A Demonstration Project of a Smart Energy House in an Apartment Block

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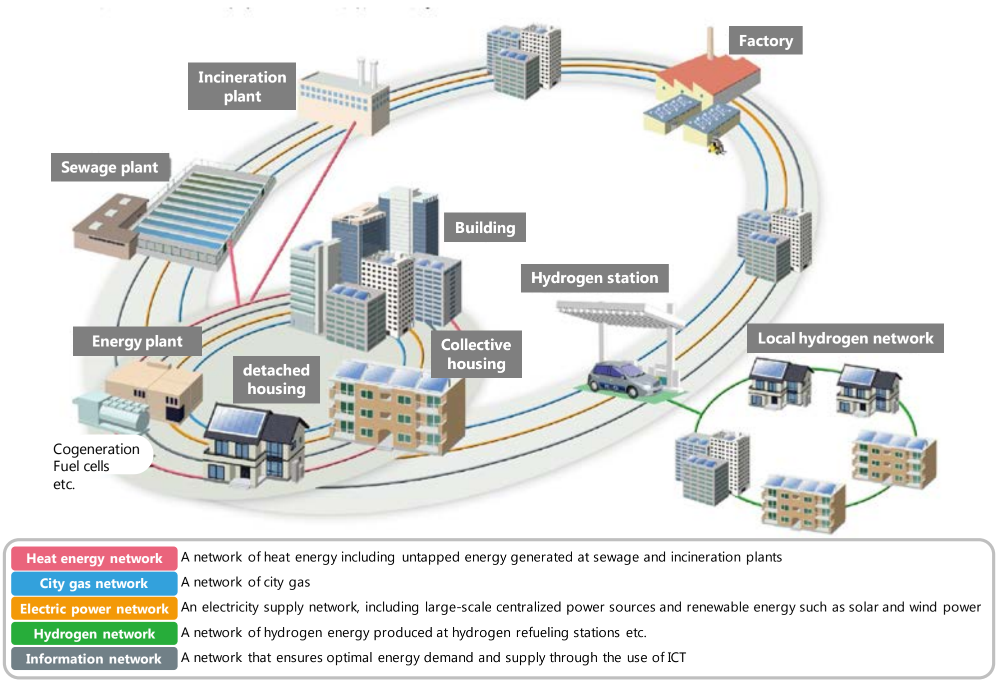
We conduct a test to demonstrate the Smart Energy House, which incorporates a shared system of fuel cells, solar cells and a storage battery, in apartment blocks in supply area of our city gas, as part of moves toward realizing an environmentally harmonious society. Compared to conventional systems, energy saving of 39% and a CO_2 reduction rate of 50% were obtained within a year. This paper reports on the current system and results.

1. Introduction

1.1 Background

Global warming is a pressing issue, and the importance of efforts in achieving an environmentally sustainable society that excels in conserving energy and reducing CO_2 emission is increasing every year. Individual energy consumers have been making efforts of their own in utilizing photovoltaics ("PV") and other renewable energies, as well as cogeneration systems ("CGS") known for its highly efficient energy conservation and CO_2 reduction characteristics. Going forward, we must further enhance the efficiency of energy use.

"Smart Energy Network (SEN)" is proposed as one of such approaches. SEN, defined as the next-generation energy and social system for optimum energy use, is designed to share among multiple energy consumers electrical and heat energies produced by a combination of renewable energy facilities and distributed energy systems. Various SEN approaches are made in the following elements: (1) detached housing, (2) collective housing, (3) commercial facilities, (4) industrial facilities, and (5) districts (Figure 1).



Heat energy network	A network of heat energy including untapped energy generated at sewage and incineration plants
City gas network	A network of city gas
Electric power network	An electricity supply network, including large-scale centralized power sources and renewable energy such as solar and wind power
Hydrogen network	A network of hydrogen energy produced at hydrogen refueling stations etc.
Information network	A network that ensures optimal energy demand and supply through the use of ICT

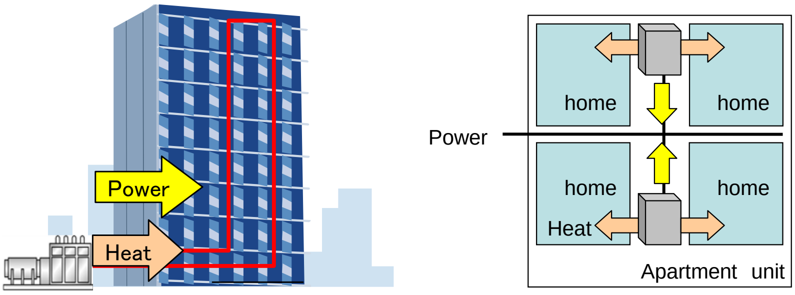
Figure 1: Example of a smart energy network

1.2 Demonstrative Approach

Collective housing, one of the SEN elements, was selected to be reviewed with the demonstrative approach. Compared to detached housing, collective housing has less energy demand and solar panels installation capacity per housing unit, and therefore return on investment on energy equipment is difficult. In addition, collective housing has less space to install energy equipment. One of the rational systematic approaches to address these would be the shared use of equipment as well as electrical and heat energies to the possible extent.

The "Central System for residential buildings" and "n-units/Single" methods are utilized to distribute heat in collective housing (Figure 2). The Central System for residential buildings circulates heat throughout the entire building by using water heaters and CGS for business use, and is used mainly in a large-scale collective housing of one hundred or more housing units.

On the other hand, the multiple-units/1 System installs a single domestic CGS or other fuel cell in multiple housing units. A generator is shared to reduce initial costs, which in turn enhances the generator's operating ratio. A simplified control system is required for housing of such a scale as collective housing, due to its limited funds for control devices.



(a) Central System for residential buildings

(b) multiple-units/Single System

Figure 2: Examples of Heat Distribution Types

A smart-energy-house demonstration project with a shared system of fuel cells, solar cells, and batteries is currently implemented at rental collective housings located within our company's supply area. After a year since the project began on August 2012 when the residents started to move in, it conserved energy by 39% and reduced CO_2 emissions by 50%, compared with the conventional system.

This paper describes the current system and its results, as well as report issues and proposals on future system improvements.

2. Project Overview

1.1 Shared Equipment

A total of two collective housing buildings (A and B) with four housing units each, a total of eight housing units, participated in the demonstration project.

Table 1 shows the energy equipment in shared use. Each residential building was installed with a solid oxide fuel cell ("SOFC"), a polymer electrolyte fuel cell ("PEFC"), a single battery (lead storage battery), and a photovoltaic generation ("PV"), and were shared among the four housing units in the building.

SOFC has high efficiency power generation and suited for continuous operation, whereas PEFC has a short start-up time and easy to start and stop. PEFC and SOFC were combined and installed as a shared system to take advantage of both characteristics.

Table 1: Energy equipment in shared use (four housing units per building)

Equipment configuration		Rated output (kW)	Rated capacity (kWh)	Number of installed equip.
Fuel Cell	SOFC	0.70	–	1
	PEFC	0.75	–	1
PV		5.5	–	1
Battery		3.0	9.36	1

(2) Energy supply method

Figure 3 shows the electrical and heat distribution system of collective housings in the demonstration project. Combined electricity from SOFC, PEFC, and PV is shared among housing units. Any surplus electricity generated by PV is sold to the power company. In addition, electricity is purchased from the power company in case of an electricity shortage.

Exhaust heat (hot water) generated from fuel cells is supplied to a city gas fired water heater to preheat hot water, and a mixing unit (solar water heater product) is used between the above process to control the hot water temperature of the water heater.

In addition, the battery is combined with the SOFC and PV and is connected to the emergency power outlets of individual housing units to feed electricity during blackouts.

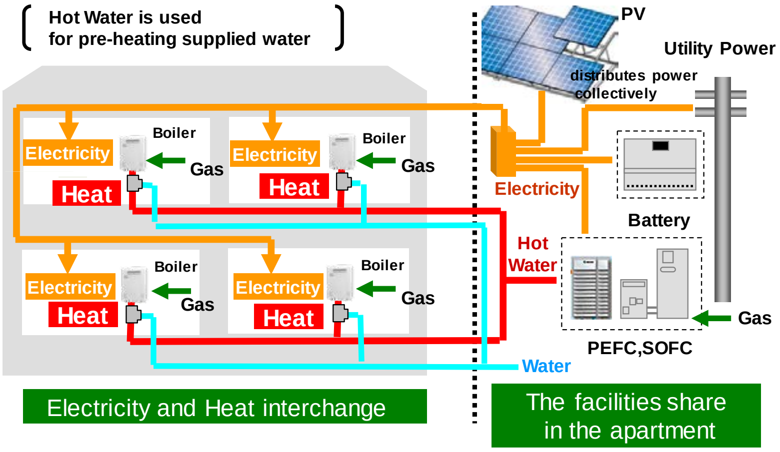


Figure 3: The electricity and heat flexibility system

3. Project results and observations

(1) Energy demand

Table 2 shows the annual demand (electricity and heat) of the all individual units in each of the residential buildings. Building A had higher electricity demand than building B, whereas building B had higher heat demand (hot water consumption) than building A. Even when energy demands of about four housing units are consolidated, the smoothing effect had little impact to leveling demands. Heat and electrical demand varied greatly depending on the family makeup of the unit residents, which is similar to that happens in detached housing.

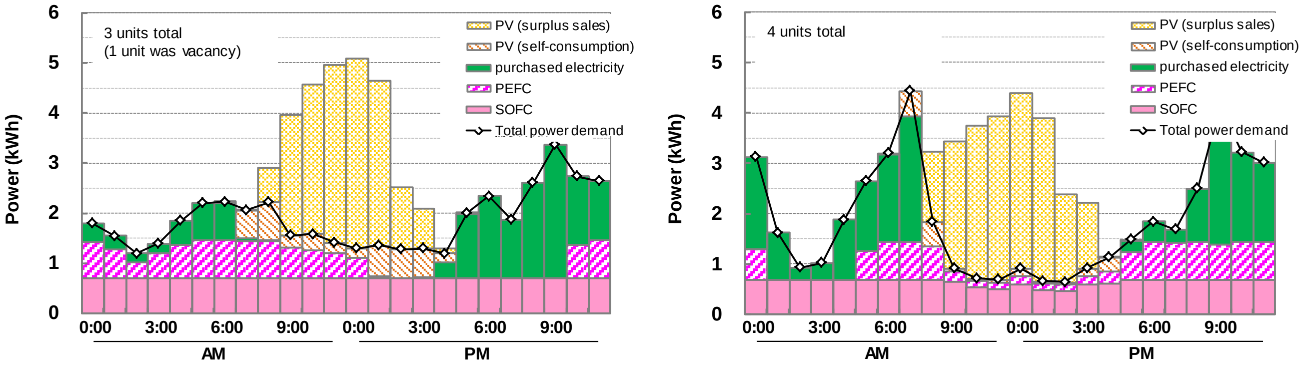
Table 2: Energy demand of the occupied areas (August 2012 – July 2013)

Demand	Building A	Building B
Electricity demand	10.56 MWh	8.56 MWh
Heat demand (hot water demand only)	8.97 MWh	11.52 MWh

(2) Electricity supply

Figure 4 shows the power generation pattern for each residential building on a typical day in February. The electricity demand per housing unit of the collective housing in the demonstrative project is smaller than of detached housing, but combining the power demand of individual housing units and common areas indicated that SOFC, known for its high generation efficiency, was in continuous operation at near maximum output, even during at low-demand hours. In addition, the PEFC started and stopped according to demand, following the demand fluctuation as shown in the difference between buildings A and B. It is believed that the characteristics of individual fuel cells were well-utilized in supplying electricity.

Table 3 shows the annual power generation volume generated by individual equipment. SOFC in building B generated slightly less power, perhaps due to lower electricity demand and longer partial load operation hours than in building A. In addition, PEFC with thermal-load-following-operation had generated slightly more power in building B, where demand for hot water is higher.



(a) Building A

(b) Building B

Figure 4: Power generation pattern on a typical day in the month of February

Table 3 Annual power generation volume of individual equipment (August 2012 – July 2013)

Equipment configuration		Building A	Building B
Fuel cells	SOFC	5.74 MWh	5.56 MWh
	PEFC	2.28 MWh	2.20 MWh
PV		7.35 MWh	6.93 MWh

Figure 5 is the breakdown of electricity supply to residents. The fuel cells (SOFC and PEFC) and PV self-consumption supplied 56% and 11%, respectively, and kept the purchased electricity level at 33%. In addition, the amount of PV surplus electricity sales was 39% and was more than the purchased electricity. As a result, the electricity self-sufficiency level exceeded the 100% level.

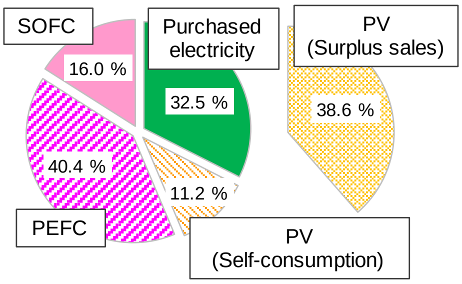
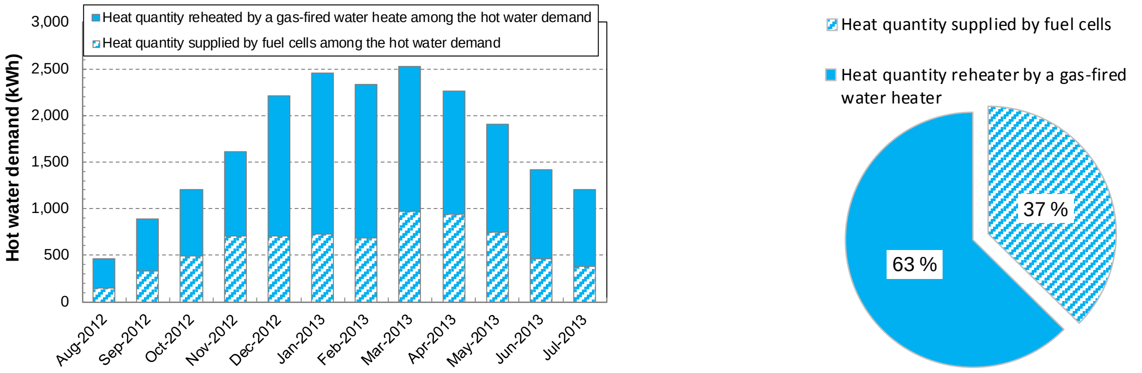


Figure 5: Breakdown of electricity supplied to residents (August 2012 – July 2013)

(3) Heat supply

To stabilize the temperature of hot water supplied by a water heater installed in individual housing units, the temperature of hot water supplied from fuel cells to individual housing units was set at its lowest level of 32 °C, and was used to preheat the hot water. As a result, the heat supplied by fuel cells covered 29 to 44%, or an annual average of 37 % of the hot water demand for all housing units (Figure 6).



(a) Monthly hot water demand

(b) Annual breakdown (August 2012 – July 2013)

Figure 6: Primary energy for the hot water demand (sum of two buildings)

Going forward, making higher water temperature settings of fuel cells to increase its exhaust heat volume, as well as reducing the re-heat process of water heaters in individual housing units should contribute toward further reduction of energy use and CO_2 emissions.

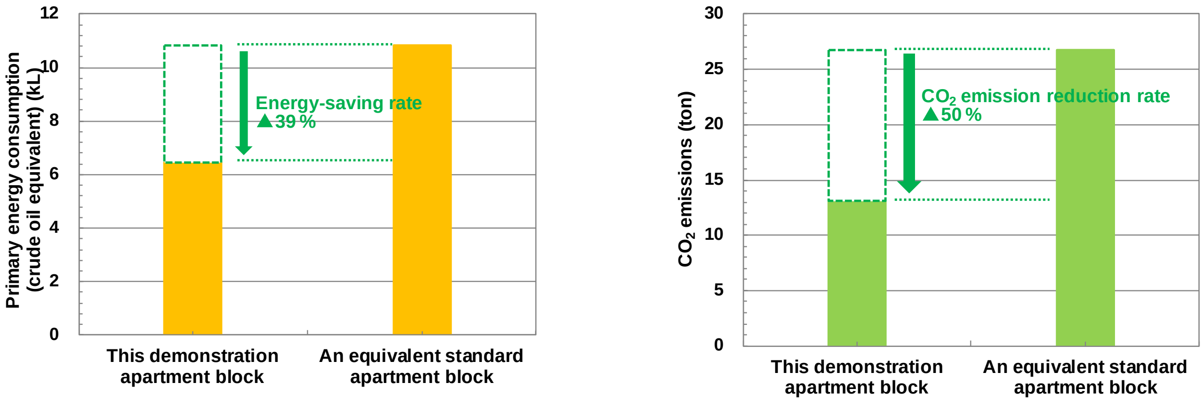
(4) Energy saving and CO_2 reduction

Calculation of the effects of introducing this system revealed that compared with an equivalent standard collective housing (*1), energy was saved (*2) by approximately 39% and CO_2 emissions (*3) were reduced by about 50% (Figure 7).

(*1) A collective housing that purchases electricity from a power company and feed hot water from gas fired water heater per individual housing units

(*2) Crude oil conversion factor... electricity: 0.252 L / kWh; gas: 1.137 L / m^3

(*3) CO_2 conversion factor... electricity: 0.69 kg-CO_2 / kWh; gas: 2.36 kg-CO_2 / m^3



(a) Energy saving

(b) CO_2 reduction

Figure 7 Energy saving, and CO_2 reduction

4. Challenges and future approaches

Challenges to further enhance energy saving and CO_2 reduction include increasing the usage of exhaust heat volume from fuel cells to meet hot water demand and improving the fuel cell operating ratio. Going forward, the system will be added with simplified control measures, and new technology will be developed to build a shared fuel cell system more suited to collective housing.