

Honda Smart Home System Experiment Results

Yasushi KANAI* So YAMADA*

ABSTRACT

An experiment has been carried out over a period of approximately three years using the Honda Smart Home System, which comprises micro combined heat and power generation system in combination with photovoltaic power generation, electric vehicle, and Smart e Mix Manager and is conceived to reduce CO₂ emissions from ordinary homes to one-half and then eventually to zero. The purpose of the experiment was to study the effectiveness of the system in reducing CO₂ emissions from the home, to examine the issues involved in reducing CO₂ emissions without lessening the quality of life, and to explore possible approaches to achieving zero CO₂ emissions. At a building identical to the experimental house, electric power was purchased from an electric utility company and a highly efficient gas hot water heater was used to make hot water on the assumption that a conventional household was consuming the same amount of electric power and heat as the household where the experiment was conducted. The result was that the experimental house achieved a 51% reduction in CO₂ emissions. When solar water heaters, biofuel, and other such renewable energy sources were used, a potential direction was found for achieving zero CO₂ emissions.

1. Introduction

There are calls at present to reduce emissions of greenhouse gases (GHG) that are one of the major causes of global warming. The use of photovoltaic (PV) power and other such forms of renewable energy is being pursued as one measure to that end⁽¹⁾. Measures are also being taken to build systems of local production for local consumption of energy⁽²⁾. This involves the use of distributed energy sources in an area-wide fashion within communities of a certain size so that in normal times the systems function to conserve energy and in times of emergency they can function to assure the supply of energy. There are movements among local governments to use such systems to revitalize local industry as well as to seek out ways to strengthen local communities against disaster. Within this context, Honda Motor Co.,Ltd and Saitama City entered into an agreement to implement the E-KIZUNA Project to use a diversity of energy sources and a variety of electric-powered vehicles in an initiative leading to proposals for a disaster-resistant environmental city of the future⁽³⁾. Specifically, this calls for the construction of houses for experimental use on land owned by Saitama City where experiments are being conducted to examine the local production of energy for local consumption and the possibilities for a community of homes capable of functioning independently, as well as to verify the effectiveness of the Honda Smart Home System⁽⁴⁾

(HSHS) as a supply of energy for household use that is also capable of dealing with emergencies.

2. Purpose

- (1) The first purpose is to demonstrate the effectiveness of the HSHS, with the objective of halving CO₂ emissions.
- (2) The second purpose is to propose a direction to pursue in order to achieve reduction of CO₂ emissions to zero in 2020.

3. Experiment Method

An overview of the experiment's measurement and observation period, the objects of measurement and observation, the equipment used, and other such details, is given in the following.

3.1. Overview of the Period of the Experiment

The buildings and measurement systems were completed at the end of April 2012, and occupancy of the buildings began in May. After a period for confirmation and adjustment of measurement system operation, the data from July onward was used for analysis in the experiment. The electric vehicle (EV) was used from December 2012 to the end of November 2014. The experiment was performed after obtaining approval from the Honda Bioethics Committee.

* Power Products R&D Center

3.2. Object of the Experiment

The experimental house is a two-story, light-gauge steel prefabricated house manufactured by Sekisui House, Ltd. The exterior appearance of the house is shown in Figs. 1 and 2.

Table 1 shows a summary of the house specifications. The building has a heat loss coefficient [$2.7 \text{ W}/(\text{m}^2 \cdot \text{K})$ or lower]⁽⁵⁾ that satisfies the revised “Builder Judgment and Standards Regarding the Rationalization of Energy Use Involving Residences” announced by Saitama City in 1999.

One air conditioner for heating and cooling is installed in each room of the house, and Table 2 shows a summary of the air conditioner specifications. The summary below presents published figures.

Table 3 shows a summary of the gas fan heater and hot water heater specifications. Table 4 shows a summary of the hot water floor heating specifications. These items of heating equipment are installed on the first floor.

A summary of the residential facilities in the experimental house is given in the following:

- LED lighting and a 24-hour ventilation system were used.
- A micro combined heat and power generation system was used as the heat source for the hot water supply and hot water heating equipment.
- In December 2013, the Japanese-style room on the first floor was equipped with a gas fan heater.
- A gas range was used for kitchen equipment.
- City gas (13A) was used for the gas.



Fig. 1 Southwest side appearance of experimental house



Fig. 2 Northwest side appearance of experimental house

Table 1 Experimental house specifications

Total floor space	171.13 [m^2]
Heat loss coefficient	2.03 [$\text{W}/(\text{m}^2 \cdot \text{K})$]
Building orientation	South

Table 2 Air conditioner specifications

Installation location	Cooling capacity	Heating capacity
1st floor living room	7.1 [kW]	8.5 [kW]
1st floor Japanese-style room	2.2 [kW]	2.5 [kW]
2nd floor master bedroom	2.2 [kW]	2.5 [kW]
2nd floor south bedroom	2.2 [kW]	2.5 [kW]
2nd floor north bedroom	2.5 [kW]	2.8 [kW]

Table 3 Heater specifications

Heater type	Installation location	Heating capacity
Hot water heater	1st floor Japanese-style room	3.5 [kW]
Gas fan heater	1st floor Japanese-style room	5.81 [kW]
Hot water heater	1st floor bathroom	4.1 [kW]

Table 4 Hot water floor heating specifications

Installation location	Heating area
1st floor kitchen	2.4 [m^2]
1st floor living room	8.0 [m^2]
1st floor dining room	7.2 [m^2]

3.3. Equipment Used and Equipment Comparison

The equipment used in this experiment is described below together with the equipment envisioned for comparison.

3.3.1. Micro combined heat and power generation system

The micro combined heat and power generation system (MCHP) comprises a generator unit that uses a gas engine generator and a hot water tank unit with a built-in auxiliary boiler. All the electricity generated by the generator unit is consumed in the house to which the MCHP is connected. When surplus electric power is produced, it is converted into hot water using a heater built into the generator unit. The experimental house was equipped with a system that has the same performance as the ECOWILL (a registered trademark of Osaka Gas Co., Ltd.)⁽⁶⁾, which is a commercially available MCHP, but it was given the additional functionality of operating independently to generate power on command from the Smart e Mix Manager (SeMM)⁽⁴⁾ during a power outage. Table 5 shows the generator unit specifications and Table 6 shows the hot water tank unit specifications.

3.3.2. Photovoltaic power generation

The photovoltaic power generation system uses solar cells and a power conditioner (PCS) manufactured by Honda Soltec Co., Ltd. The electricity generated by the PV system is consumed in the house to which the PV system is connected. When surplus electric power is produced, it

Table 5 MCHP power generation unit specifications

Power generation output	1.0 [kW]
Exhaust heat output	2.5 [kW]
Gas consumption	4.21 [kW]

Table 6 MCHP hot water tank unit specifications

Hot water temperature	Approx. 75 [°C]
Hot water storage tank capacity	90 [L]
Reheating capacity	12 [kW]
Heating capacity	17.4 [kW]
Maximum gas consumption	50.0 [kW]

is supplied to an electric utility company by reverse power flow. The general specifications for the solar cell array are shown in Table 7 and those for the PCS in Table 8.

3.3.3. Smart e Mix Manager

The SeMM is a device for the integrated control of heat and electric power when the MCHP, PV, and EV are used in combination. It also has the functionality to start up the MCHP during power outages and supply electric power, combined with that from the PV system, to designated wall sockets. Figure 3 shows a schematic diagram of the HSHS.

3.3.4. Vehicle

A FIT EV⁽⁷⁾ was used as the main means of transportation for the experimental house residents. An on-

Table 7 Photovoltaic array specifications

Manufacturer	Honda Soltec
Cell type	CIGS
Nominal maximum output	4.44 [kW]

Table 8 PCS specifications

Manufacturer	Honda Soltec
Rated capacity	4.0 [kW]
Power conversion efficiency	94.5 [%]

board logger was installed on the FIT EV to record such measurements as distances traveled and amount of charge.

3.4. Measurement

For the present experiment, certain measurements were made every second under approximately 200 headings, including electric power, pressure, temperature and flow rate, in order to analyze the house, the MCHP, and the PV in terms of the amounts of electric power, the amounts of heat demand and supply, and environmental conditions. Since the amount of heat could not be measured directly, it was calculated from the measured temperature, pressure, and flow rate.

3.5. Method for Evaluating CO₂ Reduction Effect

In the present experiment, data was actually collected for only one household. It was reasoned that the CO₂ reduction

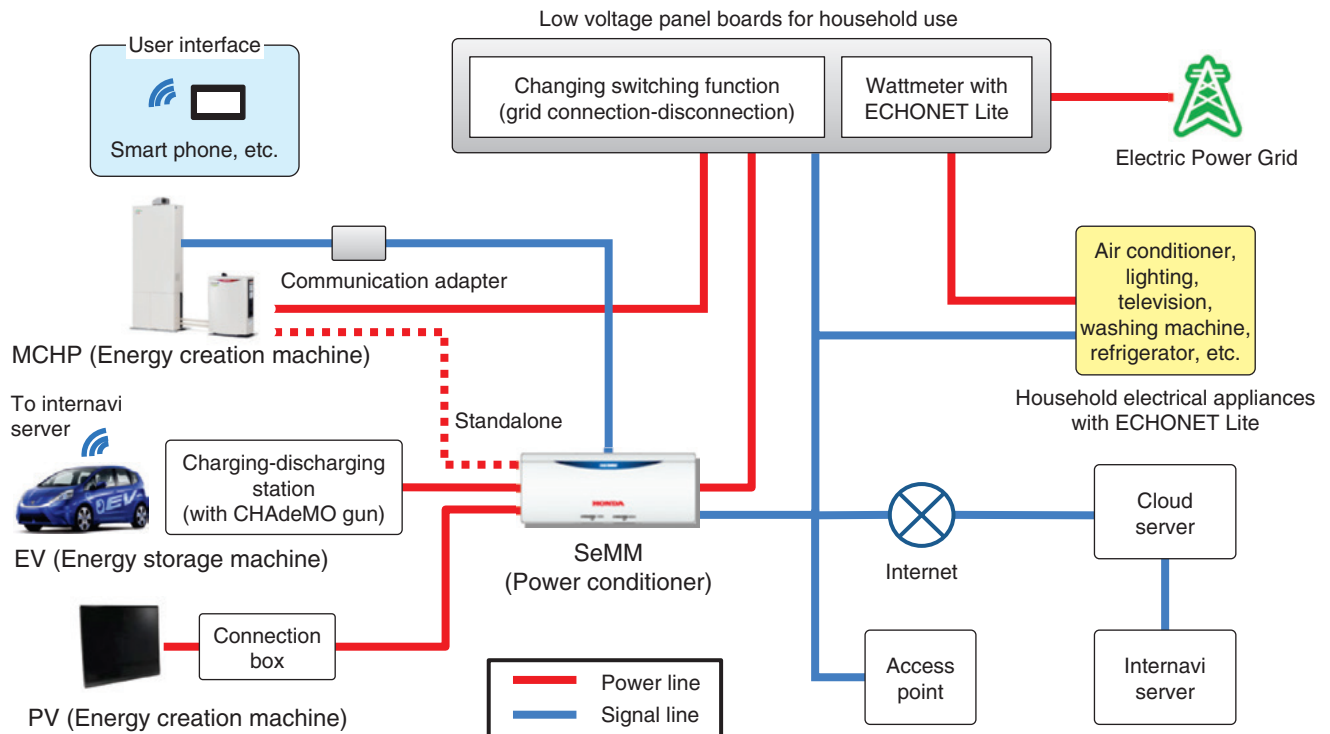


Fig. 3 System configuration of HSHS

amount due to the HSHS could be appropriately compared against measurements made in a house with entirely the same living environment and lifestyle but without HSHS. The conditions and method were therefore configured as shown below.

- Assume that there is a conventional house where HSHS has not been introduced and estimate the amounts of electric power and gas purchased in order to satisfy the same energy demand as in the experimental house. This house will serve as the object for comparison of the CO₂ reduction amount, and it will be designated the conventional house. The differences between this conventional house and the experimental house in the actual electric power and gas purchase amounts are the energy reduction effects. They are converted to CO₂ reduction amounts using the CO₂ emissions per unit of their respective energy sources. Table 9 shows the CO₂ emissions per unit⁽⁸⁾ used for this calculation.
- The electric power demand in the conventional house is considered to be the sum of the “electric power and lighting” used by means of the wall sockets or other such sources in the experimental house and the power consumed by air conditioners. This electric power is purchased from the electric utility company. The amount of electric power purchased W_{vhc} is obtained from the “electric power and lighting” amount W_{dpl} and the “air conditioning” power consumption W_{acu} by means of Eq. (1).

$$W_{vhc} = W_{dpl} + W_{acu} \quad (1)$$

- In the conventional house, gas was purchased from the gas company, and a high-efficiency water heater and gas range were used for hot water and cooking. Rooms were heated and cooled using air conditioners and hot water heating from the high-efficiency water heater. For the high-efficiency water heater⁽⁹⁾, equipment capable of hot water supply and hot water heating that was commonly available on the market in 2015 was selected. The general specifications are shown in Table 10.
- The conventional house heat demand Q_{dhc} was obtained from the experimental house “hot water supply” demand Q_{hws} , the experimental house “reheating” demand Q_{rh} , the experimental house “floor heating” demand Q_{wh} , and the high-efficiency hot water heater efficiency η_{ej} using Eq. (2).

$$Q_{dhc} = (Q_{hws} + Q_{rh} + Q_{wh}) / (\eta_{ej} / 100) \quad (2)$$

- The conventional house amount of gas purchased V_{vhgc} was obtained from the conventional house heat demand Q_{dhc} , the amount of heat from city gas Hu_g , the amount of gas consumed by the experimental house gas fan heater V_{gfr} , and the amount of gas consumed by the experimental house gas range V_b using Eq. (3).

$$V_{vhgc} = Q_{dhc} / Hu_g + V_{gfr} + V_b \quad (3)$$

Table 9 CO₂ emissions per unit

Type	CO ₂ emissions per unit
Electric power	0.192 [kg-CO ₂ /MJ]
City gas 13A	0.057 [kg-CO ₂ /MJ]
Gasoline	2.322 [kg-CO ₂ /L]

Table 10 High-efficiency water heater specifications

Energy consumption efficiency	Energy consumption efficiency	93 [%]
	Hot water supply	95 [%]
	Hot water heating	87 [%]

Table 11 Vehicle specifications

		Experimental house	Conventional house
Name		FIT EV	FREED
Model		ZAA-ZA2	DAB-GB3
Dimensions	Full length	4,115 [mm]	4,215 [mm]
	Full width	1,720 [mm]	1,695 [mm]
	Total height	1,580 [mm]	1,715 [mm]
Mass		1,470 [kg]	1,290 [kg]
Fuel consumption (JC-08)			16.6 [km/L]
		106 [W·h/km]	
Battery	Type	Lithium ion	
	Capacity	20 [kW·h]	

- The distance traveled by the vehicle used at the conventional house was made the same as the distance traveled by the FIT EV used at the experimental house. A Honda Freed⁽¹⁰⁾, which is about the same overall size as the FIT EV, was chosen as the vehicle. Table 11 shows the general specifications of the Fit EV and the Honda Freed.

3.6. Residents

The household consisted of a family of four, with a husband and wife, both of whom work, an adult child who works, and a second child who is a university student.

4. Results

The amount of electric power purchased, the amount of gas purchased, and the heat demand as measured in the experimental house are shown in the following.

4.1. Amount of Electric Power Purchased and Amount of Gas Purchased

Figure 4 shows the amounts of electric power and gas purchased per year during the measurement period and as averages for the entire period, categorized by type. Annual data is for the period from July to June of the following year. Electric power was used within the household and for EV charging. In order to clarify the differences in quantity involved, these are shown separately as electric power (without vehicle) used within the household for “electric power and lighting” and “air conditioning” and as electric

power (EV charging) used for “EV charging.” The amount of PV power generated shows “PV power usage” used in the household and the remainder sent to the electric utility company by reverse power flow as “PV reverse power flow” separately in order to clarify the differences in quantity involved. The reduction in the amount of electric power purchased corresponded to the amount of PV power generated and used in the household. The electric power sent to the electric utility company by reverse power flow was consumed through that company, and the power generated at the power plant can be reduced by that amount, so these amounts were shown as negative figures. The amount of gas is the total amount consumed by the MCHP, gas range, and gas fan heater. In this figure, the portion from July 2014 to March 2015 is nine months’ worth of data. The figures at the far right combine the average monthly figures for the year to produce average annual figures for the total measurement period. The total amount of electric power and gas purchased amounted to approximately 68,000 MJ.

4.2. Energy Demand

Figure 5 shows the energy demand figures from Fig. 4 recategorized by use. The national averages⁽³⁾ for 2013 are also shown on the right end of the figure for reference.

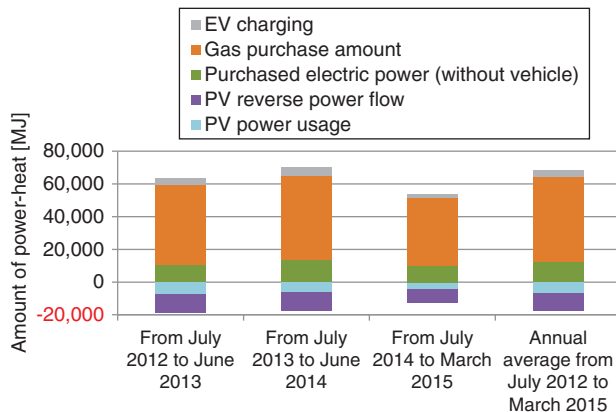


Fig. 4 Electricity and gas annual purchase amount

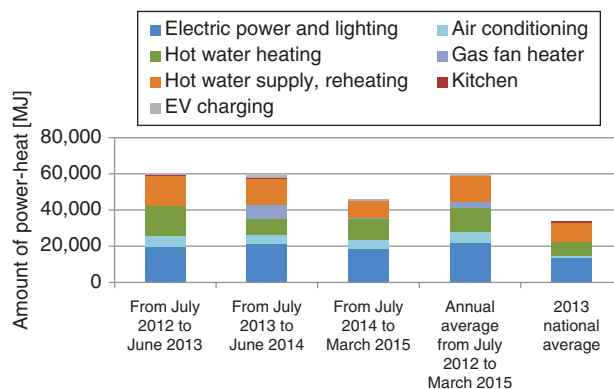


Fig. 5 Annual power and heat consumption

The amount of gas consumed by the MCHP cannot be categorized by use, so it was shown as heat demand divided between “hot water supply and reheating” and “hot water heating.” Figures other than those are shown as the “amount of electric power supplied” and the “amount of gas purchased.”

The annual demand for electric power and heat, excluding EV charging, amounted to approximately 61,000 MJ. This figure is lower than the total purchased amount shown in Fig. 4 because the demand for “hot water supply and reheating” and “hot water heating” is shown in the amount supplied by the MCHP, so that the figure is influenced by the MCHP gas-to-heat conversion efficiency.

The annual demand for electric power and heat came out larger than the national average of approximately 36,000 MJ by a factor of 1.7. The consumption for “electric power and lighting” and for “air conditioning” was greater than the national averages.

In “electric power and lighting,” the component percentages of consumption as a whole were generally the same as the national averages. However, the amounts consumed were 1.7 times greater than the national averages. Moreover, “air conditioning” was 6.4 times greater than the national average, and “heating” (in the experimental house, this was hot water heating and the gas fan heater) was twice the national average.

Figure 6 shows electric power consumption, heat demand, and gas consumption by application and by month. “EV charging,” “hot water supply and reheating,” “hot water and gas heating,” “air conditioning,” and “electric power and lighting” show the amounts of electric power consumed by the respective applications and their heat

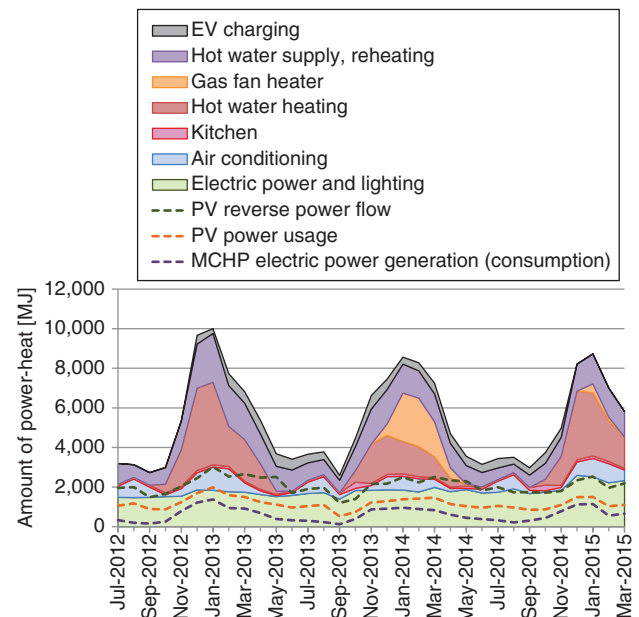


Fig. 6 Monthly electricity and heat consumption by application

demand. They are presented in a stacked area graph. The PV power generated is divided and shown as “PV power usage” and “PV reverse power flow.” The PV power generated and MCHP power generated are shown in a stacked line graph. Showing consumption of electric power, the total of “air conditioning” and “electric power and lighting” and the total of “PV power usage,” “PV reverse power flow,” and “MCHP power generated” are very similar figures in every month.

In December 2013, a gas fan heater was introduced into the Japanese-style room on the first floor to replace the gas fan heater and hot water heater with the aim of raising the efficiency per quantity of heat used for heating. The amount of electric power for air conditioning and the heat demand for the period from January to March 2013 (before introduction of the gas fan heater) and the period from January to March 2014 (after introduction of the gas fan heater) were compared. As a result, it was found that the electric power for air conditioning was reduced to 63% of what it was before introduction of the gas fan heater. However, use of the gas fan heater caused gas usage to increase, and the heat demand with the use of floor heating and the gas fan heater increased to 131% of what it was before introduction of the gas fan heater. Consequently, the electric power and heat consumption for heating during this period increased to 114% of what it was before introduction of the gas fan heater, and no reduction effect was obtained with regard to electric power and heat demand.

4.3. Electric Power Consumption

As can be see in Fig. 6, electric power consumption is greater in the summer and winter, due to air conditioning (heating and cooling) consumption.

Figure 7 shows hourly electric power consumption excluding EV charging in January (winter), May (intermediate period), and August (summer). In every case, consumption has peaks in the morning and evening, and is greater at night in particular.

Figure 8 shows the relationship between the average outdoor air temperature per month and the electric power

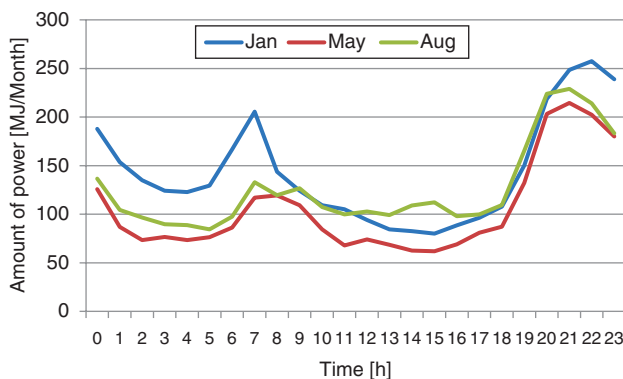


Fig. 7 Hourly electric power consumption with EV charging excluded

consumption in those months. The difference in air conditioning power consumption is not due to the difference between heating and cooling but is rather influenced by the outdoor air temperature.

4.4. Gas Consumption

Figure 6 shows that the consumption of gas in winter is approximately five times greater than in summer, since, in addition to kitchen use, it is used as a heat source for the hot water supply and for heating.

Figure 9 shows hourly MCHP gas consumption for January, May, and August. Regardless of the season, consumption was greater in the morning and evening, when more was consumed for hot water supply and reheating.

4.5. Heat Demand

Figure 5 shows that heat demand accounts for one-half of all energy consumption and that heat demand for heating makes up one-half of total heat demand. This can be broken down as follows.

4.5.1. Hot water heat demand for heating

Figure 10 shows monthly heat demand for hot water used for heating. Heating with hot water used from October

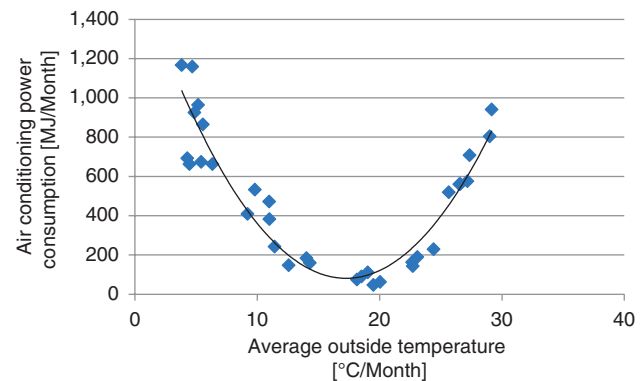


Fig. 8 Average air temperature and air conditioning power consumption

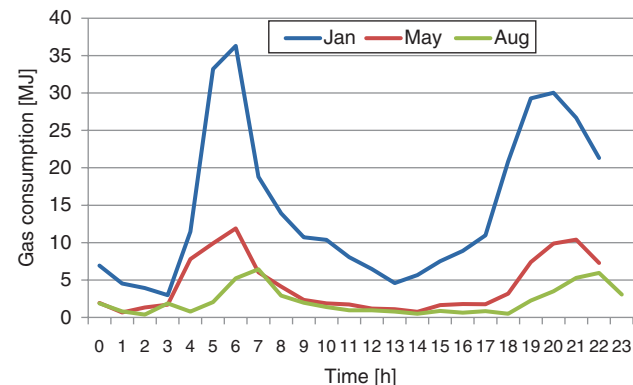


Fig. 9 Hourly MCHP system gas consumption by month

to May of the following year and consumption reached a maximum of 4,200 MJ/month. December 2013 showed a lower level than that month in other years because the hot water heater was changed to a gas fan heater.

Figure 11 shows the relationship between the average outdoor air temperature for a month and the hot water heat demand for use in heating in that month. Hot water heating began to be used from around when the average outdoor temperature fell below 20°C, and the demand increased as the average outdoor air temperature dropped.

4.5.2. Hot water supply and reheating heat demand

Figure 12 shows the hourly hot water supply and reheating heat demand for January, May, and August. Residents commented that they bathed in the morning, and this was supported by the higher morning demand. There was also daytime demand in the summer, seen in August, which differed from consumption for heating.

4.6. Reduction Effect on CO₂ Emissions

Figure 13 shows CO₂ emissions by type for the conventional house and for the experimental house, which were evaluated by the method described in Section 3.5. from the energy consumption shown in Figs. 4, 5, and 6. In the experimental house, the use of the MCHP meant

that gas consumption was higher and CO₂ emissions, therefore, increased by a corresponding amount. On the other hand, power generation by the MCHP and PV meant that the amount of electric power purchased was lower, and CO₂ emissions decreased by a corresponding amount. On balance, CO₂ emissions from the experimental house showed a decrease of 51% compared to the conventional house.

Figure 14 shows application-specific CO₂ emissions by month. In this figure, the CO₂ emissions for “air conditioning,” “electric power and lighting,” and “EV charging” are from electric power consumption, while the CO₂ emissions for “hot water and gas heating” are from the consumption of gas used for hot water and heating. For “hot water supply and reheating” and “hot water heating,” MCHP gas consumption was differentiated by the percentage of heat demand under each heading and the CO₂ emissions were calculated accordingly. These were all represented in a stacked area graph. Since the CO₂ reduction effect cannot readily be categorized by application, it was categorized instead by equipment type and displayed in the graph accordingly. The “EV use effect” is the difference in CO₂ emissions between the gasoline vehicle that is the

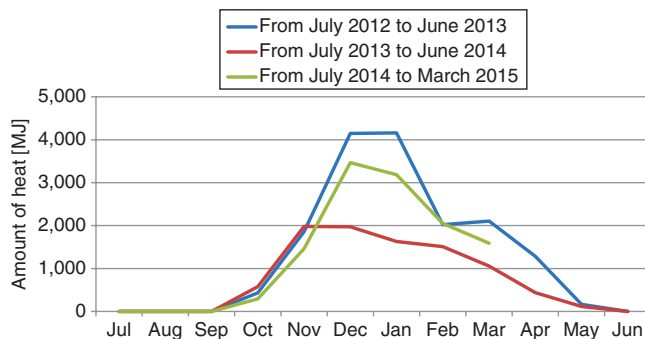


Fig. 10 Monthly hot water heat consumption for heating

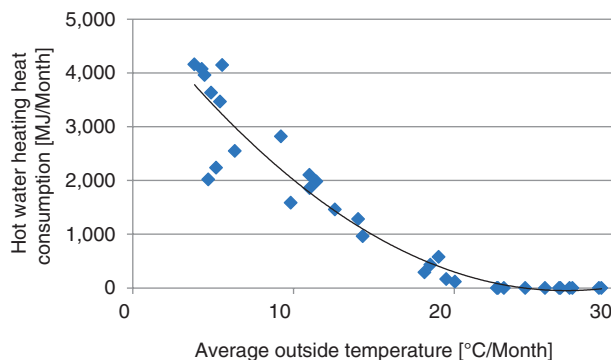


Fig. 11 Average outside temperature and hot water heat consumption for heating

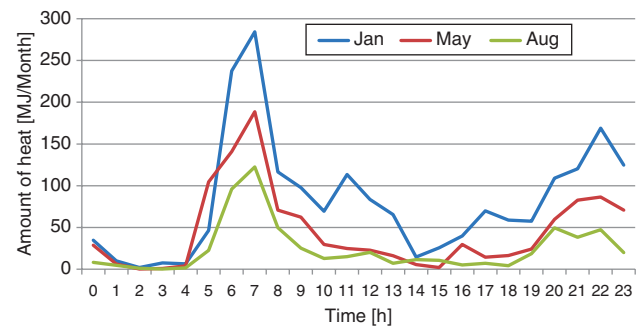


Fig. 12 Monthly hot water supply - Reheating heat consumption by hour

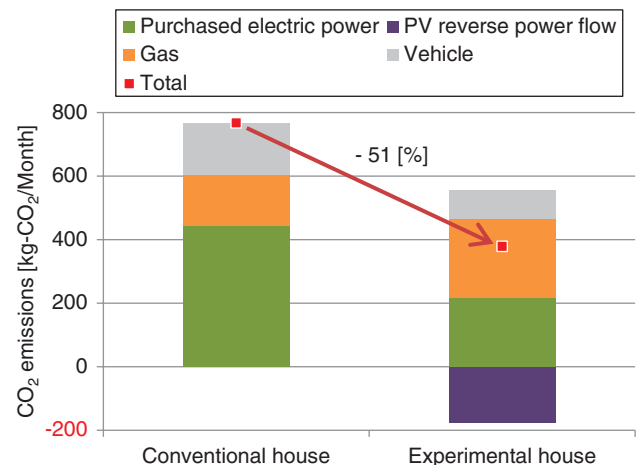


Fig. 13 CO₂ emissions by type

object of comparison and the FIT EV for travel over the same distance. The “MCHP use effect” is the difference in CO₂ emissions from the amount of power purchased from an electric utility company if an amount corresponding to MCHP power generation were to be purchased instead, when CO₂ emissions corresponding to the amount from gas consumption for MCHP power generation are subtracted. The amount of gas consumed for MCHP power generation in this case is separated out from the amount of gas consumed by the MCHP generator unit according to the ratio of the amounts from power generation and heat generation. The resulting figure displayed corresponds to the amount from power generation. The “PV power usage” represents the amount of CO₂ emissions from the portion of PV-generated electric power consumed within the household that would have been emitted if that amount of electric power had been purchased from the electric utility company. The “PV reverse power flow electric power” likewise represents the amount of CO₂ that would have been emitted if the amount of PV-generated power that went to reverse power flow had been generated by the electric utility company. These are shown by dotted lines in the stacked graph that represent the CO₂ reduction amounts.

While the seasonal variation in CO₂ emissions from “electric power and lighting” and “hot water supply” is small, the variation in “air conditioning” and “hot water and gas heating” is large. The total reduction in CO₂ emissions from MCHP, PV, and EV came out as a figure close to the

sum of emissions from “electric power and lighting” and “hot water supply.” In the spring and autumn, in particular, when energy consumption within the household is lower, those figures were practically identical. Viewed from the perspective of the contribution to CO₂ reduction, the PV has a significant effect throughout the year while the MCHP had a lesser effect in the summer, when heat consumption is lower and operating times are shorter.

Figure 15 shows CO₂ reductions as percentages of the annual average. The PV has a major effect, and when the effects of the PV generated electric power used within the household and the reverse power flow of electric power to the electric utility company are combined, they account for 72% of the total CO₂ reduction.

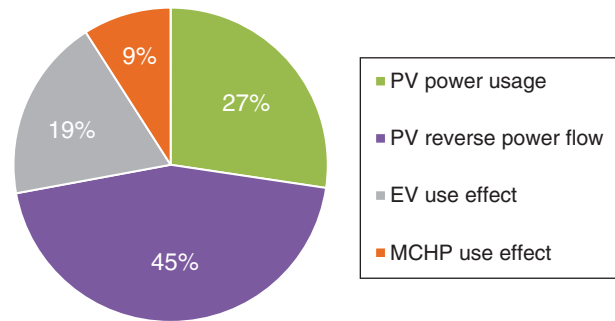


Fig. 15 CO₂ reductions

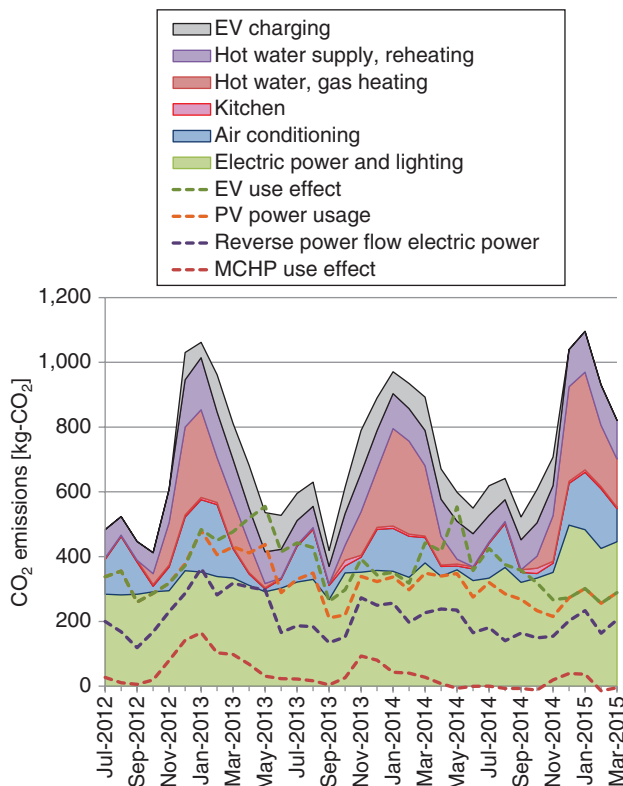


Fig. 14 Application-specific CO₂ emissions by month

5. Discussion

It became apparent in Section 4 that the PV is highly effective in reducing CO₂ emissions. However, if PV output were to be increased with the aim of achieving a still higher CO₂ emissions reduction effect, and the amount of reverse power flow in the region as a whole were to increase, there is a possibility that restrictions would be placed on PV output⁽¹⁾. This means that zero CO₂ emissions cannot readily be achieved simply by increasing PV output. The approach to be examined, therefore, will be a method that takes local production of energy for local consumption into account and works to achieve zero CO₂ emissions in households where the amount of electric power purchased and the amount of reverse power flow of power generated by PV are normally the same.

It became clear in Section 4 that it will be necessary to reduce the CO₂ emissions originating in heat demand that is supplied mainly by purchased gas. The following are conceivable methods for practical implementation of this aim.

- (1) Use solar water heaters, heat pumps, and other such heat source equipment that is more highly efficient to reduce the amount of gas purchased.
- (2) Replace purchased gas with biofuel or other such renewable energy sources.

For method (1), the possibility of using a solar water heater to reduce CO₂ emissions from gas purchased for hot water supply, reheating, and heating will be examined.

Figure 16 shows average monthly heat absorption efficiency for a vacuum tube-type solar water heater from measurements made separately from the present experiment.

Based on these results, the effect of installing an additional solar water heater like that in Table 12 is estimated, with the conditions shown below.

- The heat energy supplied by the MCHP auxiliary boiler is replaced entirely by the heat generated in solar water heaters. Operation of the auxiliary boiler is stopped by a corresponding amount.
- When heat demand is exceeded by the heat generated by solar water heaters, the operating hours of the MCHP generator unit are shortened by an amount that will result in that surplus heat not being generated.
- When the amount of electric power generated is reduced due to the shortened operating hours of the MCHP generator unit, that reduction will be made up with power purchased from the electric utility company.

Figure 17 shows the results from simulation of CO₂ emissions. If the experimental house has 4 m² of solar water heater installed, a CO₂ reduction effect of 10% can be anticipated by comparison without the installation. The operating hours of the MCHP generator unit become shorter

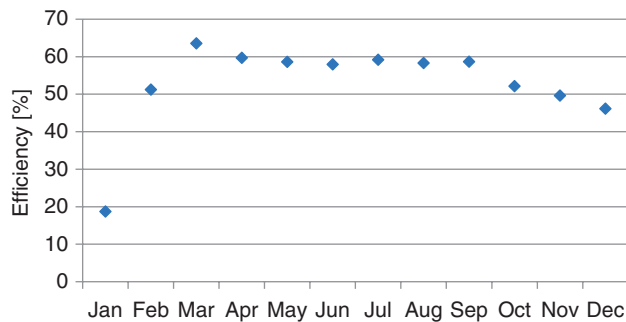


Fig. 16 Measured heat absorption efficiency of solar water heaters

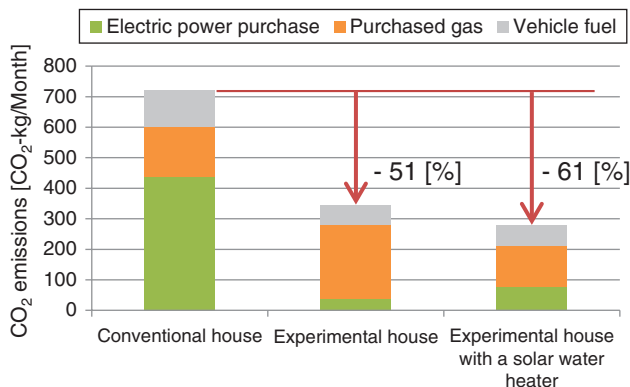


Fig. 17 Simulated CO₂ reduction effect of HSHS

Table 12 Solar water heater

Heat collection area	4 [m ²]
Endothermic efficiency	50 [%]
Amount of insolation	By experimental house data

than when a solar water heater is not installed. Although this causes the amount of electric power purchased to increase, the amount of gas purchased decreases, reducing CO₂ emissions as a whole.

Next, Fig. 18 shows an estimation of the CO₂ reduction effect obtained when the solar water heater area is further increased.

Even when the area of the solar water heater is increased to 32 m², the CO₂ emissions reduction rate remains 71%. This is due to the trade-off between the reduction in CO₂ emissions resulting from the effect of the solar water heater and the increase in CO₂ emissions accompanying the increase in the amount of electric power purchased. It was found, therefore, that CO₂ emissions could not be reduced to zero solely by installing additional solar water heaters.

In order to achieve zero CO₂ emissions from the purchase of gas, it is necessary to satisfy the heat demand within the household without using any fossil fuels. The following methods may be considered as possible means for this:

- Replace gas with hydrogen produced by renewable energy, biofuel, or some other such fuel that can be considered to have zero CO₂ emissions; or
- Replace heat source equipment with heat pumps or other such electrically driven equipment, and operate it using PV-generated electric power.

For method (b), an estimate is made of the PV output required in order to reduce CO₂ emissions to zero in the case of all heat being supplied by heat pumps, and in the case of it being supplied by a solar water heater of 4 m² together with a heat pump as an auxiliary heat source. The efficiency of the heat pump, which was measured separately from the present experiment, is shown by the data in Fig. 19.

The estimation results are shown in Table 13. It was found that a PV output nearly double that of the experimental house is required even when the combination of solar water heater and heat pump is used as the heat

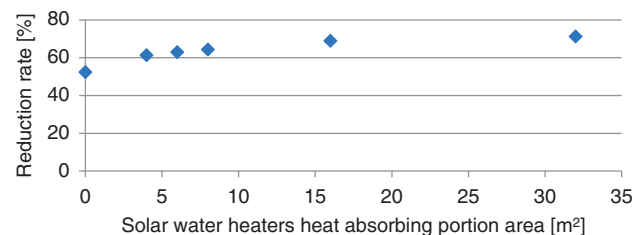


Fig. 18 Simulated CO₂ reduction effect of solar water heaters

Table 13 Estimated PV output required to achieve zero CO₂ emissions with heat pump

Conditions	PV output [kW]
Heat pump	10.1
Heat pump with solar water heater 4 [m ²]	7.1

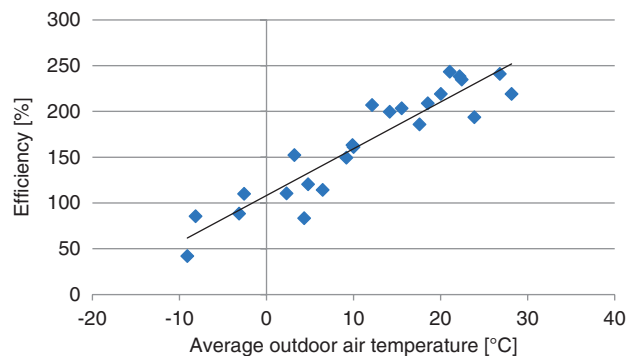


Fig. 19 Measured efficiency of heat pump

source equipment instead of the MCHP. Implementing this would require an installed PV area that is greater than the roof area, indicating that this cannot readily be adopted as a practical solution.

It was found from the above information that when the amount of electric power purchased and the reverse power flow of PV electric power are generally the same, zero CO₂ emissions cannot readily be achieved with the HSHS even when the following changes are made.

- The MCHP is replaced with a heat pump.
- The MCHP is replaced with the combination of solar water heater and heat pump.

In order to achieve zero CO₂ emissions, therefore, it will be necessary to add other approaches for future consideration of method (2) given at the start of Section 5, which was to replace purchased gas with a fuel that is considered to have zero emissions of CO₂.

6. Conclusion

The first purpose and objective were achieved by the determination of the CO₂ emissions reduction effect obtained when using HSHS and the one-half reduction in CO₂ emissions obtained as a result. It was also found that CO₂ emissions from energy used for heating and other such heat source applications will be crucial to the movement toward zero CO₂ emissions.

In the next step of the experiment, a solar water heater is scheduled to be added to the present form of the HSHS in order to verify the CO₂ emissions reduction effect described in Section 5. However, Section 5 also indicated that this addition alone would not be able to achieve zero CO₂ emissions. Therefore, an approach using hydrogen produced by renewable energy, biofuel, or other such fuel that can be

considered to have zero CO₂ emissions has been proposed as a further future step.

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■ Author ■



Yasushi KANAI



So YAMADA