Study on Energy Conservation and Economical Condition of "PEFC Apartment House"

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ABSTRACT

For reduction of Green house Gas emissions, Polymer Electrolyte Membrane Fuel Cells (PEFC) is promoted by the government in Japan as more efficient co-generation system (CGS). On this study for the purpose of finding the efficient energy supply system with PEFC in the apartment house, first the author proposed "PEFC Apartment House" as more efficient system than the current one (boiler and electric power), which consists of PEFC-CGS, thermal storage tanks, power network and management system. Second, in order to develop the planning method of facilities with PEFC, the author has built up a database of PEFC performance by carrying out measurements at a residential house, and has developed an environmental and economical evaluation system. Third, for prediction of energy conservation and environmental effect of "PEFC Apartment House", with the evaluation system the author has predicted annual primary energy consumption and carbon dioxide emissions at a 30-unit apartment house in Tokyo. As a result, the author estimated about 14% reduction of annual primary energy consumption and about 28% reduction of carbon dioxide emissions. At last, in order to confirm an economical condition to compose this system, the relation between the price of the city gas and the profit of the energy supplier was examined. As a result, it was found that if the city gas unit price falls up to about 2.4 [yen/MJ], the profit is added and if the city gas unit price falls up to about 1.4 [yen/MJ], the investment collection years would become ten years or less.

INTRODUCTION

The national government of Japan is diffusing polymer electrolyte membrane fuel cells (PEFC) as a means of more efficient energy use, for reducing greenhouse gas emissions and preserving fossil fuels. PEFC are expected to be employed in buildings and automobiles. This study proposed PEFC-operated apartment houses as an application of PEFC to buildings and simulated their energy saving effect and reduction of carbon dioxide emissions effect. At last, in order to confirm an economical viability for this system, the relation between the price of the city gas and the profit of the energy supplier is examined. The results are described in this paper.

SYSTEM OUTLINE IN A PEFC-OPERATED APARTMENT HOUSE

The system is composed of a PEFC system (fuel cell stack, reformer, hot water storage tank and supplementary water heater) installed at each apartment and a distribution network connecting PEFC systems. Electric power is shared by apartments and waste heat is used individually by each apartment. PEFC are operated starting at an apartment with lower heat storage. When the capacity of storage is filled to the full, output from the fuel cell stack attached to the storage is discontinued. Then, the efficiency of PEFC operation will be increased; the number of PEFC will be reduced (load factor will be increased) and surplus waste heat will be reduced (more recovered waste heat will be used) through integrated control; and heat loss will be reduced as shorter heat pipes will be required.

EVALUATION OF ENERGY SAVING CAPACITY AND CO_2 REDUCTION EFFECT

The energy saving capacity of PEFC-operated apartment houses is evaluated in terms of reductions of annual primary energy consumption and carbon dioxide emissions.

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Outline of the Building

Evaluation is made at an apartment house accommodating 30 80-m^2 apartments in Tokyo. Power, water heating, and cooling and heating loads are applied for a year (8,760 hours) in increments of one hour using the basic unit[3]. Cooling and heating loads are converted to power load on the assumption of use of air conditioners with COP (coefficient of performance) of 4.9 [4]. Load characteristics are assumed to be the same in all apartments.

Cases of Calculation

Calculations are made in two cases with a conventional apartment house generally available at present (Table 1) and with a PEFC-operated apartment house (Table 2). In the conventional apartment house, commercial electric power is supplied and hot water is provided using water heaters driven by city gas. The basic units used are listed in Table 3.

Results of Evaluation and Discussion

Figures 1 and 2 show annual consumption of primary energy and carbon dioxide emissions in two types of apartment houses, respectively for comparison. It is find out that in the PEFC-operated apartment house, annual consumption of primary energy and carbon dioxide emissions are lesser than in the conventional apartment house by 14.1% and 27.6%, respectively.

Figures 3 through 5 show how PEFC are operated in a PEFC-operated apartment house throughout the day. Findings are described below.

1. On a winter day (Figure 3), heat demand is higher than in other months, so the hot water storage tank is not filled to the full capacity. Fuel cells stop operation due to load variations. The number of PEFC in operation at 17:00 hours is less than 20, resulting in power shortage. It is therefore necessary to purchase commercial electricity.

Table 1. Specifications and Operation of PEFC

Specifications
(i) Capacity: 1 kW
(ii) Efficiency: 31.5% (HHV (high heating value) (power generation), 41.5% (HHV) (waste heat recovery) [1]
(iii) Fuel: City gas
(iv) Power for driving auxiliary machine: 5% of generated power
(v) Hot water storage tank: 200 L
(vi) Heat loss: 6% of recovered heat
(vii) Tapping temperature: 60?
(viii) Power of water heating pump: Water heating load (MJ/h)/(10? x 4.186) x (196,000 Pa x 0.163)/(0.65 x 60)
(ix) At the time of power shortage: Commercial electricity is purchased.
(x) At the time of heat shortage: Supplementary water heater is operated. (Capacity: 837 MJ/h, COP0.82 [2])
Operation
(i) PEFC are operated according to power demand, and operation is discontinued when the hot water storage tank is filled to the full.
(ii) PEFC operation is started at an apartment with low heat storage.
(iii) The number of PEFC units is controlled by turning them on or off.
(iv) PEFC are operated around the clock.
(v) PEFC are turned on and off only once a day.

Table 2. Specifications for Equipment at a Conventional Apartment House

Power: Purchasing commercial electric power
Hot water: Using water heater (one heater installed per apartment)
Fuel for water heater: City gas
Capacity of water heater: 837 MJ/h
Efficiency of water heater: 82% [HHV]

Table 3. Basic Units Used

Item	Unit	Value
City gas (13A) (low heating value) [5]	$MJ/m^3(N)$	41.66
Basic unit of carbon dioxide emission from city gas (13A) [6]	$kg\text{-}CO_2/MJ[HHV]$	0.0513
Commercial electric power converted to primary energy [5]	MJ/kWh	9.83
Basic unit of carbon dioxide emission from thermal power generation (at the receiving end) [7]	$kg\text{-}CO_2/kWh$	0.66

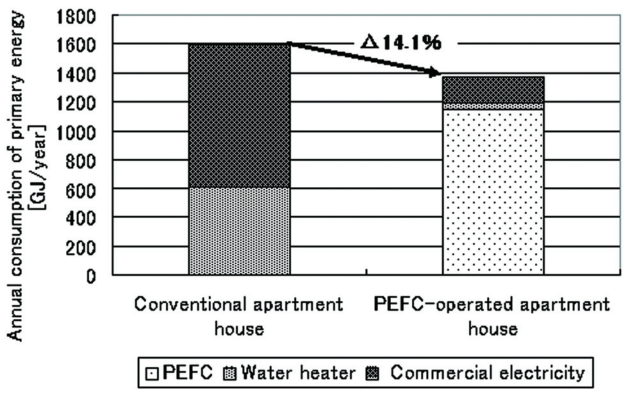

Figure 1 Annual consumption of primary energy.

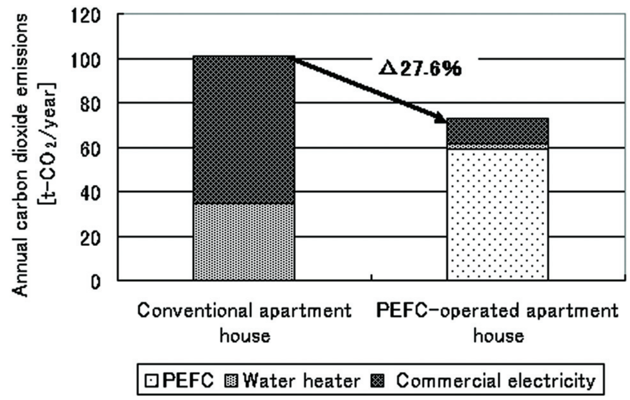

Figure 2 Annual carbon dioxide emissions.

2. On a spring or autumn day (Figure 4), heat demand is higher than in other months as in winter, so the hot water storage tank is not filled to the full capacity. Power power meets the power demand almost completely.
3. On a summer day (Figure 5), heat demand is less than in other months, so the hot water storage tank is filled to the full capacity at 11:00 hours. All of the fuel cells stops operation. As a result, only three units are in operation after 14:00 hours. There occurs power shortage and commercial electricity have to be purchased.

EXAMINATION OF ECONOMICAL CONDITION

When thinking about the account for residents, new energy supplier is necessary between existing energy company (electric power company and gas company) and residents. And considering this PEFC-operated apartment system, it is necessary that energy supplier's profit must be secured within the range where the utility bill of the resident doesn't go up. On the other hand, the profit of the energy supplier is influenced by the price of city gases that this system is consuming a lot. And in Japan the city gas corporation is thinking of a new reduced price of the city gas for bulk order clients who use Fuel Cell. Therefore, in this chapter, I examine the relationship between the price of the city gas and the profit of the energy company.

Cash Flow Model of a New Energy Supplier

Figure 6 shows the model of the cash flow for a new energy supplier. This new energy supplier owns the PEFC-operated apartment system and makes contract with maintenance company for their maintenance. Also for selling the hot water(5) and electricity(7) to the residents, the new energy supplier buys city gas from the gas company(1) and the electric power from the electric power company(3). Therefore, the profit of the energy supplier is shown in Equation 1:

$$\sum P = \sum(E_s \times P_{es} + H_s \times P_{hs}) - \sum(E_b \times P_{eb} + H_b \times P_{hb}) - \sum(E_g \times P_m) \quad (1)$$

where

P = annual profit of the energy supplier [\$/year]

E_s = amount of sales of electric power to residents [kWh/year]

P_{es} = sales unit price of electric power [\$/kWh]

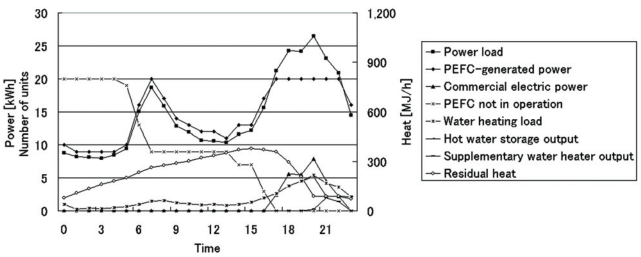

Figure 3 *PEFC operation throughout a winter day.*

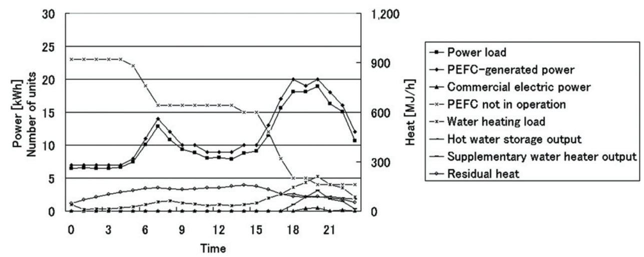

Figure 4 *PEFC operation throughout a spring or autumn day.*

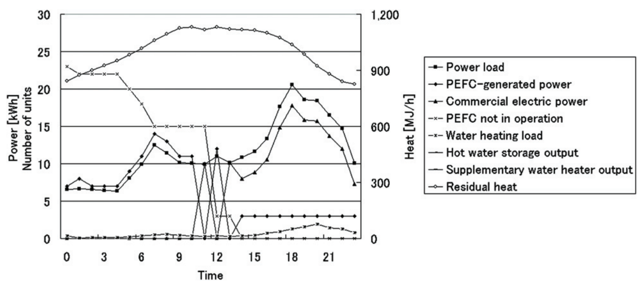

Figure 5 *PEFC operation throughout a summer day.*

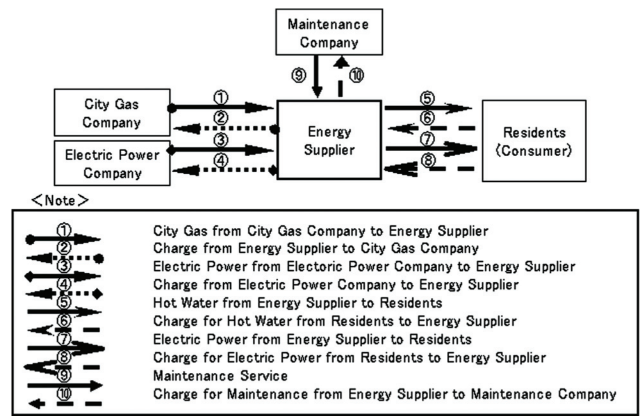

Figure 6 *Cash flow model of enterprising body.*

H_s = amount of sales of heat to residents [MJ/year]
P_{hs} = sales unit price of heat [$/MJ]
E_b = amount of purchase of electric power from electric power company [kWh/year]
P_{eb} = purchase unit price of electric power [$/kWh]
H_b = amount of purchase of city gas from city gas company [MJ/year]
P_{hb} = purchase unit price of city gas [$/MJ]
E_g = amount of power generation by PEFC [kWh/year]
P_m = maintenance unit price [$/kWh]

Calculation Cases

Calculations are carried out for in 7 cases at the point of purchase unit price of city gas (Table 4). The reference case is a city gas unit price which the residents are paying to the city gas company in the conventional system (Figure 7). The case are set from 10% reduction case (Case-1) to 70% reduction case (Case-7). Table 5 shows calculation conditions.

Results of Evaluation and Discussion

Table 6 shows annual profit of the energy supplier and the collecting period for each case. Findings are described below.

1. If the city gas unit price falls to about 0.92 [$/m^3], the profit is added.
2. If the city gas unit price falls to about 0.4 [$/m^3], the investment collection years would become ten years or less.

CLOSING REMARKS

In this study, the energy saving and reduction of carbon dioxide emissions effects of PEFC-operated apartment houses are estimated by simulation. As a result, it is find out that less energy is consumed than in conventional apartment houses by 14.1% and carbon dioxide emissions is lesser than in the conventional apartment house by 27.6%. It is also revealed that there remains room for optimizing the numbers of PEFC units and the capacity of heat storage to further increase energy saving capacity. And also in this study, in order to confirm an economical condition for composing this system, the relation between the price of the city gas and the profit of the energy supplier is examined. As a result, it is find out that if the city gas unit price falls to about 0.92 [$/MJ], the profit is added and if the city gas unit price falls to about 0.4 [$/MJ], the investment collection years would become ten years or less.

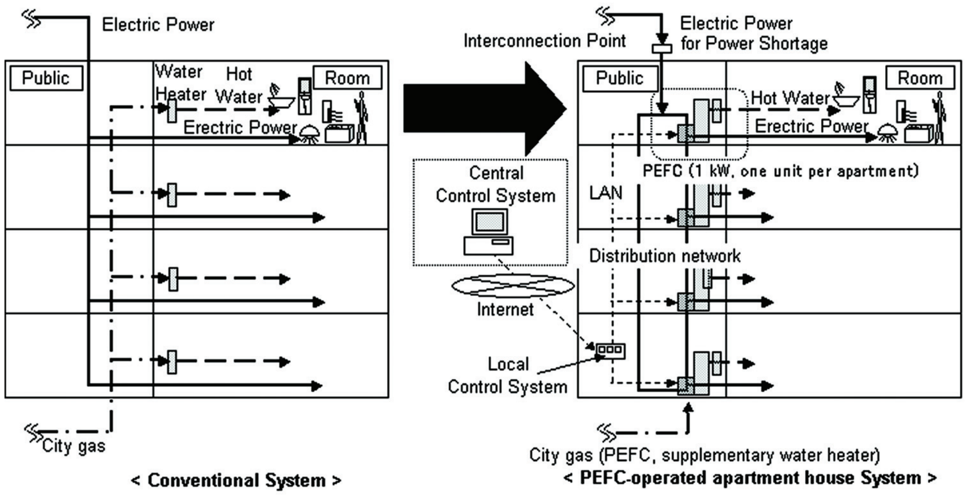

Figure 7 *System outline at a PEFC-operated apartment house.*

Table 4. Calculation Cases

	Unit	Reference	Case-1	Case-2	Case-3	Case-4	Case-5	Case-6	Case-7
			Δ10%	**Δ20%**	**Δ30%**	**Δ40%**	**Δ50%**	**Δ60%**	**Δ70%**
Purchase Unit Price of City Gas	$\$^*/m^3$	1.32	1.19	1.05	0.92	0.79	0.66	0.53	0.40

* $1=119 Yen

Table 5. Calculation Conditions

Item	Unit	Value	Remarks
Purchase Unit Price of Electric Power	$/kWh	0.17	Same to the Price from Electric Power Company to Residents in the Conventional System[1]
Sales Unit Price of Electric Power	$/kWh	0.17	Same to the Price from Electric Power Company to Residents in the Conventional System[1]
Sales Unit Price of Heat	$/MJ(HHV)	0.03	Same to the Price from City Gas Company to Residents in the Conventional System[2]
Amount of Sales of Electric Power to Residents	kWh/year	100,380	From the Power Loads at 30 Apartments (Figure 8)
Amount of Sales of Heat to Residents	MJ/year	439,530	From the Water Heating Loads at 30 Apartments (Figure 9)
Amount of Purchase of Electric Power from Electric Power Company	kWh/year	17,419	From Annual Consumption of Primary Energy (Figure 1)

Table 5. Calculation Conditions *(continued)*

Item	Unit	Value	Remarks
Amount of Purchase of City Gas from City Gas Company	MJ(HHV)/ year	1,151,310	From Annual Consumption of Primary Energy (Figure 1)
Amount of Purchase of City Gas from City Gas Company	MJ(HHV)/ year	46,519	From Annual Consumption of Primary Energy (Figure 1)
Maintenance Unit Price of PEFC	\$/kWh[3]	0.03	Same to the Gas-Engine Co-Generation System
Amount of Power Generation by PEFC	kWh/year	91,132	From the Result of Simulation in 3-3
The Cost of Construction	\$[4]	168,067	**Breakdown** Control System: 84,033[\$] PEFC: 8,403[\$/unit]×30[unit] Subsidy: 1/2 of Control System and PEFC

[1]Resident's Annual Charge to Electric Power Company (577\$/year/room)/Resident's Annual Electric Power Consumption (3.346kWh/year/room)

[2]Resident's Annual Charge to City Gas Company (421\$/year/room)/Resident's Annual Heat Consumption (14,651MJ/year/room)

[3]Electric Power Output of PEFC

[4]1\$=119Yen

Table 6. Result of Evaluation

Item		Unit	Reference	Case-1	Case-2	Case-3
Purchase Unit Price of City Gas		\$/m^3	1.32	1.19	1.05	0.92
	Reduction Ratio	%	0	10	20	30
Electric power sales Income		\$	17,382	17,382	17,382	17,382
Heat Sales Income		\$	12,553	12,553	12,553	12,553
	Annual Income	\$	29,935	29,935	29,935	29,935
Electric Power Expense		\$	3,015	3,015	3,015	3,015
City Gas Expense for PEFC		\$	32,895	29,605	26,316	23,026
City Gas Expense for Sub-Boiler		\$	1,329	1,196	1,063	930
Maintenance Expense for PEFC		\$	2,298	2,298	2,298	2,298
	Annual Expense	\$	39,537	33,099	29,677	26,254
	Annual Profit	\$	–9,602	–3,164	258	3,681
	Investment Collection Years	Year	—	—	—	46
Item		**Unit**	**Case-4**	**Case-5**	**Case-6**	**Case-7**
Purchase Unit Price of City Gas		\$/m^3	0.79	0.66	0.53	0.40
	Reduction Ratio	%	40	50	60	70
Electric power sales Income		\$	17,382	17,382	17,382	17,382

Table 6. Result of Evaluation *(continued)*

Item	Unit	Reference	Case-1	Case-2	Case-3
Heat Sales Income	$	12,553	12,553	12,553	12,553
Annual Income	$	29,935	29,935	29,935	29,935
Electric Power Expense	$	3,015	3,015	3,015	3,015
City Gas Expense for PEFC	$	19,737	16,447	13,158	9,868
City Gas Expense for Sub-Boiler	$	797	665	532	399
Maintenance Expense for PEFC	$	2,298	2,298	2,298	2,298
Annual Expense	$	25,847	19,409	15,987	12,565
Annual Profit	$	4,088	10,525	13,948	17,370
Investment Collection Years	Year	41	16	12	10

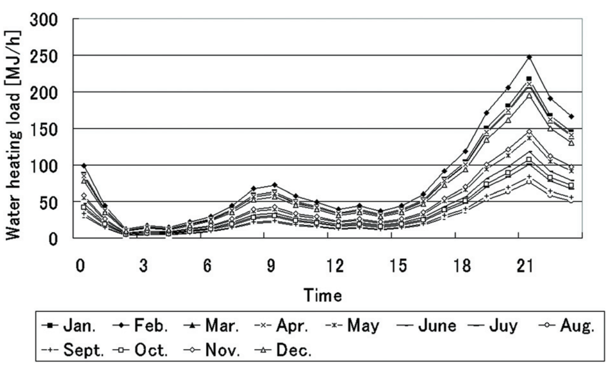

Figure 8 *Power loads at 30 apartments (including cooling and heating loads).*

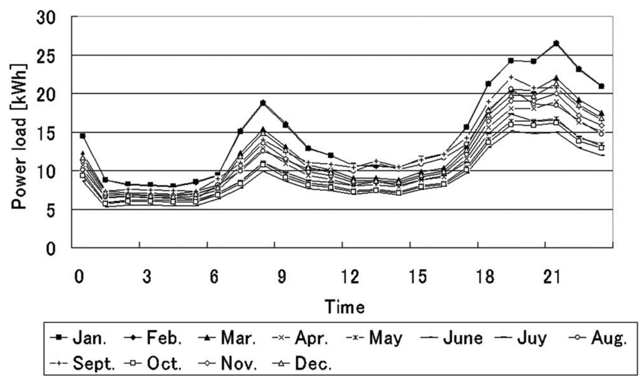

Figure 9 *Water heating loads at 30 apartments.*

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