Study on Renovation to Solar Houses with Air Collector
Part 1 House T – Renovation to the Net Zero Energy House

Mitsuhiro Udagawa [1], Hyunwoo Roh [2] and Takafumi Kusunoki [3]

[1] Kogakuin University, 1-24-2, Nishi-Shinjuku, Shinjuku-ku, Tokyo, Japan, Phone: +81-3-3340-3436, Fax: +81-3-3340-0150, E-mail: udagawa@cc.kogakuin.ac.jp

[2] OM Solar, Inc., 4601, Murakushi-cho, Nishi-ku, Hamamatsu, Japan, Phone: +81-53-488-1715, Fax: +81-53-488-1556, E-mail: roh@omsolar.jp

[3] Kogakuin University, 1-24-2, Nishi-Shinjuku, Shinjuku-ku, Tokyo, Japan, Phone: +81-3-3340-3436, Fax: +81-3-3340-0150, E-mail: re12007@ns.kogakuin.ac.jp

Abstract

For reducing the environmental load in the housing sector, the house renovation to improve the energy efficiency and the thermal comfort is desirable rather than the rebuilding after destruction. In this paper, the renovation method and the related element technologies for the small solar house, House T with air collector are described. The house located at a suburb of Takasaki (36.32 N, 139.01 E) was lived by a young couple and two small children. In order to increase the thermal resistance, the envelopes have been replaced by the well insulated exterior walls and roofs and the double pane windows. The roof is provided with the PVT pre-heating collectors of 54m^2 with a PV capacity of 5.2kWp and the glazed air collectors of 10m^2 to be used for space heating and domestic hot water heating in heating season. In summer, the solar collectors are used for only domestic hot water heating. The heat pump air conditioners are used for auxiliary space heating and cooling. The heat pump is also used for auxiliary domestic hot water heating. As a result of the detailed simulation using EESLISM, it is expected that the total energy use of the renovated house will be reduce to 36% of the house before the renovation and the house will work as a net zero energy house using PV system.

1. Introduction

In this study, a small house was selected to develop the renovation technology combined with the improvement of thermal insulation and solar air collector. The house(House T) is located at a suburb of Takasaki (36.32 N, 139.01 E) about 100km north-west of Tokyo and it was a modern traditional house built approximately 20 years ago. House T is a one storied house composed of wooden frame with a total floor area of 76m^2 as shown in Figure 1. Using the renovation technology, the house was considered to be converted into an energy efficient and comfortable solar house using solar thermal and also PV system combined with passive solar technologies[1].

2. Renovating House

As shown in Figure 1, front of the house is faced to south. The thermal insulation of the house is shown in table 1. The insulation thickness of the outside walls was 50mm and the ceiling was insulated with 100mm thick insulation. While curtains and rain proof sliding doors were provided, single pane windows were used. The insulation of the house was poor and renovation of the envelope was necessary to improve the thermal comfort of the room and to reduce the energy use by space heating.

Space heating was provided with a heat pump room air conditioner and a gas heater for the auxiliary. As the space cooling is necessary in summer, a heat pump room air conditioner was used. For the domestic hot water heating, a gas boiler was used. The house was occupied with a family of four with two small children.

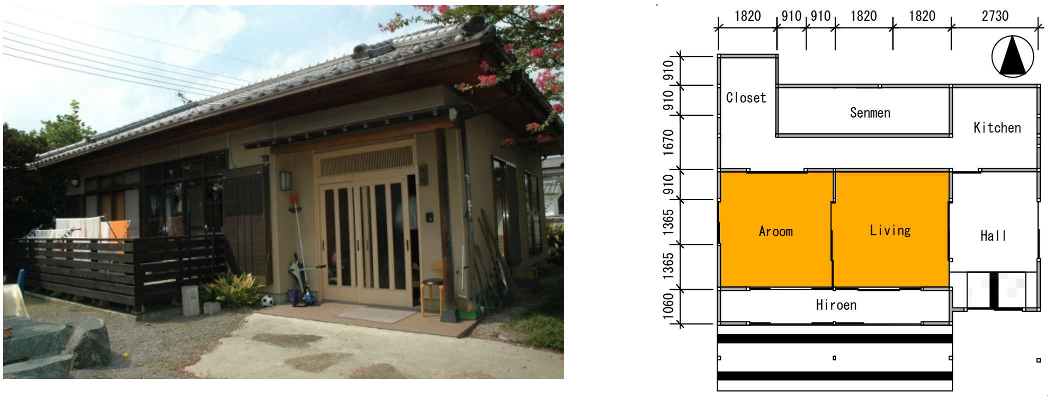


Figure 1. Floor plan and outside view of House T before renovation.

Table 1. Thermal insulation of House T.

Before renovation	After renovation
Roof: phenol foam 35mm	Roof: phenol foam 120mm glass wool 50mm
Ceiling: glass wool 100mm	Ceiling: glass wool 100mm
Floor: glass wool 50mm	Foundation: polystyrene foam 100mm
Outside wall: glass wool 50mm	Outside wall: glass wool 100mm phenol foam 35mm
Window: single pane	Window: low-e double pane U=2.08W/m^{2}K

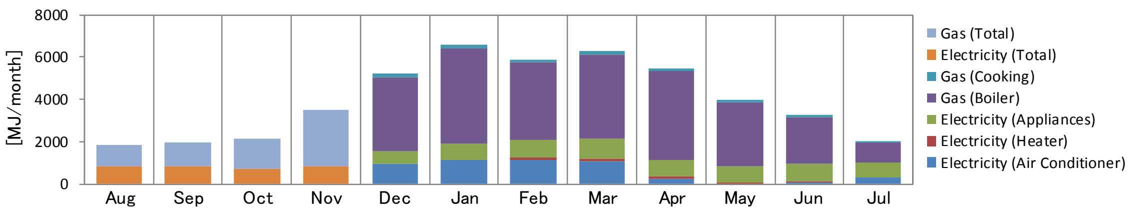


Figure 2. Energy use of House T before renovation (August, 2010 – July, 2011).

The energy use and lived environment of the house had been monitored from December 2010 to July 2011 when the renovation of the house started. The energy used in the house was electricity from the grid and LP gas. The electricity use and the LP gas flow rate were accumulated at a time interval of 10minutes by the monitoring system. The room air temperatures and the domestic hot water temperatures and hot water flow rates were also measured.

Figure 2 shows the energy use of the house for a year. In Figure 2, while the monthly energy use started from August, the data from August to November were estimated from the invoices of the purchased electricity and LP gas, since the monitoring started from November, 2010. The annual energy use of the house before renovation was estimated to be 48GJ/year.

3. Renovation Design

Recently, there were two major purposes for the house renovating project in Japan. One is to improve the energy performance, reduce the energy use and CO2 emission and the other is to improve the earthquake resistant. While to improve the earthquake resistance is important, this paper focuses on the renovation to improve the energy performance using the passive and active solar energy use including PV system. The renovation to improve the thermal insulation of the house envelopes was the basic method of reducing the energy use for space heating and to improve thermal comfort of the rooms.

The floor plan and section of the renovated house are shown in Figures 3 and 4. The outside view of the house after renovation is shown in Figure 5. The total floor area was slightly increased and it is $82m^2$. The rooms are extended to two rooms in addition to the living room. The envelope of the house was completely replaced by the insulated exterior walls of 135mm thick insulation and roofs of 170mm thick insulation. The double pane windows were provided. The insulation of the envelopes is summarized in Table 1. The roof shape was modified to mount the solar collectors and PV array with suitable tilted angles. The double pane windows are used.

Air heating collectors are used to heat the air supplied for space heating and also to heat the domestic hot water using an air-to-water heat exchanger is also used as shown Figure 4. The air collector system is an all fresh air heating system that consists of three types of air collector. The first stage is preheating collector without glazing, the second stage collector is PVT type consist of PV modules as heat absorbing sheet without glazing and the third one is glazed air collector. All collectors are roof integrated type. The collector areas are shown in Table 2.

For the space heating, the heated air is introduced into the under floor space surrounded by concrete foundation walls and foundation floor slab. In order to increase the heat capacity of the under floor space, total volume of 580 liters of water is placed using the small containers. The room air conditioners are mounted in the living room and rooms A and B. The room air conditioners are air source heat pump unit which are used for the auxiliary space heating and also for cooling in summer.

The domestic hot water is preheated by the solar energy and the heat pump hot water heater is used for the auxiliary water heating. he renovation was completed in March, 2012.

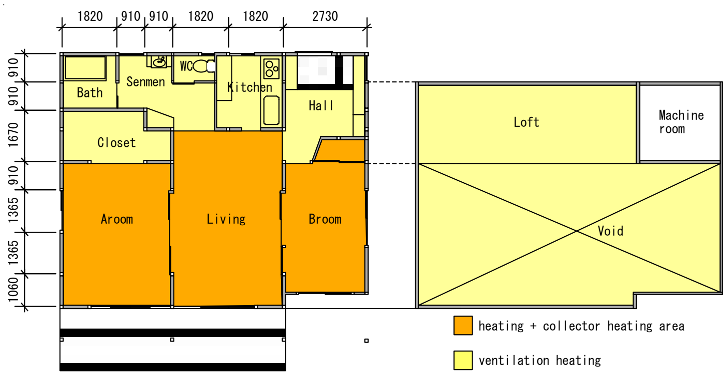
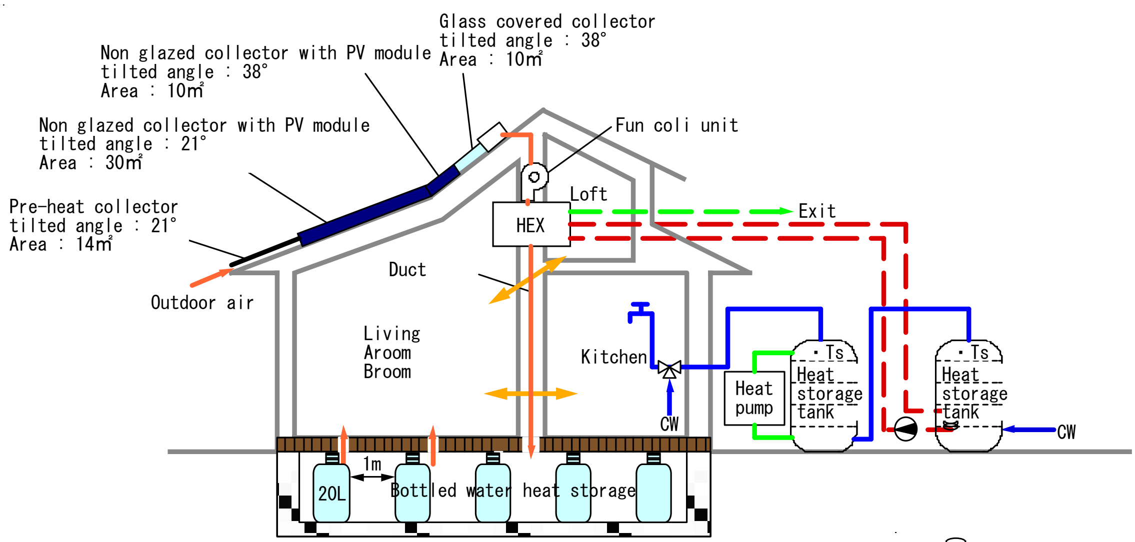


Figure 3. Floor plan of House T after renovation.



Water heat storage using bottles	
Under floor space	20 m^3
Heat storage volume	580 litters
Heat capacity	2341 kJ/K
Effectiveness as a heat exchanger	0.25

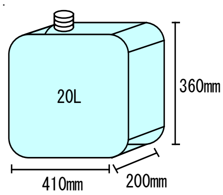


Figure 4.Solar thermal system of House T after renovation.

Figure 5. Outside view of House T after renovation.

Table 2. Heating, cooling and domestic hot water heating system of House T after renovation.

Air heating collector -Total collector area 64m^2 -Total PV area 40m^2,5.2kWp	1) non glazed pre-heating 14m^2 21degrees 2) PVT collector (non glazed) 30m^2 21degrees 3) PVT collector (non glazed) 10m^2 38degrees 4) Glazed collector 10m^2 38degrees
Domestic hot water heating (DHW)	1)Solar heated tank, 200 litters 2)Heat pump with tank , 370 litters, COP=3.2 Heating 4.5kW
Space heating and cooling	Heat pump air conditioner
Room B (east)	Heating 2.2kW ,COP=5.4 Cooling 2.2kW, COP=4.6
Room Living	Heating 3.6kW ,COP=4.4 Cooling 2.8kW, COP=3.9
Room A (west)	Heating 2.8kW ,COP=5.0 Cooling 2.5kW, COP=4.4

4. Improvement of Energy Performance

The simulation study with a generalized simulator tool EESLISM was carried out to examine the renovated performance of the house. EESLISM is a simulation tool for the energy and environment performance of the building including solar buildings[2],[3],[4]. The weather data at Maebashi weather station 20km away from the housing site. The room thermal conditions, the use of household equipment and the domestic hot water use were assumed based on the monitored data of the house before renovation. In the heating season, the room set point for space heating is 18 degree C of the operative temperature defined by the mean of a room air temperature and a mean radiant temperature of a room. The space heating system is assumed to be operated from early morning to midnight. The solar heating provides basic heating and the room air conditioners are used for the auxiliary.

The domestic hot water heating load is based on the hot water use of 450-330 litters and the hot water temperatures of 50 degrees C for the bath room and 35 degrees C for other hot water demand. The hot water heat pump is operated when temperature of the solar heated hot water is lower than the required hot water temperature.

Figure 6 shows the simulation results of the typical winter days in January. Figure 6 shows the solar heat collection, the PV power generation, the temperatures of the collectors, the room temperature and the heat loads of space heating, cooling and domestic hot water heating(DHW). The heat collected by the solar collectors and the power generated by the PV arrays are shown Figures a) and b), respectively. The total collector efficiency of four collectors in Table 2 is approximately 15%, while for the glazed collector the efficiency is 30% on the sunny days. The collector inlet temperatures for the four collectors are also shown. While all fresh air collector system is used, the outlet air temperature of the first stage collector, the pre-heating collector is higher than the room air temperature on the sunny days. As the inlet temperature of the glazed collector reaches 40degrees C on the sunny days, the all fresh air collector system can collect enough useful heat by the preheating effects of the pre-heat system including PVT collectors. The total efficiency of the PV arrays is approximately 9% on the sunny days.

Figure 7 shows the variation of the monthly values of domestic hot water heating(DHW), space heating supplied by the solar energy and the auxiliary heating systems. Figure 7 also shows the heat loads for domestic hot water heating, space heating and cooling to be supplied by the heat pumps as the auxiliaries. Figure 7d) shows the demand of electricity by its usage. The LP gas is not used in the renovated house, since the gas is not used for cooking and hot water heating, after the renovation.

Table 3 shows the summary of the annual performance based on the secondary energy. The simulation results showed that total purchased energy is 17GJ/year. The expected power generation of the PV arrays is 20GJ/year which excesses the total energy demand of the house. Therefore, after the renovation, the house will become a net zero energy house.

Table 3. Comparison of annual performance in secondary(purchased) energy.

Before the renovation (Aug. 2010 to Sept. 2011)	After the renovation (Prediction by simulation)
Electricity 14.7GJ /year (4.08MWh/year)	Electricity 17.4GJ/year (4.8MWh/year) Space heating 0.15 GJ Space cooling 2.07GJ Domestic hot water(DHW) 5.11GJ Cocking 1.25GJ Appliances, Lighting 8.82GJ
LP gas 33.4GJ/year (9.28MWh/year)	LP gas none
Total 48.1 GJ/year (13.36MWh/year)	Total 17.4GJ/year (4.8MWh/year) PV generation 19.8GJ/year (5.5MWh/year)

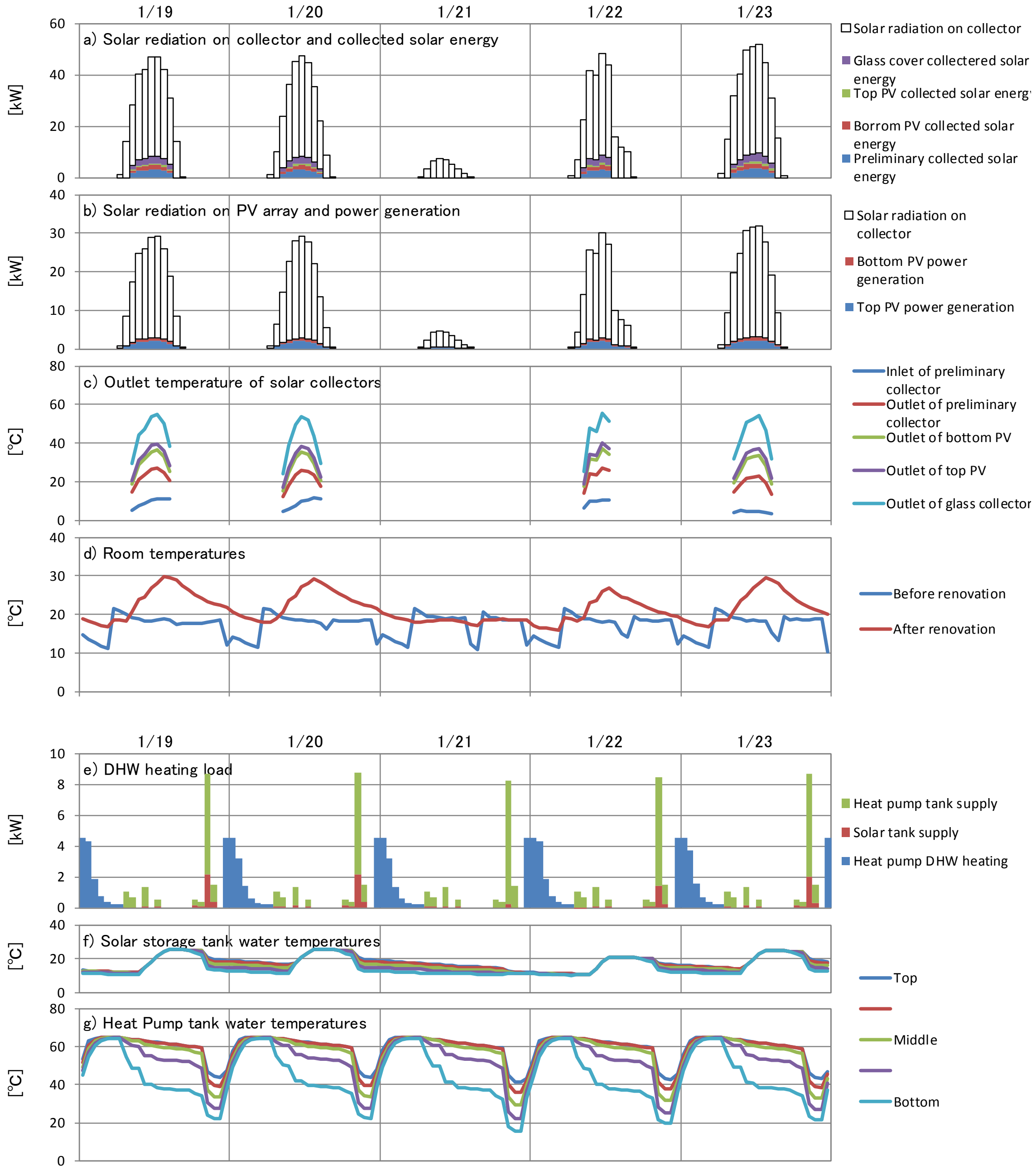


Figure 6. Simulated results in typical winter days.

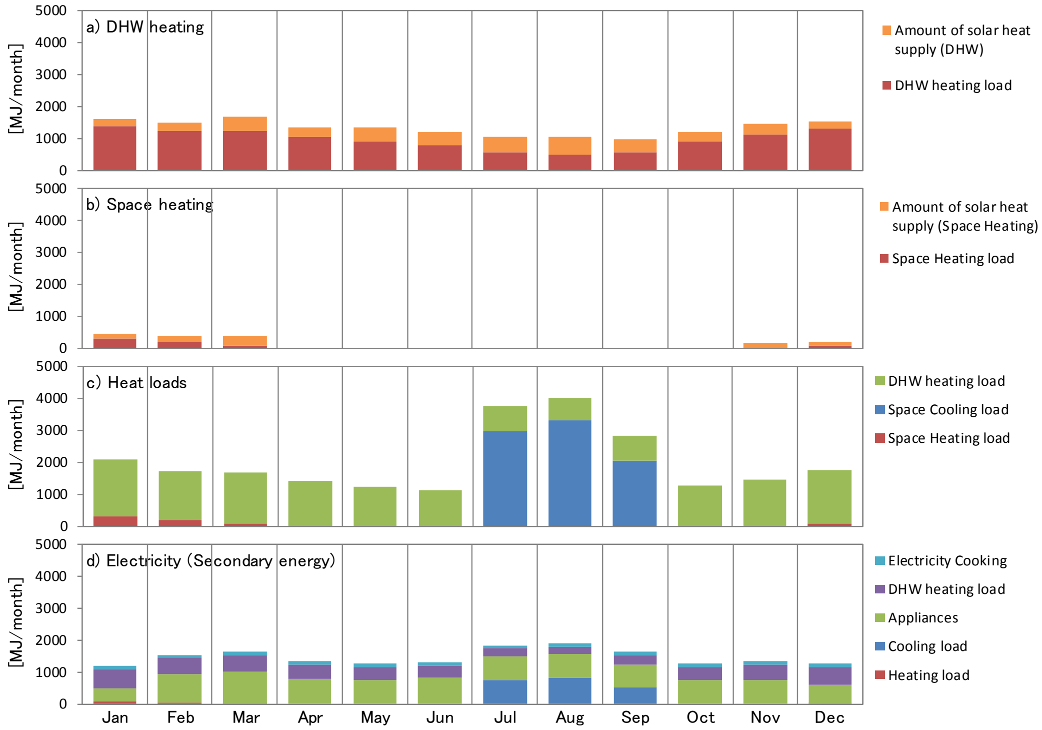


Figure 7. Simulated results of House T for a typical year.

5. Conclusion

A small single story house, House T was renovated to an energy efficient and comfortable solar house using the solar air collectors and the PV array. As a result of the detailed simulation using EESLISM, it is expected that the total energy use of the renovated house will reduce to 36% compared to the house before the renovation and the house will work as a net zero energy house. The monitoring of the house after the renovation is conducting to examine the simulation results.

Acknowledgment

This study was partially supported by the Ministry of the Environment Government of Japan.

References

[1] Y. Matoba, M. Udagawa, T. Kusunoki, K. Hirayanagi, H. Roh, Evaluation the renovated solar houses using air collectors by simulation, Part 2 T House in Takasaki, Proceedings of JSES/JWEA Joint Conference (2011), 113-116 (in Japanese).

[2] K. Hirayanagi, M. Udagawa, Y. Matoba, T. Kusunoki, M. Satoh, H. Roh, Simulation models of building integrated collectors and PV modules, Proceedings of ISES SWC 2011, Kassel, 2011

[3] Y. Matoba, M. Udagawa, T. Kusunoki, K. Hirayanagi, H. Roh, Simulation study on the heat storage systems combined with air collectors, Proceedings of ISES SWC 2011, Kassel, 2011

[4] M. Udagawa, M. Satoh, Energy simulation of residential houses using EESLISM. Proceedings of Sixth International IBPSA Conference, Kyoto, Japan (1999), 91-98.