International Gas Union Research Conference
IGRC COPENHAGEN 2014
September 17-19

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

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September 17, 2014

Presentation Contents

1. Outline of Experimental Multi-Unit Housing Complex
   - NEXT21 -
2. Demonstration of Reverse Flow (Exporting Electricity Back into the Grid) and Interchange of Electricity Generated by SOFC
3. Demonstration of Heat Interchange in System that Utilizes SOFC's Exhaust Heat and Solar Heat
4. Demonstration of Self-Sustained Power System That Operates during Outage
5. Test Operation of Next-Generation High-Efficiency SOFC Prototype
6. Conclusions

1. OUTLINE OF EXPERIMENTAL MULTI-UNIT HOUSING COMPLEX - NEXT21 -

1.1 What is NEXT21?

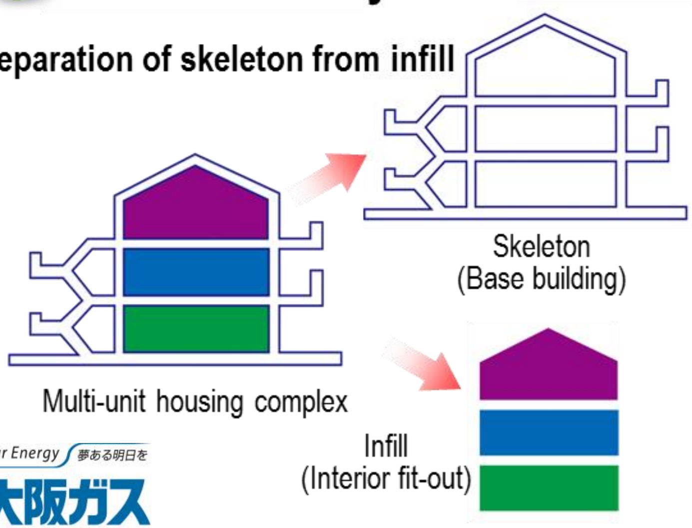
An experimental multi-unit housing complex constructed to propose and demonstrate an ideal style of urban multi-unit housing for the near future

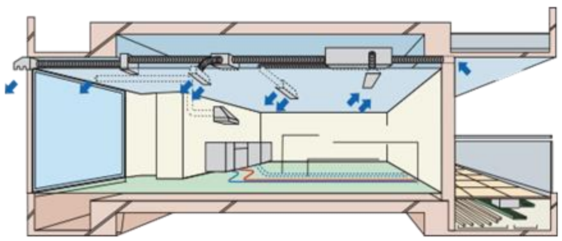
Outline

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 (floor area: 32 ~ 166 m^2 (average 115 m^2))
Total floor area	:	4,577 m^2
Green area	:	934 m^2

Construction system

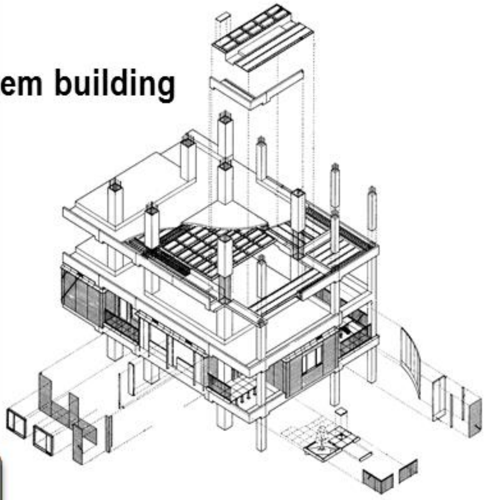
■ Separation of skeleton from infill





■ Flexible piping system

■ System building



Free to arrange rooms in response to need for living style change

1.2 History of Experimental Multi-Unit Housing Project

Osaka Gas Experimental Multi-Unit Housing Complex
NEXT21

Theme

- **1994 — Phase 1**: Simultaneous realization of “amenity” and “energy-saving, environment-friendly living”
- **2000 — Phase 2**: Special consideration for the global environment and comfortable daily living
- **2007 — Phase 3**: Housing and energy systems that support sustainable urban living
- **2013 — Phase 4**: Environmentally friendly, spiritually rich living

Actual dwelling experiment by Osaka Gas’s employees and their families

Significances

Demonstration model of environmentally symbiotic housing
- Large-scale greening of building
- Energy-conscious advanced energy system
- Energy-saving lifestyle

Demonstration model of sustainable housing, characterized by long-lasting skeleton and infill
- Housing suitable for aging society with declining birth rate
- Renovation experiment
- Promotion of community among residents

Opportunity for experimenting, monitoring and evaluating household ppliances and housing facilities/systems
- Fuel cell for household use
- HEMS
- Various newly developed household equipment

1.3 Phase 4 Habitation Experiment Concept

Envisioning urban multi-unit housing up to 2020, Phase 4 of the NEXT21 experiment reviews the relationships among people, nature, energy and housing, in quest of "environment-friendly, spiritually rich living."

Experiment in "Housing and Living"

Verification and proposal of housing and living that can realize a diverse range of future lifestyles

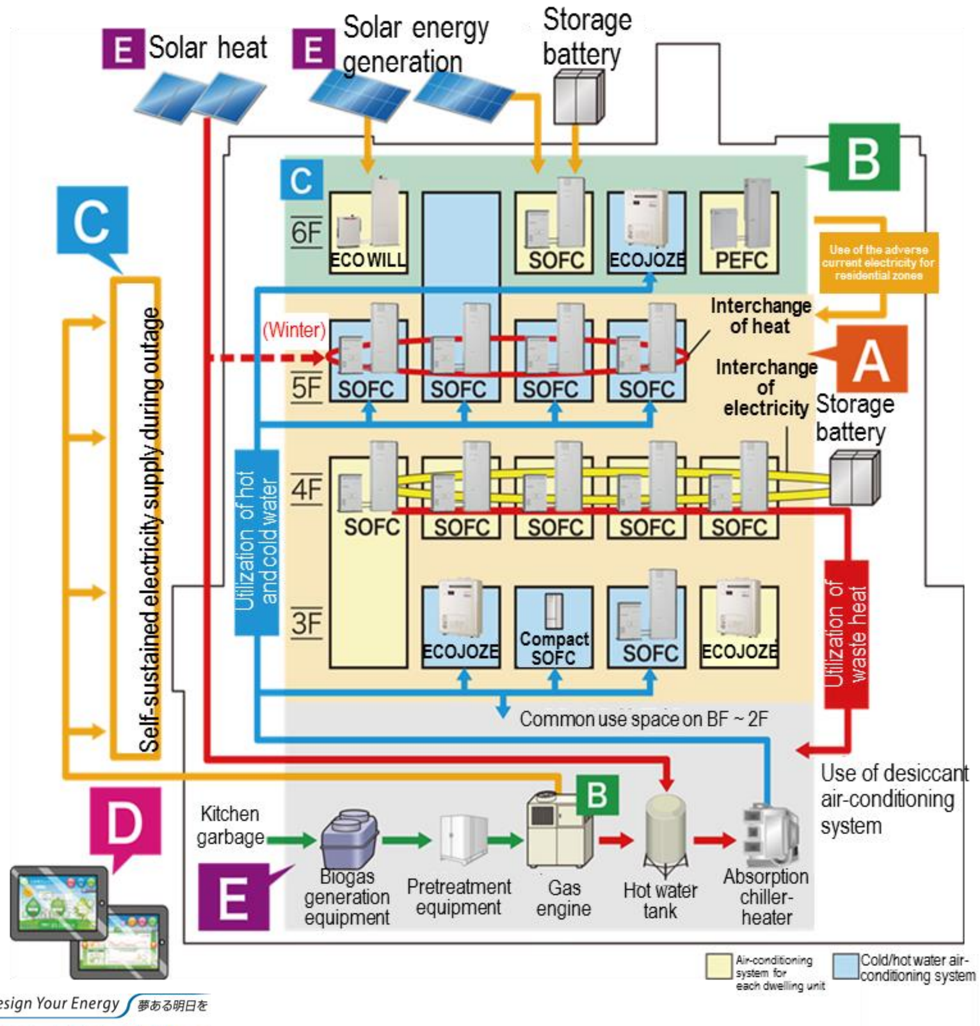
Experiment with New Energy System

Demonstration of next-generation energy system that will help realize the smart multi-unit housing complex

Phase 4 of the experimental project has been under way since June, 2013.

1.4 Outline of Energy System Experiment

- Demonstration experiment aimed at further energy saving, CO_2 emissions reduction and energy self-sufficiency by effectively using gas co-generation system in concert with the characteristics of the multi-unit housing complex
- This presentation focuses on demonstrating the energy supply system that used SOFCs (ENE-FARM type S).



A Decentralized installation of SOFCs, and energy interchange

- Interchanging generated electricity and combining SOFCs' exhaust heat with solar heat
- Testing operation of compact SOFC prototype

B Demand response scheme and reverse flow operation

- Saving electricity and upgrading CGS' generation capacity
- Maximizing energy-saving capability by reverse flow operation

C Constructing a self-sustained power system that operates during outage

- Ensuring independence with central CGS that can operate even during outage
- Electricity generation by SOFC in each dwelling using independent sources of electricity

D Introduction of HEMS

- Installing HEMS tablet in each dwelling
- Verifying performance of next-generation HEMS

E Combination with renewable energy

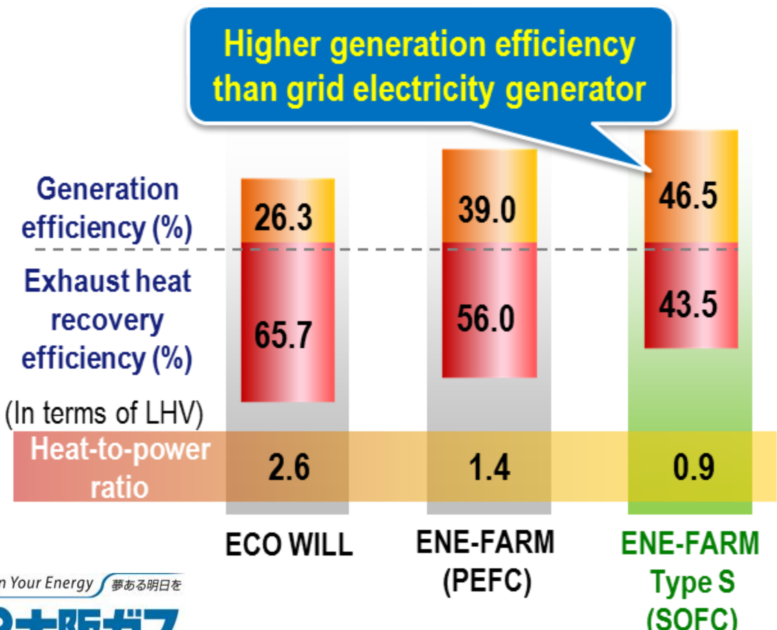
- Combining with solar light, solar heat and biogas

1.5 Demonstration Experiment of System that Uses SOFCs

- Demonstration of system that maximizes the potential performance of SOFC
- Evaluation of energy-saving performance, identification of optimal specifications and operating conditions, clarification of problems to be solved before practical use of system

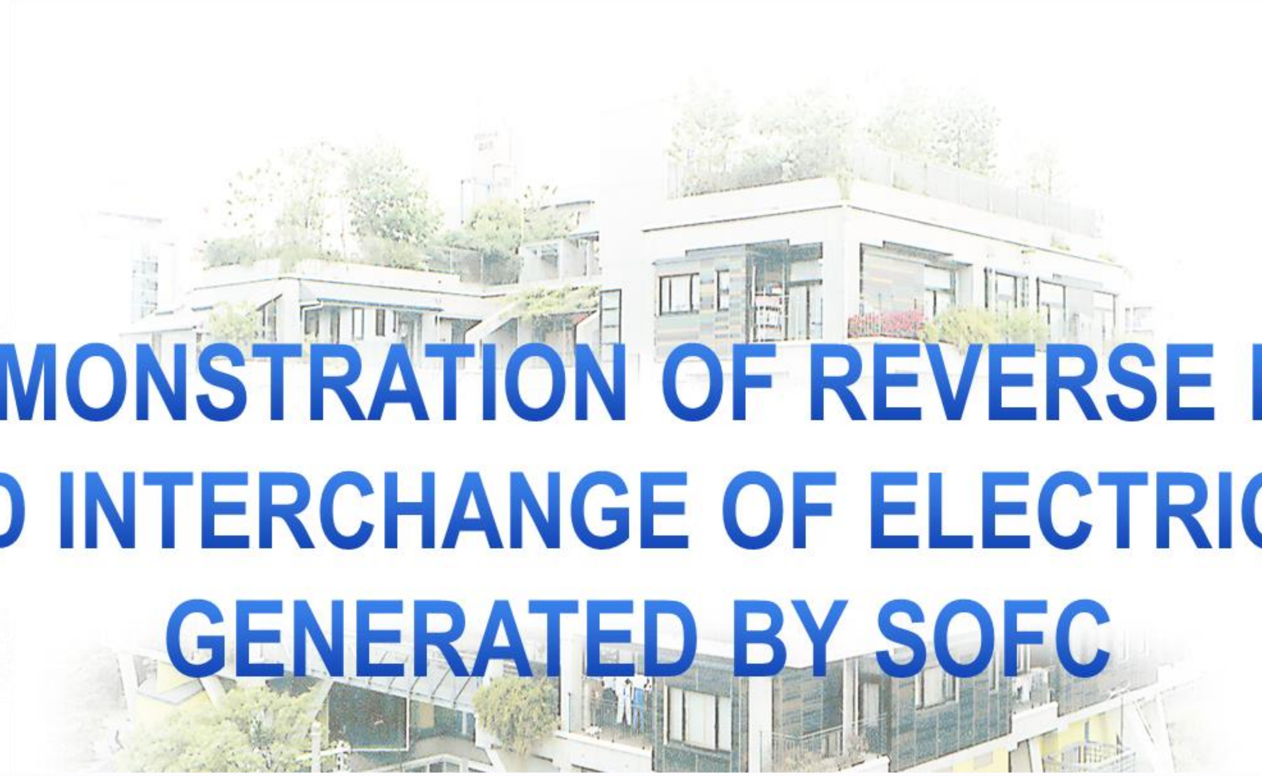
Original model | Current model

Released in April 2012 | Released in April 2014



Contents of Demonstration Experiment (presented today)

- Reverse flow/interchange demonstration of electricity generation by SOFC
  - ⇒ Making the most of high generation efficiency in rated operation
- Heat interchange demonstration of system that uses SOFC's output and solar heat
  - ⇒ Compensating for low heat-to-power ratio by combining with solar heat
- Test operation of next-generation, high-efficiency SOFC prototype
  - ⇒ Pursuing the possibility of further efficiency enhancement and downsizing



2. DEMONSTRATION OF REVERSE FLOW AND INTERCHANGE OF ELECTRICITY GENERATED BY SOFC

Reverse flow and interchange of electricity generated - - - 4 dwelling units on 4th floor

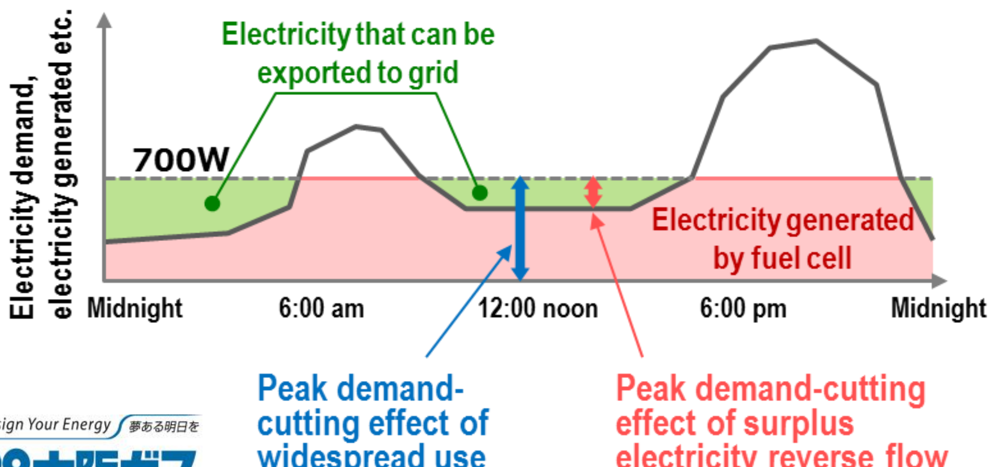
Demand-response (DR) scheme - - - 3 dwelling units on 6th floor (SOFC installed in 1 dwelling unit)

2.1 Outline of Demonstration System

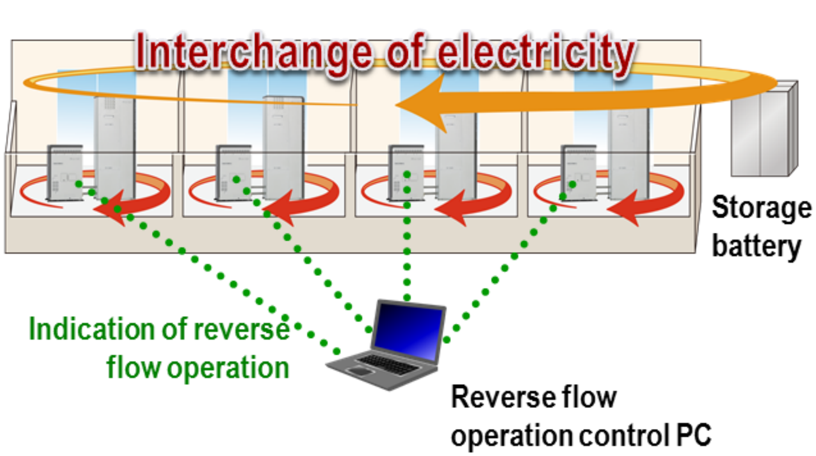
Making the best use of electricity through high-efficiency generation of electricity exceeding consumption of each dwelling unit

Reverse flow operation of system Interchange of surplus electricity among dwelling units	Rated operation (700 W)	Reverse flow operation (24 hours)
		Reverse flow operation in daytime (7 am – 11 pm)
		Reverse flow on DR scheme (DR time zone) → Accompanied by residents' electricity saving
Interchange among dwelling units on same floor	Rated operation, to extent possible	• Interchange or storage of surplus electricity in battery • Determining a combination of SOFCs to be interchanged to minimize CO_2 emissions, based on electricity consumption and heat stored in hot water tank of each dwelling unit

Image of reverse flow operation of system



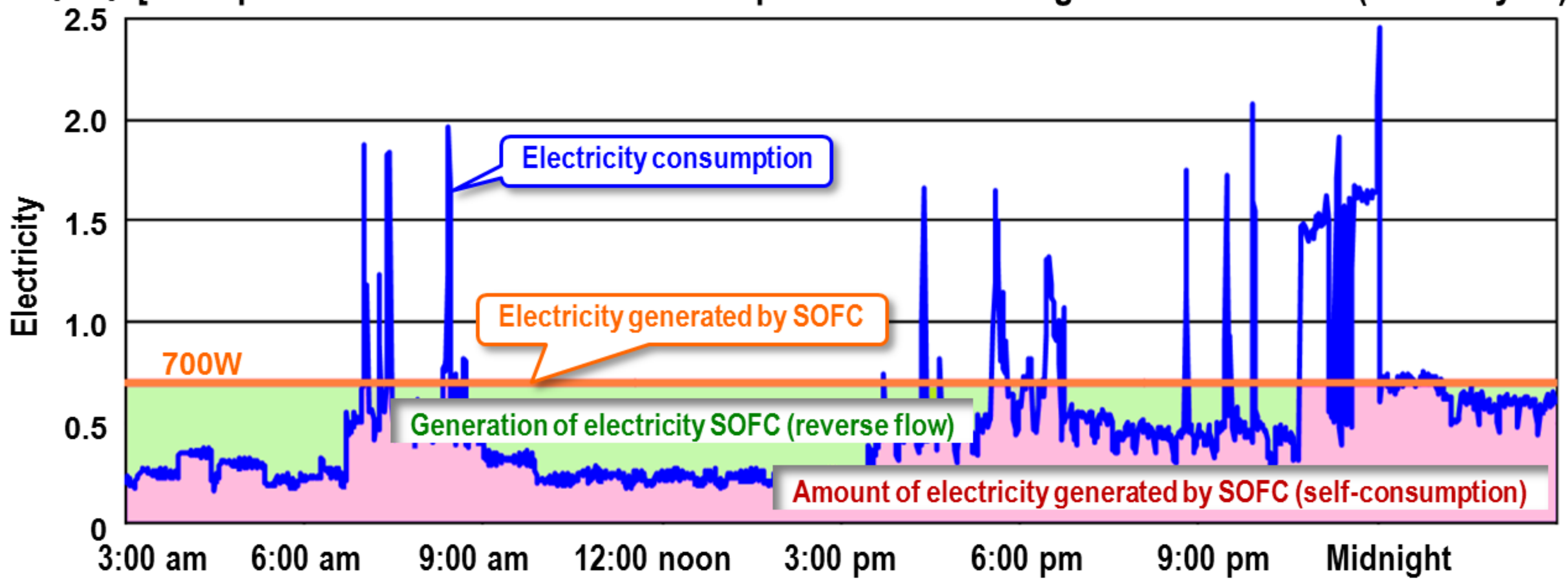
Interchange among dwelling units on same floor

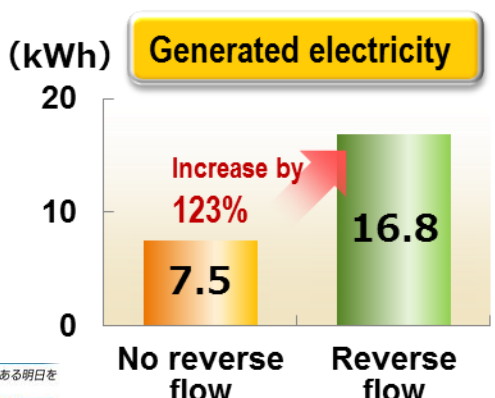


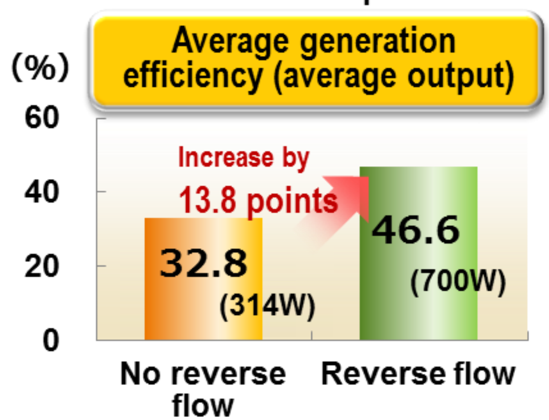
2.2 Continuous Reverse Flow Demonstration Results ①

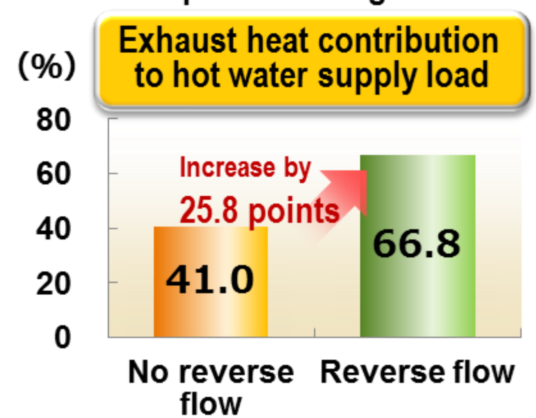
Since electricity could be generated at rated output of 700 W for 24 hours, it became possible to export surplus electricity to the grid (inside the complex) at dawn and during daytime, when less electricity is consumed.

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





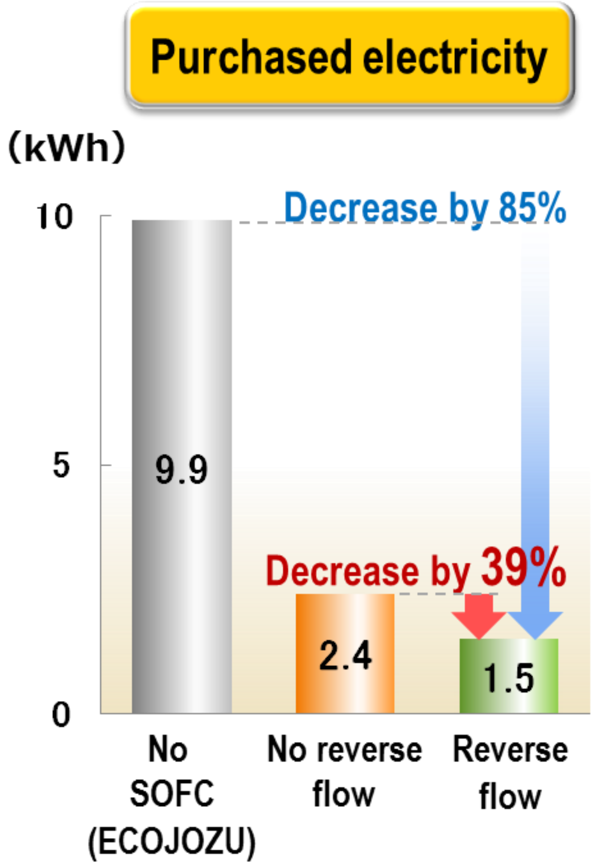


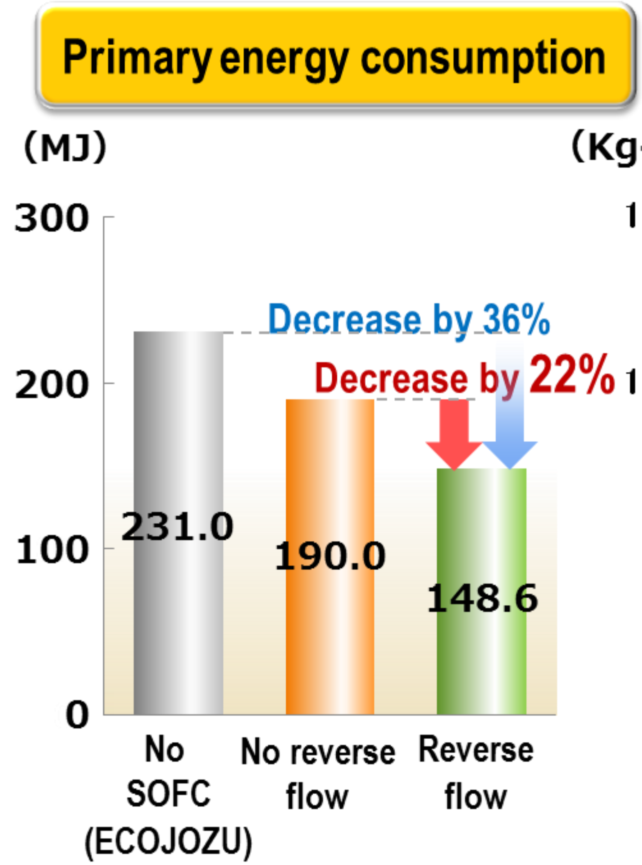


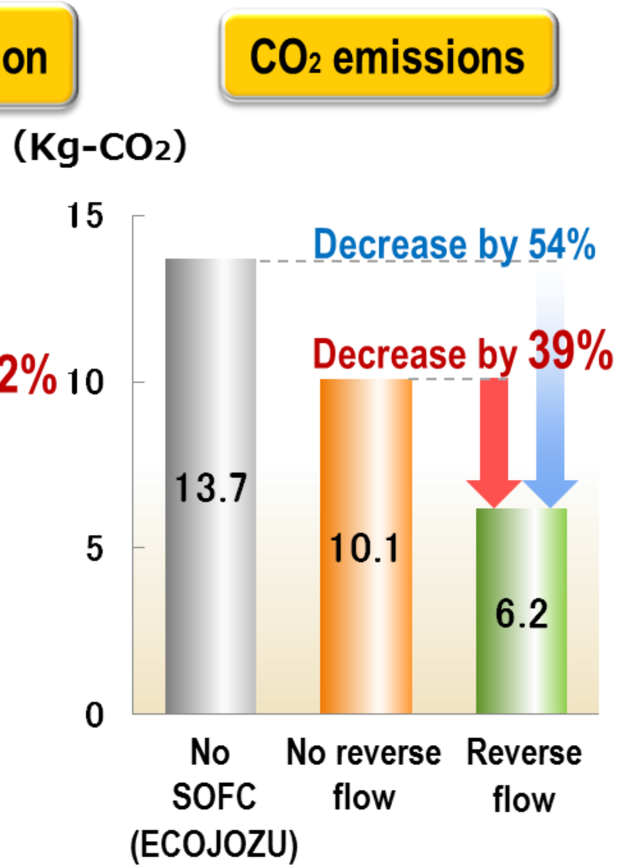
＊ Average value for 81 days from December 2013 to June 2014

2.2 Continuous Reverse Flow Demonstration Results ②

Since electricity could be generated at a rated output of 700 W for 24 hours, it became possible to reduce purchased electricity, primary energy consumption and CO_2 emissions.







* Average value for 152 days average from December 2013 to June 2014

2.3 DR Reverse Flow Demonstration Method ⑦

Osaka Gas Experimental Multi-Unit Housing Complex NEXT21

① Electricity saving by residents

② Increase in electricity generated by SOFC

▶ Reduction of grid electricity consumption

DR time zone	• Summer: 1:00 pm – 4:00 pm (3 h) • Winter: 9:00 am – 9:00 pm (12 h)
DR scheme	CPP (increasing electricity rates during DR time zone) • Summer: ¥60, ¥80, ¥100/kWh • Winter: ¥40, ¥60/kWh * Normal unit rate: approx. ¥20/kWh
Effect evaluation method	Comparison with average daily consumption during three days having atmospheric temperature nearly equal to that on the day DR scheme was introduced

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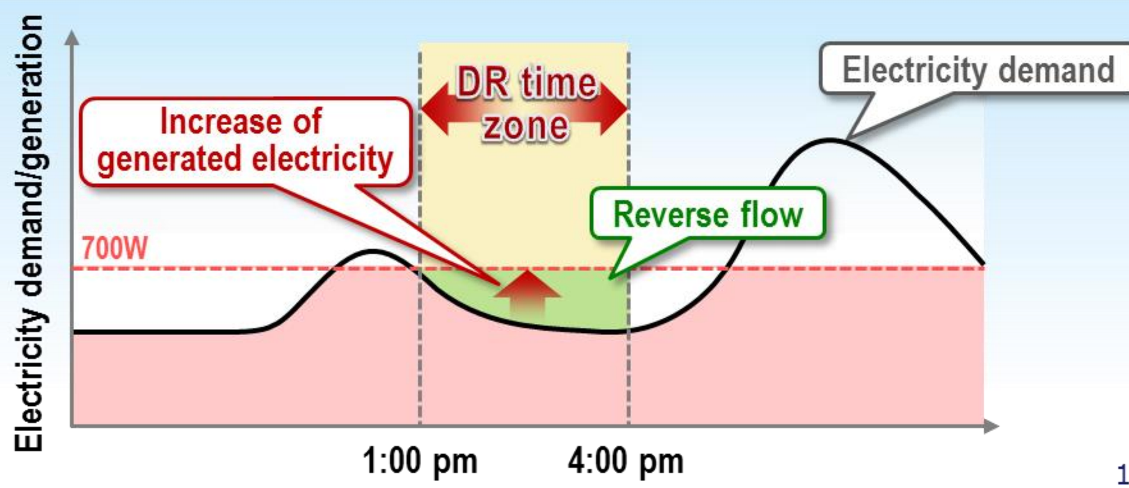
2.3 DR Reverse Flow Demonstration Method ②

One day in advance, request to save electricity was communicated to residents via HEMS terminal display and mobile phone e-mail.

- DR time zone
- Electricity rate

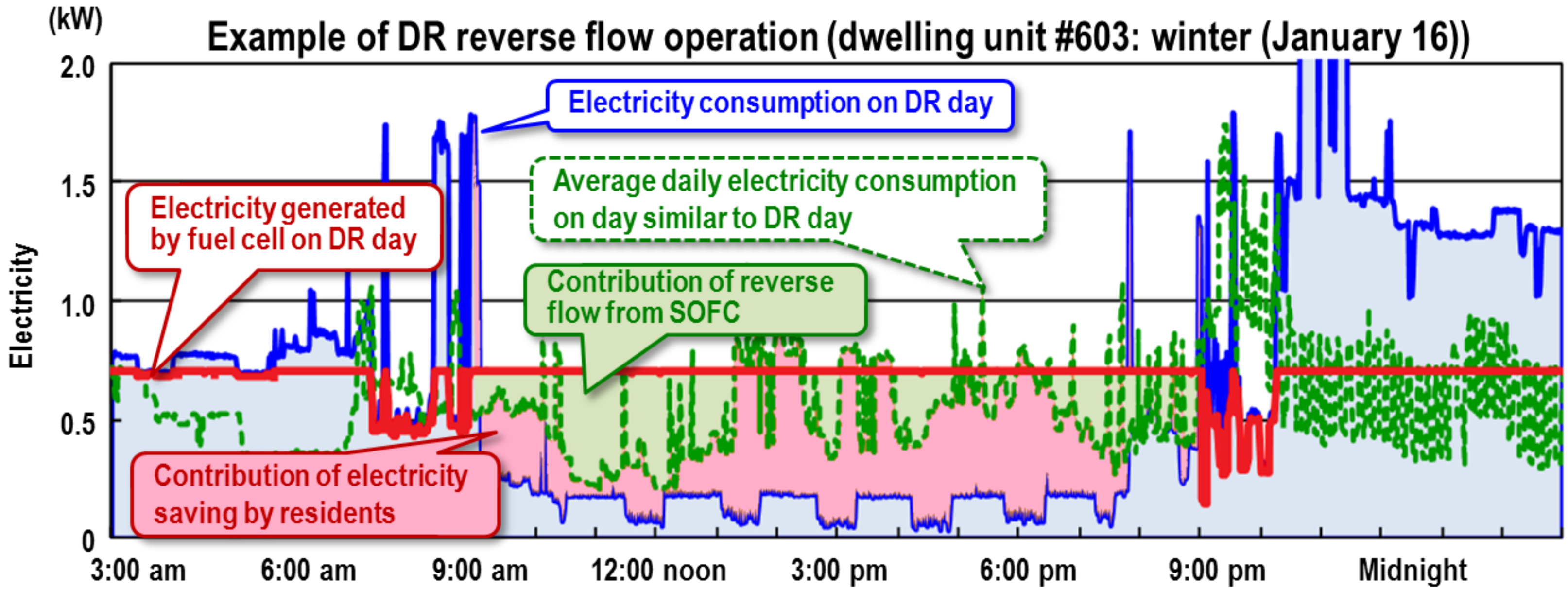
Request displayed on HEMS terminal ▶

In DR time zone, SOFCs were subjected to automatic rated operation.



2.4 DR Reverse Flow Demonstration Results ①

Electricity saving by residents and increase in electricity generated by SOFC doubled DR effect.



Electricity consumed ⇔ Electricity generated

Electricity consumed		Electricity generated
6.4	No DR	5.4
3.6	DR	8.4

Decrease by 2.8%

Increase by 3.0%

Electricitysaving by resident

Increase in electricity generated by SOFC

Decrease in purchased electricity 0.8

5.0 Amount of reverse flow

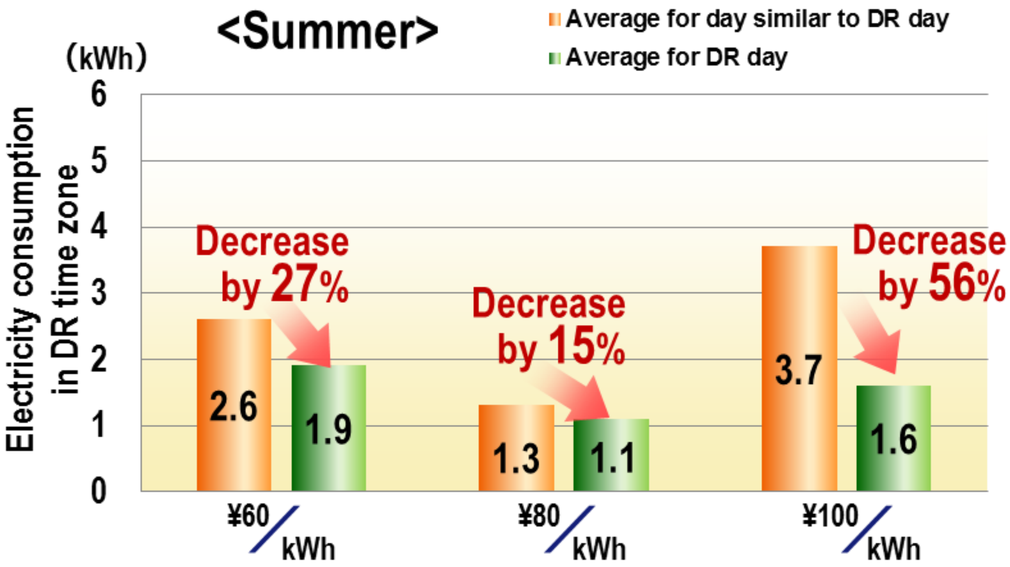
Decrease in grid electricity consumption 5.8

(Unit: kW/h)

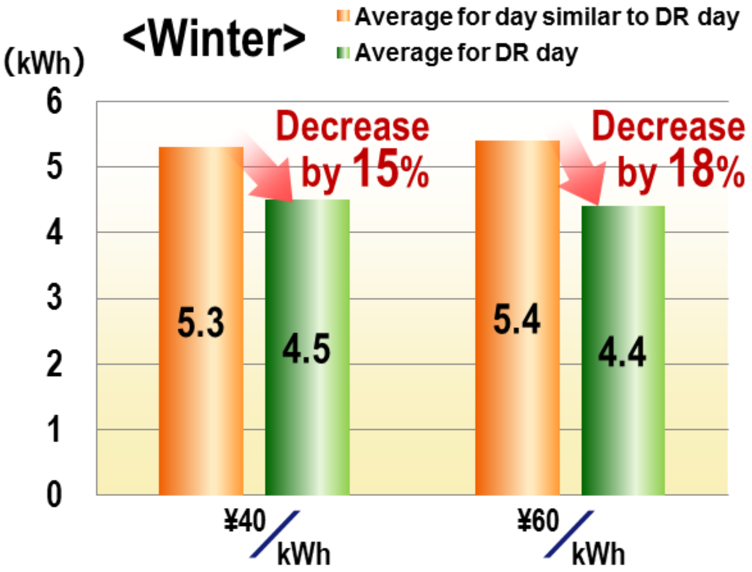
＊Dwelling unit #603: average value for 8 days from January 16 to February 14

2.4 DR Reverse Flow Demonstration Results ②

Effect of DR on reduction of electricity consumption



＊ Three dwelling units: average for each electricity rate during 4 days from August 27 to August 30



＊ Three dwelling units: average for each electricity rate during 8 days from January 16 to February 14

Examples of electricity saving measures taken by residents in DR time zone (questionnaire/hearing results)

- Shopping in DR time zone
- Use of gas range instead of electric kettle and microwave oven
- Turning up air conditioning temperature from usual 23°C to 26°C (summer)
- Finishing microwave oven and dish washer/dryer usage by 9 o'clock (winter)
- Using floor heating system instead of air conditioner (winter)

2.5 Reverse Flow/Interchange Demonstration of Electricity Generation by SOFC　Conclusions

Continuous reverse flow

- Reverse flow of surplus electricity generated for 24 hours at rated output power enabled SOFC to increase electricity generation at high efficiency, thereby contributing to significant reduction in purchased electricity and CO_2 emissions.

DR reverse flow

- Electricity-saving measures taken by residents and increase in electricity generation by SOFC halved grid electricity consumption.
- Setting electricity rate at ¥100/kWh led to remarkable reduction of electricity consumption.
- Opinions/requests of residents (questionnaire/hearing results) are as follows:

2.5 Reverse Flow/Interchange Demonstration of Electricity Generation by SOFC Conclusions

Continuous reverse flow

- Reverse flow of surplus electricity generated for 24 hours at rated output power enabled SOFC to increase electricity generation at high efficiency, … y and

DR reverse flow

- … tricity
- Setting electricity rate at ¥100/kWh led to remarkable reduction of electricity consumption.
- Opinions/requests of residents (questionnaire/hearing results) are as follows:

■ It was difficult at first to understand the merits of cooperating with DR.

■ Taking electricity-saving measures was not in itself troublesome.

■ Show typical examples of electricity-saving measures.

■ Forced household appliance control (turning off air conditioner, changing temperature setting etc.) was unfavorable

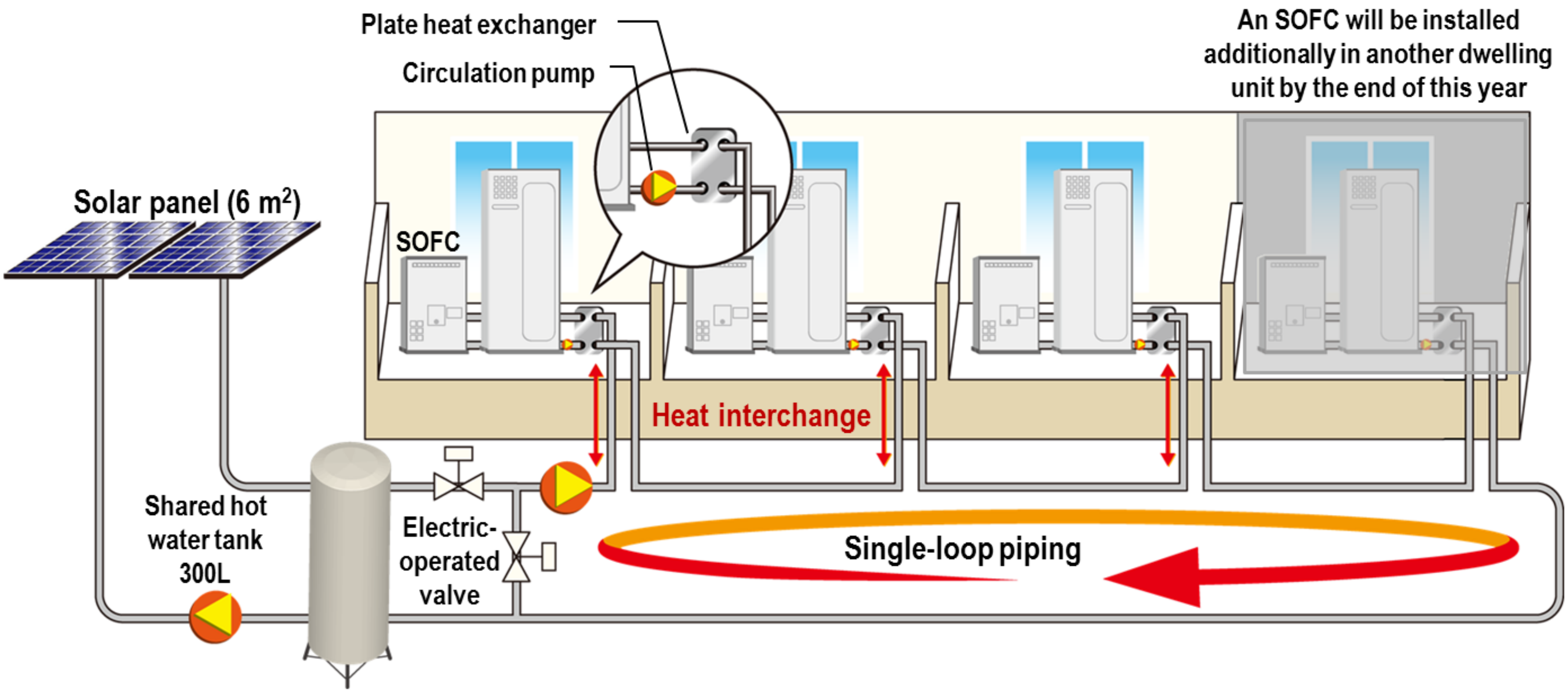
Advice function will be added to HEMS in future.

3. HEAT INTERCHANGE DEMONSTRATION OF SYSTEM THAT COMBINES SOFC HEAT AND SOLAR HEAT

3 dwelling units on 5th floor + Solar panel (6 m^2)

3.1 Outline of Demonstration System

In consideration of improvement in electricity generation efficiency of SOFC and consequent decrease in exhaust heat in future, shortage of thermal output in winter was compensated for by solar heat.

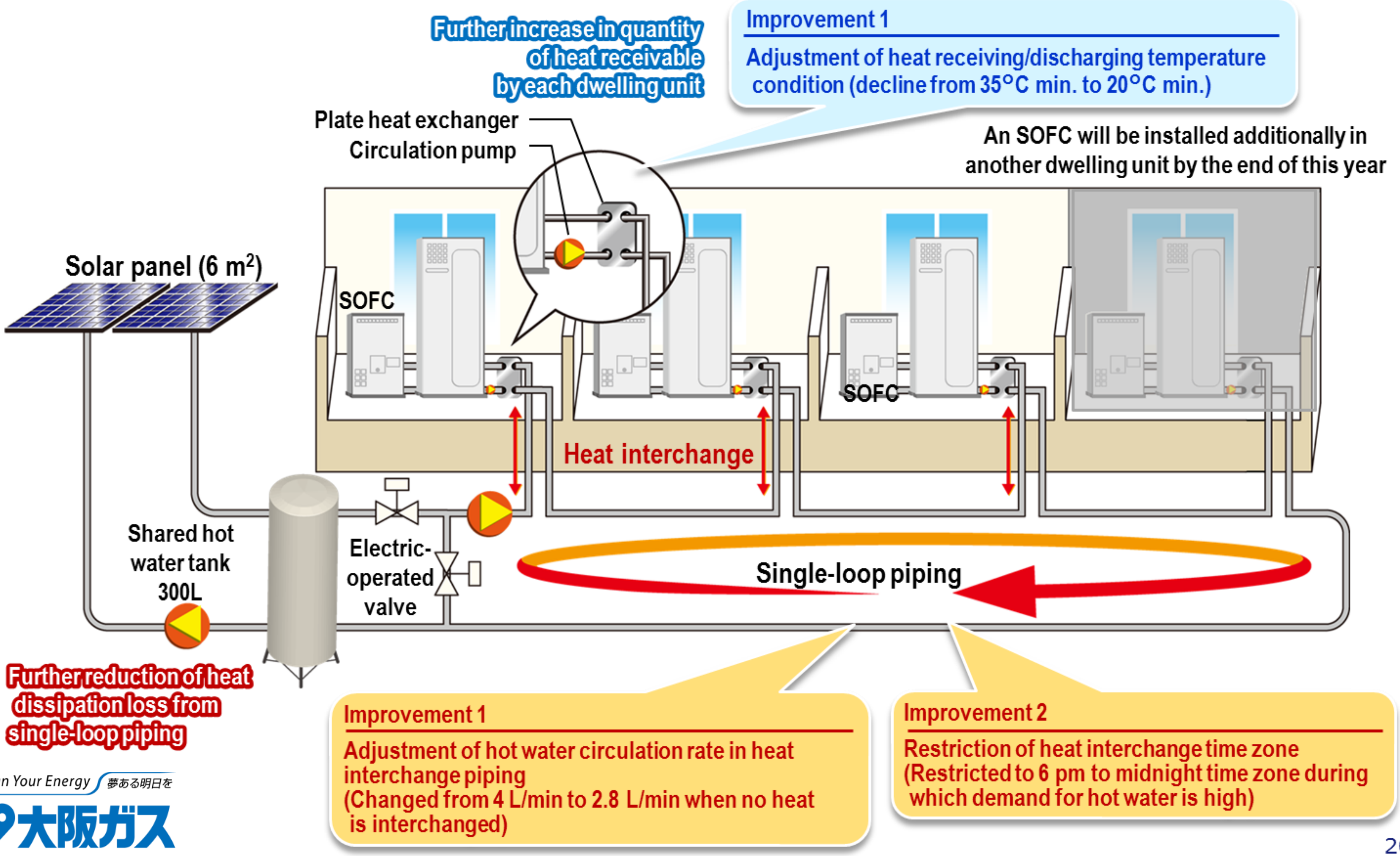


Operation method

- SOFC in each dwelling unit was subjected to electrical power operation as usual.
- Heat collected by solar panel was stored in shared hot water tank.
- Heat was distributed to each dwelling unit through single-loop piping.

3.2 Demonstration Results ①

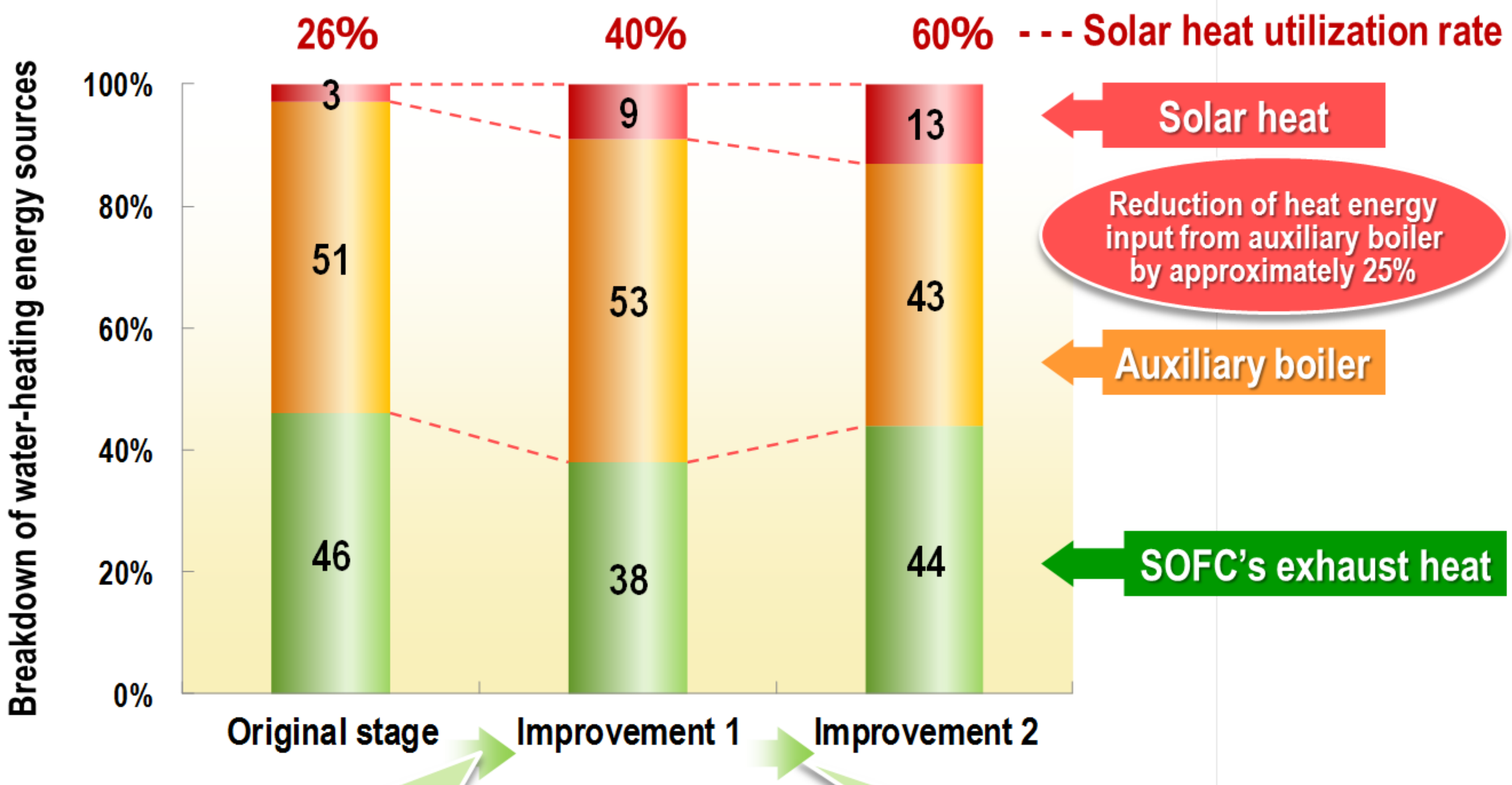
Establishing control system that enables maximum use of heat interchange further increased the quantity of heat receivable by each dwelling unit and reduced heat dissipation loss from single-loop piping.



3.2 Demonstration Results ⑦

Osaka Gas Experimental Multi-Unit Housing Complex NEXT21

Improved operation control conditions enhanced solar heat utilization rate.



Improvement of control method

- Hot water circulation rate in heat interchange piping was adjusted.
- Heat receiving/discharging temperature condition was adjusted.

- Heat interchange time zone was restricted.

＊ Total for three dwelling units during one week in winter

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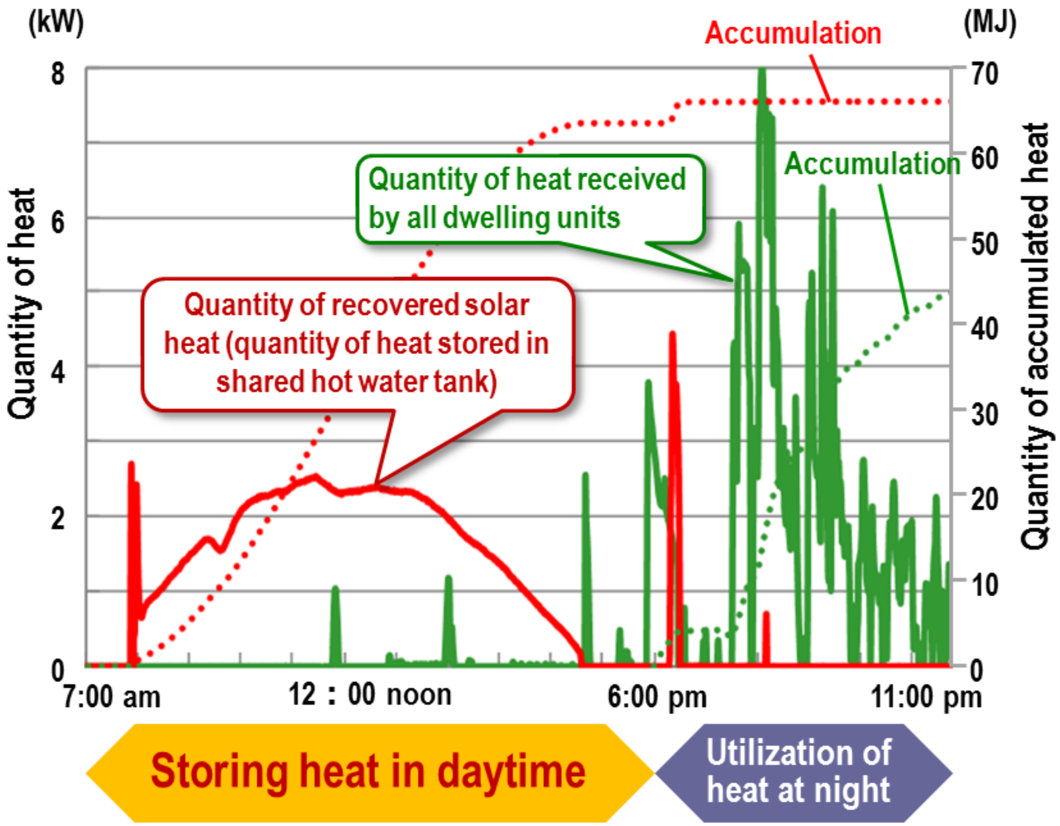
3.2 Demonstration Results ③

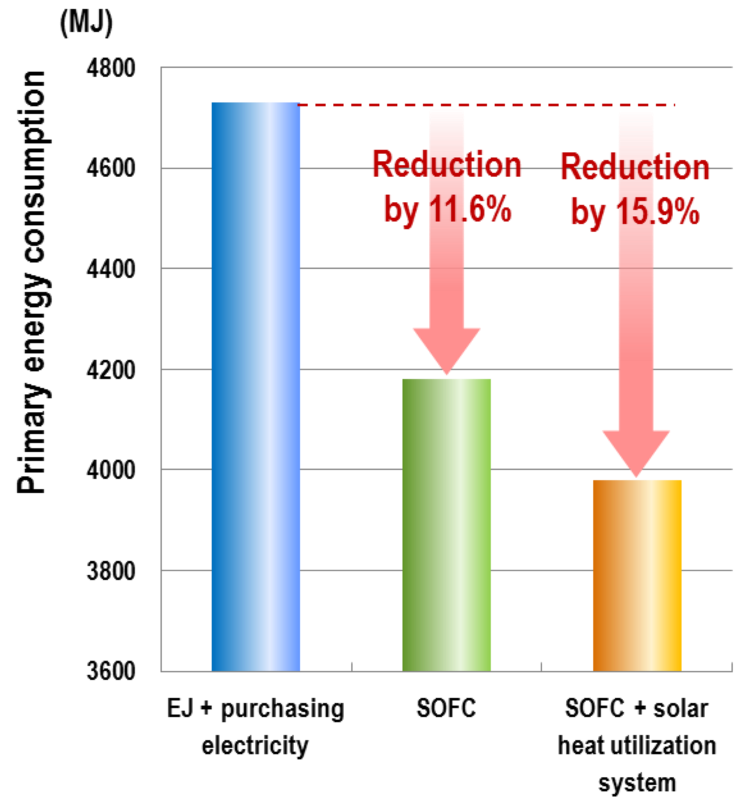
- Storing solar heat in the daytime and using it intensively in the time zone of high hot water demand reduced heat dissipation loss from piping, which was effective for energy saving.
- Heat interchange improved primary energy saving rate by 4.3%.

Quantity of recovered solar heat and heat received by each dwelling unit



＊ Total for three dwelling units on March 17

Primary energy saving effect



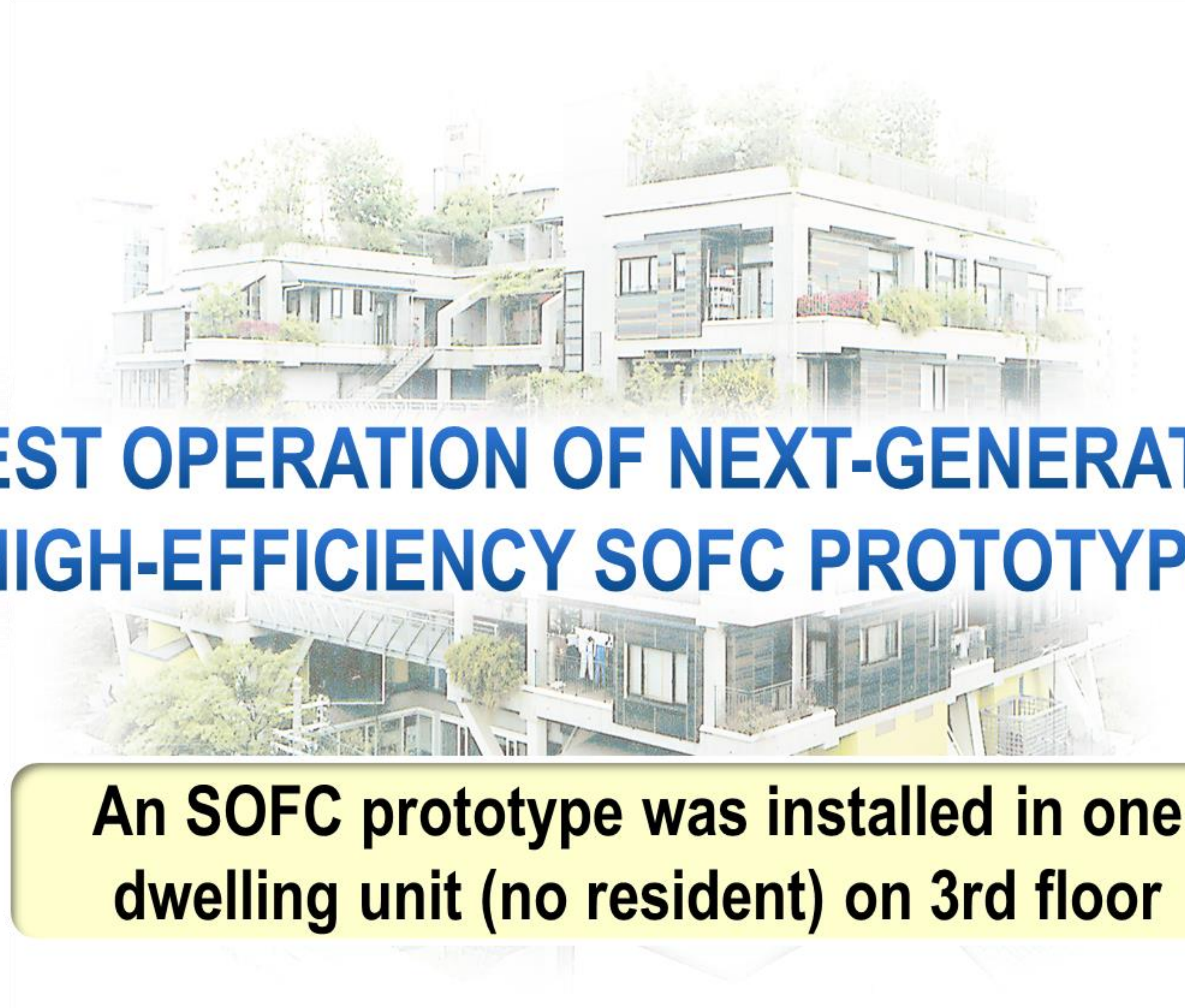
＊ Total for three dwelling units during one week in winter

3.3 Conclusions for Heat Interchange Demonstration of SOFC + Solar Heat Utilization System

- In the case of solar heat utilization, operation control conditions had considerable effect on energy saving performance. In this demonstration, the quantity of heat to be interchanged, heat receiving/discharging temperature condition and heat utilization time zone were adjusted. As a result, solar heat utilization rate and energy saving performance were improved.

- In winter, the dependence of hot water supply load on solar heat reached 13%, while that on SOFC's exhaust heat was 44%.
  - ⇒ Reduction of heating energy source used for auxiliary boiler by approximately 25%
  - ⇒ Improvement of energy saving rate by 4.3%

- We will continue demonstration experiments to further verify control conditions and evaluate energy saving performance. In particular, we will assess the possibility of specification/control optimization and further energy saving by conducting simulations under predicted conditions based on measured data (number of dwelling units, scale etc.).



4. TEST OPERATION OF NEXT-GENERATION, HIGH-EFFICIENCY SOFC PROTOTYPE

An SOFC prototype was installed in one dwelling unit (no resident) on 3rd floor

4.1 Outline of Next-Generation,High-Efficiency SOFC Prototype

An SOFC that is easy to install in multi-unit housing complex dwelling unit because of its compactness and extremely high electricity generation efficiency

Target specifications

	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>

Advantages

<External appearance of SOFC prototype>

- High-efficiency hot module
- Built-in radiator
- Built-in 10 L hot water tank

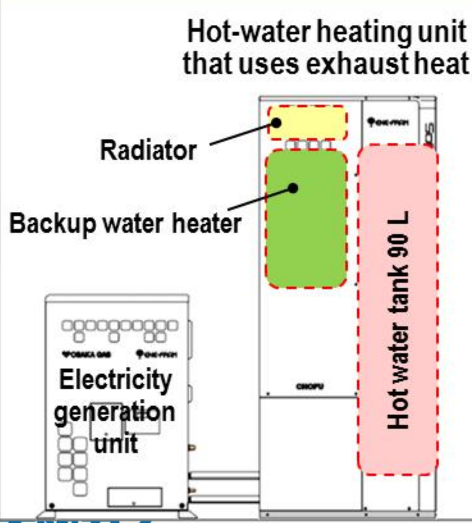
(Unit: mm)

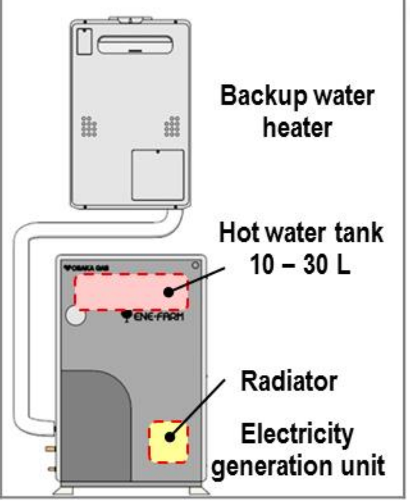
- Homogenized heat distribution in stack
- Improved heat insulation performance
- Improved combustion characteristics

▶ Higher efficiency

System configuration (plan)

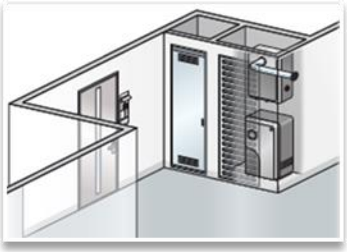
2014 model	Next-generation model





Installation flexibility (idea)

<Multi-unit housing complex>



<Detached housing>

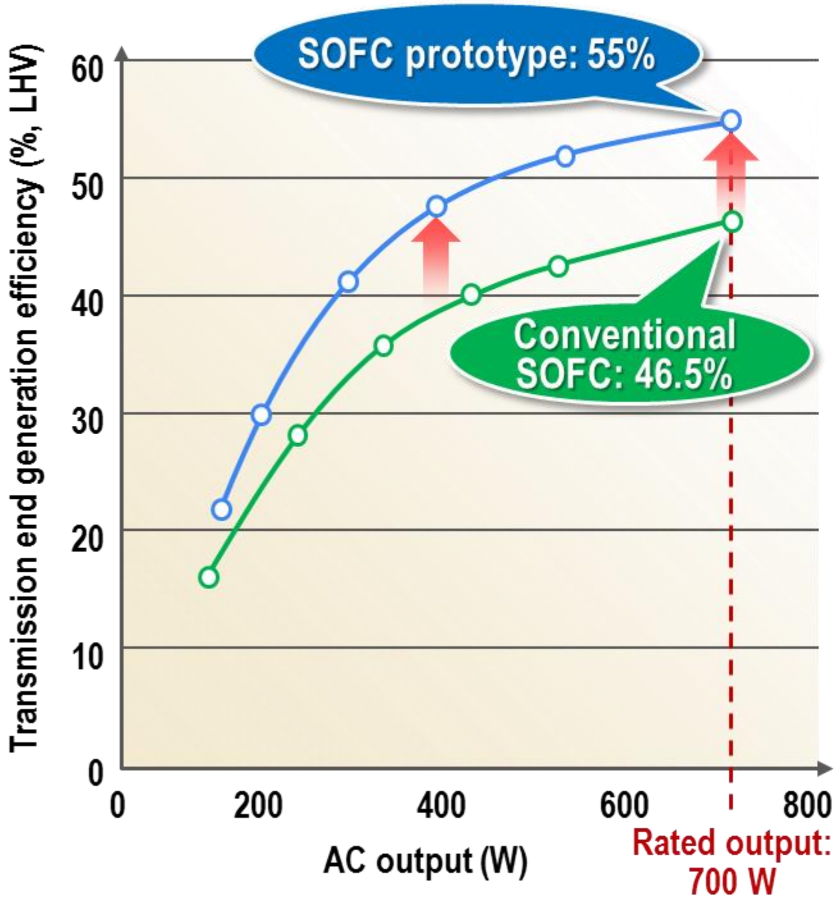
Keeping in mind the possibility of combination with water heater used in existing housing

4.2 Trial Operation Results

- Transmission end electricity generation efficiency of 55% (LHV) during rated operation and high partial load performance were confirmed.
- We will strive to commercialize the SOFC prototype as early as possible, by using equipment manufacturer's mass production technology, finalizing total system specifications including exhaust heat utilization, and verifying reliability/energy- saving performance.

SOFC prototype installed in dwelling unit

Generation efficiency test result



5. Conclusions

- Promising systems that can be operated by interconnection with SOFCs were installed in actual dwelling units for demonstration. Improvement of operating conditions and other factors enabled these systems to achieve anticipated performance levels.
- We will continue demonstration experiments to evaluate yearly energy-saving performance of the systems, as well as to review their operating conditions and specifications.
- The system demonstration results can be used for multi-unit housing complexes, detached houses, smart communities and other societies.
  In parallel with demonstration experiments in NEXT21, we will study the following:
  - Verification of the performance and operating conditions of specific systems by simulation in various buildings
  - Development of engineering design specifications
  - Institutional design/request for business scheme/feasibility and introduction of the systems

Thank you for your attention

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