Application of Solar Water Heating System in Multi-House Apartment

Masaharu Itagaki
m-itagak@tokyo-gas.co.jp
Tokyo Gas Co., Ltd, Japan
Kazuaki Bohgaki
bogakik@tcu.ac.jp
Professor Faculty of Urban Life Studies, Tokyo City University
Natsuko Enomoto
natsuko@tokyo-gas.co.jp
Tokyo Gas Co., Ltd, Japan
Takeshi Sase
t-sase@tokyo-gas.co.jp
Tokyo Gas Co., Ltd, Japan

Abstract

It becomes increasingly important to utilize renewable energy to realize low carbon society. Renewable energy, such as solar power, wind, biomass and hydro, approximately accounts for 5% of the total energy consumption in Japan. Due to the geographical limitation, use of wind power is less promising, neither of further hydro powers. Solar energy is expected to play the major role. But it accounts for only 2% of the total renewable energy in Japan.

About 70% of newly built houses in Tokyo Metropolitan area are multi-house apartments. It is very difficult to install solar energy systems into multi-house apartments, since they are usually built in very restricted space and their limited roof spaces are too small to install photovoltaic to supply enough electricity for residents.

While photovoltaic require a good size of roof to install, solar thermal system require less installation space, which will help reduce the energy use for hot water supply. So, solar thermal system can be more effective in reducing energy consumption in Tokyo Metropolitan area.

Tokyo Gas and Building Research Institute have developed the solar heating system that is designed to be installed on balcony of apartments. The system is composed of solar thermal collectors (installed vertically on balconies), a hot water storage tank and backup supply boiler. Heating medium in the collectors absorb heat from the solar energy. The collected heat is exchanged to heat up water in the storage tank.

Tokyo Gas and Building Research Institute conducted a series of field tests to evaluate the performance of the prototype of the system. The field test shows a promising result that the developed system should help to reduce the hot water supply energy consumption by 10 to 15 %.

This solar water heating system is expected to help reducing the energy consumption in multi-houses sectors.

Keywords

Renewable energy; Solar heating system; Solar thermal system; Re-heating load

1. Introduction

1.1 Energy-Saving Effect by Solar Power Residential Sector in Japan

It becomes increasingly important to utilize renewable energy to realize low carbon society. The use of renewable energy is also important for Japan from the energy security reason, since the domestic primary energy source is limited to 4%.

Renewable energy, such as solar power, wind, biomass and hydro, approximately accounts for 5% of the total energy consumption in Japan, and it is expected to grow more than 20% in the future.

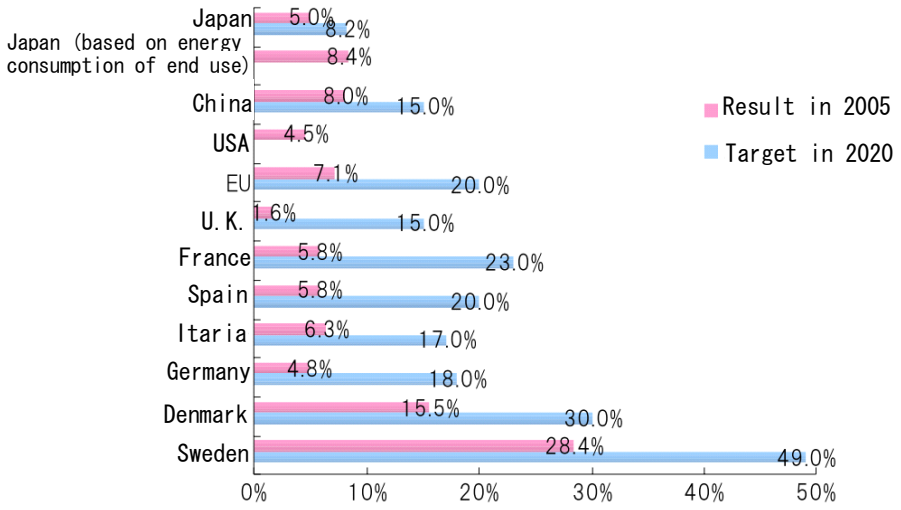
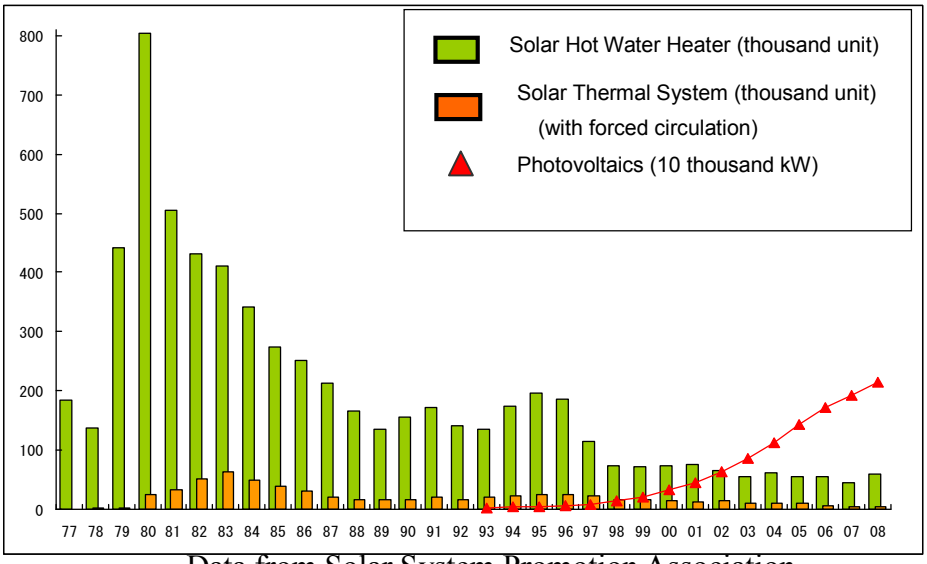


Fig. 1 Rate of Renewable Energy to the Total Energy Consumption [1)]

Due to the geographical limitation, use of wind power is less promising, neither of further hydro powers. Solar power is expected to play the major role in Japanese renewable energy. It is important to evaluate effectiveness by solar power and solar thermal system to save energy in the residential use in Japan.

1.2 Histrical Numbers of Solar System Installations

Fig.2 shows number of solar thermal systems installation history in Japan.



Data from Solar System Promotion Association

Fig. 2 Number of Solar system installation

Solar hot water systems market was created in late 1970s, after the “oil crisis”. The number of installation peaked at more than 800 thousand in 1980, and the market gradually decreased as much as 200 thousand in 1990s.

Due to relatively low oil price between 1997 and 2005, the market now has dropped as much as less than 100 thousand.

Solar hot water and solar thermal systems are mainly installed for replacing old ones. If they are installed on newly built houses, their market would increase.

Photovoltaic system market started in late 1990s. The government support, including subsidies, helped the photovoltaic system market grow steadily, exceeding solar thermal market in 2003, now reaches more than 200 thousand kW (about 670 thousand systems) installations.

2. Potential of Solar Energy System Installation in Japan

The maximum number of solar power systems, which include solar thermal systems and photovoltaic systems, installed in Japanese detached houses is estimated under next assumptions.

- 1. The number of detached houses can be obtained from the data of Statistics Bureau of Ministry of Internal Affairs and Communications
- 2. All houses are assumed to have 2 floors, thus total roof area is half of area of floor space.
- 3. The roof space on which solar energy system can be installed is calculated considerating roof shape (Fig.3) and human operation space. (For example, total roof area * 1/2(type A) * 0.6)
- 4. The solar thermal panel size is chosen among 2, 4 and 6 (m^2) according with the roof space, calculated in 3.
- 5. The Photovoltaic system should generate more than 2.5 kW to supply enough electricity for residents.

Type A Type B Type C

Fig. 3 Typical roof shape in Japan

The results are shown in table1. Compared with photovoltaic systems, solar thermal systems can be settled on smaller houses, so they have a larger potential market than photovoltaic system.

Table1 Market of Solar Energy System (Solar Thermal System, Photovoltaic System) for Japanese detached houses

		Solar thermal system	Photovoltaic system
Number of houses	New built houses	450 thousands per year	
	Existing houses	25.9 millions	
Maximum number of solar energy system installation	New built houses	380 thousands per year	300 thousands per year
	Existing houses	12.9 millions	9.8 millions

3. Application of Solar Water Heating System in Multi-House Apartment

3.1 Necessity of Solar Thermal System for Multi-House Apartment

Fig.4 shows number of newly constructed houses, apartment and detached houses, in Japan and Tokyo Metropolitan area. In Japan, 61% of new houses are apartment houses.

Especially in Tokyo Metropolitan area, 74% of new houses are apartment house.

So it is important to install solar energy systems, such as solar thermal systems, photovoltaic systems in apartment houses.

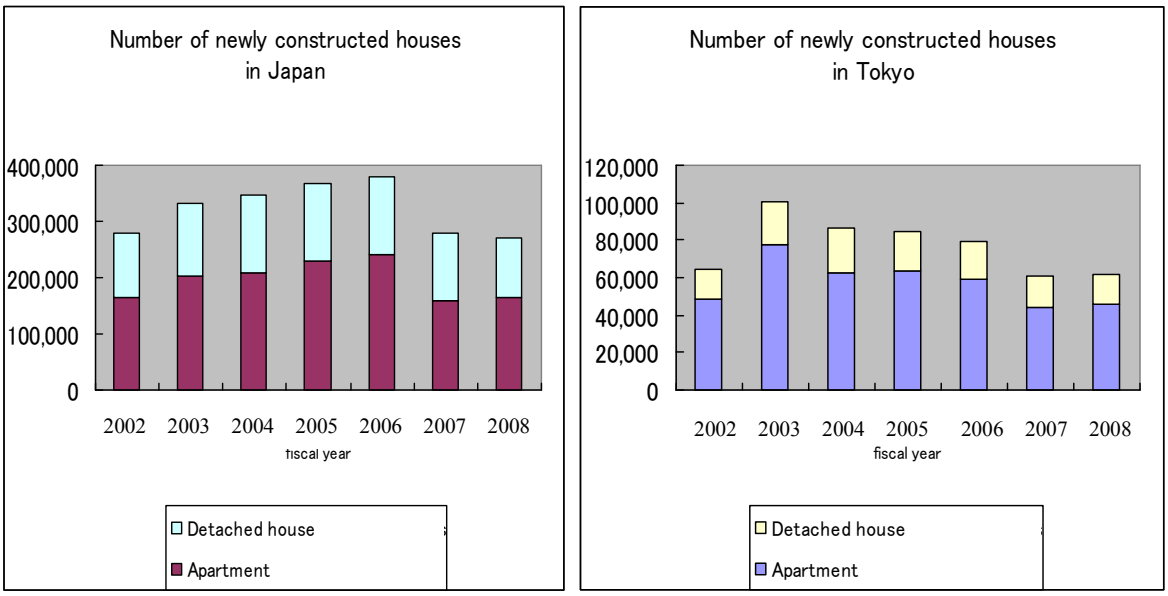


Fig. 4 Number of newly constructed houses

But it is still difficult to install solar thermal systems into multi-house apartments, since they are usually built in very restricted space. While photovoltaic system requires a good size of roof to install, solar thermal system require smaller installation space. So, solar thermal system is suitable to install.

Tokyo Gas and Building Research Institute have developed the solar heating system that is designed to be installed on balcony of apartment houses.

3.2 Structure and Mechanism of Solar Heating System

The system is composed of solar thermal collectors, a hot water storage tank and backup supply boiler, shown in Fig.4. And Fig.5 is the appearance of solar thermal collectors installed vertically on balconies.

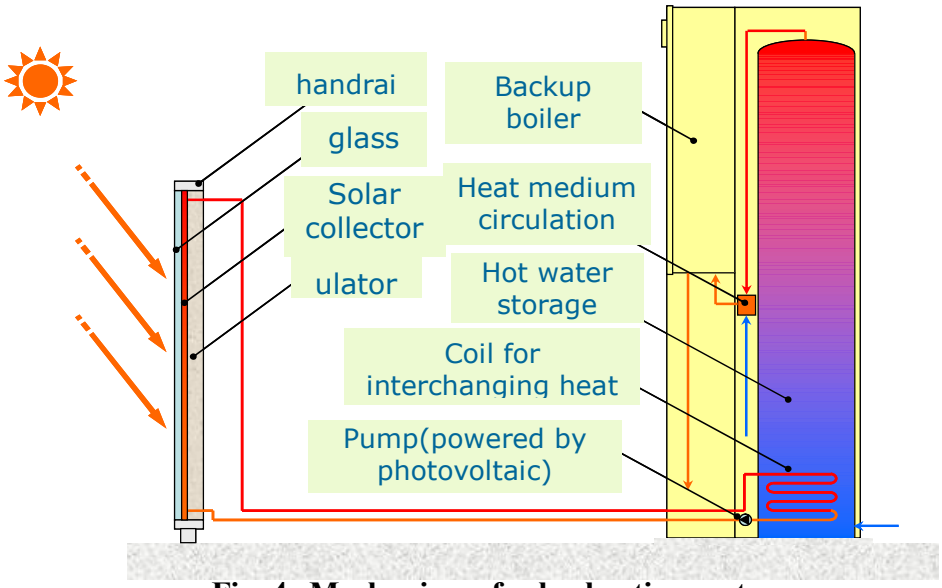


Fig. 4 Mechanism of solar heating system

Fig. 5 Appearance of solar thermal collectors installed vertically on balconies

Heating medium in the solar collector absorbs heat from the solar energy. The collected heat is exchanged to heat up water in the storage tank.

When the stored water temperature is warm enough to use, warm water is provided to bath, shower, or tap. When the stored water temperature is not warm enough, the water is heated up by a backup boiler.

3.3 Test Project to Evaluate Prototype Performance

Tokyo Gas and Building Research Institute conducted a series of field tests to evaluate the performance of the prototype of the system. The specification of the prototype is shown in Table2.

Table2 The specification

Name	Main specification
Solar thermal collector	Effective collection of heat are $1.06m^2$ *2 stands
Hot water storage tank	100 liter (Active storage 86 liter)

A hot water demand model (Model M1; Table3), representing an average hot water use in Japan, is used to evaluate the efficiency of the system.

Table3 Hot Water Demand Load: Model M1 [2)]

	Per month	Kitchen	Bath	Shower	Lavatory	Total
Weekday(Large)	11days	120	150	140	60	470
Weekday(Small)	11days	100	150	80	50	380
Weekend (Large)	2days	160	150	140	100	550
Weekend (Small)	4days	200	150	200	100	650
Weekend going-out(Large)	1day	10	-	200	30	240
Weekend going-out(Small)	1day	10	150	200	20	380

[unit. Liter-40℃]

Because both seasonal/daily solar condition changes frequently in Japan, the field test has been carried out through one year.

Table 4 shows primary performance data from the field test.

Table4 Average through the one year around test [3)]

Outside air temperature	14.3 ℃
Inset water temperature	16.0 ℃
Solar radiation to the vertical panels	7.7 (MJ/m^{2}day)
Collected solar thermal energy	6.3 (MJ/day)
Utilized solar thermal energy	5.0 (MJ/day)
Efficiency of the backup boiler (%)	87.0 %
Highest water temperature in the tank	55.1 ℃
Efficiency of Collecting solar thermal energy *1	33.8 %
Highest efficiency of Collecting solar thermal energy	52.5 %
Efficiency of Utilizing collected solar thermal energy *2	31.0 %
Dependence on the solar thermal energy	10.9 %
COP *3	0.973

*1 Efficiency of Collecting solar thermal energy
(Collected solar thermal energy) / (Solar radiation to the vertical panels) * (Space of solar collectors)
*2 Efficiency of Utilizing collected solar thermal energy
(Utilized solar thermal energy)/ (Solar radiation to the vertical panels) * (Space of solar collectors)
*3 The first conversion COP
(energy of hot water) / (required gas energy)

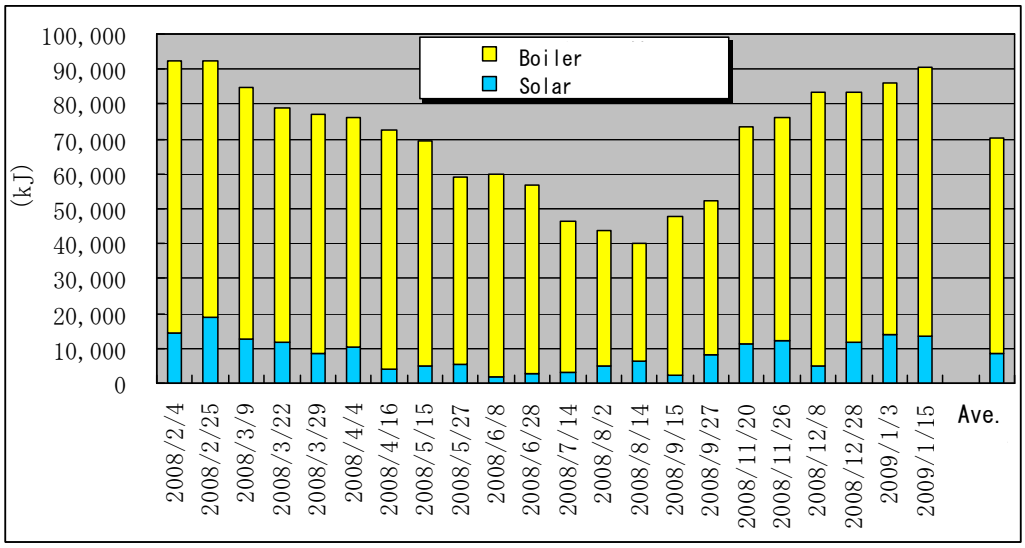


Fig. 6 The relation between the amount of energy supplied by the boiler and solar

Fig.6 shows the relation between the amount of energy provided by the boiler and solar thermal system. There is a seasonal change of the proposition of boiler energy supply / solar energy supply. Since solar panel is installed vertically, solar energy is effectively supplied when sun altitude is low. Thus, the system efficiency in winter season is higher than that in summer season.

Through one year, 10.9% of the energy is supplied by the solar thermal system. The result was evaluated based on the energy demand of family of four. The average number of family person is 2.55 in Japan, so the solar thermal system contribution should be larger than 10.9% in actual use.

The field test shows a promising result that the developed system should help to reduce the hot water supply energy consumption by 10 to 15 %.

3.4 Test Model Project in Actual Use

After the field test using a laboratory-made system under a modeled load, Tokyo Gas continues a model project using a manufactured made product under an actual use. The model project intends to realize,

-1. System installation on balconies, to ensure safety, the integrity of balconies with a solar system additional load and the compliance of Fire Regulation requirement of escape space on balconies.
-2. Extended outlook / design, to match the solar thermal panel, dark color with the apartment exterior.
-3. Efficiency measurement and a possible green thermal credit.

The system efficiency is measured under actual 3 residents. The model project has started in March 2010. It will last the next 1 year.

3.4.1 The test subject multi-house apartment

The test subject multi-house apartment has 3 floors and 9 rooms, and the building faces the south (Fig.7). The test data have been measured in 3 rooms – Room 102, 103 on first floor and 203 on second floor. The specification of the prototype is shown in Table5.

Fig.7 Appearance of solar thermal collectors installed vertically on balconies in test subject apartment-house

Table5 The specification

	Main specification
Solar thermal collector	Effective collection of heat are0.97m^2 *3 stands
Hot water storage tank	100 liter (Active storage 93 liter)

3.4.2 The early results obtained from March to May 2010

As we said above, this test project is conducted under an actual use. So a hot water load is actually what a resident use. We can obtain some results for three months from March to May.Fig.8 shows the relation between the amount of energy provided by the boiler and solar thermal system.

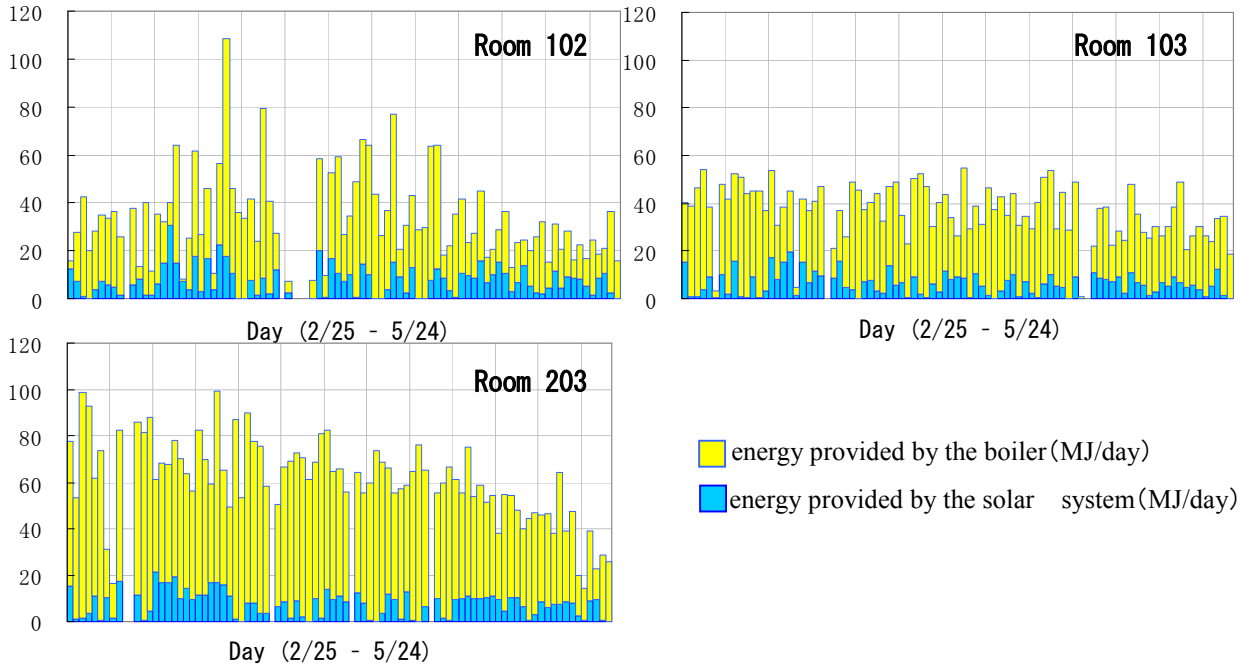


Fig. 8 The relation between the amount of energy supplied by the boiler and solar thermal system

Table6 Average data (2010.2.25 ~ 2010.5.24) [4)]

Room	102	103	203
Number of residents	2	3 (one child)	3 (one child)
Outside air temperature (℃)	13.1		
Inset water temperature (℃)	14.9		
Hot water load (MJ/day)	31.8	35.8	60.7
Hot water load (without bath re-heating) (MJ/day)	31.1	22.5	57.9
Utilized solar thermal energy (MJ/day)	7.0	6.1	7.5
Highest water temperature in the tank (℃)	60.9	53.6	49.3
Efficiency of Utilizing collected solar thermal energy (%)	30.1	26.0	32.1
Dependence on the solar thermal energy(%)	22.0	16.9	12.4
COP *	1.095	0.936	0.988

* The first conversion COP: (energy of hot water) / (required gas energy)

And Table6 says that dependence on the solar thermal energy, COP is better than that of the laboratory-made system because of increase of panels, except for room 103.

Room 102 has almost same hot water load as 103, but as for COP of the system, 102 is higher than 103. In the case of 102, hot water loads changes everyday, but they are large enough to utilize stored solar energy. On the other hand, in the case of 103, bath re-heating load degrease almost 40% of hot water load, so 103 people could not used up stored solar energy and the efficiency of system was not good compared with the one of 102. In the case of 203, hot water load was almost double of 102, so solar thermal energy could be fully utilized. Dependence on the solar thermal energy is smaller than 102 or 103, but utilized solar thermal energy is higher than 102 or 103.

If the collected solar energy could be lager and be fully, the efficiency could be higher. In the case of room 102, collected solar energy is fully used before sunrise, so the system can collect solar energy for full volume of hot water storage tank and it was used for hot water usage in night. (as shown in Fig.9). On the other hand, in the case of 103, the collected solar energy is not fully used before sunrise, so the system cannot collect solar energy to its full capacity (shown in Fig.10).

Another reason for the lower COP is energy used for bath re-heating load. The backup boiler in this system has bath re-heating function. So, when the efficiency of this system is evaluated, energy of hot water should contain bath re-heating energy. Solar thermal energy cannot be used

for bath re-heating because of its low temperature, so re-heating energy is provided by backup boiler. So COP becomes lower because of required gas energy for re-heating.

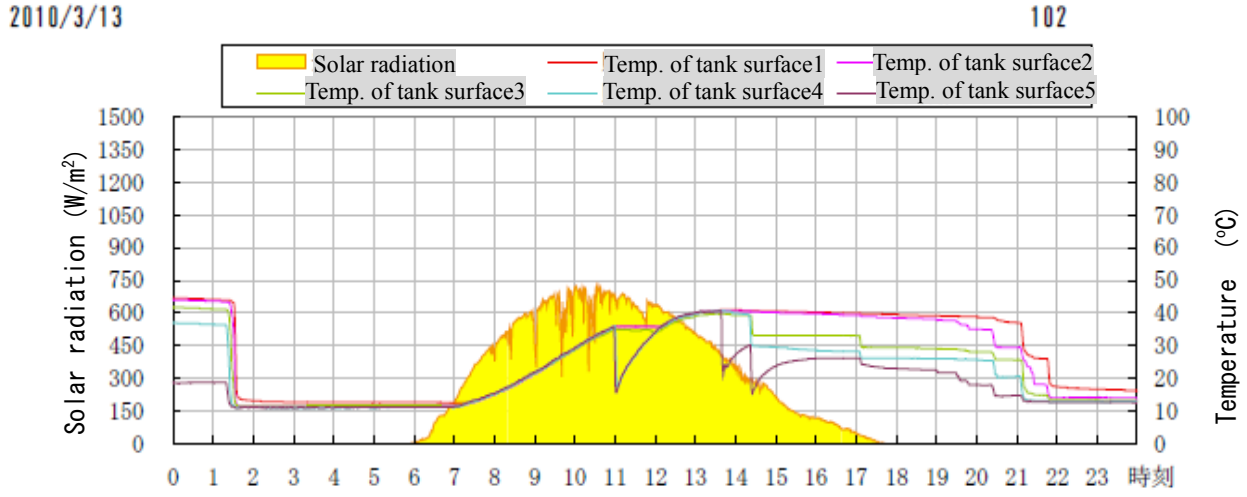


Fig. 9 Trend of surface temperature of the storage tank (room 102)

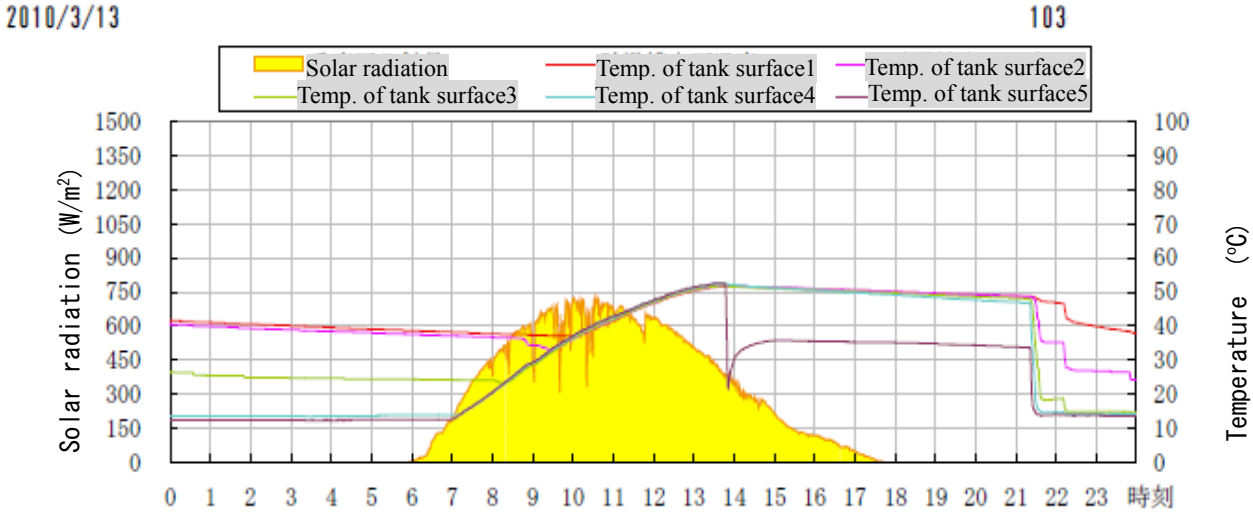


Fig. 10 Trend of surface temperature of the storage tank (room 103)

Fig. 11 shows the relation of hot water load (without bath re-heating) and utilized solar thermal energy. Square dots are average data during 3month. Circle dot means laboratory data. Fig.11 says that utilized solar thermal energy is bigger when the hot water load is lager. But if the hot water load is large enough, utilized solar thermal

energy saturate. This seems due to the size of hot water storage tank, 100 liter, collecting thermal energy.

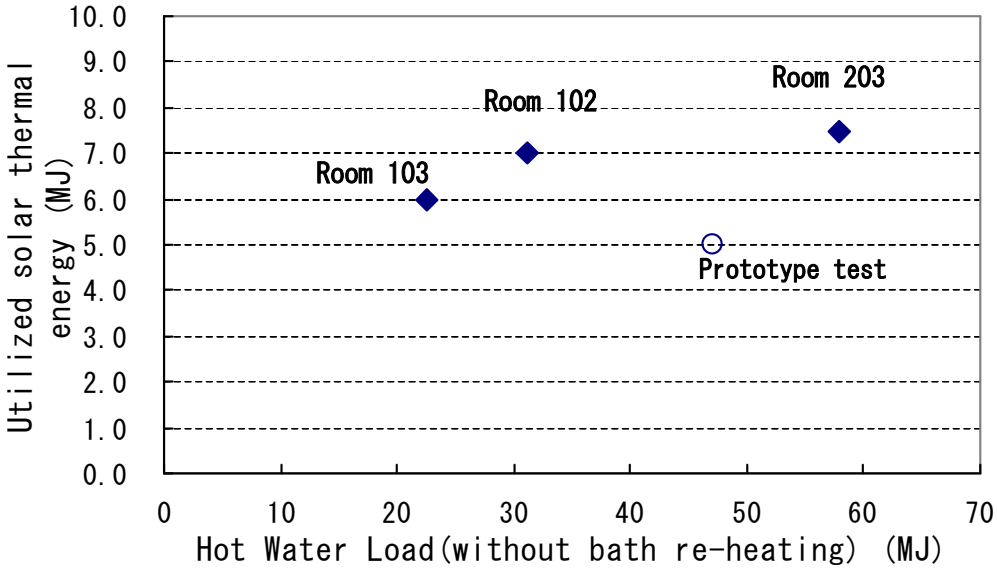


Fig. 11 Relation between Hot water load and Utilized solar thermal energy

4. Conclusion

- The one year around test of prototype of solar thermal system shows that 10.9% of the hot water load is supplied by the system.
- The test of manufactured made products in actual apartment house shows that dependence on solar energy could exceed 20% due to increase of collector panels.
- The result shows that the utilized solar thermal energy increases as the hot water load increase. If the hot water load is large enough, utilized solar thermal energy saturates. This seems due to the size of hot water storage tank.

5. Reference

1) The Ministry of Environment, ”A suggestion about the plan to spread renewable energy for construction low carbon society” (2009.2)
2) Masayuki Mae, et al. (2009),“Practical Use and Efficiently Usage of Boilers”, *Blue & Green Project Seminar 2009*
3) Natsuko Enomoto, Kazuaki Bohgaki, et al., “APPLICATION OF SOLAR WATER

HEATING SYSTEM IN MULTI-HOUSE APARTMENT"; 4th International Solar Energy Society Conference, Asia Pacific Region, (2010.6-7)
4) Kazuaki Bohgaki, "Effectiveness of Solar Thermal Utilization"; The 2nd Solar Energy Utilization and Promotion Symposium, (2010.6)

6. Presentation of Author

Masaharu Itagaki has worked on the gas appliances efficiency nearly two decades since he joined Tokyo Gas in 1990. He is now deeply involved in the development of national building/housing efficiency codes in the fields of hot water supply, air conditioning and residential CHP (Combined Heat and Power) application.