UDC 697.329

SOLAR SYSTEM FOR HOT WATER SUPPLY DELIVERED TO FUJITSU FANUC LTD, FUJI FACTORY

Nariyasu Matsuzaki
Hiroyuki Yokomaku
Akiyoshi Saito

I. INTRODUCTION

Fujitsu Fanuc has constructed the latest unattended machining factory employing an automatic system for machining as a special factory for industrial robots, wire-out EDMs, and other electronic machine systems in scenic the foot of Mt. Fuji. Fuji Electric has delivered a large scale solar system for hot water supply for the boarding house and company housing constructed on the grounds of this factory as one of its modern facilities. This system is not only the largest nonfederal commercial solar system in Japan, but was installed to incorporate freezing protection, collector arrays and building structural coupling, system automation, and other technological features. Its main construction points are:

(1) Construction site (See *Fig. 1*.)
Fujitsu Fanuc Ltd Fuji Factory
Yamanakako Mura, Oshino Mura, Minamitsuru-gun, Yamanashi Prefecture

(2) Factory scale: Building area 20,268m^2, floor space 22,693m^2 Flat roof construction, height 10m, outside walls ALC, rood, thin plate 0.8mm thick

(3) Collector arrays installation: Factory roof, Approx 2500m^2

(4) Storage system, supply system, control system installation: Factory machinery room (18 x 6.25m)

(5) Operational data: December 29, 1989

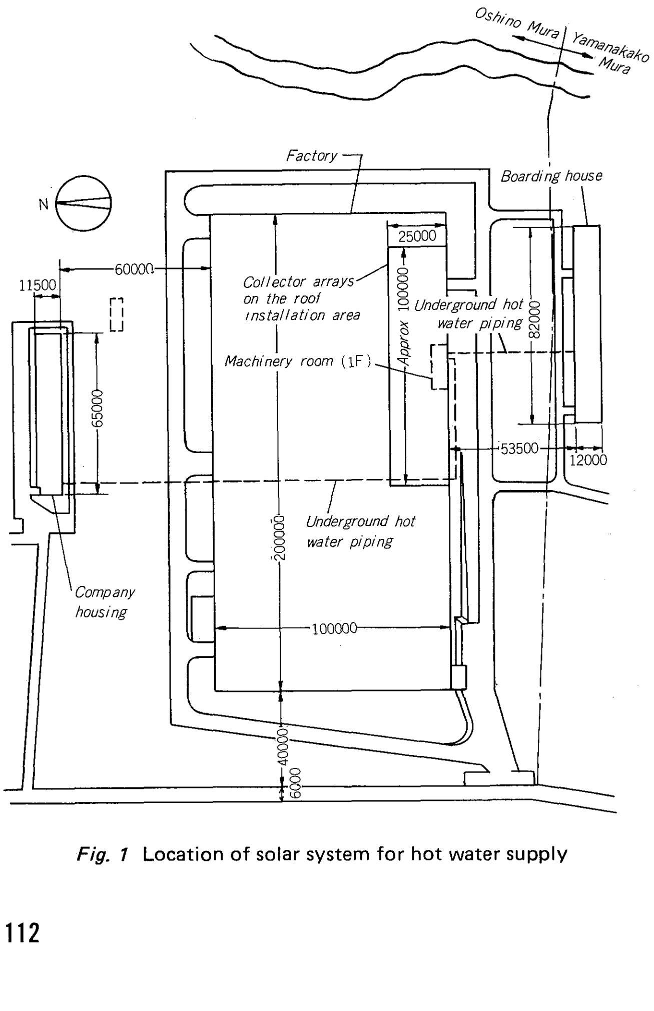


Fig. 1 Location of solar system for hot water supply

II. SYSTEM OUTLINE

This system consists of collection, storage, supply and control systems. *Fig. 2* shows its system diagram. Basically, to realize a large scale hot water supply system, reliability is of utmost importance and the solar heat was stored and transferred as a liquid system so a large energy saving effect can be expected.

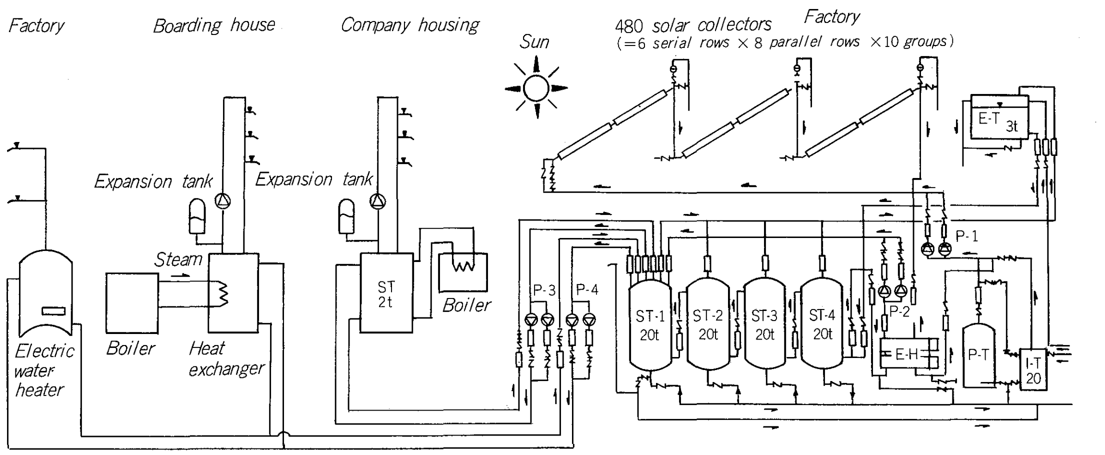
1. Calory calculation

The bath kitchen, lavaratory and other hot water supply loads at the factory, boarding house, and company housing was made the objective. Converted to well-water supply, hot water temperature in winter 50°C, summer and intermediate season 45°C, supply amount approximately 32m^3/d, the heat load is 385.5 x 10^6 kcal/year. Since the average varia tion of the heat load each month of the year is comparatively small, 480 flat plate type collectors (collector area 1.9m^2) having a direction of collection of 180° (south) and tilt angle of α=30° was used at the solar system so an annual collection amount of 288.3 x 10^6 kcal can be expected.

Therefore, the solar percent is,

σ= Annual collection amount/heat load=288.3 x 10^6/385.5 x 10^6=74.8%

If energy saving is planned on this annual collection amount, and the annual energy saving is assumed to equivalent to



ST-1~4 : *Storage tank*
E-H : *Heat exchanger*
P-T : *Closed type expansion tank*
I-T : *Anti-freezing solution delivery equipment*
E-T : *Open type expansion tank*
P-1 : *Circulating pump for collector*
P-2 : *Heat exchanger pump*
P-3 : *Hot water supply pump (for boarding house)*
P-4 : *Hot water supply pump (for factory and company housing)*

Fig. 2 System diagram of solar system for hot water supply

49,980ℓ of light oil (calorific value 8,240 kcal/*l*) at ¥75/*l*, the fuel saving will be 75 x 49,980=¥3,748,500.

2. Applicable standards, ratings, etc.

Generally, the history of solar systems is still short and about the only existing standard is the JIS for the old solar water storage heater and natural circulation type solar water heater and standardization of systems, devices, etc. can be said to be in the creation stage. Besides JIS and JEC, the equipment of this facility were designed and manufactured on

(1) Steel construction design standard (Association of Architects)
(2) Welding standard (Japanese Welding Association)
(3) Air conditioning and sanitary facilities work standards
(4) Architecture Facilities earthquakeproof design policy (Facilities Earthquakeproof design comittee)

and other standards. Because the water supply is well water, its water quality was tested and the absence of problems with the material to be used was confirmed in advance.

III. SOLAR COLLECTOR SYSTEM

1. Flat-type solar collector

The solar collector, the nucleus of the solar system, must have a high collector efficiency, must be durable (against wind, snow fall, earthquakes and other external force and against heat cycle), and must have superior anticorrosion characteristics and the flat type solar collector widely used in the proven solar systems of the Fuji Electric Kawasaki Factory and Tokyo Factory club houses was used. *Table 1* gives the specifications of this solar collector.

Table 1 Specifications of flat plate collector

Item		Specification	Remarks
Type		FS-211	
Outside dimensions		2,024x1,024x101,5 (mm)	
Effective collection area		1.9m²	
Weight (operating/system)		40/38kg	Water flow 2ℓ
Absorber	Fin material	Copper	
	Wet parts material	Copper	
	Absorptance	0.9 or more	Black chrome selective coating
	Emittance	0.12 or less	
Glazing	Material	Semi-reinforced glass	Thickness 3mm
	Number of plates	1 plate	
	Transmittance	0.85 or more	
Insulator	Material	Glasswool (with aluminum foil)	
	Overall heat transfer coefficient	0.7 kcal/m²-h-°C or less	
Casing material		Corrosion-resistant aluminum	
Wet parts construction	Normal pressure	2.5kg/cm³ or more	
	Pressure losss	20mmAq or less	At 2ℓ/min
	Pipe construction	Water draining and air bleeding possible	
Piping connections		15.88mm (copper pipe)	With bulge machining
Load test		500kg/m² or more	
Drop test		Steel ball 225g-40mm dia.-4m height	
Vibration test		Horizontal, vertical 0.3G	

2. Collector arrays

The solar heat is collected by the 480 flat type collectors having a 180° (south) direction of collection and α=30° tilt angle previously described and an annual 74.8% energy saving for the heat load was made possible. However to obtain a comparatively high 75~85° collector outlet

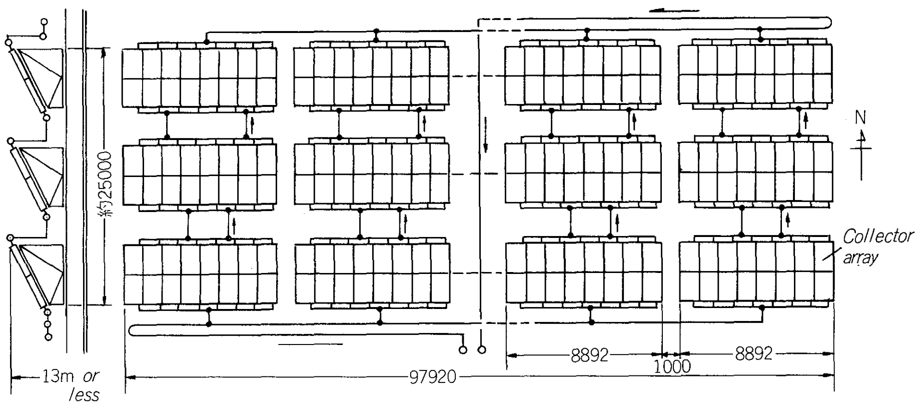


Fig. 3 Collector arrays and piping arrangements on the roof

temperature and increase the collector→storage efficiency, the temperature rise per circulation of the fluid during collection should be high. Therefore, a collector array group configuration of 6 serial rows X 8 parallel rows X10 groups=480 collectors was employed.

Increasing the number of serial rows for this collector group configuration generally has many merits and is advantageous from the standpoints of simplification of the collector arrays piping, low collection pump loss, facilities cost, maintenance and aesthetics.

Fig. 3 shows the collector arrays arrays arrangement. The connecting position of the piping between the groups was changed so the inlet→outlet flow of fluid is deviation flow. Moreover, since this facility is installed in a scenic zone, the connections are special 6 series rows [(2 +2 + 2) serial rows] connection to accommodate the system within the GL + 13m or less building height limit.

3. Freeze protection method

According to the meteorological data for the installation site, since a temperature of-20°C has been recorded in the winter, especially at night, solar collectors freeze protection is an important theme. Generally, the freeze protection methods for solar systems are (1) drain down system, (2) warm water recirculation system, and (3) antifreezing solution system. However, corrosion protection must be condidered for any system.

This facility uses the anti-freezing solution system, the most reliable system. The collector arrays are filled with a 75% propyleneglycol antifreeze solution and the arrays are isolated from the stroage system by heat exchanges. However, a specialcorrosion inhibitor is mixed in the antifreezing solution and the collector arrays a piped with steel pipe for economy.

The state of the antifreeze being used and the corrosiveness of various test pieces (inserted into the heat collection circuit) are checked semi-annually. Of course, these materials were tested beforehand.

4. Collector array mounting and support on the roof

Since the collector arrays of most large scale solar systems are installed on the roof of a building, their load on the roof, the roof supports and piping, the method of going through the outside wall, and astheticity are important problems and harmonizing the structure design and collector arrays functions is vital. Therefore, the previously described cellector arrays serial/parallel configuration can also be said to be an important theme on the roof load.

In this facility, the total weight of the collector arrays, piping, fluid, base, and other parts is approximately 100t. However, the following external conditions were added to

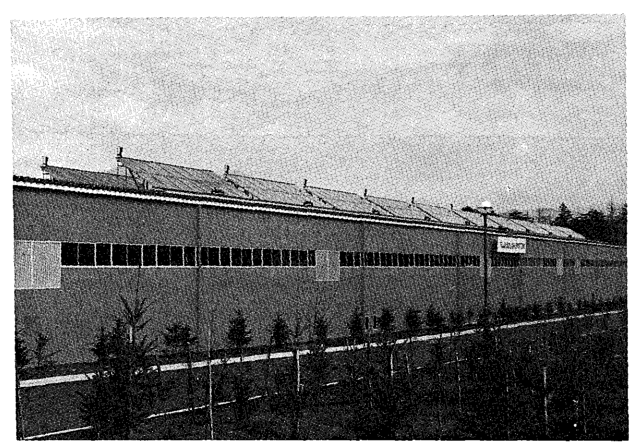


Fig. 4 Out-view of collector arrays

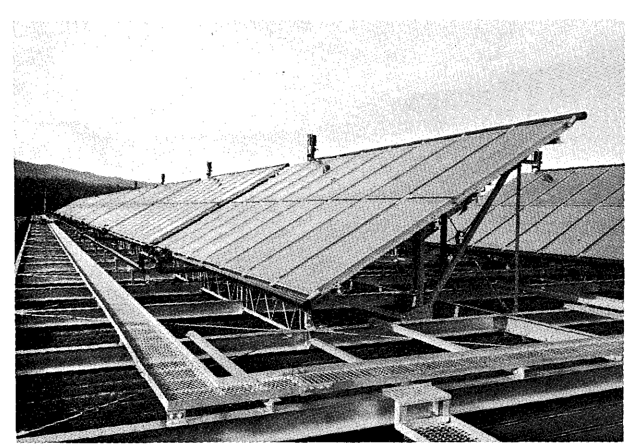


Fig. 5 Collector arrays mounting and support

structural design:

(1) Must withstand a wind velocity of 60m/s (speed pressure q=210kg/m^2).
(2) Must withstand a snowfall of 70cm and a load of 140kg/m^2.
(3) Must withstand a grade 5 earthquake.
(4)

Moreover, since the factory roof has a thin plate (0.8mm thickness) construction, the collector arrays were installed onto the roof by a special frame and support structure so the load is applied to the main truss of the building and not the thin plate. In this case, the frame was made sufficiently durable by using zincromatic coating treated material and the tightening torque of the main bolts installing the collector arrays on the roof was checked and the pipes were led into the factory not from the top of the roof but were amply rainproofed and led in from the side of the building. *Fig. 4* is an out-view of the collector arrays and *Fig. 5* shows the collector arrays mounting and support.

IV. STORAGE SYSTEM

1. Storage system capacity setting

Solar heat is caught by solar collectors through the duration of sunshine according to the solar radiation, collection temperature, outside air temperature, and heat collection efficiency. However, since heat collection and load pattern time deviations cannot be avoided, the collected heat energy is temporarily stored in heat storage tanks and supplied to the load as necessary. The storage system was set as shown in *Table 2* so that is has enough capacity to store a certain surplus of heat when the heat is not saturated from the storage tank even when the solar radiation shows a peak throughout the year or even when it rains containuously.

Table 2. Condition of heat transfer for storage system

		Summer	Winter	Remarks
Collector arrays	Collected heat energy	400,550	365,500	
	All-day collected heat energy	2,785,070	1,593,740	
	Heat exchanger primary side inlet temperature t_2 (°C)	44	34	
	Heat exchanger primary side inlet temperature t_1 (°C)	85	75	
	Heat exchange outlet/inlet temperature difference Δt (deg)	41	41	$=t_1-t_2$
	Heat collection pump flow rate q_1 (l/min)	179	159	
Storage system	Heat exchanged energy q_2 (kcal/h)	400,550	356,500	$=Q_1$
	Heat exchanger secondary side inlet temperature t_3 (°C)	16	11	Well-water temperature base
	Heat exchanger secondary side outlet temperature t_4 (°C)	65	55	
	Heat exchange pump flow rate q_2 (l/min)	136	135	
	Heat storage tank capacity V(l)	80,000	80,000	
	Heat storage energy Q_3 (kcal/d)	3,136,000	2,816,000	$>Q_1, Q_0$
Average load heat energy Q_0 (kcal/d)		1,044,600	1,120,000	

2. Heat exchanger

The Fluid (antifreeze) that collected the heat by means of the collector arrays exchanges its heat with the storage system cold water flowing inside a tube while it is flowing through the shell side of a shell and tube type heat exchanger and the heat energy is stored at the heat storage tank. As shown in *Table 2*, since the heat exchange energy is compartively high in the summer and winter and heat exchange is performed between the primary and secondary side liquid of the heat exchanger, and the heat transmission area is a comparatively large 35.2m^2, heat exchange is considered sufficient when the primary side and secondary side flow rate and outlet/inlet temperature conditions are matched.

3. Storage tank

Four 20m^3 storage tanks are connected in series for a total capacity of 80m^3. Each tank is a special partition laminated type having inside dimensions of 2200mmϕ x 6010mm, steel plate inside epoxy-lining, and a maximum usable temperature of 65°C. Cold water is taken from the bottom of the tank four and is circulated to the top of tank one through the heat exchanger.

Supply to the load is taken from the top of tank one and cold water is replenished from the bottom of tank four. Recently, stress corrosion of the inside of stainless steel (SUS304) heat storage tanks or hot water storage tanks has frequently occurred in hot-water supply equipment and the present trend is toward the use of electric corrosion inhibiting devices inside tanks or the use of expensive SUS444 tanks. In either case, the action of the oxygen in the hot water is a cause of stress corrosion. However, the closed type expansion tank (expansion is absorbed by an expansion tank on the roof) used in this facility prevents contact with the outside air and the inside of the tank is protected by an epoxy-lining that has been amply inspected for pitting.

4. Pumps

Two of each kind of pump are connected in series-parallel so either pump can serve as a standby. However, the heat collection pump and heat exchange pump use a PS motor because of their speed change operation to be described later.

5. Piping insulation

The heat insulation of the heat storage tank, heat exchanger, piping, and other parts of a solar system has a considerable effect on the heat exchange efficiency of the entire system and the running cost of the auxiliary heat

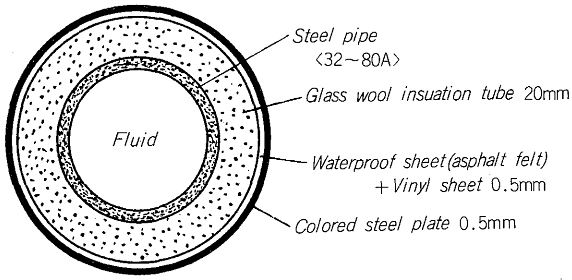


Fig. 6 Example of pipe insulation

source. *Fig. 6* shows the typical specifications of insulated piping in this facility according to the air conditioning and sanitation facility work standartds.

6. Hot water supply piping

The heat energy stored in the heat storage tank inside the machinery room is transferred to the hot water loads of the factory, boarding house, and company housing by insulating cover copper pipe (about 65A and having a hard urethananic foam insulation layer and hard polyvinylchloride jacket) buried 1.2m underground.

The polyperma pipe is burined in the ground to reduce the construction cost and maintain the insulation performance. However, according to actual measurement of normal pressure feed and hot water return from the factory machinery room to the boarding house, a piping distance of about 140m by this polyperma piping, the hot water pump outlet temperature was 40°C, the earth temperature was 5°C (outside air temperature=0°C), and the return temperature at a flow of 1801/min was 39.5°C and did not show much of a temperature drop. Therefore, hot water is obtained at the load whenver necessary.

V. ELECTRIC AND MEASUREMENT SYSTEMS

The economical value of a solar system is determined by quantitively grasping (1) if thermal radiation is effectively collected, (2) operating costs have been minizied, and (3) if the use of the auxiliary heat source (gas, oil, electric, etc.) is small throughout the year. Therefore, specifically,

(1) The operation of the heat transfer pumps is limited to the minimum output in the solar heat collection time band. (speed control)
(2) The heat is stored at the highest possible temperature.
(3) An automatic operation system is employed for energy saving according to circumstances.

and other conditions are necessary.

The electric and measurement facility of this facility is outlined below.

1. Data-logger set

In a solar system collector array, heat storage and hot water supply system, the data-logger is used not only to convert the analog quantity transmitted by the sensors that measure the solar radiation, temperature, flow, etc. into a digital quantity and print it at high speed every hour, but also for heat collection control and pumps speed control, such as bubbling protection control, while performing preset process analysis on the quantities.

2. Control system

1) Circulating pump control

The heat circulating pumps and heat exchange pumps use a PS motor and heat exchanger outlet constant temperature control according to the solar radiation. If the solar radiation is made H (kcal/m^2.h) and the base set value is made B (°C), the logical setting temperature SV (°C) is given by,

$$SV=20/750X(H-100)+B$$

The circulating pump is PID controlled to match the heat exchanger outlet temperature to this SV. The heat exchange pump is PID controlled so the heat exchanger secondary outlet temperature matches the specified value, with coupling with the heat circulating pump as a condition.

2) Automatic control

If the conditions heat exchanger outlet temperature 40°C or more, in the duration of sunshine (this varies with the month) and solar radiation 100kcal/m^2.h or more are satisfied, the heat circulating pump and heat exchange pump are started. However, to make the temperature of each part of the solar system uniform, after the circulating pump has been operated at 100% (1200rpm) and the heat exchange pump has been operated at 0% (250rpm) for thirty minutes, the two pumps are PID controlled as previously described.

When any of the conditions solar radiation 100kcal/m^2.h or less, collector outlet temperature 40°C, or outside the duration of sunshine (varies with the month) is satisfied, the circulating pump and heat exchange pump are automatically turned off.

When the solar radiation drops below 100kcal/m^2.h or the collector outlet temperature drops below 40°C, both pumps are turned off, even if in the duration of sunshine. When the condition recovers, the pumps are restarted.

3) Bubbling protection control

When the collector outlet temperature exceeds 85°C, circulating pump and heat exchange pump PID control is released and the two circulating pumps and heat exchange pumps are operated in 100% parallel to remove the heat by doubling the flow until the collector outlet temperature drops below 85°C to prevent bubbling of the collector. If the collector outlet temperature still continues to rise, when it exceeds 95°C, or when the heat storage tank temperature exceeds 70°C, the electro-magnetic valve at the bottom of the heat storage tank automatically opens and the heat is discharged.

4) Alternate operation of pumps

The pumps are automatically operated alternately with the No. 1 pump being operated on odd numbered days and the No. 2 pump being operated on even numbered days.

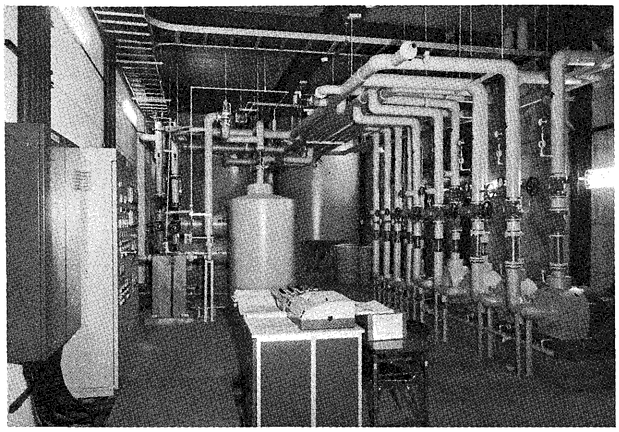


Fig. 7 Machine room for solar system

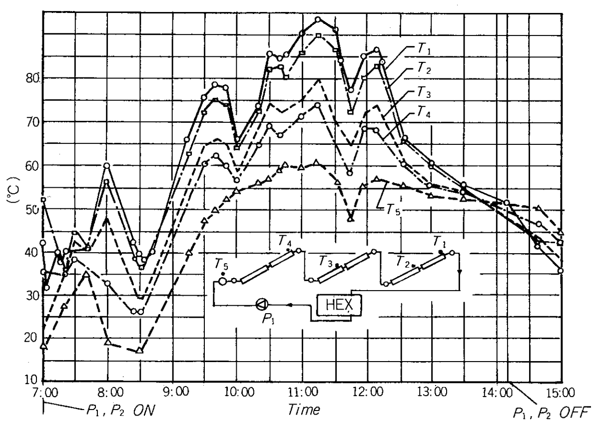


Fig. 9 Test data (No. 2) May 2, 1981

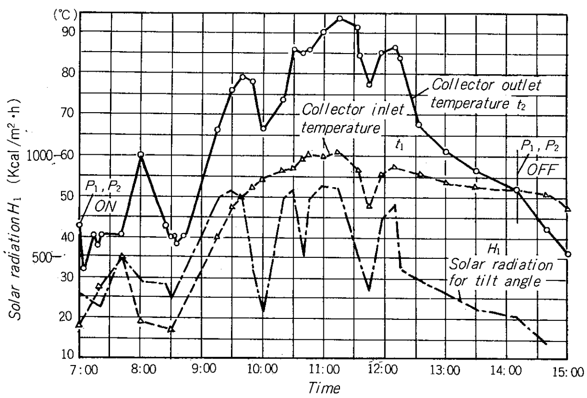


Fig. 8 Test data (No. 1) May 2, 1981

The reason for the collector outlet constant temperature control described in item 1) Circulating pump control at such a control is that the heat collection efficiency must be maximized within the duration of sunshine by speed control of the circulating pump so the collector outlet temperature proportional to the sloar radiation is as close as possible to the theoretical value. In other words, because the collector outlet and inlet temperature difference must be maintained constant. Furthermore, since the collector arrays in a heat exchange system such as that of this facility (differs from a system that consumes the collector arrays fluid by transferring it directly) is a closed cycle, maintaining the collector outlet/inlet temperature difference constant also increases the heat collection efficiency and increases the collected heat energy (and subsequently, the storage heat energy). *Fig. 7* shows the machine room of this facility.

VI. SITE ADJUSTMENT AND TESTING

After installation, adjustment, and esting, this facility continued automatic operation. *Fig. 8* and *Fig. 9* shown typical heat collection data for May 2, 1981.

In the analzed results of these data (outside air temperature 19-20°C):

(1) Heat collection efficiency in the strong solar radiation time frame ηct=0.47~0.56, collector outlet/inlet temperature difference =28.5~30.5 deg, and temperature rise per collector series-parallel array=28.5/6~30.9/6= 4.8~5.2deg/plate. These conform to the design values.

(2) The collector oulet temperature variations in the parallel direction of the collector arrays is within ±3°C at 85°C and the branch flow between parallel groups is considered to be almost uniform.

VII. CONCLUSION

A precious record of achievements in large capacity solar systems for hot water supply was obtained through design→manufacture→installation→adjustment→operation. We will continue to follow-up these achievements so as to connect to economical comments by analyzing the data throughout the year.

The authors wish to thank Fujitsu Fanuc Ltd., which gave us this important opportunity, and Sohara Kikuchi Architectural Design and Tokyu Construction Co., Ltd. for their guidance in the design and on-site construction.