RESEARCH AND DEVELOPMENT OF A NEXT-GENERATION SOLAR-ASSISTED WATER HEATING SYSTEM

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1. INTRODUCTION

To counter global warming and rising crude oil prices as social backgrounds, we have been working on a housing and building related advanced technology development project with a grant from the Ministry of Land, Infrastructure, Transport and Tourism in FY2007. In this project, we are conducting research and development of a low-cost, next-generation solar-assisted water heating system, which combines an instantaneous water boiler for residential use and a balcony-installed solar thermal water heater, to expand the use of such systems mainly at apartments and condominiums.

To improve the energy efficiency of instantaneous water boilers at residential houses, we have focused on latent heat recovery boilers to date. However, the COP of such boilers, with gas as the primary energy source, theoretically cannot exceed 1. Therefore, in this project we aimed to develop a solar-assisted water heating system with a system COP of better than 1 by using solar heat. We also intend to incorporate into this system such features as a solar collector neatly designed to match the appearance of apartments and condominiums, a compact hot water tank, a low-cost solar blender, and a solar-assisted energy-saving navigator to make the system more attractive to customers. Thus, the system will reflect our traditional emphasis on amenity and ease of installation.

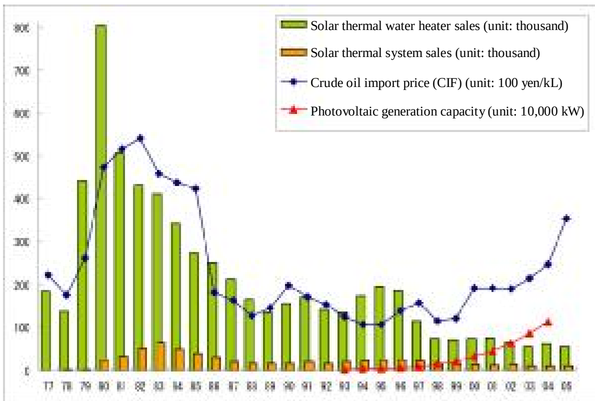
This paper describes the trend of solar heat utilization, the concept of our next-generation solar-assisted water heating system, the results of simulation studies we had completed by the end of last fiscal year, and the results of tests using a prototype system.

2. THE RISE AND FALL OF SOLAR HEAT UTILIZATION

The first solar thermal system in Japan was Unit 1 at the Yanagimachi Solar House, built in 1956. In the 1960s, open water storage type solar thermal water heaters became popular, particularly in rural areas, but because many of them were built with weak materials such as vinyl, they were short-lived and were gradually abandoned as cheap petroleum fuels became available.

After the first oil crisis in 1974, solar thermal water heaters attracted renewed interest, and closed water storage type water heaters that did not suffer the problems of earlier water heaters were installed at many residential houses. Some new solar systems incorporated a design that separated the solar collector and the hot water storage, and forcibly circulated water or medium between them. As shown in Graph 1, sales of solar thermal water heaters were about 800,000 units in 1980, and sales of solar thermal systems peaked in 1983 at about 650,000 units. However, crude oil prices gradually dropped from 1981 after the end of the second oil crisis, and sales of solar thermal equipment fell year after year. In contrast, the use of photovoltaic systems has expanded in recent years thanks to the development of roof-integrated solar panels.

Thus, the history of solar thermal utilization is closely linked to the history of crude oil prices, and the recent rise of crude oil prices is creating renewed interest in solar heat. A major difference from the past, however, is the growing awareness of global warming. This has led to high expectations for solar energy as a renewable energy, and has revolutionized the water heater market in such forms as the advent of residential cogeneration systems and highly efficient electric water heaters.

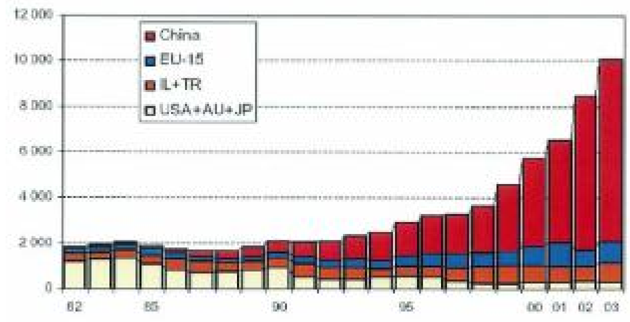


Graph 1 *Trend of solar thermal equipment sales*
Source: Solar System Development Association

3. OVERSEAS TREND

Although solar heat utilization has diminished in Japan, the use of solar thermal equipment has been rapidly expanding in China and EU countries, as shown in Graph 2. The growth is particularly strong in China, driven by the expanded use of vacuum glass tube type solar collectors. By the end of 2004, the total surface area of installed solar collectors exceeded 62 million m^2.

A recent NEDO Overseas Report, No. 1011, titled "Solar Thermal Barometer 2007 (EU)," reported that the solar thermal market in Europe grew by 44.3% in 2006, and that the total installed solar collector surface area had exceeded three million m^2.



Graph 2 *Trend of solar collector (with glass) installed capacity by economic region* (Unit: MW/year)

Source: "SOLAR HEATING WORLDWIDE Edition 2005," IEA Solar Heating & Cooling Programme, May 2005

4. CONCEPT OF OUR NEXT-GENERATION SOLAR-ASSISTED WATER HEATING SYSTEM

In response to the social background described above and the problems of earlier solar thermal water heaters, we developed the concept of our next-generation solar-assisted water heating system as shown in Table 1.

Table 1 *Concept of our next-generation solar-assisted water heating system*

Item	Description
Market	Apartments and condominiums, due to their lack of space for introducing in-house power generation.
Social contribution	Contribution to the national policy for new energy deployment by reducing energy for water heating by 10-20%
Design (appearance)	Excellent appearance with balcony-integrated design (vertical installation)
Target cost (excluding installation)	$1m^2$ panel + tank unit = approx. 100,000 yen $2m^2$ panel + tank unit = 150,000–200,000 yen
Tank capacity	Effective capacity of 86 L (presently under review)
COP	1.0 or better (with gas as the primary energy source)
Maintenance	Covered by the maintenance program for instantaneous water boilers.
Remote controller	Should display the level of solar heat utilization.

Based on the above concept, we developed a next-generation solar-assisted water heating system, comprising the solar collector, hot water tank, solar blender and latent heat recovery boiler illustrated in Figure 1. The circulation of heat medium between the hot water tank and the solar collector panel is achieved using photovoltaic generation.

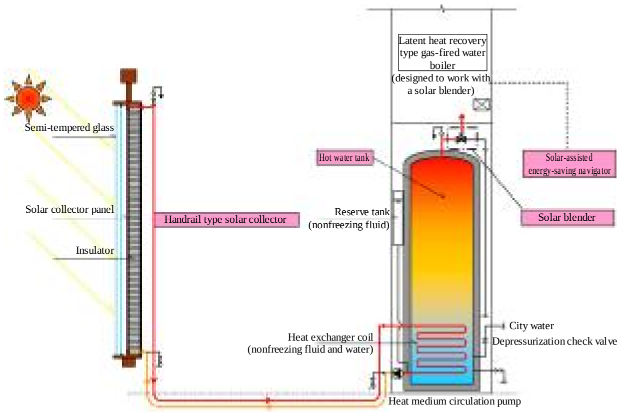


Figure 1 *Outline of the next-generation solar-assisted water heating system*

5. SIMULATION RESULTS

Table 2 shows the results of our simulation in which we assumed a solar collector area of 2.0 m^2, hot water tank capacity of 100 L, and the panel installed vertically at 90 degrees and facing exactly south. The simulation revealed that, for the M-mode water heating demand defined by the Institute for Building Environment and Energy Conservation (IBEC), the system will reduce annual CO_2 emissions by 294 kg taking into account the energy efficiency improvement achieved by the latent heat recovery boiler, and by 138 kg taking into account only the contribution of the solar thermal equipment.

As shown in Figure 2, the simulation showed that solar heat of about 200 MJ per month could be used throughout the year. Thus, even with a vertically-installed solar collector, it would be possible to collect a reasonably large amount of solar heat even when water heating demand is high in winter.

Table 2 *Energy saving and CO_2 reduction performance of the solar-assisted water heating system (calculated values)*

[Solar collector area 2.0 m^2, hot water tank capacity 100 L. panel installed vertically at 90 degrees, facing exactly south]

	Solar-assisted water heating system	Latent heat recovery boiler system	Solar-assisted water heating system	Conventional boiler system	Remarks
Water heating demand [MJ/y] Solar heat utilization [MJ/y] Gas-fired boiler load [MJ/y] City gas consumption [m^2N/y] Electricity consumption [kWh/y]	13,800 2,439 11,361 281 0	13,800 - 13.800 341 -	13,800 2,439 11,361 281 0	13,800 - 13.800 409 -	Heat source machine efficiency: L.H. recovery boiler 0.90 HHV [-] Conventional boiler 0.75 HHV [-] City gas HHV: 45 MJ/m^3N
Energy consumption [MJ/y]	12,645	15,345	12,645	18.405	Conversion into primary energy consumption: 45 MJ/m^3N (city gas) Energy-saving rate for water heating demand
Primary energy consumption [MJ/y]					
Breakdown - city gas	12,645	15,345	12,645	18.405	
Energy saving [MJ/y]	2,700	-	5,760	-	
Energy saving [%]	17.6	-	31.3	-	
CO_2 emission [kg-CO_2/y]	643	781	643	937	CO_2 emission intensity: 2.29 kg-CO_2/m^3N (city gas)
Breakdown - city gas	643	781	643	937	
CO_2 reduction [kg-CO_2/y]	138	-	294	-	
CO_2 reduction [%]	17.7	-	31.4	-	
Total energy efficiency [-]	1.1	-	1.1	-	Total energy efficiency (*) = water heating demand / primary energy consumption

*: equivalent to system COP

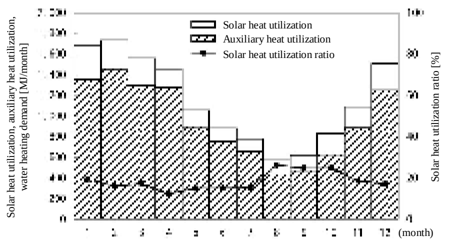


Figure 2 *Quantity and ratio of solar heat utilization (calculated values)*

6. RESULTS OF DEMONSTRATION TEST WITH PROTOTYPE SYSTEM

Table 3 shows the solar heat collection efficiency and the maximum temperature in the hot water tank recorded during a demonstration test conducted at Tokyo Gas premises in Minami Senju.

The solar heat collection efficiency was calculated with respect to the solar radiation on the vertically-installed panel surface. The maximum temperature in the hot water tank was measured after about eight hours of effective solar radiation.

Table 3 *Solar heat collection efficiency and maximum temperature in the hot water tank of the prototype system*

	Panel	Solar heat collection efficiency	Maximum temperature in the hot water tank	Test period
1st generation machine (prototype #1)	$1m^2$	46.3%	38.3℃	2007/11/20-26
	$2m^2$	41.8%	58.2℃	2007/11/8-19

With the 2 m^2 panel, the maximum effective solar thermal output was 14.5 MJ/day, and 9.2 MJ/day when averaged over the test period. With the 1 m^2 panel, the respective values were 9.1 MJ/day and 6.3 MJ/day.

7. CONCLUSION

The demonstration test with a prototype system during the above-mentioned period yielded performance values that were better than the calculated values. This is because the solar radiation on the vertically-installed panel surface was larger than expected. Even though we have not yet tested the performance in an intermediate season and in summer, the test results so far suggest no problem with the performance. We have therefore started the second phase of the project to finalize product details prior to market release.

In view of prevailing social trends, discussions and technical development of combined solar-gas systems are expected to intensify, for which our R&D project will play a useful role.

ACKNOWLEDGEMENT:

Within the framework of the activities of the Next-Generation Solar Water Heating System Study Group, this R&D project has been conducted jointly with the Building Research Institute. We are grateful for the support received from Prof. Yuichiro Kodama (Kobe Design University), Dr. Kazuaki Bogaki (Musashi Institute of Technology and Guest Researcher, Building Research Institute), and Prof. Takashi Akimoto (Shibaura Institute of Technology), among others.