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Solar Energy in China

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Abstract

The report presents the progress, status and goals of the Chinese national solar energy programmes since 1970's. It applies specially to solar water heating, solar drying, passive solar, solar cookers, and solar photovoltaics. In China, an expertise team has been organized, a number of technology development centers for new and renewable sources of energy have been set up and some demonstration projects are under way.

Since 1970's Chinese Government has paid much attention to research, development and utilization of new and renewable sources of energy (NRSE). A coherent strategy governing the R&D and utilization of NRSE has been pursued for planners and descisionmakers. It is stated as "planning in accordance with local resources available and economic conditions; multienergy complementary supply; integrated use and concern of commercial and economic viability".

China's population is so large that it accounts for one fifth of the world's total. Despite its vigorous family planning efforts, the absolute population growth would still be considerable due to its enormous population base line. This can not but affect the future of the whole mankind. Shortage of energy in China can not be expected to be overcome in a short period of time. The only way out is to adopt various kinds of energy conservation measures and increase the utilization of NRSE, while expanding the production of conventional energy.

Key words

Renewable energy, solar energy, China.

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Contents

1 Introduction

In the beginning of the founding of the People´s Republic of China, an independent and initiative energy industry was established and has supplied huge amount of coal, petroleum and electric power under a weak industry base at that time. However, the gap between energy demand and supply has been widening along with the rapid development of national economy. Since the 3rd Plenary Session of Central Committee of 11th Congress of Chinese Communist Party, great changes have happened throughout the rural villages in China. The increase of agricultural input, the speedy development of rural township run enterprises and the improvement of farmers´ living standard are bringing about an accelerated growth in rural energy demands. For coping with the potential energy shortage as well as improving natural environment, a program of research, development and utilization of New and Renewable Sources of Energy (NRSE) as well as advanced energy conversion technologies, have been adopted. The R&D of NRSE will provide alternative possible solutions for easing up the rural energy shortage, especially in remote locations, and reduce the reliance on conventional energy supply in those areas.

Since the 1970´s Chinese Government has paid much attention to R&D and utilization of new and renewable energy. A coherent strategy governing the R&D and utilization of NRSE has been pursued for planners and decisionmakers. An expertise team has been organized, a number of technology development centers for NRSE have been set up and some demonstration projects are under way [5].

Shortage of energy in China can not be expected to be overcome in a short period of time. The only way out is to adopt various kinds of energy conservation measures and increase the utilization of NRSE, while expanding the production of conventional energy. At present, China´s energy production is carried out on a self-reliant basis by and large. For this reason, fluctuations in oil prices in the international market produce no major impact on the energy situation. However, China´s population is so large that it accounts for one fifth of the world´s total, despite its vigorous family planning efforts, the absolute population growth would still be considerable due to its enormous population base line. This can not but affect the future of the whole mankind. Faced with the three global problems of *population explosion, energy shortage* and the *environment deterioration,* sooner or later, China will be dragged into the global energy cycle [6].

2 Non-renewable energy sources

It is globally acknowledged that the depletion of the conventional energy resources is drawn as depicted below. Dr. J R Frisch has written a book named "Future Stresses for Energy Resources". In this book, a thorough analysis concerning the source reserves, consumption speed, exhausting time and the demand for four world's key energy resources: coal, oil, gas and uranium has been given. The results are shown in Table 1.

Table 1

Item \ Energy	**Proven Reserves (PR) & Additional Resources (AR), GTOE**	**Exhausting Time, Calender Year**
Coal	900 (PR) 2 700 (AR)	about 2200
Oil	100 (PR) 36 (AR)	before 2020
Gas	74 (PR) 60 (AR)	about 2040
Uranium	Thermal reactor 60 (PR+AR) Breeder reactor 1300 (PR), 1600 (AR)	2073 2110-2120
Total	**1 100 (PR), 3 200 (AR) (thermal reactor)**	**about 2200**

Notes 1) GTOE - 10^9 ton of oil equivalent.
2) The world's energy demand and exhausting time are estimated according to the medium economic growth, that is 15-20% annually.

Table 2

Energy demand of the world, GTOE	
Annual	**Demand**
1980	7,5
1984	7,8
2000	11
2020	15
2040	18
2060	21

Table 3

Cumulative demand, GTOE
1960-1985: 140
1986-2060: 1140

From Table 1 it can be seen that the non-renewable energy will have to be exhausted sometimes later. The mankind can only rely on renewable energy in the future, such as: hydropower, wind energy, solar energy, etc. It can be predicted that in the later period of next century, there will be a significant change in the world's energy structural pattern [12].

3 Present status and policy in China

China is a populous developing country with a very weak industrial foundation. In the past fourty years, an independent energy industry has been established, covering coal, oil and electricity generation. Towards the end of 1989 it was estimated that China´s annual production capacity was as follows [6]:

• Coal	1040 million tons
• Oils	137 million tons
• Natural gas	14 billion cubic meters
• Electricity	582 billion kWh

In the last ten years, the implementation of the reform and open policy has resulted in rapid development of the national economy. But on the other hand, the dramatic growth also gave rise to increased energy consumption, creating an imbalance between energy supply and demand. It was particularly so in the rural areas, where 80 percent of the country´s population depends on firewood as a major source of fuel for cooking. The recent boom of rural and township industry, which contributes to the formation of a diversified economy in rural China, adds to the severe energy shortage.

This is further aggravated by the increasing energy consumption needed to improve the livelihood of urban residents. China is unable to increase government inputs to satisfy conventional energy demands in industry and everyday life in urban and rural areas. The only way to ease energy shortage in rural areas is to mobilize local governments´ resources and develop small-scale production patterns suited to local conditions, which include small coal mines, small hydropower stations, small wind power stations and solar energy systems.

The acute energy shortage also has led to the worsening of the environment and caused an undesirable ecosystem imbalance. Despite the vigorous efforts by the government to plant trees, little progress was attained as indiscriminate deforestation by the peasantry in search of firewood more often than not offsets achievement made along that line. Serious consequences arose: in the last fifty years, the total area of desertified land in China has expanded by 50 000 square kilometers. It is believed that the annual agricultural wastes consumption in rural China totals 500 million tons. But the yearly need for agricultural wastes as fuel, animal feed and industrial raw materials is estimated to amount to at least 700 million tons. To ensure the basic supply of agricultural wastes for animal feed and industrial raw material, the farmers´ need for fuel can not be met. It is estimated that every year about 80 million housholds in the countryside suffer the lack of firewood for about fifty days.

In the teeth of the crisis, a number of measures have been taken by the Chinese authorities since the late 70s, which included, among other things, the adoption of a set of preferential policies to encourage the exploitation of NRSE. R&D in NRSE received national priority in the "Sixth Five-Year Plan" (1981-1985) and demonstration projects went into operation. Efforts were made to pool wisdom and resources to tackle key technological obstacles that hindered progress in that direction. A fairly big amount of financial resources were earmarked for that purpose. Under the "Seventh Five-Year Plan" (1986-1990) the central government persists in allocating a special fund for priority projects in NRSE R&D. In the meantime, extensive international exchanges and cooperation were encouraged and received a prominent place in the NRSE program, including some selected NRSE technology and equipment.

All these national efforts have contributed to the remarkable progress that have been achieved over the last 10 years. This includes the establishment of over 20 NRSE research institutes across the country and development of programs in some universities and colleges as well as industry in support of R&D in NRSE. Up to now, there are some 3000 engineers and technicians in China specialized in NRSE R&D. In the various provinces, more than 100 factories were set up and devoted to the manufacture of solar heaters, photovoltaic cells and wind powered electricity generators. Futhermore, a number of national technology development centres as well as training centres concerned with NRSE were also established to bring together and capitalise on the strengths found in different localities and ministries. They include [6]:

- Chinese Wind Energy Development Centre
- China Biomass Development Centre
- China National Photovoltaic Technology Development Centre
- Hangzhou Regional Centre (Asia-Pacific) for Small Hydropower
- China Centre of Rural Energy Research and Training
- China Chengdu Biogas Research and Training Centre for Asia and the Pacific
- Tianjin Geothermal Research and Training Centre

To complement these national efforts, extensive international exchanges and cooperations in NRSE were also conducted, so far, 23 cooperative projects between China and

- the UN system
- the European Economic Community
- Italy
- Germany
- Belgium
- England
- Denmark
- the Netherlands
- Japan

To ensure the successful completion of these cooperative projects, the Chinese government put in an enormous amount of human, material and financial resources, whereas the foreign counterparts provide the Chinese institutions involved with large quantities of equipment and expertise. These cooperative efforts have not only vigorously promoted the development of NRSE in China, but also helped strengthening the mutual understanding and friendly ties between China and these international organizations and countries. Recently, more contact have been established with East European countries [6].

The rapid development of new and renewable sources of energy in China finds expression in the following statistics from the end of 1989 [6].

- **Biogas digesters** currently in use in rural areas total 4,6 million.
- A total installed capacity of 12 400 MW of **mini-hydropower** stations had been registered with electricity generated therefrom reaching 34 billion kWh.
- Small-scale **wind power** generators 105 000, the total installed capacity of these small-scale wind turbine generators including that of medium-sized ones amounting to 15 000 kW.
- **Wind pumps** also come up to 1600 with a total capacity of 2110 kW.
- **Geothermal power** stations 20 000 kW. A total of 380 000 kW of low temperature. geothermal energy had been exploited for that application.
- **Tidal power** stations had generated some 8300 kW.
- **Solar water heaters** installed had totaled 1,5 million square meters.
- **Solar houses** built had taken up 290 000 square meters.
- **Solar green houses** constructed had occupied 110 000 hectares.
- **Solar cells** installed reached 1250 kW.

4 Solar water heating

A variety of solar water heaters have been produced in China for twenty years and now is at commercialization stage with a gradual increase of annual output. At present, there are more than a hundred of small factories and workshops manufacturing solar water heaters with a yearly output of 400 000 square meters (aperture area). The total amount of installed solar water heaters reaches 1,5 million square meters, mainly for domestic hot water supply.

The newly formed solar hot water industry, which started in 1980's, receives support from Central Government as well as technological support from research institutions and universities.

4.1 Solar water heating systems

The solar water heaters developed in China could be classified into integrated and separated systems. For integrated water heaters, a solar collector and hot water tank are integrated into the same unit, simple to install and cheaper in price. So they are of interest to the domestic sectors, of which around 15% of solar water heaters pertain to the integrated type. Separated systems, with collector and storage tank, can be operated either on pumped or natural (thermosyphon) circulation. In China most of them are of thermosyphon type [7].

The dynamic characteristics of thermosyphoning system and the effect of various factors(e.g. climate, design parameters) on system behaviour were studied in connection with computer modelling as well as experimental methods for obtaining a clear picture of its operation mechanism in order to provide performance prediction for different designs and guidance for correct installation. In recent years, the once through type water heating system has been widely installed in newly built solar water heating systems. In addition, the demonstrations of domestic solar water heating systems integrated with the multi-story apartment building have been undertaken in Beijing, Tianjin and Lanzhou with 1 m^2 collector area and 70 liter water tank for each residential flat. The flow distribution in large collector systems is often a design problem [7].

4.2 Thermal solar collectors, components and materials

The absorbers are usually coated with black paint. As a result of computer simulation, it is indicated that for low temperature heat collection, or not for year round use, the black paint is in practice a cost-effective option. Selective coatings with various preparation methods are still in laboratory stage. The radiation properties of PbS selective paint on polished aluminium reaches $\alpha(s)$ = 0,85-0,91, ε = 0,23-0,40. For black chrome and black nickel, $\alpha(s)$ = 0,91-0,98, ε = 0,06-0,14, but their durability and cost-effectiveness are still not proven. The nickel-pigmented anodized aluminium has been successfully developed ($\alpha(s)$ = 0,92-0,96, ε = 0,1-0,2) and serves as selective coating on Sunstrip absorbers [7].

4.3 Testing

The National Standard for Rating the Thermal Performance of Flat Plate Solar Collectors (GB 4271-84) and National Standard for Evaluating the Quality of Solar Collector Products (GB 6424-86) were published in 1984 and 1986 respectively. The National Supervision Bureau of Products Quality conducts spot check on flat plate solar collectors once every year based on the guidance of these standards. The typical effeciency parameters of the flat plate collector products made in China are reported as $F' (\tau\alpha) = 0{,}6\text{-}0{,}8$ and $F' U(L) = 6{,}0\text{-}8{,}5$ W/(m^2 °C)

4.4 Research

4.4.1 General

During the last decade, R&D were focused on design optimization of various kinds of solar water heaters. In early years, the collector absorbers were made of steel and in tube-in-sheet structure in which round tubing is mechanically fitted by clamps or wires leading to bad thermal bond conductance. The processing technology has now been greatly improved, for instance, the extruded fin-tubing and continuous soldering now are used in collector absorber processing [7].

A Sunstrip (nickel-pigmented anodized aluminium) production line mainly consisting of a rolling machine and an inflating-cutting machine was imported from Canada in 1986. Some aluminium fin-copper tubing production technology similar to Sunstrip´s has been domestically developed in Shanghai, Liaoning and Yunnan. Owing to the corrosion problem in water passage of steel or aluminium absorber, copper water passage are now widely used.

Plastic absorbers are still under development and the R&D work is focused on screening the materials which are able to stand ultra-violet radiation and high stagnation temperatures. At present it seems promising to install plastic collectors without glazings in some locations in Southern China.

Scientific investigations on the collector´s optimized design has been carried out, and it is found that the optimal spacing between absorber and glazing is recommended as 4-6 cm where heat transfer is mainly conducted by natural convection. The performance of the collector with transparent honeycomb insulation was proven positive in the laboratory.

A mathematical model for collector optimized design has been worked out.

For producing hot water at a temperature around/above 100 °C as well as for year round use, two types of evacuated tubular collectors in flat plate pattern are under development. The R&D of a all glass concentric tubular collector started in 1979. During the past decade, numerous fundamental research on its coating preparation method, glass-work technology, collector tube assembly and system design were carried out. A small scale of trial production and demonstration of this type of evacuated collectors are under way. A China-Germany international co-operation project on heat pipe evacuated tubular collectors started in 1986, and has completed the prototype R&D, and now it enters the intermediate experimental stage. However, there are still lots of work to do for practical uses as well as economic feasibility study of this kind of higher operation temperature collectors [7].

4.4.2 BSERI (Beijing Solar Energy Research Institute)

BSERI was founded in 1979 and now is a key unit for solar energy R&D in China. BSERI has six Labs with a technical team of more than 300 persons working in the field of solar thermal, solar photovoltaic, material science, biomass, electronics and energy conservation and conversion technologies [1-5, 14, 15].

In past decade, lots of research outcomes and demonstrations as well as international cooperative projects were completed by the researchers and engineers of the Institute, such as China-Germany Beijing Daxing Solar Village, large size industrial biogas project supported by UNIDO, joint research project on biogas powered absorption refrigerator with IDRC, Canada.

The Daxing Renewable Energy Village is a China-Germany cooperation project which started in 1982 and completed in 1987. The village is located in the south suburbs of Beijing. It features integrated demonstration of renewable energy utilization: 50 passive solar houses with different design concepts equipped with solar water heaters on their roofs and solar cookers in their house yards, solar PV powered interior communication systems (1 kW capacity) as well as water pumping station (10 kW), a 3 kW windmill driving a water pump and the other 20 kW wind generator directly connected to the grid and a 1,4 kW solar thermal pump with 25 m^2 of flat plate collector area for drinking the livestocks.

From 1979 to 1984 the research projects were basically focused on the fundamental research of low temperature solar thermal application. During this period, a solar simulator test facility and an outdoor test station for rating the performance of solar collectors were set up. A number of fundamental study on thermal application were carried out, e.g.:

- Optimization of flat plate collector design.
- Computer simulation for solar water heating system with natural circulation.
- Freezing protection technoques for a year round operation of solar water heating systems in cold climate regions.
- Performance study on the separated components of passive solar heated buildings.
- Computer simulation for predicting the performance of passive solar houses with combination of various types of elements.
- Development of a kind of blocked type solar air collector with simple installation and at lower cost.
- Theoretical and experimental study on solar drying processes as well as solar thermal energy powered water pumps.

After 1984 the main focus research activities is shifted to medium temperature application. The R&D of a evacuated tubular heat pipe collector and absorption cooling systems powered by solar heat or biogas now are underway.

A number of solar cells have been developed, such as CdS and CdTe cell and concentrated single crystal silicon cell. The amorphous silicon cell is still under R&D. At present, the standalone small size solar PV power source systems are being developed for meeting the increasingly demands of energy supply in the households in remote areas.

During the period of 1979 to 1984, the R&D projects were focused to the preparation of selective absorption coatings, such as black chrome, anodized coloured aluminium (α=0,92-0,95, ε=0,05-0,10) as well as a selective paint (α=0,90-0,94, ε=0,3-0,5). At present a high temperature selective surface is under development with a sputtering process.

After 1984 the objective of R&D is turned to thin film technology in more broaden applications. Based on thin film technology, the electric heating film was innovated to take place of coil heating in electric heating appliances.

The Beijing SUNPU Solar New Tech Corporation is a technical development and marketing department affiliated to BSERI. The innovative new products in this company are solar water heaters produced with Sunstrip technology, stoves for cooking and space heating, heat pipe electric heaters and deposited electric heating thin film for all the electric heating appliances.

Besides, the headquarters office of Chinese Solar Energy Socieaty, the Editorial Office of "Solar Energy Journal", and the headquarters Office of China Development Center for Renewable Energy are located in the BSERI´s office building.

The international cooperation projects conducted in BSERI are listed in Table 1.

Table 4

Name of the project	Cooperation partner	Duration
Daxing renewable energy village	Germany	1981-1986
R&D of evacuated heat-pipe solar collectors	Germany	on-going
Biogas refrigerator	IDRC, Canada	1986-1988
Biogas plant using distillery wastes	UNIDO	on-going

Besides, about 500 foreign specialists in the renewable field visited BSERI during the past ten years and 50 research professors and engineers in BSERI have been sent abroad for technical observation as well as working for the international cooperation projects [1-5, 14, 15].

4.4.3 Demonstration Centre

The Solar Heating and Cooling Technology Experiment and Demonstration Centre supported by the United Nations locates in Yuzhong Count, 37 km southeast of Lanzhou City. The Centre covers 85 514 m^2 of land with a solar resource of 2 690 annual sunshine hours, 60% of sunshine rate and an annual irradiance of 5 870

MJ/m^2. With abundant sunlight, beautiful environment, convenient transportation, advanced equipment and comfortable accomodation, the Centre is an ideal place for solar research work.

The first phase of the Centre building project was accomplished in June, 1983. Nine passive solar buildings of different heating patterns, covering a total area of 1 826 m^2, include an experiment complex, dormitory, dining hall, guest house, farmer´s house, reception office, pump house, monitor house and pit-type cave dwelling. Three-year performance test shows that these buildings can meet the thermal comfort demand.

The Centre has received numerous domestic and foreign experts and scholars, government leaders, engineers and farmers since it was established. In recent years, the Centre has organized several national workshops and training courses.

4.4.4 Qinghua University

The Solar Energy Group in Electronic Engineering Department of Qinghua University undertook the national key project - development and application of glass evacuated tubular solar water heaters, invented glass evacuated tubular solar collectors with a new kind of selective coating and heat pipe. The coating has solar absorptivity of 0,92 and thermal emissivity of 0,06 (100 °C), as well as low cost, high productivity and no pollution in production. Solar water heaters can be operated year round, and used in domestic water heating, industrial process heating, air-conditioning, refrigeration, drying and desalination of sea water.

4.4.5 Chinese Academy of Sciences

The New and Renewable Energy Lab of the Institute of Electrical Engineering, Chinese Academy of Sciences was founded in 1979. The Lab is engaged in theoretical and applied research mainly in the field of solar, wind and energy storage. There are four research groups in this Lab with the following research projects:

- Solar thermal application, including medium temperature collector and its industrial and agricultural application, heat pipe solar collectors, solar water heaters, solar cookers, etc.

- Solar photovoltaic application, including small and medium size solar PV power stations, small capacity solar cell powered pumps and stand-alone solar PV power supply systems for domestic lighting, TV sets and radio.

- Wind power application, including wind generators with variable speed and constant frequency brushless self-agitated generators, permanent magnetic generators, combination of wind and diesel engines, control and measurement techniques.

- Energy storage system for PV and wind power input, mainly including inverter and control system R&D.

4.4.6 Guangzhou Institute of Energy Conversion

Guangzhou Institute of Energy Conversion aims to carry out the R&D of solar energy, biomass energy, geothermal energy, ocean energy, comprehensive application of renewable energy in rural areas, and the research of energy conservation technology.

A number of achievments in research as well as technology popularization and transfer have been obtained since the founding of the Institute. They are mainly:

- Solar drying facilities.
- Solar distillation facilities.
- Solar swimming pools.
- Renewable energy village-integrated application of solar and biomass energy in rural areas.
- Geothermal power generation using binary cycle and flash steam systems.
- Biogas power station.
- Anaerobic treatment of industrial waste water.
- Heat exchangers with carbon steel-water heat pipe exchangers.
- Wave converters for navigation buoys.
- Efficient water purification systems for swimming pools.
- Fluidized-suspended-sprayed combustion technology.
- Heat pump installations.

4.4.7 Shijiazhuang Institute

The object of this Institute is to develop rural energy program and to promote the wide use of renewable energy resources in rural areas. In the past eight years, some solar and biomass appliances were developed. They are cylindrical shape integrated domestic solar water heaters, downdraft gasification combustion stoves, passive solar houses with multifunctional water storage wall, energy saving slight spurt irrigation device, etc.

4.4.8 Huazhong University

The Solar Energy Research Group at Huazhong University of Science and Technology devotes itself to solar energy thermal utilization since its foundation in 1978. The research projects consists of:

- Solar refrigerator.
- Solar air conditioning system.
- Vacuum tube CPC collector.
- Vacuum tube covered CPC collector.
- Counter flat plate collector.
- Characteristics of air collector.
- Emissivity properties of solid surfaces.
- Solar drying system.
- High efficiency collector with new design, etc.

4.5 Manufacturers

A variety of solar water heaters have been produced in China for twenty years and now is at commercialization stage with a gradual increase of annual output. At present, there are more than a hundred of small factories and workshops manufacturing solar water heaters with a yearly output of 400 000 square meters (aperture area). The total amount of installed solar water heaters reaches 1,5 million square meters, mainly for domestic hot water supply.

4.5.1 Beijing Sunpu Tech Corporation

The Sunpu Corporation was established in 1988 as an affiliation of BSERI and got significant economics in a short term of two years. The aim is to promote the commercialization and marketing of the renewable energy products based on the R&D results. It is the part of the system reform for the science and technology operational institutions.

The business scope includes:

- Flat plate collectors and solar water heaters.
- Electronic instruments.
- Efficient stoves.
- Various electric heating appliances deposited with ceramic type heating films as well as heat pipe products.

A Sunpu collector absorber production line introduced from Canada in 1986 produces solar collectors and wins the competition in the domestic market.

4.5.2 Nanjing Military Supplies Service Center

Nanjing Military Supplies Service Centre is designated by the General Logistics Department as a key factory of solar water heater production supplying LTR-3 type water heaters to institutions, companies, especially of frontiers and islands of PLA. Up to now the factory has already been supplying more than 10 000 m^2 of various types of solar water heaters to users.

4.5.3 Beijing Solar Energy Appliances Manufacturer

Beijing Solar Energy Appliances Manufacturer was set up in 1976. It is one of the earliest solar water heater manufacturers in China. The factory produces solar water heaters and selective coating materials. Their products have been sold to over 22 provinces and autonomous regions throughout China. The factory is well equipped with an annual capability of 30 000 m^2 of solar collectors.

5 Solar drying

5.1 General

In China solar drying is a lately commenced program in the scope of solar thermal application. In 1970´s a few institutions engaged in the R&D of solar drying, at that time only 7 sets of solar dryer for pilot study. However, in recent years, solar drying application has got a rapid development under the active support of Chinese Government [8].

The traditional method of drying agricultural crops and by-products used in China´s rural area is open air sun drying which mostly depends on weather and environment condition and has little control over drying quality. For instance, the dried products are often contaminated by sand, dust and insects. Usually in summer-autumn harvest season, frequent raining always causes trouble on post harvest drying. Since 1980´s the renewable energy application has been progressively widespread in China´s rural area. Solar water heaters, solar cookers and passive solar houses are appreciated in improving farmers daily life, while solar dryers are used in some process of production activities.

All the solar dryers for drying products, such as agricultural by-products, foods, lumber, medicine herbs and industrial materials, have got positive results and good economics with a short payback time of less than 3 years (some of which has got a payback time as short as half a year) according to the special survey. The advantages of solar dryer can be concluded as follows:

- Saving energy and reducing environmental pollution.
- Improving quality of dried product and reducing cost.
- Less investment and short payback time.
- Better processing condition.

5.2 The status of solar dryer development

The solar dryers developed in China can be classified into five types. They are:

- the green-house type
- the air collector type
- the combination type
- the concentrator type
- the integrated type

5.2.1 Greenhouse type solar collector

This type of solar dryer has the advantages of simple structure and low cost. Its structure is somewhat like a conventional greenhouse. The drying materials in the greenhouse absorb solar radiation directly. Most of this kind of dryer are operated in passive mode. The moisture evaporated from the drying material flows out through natural ventilation.

More than ten sets of greenhouse solar dryer have been built in Shanxi Province for drying red dates, cotton, fur and day-lilies etc. since 1970s. A large size greenhouse solar dryer was built in Yiwu County for drying wooden boards. The greenhouse solar dryers are also used to dry rabbit fur skin and preserved fruits in Hebei Province.

5.2.2 Air collector type

The so called air collector type solar dryer means the drying objects are dried by the hot air heated through solar air collector. The air is heated up to 60-70 °C and then enters the drying chamber. The drying process in the chamber is a convective heat and mass transfer process. A blower is installed in the collector system for enhancing the drying process.

Several large size air collector type solar dryers are under operation in China, such as a timber dryer in Ganzhou, a solar drying kiln for candied fruit in Xinhui, a medicine herb in Shanghai, a solar drying cabinet in Loyang Ceramics Arts and Crafts Factory and a melon seed dryer in Lanzhou.

5.2.3 Combination type

The greenhouse solar dryer generally can not meet the requirements of drying high moisture content objects, such as fruits and vegetables etc. due to its small air temperature rise despite its high efficiency. A few types of combination solar dryer have been built, the typical one is located in Dongguan County, Guangdong Province.

5.2.4 Concentrator type

Using solar concentrator would be an option to obtain much higher air temperature for fast drying. During 1979-1981, five sets of pilot concentrated solar dryer were built for grain drying. After a period of operation, no encouraging results were reported. So this type of solar dryer has been given up for further development due to its complicated structure, high cost, difficult operation and maintenance problems.

5.2.5 Integrated type

In this type of solar dryer, the solar collector is integrated with the drying cabinet. An axial blower is mounted at the connection passage between two arrays of drying unit (collector/cabinet). Since this unit has a higher aperture area/air space volume ratio, say 3-4 times larger than that of conventional greenhouse type, hence, a rapid temperature rise can be obtained. The objects for drying loaded on a tray with four rollers can be pushed into the dryer along a rail track. The forced air flow circulates through the tray. The moisture released off the materials is carried away by exhausted damp air. A part of damp hot air can be recirculated and mixed with the fresh air flowing into the system through a controllable exhaust flap. Hence, a better performance of the system can be obtained.

The integrated solar dryer has the advantage of low thermal inertia, high and rapid temperature rise, higher thermal efficiency, simple structure, low cost and flexible combination. It has been widely disseminated since it was first built in Guangzhou in

1983. At present, this type of solar dryer takes a ratio about 30% of the total amount of solar dryers in China due to its cost-effectiveness.

5.3 Research projects

The present research is focused on following items:

- Solar air collectors.
- Documentation on testing and rating the thermal performance of solar air collectors.
- Research on the characteristics of materials to be dried.
- Performance evaluation of solar drying systems.
- Further demonstration on medium size (more than 150 m^2) as well as large size (more than 600 m^2) solar dryers.
- Solar fluidized bed dryer.

It is anticipated that after the completion of the research projects mentioned above a further development of solar drying in China will no doubt be promoted [8].

6 Passive solar

In China, since 1979, passive solar heating has got a rapid development. Before 1985, passive solar houses were mainly located in the stipulated winter space heating regions and provinces, such as Gansu, Tibet, Beijing, Inner Mongolia etc. Since 1986, they have been expanded to the "space heating transition region" (say the region between stipulated space heating region and none heating region), such as Henan. According to the statistics made in the end of 1989, there are 800 sets of passive solar houses covering the varieties of rural residential houses, urban apartments, schools, hospitals, as well as commercial buildings with the energy saving fraction of 60-80% and the payback time of 2,5-10 years for excessive solar investment [9].

The R&D of passive solar heating design and its thermal performance also steps forward in parallell to the demonstration practice. A simplified calculation method developed by Dr. J Douglas Balcomb is widely used by Chinese engineers and architects. Some detailed physical and mathematical dynamic models and computer analysis softwares for predicting the thermal behaviour and the performance of passive solar houses in Chinese architectural style have been worked out. A technical document of a test method for rating the thermal performance of passive solar houses as well as evaluating their thermal comfort and economics has been drafted.

Besides adopting the traditional passive solar heating techniques, such as direct gain, Trombe Wall and attached sunspace etc., Chinese scientists and architects have developed some new passive solar heating structures and components such as lattice storage wall and rapid heat collection and transmission wall (without storage) as well as using local available low cost insulation materials for ceilings and floors. Night insulation shades, air tight door/window and selective film are being developed and tested in laboratories, and have yet been commercialized.

Among the passive solar houses in Chinese architectural style, a record of minimum diurnal temperature swing of 4 °C has been created, due to their construction traditionally made of heavy thermal mass.

Two international cooperative projects on passive solar heating started in early 1980´s and completed in recent years. One is the China-Germany cooperation project in Daxing County, Beijing and the other is the Lanzhou Experimental Demonstration Center in Gansu financially supported by UNDP. At present there are 39 institutions, widely spread in 13 provinces, autonomous regions and municipalities engaged in research, architectural design, construction and special structural components production for passive solar buildings [9].

7 Solar cookers

Solar cooker is an appliance which converts solar energy into thermal power for cooking. In recent years, the development and dissemination of solar cookers have been proceeded rapidly due to the fuel shortage becoming serious in rural/remote areas as well as the attentions from the Government. There are 113 400 sets of solar cookers produced and used in rural households totaling 200 000 m^2 of aperture area and saving around 50 million kilograms of stalks every year. They make contribution to alleviation of the severe shortage of firewood for cooking in some rural/remote areas where solar resources are rich [10].

The development of solar cookers experienced a long history in past decades. The first solar cooker was produced in Shanghai in 1956. A variety of prototypes have appeared since then, e.g.:

- the "Breadbox type" developed in Anyang,
- the concentrating solar cooker with a lotus pattern from Shanghai,
- the concentrating solar cooker with concave glass mirror from Beijing,
- a ladderlike concentrating solar cooker from Gansu,
- automatic tracking solar cooker driven by clock mechnism from Anyang,
- sided axis parabolic dish cooker from Zhenzhou,
- cement back shell cookers,
- off-axis concentrating cookers with hard paper shell,
- cookers with plastic shell,
- portable folded cookers,
- reinforced fiberglass and casting pig-iron shell parabolic dish,
- reinforced fiberglass foldable solar cookers....etc.

During 1980-1982, a massive dissemination of about 20 000 solar cookers was undertaken in Yongjing County, Gansu Province, where the rural households suffered badly from fuelwood shortage, while the land bathed in bright sunshine. The encouraging results showed the vital role of solar cookers in easing up the tension of energy supply for daily life as well as improving the eco-environment system.

From 1983 to 1985, the Chinese Academy of Agricultural Engineering Research and Planning took the responsibility of organizing a joint R&D team in which 18 units from nationwide took part to conduct further study on design theory, testing method, optimization of design parameters and structure, material selection, etc. After three year joint R&D, the design and manufacture technology of concentrating solar cookers in China was further improved and was able to be produced with acceptable quality. The main points of the achievement are concluded as follows:

1) A "Three Circle Drawing Design Method" was invented for determining the profile of the concentrator of solar cooker. A computer program was complied for mathematical solution of the "drawing method". So now the solar cooker design can be worked on CAD level.

2) For reaching the destination of commercialization of the solar cookers, the right material and manufacture technology was screened. From the feedback information from the consumers and test results, it was concluded that the casting pigiron, glassfibre reinforced cement and glassfibre reinforced plastics are the suitable raw materials for solar cooker shell. For reflective surface, the aluminium deposited plastic thin film and glass mirror are both the ideal material for obtaining good performance and low cost. Besides, a special gelatine for adhering between reflective sheets and back shell and well insulated pot for efficient cooking were also successfully developed.

3) Five series of standard design of solar cookers were proposed for meeting different cooking power demands and habits of consumers as well as suitable for scale production.

In China, the agricultural sector of local governments takes the responsibility of dissemination of solar cookers. The related ministries and commissions play the role of coordinator and advisor responsible for *monitoring* and *quality control* as well as providing certain *support* for production and demonstration.

The figures of diffusion of solar cookers in recent years are listed in Table 5 [10]:

Table 5

Year	1979	1982	1983	1984	1985	1986	1987	1988	1989
Amount (10^4 sets)	0,2	4	6	8	10	10,6	9,8	10,8	11,3

The payback period is estimated of 1-2 years for saving firewood from buying one solar cooker. The economic benefit of developing solar cookers is apparent in fuelwood lacking area where is rich in solar resources [10].

8 Solar photovoltaic

8.1 Present status

China is one of the developing countries with vast territory and abundant solar energy, hence she has a big solar PV potential market. From 1979 to 1988, the annual productivity of solar cells increased by a factor of 150 with a 6-7 fold of cost reduction. The institutions engaged in R&D as well as fabrication of PV cells increase to 40 odd units along with the growth of a technical team in PV field. The 2nd International PVSE Congress was held in Beijing in 1986 [11].

The efficiencies of various solar cells developed and produced in the end of 1988 are listed in Table 6 [11].

Table 6

Kind of cell	Research, efficiency, %	Production, efficiency, %	Test condition
PESC c-Si	20,27		AM 1,5
c-Si	15,6	10-13	AM 1,5
BSFR c-Si	13-14		AM 0
polycrystalline c-Si	13	8-10	AM 1,5
GaAlAs/GaAs	18-19		AM 1
CuS/Cd	8-9		AM 1,5
a-Si	9,8	5	AM 1,5

The highest efficiency of c-Si (19,3%) nears the top of world record (21,3%, developed by Mr. Green of Australia and 19,2% of JPL of USA).

The applications in space and in terrestrial uses are listed in Table 7 and 8 [11].

Table 7

Array	Efficiency, cell, %	Ratio of power to area, W/m^2	Ratio of power to weight, W/kg
China	10,5	25,4	9,6
Intel 4		22,1	11,9
Intel 5	11,67	94,26	75,14
China	12,1	116,0	85,04
Body array	10,5	24,6	11,1

Table 8

Type	Efficiency, %	Power, W	Price, Yuan/peak W
TDB 100x100-36-9	11-12	43	40-45
35D 1000x400	≥13,2	35	40-45
DA 60-38-8B [1]	7-8	8-9	40
8D 249x582 [2]	6-7	8	39
a-1216x912 (mm) [3]	4	44	24

In recent years, the PV market in China has been expanded, lots of solar cell has been used in various areas: agricultural, animal husbandry, transportation, telecommunication, meteorological and eartquake station, medical and military use, etc. PV systems have been installed with power range up to several thousands watts, in which three 10 kW systems are included. By the end of 1989, the cumulative installed PV power is about 1,2 MW. The market distribution in application sectors is given in Table 9.

Table 9
Installed PV power in China by the end of 1989

Area	Application sector	Installed power, kW(p)
Communication	microwave relay stations, TV transmitters, satellite terrestrial stations, carrier telephone systems,.......etc.	400
Remote area and rural use	PV power stations, lighting and TV systems, insect trap lights, electric fence, water pumping systems, ...etc.	500
Transportation	beacons, light houses, highway and railway signalling systems, ...etc.	100
Cathodic protection	sluice gates, oil pipelines, ...etc.	25
Safety	meteorological stations, fire warning systems, earthquake stations, high water warning systems, ...etc.	25
Others	military use, tour boats, street lights, clocks, toys, calculators, ...etc.	20
Exportation	portable lights, garden lights, emergency lights, ...etc.	180
Total		**1250**

[1] Circular cell.
[2] Circular cell.
[3] Amorphous cell.

8.2 Some institutions and manufacturers active in PV

8.2.1 China PV Technology Development Centre (CPVC)

China Photovoltaic Technology Development Centre (CPVC) is an organization for R&D of PV technology under the leadership of related State Commissions and Ministries. Its key task is to coordinate the PV industrial activities to research and develop the technology and to promote its aplication, i.e. to make the solar power as an alternative energy source. In the centre there are more than 20 institutions and manufacturers in charge of research and production of PV devices and systems. Its headquarters is located in the beautiful city Hangzhou and its task in detail are as follows:

- To assist the government to set up the development programme for PV research, development, manufacture and application in China, to formulate the annual plan and to coordinate the implementation of those programmes.
- To set up the standard of specifications and quality control for the PV products in China.
- To strive for reducing the cost and increasing the efficiency of system through research on new materials, devices and systems in PV field, and to carry out R&D of new products in order to enlarge the application scope and exploit the market.
- To contract the project for PV power station.
- To train the technical personel in the PV field.
- To organize the academic exchange and technical cooperation in domestic and international area.

8.2.2 The Sixth Research Institute

The Sixth Research Institute, Ministry of Machine Building and Electronics Industry, is mainly engaged in R&D of micro-computer engineering, communication, microwave energy, PV applications, etc. There are ten research labs in the Institute. One of the labs is involved in solar PV engineering. More than ten PV projects have been completed, such as the 560 W PV powered cathodic protection charging system in Inner Mongolia, the unattended PV powered microwave relay stations, the PV powered cathodic protection system for sluice gates, the PV powered TV repeated and the PV powered carrier telephone system, etc. In recent years, a series of associated software and hardware products have been developed in this Institute, such as PV system designing software-PVCAD, AN series of square-wave DC/AC inverter, DLG-2 current inverter, TC-200 universal solar cell tester, TZ series of high efficiency fluorescent light, XB series of charging controller, etc.

8.2.3 Kaifeng Solar Cell Factory

Kaifeng Solar Cell Factory is a specialized enterprise of producing solar cells and is one of the members of China Photovoltaic Technology Development Centre. The Factory started her trial production of silicon material and solar cells in early 1970s. The main products are "TDA" series single crystalline and "TDP" series poly-crystalline silicon solar cells, modules and arrays. In 1985, the Factory imported some advanced solar cell fabricating technologies and equipment from the United States. Since then, the quality of the products has been significantly improved and the production capacity was enhanced. The products have been sold to 24 provinces and entered into international market.

8.2.4 Huamei Photovoltaic Electronics, Ltd

Huamei Photovoltaic Electronics, Ltd is a TV enterprise jointly run by Hong Guang Electron Tube Plant and Qinhuangdao Electron Tube Factory. It is one of the modern single crystal silicon solar cell fabricators in China equipped with three production lines which were imported from United States. The major products of this company are single crystal silicon ingots and wafers, solar cells, concentrating solar cells, solar cell modules and their appliances.

8.3 Future efforts

China is a large country, 30% of her villages still do not have electricity. It is not possible to cover the electric grid everywhere, particularly in remote areas, as well as offshore isles even in future. No doubt PV will play an active role for providing decentralized power sources in these areas. Today, just a very small part of PV market has been exploited. The cost of PV in future China´s market will be expected as follows [12]:

Table 10
Forecast for the PV market of China

Year	Annual production, MW(p)	Module price, Yuan/W(p)	System cost, Yuan/W(p)	Application sectors
1989-1990	0,5-1,0	**c-Si** 30-40, **a-Si** 18-20	**c-Si** 60-100, **a-Si** 50-90	Decentralized systems, communication systems, small-scale pumping systems, etc (up to few kW)
1991-1995	5-10	**c-Si** 20, **a-Si** 12	**c-Si** 40-60, **a-Si** 30-50	Medium size power stations, large pumping systems, desalination systems, etc. (10-100 kW)
1996-2000	10-50	**c-Si** 15, **a-Si** 8	**c-Si** 30-50, **a-Si** 25-45	Large-scale stand alone systems for commercial, industrial and residential uses. (100 kW-1 MW)
2100	>100	5-10	20	Central utility (>1 MW)

Note 1 US $ = 5,2 Yuan (RMB).

A program on solar PV further development is under planning for meeting the needs of space technology development, such as synchronous orbit satellite, space station etc. The aim of the program will pace in two steps. In the first stage, the efficiency of c-Si cell will be improved to the level of 16-17% (AM 0, for the area size of 2x4 and 2x6 cm). After then, the multijunction cell with efficiency as high as 30-40% will be developed and in the meantime, the target of characters of PV array, say, the ratio of power to area, the ratio of power to weight and voltage limitation will reach 300 W/m, 300 W/kg and 300 V respectively.

For terrestrial use, the target is focused on the commercialization of amorphous silicon cell with efficiency of 8-10% and cost of 7-10 Yuan/peak W (module).

The development of hybrid renewable energy system integrated with the use of solar PV system is also an attractive potential development.

It is suggested that Chinese Government will formulate the suitable policy including tax reduction for assisting this new and promising industry to play an active role in easing the energy shortage in the rural/remote area of China [11].

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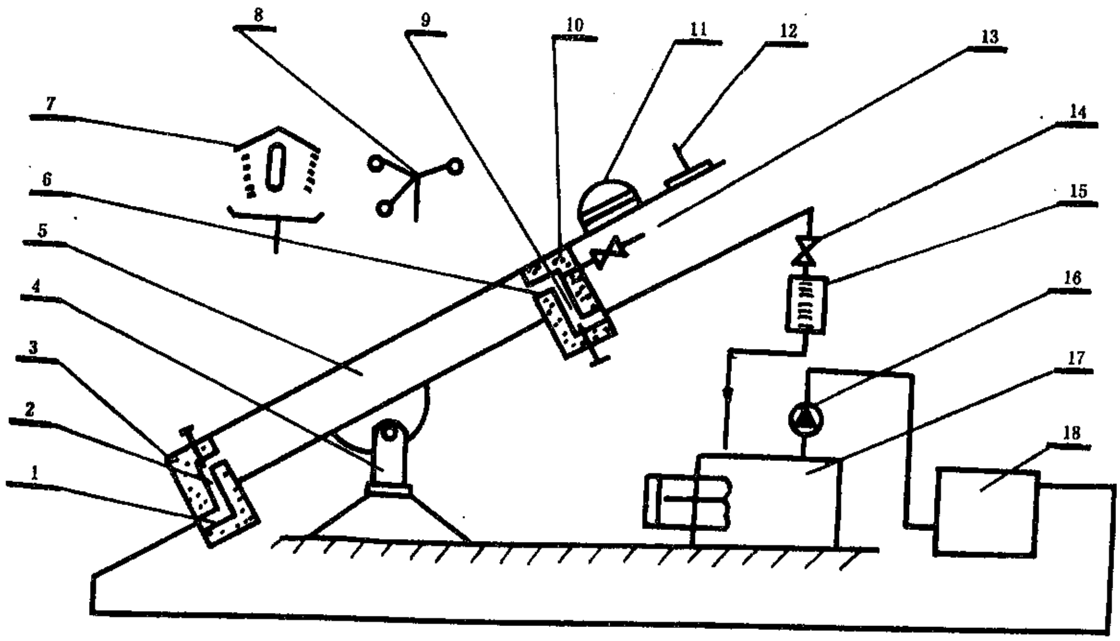

Figure 1
Test rig for rating performance of solar collectors.

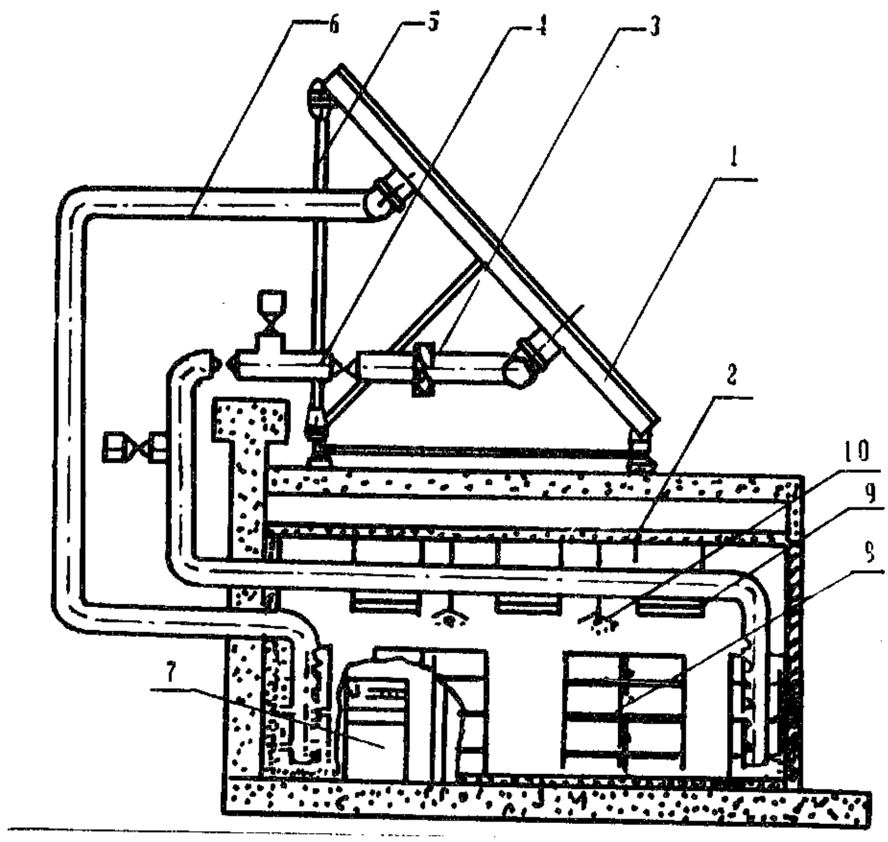

Figure 2
Solar dryer at Loyang Ceramic Arts and Crafts Factory.

1	solar air heater	2	drying chamber
3	axial fan	4	inlet pipe system
5	support	6	exhaust pipe
7	operation controller	8	unbaked ceramic stand
9	IR ray heating plate	10	lighting lamps

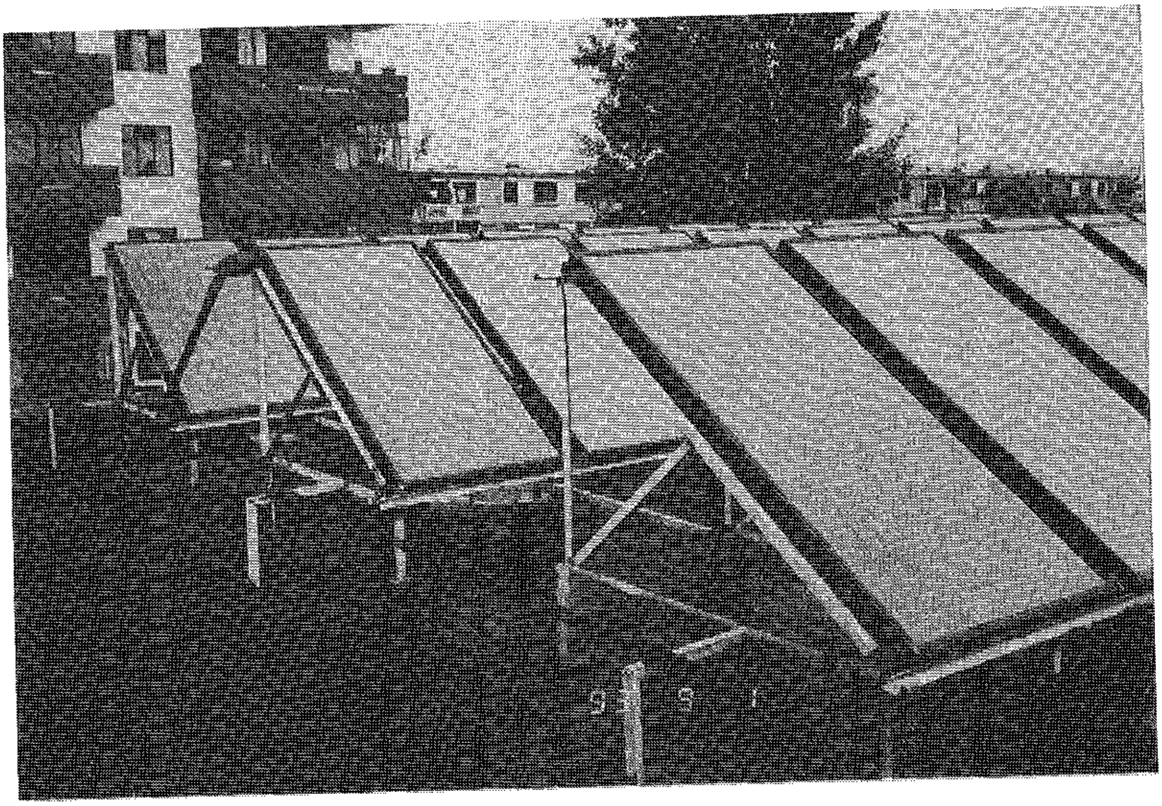

Figure 3
Solar water heating system.

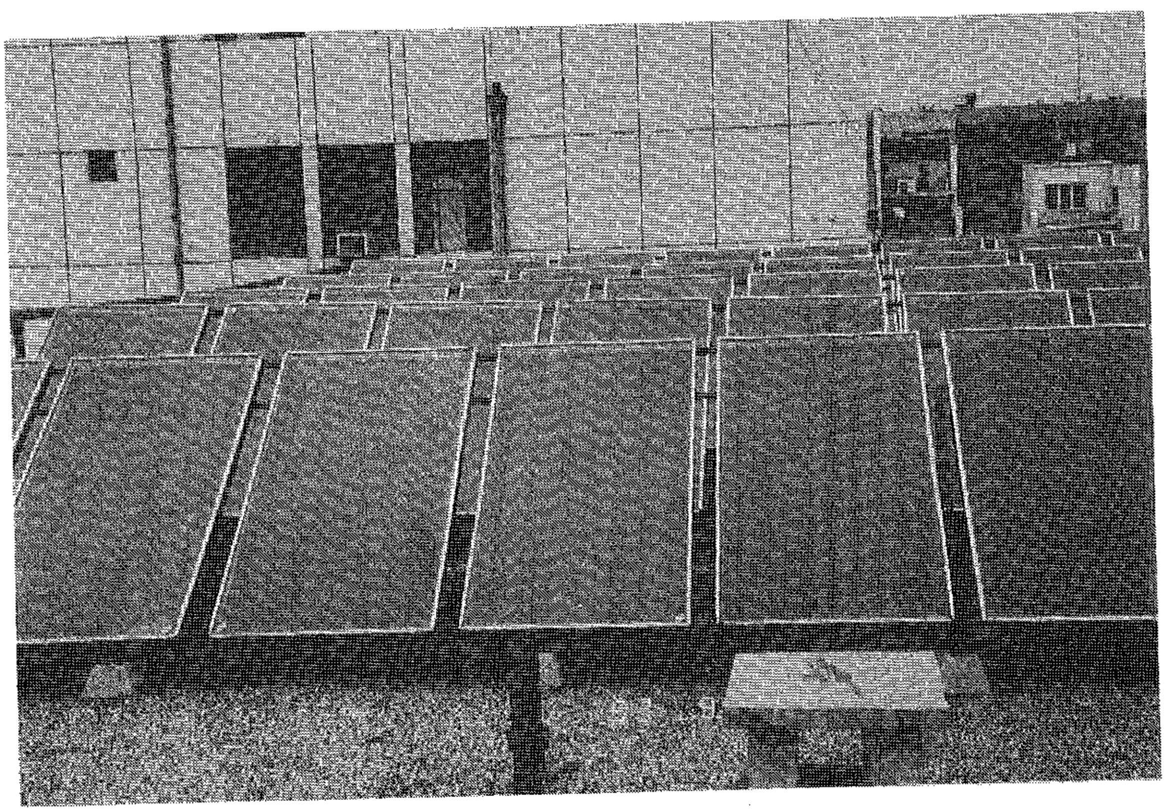

Figure 4
Solar water heating system.

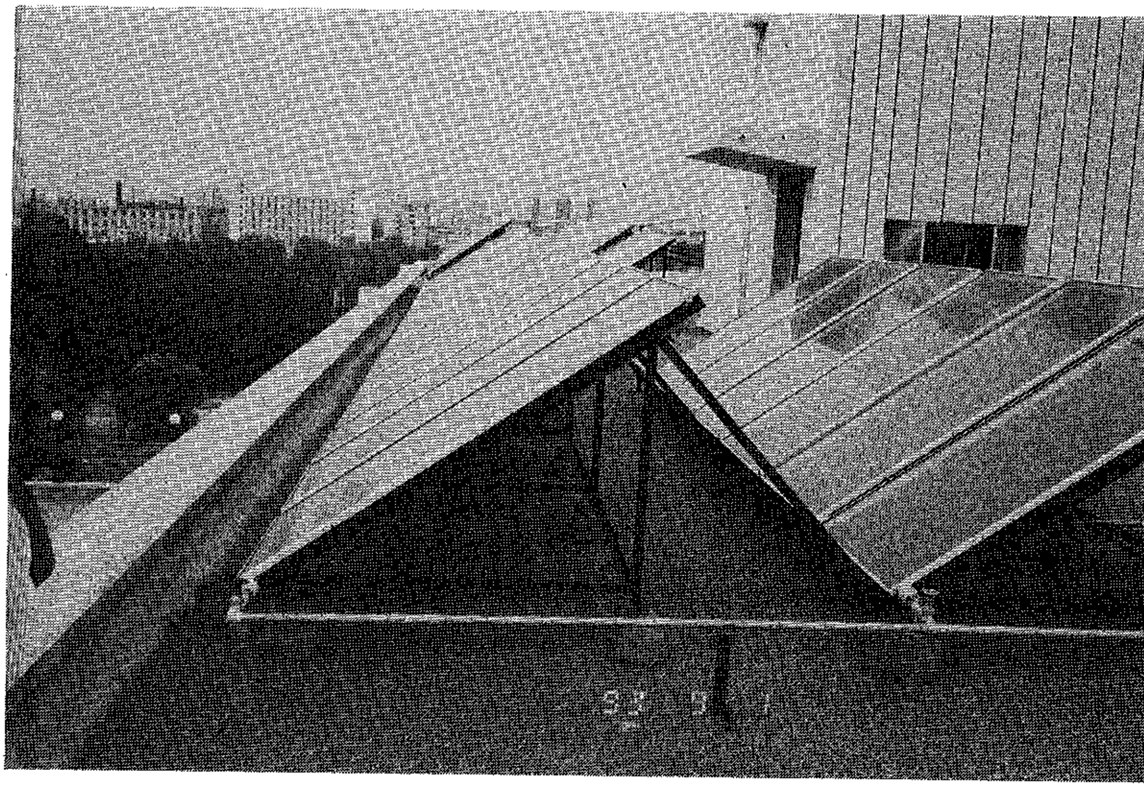

Figure 5
Solar water heating system.

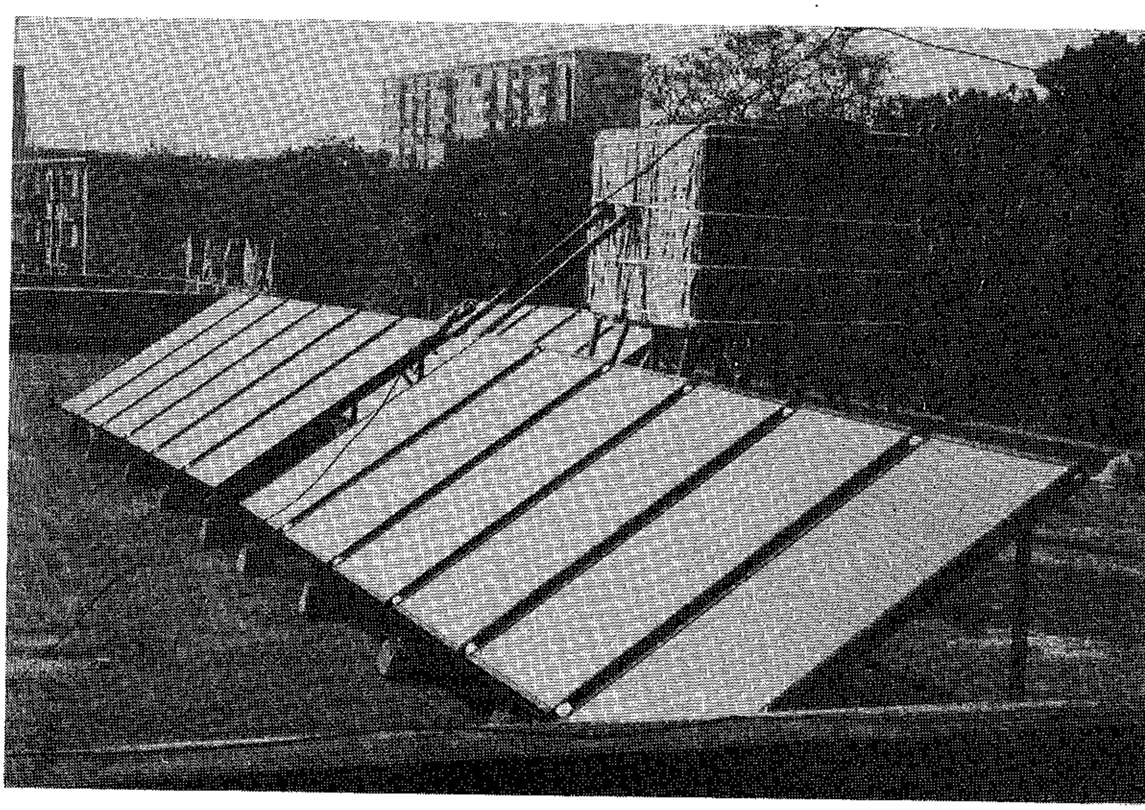

Figure 6
Solar water heating system with hot water tank.

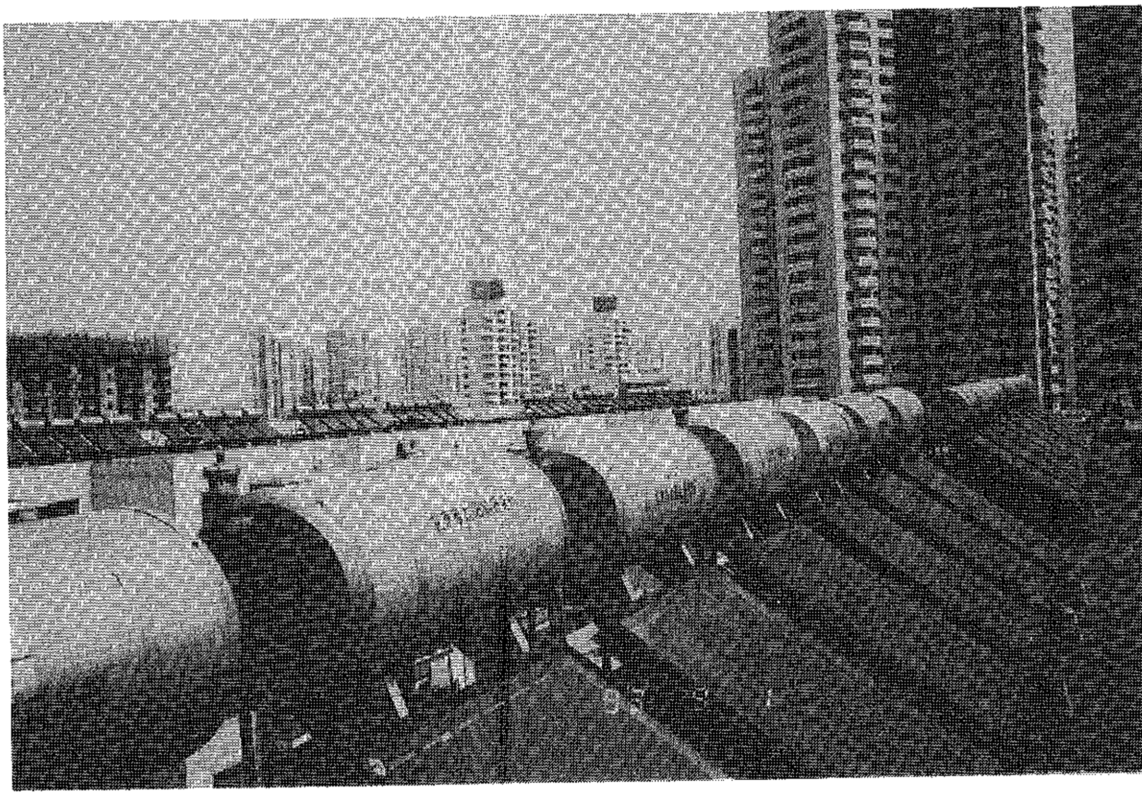

Figure 7
Solar water heating systems of thermosyphon type in multi-storey apartment building, with 1 m^2 and 70 liter water tank for each residential flat. Parliament area in Beijing.

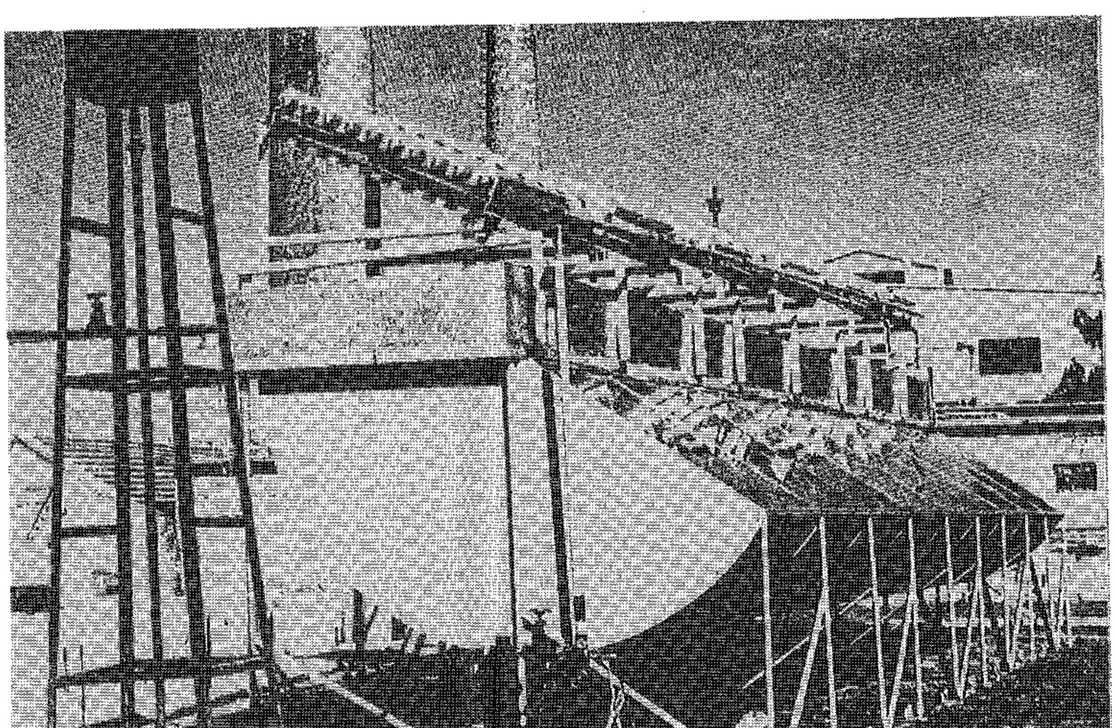

Figure 8
Medium temperature solar collectors.

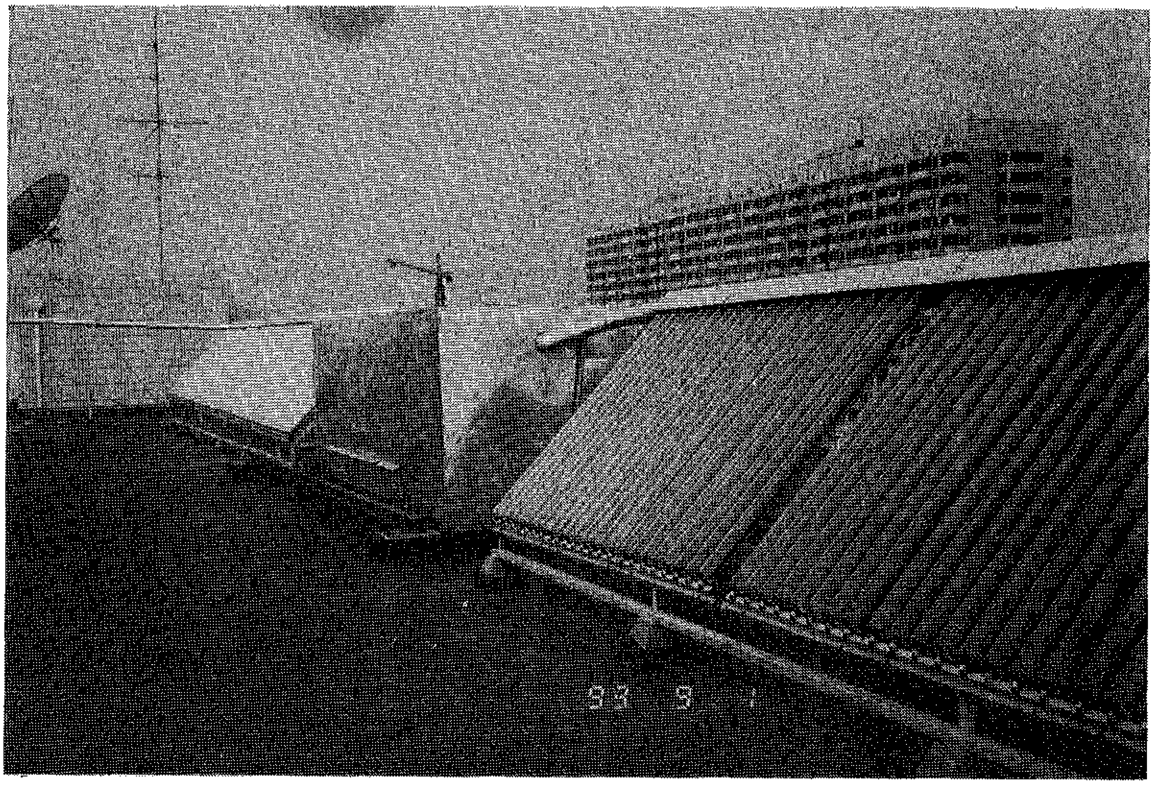

Figure 9
Evacuated solar collector with heat pipe-installed on the building as all-year-round solar water heating system.

Research and Produce:	BSERI.
Cooperation with:	Dornier System GmbH, Germany.
Solar collector type:	BTZ-1
Appearence of glass tube:	Ø=66 mm, L=1660 mm
Heat pipe:	Copper-water gravity heat pipe
Absorber plate:	Copper-foil with black cobalt coating, α=0,9, ε=0,08
Vacuum:	<1,33x10^{-2} Pascal with barium getter
Performance:	Stagnation temperature 225 °C (insolation 800 W/m^2)
Output:	(single tube, insolation 1000 W/m^2)
	55 W (condenser temparature ≈ 75 °C)
	47 W (condenser temperature ≈ 110 °C)
Weight:	2 kg per tube

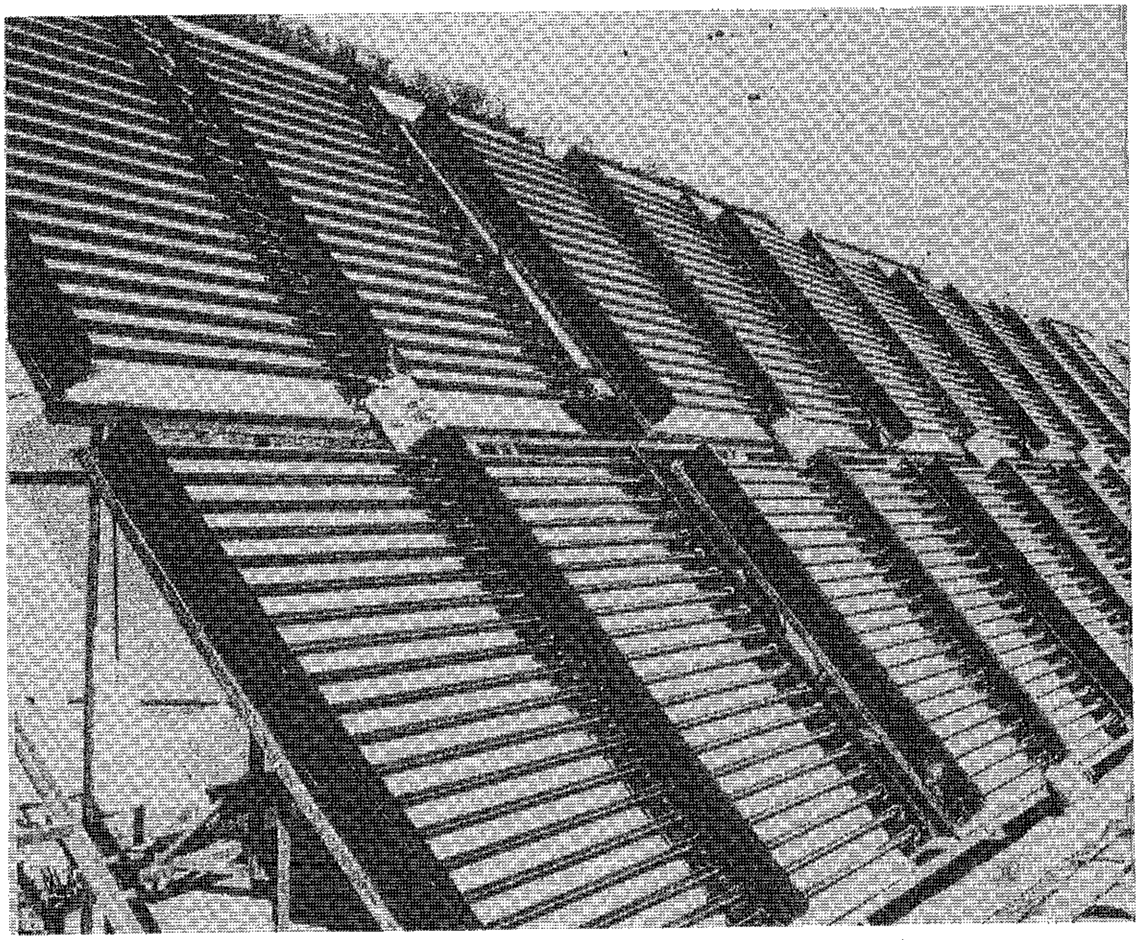

Figure 10
Hot water system with evacuated tubular solar collectors.

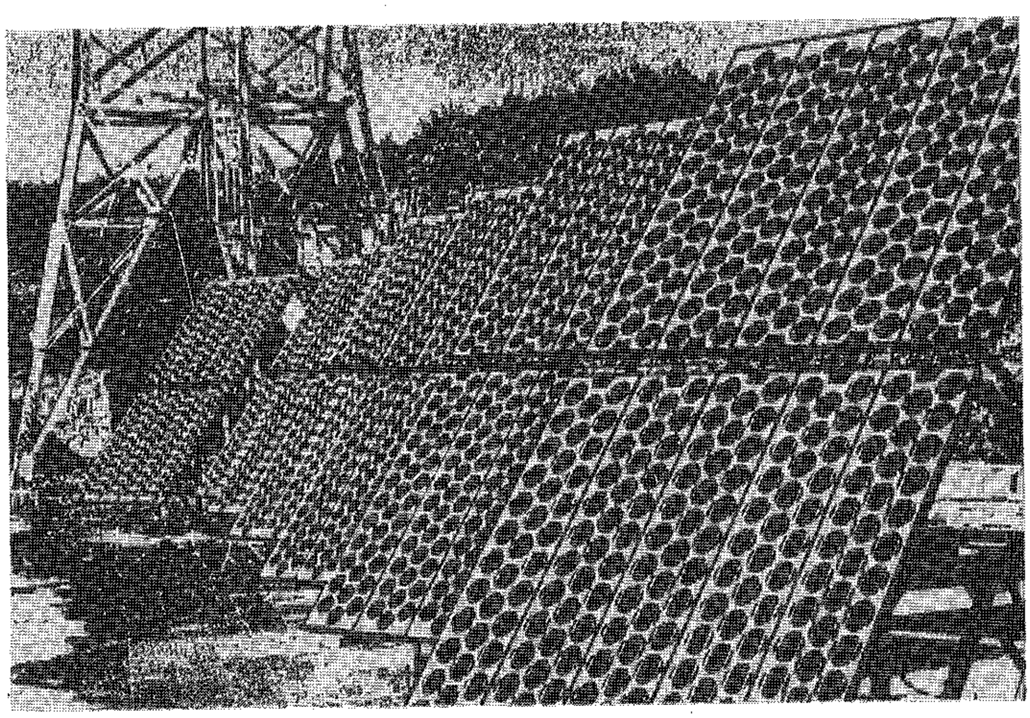

Figure 11
Solar powered channel microwave relay station Changzhi-Jincheng, Shanxi Province.