Next-generation household energy system demonstration at NEXT21 Experimental Multi-Unit Housing Complex

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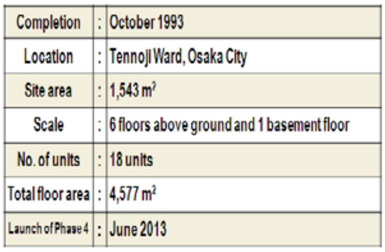
1. Introduction

NEXT21 is an experimental multi-unit housing complex constructed in October 1993 by Osaka Gas Co., Ltd. with the objective of proposing an ideal style of urban multi-unit housing for the near future. Establishing themes and issues that reflect the times, dwelling demonstration experiment Phases 1 through 3 have been conducted at NEXT21 during the last 15 years, with the company's employees and their families actually residing there.



Completion	:	October 1993
Location	:	Tennoji Ward, Osaka City
Site area	:	1,543 m^2
Scale	:	6 floors above ground and 1 basement floor
No. of units	:	18 units
Total floor area	:	4,577 m^2
Launch of Phase 4	:	June 2013

Figure 1 Overview of NEXT21

2. Concept of Phase 4 Demonstration Experiment

The Phase 4 demonstration experiment has been designed to pursue "environmentally friendly, spiritually rich living" on the premises of urban multi-unit housing complexes up to around 2020. The Phase 4 experiment focuses particularly on "residence and way of living" and "energy system" that will ensure "restoration of the relationship between people and nature," "creation of connection between people," and "realization of a smart, energy-saving style of living."

Figure 2 Concept of Phase 4 demonstration experiment

3. Outline of Habitation Experiment of Energy System

In the latest habitation experiment, a cogeneration system is effectively used in concert with the characteristics of the multiple-unit housing complex. This experiment has two objectives: (1) to pursue the possibility of further energy saving and (2) to demonstrate smart energy supply technology and systems that will resolve problems in energy supply (distribution of energy sources, energy self-sufficiency, electricity saving, peak demand leveling etc.) that were revealed by the Great East Japan Earthquake.

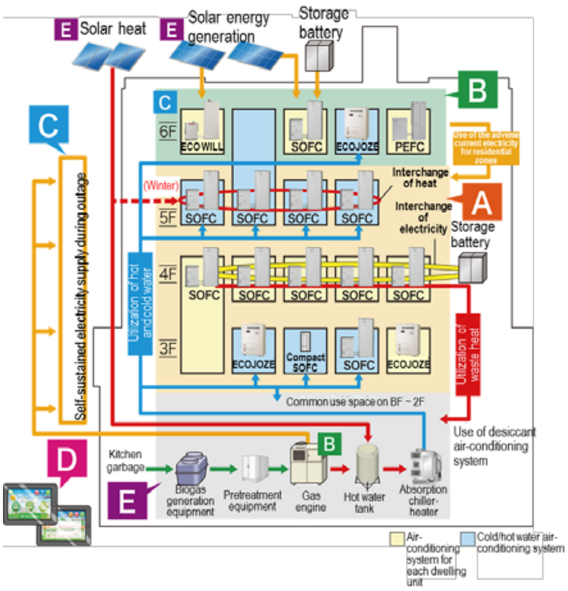


Figure 3 Overview of Habitation Experiment with Energy System

Five major experiments, shown in Figure 3, are under way at present. These are (A) distribution of solid-oxide fuel cells (SOFCs) to dwelling units and energy interchange among these units, (B) demand response (DR) scheme and reverse flow operation (operation to export surplus electricity back to the grid), (C) construction of self-sustained electricity supply system for surviving electricity outage, (D) introduction of home energy management system (HEMS), and (E) interconnection of self-sustained electricity supply system output with renewable energy.

This report mainly discusses experiments involving systems that use SOFCs (ENE-FARM, type S) (experiments (A), (B), and (C) above).

An SOFC is a fuel cell with high electricity generation efficiency. Experiments have been conducted to maximize the potential performance of SOFCs for the multiple-unit housing complex. The experiments focus particularly on evaluating energy-saving performance, determining optimal specifications and operating conditions, and identifying the problems to be resolved before practical use of SOFCs.

The demonstration items and their significance are described below.

(1) Reverse flow/interchange demonstration of electricity generation by SOFC
    - ⇒ Making the best use of high generation efficiency at rated operation
(2) Heat interchange demonstration of system that uses SOFC exhaust heat and solar heat
    - ⇒ Compensating for low heat-to-electricity ratio by combining with solar heat
(3) Demonstration of self-sustained electricity supply system that survives outage
    - ⇒ Increasing electricity supply capacity by combining with self-sustained source of electricity
(4) Test operation of next-generation, high-efficiency SOFC prototype
    - ⇒ Pursuing the possibility of further efficiency enhancement and downsizing

4. Energy System/ Habitation Demonstration Experiment Results

4-1. Reverse flow/interchange demonstration of electricity generation by SOFC

The demonstration experiment was conducted in two stages: (1) continuous reverse flow operation in which each SOFC was operated continuously for 24 hours at rated output of 700 W to export the electricity exceeding each dwelling unit’s consumption back into the grid (inside the housing complex) and (2) DR reverse flow operation to save electricity from the grid by residents’ electricity-saving efforts and by increasing electricity generation by SOFC.

In continuous reverse flow operation (4 dwelling units on the 4th floor), it was confirmed that continuous SOFC operation at rated output of 700 W for 24 hours reduced purchased electricity, primary energy consumption and CO_2 emissions.

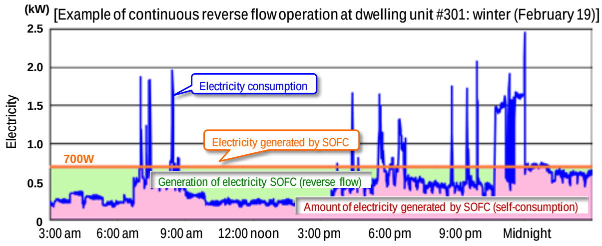
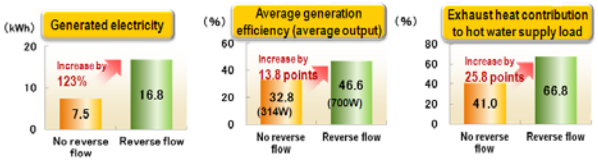


Figure 4 Example of continuous reverse flow operation at dwelling unit #301: winter (February 19)



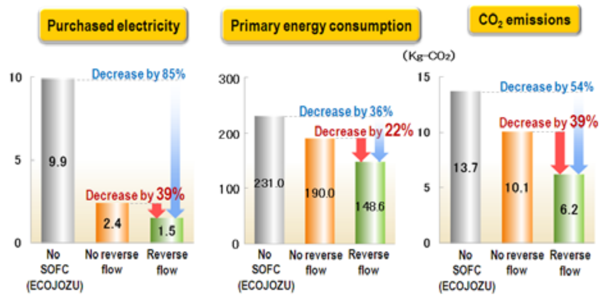


Figure 5 Effects of continuous reverse flow operation (27-day average of one of 4 dwelling units from Dec. 5 to Mar. 23)

In DR reverse flow operation (1 dwelling unit on the 6th floor), electricity supply was restricted during the time zone from 9:00 am to 9:00 pm in winter. Along with a rise in electricity rate per unit consumption, residents were requested one day in advance via mobile phone e-mail and HEMS terminal display to save electricity during the above time zone. In the same time zone, SOFCs were operated at rated output. As a result, consumption of grid electricity dropped to one-half, owing to residents' electricity-saving efforts and increased output of SOFCs.

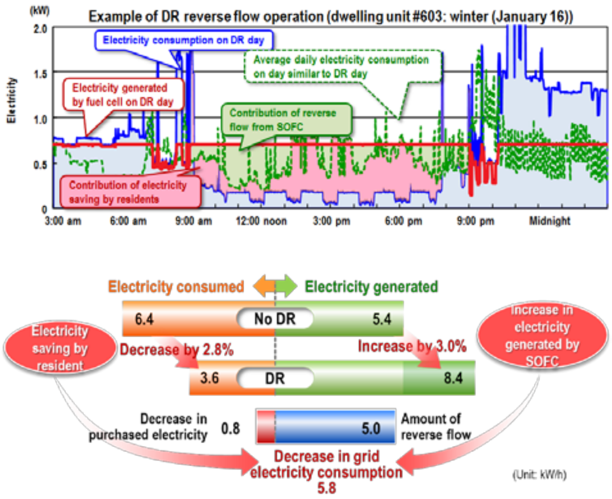


Figure 6 Effects of DR reverse flow operation (8-day average for 1 dwelling unit from Jan. 16 to Feb. 14)

4-2. Heat Interchange Demonstration of System Using SOFC's Exhaust Heat and Solar Heat

In consideration of in SOFC electricity generation efficiency improvement and consequential decrease in exhaust heat generation in future, this system used solar heat to compensate for thermal output shortage in winter. SOFCs installed in three dwelling units on the 5th floor were operated to generate electricity as usual in response to demand. On the other hand, heat collected by the solar panel (6 m^2) installed on the roof of the housing complex was stored in a shared hot water tank. When dwelling units became deficient in heat, they received heat from the shared tank, while feeding heat back into the shared tank when they had excess heat, thereby achieving heat interchange.

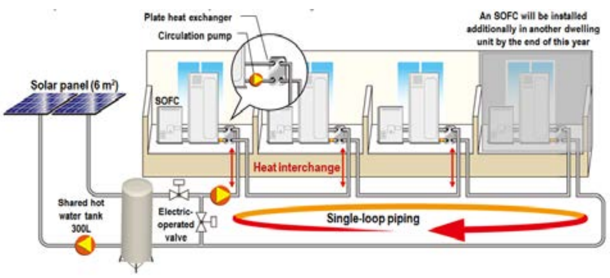


Figure 7 Outline of Demonstration System

Improvement mainly of water heating operation control conditions increased the solar heat/total heat demand ratio to 13%, saving the quantity of heating energy source used for auxiliary boiler by approximately 25%. In addition, primary energy consumption was cut by 4.3 points from that of a system using only SOFCs.

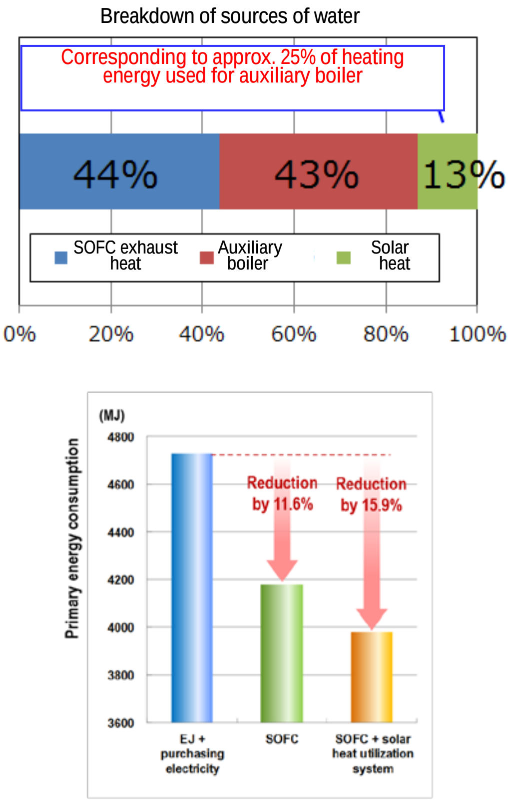


Figure 8 Quantity of heating energy source used for auxiliary boiler and energy usage reduction effect (One-week total for 3 dwelling units in winter)

4-3. Demonstration of Self-sustained Electricity Supply System that Survives Outage

Two objectives of this demonstration were (1) to verify the operation of a self-sustained electricity supply system that interconnects the gas engine cogeneration system (GE) installed in the housing complex with the SOFC installed in each dwelling unit, both of which can survive electricity outage, and (2) to evaluate the effectiveness of the self-sustained electricity supply system. In this demonstration, electricity was supplied to 10 dwelling units on the 3rd to 5th floors (8 of which units are equipped with SOFCs), lighting apparatuses and other common loads, and service/waste water pumps and other electric loads. In particular, electricity was supplied evenly to each dwelling unit and an electricity consumption restrictor was installed in each unit.

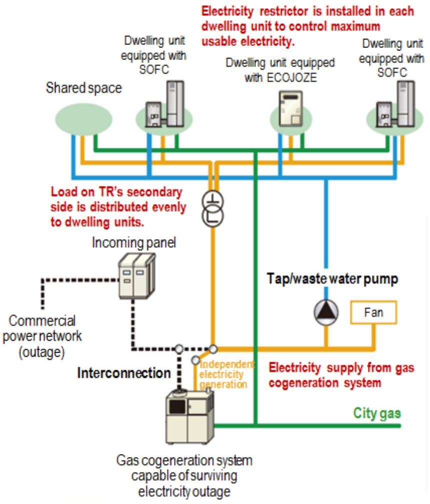


Figure 9 Outline of self-sustained power system

The experiment was carried out during the time zone of 5:00 pm to 8:00 pm on two or more days in October through December, with residents staying in their units, under restrictive conditions (1) and (2) described below. Experimental participants responded to a questionnaire/hearing regarding their electricity consumption under, and their tolerance of, the two restrictive conditions. The questionnaire/hearing results showed that participants' score of acceptance (evaluation score was set between +3 and -3) increased when electricity supply from SOFCs was added and they could use more appliances. However, lack of information about remaining electricity available prevented them from sufficiently utilizing self-sufficient electricity.

(1) Electricity supply from only GE (upper limit of usable electricity: 500 W)
(2) Electricity supply from GE and SOFCs installed in each dwelling unit (additional supply of 700 W)

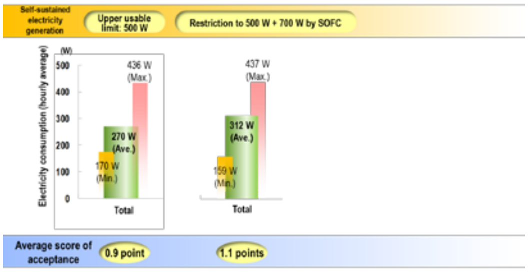
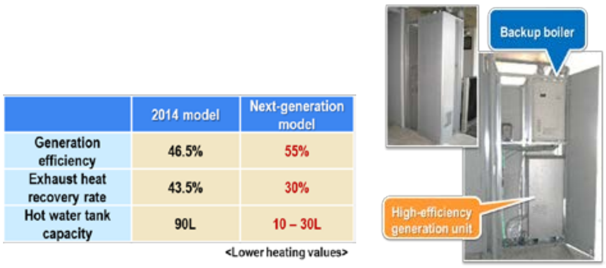


Figure 10 Comparison of electricity consumptions under restrictive use conditions and acceptance evaluation by experiment participants

4-4. Test Operation of Next-Generation, High-Efficiency SOFC Prototype

A next-generation, high-efficiency SOFC prototype, which is easy to install in a multiple-unit housing complex because of its compactness and extremely high electricity generation efficiency, was test-operated (the prototype was installed in one vacant dwelling unit on the 3rd floor).

The test result showed a transmission end output efficiency of 55% (in LHV) during rated operation and a high partial load performance. The data acquired from the test operation can be used in putting the new SOFC to practical use.



	2014 model	Next-generation model
Generation efficiency	46.5%	55%
Exhaust heat recovery rate	43.5%	30%
Hot water tank capacity	90L	10 – 30L

<Lower heating values>

Figure 11 Target specifications of next-generation SOFC and its prototype installed in dwelling unit

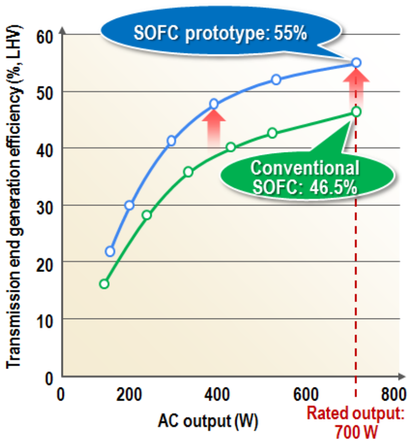


Figure 12　Generation efficiency test result

5. Conclusions

The authors carried out demonstration experiments of promising systems through interconnecting with SOFCs installed in actual dwelling units. As we improved system operating conditions and other factors, the systems demonstrated the same level of performances as we originally anticipated. We will continue demonstration experiments to evaluate the yearly energy-saving performance of the systems, as well as to review and improve, as needed, their operating conditions and specifications.