AN EXAMPLE OF CLUSTER ENERGY MANAGEMENT SYSTEM IN AGING SOCIETY

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SUMMARY: Under the Paris Agreement, Japan promises reducing 26 % from greenhouse gas emissions in 2013 by 2030. We have proposed a concept of Cluster Energy Management System, CEMS, which can design a highly saving-energy network based on demand simulation of communities consisting various different residents. As an example of CEMS designing a good thermal and electricity demand-balance among a network of residential houses, commercial and nursing facilities is introduced. The network can use almost whole exhaust heat from distributed power plant such as fuel cell with solar power and thermal utilization. We can simulated saving about 40 % in prime-energy consumption and about 45 % reduction of CO_2 emission by designing an example case of the CEMS, which combines fuel cells and electric vehicles in a community, where 200 families including elderly people are living. We concluded that it would be possible to reduce primary energy consumption and CO_2 emission by nearly a half amount or more by introducing the CEMS.

Keywords: CEMS, CGS, demand simulation, saving energy, community design

1. INTRODUCTION

The Paris Agreement reached a consensus among about 200 countries so far, and Japan aims to reduce 26 % of global-warming-gas emissions from that of 2013 by 2030[1]. To achieve the goal, utilization of waste heat might be the most powerful realistic measure because heat demand in household is more than 60 %[2]. The waste heat is provided not only from distributed-power-generation facilities but also from many human activities including PV panels, which might be important to be utilized in future. However, transportation of heat is required to consume electricity, thus we need carefully designing the infrastructure, which we can supply heat for the demands of heating, cooling, and hot-water supply.

In order to establish a highly-effective energy-utilization society, we are proposing Cluster Energy Management System, CEMS. The CEMS utilizes exhaust heat from not only power generation but also solar-energy-utilization facilities. Cluster means the energy-demand network, which has a win-win relationship of a good thermal and electricity demand-balance such as a network among residential houses, commercial, nursing, and sports facilities.

The CEMS can manage an advanced heat utilization and load leveling, therefore it can be realized as an advanced best energy management way for energy saving and low-environmental load.

We simulated an example case of the CEMS, which constitutes of power generation facilities and electric vehicles with a multi-dwelling building or a small community of 200 families, living about 400 people with large proportion of elderly people. We will apply our simulation method for predicting energy demand in residential houses for confirming the possibility of reducing the primary-energy consumption and CO_2 emission when renewable energy is introduced to the CEMS.

2. Materials and Methods

2.1 Prediction of energy demand in residents

We have developed a simulation program for predicting the energy demand in residential houses in any different climate area for any different size of family in Japan. The demand is predicted from Monte Carlo method on the basis of the statistics by NHK survey for the time in Japanese daily life [3]. The Monte Carlo method is possible to express the variation of behaviors of each resident. It makes possible to predict the demand for electricity, heating, cooling, hot water supply, and cooking every fifteen minutes throughout a year. The reliability of the demand prediction has been confirmed by comparing the actual data by our colleagues, which is explained by Kono[4].

On the other hand, demands in other facilities except residents were adapted the data of their annual thermal and electricity demands in the data book[5].

2.2 Simulation

2.2.1 Model in CEMS

A community, where elderly people can live higher quality of life, was designed. The community of multi-dwelling house has a public bathhouse, which has large demand of heat, a commercial facility, and a meeting place, which have large demand of electricity. The public bathhouse includes nursing facility for elderly people, who cannot take a bath by oneself, and the meeting place promotes interaction with residents. In addition, electric vehicles were introduced for mobility of residents, which is also used as an electric storage. Figure 1 shows the outline of a community to be assumed in this study.

We assumed a model community as similar community as Suwa/Nagayama, Tama-city, Japan, where is aging area like a future in Japan. The composition of residents is assumed from the statistical information in this area.

The number of households of this community is 200, 408 people are living. The commercial facility is assumed as a small convenience store. The size of public bathhouse is determined from the possibility based on the number of residents, which is assumed from the document information. The scale of the meeting place is determined from the most convenient size for leveling power consumption as explained below.

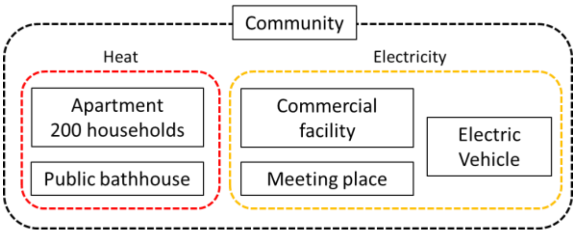

Figure 1. Model community assumed in this study.

2.2.2 Energy demand estimation in residents

Figure 2 shows the demand for multi-dwelling house. The demand for kitchen is classified to the electricity demand. The electricity demand is almost constant throughout a year, and heat demand has a peak in winter.

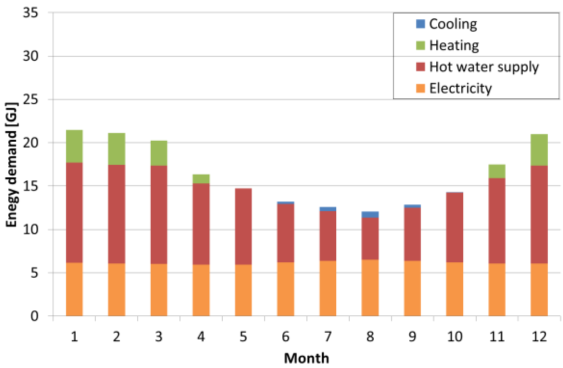

Figure 2. Average daily energy demand per month at a multi-dwelling house.

To secure the validity of results, annual energy consumption was compared in Table 1.

Table 1. Comparison of annual energy consumption between actual and predicted values in Tama-city

Actual value	Prediction
1940 TJ	1848 TJ

As shown in Table 1, the prediction almost agrees with the actual consumption by about 5 %.

2.2.3 Power leveling

Power-leveling was performed by changing the size of meeting place. We fixed the sizes of public bath and commercial facility, and calculated the best size of meeting place as shown in Fig. 3. The area of meeting place is decided as 67 m^2.

2.2.4 Total demand of this community

Figure 4 shows a total demand in the community. As shown in Fig. 4, heat demand in summer increases for cooling, thus the balance of electricity and heat demands improves.

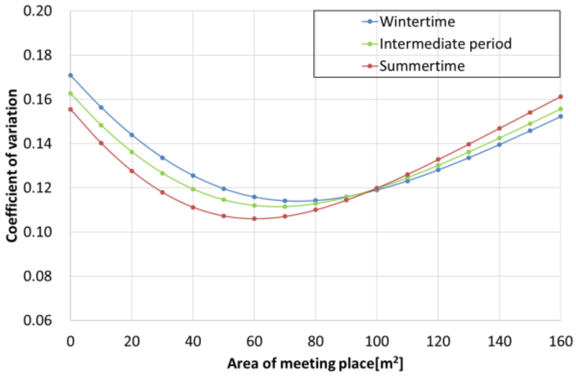

Figure 3. Coefficient of variation per area of meeting place.

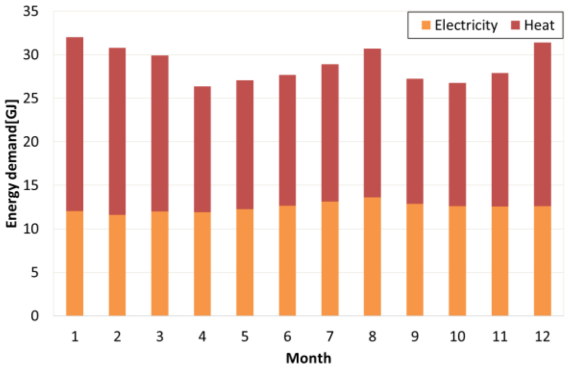

Figure 4. Average daily energy demand per month in the community in case of climate information at Tama-city.

2.2.5 Energy supply model

We assumed to supply electricity and heat by fuel cells in this study. Figure 5 shows the supply model of CEMS community. The demand for cooling is supplied by absorption-refrigerator, which uses the exhaust heat of fuel cells. Excess electricity is stored in electric vehicles, EV. Not only EVs can run, but also they can supply electricity without operation of the fuel cells. When exhaust heat of fuel cells exceeds heat demand, the excess heat is stored in a storage tank, and possible to be used in case that the amount of exhaust heat is insufficient.

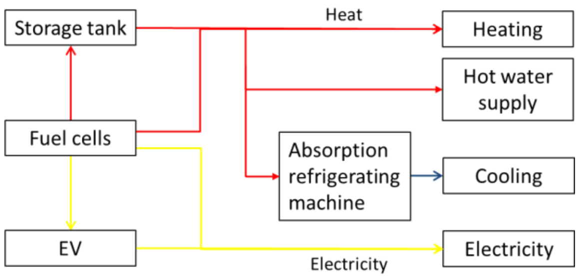

Figure 5. Assumed supply model in CEMS.

To design a supply system of the community, we focused on thermal demand. We assumed to changing the number of operating fuel-cells for keeping the heat supply just exceed thermal demand with operating storage tank. We assumed changing the number of operation by every hour for supplying daily energy demand, and predicted the saving amount of the primary energy consumption and carbon dioxide emission. The electric-power usage of this system is always assumed to set 95 % during the operation.

For comparison with the present results, a conventional supply system is decided as shown in Figure 6. The demands for heating and cooling are supplied by air conditioner, and hot water is supplied by gas heater, and vehicles consume gasoline.

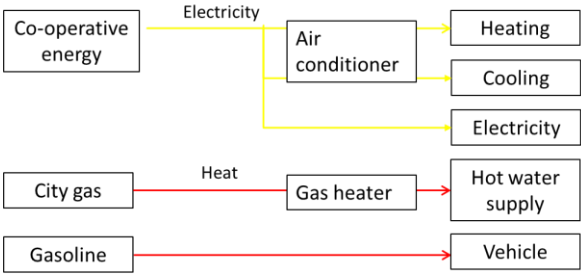

Figure 6. Supply model of conventional community

Table 2 shows assumed performances of facilities. Those are the nominal performances in the catalogs of latest available facilities.

Table 2. Performances of facilities

Fuel cell	
Rated output	136 kW
Heat output	120 kW
Power efficiency	48 %
Heat efficiency	42 %
Fuel consumption	25 m^3/h
Hot water driven absorption refrigerating machine	
Cooling capacity	844 kW
Heat recovery	1189 kW
Power consumption	4.6 kW
Electric vehicles and EV power station	
Capacity	40 kWh
Distance	240 km
Charging efficiency	90 %
Efficiency of electric supply	85 %
Vehicles	
Fuel consumption	17 km/L
Air conditioner	
APF	4.7
Gas heater	
Heat efficiency	91.4 %
Heat storage tank	
Heat loss rate	0.5 %/h

2.2.6 Coefficient to calculate energy saving

In order to calculate primary energy consumption and carbon dioxide emission, we used the data values as shown in Table 3 and Table 4.

3. Results and Discussion

3.1 Evaluation of energy saving

Primary energy consumption and carbon dioxide emission are calculated for each case. Table 5 and Figure 7 show the primary-energy consumption and Table 6 and Figure 8 show the carbon-dioxide emission. We assumed that conventional vehicles can drive the same distance as that in the catalogs.

Table 3. Primary energy consumption unit [5]

Co-operative energy	8:00-22:00	9.97 MJ/kWh
	22:00-8:00	9.28 MJ/kWh
Natural gas	-	45.0 MJ/m^3N

Table 4. Carbon-dioxide emission unit[5]

Co-operative energy	0.518 kg-CO_2/kWh
Natural gas	0.0509 kg-CO_2/MJ
gasoline	2.32 kg-CO_2/L

Table 5. Primary-energy consumption results

Month	Conventional community [GJ]	CEMS Community [GJ]	Reduction rate [%]
1	2605	1492	42.7
2	2258	1290	42.9
3	2299	1333	42.0
4	1841	1106	39.9
5	1972	1238	37.2
6	1836	1198	34.7
7	2264	1428	36.9
8	2441	1587	35.0
9	1902	1229	35.4
10	1842	1175	36.2
11	1863	1106	40.6
12	2410	1397	42.0
Total	25533	15579	39.0

Table 6. Carbon-dioxide emission

Month	Conventional community [ton]	CEMS Community [ton]	Reduction rate [%]
1	151.9	75.9	50.0
2	131.5	72.7	44.7
3	132.0	67.9	48.6
4	103.5	58.2	43.8
5	112.1	63.0	43.8
6	104.3	63.0	39.6
7	131.6	72.7	44.7
8	142.8	80.8	43.4
9	108.5	64.6	40.5
10	103.5	59.8	42.2
11	104.7	58.2	44.5
12	139.2	71.1	48.9
Total	14665.7	15587.9	44.9

As shown in Tables 5 and 6, the total reduction rate of the primary-energy consumption reaches 39 %, and that of the carbon dioxide emission reaches 45 %.

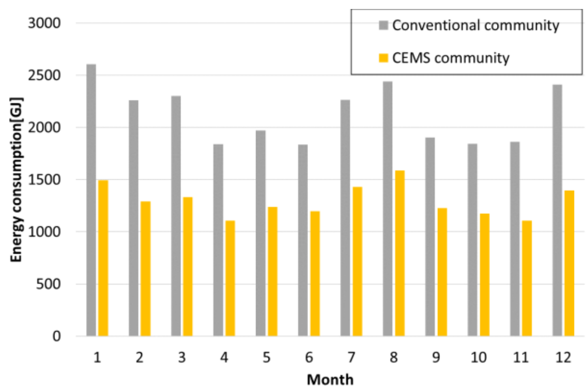

Figure 7. Primary-energy consumption results.

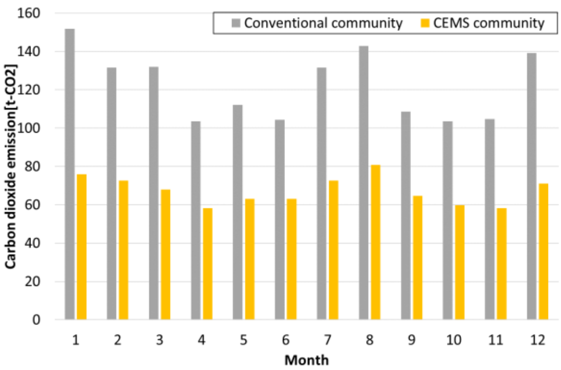

Figure 8. Carbon-dioxide emission in a community.

As shown in Figure 7, the reduction rate of the primary-energy consumption is higher in winter and lower in summer. In winter, the demand for heating and hot-water supply makes it higher, thus the amount of exhaust heat of fuel cells is large enough. On the other hand, the demand for cooling makes it higher in summer, but the thermal efficiency of the absorption refrigerating machine is low, thus the fuel consumption increases. To solve this problem, higher efficiency refrigerator is needed.

As shown in Figure 8, the reduction of the carbon-dioxide emission is high in both summer and winter, and relatively lower in intermediate periods. The specific carbon-dioxide emission rate of gasoline is high, therefore EVs can reduce carbon- dioxide emission because of their very high mileage. In intermediate period, the electric storage is requested at smaller amount as shown in Fig. 9, which means shorter travel distances are requested for the EVs or charging by outer electricity is requested. The percentage of fossil-fuel consumption is great portion in the transport sector, including EVs in the CEMS is effective way.

The increase of electric storage requests the heat demand to be high because fuel cells are a kind of co-generation systems. We need to control the fluctuation of the electricity amount in the battery by applying several ways. For example, supplying electricity outside the community is one of the ways for solving the problem.

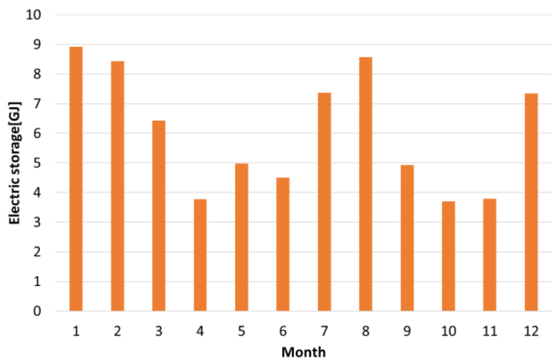

Figure 9. Daily requested electric storage per month.

3.2 Renewable energy utilization in CEMS

As discussed in the previous section, heat demand is high in both summer and winter, thus there is excess electricity for the community. To utilize the excess electricity, we propose CEMS combined with renewable energy.

Photovoltaic/thermal (PVT) solar panel has been developed by coupling decompression boiling for utilizing the solar heat[6]. The PVT panel can provide hot water about 40 °C throughout a year and can generate electricity than that of conventional PV panels. In addition, this panel can control the temperature by controlling the flow-rate of working water.

By introducing the PVT panel, which mainly collect heat both in summer and winter, and mainly generate power in intermediate periods, the balance of the heat and electricity demand is possible to be improved over a year, and the fuel cells don't need to generate much electricity, thus the electric storage balance is also improved. It can reduce huge amount of not only primary-energy consumption but also carbon-dioxide emission by nearly a half amount or more in case of introducing renewable energy resources in the simulation.

4. Conclusion

In this study, we introduced an example case of the CEMS, which combines fuel cells with electric vehicles in a multi-dwelling house, or a small community, living about 400 people including more than 140 elderly people. We can conclude that it would be possible to reduce primary-energy consumption and carbon-dioxide emission by nearly a half amount or more in case of introducing the CEMS including renewable energy resources, RE-CEMS.

We will continuously study to establish the present RE-CEMS for contributing the development of the highly-effective utilization society.

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