input-type absorption refrigerator is increased by use of exhaust heat from power generation. Further, according to the guideline concerning levelling of electricity demand newly incorporated into the Energy Conservation Act amended in 2013, when 1kWh of the system electric power consumption in the specific time zone (8:00 - 22:00) is reduced, it will translate as 1.3kWh of the consumption being reduced (energy saving bonus). As such, it is considered that as a result, the net primary energy is saved and the energy saving performance is maintained.



	Case 1	Case 2	Case 3	Case 4
Generated power for sale	-44.77	-1.62	0.00	0.00
Generated power for self-use	-186.07	-184.59	0.00	0.00
Gas consumption for waste-heat-use gas absorption chiller	31.46	35.14	0.00	0.00
Gas consumption for gas engine	243.20	205.69	0.00	0.00
Purchased power at non-peak	0.90	0.90	0.90	0.90
Purchased power at critical peak	5.63	7.40	267.27	281.67
Gross primary energy consumption	281.20	249.13	268.17	282.57

Figure 5: Primary energy consumption by cases

3.3.4 Additional financial incentive for cogeneration owner

In some of the DR cases in the U.S., the demonstration experiment in Kitakyushu City and so forth, incentives 6 to 10 times higher than the normal electric power charge for 1 kWh electricity during DR control were provided. In this pilot study, referring to past research (Yokohama Smart City Project (YSCP), the result of the demonstration in summer 2014 (preliminary) in the building sector in Yokohama City (October 28, 2015)), the incentives were estimated as 15 to 30 yen/kWh.

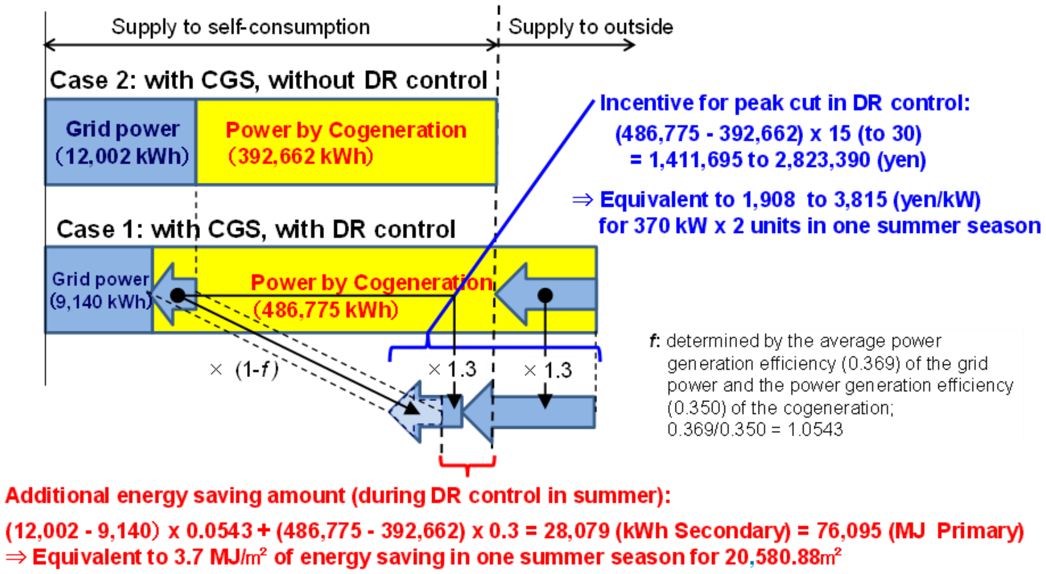


Figure 6: Estimated additional financial incentive to cogeneration with DR control

According to this estimation, in this case, the incentives by DR peak cut became 1.4 to 2.8 million yen and about 1.9 to 3.8 thousand yen for 1 kW of the capacity of the introduced cogeneration power.

3.3.5 Overall evaluation

According to the results (Figure 4, Figure 5 and Figure 6), in Case 3, without CGS, office workers are forced to endure the conditions. Alternatively, in Case 4, without CGS, they are forced to pay additional cost as peak price. But in Case 1 with DR control using CGS, although the energy consumption increased by about 5%, the values as a regulated power supply that contributes to the grid power were provided. In addition, PMV is maintained, that is, deterioration of the thermal environment is avoided and the quality of business operations and daily life is maintained. Through the BEST simulation to adaptation to DR, a trade-off relationship is clarified.

4. CONCLUSION

In this study, as one of the methods of dealing with DR on the building side, using the BEST simulation is proposed to determine system configuration or operation plan in the case of use of cogeneration power. In this study, pilot case study is conducted to simulate DR control in several assumed cases including the case where relatively large-sized gas engine cogeneration is introduced in an office building of about 20,000m^2.

The comparison of the net primary energy consumptions between the cases showed that in the case of DR control using CGS, the energy consumption increased by about 5% compared to the case where office workers were forced to endure the conditions, but the values as a regulated power supply that contributes to the grid power were provided, and in addition, PMV was maintained, that is, deterioration of the thermal comfort was avoided and the quality of business operations and life was maintained. A trial calculation of this economic value is also made and clarified the trade-off relationship. When such a value trading market is formed, it can be expected that projects are undertaken with consideration given to added financial values created by cogeneration capacity and prosumers positively participate in the market.

In this study, the DR control level according to the temperature was set. In view of the increasing tendency of electric power originating from renewable energy, however, it is also necessary to conduct simulations for DR based on the conditions of sunshine, wind and so on that are not always based on temperature. With the regional weather data such as sunshine and wind conditions with which BEST is provided, further simulations of DR control in which the behaviour of various component devices (heat storage, electricity storage and lighting) is also reproducible.

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