JAPAN'S
SUNSHINE PROJECT

SOLAR ENERGY R&D PROGRAM

MAY 1981

SUNSHINE PROJECT PROMOTION HEADQUARTERS
AGENCY OF INDUSTRIAL SCIENCE AND TECHNOLOGY
MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY

I. Introduction

In the face of the energy crisis and environmental pollution, Japan, to which a solution to these problems is of particular importance, must make the development of new energy technology a national project.

"Sunshine Project" is an ambitious national technological development program commenced in 1974 by the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry and to be completed by the year 2000.

Through the utilization of inexhaustible, pollution free solar energy, geothermal energy, etc., "Sunshine Project" is expected to alleviate the energy crisis resulting from the exhaustion of petroleum resources, and to give back to the earth its fresh green and lifegiving sunshine. To expedite the project, the research and development is to be carried out on a long-term timetable, planned as far as the year 2000 and, at same time a medium-term schedule.

Energy sources to be treated as the objects of the project from the year 1974 are as follows:

(i) Solar Energy
(ii) Geothermal Energy
(iii) Coal Gasification and Liquefaction
(iv) Hydrogen Energy
(v) Supporting Research

"Sunshine Project" is to be promoted on a national scale with full cooperation from national research institute organs, universities and private enterprise, as well as through international cooperation with projects in other countries. Generally, the solar energy is highly expected as a new energy sources because of the following features.

(i) Surprising amount of supply

The radiant energy of 1.04×10^{17} kcal every hour is given to the earth from the sun. Since the total energy consumption of the world came up to 5×10^{16} kcal in 1970, that is to say, "The quantity of solar energy which pours into the earch every 30 minutes is equal of the amount of yearly energy consumption of the world."

(ii) Exhaustless energy

It is everlasting energy which does not decrease in spite of its utilization, which is very much different from underground resources such as oil and coal.

(iii) Clean energy

The utilization of solar energy does not change the thermal equilibrium of the earth as described above. It is, namely, the energy which effectively ensures the control of environmental polution and the stable supply of energy.

(iv) No partiality

There does not exist extreme partiality as seen in the case of fossil fuel. It can be used everywhere though small deviation is observed in its distribution.

Although the solar energy has a number of prominent points, there are some difficulties in its application, i.e., (1) the energy density of $1kW/m^2$ is rather low, (2) daily cycle of insolation and weather conditions cause unsteady supply, which may mismatch energy demand. It is, therefore, essential to overcome these demerits as well as low competitiveness in cost by intensive research and development.

The R & D program of solar energy in the Sunshine Project is now carrying out in the specific three field.

The first is the utilization of thermal evergy where the solar energy is caught in the form of thermal energy and this energy is used for heating, cooling and hot water supply in residents, buildings etc.

The second is another utilization of thermal energy where the solar energy is collected as steam at a high temperature for solar thermal power generation.

The third is the direct conversion of solar light energy into electricity by using solar cells.

II. Program Overview--Planning, Strategy and Promotion Organization

The general management of the Shunshine Project has been conducted by the Shunshine Project Promotion Headquarters set up at the Agency of Industrial Science and Technology, Ministry of International Trade and Industry, as shown in Figure 1.

Table 1 shows the transitions of the government budget funded to the Shunshine Project. As shown in this table, the budget of 9.6 billion yen in fiscal year 1980 and 8.0 billion yen in fiscal year 1981 have been assigned to the solar program. The research and development program of solar energy was accelerated and the fund has been selectively allocated for photovoltaic conversion system from fiscal year 1980.

Although the final target year of the Sunshine Project is 2000, the research and development will be conducted in several stages and the achievements in each stage will be put into practical use successively. Figure 2 shows the national R & D program of solar energy in the Sunshine Project and the following are aimed at this moment:

1. Construction of a experimental mass-production line (500 kw/ year) for solar cells (1981 to 1982)
2. Construction of four demonstration systems and two central power station systems for solar photovoltaic conversion. (1981 to 1985)
3. Fundamental Research on amorphous solar cell.
4. Test and operation of 1000 kWe x 2 solar thermal power generation systems.
5. Construction of solar systems for industrial process heating. (1981 to 1982)

Table 1. Transition of budget related to Sunshine Project

(Unit:100 million yen)

	1974	1975	1976	1977	1978	1979	1980	1974-1980 total	1981
Solar energy	8.5	11.0	14.5	14.5	20.5	38.0	95.5	202.5	79.9
Geothermal energy	5.5	11.0	15.5	25.5	32.0	35.5	86.0	211.0	98.2
Coal energy	4.0	8.5	9.0	10.5	14.5	29.0	86.0	161.5	135.5
Hydrogen energy	3.5	4.5	4.5	5.0	6.0	7.0	9.5	40.0	9.5
Supporting research and management,etc.	2.5	4.5	5.5	6.5	8.5	10.0	9.5	47.0	13.5
Total	24.0	39.5	49.0	62.0	81.5	119.5	286.5	662.0	336.6

Fig. 1. Organization of the Sunshine Project Promotion Headquarters
As of 1981

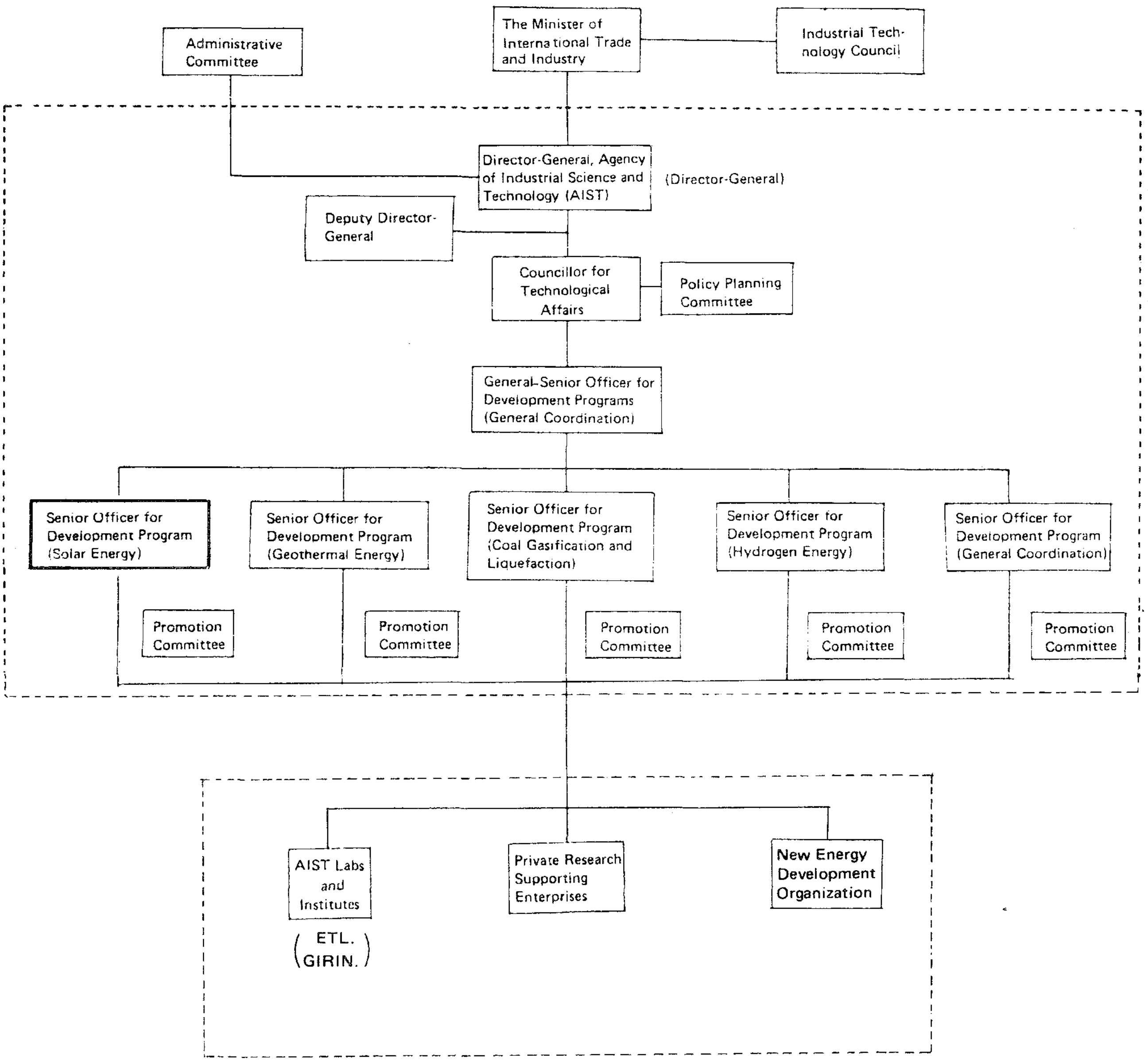


Fig.2. National R & D Schedule of Solar energy

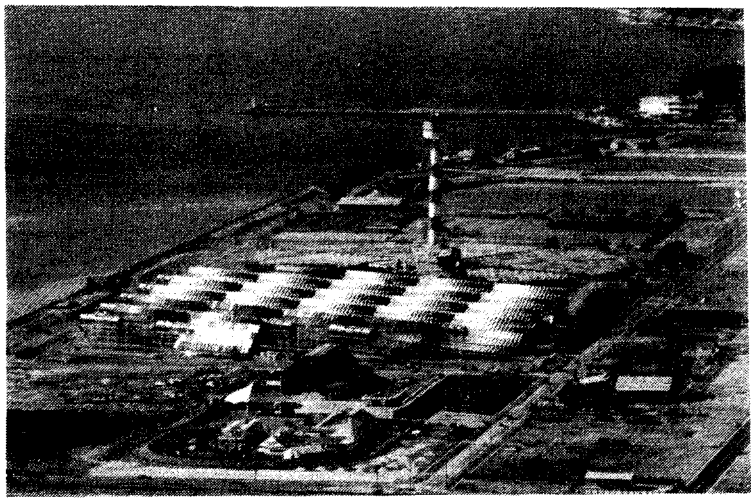
design development operation

PROJECT		SCHEDULE 54	55	56	57	58	59	60	61
1. Solar System	(1) Application for Industrial Process Heat					2 systems			
	(2) R&D of Seasonal Thermal Energy Storage								
	1) Energy Storage by Underground								
	2) Energy Storage by Metal Hydrides								
	3) Energy Storage by Heat of Dilution								
	(3) Fundamental Research on Solar System				basic research				
2. Photovoltaic Conversion System	(1) Mass-Production Technology Development of Solar Cells								
	1) Silicon Material Technology			10t		100t		1000t	
	2) Panel Fabrication Technology			500kw line		5000kw line		50,000kw line	
	3) Test Standards and Procedures of Solar Cells								
	(2) Photovoltaic Power System Technology Development								
	1) Demonstration System			4 systems	for a few houses 3kw for corporated house 60kw for school 200kw for factory 200kw			a-Si Solar Cell 1000kw system	
	2) Central Power Station System					1000kw x 2 systems			
	3) Photovoltaic/Thermal Hybrid System				30kw system				
	4) System Support Technology	3 kw		6kw system					
	(3) R&D of Solar Cells								
	1) CdS Solar Cell Development								
	2) SnO_2 Solar Cell Development	basic research					R&D		
	3) Amorphous Solar Cell Development								
	(4) Fundamental Research on Solar Cells				basic research				
3. Solar Thermal Power System	(1) R&D of Solar Thermal Power System		$1000kw_e + 6000kw_t$ system						
	(2) System Analysis				basic research				

III. R & D OF SOLAR THERMAL ELECTRIC POWER GENERATION SYSTEMS

Two types of 1,000 kW pilot plant were completed in March, 1981 as a link in the chain of R & D of Solar Thermal Electric Power Generation System (STEPS) under the Sunshine Project which has been carried out by Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry (MITI) since 1974.

Complete view of the two pilot plants is shown in Fig. 1.



The two plants are identified as the Central Receiver System which concentrates light at the top of a tower by plane mirrors, and the Plane Parabolic System which concentrates light by a combination of plane mirrors and parabolic mirrors.

The objectives to construct these two types of pilot plant are to accumulate foundamental data through construction and installation of each device and measurement of plant operation performance, stability and durability, and to make use of these data to construct and operate a larger commercial plant after analysis of some problems about performance increase, cost down, etc.

Development of the pilot plant is based on foundamental research which has been done by Electrotechnical Laboratory (ETL), AIST of MITI, and on R & D of elementary devices and systems which was done after the Sunshine Project started. (Ref. 6-(1)).
A former salt field at Nio, Kagawa prefecture was selected to be the construction site of the pilot plant because of its optimal insolation after investigation of optimal site carried out at the same time as R & D.

Electric Power Development Co., Ltd. is wholly entrusted with determination of the plant specifications and construction. With respect to design and manufacturing, Mitsubishi Heavy Industries, Ltd. takes charge of the Central Receiver System and Hitachi, Ltd. takes charge of the Plane Parabolic System.

Schedule of the R & D of STEPS is shown in Table 1.

Foundamental specifications of the pilot plants are shown in Table 2.

Table 1

Fiscal Year	1970 - 1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
ETL	← Basic R & D - - - - - - -										
Sunshine Project		← R & D on plant elements, materials and system →									
					← Plant design →						
						← Manufacturing & Installation test run →					
								← Operation for R & D →			

Table 2

Item	Plane - parabolic type	Central receiver type
1. Output of generator	1,000 kW	1,000 kW
2. Designed direct solar radiation	0.75 kW/m² at 2:00 pm on the vernal equinox	0.75 kW/m² at 2:00 pm on the summer solstice
3. Collector system	Plane - parabolic	Central tower/receiver
4. Thermal storage capacity	3 hours (1,000 kW)	3 hours (1,000 kW)
5. Pattern of operation	Middle load operation as a standard pattern; no operation at night as a principle	(Same to the left)
6. Tracking	Computer control	Computer control
7. Wind conditions	Working wind velocity Average: 10 m/s or less Maximum resistance: 50 m/s to gusts	(Same to the left)
8. Cooling water for condenser	Sea water	(Same to the left)
10. Duration of sunshine	2,200 hours (average of 10 years)	(Same to the left)

Since April 1981, New Energy Development Organization is entrused by AIST and take charge of trial operation and actual operation of the plants for research. The plant operation for research are scheduled to continue for 2 or 3 years being improved as much as possible, while the plants are operated to obtain informations about efficiency, operational characteristics, optimal operation method, safety, durability, maintenance method, etc. of the whole system and an each device in various operation mode in relation to the thermal storage operation and weather conditions; such as insolation, wind velocity, etc. and in a long term operation mode.

IV. R&D OF PHOTOVOLTAIC CONVERSION SYSTEMS

1) Solar Cell and its Terrestrial Application

What is called SOLAR CELL converts light energy directly into electricity in the microscopic region formed with semiconductor materials such as silicon. Fig. 4.1 illustrates an example of cell structure. For the system, the electrical storage which compensates the variation of incoming solar energy, the invertor which converts the direct current output of solar cell into alternating current, and the interconnector which interfaces the photovoltaic system with conventional electrical network are required in addition as shown in Fig. 4.2.

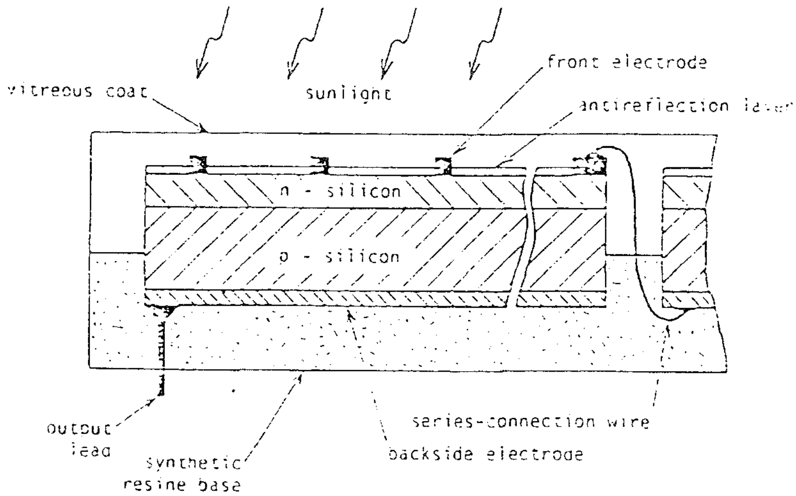


Fig. 4.1 An Example of Solar Cell Structure

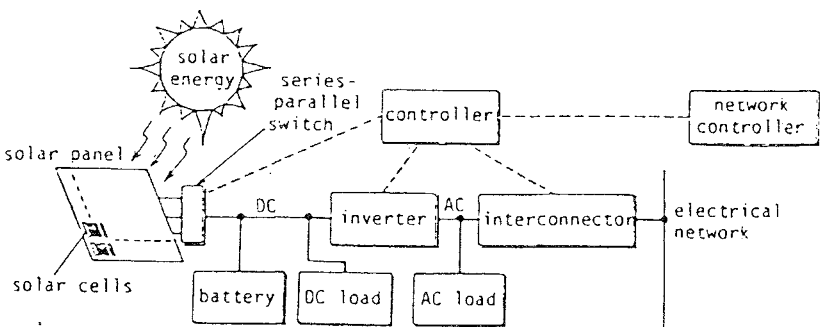


Fig. 4.2 General Schema of Solar Photovoltaic Conversion System

Though the system of photovoltaic conversion by solar cells is actually practised to some extent, for instance by satellites, unmanned lighthouses, radio-emitters or repeaters and others, its energy cost is still extremely high, showing 15-30 $/W, usually being manufactured in a small scale, and a plant of this type can not compete with a traditional ones, unless its cost is cut to approximately 1/50-1/100 of the present level. To cope with this situation it is necessary to make efforts for technological break-through and remarkable reduction in cost of materials and solar cells as well as for the automation of manufacturing processes.

2) Research and Development under the Sunshine Project

The basic study on the technology of photovoltaic conversion has been made since 1974. As the second phase, the technological development of the automation processes and the practical application has now started.

The Sunshine Project is presently being advanced with the target of establishing new and economical technologies permitting photovoltaic power generation that would be competitive with the existing power generation systems by about 1990.

Subject of the research are as follows: Development of,-

a) inexpensive solar cells,
b) continuous and automated process for the mass production of solar cells and modules,
c) technologies for the refining method of silicon raw materials with a low price and large quantity,
d) efficient photovoltaic power generation systems and their applications.

In parallel, surveys and studies are being conducted on such subjects as the future outlook of system economies, future market situations, method of operation and methods for system evaluation. An extensive research is also being made on new types of solar cells, i.e., II-VI compound semiconductor cells, silicon heteroface cells and amorphous silicon cells.

3) Mass-Production Technology Development of Solar Cells

The objective of the program is to develop the automation processes of solar cell and module manufacturing and to demonstrate annual production, including (1) the closed cycle of solar grade (SOG) silicon refining, (2) ribbon crystal growth, (3) polycrystal wafer casting and multi-slicing, (4) diffusion and electrode formation by painting and screen-printing, (5) another method of cell fabrication by ion-implantation and electroless plating, and (6) module assembly provided with auotomatic wiring and superstrative glass panelling.

In the course of the development a quality control of the process becomes important . The appreciation system of solar cells and modules are, therefore, being studied to establish testing standards.

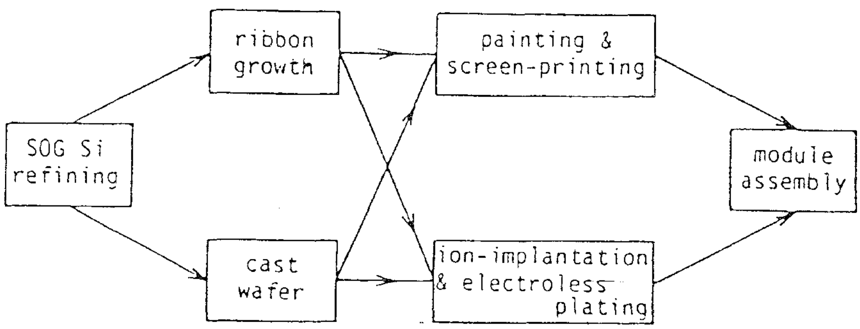


Fig. 4.3 Block Diagram of Solar Cell Mass-Production

4) Photovolaic Power Systems Technology Development

It is the points for the practical use of the photovoltaic conversion systems, firstly, to establish the production process of low-cost solar cell and, secondly, to create a demand for it. This program belongs the latter category.

The field which photovoltaic conversion can be applied to is considered to be both a centralized power station and a type closely located near a demanding place.

As the former type two projects were adopted to be completed until 1984. One has a centralized array yard, which will be located in Saijo, western part of Japan. In another type solar arrays are dispersed in the region of a control station while they are operated as a power station via a power distribution network.

In the scheme of latter type, applications for a private home, a multi-family house, a school building and a factory will come into operation in FY 1981-82. A photovoltaic, solar-thermal total mode system with concentrating optics will also be constructed until the end of FY 1982.

The most promising system may be the residential application, considering the amount of realizable energy resources in Japan. A 3 kW demonstration is to be developed. The function of interlinkage with power network are given although power reversal is not allowed by the regulations at the moment. The structure of a unified roof-array and a compact transistor invertor are adopted as well.

A twenty-family house is rated 60 kW. This system is backed up by an automatic switch interconnected with an AC network. A GTO (gate turn-off thyristor) inverter is developed.

The school system is given 200 kW solar arrays accompanied by two sets of high efficiency GTO invertors. It can be operated in parallel with power network as well as in the case of its interruption. It will be locataed in the campus of Tsukuba University.

A battery industry is chosen for the industrial application. It is a representative of the case of DC direct use. 100 kW solar arrays are installed for initial charging of automobile battery.

5) Amorphous Solar Cells

The program of amorphous solar cells started in FY 1978 to develop further low cost cells than conventional cells. To accelerate the development speed, stress is placed on both fundamental research on material and physics, and development of cell production technology.

Fundamental research is shared by Electrotechnical Laboratory and universities. Development od cell production technology in private companies is supported by the contract of 8 subprograms including following technical key points:

fabrication process of low cost silane,
large area cell,
high efficiency cell,
tandem cell,
integrally series connected cell,
flexible substrate cell,
ceramic substrate cell.

Milestones in cell efficiency is 6 % in FY 1982 and 8 % with 100 cm^2 area in 1984. Demonstration by 1000 kW power generation terrestrial array system is scheduled from FY 1985.

V. R & D OF SOLAR HEATING, COOLING AND HOT WATER SUPPLY SYSTEMS

In the period from 1974 to 1979, greater emphasis is places upon system analysis, R & D on components and materials, construction of experimental installations, testing and evaluation of solar heating, cooling and hot water supply systems. R & D activities have been directed to the residentail solar house, retrofitting system, multi-family residential house, and large buildings, as well as R & D of solar collectors and collector testing procedures. Solar collector R & D has been assigned to R & D on plastic, metal and glass materials.

Most of these R & D works have been subsidized to the private sectors while R & D on solar collector materials, collector testing procedures and thermal energy storage techniques have been carried out at the Solar Research Laboratory, Government Industrial Research Institute, Nagoya, AIST. Specific features of these solar heating and cooling installations of four types are described in the Table 1 and appear in Figs. 1 - 4 respectively.

In the second five year plan (1980 - 1984), R & D programmes on seasonal thermal energy storage have been inaugurated in addition to the research on systems performance evaluation and fundamental research on solar collector materials and heat storage techniques. The seasonal heat storage techniques include heat storage by underground, chemical reaction and heat of dilution.

In addition to the R & D efforts of national level, the Japanese government has been playing an active role in international cooperative works in IEA in the field of Solar heating and cooling. The Sunshine Project Promotion Headquearters have joined IEA Task I, Investigation of the performance of solar heating and cooling system; Task II, Coordination of R & D on solar heating and cooling components; Task III, Performance testing of solar collectors and Task VI, Performance of solar heating, cooling and hot water systems using evacuated collectors since 1977. And further, Japan has been acting as the Operating Agent in Task II.

Among the bilateral cooperation of R & D on solar heating and cooling,cooperative works have started between Australian and Japanese Governments on testing of advanced flat plate solar collectors for three year programme since 1980. Also it should be mentioned that the Interregional Symposium on Solar Energy For Development was jointly sponsored by the United Nations and the Japanese Organizing Committee in February, 1979 in Tokyo for developing and promoting solar energy technology in developing countries.

Table 1 Specific features of solar heating and cooling installations of four types

Category of Building	New Single Family House	Retrofitted Single Family House	Multi-Family Apartment	Large Scale Building
Project Executed by	Sanyo Electric Ohbayashi-gumi	Mitsubishi Elec. Taisei Construc.	IHI Takenaka Construc.	Kawasaki Heavy Ind. Kajima Corporation Toyo Thermal Eng.
Location	Hirakata City Osaka Pref.	Ayase Town Kanagawa Pref.	Chofu City Tokyo Pref.	Oita City Oita Pref.
Date Completed	Mar.1977	Mar. 1977	Dec. 1978	Mar. 1978
Bldg Administrater	Sanyo Co.	Taisei Co.	Tokyo Elec. Power	Oita University
Total Floor Area	118.52 m^2	97.52 m^2	2240 m^2	1860 m^2
Construction	RC, 2 story	Wooden, 2 story	RC, 3 story	RC, 3 Story
Collector	Evacuated Tube	Flat-Plate	Flat-Pl Evacuated	Flat-Plate
Absorber	Al plate,selective	Al pl., selective	Al,Selec.parabolic	Steel pl., black
Glazing	Glass tube	2 pane glass	2 pane cylinder	2 pane glass
Unit Size	100mmø, l=1.2m	1500x2000 mm	0.95x3.6m 1.0x1.7m	1865x7520x225 mm
Total Area,effec	40.6 m^2 (roof)	48 m^2 (roof)	366,roof 19,roof	508 m^2 (roof)
Tilt Angle	0°	17°	20° 20°	10°
Storage(high T)				
Volume	1 m^3	1040x840x680	10 m^3	None
Media	water	$NH_4Al(SO_4)_2.12H_2O$	water	
Temperature S/W	60°C	94°C	90-95/10-40°C	
Storage(low T)				
Volume	8 m^3	5.5 m^3	80 m^3	45 m^3 x 2
Media	water	water	water	water
Temperature S/W	10°C/45°C	5-10°C/50-60°C	8-13/40-60°C	
Refrigeration Ma.	Absorption	Rankine/Comp.Ref.	Rankine/Heat Pump	Absorption,Double Eff.
Capacity	6000 kcal/h	3100 kcal/h	20 USRt	30 USRt
Input Temperat.	85°C	90°C	90°C	85°C
Cond/Evap Temp.		38/5°C	35/7°C	
Expander		Sliding vane 750W,2800rpm	Rotary volume vane 12kW,1500rpm	
Working Media	H_2O-LiBr	R 114/R 22	R 11/R 22	H_2O-LiBr
Chilled Water T	15-10°C	10-7°C	12-7°C	14-9°C
Cooling Water T	31-35°C	33-35°C	30-33°C	30-38°C
COP	0.67 at 85°C	0.4(overall)	0.41(overall)	0.65(solar)/1.0(aux.)

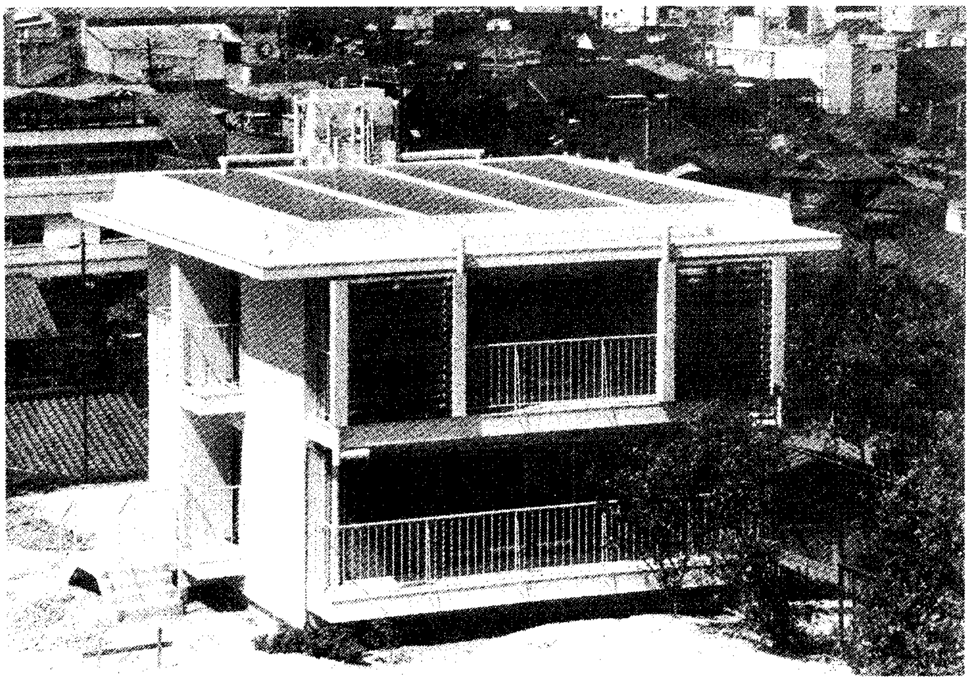


Fig. 1 Single family residential solar house

Evacuated Tubular collectors with LiBr-water absorption unit are used.

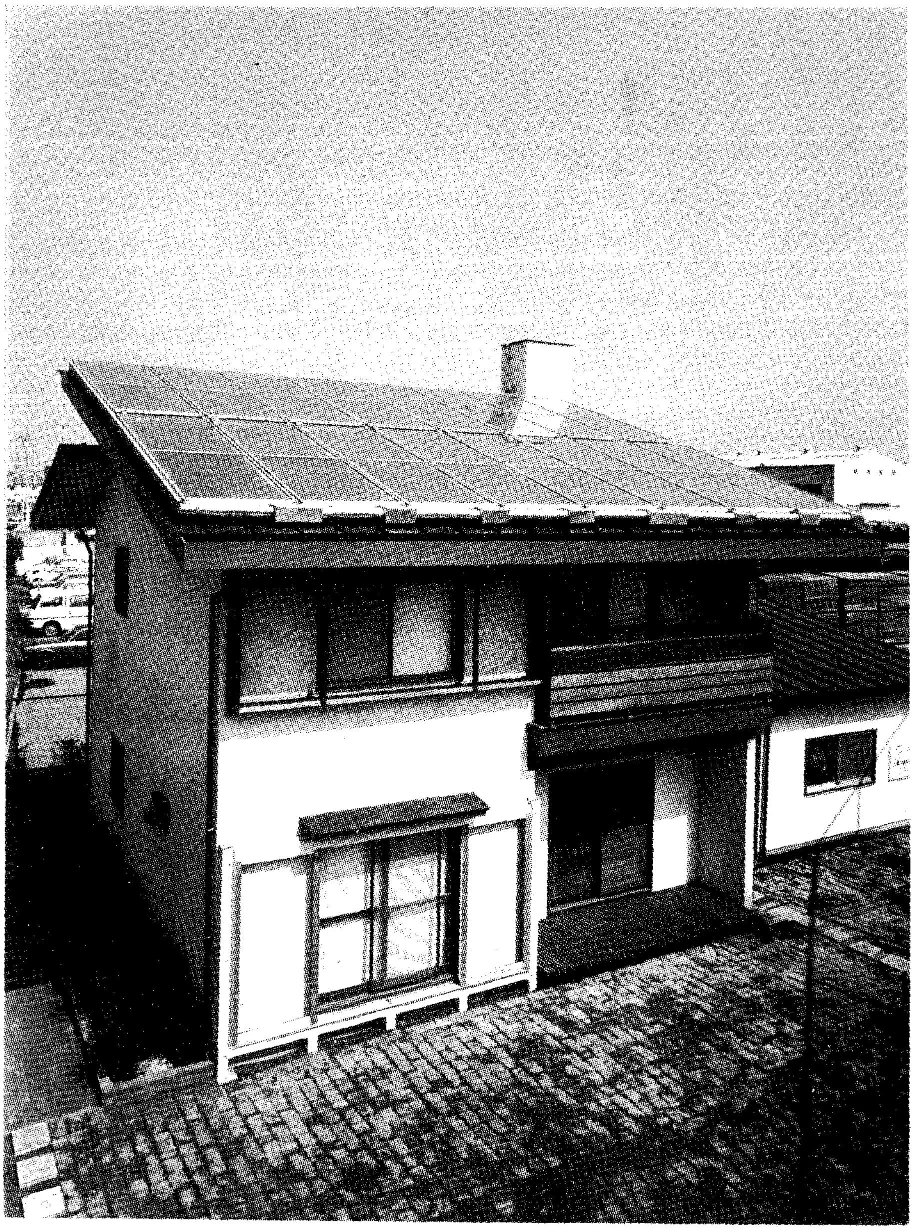


Fig. 2 Retrofitting system for single family house.

Selective absorber collectors and Rankine cycle unit of 0.7 KW are used.

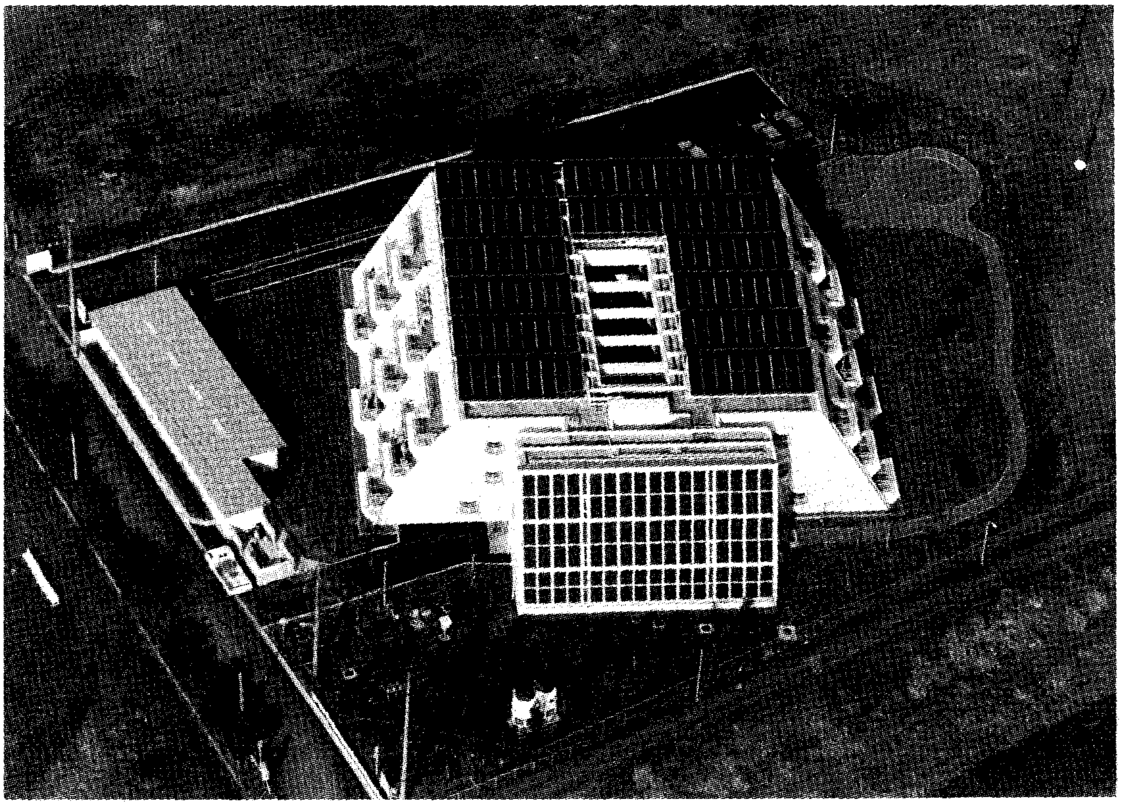


Fig. 3 Multifamily residential soalr house

Evacuated tubular collectors and Rankine cycle unit of 20 RT were used.

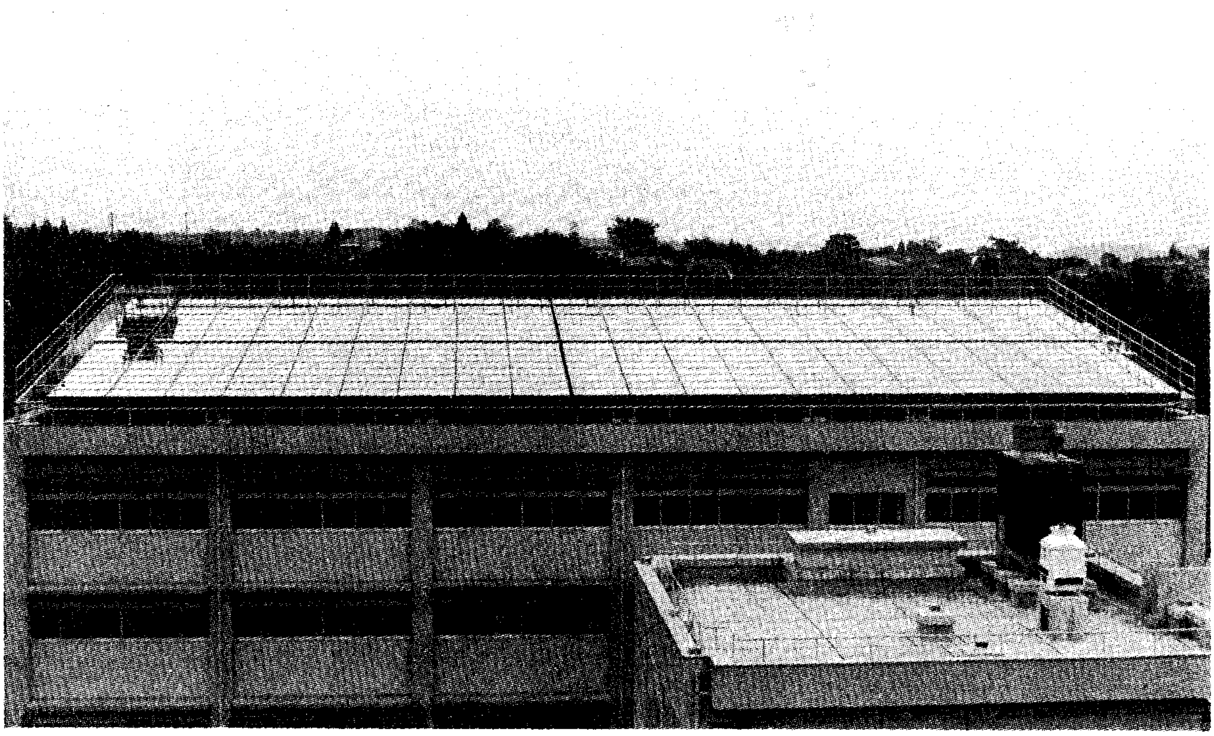


Fig. 4 Large scale solar system for school building

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