UDC 697.329

SOLOR SYSTEM FOR HEATING, COOLING AND HOT WATER SUPPLY

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I. INTRODUCTION

Fuji Electric has been developing various solar systems ever since it completed the solar heating, cooling and hot water supply system for the clubhouse of the Kawasaki Factory Club in 1978. A heating, cooling, and hot water solar system for business has now been developed and practical operating data accumulated and the system has been adopted at the clubhouse of the Tokyo Factory No. 1 Club of the Fuji Electric Tokyo Factory.

The Tokyo Factory No. 1 Club clubhouse was built in July 1980 and the solar system has been operating continuously since September of the same year. This solar system is outlined.

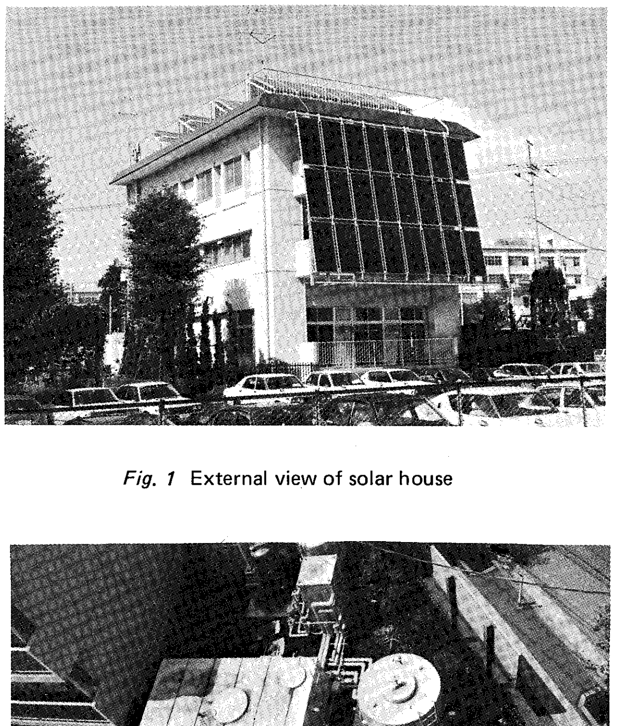

Fig. 1 External view of solar house

II. OUTLINE OF SOLAR HOUSE

Fig. 1 is an external view of the solar house. The Tokyo Factory No. 1 Club clubhouse is a three story ferroconcrete building. The first floor consists of a dining room, kitchen, bath and machinery room, the second floor consists of conference rooms (two western style rooms) and the manager's room, and the third floor is guest rooms (three Japanese style rooms). The building has a floor space of 414 m^2.

The heating and cooling area is 67.9 m^2 at the first floor, 87.5 m^2 at the second floor, and 64.8 m^2 at the third floor for a total of 220.2 m^2, or about 53% of the total floor space. All heating and cooling is performed by the solar system. Hot water from the solar system is supplied to the bath on the first floor and the lavatory on the third floor. The first floor bathroom has a 2 m^3 bath tub. The hot water from the solar system is not supplied to the first floor kitchen or to the second floor.

The solar collector employs a flat plate type collector and an evacuated glass-tube collector. Thirty-eight flat plate type collectors (effective heat collection area 72.2 m^2) and 12 evacuated glass-tube collector modules (effective heat collection area 30.6 m^2) are used. Twenty-four of the flat plate collectors can be seen in *Fig. 1*. The collectors are installed to the sourth wall from the top of the first floor to

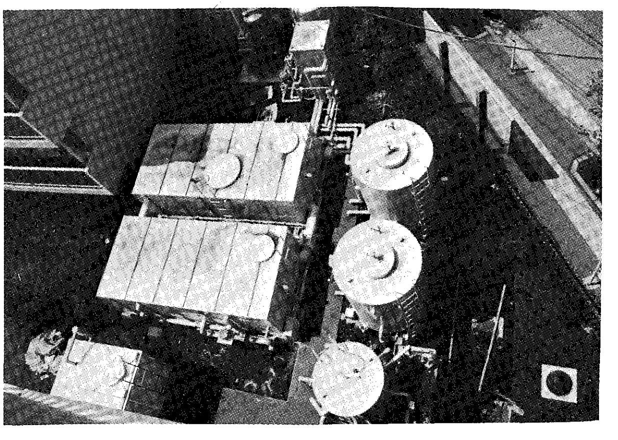

Fig. 2 Storage tanks

the roof at a tilt angle of 80 °. The remaining collectors are installed on the roof facing south and at a tilt angle of 30 °. The entire roof is occupied by the collectors and their maintenance space.

The gas boiler for auxiliary heating and the control equipment are installed in the machinery room and heat storage tanks and pumps are installed on the ground at the north side of the building. In the figure, the high temperature heat storage tank, hot water supply storage tank, and hot water storage tank are shown from the bottom right and the receiving water tank, heat storage tanks for air conditioning (two tanks), and the absorption chiller are visible from the bottom left.

III. SOLAR SYSTEM

Fig. 3 is a schematic diagram of the solar system and *Table 1* lists the specifications of the main components.

1. Heat collection system

The heat collection system consists of flat plate type collectors, evacuated glass-tube collectors and high temperature heat storage tank.

Twenty-four black chrome selective surface copper collectors arranged in eight parallel rows of three collectors each tilted at 80 degrees (effective heat collection area 45.6 m^2) and 14 black chrome selective surface copper heat collectors arranged in 14 parallel rows tilted at 30 degrees (effective heat collection area 26.6 m^2) are used as the flat type heat collectors. *Fig. 4* shows the flat plate type collectors tilted at 30 degrees on the roof.

Twelve parallelrows of chrome selective surface collectors tilted at 30 degrees (total heat collection area 30.6 m^2) are used as the evacuated glass-tube collectors. *Fig. 5* shows the evacuated glass-tube collectors.

Viewed from the east and west, the 30 degree tilted heat collectors on the roof are installed on saw frames in two rows of each type, for a total of four rows. Therefore, the heat collectors from the second row are affected by the shadow cast by the front row of collectors. To cover this shadown to some extent, stainless steel reflectors are installed behind each row of collectors as shown in *Fig. 6* to

Table 1 Specifications of the main components

Collectors Flat plate type collector Type: Flat plate type, tube on sheet Collector: Copper, black chrome selective coating Collection tube: Copper Cover glass: Semi-reinforced soda-lime glass 3 mm thick Effective heat collection area: 1.90 m^2/plate (total 38 plates 72.2 m^2) Evacuated glass-tube collector Type: Evacuated glass-tube, double glass-tube system Heat collection surface: Heat-resistant glass, with selective coating Collection tube: Same as above. Glass cover: Heat-resistant glass Effective heat collection area: 2.55 m^2/module (total 12 modules 30.6 m^2)
Heat storage tank Type, capacity: Open type, 1.5 m^3 Material: SUS304 Heat storage tank for air conditioning Type, capacity: Open type, 9 m^3 (X2 = 18 m^3) Mateiral: Plastic Hot water supply heat storage tank Type: Enclosed type, 3 m^3 Material: SUS304 Hot water storage tank Same as hot water supply heat storage tank.
Heat exchanger Heat exchanger for air conditioning (in heat storage tank for air conditioning) Material, capacity: Copper, 60,000 kcal/h Heat exchanger for hot water supply (in high temperature heat storage tank) Material, capacity: Copper, 35,000 kcal/h
Absorption chiller Output: 30,000 kcal/h COP: 0.7
Auxiliary heat source Auxiliary heat source for air conditioning Type, output: Hot water storage system gas boiler, 75,000 kcal/h Auxiliary heat source for hot water supply Type, output: Gas instantaneous hot water heater, 22,500 kcal/h

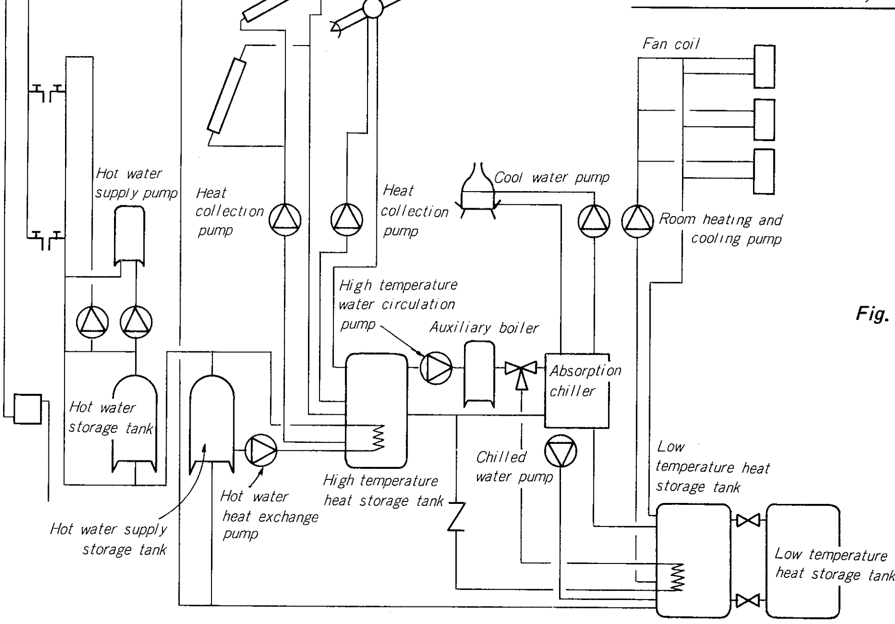

Fig. 3 Schematic diagram of solar system

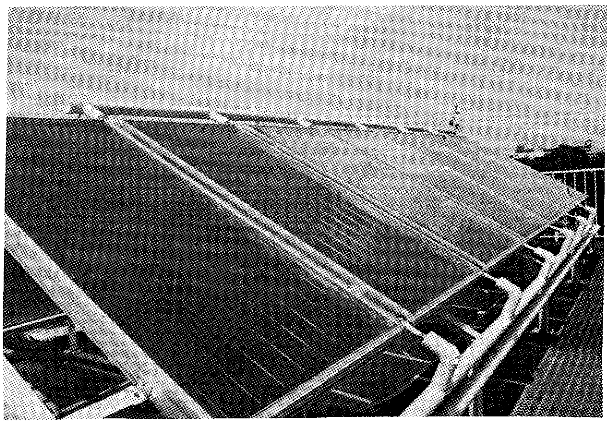

Fig. 4 Flat plate type collectors tilted at 30 degrees

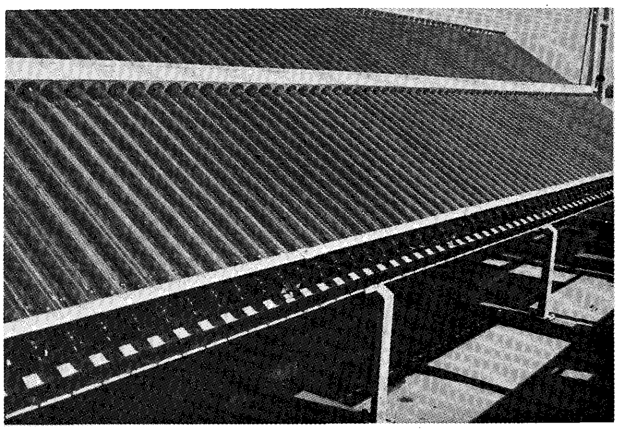

Fig. 5 Evacuated glass-tube collectors tilted at 30 degrees

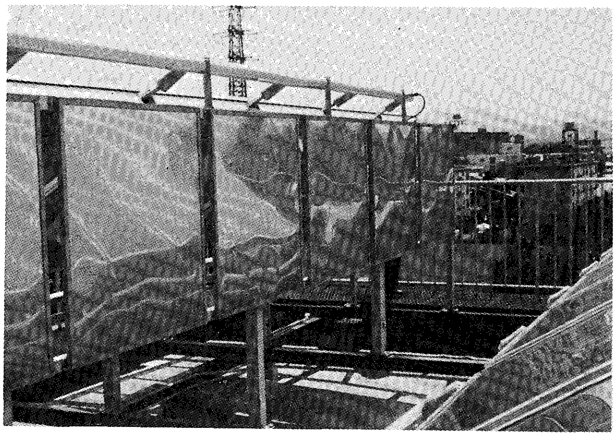

Fig. 6 Diffuse reflectors installed collector array

obtain sky radiation from the rear of the collectors. The piping system is a separate circulation system for each type of collector. The piping of the flat plate type collectos runs from the bottom of the high temperature heat storage tank to the heat collector and returns to the center of the tank.

The piping of the evacuated glass-tube collectors runs from the center of the tank and returns to the top of the tank – that is, the top portion of the high temperature heat storage tank is heated by the evacuated glass-tube collectors and the bottom portion of the tank is heated by the flat plate type collectors.

The flat plate type collector is controlled by differential control which compares the temperature of the collector and the temperature of the heat storage tank and operates the heat collection circulation pump only when the temperature inside the heat collector is higher than the temperature of the heat storage tank. Freeze protection is provided by a drain back system that returns the water inside the collector to the heat storage tank. When the heat collection circulation pump is operating, its dynamic pressure sucks water into the heat collector. When the pump stops, the water is returned to the tank by its own weight. The evacuated glass-tube heat collector circulation system uses the differential control described above and freeze protection hot water circulation control. This control operates the circulation pump and replaces the cold water inside the collectors with the warm water inside the heat storage tank whenever the water temperature inside the collectors drops to a temperature at which there is a danger of freezing.

Because the flat plate type collectors employ the drain back system previously described, the high temperature heat storage tank is an open type having an internal volume of approximately 1.5 m^3 and a capacity of 1.0 m^3. The piping to the air conditioning system is installed at the top of the tank and the heat exchanger to the hot water supply system is inside the bottom of the tank. That is, the heat from the part of the tank heated by the flat plate type collectors is supplied to the hot water system and the heat from the evacuated glass-tube collectors is supplied to the air conditioning system. When there is no air conditioning load, all the heat is used by the hot water supply. This high temperature heat storage tank is also used as a buffer so the heat from the collectors is quickly sent to the air conditioning and hot water supply heat storage tanks.

2. Air conditioning system

The air conditioning system is centered about the high temperature heat storage tank and consists of a heat storage tank for air conditioning, absorption chiller and auxiliary heat source for air conditioning.

As previously described, heat is supplied to the air conditioning system from the high temperature heat storage tank from the piping at the top of the tank. An auxiliary heat source gas boiler is installed in this circulation system.

During the cooling season, this circulation system enters at the absorption chiller and during the heating season, it enters at the heat exchanger in the heat storage tank for air conditioning. Switching is performed by manual valve.

A gas boiler is used as the auxiliary heat source for air conditioning. The cooling season output temperature is set at 83 °C and the output temperature in the other seasons is set at 55 °C. Switching is performed by manual switch.

The heat storage tank for air conditioning consists of

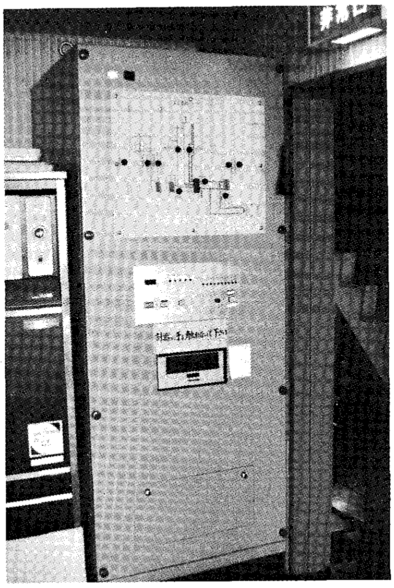

Fig. 7 Data logger

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10°	2460	2540	3350	3060	3320	3100	3100	3220	2380	2160	2080	1970	2730
20°	2780	2770	3520	3090	3260	3030	3050	3220	2450	2310	2310	2240	2840
30°	3030	2940	3610	3040	3140	2900	2940	3160	2470	2400	2490	2450	2880
40°	3210	3040	3610	2940	2950	2720	2770	3030	2440	2450	2610	2600	2860
50°	3300	3070	3540	2770	2710	2480	2540	2840	2360	2430	2670	2690	2780
60°	3320	3020	3380	2540	2420	2200	2270	2590	2230	2370	2670	2720	2640
70°	3260	2910	3140	2260	2090	1890	1960	2290	2050	2250	2600	2680	2450
80°	3110	2740	2840	1940	1740	1550	1630	1960	1830	2080	2470	2570	2200
90°	2890	2500	2470	1600	1370	1210	1280	1600	1580	1870	2280	2400	1920

Fig. 8 Calculated example of radion on tilted surface in Tokyo

two open type 9 m^3 plastic water tanks. Only one side (9 m^3) of the internal heat exchanger is used during the heating season. Both tanks (18 m^3) are used during the cooling season. Switching is performed by switching a manual valve in the piping that connects the two tanks.

The absorption chiller is set to operate at a solar system heat source temperature of about 80 °C. Its maximum output is 30,000 kcal/h. The output cold water temperature is 9 °C. This cold water is stored in the heat storage tank for air conditioning. Air conditioning is performed by fan coil. During the air conditioning season, cold (hot) water is circulated to the fan coil from the heat storage tank for air conditioning and the fan inside the fan coil is operated by a thermostat in the rooms.

3. Hot water supply system

The hot water supply system consists of a high temperature heat storage tank, heat storage tank for hot water supply, hot water storage tank, and auxiliary heat source for hot water supply. The hot water is constantly circulated from the hot water storage tank to the hot water supply piping so hot water is immediately supplied when a faucet is opened. This circulation system is controlled so the circulation pump is only operated when the temperature of the high temperature heat storage tank is higher than the temperature of the heat storage tank for hot water supply. Both the heat storage tank for hot water supply and the hot water storage tank have a 3 m^3 capacity. At hot water supply, the water flow is city water supply → heat storage tank for hot water supply → hot water storage tank → hot water supply. The 3 m^3 capacity of each tank corresponds to the estimate daily load of 3 m^3. The hot water in the hot water storage tank is consumed in one day and this portion is transferred from the heat storage tank for hot water supply to the hot water storage tank, new city water is supplied to the heat storage tank for hot water supply, and this water is heated by the heat exchanger inside the high temperature heat storage tank. Therefore, the heat from the high temperature heat storage tank is considered to be for the next day's use.

The water temperature is the hot water storage tank is controlled at the set temperature (60 °C) or higher. When the hot water of the circulation system to the faucets is above the setting, the water is not passed through the gas boiler and when it is below the setting, the water is passed through the gas boiler and circulated. The gas boiler is a gas instantaneous hot water heater having a heat output of 22,500 kcal/h.

4. Measuring system

To indicates the operating status of the solar system, the temperature, calorific value, and flux of solar radiation are measured. The water temperature inside the piping, the water temperature inside the tanks, the room temperature, and the outside air temperature are measured at 60 points by platinum temperature measuring resistors, the output heat (for example, heat collection calorific value, hot water supply calorific value) of each system is measured at 12 points by calorimeters, and the flux of solar radiation is measured at three tilted surfaces of 0 °, 30 ° and 80 ° with a pyranometer.

The data are collected on floppy disk by the data logger shown in *Fig. 7*. The collected data is later read and processed by a data analysis system. The data logger and analysis system both use a microcomputer.

IV. LOAD AND HEAT COLLECTION PREDICTION

Table 2 shows the designed load and predicted collecting solar energy of the solar system. The collecting solar energy was predicted by the method given in the Collecting Solar Energy Calculation of Solar System by Computer section of this special issue (pages 29 – 34). Collecting solar energy calculation was performed by using HASP-ACLD standard metereological data for constant temperature heat collection condition of summer 80 °, winter 60 °C, intermediate season 50 °C. *Fig. 8* shows an example of the value of the tilted surface flux of solar radiation that was the foundation of the calculations.

Table 2 Designed load and predicted collecting solar energy

Item / Season	Air conditioning load (x 10^6 kcal)	Hot water supply load (x 10^6 kcal)	Total load (x 10^6 kcal)	Collecting solar energy (x 10^6 kcal)
Winter November ~ March	12.2	14.1	26.3	17.0
Intermediate April, May, September, October	0	9.9	9.9	13.1
Summer June ~ August	10.4	6.6	17.0	8.7

V. CONCLUSION

The solar system for heating, cooling, and hot water supply of the Fuji Electric Tokyo Factory No. 1 clubhouse was described. This solar system uses two kinds of solar collectors, flat plate type and evacuated glass-tube type, having different collecting characteristics. The flat plate type collectors are installed at different tilt angles of 30° and 80° This point poses problems different from a standard system.

First is balancing of collectors having different collecting characteristics. Second is balancing of collectors installed at different tilt angles at which the ratio of the surface flux of solar radiation changes with time according to the sun's altitude. The first problem was solved by forming two layers having different temperature levels inside the tank according to the position of the piping to the high temperature heat storage tank and installing the flat plate type collectors and evacuated glass-tube collectors in series. The second problem was solved by adjusting the circulation flow to the collectors of both tilted surfaces to the practical range. The data collection so far was analyzed and the effects of these actions, together with the performance of the overall system, were clarified.