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Design of solar water heating system for detached house in cold climate area

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Abstract

Awareness of an environmental problem and high energy cost, people is interested in renewable energy. Solar energy is one of the renewable energy which it is the simplest and is easy to use. In this report, design method for solar water heating system in severe cold region at middle latitude is discussed. 1st: the measurement result of the solar water heating system combined with heat-pump system was introduced. 2nd: the results of the numerical analysis for the above system are introduced. 3rd: the solar water heating system for detached house in a cold climate area based on the above result was proposed. Also, the numerical analysis for the system is conducted. The result indicates multiple tank system is more efficient than single tank with thermal stratification

Selection and peer review by the scientific conference committee of SHC 2013 under responsibility of PSE AG

Keywords: Solar water heating system; detached house; cold climate

1. Introduction

Recently, solar water heating system for a detached house has been paid attention. In general, solar water heating system operates more advantageously in hot or warm regions. Although, there are huge heat loads for hot water supply and heating in cold climate regions. There is the possibility that solar water heating system helps to decrease effectively those energy consumptions. When we use solar water heating system in cold climate area, we have to think about the defect of it. In winter season, 1st: the daytime period is short. 2nd: the heat loss from the panel is bigger. Therefore solar water heating system cannot produce enough energy to use without any other system. It means that solar water heating system in cold climate region needs auxiliary heat sources and thermal storage tank. The system is very complex. To design reasonably contents of system and operation method is important for total performance.

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In this paper, the measurement results and the numerical simulation of the solar water heating system in the middle latitude city with severe cold climate are introduced. Those results indicate that the performance of installed system is better in summer season than that in winter season. Also, the angle and the area don't have the effect on the energy consumption. The most effective parameter is operation method of the system. Therefore, we suggest multiple tank system to use effectively solar water heating system in cold climate area.

Nomenclature

Q_{HT}	water supply into tank (m^3/min)
Q_H	hot water supply (m^3/min)
Q_p	water flow into panel (m^3/min)
θ_{HWS}	temperature for hot water supply (°C)
θ_w	temperature for water supply (°C)
θ_{tn}, V_{tn}	temperature for tank n (°C), Volume of tank n (m^3)
θ_{ex}, V_{ex}	temperature for heat exchanger (°C) , Volume of heat exchanger (m^3)
θ_o	outdoor temperature (°C)
θ_p, V_p	temperature for panel (°C), Volume of panel (m^3)
c_w	specific heat of water (J/kgK)
ρ_w	density of water (kg/m^3)
K_p	conductance of panel (W/m^2K)
S_p	area of panel (m^2)
K_w	conductance of tank (W/m^2K)
H	power of heater (W)

2. Measurement results

In order to understand the performance of the solar water heating system, we measured the existing system. Figure 1 shows the picture of the test house and the schematic diagram of the system. The system consists of the heat collection panel, the hot water storage tank and the heat pump system. Figure 2 shows the climate of Kushiro city where the test house is located. The outdoor temperature is very severe in winter season. But there is much solar radiation in this area during winter season.

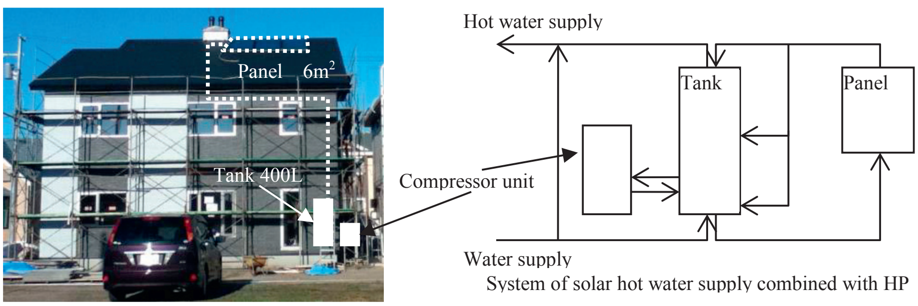

Fig. 1 the test house and schematic diagram for the measurement

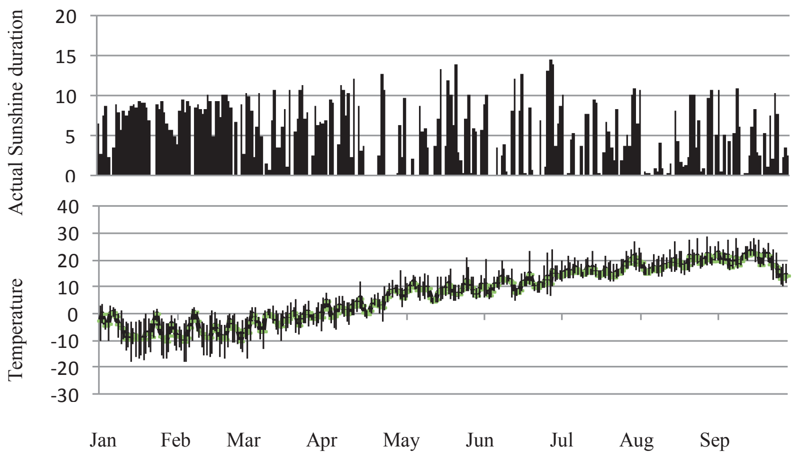

Fig. 2 Climate during the measurement

Figure 3 shows the solar heat collection and the electricity consumption on the heat pump from January to August in 2012. The hot water load for the measurement is based on the standard hot water usage in this area. Total amount of the hot water supply is about 400L/day. The ratio of solar water heating for total hot water supply is about 20% in winter, over 80% in summer season. Because the heat losses from the panel and hose in winter season are bigger than that in summer season. Also, the miss-matching was caused between the heat-pump and the solar system. Heat pump system has to work in night time, because the electricity fee is much cheaper than daytime. In the winter season, the panel cannot get enough solar collection, therefore, the heat-pump works harder in night time and the tank is full of hot water in a morning. As a result, the operating time of the panel is very short.

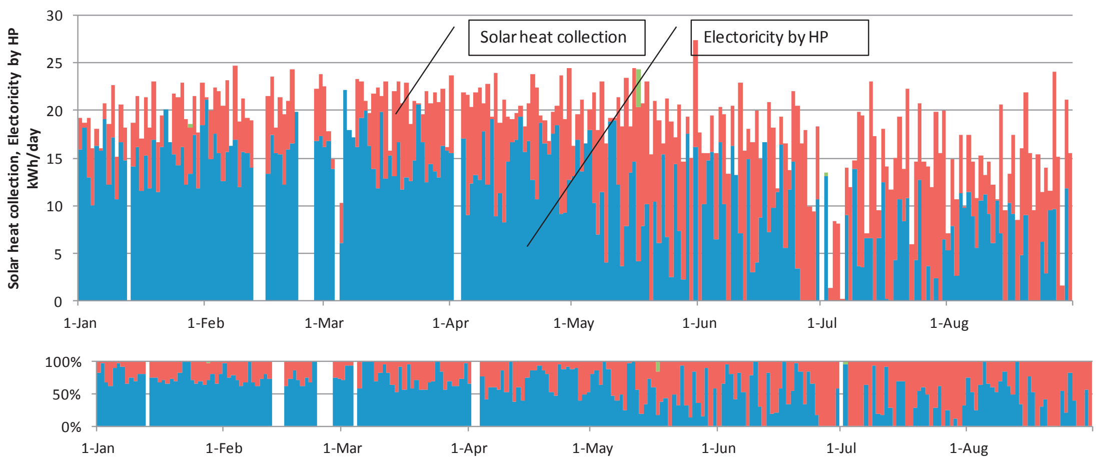

Fig. 3 Measurement result of the system

3. Numerical simulation

3.1. The system of numerical simulation

At first, the numerical analysis for the above system was conducted. The parameters of the analysis are panel angle and operating method. Figure 4 shows the schematic diagram of the numerical simulation.

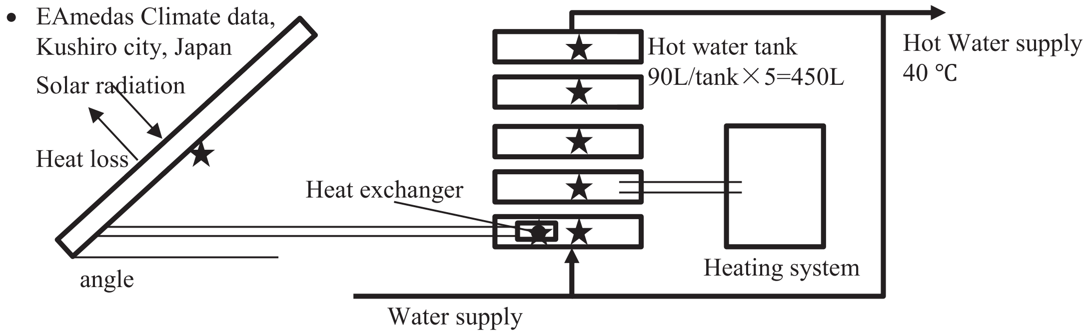

Fig. 4 Schematic diagram of numerical simulation

The procedure of the numerical simulation is as follows.

1st; the calculation of the hot water supply from the top tank. The temperature of the hot water supply (HWS) is 40 ℃, the modified M1 mode (Japanese standard hot water supply) is used as the schedule of HWS. The system supply the hot water (40 ℃) by mixing the hot water from the tank with the water. The HWS from the tank is calculated by the following equation.

$$Q_{HT} = \frac{\theta_{HWS} - \theta_w}{\theta_{t1} - \theta_w} Q_H \tag{1}$$

2nd, the calculation of the temperature of the points. The star marks in the diagram mean the points of the calculation. The following equation is used for the panel.

$$c_w \rho_w V_p \frac{d\theta_p}{dt} = K_p S_p \left(\theta_o - \theta_p\right) + c_w \rho_w Q_p \left(\theta_{ex} - \theta_p\right) + \varepsilon S_p I \tag{2}$$

The following equation is used for the tank 1 to tank 4.

$$c_w \rho_w V_{tn} \frac{d\theta_{tn}}{dt} = c_w \rho_w Q_{HT} \left(\theta_{tn+1} - \theta_{tn}\right) + K_w \left(\theta_r - \theta_{tn}\right) + D_u \left(\theta_{rn-1} - \theta_{tn}\right) + D_d \left(\theta_{rn+1} - \theta_{tn}\right) + H \tag{3}$$

The following is used for the tank 5 and the heat exchanger,

$$c_w \rho_w V_{t5} \frac{d\theta_{t5}}{dt} = K_w \left(\theta_r - \theta_{t5}\right) + K_w \left(\theta_r - \theta_{t5}\right) + D_u \left(\theta_{rn-1} - \theta_{tn}\right) + K_{ex} \left(\theta_{ex} - \theta_{t5}\right) \tag{4}$$

$$c_w \rho_w V_{ex} \frac{d\theta_{ex}}{dt} = K_{ex} \left(\theta_{t5} - \theta_{ex}\right) + c_w \rho_w Q_p \left(\theta_p - \theta_{ex}\right) \tag{5}$$

Figure 5 shows the relationship between calculation result and the measurement result. The tendency of the tank temperatures looks similar each other. Therefore the system is used for the analysis.

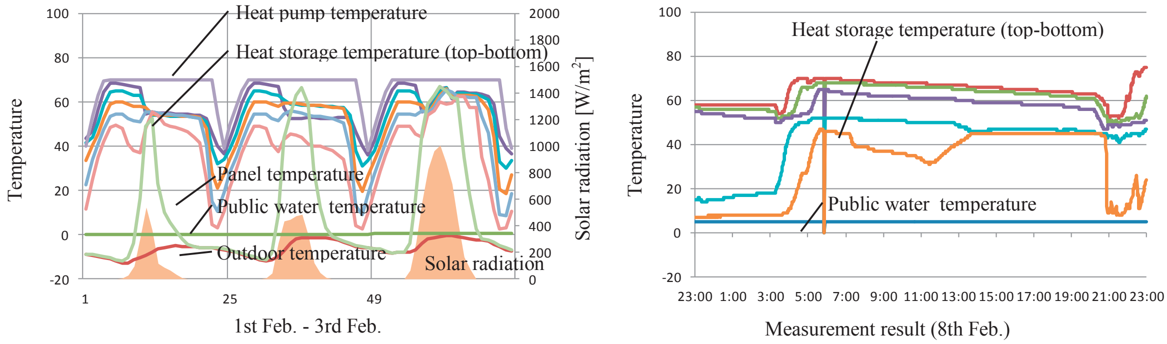

Fig. 5 Comparison of the simulation result with the measurement result

3.2. What should we design in solar hot water system in severe cold climate?

The figure 5 shows the solar collection and electricity consumption in a year. The solar collection is gradually increasing with the angle. But the electricity consumptions are about constant. The working time of heat pump in the case of 50 deg -2 is shorter than the others. The system achieves to decrease electricity consumption. The result indicates that it is necessary for decreasing energy consumption of the system to minimize the working time of the heat pump system. Although, to decrease working time, accurate prediction of weather condition is necessary, because it cause lack of hot water and re-heat by expensive electricity, if the system mistakes the weather prediction. Also, It is very difficult. Moreover, heat loss from panels and hoses is bigger in severe cold area than in other area. It is one of the reason of low efficiency of panel angle on energy consumption.

The measurement result and the calculation result indicate that efficiency of existing solar hot water supply system with heat pump is not so effective, because the system cannot get high temperature water. But low temperature water is useful in severe cold area. Temperature around our life is very low in this area. Other way for solar hot water supply should be found in severe cold season.

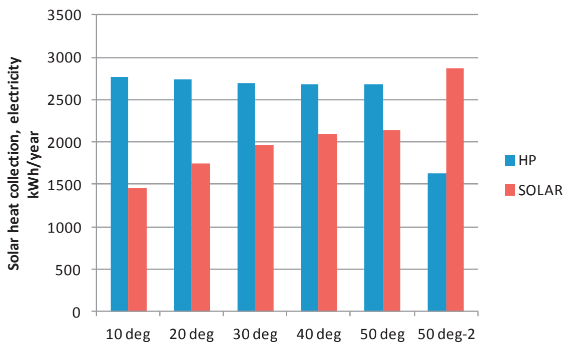

Fig. 6 The result of the numerical analysis

3.3. Two tank system

We proposed the system of figure 6. The system has two tanks. The one is for high temperature. It use for hot water supply with auxiliary heat sources. The other is for low temperature. It uses for pre-heating for ventilation and road heating. In the cold climate area, there are many places under 0°C. The tank for low temperature helps to decrease thermal loads which are generated in such places. Fig 7 shows the air temperature and thermal load calculated by Esp-r. The numerical model for the simulation has the thick insulation (200mm EPS), the large south window and pre-heating system for the ventilation by solar (trombe wall). The temperature of fresh air controls 20 ℃ before supply by the heat exchanger and heater. The heat exchanger uses hot water from the tank for low temperature during night time. The outdoor temperature in this area is usually under -15 ℃. Such low temperature cause dew and frozen trouble in ventilation system. The system can heat up fresh air with renewable energy before heating by electric energy.

The numerical simulation is conducted for the simulation by the above method.

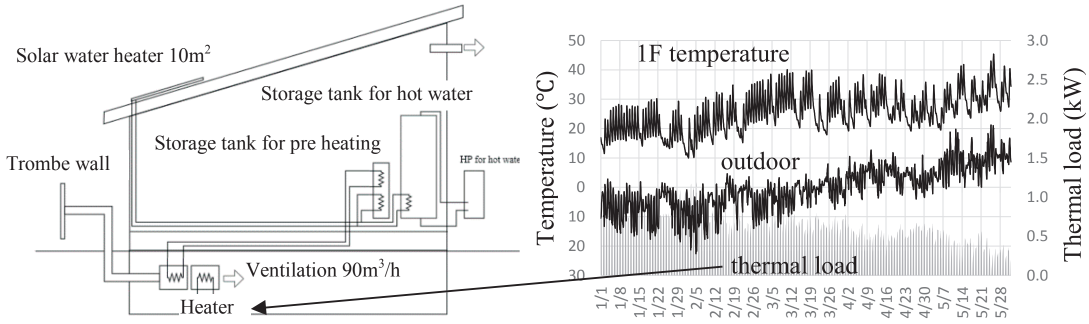

Fig. 7 The schematic of the system and the result of numerical simulation by Esp-r

Table 1 shows the parameter of numerical simulation. The case 1 means the existing system without low temperature tank. The difference between the case 2 and the case 3 is the operating method of the hot water circuit after heating in the panel. In Case 3, the circuit through hot water tank just use during the period θ_{t5} + 30℃ < θ_p. The hot water heated by the panel mainly come through the low temperature tank.

Table 1. An example of a table.

	Area of panel	Tank
Case1(existing system)	6 m^2	Hot water tank 450L
Case 2	10 m^2	Hot water tank 450L
Case 3	10 m^2	In θ_{t5} +30℃< θ_p -> hot water tank. The water after hot water tank come into low temp. tank.

3.4. Result of simulation

Figure 8 shows the result of case 1. The peak of the solar radiation incident on the panel over 700 W/m^2. The temperature of the panel are over 70 ℃ in the situation. The effect of the high temperature rise the temperature of the tank 5 (bottom of the tank) up to 45 – 50 ℃. Hot water use mainly in evening time. Especially, Japanese people use much hot water for bath. During that time, much water comes to tank. It makes the temperature of tank 5 low. After that, the temperature of the tank recover up to 50 ℃ by cheap electricity. The thermal energy obtained by the panel is around 5000 Wh during January. The energy gradually increase with season, because the panel angle, 50 deg., match solar angle. The percentage of solar energy in total energy use gradually increase with season in the same way.

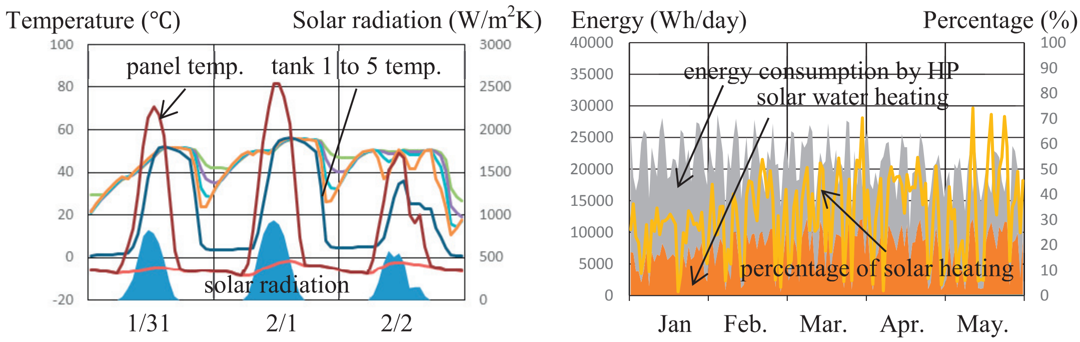

Fig. 8 the results of the case 1

Figure 9 shows the result of case 2. The panel area is 1.6 times bigger than case 1. The panel temperature is about 10 °C higher than case 1. But the thermal energy obtained from the panel is not so higher than case 1. Because the tank has to warm up until morning by cheap electricity. Then the volume which solar radiation can heat up is small before user use hot water.

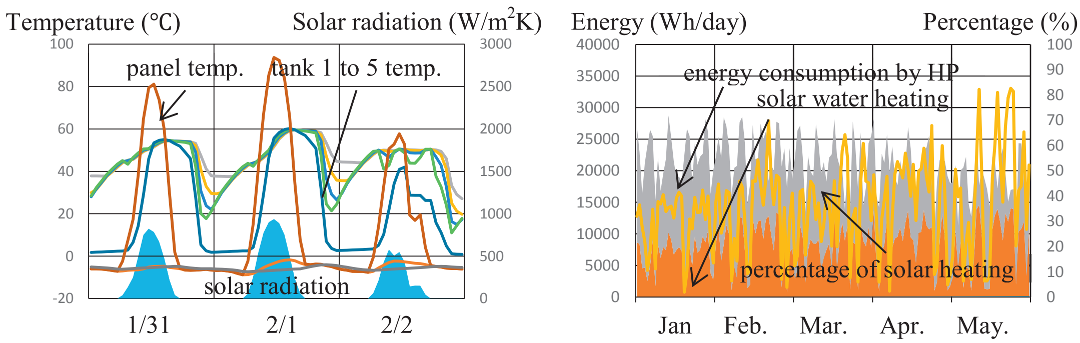

Fig. 9 the results of the case 2

Figure 10 shows the result of case 3. In case 3, the water heated by the panel go through the first tank (for high temperature) when the temperature difference with the bottom of it is over 30 °C. Also, the water after the heat exchanger go through the second tank before come back to the panel. The second tank temperature rise up to 60 °C in day time. It is higher than first tank because the cold water always supply into the first tank. After 17 o'clock, the second tank temperature gradually down toward the outdoor temperature. It indicates that the water uses for the pre-heating for the ventilation. The peak of the percentage in Jan. is around 50 %. It improve 20 % comparing with case 1.

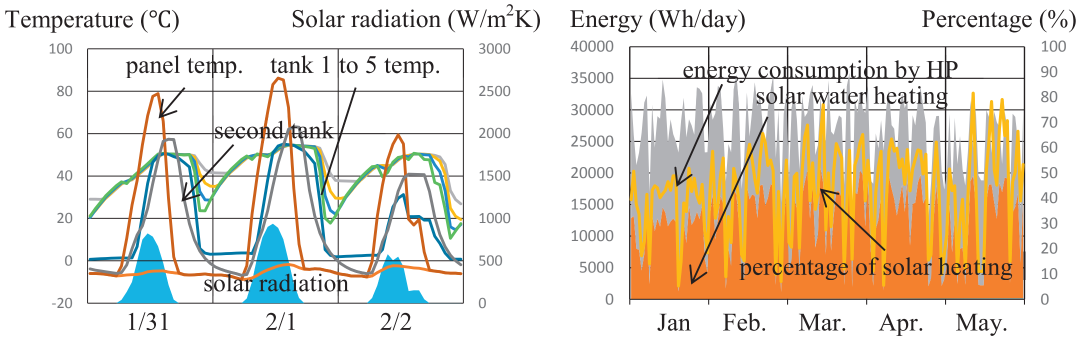

Fig. 10 the results of the case 3

4. Concluding remarks

- In severe cold area, existing solar hot water heating is not so effective. Because heat loss from the panel is bigger than other area. Vacuum tube improve that situation. But cost of those system is much higher than existing system.
- The measurement results indicates that the percentage of solar energy in total hot water supply is about 20 % during severe cold period. Also, it can get enough thermal energy in summer time. If the system improve efficiency during winter season, the total efficiency is much higher than existing system. It makes a payback time short.
- The method of numerical simulation can makes good enough result to analyze the effect of solar panels, control of system on the total efficiency.
- Panel angle effect on energy of solar hot water heating. But it doesn’t effect on an energy consumption of Heat pump system. To decrease energy consumption, it needs decrease working time of HP system by predicting weather condition before time of expensive electricity.
- Enlarging panel area effect on total quantity of heat. But the effect is not so large. Because the storage tank is heated up before sunrise to use cheap electricity.
- Low temperature tank for pre-heating of ventilation is useful for increasing efficiency of solar hot water system.

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