Evaluation of a Solar House with Air Collector System Using Measurement and Simulation

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Abstract

A single family house provided with the air solar collector system combined with the pebble bed heat storage system had been measured since March of 2009 to April of 2010. The house is occupied by a family of three. The measured contents are temperatures humidities of the rooms and the air collector system as well as a horizontal solar radiation as and weather data. The measured data show that the occupants satisfy the room thermal environment. In order to evaluate the solar house the study is carried out with the followings;

1) The measured data such as consumption of the gas and the electricity were compared with the average energy use for the similar size of the house in Kanto region in 2007. The results showed that the energy use of the measured solar house was less than the average value by 21%.

2) For the detailed comparison between the similar solar house and the house without solar system, the simulation was carried out to show the reduction of the boiler heat load and living and dining room heat load as well as indoor thermal environment.

Keywords: Air solar collector, Pebble bed heat storage, Simulation

1. Introduction

The single family house built in Kanagawa Prefecture provided with the air solar collector system combined with the pebble bed heat storage system had been measured since March of 2009 to April of 2010. First, the energy performance with the measured house and the similar size house in Kanto region was compared. Second, the simulation was carried out for the two simulation models; one is the similar as the measured house and the other is the house without solar system.

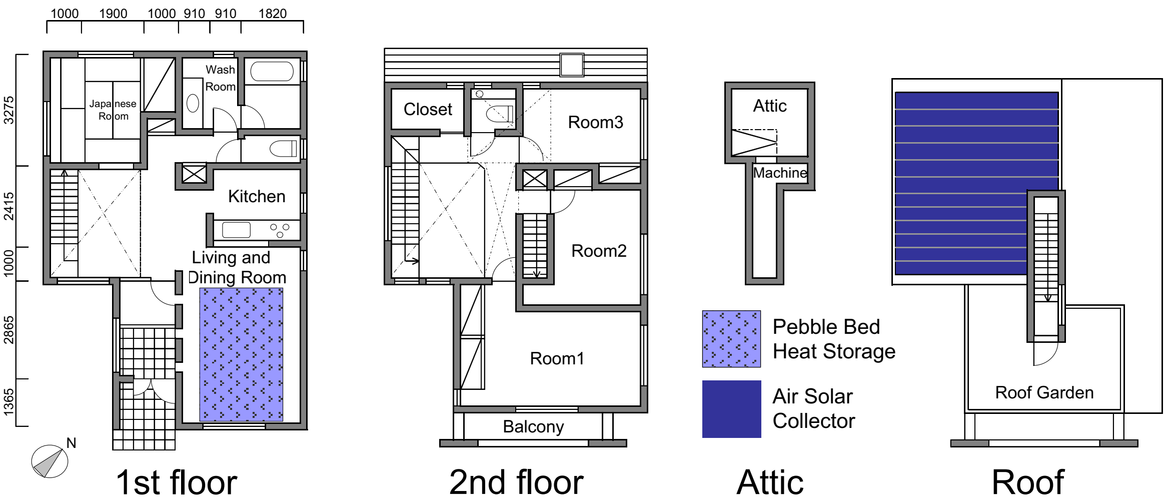
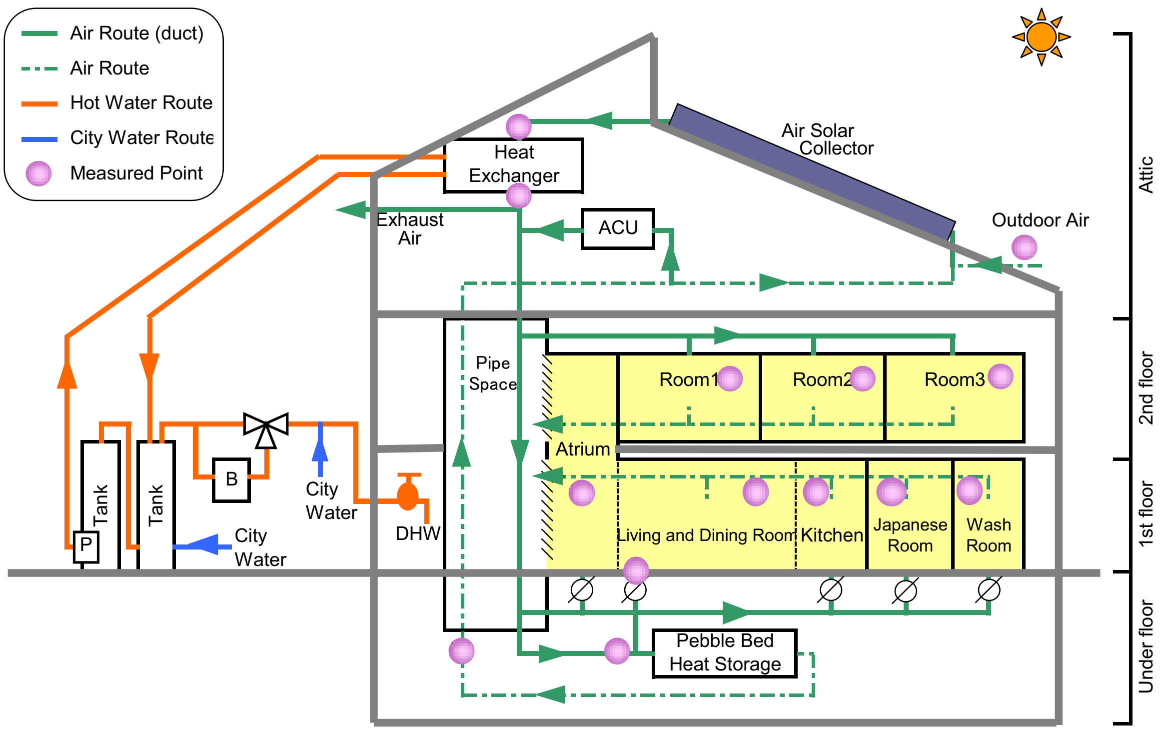


Fig.1. Floor plan of the measured house



DHW : Domestic Hot Water B : Boiler P : Pump ACU : Heat Pump Air Conditioning Unit

Fig.2. System diagram of the measured house

2. The measured solar house

Figure 1 shows the floor plan of the measured house. The house is a two storied wooden single family house with a total floor area of 133m^2. The house is occupied by a family of three and is consist of a living and dining room, a kitchen, three bed rooms and a Japanese room. In addition, under the floor of the living and dining room pebble bed heat storage with 6.3m^3 is provided, and the air solar collector of 27.7m^2 areas, tilted angle of 23.8 degrees is integrated on the west roof.

Figure 2 shows the system diagram of the measured house. The solar heating system is composed of the air solar collector, heat exchanger, collector fan, air conditioning unit and the pebble bed heat storage. Domestic hot water supply system is composed of two heat storage tanks, gas boiler, circulation pump and motor switch valve.

The starting temperature for the solar heat collection is designed to be set by the occupant in each season. When the temperature of the collector outlet is over the set point temperature, the collector fan is switched on. Then heated air by the collector is used to pre-heating the city water and exhausted during spring to fall. In winter, after pre-heating the hot water the air is supplied to the rooms and the pebble bed heat storage.
When the pebble bed heat storage stores enough heat, supply the hot air to the rooms without running the air conditioning unit.

3. The energy peformance of the measured house

Figure 3 shows the energy peformance of the similar size of the house in Kanto

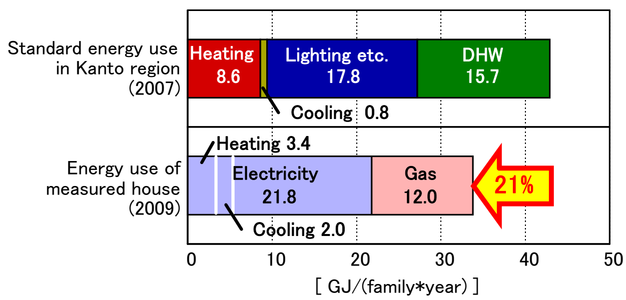


Fig.3. the energy peformance

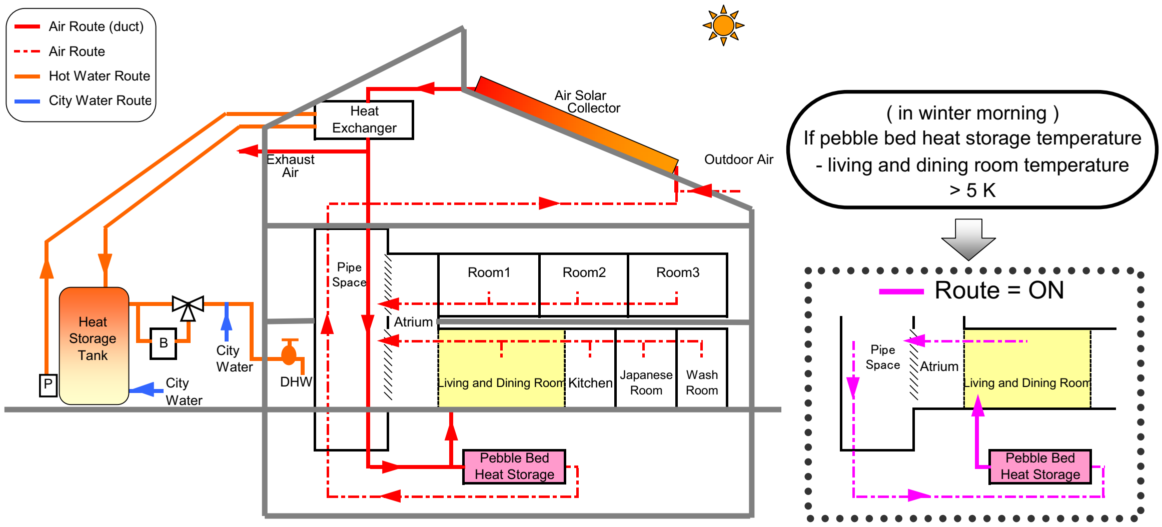


Fig.4. Simulation model of the solar house

Table1. Simulation schedule

Weather data	Expanded AMeDAS (Tokyo)		
Calculation interval	1 hour		
	Winter	Middle	Summer
Month	Jan.-Mar. Nov.-Dec.	Apr.-Jun. Sep.-Oct.	Jul.-Aug.
	Weekday	Weekend	Holiday
Day	Mon-Fri	Sat	Sun
Room temperature control time	5:00-7:00 17:00-21:00	5:00-7:00 13:00-21:00	6:00-21:00
	Winter	Middle	Summer
Room set point temperature [degree C]	22	–	26
Starting temperature for the solar collection [degree C]	35	50	65
Boiler outlet temperature [degree C]	1:00-12:00 37 13:00-24:00 52	1:00-12:00 37 13:00-24:00 47	1:00-12:00 37 13:00-24:00 42
Domestic hot water supply temperature [degree C]	1:00-12:00 35 13:00-24:00 50	1:00-12:00 35 13:00-24:00 45	1:00-12:00 35 13:00-24:00 40

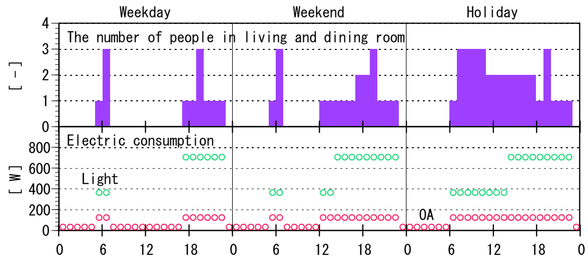


Fig.5. Simulation input data

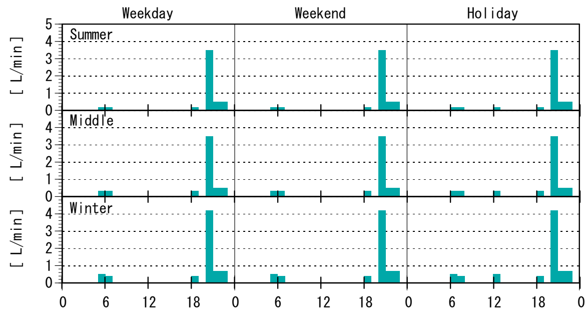


Fig.6. DHW supply schedule of each season

region and measured house. The measured data were the temperatures of the system components of solar system and the room temperatures and humidities. The electricity and gas were also measured [1]. In comparison with the standard energy use for the similar size house in 2007, the energy use of measured house in 2009 is 21% smaller.

4. Simulation

Two cases of the simulation models was prepared. One is the similar as the measured house. The other is the house without solar system. The difference between the solar house and the house without solar system shows the effect of solar energy use. In this study the simulation tool EESLISM6.1 was used.

Figure 4 shows the simulation model of the solar house. The solar house model is composed of the air solar collector (27.7m^2 areas, tilt angle 23.8 degrees), heat exchanger, the pebble bed heat storage (6.3m^3), heat storage tank (600L), DHW auxiliary heating (gas boiler), circulation pump and valve.

Table 1 shows the simulation schedule. Figure 5 shows the number of people in the living and dining room and the electric consumption. Figure 6 shouws the DHW supply schedule of each season. In simulation, heated air by the collector is used to pre-heating the city water and after pre-heating air supply to the living and dining room and the pebble bed heat storage in winter. And if the air temperature of pebble bed heat storage is 5 K higher than the air temperatures of the living and dining room, the air in pebble bed heat storage is supplied to the living and dining room during one hour before starting to control the room air temperature controled

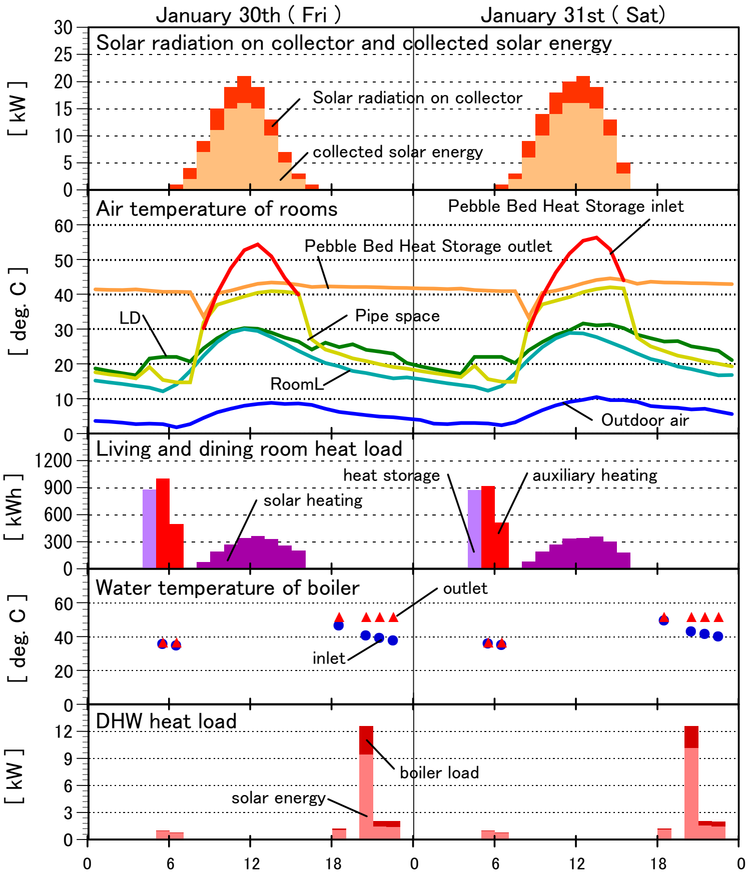


Fig.7. Hourly simulation results on winter sunny days

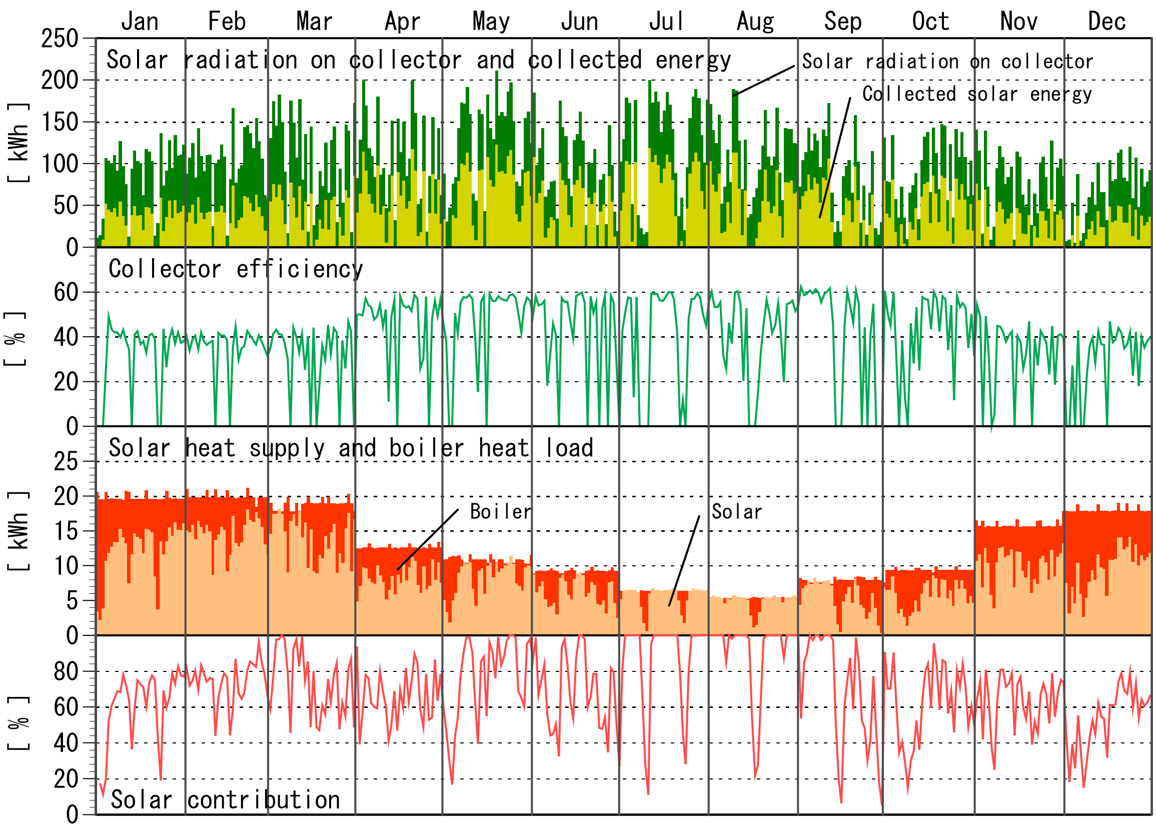


Fig.8. Annual simulation results by daily average and daily total data

Table2. Monthly collector efficiency and DHW solar energy contribution

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Solar radiation on collector [MJ/month]	9,840	10,611	11,836	12,055	14,425	10,382	13,847	12,580	9,324	9,904	8,487	7,530	130,822 [MJ/year]
Collected solar energy [MJ/month]	3,815	4,028	4,575	6,205	7,659	5,270	7,255	5,988	4,948	4,878	3,382	2,754	60,758 [MJ/year]
Collector efficiency [%]	38.8	38.0	38.7	51.5	53.1	50.8	52.4	47.6	53.1	49.2	39.8	36.6	45.8 [%]
DHW Solar heat supply [MJ/month]	1,356	1,485	1,556	890	931	676	633	557	595	646	1,075	1,085	11,485 [MJ/year]
DHW Boiler heat load [MJ/month]	852	526	550	478	285	323	89	52	269	408	635	927	5,395 [MJ/year]
DHW Solar energy contribution [%]	61.4	73.9	73.9	65.0	76.5	67.7	87.6	91.4	68.9	61.3	62.9	53.9	70.4 [%]

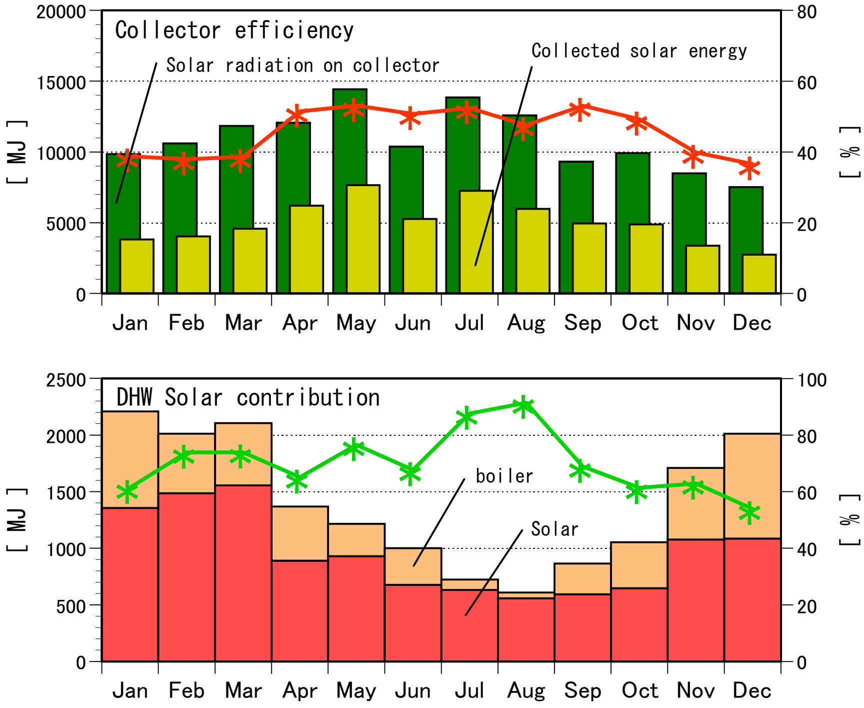


Fig.9. Monthly collector efficiency and solar contribution

in the morning by the auxiliary heating.

The curtains of the windows of living and dining room are closed the curtain during 17:00 to 5:00 and opened the curtain during 5:00 to 17:00 in winter. In summer, the curtains are opened during 19:00 to 5:00 and the blinds are closed during 5:00 to 19:00.

5. Simulation result

Figure 7 shows the hourly simulatuon results on winter sunny days. Early in the morning, the air tempereture of pebble bed heat storage is 40 degrees C and the air temperature of living and dining room is 18 degrees C therefore during 4:00 to 5:00 the hot air is supplied from the heat storage air to the living and dining rooms. During the solar heat collection, the air temperatures of living and dining are over 30 degrees C because of the air after heat exchanged is supply to the living and dining room. In the evening, the air temperatures of living and dining room are kept over 22 degrees C. The solar contribution is about 80%.

Figure 8 shows the solar radiation on collector and collected energy, collector efficiency, solar heat supply and boiler heat load, solar contribution. The maximum collector efficiencies are 40% during November to March and 60% during April to October.

Table 2 shows monthly collector efficiency and solar energy contribution. Figure 9 shows the monthly collector efficiency and DHW solar contribution. In May, the monthly solar radiation on collector and collected solar energy show the highest in a year. In August, the solar radiation on the collector is about 12.6GJ/month but the collected solar energy is about 6.0GJ/month because of the air temperature into the collector is high. Therefore, the collector efficiency is lower. The annual mean of collected efficiency is 46%. In summer, the DHW supply is decreased and the collected

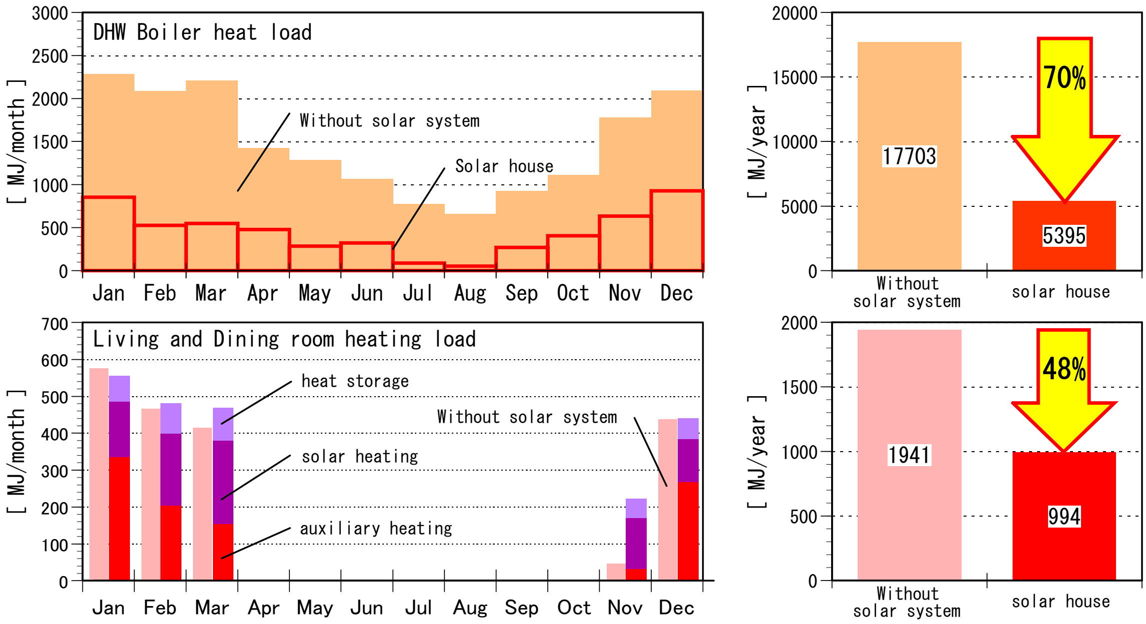


Fig.10. Comparison of the house without solar system and solar house

solar energy is increased, thus the solar contribution becomes over 85%. From autumn to spring, the solar contribution is 50% to 75%. The annual mean of the solar contribution is 70%.

Figure 10 shows comparison of the house without solar system and the solar house. The boiler heat load of the house without solar system is 17.7GJ/year and the boiler heat load of the solar house is 5.4GJ/year. Since the heated air by the collector is used for pre-heating the city water, the boiler heat load is reduced to 30%. The heat load of the living and dining room of the house without solar system is 1.9GJ/year and the heat load of the living and dining room of the solar house is 1.0GJ/year so heat load of the living and dining room is reduced to 52%.

6. Conclusion

1) The energy performance of the solar house was evaluated by the data of monthly energy use. The energy use of the measured house in 2009 is 21% smaller than the standard energy use for similer size of house in Kanto region in 2007.

2) The simulation was carried out to examine the detailed performance of the measured house. The simulation results shows the variations of the temperatures and the heat flow of all the system components of the solar house.

3) In winter, early in the morning, when the difference of the air temperatures between the pebble bed heat storage and the living and dining room is more than 5 K, the heat storage hot air is supplied to the living and dining room from the pebble bed heat storage to reduce the space heating load.

4) In the evening, the air temperatures of living and dining room are kept over 22 degrees C because of the air after heat exchanged is supplied to the living and dining room during day.

5) Annual simulation results show that the collector efficiency is 45.8% and the soalr energy conribution is 70.4%.

6) The comparison of two houses without solar system and the solar house, the boiler heat load of the solar house is reduce to 30% and the heat load of the living and dining room is reduce to 52% because of collected solar energy.

7) The comparison between the measured data and the simulation results show the difference. For the future work, it is necessary to examine the simulation input data for finding the better results to coincide with the measured data and to be used for the improvement of the control storategy of the measured solar house.

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