ENERGY-SAVING AND CO2 EMISSION REDUCTION BY INTRODUCTION OF PEFC (POLYMER ELETROLYTE FUEL CELL) CO-GENERATION INTO RESIDENCES AND CONVENIENCE STORES

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1. INTRODUCTION

An effective usage of primary energy in the residential and commercial buildings is the urgent issue from the view point of decrease of CO_2 emission. Recent years, application of PEFC (Polymer electrolyte fuel cell) co-generation system to residential buildings is considered as one of the key technologies for reduction of energy use in the residential buildings. In 2002, Japan nearly quadrupled its budget for PEFC to \$156 million and created a 10-year PEFC development program [1]. And target dates for commercialization of Japanese residential systems – which range from 2003 to 2008 – seem achievable [2]. The efficiency of fuel utilization in the co-generation system is higher than that of with the separate production of electricity and heat, whereby it is presupposed that the produced heat can also be used and is not transferred to the environment due to a lack of demand.

In this study, the effectiveness of PEFC co-generation system was analyzed by comparing the energy saving, CO_2 emission reduction and economic aspects between two cases: (1) PEFC cogeneration systems were installed to a single-family residence, an apartment house and an apartment house combined with a convenience store; (2) conventional energy system in which electricity is supplied with grid and hot water is supplied by a city gas-fired water heater.

2. THE BUILDINGS AND ITS ELECTRICITY / HEAT DEMAND

The buildings selected for this study are 4 types of single-family residences, 3 types of apartment houses and 2 types of apartment houses combined with convenience store, as shown in Table 1. The magnitude and patterns of electricity and hot water demands of each single-family house vary with the family size. The variation of demand pattern among apartment houses was not so large as that among single-family residences. The examples of the demand patterns of a single-family residence and an apartment house combined with a convenience store are

Buildings	Symbols	Notes
Single-family residence		40s age couple
	type-2	40s age couple + 2 univ. students
	type-3	40s age couple + 80s age woman
	type-4	40s age couple + two children + 70s age couple
Apartment house	Type-1	low electricity and middle heat demand
	Type-2	middle electricity and high heat
	Type-3	high electricity and high heat demand
Apartment house combined with a convenience store	Type-1	apartment house (1) + convenience store
	Type-2	apparartent house (2) + convenience store

Table 1. Object buildings

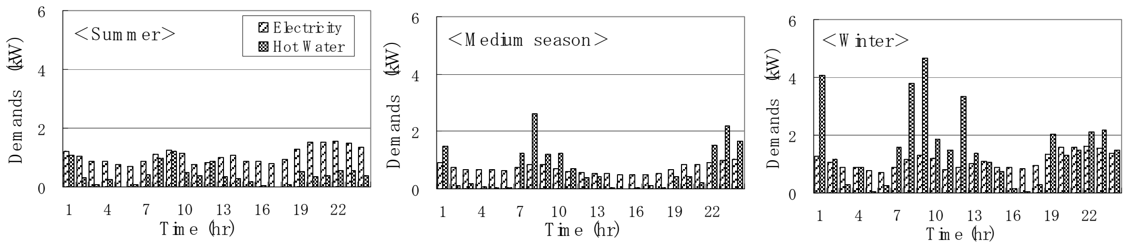

Figure 1. Electricity and hot water demands of a single-family residence

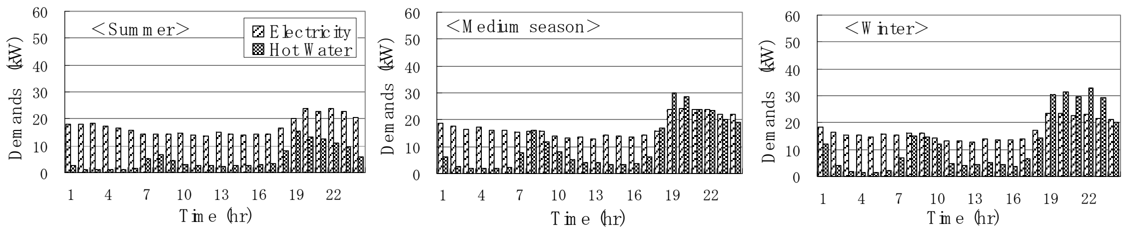

Figure 2. Electricity and hot water demands of an apartment house combined with a convenience store

shown in Figure 1 and Figure 2 respectively. In the single-family residence there are variances between electricity demand and hot water demand, especially in winter. On the contrary, as shown in Figure 2, the electricity demand and heat demand in an apartment house [3] combined with a convenience store, become closer to each other than those of single-family residence. This is because of mutual accommodation of electricity and hot water.

3. PEFC CO-GENERATION SYSTEM

The PEFC co-generation system investigated here is shown in Figure 3. In residential buildings, electricity demands are for power and illumination, and heat demands are for hot water use. The electricity is supplied with PEFC and auxiliary grid, and the hot water is supplied with the waste heat from PEFC and auxiliary hot water heater. The energy conversion systems are supplied with the primary energy (city gas in this study) in accordance with the demand side requirement. The power generating efficiencies of PEFC and grid electricity, and heat conversion efficiencies of waste heat recovery and water heater were assumed to be as shown in Table 2.

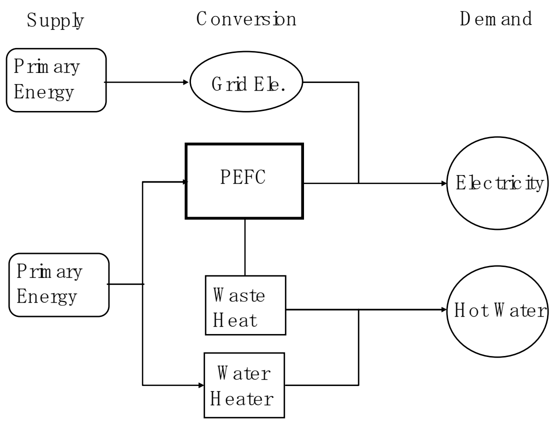

Figure 3. PEFC co-generation system

Systems		Efficiencies	
PEFC co-generation	PEFC	power generation	35%
	Waste heat	heat generation	40%
Conventional	Grid	power generation	35%
	Hot water heater	conversion	85%

Table 2. Efficiencies of systems

4. PEFC OPERATION

In order to investigate the way the primary energy consumption and CO_2 emission are minimized, 12 cases of PEFC operation patterns shown in Figure 4 are selected. Loads are expressed by the load ratio to full capacity of PEFC. The full capacity of the PEFC installed is 1 kW for the single-family residence and 10 to 20 kW for an apartment house combined with a convenience store.

4.1 Primary energy use evaluation

Primary energy use of the co-generation system for each building and season is calculated as follows :

The daily total primary energy use is represented by equation (1):

$$E_{prm}(i) = \sum_{t=0}^{23} E_{prm}(i,t) \qquad (1)$$

where, t is time, and i is the number of case (No.1 to 12) representing PEFC operation pattern shown in Figure 4. For case i, hourly primary energy use is given by summing up of primary energies for the auxiliary grid electricity, PEFC and auxiliary heat as shown in equation (2):

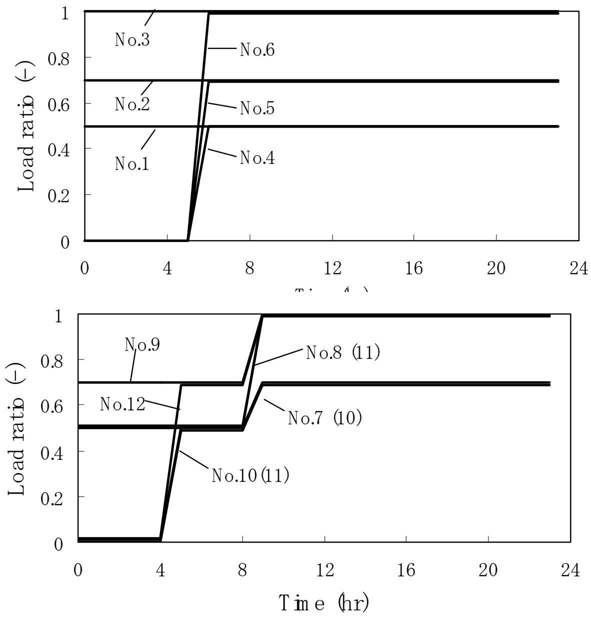

Figure 4. PEFC Operation Patterns

$$E_{prm}(i,t) = E_{aux}(i,t)/0.35 + P \bullet X(i,t)/\eta + H_{aux}(i,t) \qquad (2)$$

where, $X(i,t)$ is the PEFC load ratio shown in Figure 4. The auxiliary grid electricity and auxiliary heat is represented as equations (3) and (4) respectively:

$$E_{aux}(i,t) = E_{dem}(t) - P \bullet X(i,t) \qquad (3)$$

$$H_{aux}(i,t) = H_{dem}(t) - P \bullet X(i,t) \bullet (1/\eta - 1) \qquad (4)$$

where, $E_{dem}(t)$ and $H_{dem}(t)$ are hourly demand of electricity and heat, P is the installed PEFC capacity; $P = 1$ for a single-family residence and $P = 10$ for an apartment house and P = 10 - 20 for an apartment house combined with a convenience store, and η is the power generation efficiency of PEFC.

4.2 CO_2 EMISSION EVALUATION

CO_2 emission from the system is evaluated as follows:

CO_2 emissions $C_{auxe}(i.t)$ from the auxiliary grid electricity, $C_{auxh}(i,t)$ from city gas for auxiliary heat, and $C_{PEFC}(i,t)$ from power generation by PEFC can be calculated respectively from equations (5), (6) and (7):

$$C_{auxe}(i,t) = C_{grd} \bullet E_{aux}(i,t) \qquad (5)$$

$$C_{auxh}(i,t) = C_{gas} \bullet H_{aux}(i,t) \qquad (6)$$

$$C_{PEFC}(i,t) = C_{gas} \bullet P \bullet X(i,t)/\eta \qquad (7)$$

where, C_{grd} and C_{gas} are the CO_2 emission factors of the grid (0.42 kg-CO_2/kWh [4]) and city gas (0.18 kg-CO_2/kWh [4]). The total daily CO_2 emission is:

$$C(i) = \sum_{t=0}^{23} \{C_{auxe}(i,t) + C_{auxh}(i,t) + C_{PEFC}(i,t)\} \qquad (8)$$

5. RESULTS AND DISCUSSION

5.1 ENERGY SAVING AND CO2 EMISSION REDUCTION

The effects of the PEFC co-generation on energy saving and CO_2 emission reduction compared with the conventional system to which electricity is supplied by grid and hot water by boiler, are discussed in this section. The evaluations are described with the energy saving and CO_2 emission reduction for 12 operation patterns.

In the case of installation of PEFC co-generation in a single-family residence, the result for the Type-2 single-family residence is shown in Figure 5. In summer primary energy and CO_2 were not so much decreased from the conventional system. This is because the waste heat can not be utilized effectively and is discarded due to the small heat demand in summer as shown in Figure1. In medium season and winter the highest energy saving of about 20% and CO_2 emission reduction of 12 to 13% were attained by the operation with the operation pattern No.1 in medium season and with the operation pattern No.9 in winter. In this study, spring and autumn are defined as the medium season. It was clarified that in order to maximize the energy saving and CO_2 emission reduction it is essential to alter the operation pattern every season. When the operation pattern does not meet the demand pattern, neither sufficient energy saving can be attained nor CO_2 emission decreases such as the case in which operation pattern No.9 is applied to medium season. Figure 6 shows the result of Type-3 single-family residence. In this case CO_2 emission reduction couldn't be expected due to very small hot water demands compared to relative large electricity demands in summer and medium season. Thus installation of PEFC co-generation system in a single-family residence is not always effective for reduction of primary energy use and CO_2 emission.

In case of installation in apartment house with 15 households, the results are shown in Figure 7. Energy savings and CO_2 emission reductions were smaller than those of a

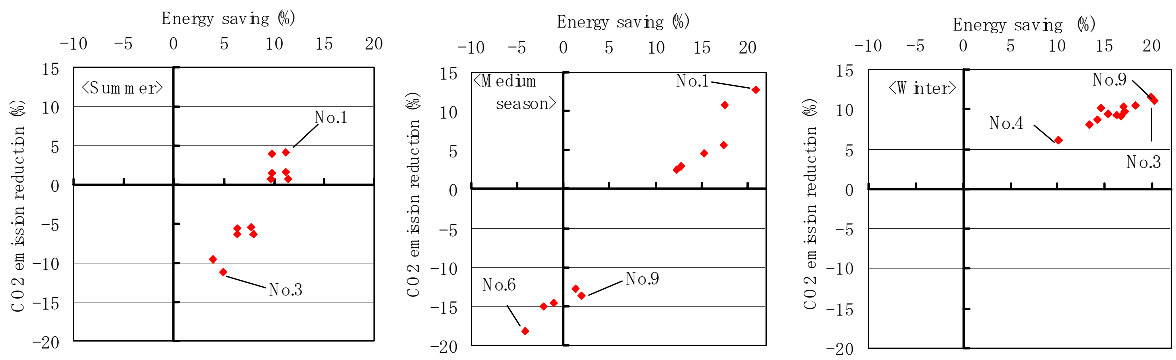

Figure 5. CO_2 and energy use of PEFC cogeneration compared with those of conventional system (for Type-2 single family residence)

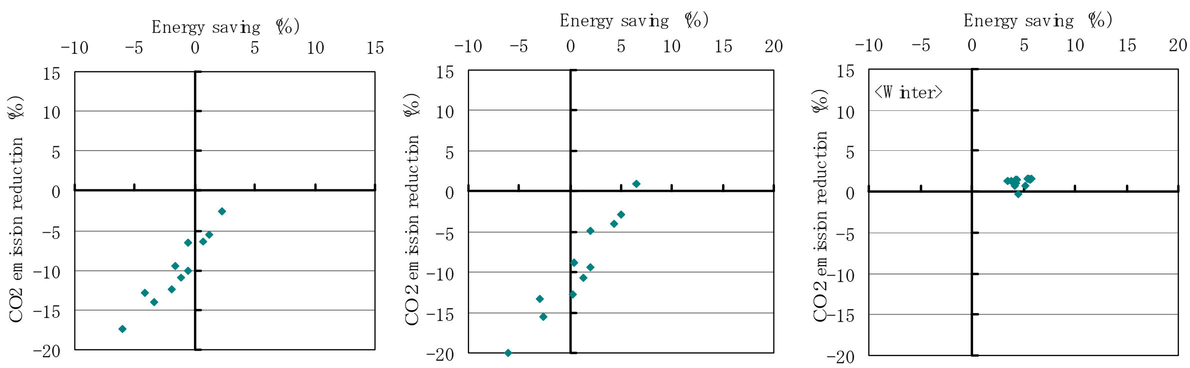

Figure 6. CO_2 and energy use of PEFC co-generation compared with those of conventional system (for Type-3 single family residence)

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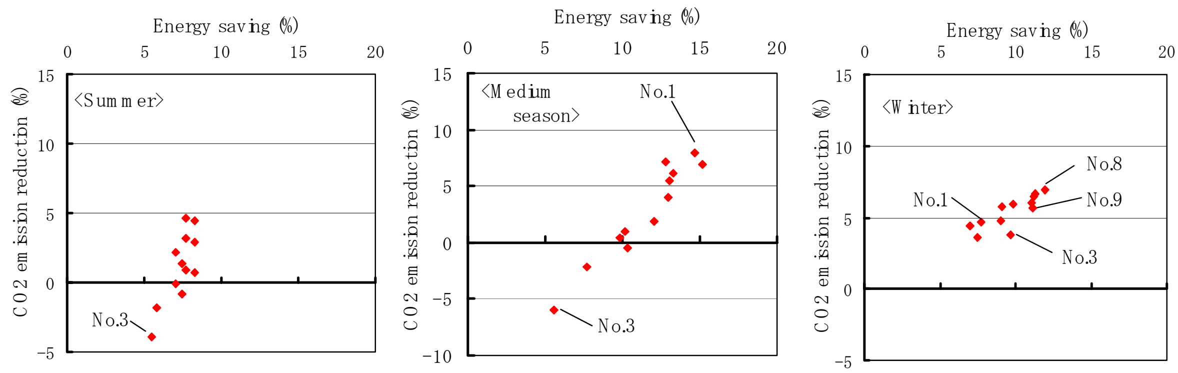

Figure 7. CO_2 and energy use of PEFC co-generation compared with those of conventional system (for an apartment house alone)

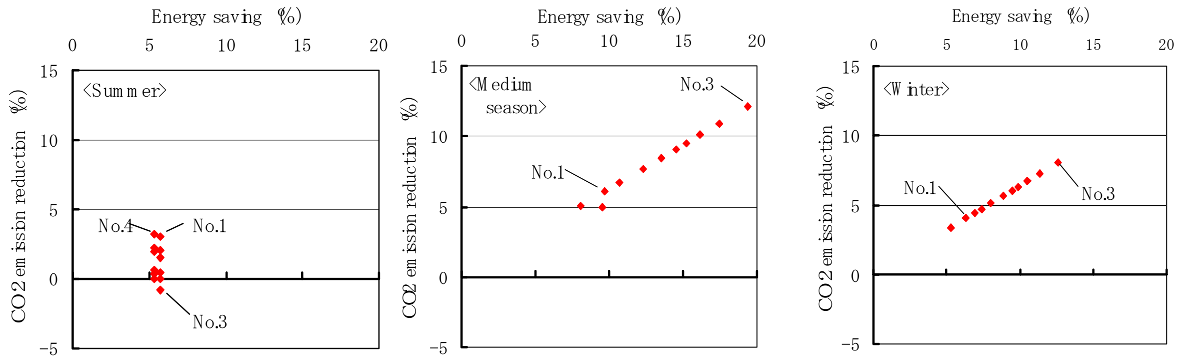

Figure 8. CO_2 and energy use of PEFC co-generation compared with those of conventional system (for an apartment house combined with a convenience store)

single-family residence Type 2 and larger than those of Type 3.

The result for an apartment house combined with a convenience store is shown in Figure 8. In medium season and winter CO_2 emission reduction was much larger than that of apartment house alone. And in these seasons the maximum CO_2 emission reduction was attained with the operation pattern No.3 in which PEFC is operated at full load (10 kWh/h) in 24 hours. This is because as the waste heat generated by PEFC is almost coincide with the hot water demands, the auxiliary heat could be minimized. And as the electricity demands of the convenience store is almost constant day long and no heat demand, most of the waste heat from PEFC can be utilized as hot water required by combined apartment house.

5.2 CRITICAL NUMBER OF HOUSEHOLDS AND PEFC CAPACITY

When the PEFC co-generation system is installed in the apartment house combined with a convenience store, investigations were made for the variations in energy saving and CO_2 emission reduction with the number of households of the apartment house and with the PEFC capacity, for the medium season. The results are shown in Figure 9. There can be seen optimum ranges of number of households which give a peak value of energy saving and CO_2 emission reduction. When the capacity of PEFC is selected as 10 kW, the maximum energy saving appears at 15 households. It can be seen the 15 kW PEFC is optimum for 25 households, and the 20 kW PEFC is optimum for 35 households. For CO_2 emission reduction, the FC capacities and households which show maximum reduction are almost the same as the tendencies of energy saving. But miss-matching of PEFC capacity and numbers of households will cause of CO_2 increase compared with the conventional system.

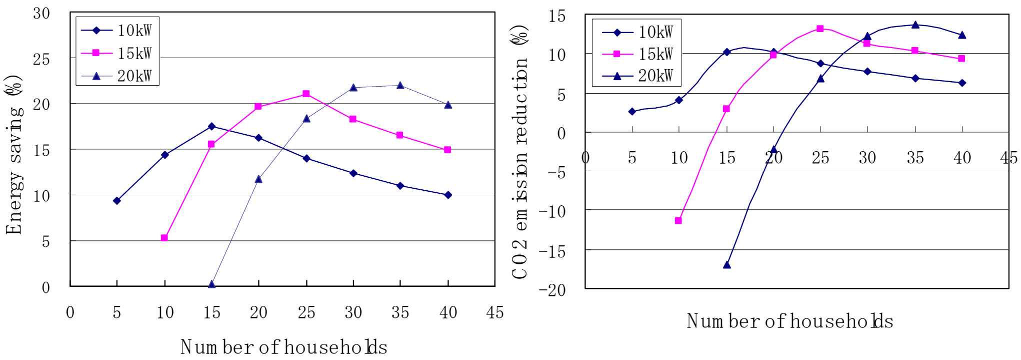

Figure 9. Critical number of households with PEFC power generation capacity

5.3 ANNUAL REDUCTION OF PRIMARY ENERGY, CO_2 AND COST

The annual reductions of primary energy use, operation cost and CO_2 emission when the PEFC co-generation is applied to three kinds of buildings are shown in Table 3 compared with the conventional system. If the demand of electricity and hot water is nearly equivalent, the single family residence such as Type-2 can attain a reduction of 18% for energy and 8.6% for CO_2. Fifteen households apartment house of which demand can be averaged to that of each household showed a reduction of 10% for energy and 6% for CO_2. By combination of an apartment house and a convenience store, reductions of 13% for energy, of 6.5% CO_2 and of US$2,300/year are attained.

Buildings	Systems	Primary Energy		CO2 emission		Operation Cost	
		use	reduction	emission	reduction	cost	reduction
		kW/year	%	kg-CO2/year	%	US$/year	%
Single-family residence (Type-2)	Conventional system	29,313		4,592		1,912	
	Co-generation system	24,013		4,198		1,805	
	Reduced	5,299	18.1	394	8.6	107	5.6
Apartment house (15 households)	Conventional system	559,971		87,003		38,098	
	Co-generation system	500,445		81,747		36,502	
	Reduced	59,526	10.6	5,256	6.0	1,596	4.2
Covenience store + apartment house	Conventional system	632,169		96,822		40,642	
	Co-generation system	547,623		90,549		38,286	
	Reduced	84,546	13.4	6,273	6.5	2,356	5.8

Table 3. Summary of annual reduction

CONCLUSION

Application of PEFC co-generation system to residential sector could decrease primary energy use, CO_2 emission and operation cost compared with those of conventional system. Especially for an apartment house combined with a convenience store, maximum 22% of primary energy reduction and 14% of CO_2 emission could be attained when the number of households and the PEFC capacity is appropriately selected. On the contrary, for the single-family residence the effectiveness of applying PEFC co-generation largely depends on the energy demand pattern.

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