Session 3 — Solar Energy

SOLAR ENERGY IN ISRAEL — UTILIZATION AND RESEARCH

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ABSTRACT. The State of Israel has been a pioneer in solar energy development and utilization since it was founded. In the 50's, Solar Domestic Hot Water Heaters (DHWS) became commercially available. At the same time research work was started in different areas of solar energy, which led to more advanced solar systems for additional applications. The presentation includes some details on commercial utilization of solar energy and a brief description of the main R&D projects in industry, universities and research institutes.

INTRODUCTION

Currently, solar energy accounts for over 3% of the total energy consumption in Israel, mainly by DHWS use. It makes Israel the world's largest solar energy user per capita. The share of solar power in the energy market is expected to rise to 4.5% by the year 2000. Local industry provides the components for DHWS and other applications of solar energy. Most DHWS use natural circulation systems for hot water supply to small residential units. Forced flow installations have become common as well and are used in high-rise buildings, hotels and in agriculture and industry. About 65% of all households in the country have DHWS. Their reliability is demonstrated by the fact that their manufacturers guarantee them for up to 8 years. Israeli legislation requires that every new apartment building up to 9 stories will employ a DHWS.

While Israel does not yet have a commercial solar power plant, the Jerusalem-based Luz Company has manufactured concentrating trough collectors for the construction of thermal power plants in the USA. The company has installed a number of electricity generation units with overall capacity of more than 350 MW; these comprise about 95% of the world's electricity supply produced by solar energy. The Negev Desert is the region best fit for solar power stations in Israel due to abundant sunshine and extensive undeveloped space. A solar radiation and land survey is being carried out there to choose the best location for future solar power stations.

Two types of Solar Ponds have been investigated in Israel. The first large-scale efforts to utilize solar energy trapped in salt-gradient Solar Ponds, by means of organic Rankine cycle turbines and applications to solar desalination, were done by Solmat (a subsidiary of Ormat Industries). The other was a Thermal Diode Solar Pond based on use of fresh water and developed by the Arel/Argaman Company. Various solar thermal units with novel solar collectors (Paz/Pimat), selective coatings and cooling systems have been constructed. The technology of solar space heating and absorption air conditioning (Paz-Gal) has been developed, demonstrating technological feasibility in various applications.

Solar energy is extensively utilized on a large scale for industrial evaporation at the Dead Sea Works and in sophisticated greenhouses all over the country. The use of photo-voltaic systems is rapidly increasing, mainly in small-scale systems. The applications include an experimental project for the supply of electricity to single houses in a small community, spot illumination and emergency communication. Passive climate control principles were developed and are being increasingly considered in designing new buildings.

At present, advanced R&D is being carried out by research institutes, universities and industry. Some of the projects are close to commercialization. Two large facilities for solar R&D, the Sde Boqer Test Center and the Weizmann Institute Solar Tower, are in operation — investigating various methods of electricity production and thermal utilization. This presentation describes the main areas of solar energy utilization and current solar research in Israel.

UTILIZATION OF SOLAR ENERGY

Israel was the first country to utilize solar energy on a commercial basis. Considering the lack of fossil fuels, the very limited hydro-power potential, and the relatively large number of clear days during the year, the orientation towards solar energy development was natural.

1. Solar Hot Water Supply
People in Israel began to buy solar flat plate collectors for heating water about 40 years ago. These systems were based mainly on natural circulation (thermosyphon) and served individual families. With the growth of high-rise buildings, forced circulation systems have become increasingly common. The energy crisis following the Yom Kippur War in 1973 caused the acceleration of R&D activity to improve the performance of existing collectors and to develop more advanced systems. It is interesting to note that 16 years ago, the installment of solar heaters and water tanks on building roofs was forbidden in several municipalities, due to esthetic reasons. Today, roofs covered with DHWS systems are a common sight in Israel (Fig. 1).*

Thermosyphon systems of variable sizes, for single family homes, are marketed extensively. The common system includes a $2m^2$ flat plate collector with a 160 liters tank. Since there is no pump and no moving parts, little maintenance is required, involving mostly occasional cleaning of the collectors.

The common collector is constructed of a transparent cover, an absorber plate and black painted steel tubes. The leading manufactures (Chromagen, Miromit, Amcor, etc.) have made some improvements, like selective coatings on the absorber plate to reduce radiation losses, finned structure in the air gap between the cover and the absorber to decrease heat convection losses, and copper tubes to increase heat conductivity.

Natural circulation systems are obviously not suitable for large-scale applications, i.e. high-rise buildings and industry. Thus, the development from thermosyphon systems to a forced circulation was necessary. Forced circulation systems are controlled by differential thermostats which activate the pumps whenever the temperature of the liquid in the collector exceeds that of the storage tank. Many such systems have been built for hotels, hospitals, military camps, dormitories and kibbutz communities. The cost of additional components, such as the pump, controller and piping, is quite small per family unit, and therefore in many cases forced circulation systems are used in apartment buildings as well.

Today, solar hot water systems are extensively used in Israel. There are a few dozen firms that produce and market collectors or systems incorporating them. Many of the systems meet the requirements of Israel Standards Institute's (ISI) codes and are manufactured under ISI supervision. DHWS systems are reliable and their prices have gone down. The leading manufacturers guarantee the systems for 8 years and have sold millions of collectors in Israel and abroad. The price of a complete thermosyphon system ranges between $600 to $800, about half of it for the collector. The forced circulation central system is priced in the range of $800 per apartment. Experience shows that the payback period is in the range of 4-7 years for most families. It is noted that in the mid-seventies, the universities and research institutes, especially the Technion, Ben-Gurion University and Weizmann Institute, cooperated with industry in developing this kind of systems.

The government has encouraged the installation of solar heating units by reducing taxes and by promulgating regulations requiring solar systems in all new buildings having up to 9 floors (except hospitals and industry). The Ministry of Energy and Infrastructure gives partial financing for solar energy conservation in the public and private sectors. The Ministry also provides information to the public through the printed and electronic media and individual consultations in Advisory Bureaus.

2. Swimming Pool Heating
Swimming pool heating seems to be one of the most feasible applications of solar energy, due to low temperature requirements and the built-in energy storage in the pool water. Since pool water temperature does not exceed 28-29°C, the outlet water temperature of the collector can remain below 40°C. There are two possibilities of delivering heat — by using regular flat plate collectors at relatively high efficiency (over 60%), or by using inexpensive plastic collectors at lower efficiencies. The second option is becoming more popular in Israel and several companies produce and install these plastic collectors. Plastic collectors can also be used for pre-heating water in open systems.

3. Natural Evaporation and Utilization in Agriculture
One of the Israel's main natural resources is the Dead Sea, with its very high concentration of salts. The Dead Sea Works, one of the most successful Israeli chemical industries, processes and exports large volumes of potassium chloride produced by natural solar evaporation of the Dead Sea brine. The salt solutions flow into large evaporation ponds. The first one, about 70 km^2, is used to deposit sodium chloride, which is not marketed in such large quantities. The brine is then transferred to smaller ponds to deposit the main raw material, carnallite — for production of potassium chloride and other chemicals.

* *All color figures appear at the end of the article; the pages have been misnumbered*

The abundant solar energy, coupled with a severe shortage of water in Israel, has led to very advanced agricultural production in greenhouses. Solar heating has been adapted to enable the export of vegetables and flowers during the winter. Israeli researchers have developed several types of solar greenhouses, which can absorb and store the excess energy during the day and release it as heat at night (Fig. 2). Different design techniques have been adopted to maintain temperature and humidity at the required levels: sloped greenhouses, soil and space heating, natural and forced ventilation, storage of energy in water pool or in rock bed, etc. As a result, the average energy requirement of a greenhouse has been reduced by a factor of two over the last 30 years. On-site computerized systems for greenhouse control, including irrigation, have been developed to optimize growth of various crops.

Several agricultural products, such as tobacco, spices, herbs and vegetable seeds require air-drying at moderate temperatures and are natural candidates for innovative solar drying systems (Fig. 3).

4. High Temperature Hot Water and Steam Production

The solar heated water systems discussed in the previous sections are based on flat plate collectors.

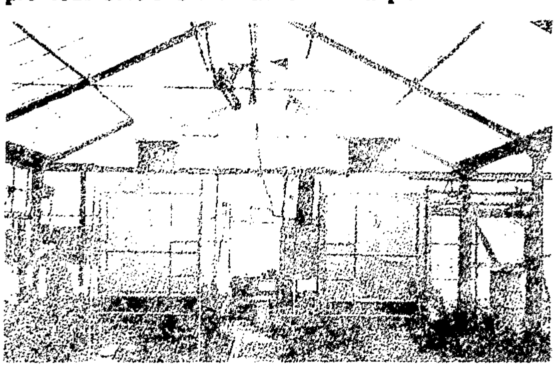


Fig. 2. Storage of solar heat in salts to cool and heat a greenhouse

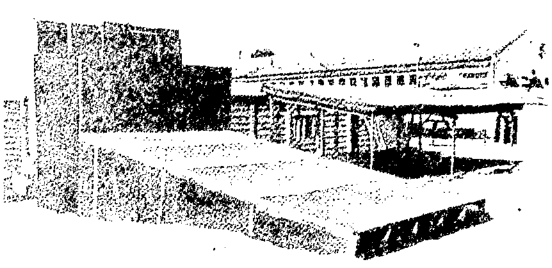


Fig. 3. Low-cost thermosyphon dryer

To produce hot water at higher temperatures or steam, concentrating collectors are necessary. In the past such systems were too expensive, but today they compete quite favorably with other energy sources.

Paz Oil and Pimat have together developed and installed several novel fixed concentrating systems for heating water to temperatures of 80-90°C and tracking systems for producing steam at 150-200°C. These systems are suitable for laundries, hotels, hospitals, apartment houses and industry.

Hot water heaters, based on an original design for a low-profile collector which is similar to a compound parabolic concentrator with a working fluid tube at the focus of the mirrors, have been developed (Fig. 4). This system consists of an aluminum mirror reflecting a beam onto a selectively coated steel pipe at the line focus and has a collector efficiency of about 50% at 90°C (Fig. 5). The collector stand allows simple adjustment of orientation to summer and winter positions.

Figure 6 shows a steam generation system with higher concentration ratio than the water heater; it has modules of parabolic mirrors positioned on a rotating axis which reflect sunlight onto a glass pipe located above them.

Recently, a system combining 500m^2 of collecting areas was installed to supply hot water and steam to the Hillel Yaffe Medical Center in Hadera (Fig. 7). In all, 20 such units are now in operation in Israel.

5. Solar Cooling, Refrigeration and Desalination

A unique solar-powered cooling system has been developed at Ben-Gurion University. This system uses solar energy at 90-95°C; the heat drives an absorption cycle by using an organic working fluid (Fig. 8). The system is able to lower the refrigerate temperature below 0°C, in contrast to conventional systems which are limited by the freezing point of water. The Paz-Gal firm applies this technology to industrial systems with up to 120 tons of refrigeration (Fig. 9).

A desalination process which can be powered by solar energy was developed by Israel Desalination Engineering (IDE) and has been used in different locations over the world. However up to date, IDE's low-temperature multi-distillation desalination units have been powered by fossil fuels due to economic reasons. Such a system at an installed capacity of 20,000m^3 of fresh water per day has been operating near the southern Israeli city of Ashdod, adjacent to a coal power station.

6. Solar-Thermal Electricity Production

Three main concepts have been tested in the world to produce electricity by solar thermal processes. The only one which has succeeded on a large scale is the

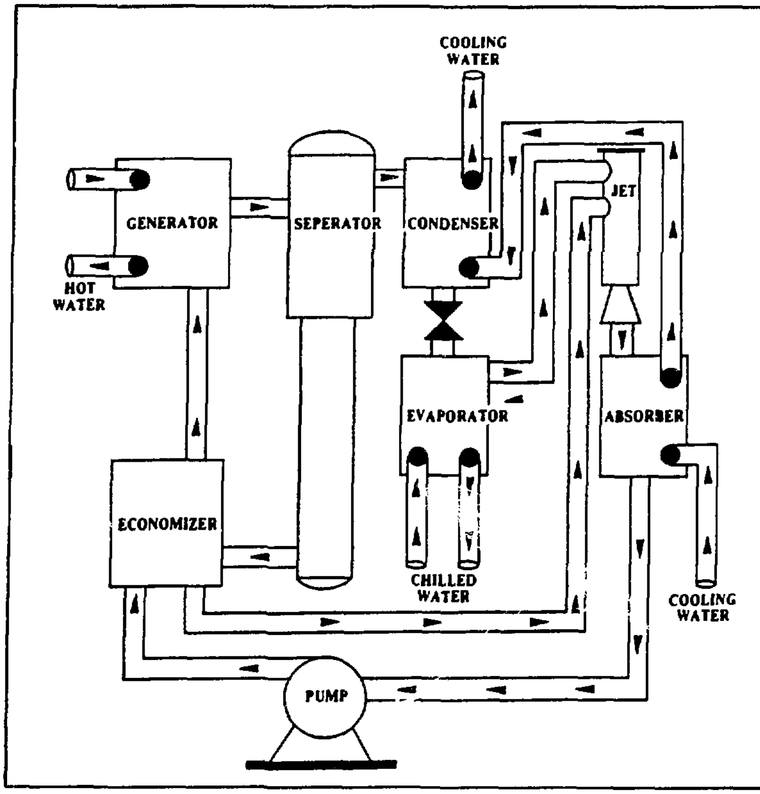


Fig. 8. Flow chart of the Pazgal Absorption Machine

Luz parabolic trough collector system. The Luz corporation has constructed eight power plants in Southern California, USA (Fig. 10), with a total capacity of more than 350 MW. The collectors have been developed and manufactured by the Luz plant in Jerusalem, Israel, which continuously improved its technology from one generation to the next. These improvements include the type, size, shape and material of the mirror, the tracking system, the various coatings and materials for vacuum tubes, vacuum technology, connections between metal and glass, etc. (Fig. 11).

Figure 12 is a schematic presentation of a Luz plant. The unit consists of a series of modular solar through collectors (large parabolic mirrors), which track the sun and concentrate the solar radiation on a heat-collecting pipe placed at the linear focus of the reflectors. The working fluid is oil, which can reach temperatures of about 380°C. The hot oil is pumped through a heat exchanger to produce superheated steam. The steam then powers a conventional, electricity generating, Rankine-cycle steam power plant. A natural gas fired boiler provides back up steam for the turbine.

Today, the Luz power plants are the only large scale solar thermal power production in the world — a 10 MW power plant using the solar tower concept was shutdown some years ago in Southern California and the operation of a 5 MW Solar Pond at the Dead Sea in Israel was also stopped. The last two concepts are further discussed in the R&D chapter. Finally, Luz has carried out feasibility studies in India, Mexico and Italy and has been negotiating additional programs in several countries, including Israel.

7. Direct Sunlight Conversion to Electricity by Photo-Voltaic Solar Cells

Although the price of photo-voltaic (PV) systems has considerably decreased in the last few years, they are still too expensive to replace electricity obtained from the national grid. Since the electricity supply network is highly developed in Israel, the market for PV systems is rather limited and it does not appear that it will become very attractive in the near future either. Several applications do exist, however, where it is not cost-effective to invest in an electricity distribution system. These include communication systems in remote areas; illumination of bus stops, cross roads and even street lighting (as shown in Figure 13); control elements in large irrigation systems; cathodic protection to prevent piping corrosion, etc.

The Ministry of Energy and Infrastructure supports a demonstration project to supply all the energy needs by solar energy to 18 private houses at the small village of Klil, in the Galilee. Each house receives 2.5 KWh per day entirely from PV panels. The hot water is provided by solar DHWS. Batteries are used to store the power. Recently PV panels have started to appear in the market for several private applications, such as garden and front-house illumination, water pumps, etc. These are affordable to many people, showing that the cost of PV systems is, indeed, going down and a potential of increasing utilization exists.

Unlike the solar thermal applications, there is no real effort towards large scale commercial production of solar cells in Israel. Two Israeli companies (Manor and Sonerco) have designed and installed imported solar cell systems for public organizations, like the government and local municipalities. The companies have also developed a smart system, which increases the illumination when it senses the presence of people at a bus station. This device helps to reduce the size of both panels and batteries, as well as the cost of the whole system.

SOLAR RESEARCH AND DEVELOPMENT

Solar research in Israel started in the early 1930's. During the 50's research and development begun on selective coatings for DHWS, parabolic-trough tracking concentrators and solar ponds. After the oil crisis of 1973, solar R&D picked up considerable momentum. In 1977, the new Ministry of Energy and Infrastructure took over responsibility for energy programs, including solar energy. Since its founding, the Ministry has spent more than $50 million on solar R&D and a comparable investment has been made by the industrial and academic sectors. Currently, research and development in solar energy is carried out by many Israeli organizations — universities, research institutes and industry. Even in areas where solar systems are used on a commercial basis, industry continuously works to improve design, materials, coatings and production methods to develop more efficient, less expensive systems.

1. Test Facilities

In 1987, the Sde Boqer Solar Test Center was built in the Negev Desert by the Ministry of Energy to facilitate the comparative evaluation of solar powered technologies under actual field conditions. Today, the facility is operated by the Ben-Gurion University. Several Israeli firms utilize the center to test various units, using on-site computerized data-logging and processing systems. The layout of the site is shown in Figure 14.

Another facility for R&D is the 3 MW Solar Tower at the Weizmann Institute of Science, in Rehovot (Fig. 15). Sunlight is reflected to a target at the focus of 64 concave, computer controlled heliostats arranged in a field (Fig. 16). The heliostats 2-axes tracking system makes it possible to obtain high concentration of solar radiation at the central receiver aperture, generating working gas temperatures of up to 600-1000°C (Fig. 17). Since 1988, the facility has been used for high temperature solar research, such as methane reforming with solar energy providing "chemical storage" in a solar "chemical heat pipe" (Fig. 18). The product gas (syngas) can be transported at ambient temperature by pipeline to a distant terminal and reacted to release heat for various applications. The Solar Tower can provide sunlight at a concentration ratio of more than 10,000. The facility can also be used for testing high temperature gas turbines (a further description follows in Section 3), oil-shale gasification and converting solar radiation to monochromatic laser light, required for efficient photo-chemical reactions.

The following sections describe briefly the main R&D projects.

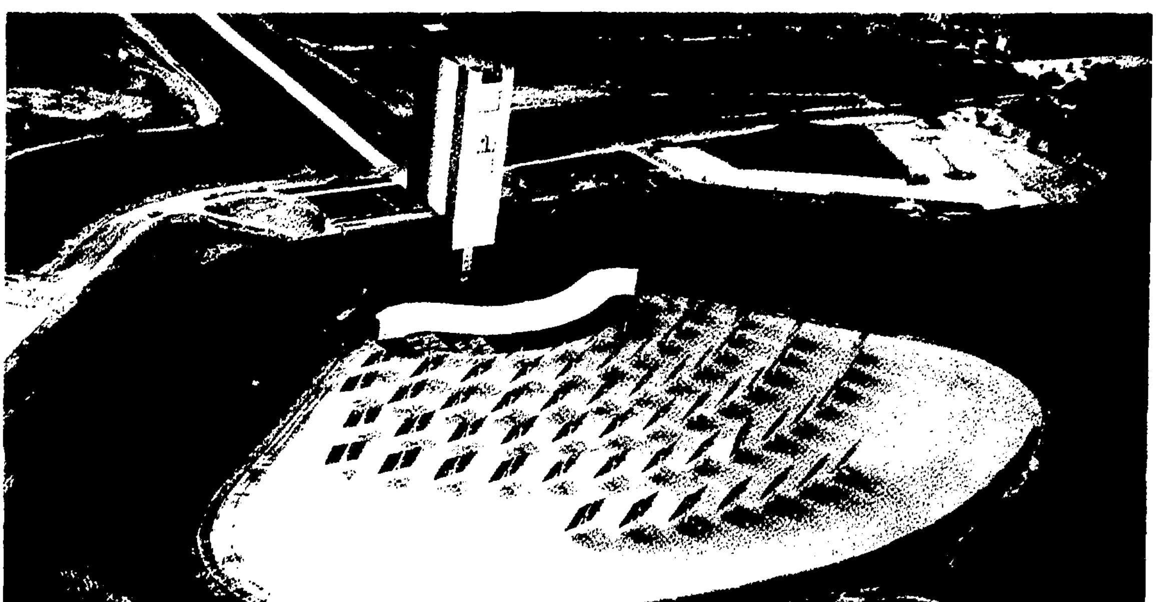


Fig. 15. The Solar Tower at the Weizmann Institute

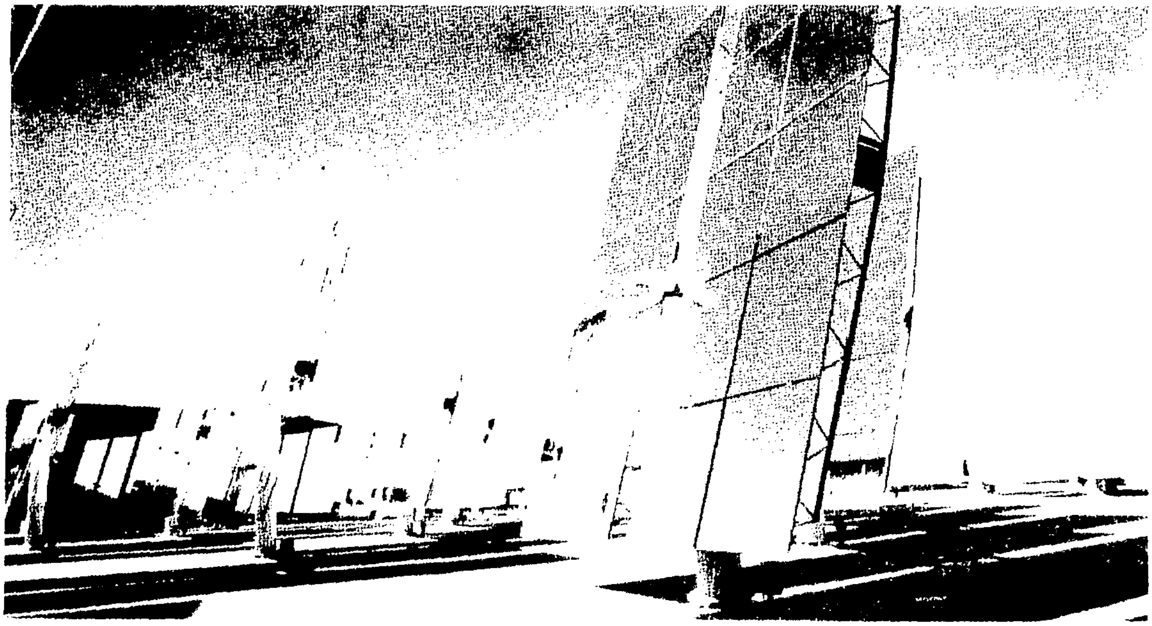


Fig. 16. Heliostats arranged in a field at the Weizmann Institute

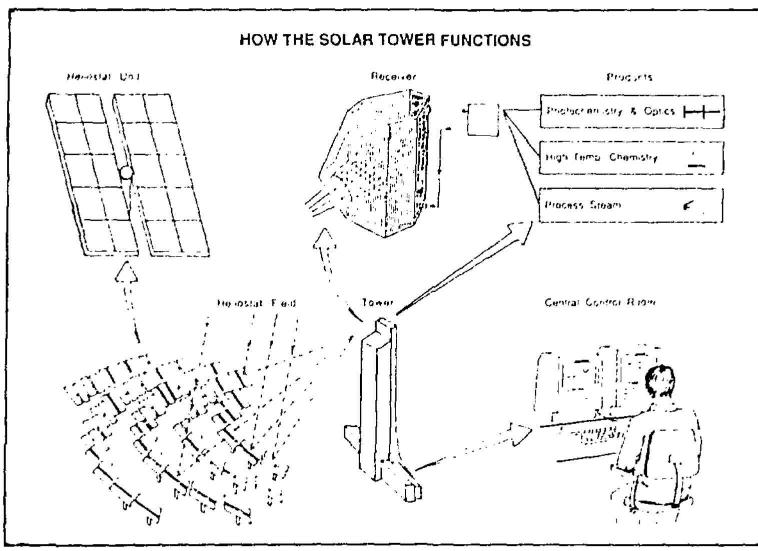


Fig. 17. The Solar Tower Functions

2. Climate Control in Buildings: Room Heating and Cooling

In principle, solar panels for heating water can also be used for home heating. However, this application is not yet economical due to the large investment in collectors and storage needed for only a few winter months with many cloudy and rainy days. A large system to supply heat for a library, constructed at the Technion, was the first attempt at solar space heating in Israel. This demonstration facility has been operating for about 15 years, much longer than was previously estimated. The accumulated experience from the Technion unit was used later for the design of more advanced forced circulation solar heating systems.

Solar-powered air conditioning is also not economical, because the temperature provided by flat plate collectors is barely sufficient to operate an absorption system. Furthermore, a large collector area is needed for a limited period of time. A demonstration system with a nominal cooling capacity of 200 tons of refrigeration, powered by a 3000 square meters of solar collectors, was built about 12 years ago by Tadiran — to supply air conditioning at the Sheba Hospital in Tel-Hashomer. This system has proven to be technologically sound, but not economical. A more realistic concept would be the use of the same collectors for heating in the winter and air conditioning in the summer. Indeed, the Paz Corporation is experimenting with a novel absorption system of concentrating collectors which is described under Utilization of Solar Energy, Sections 4 & 5. The first demonstration project has

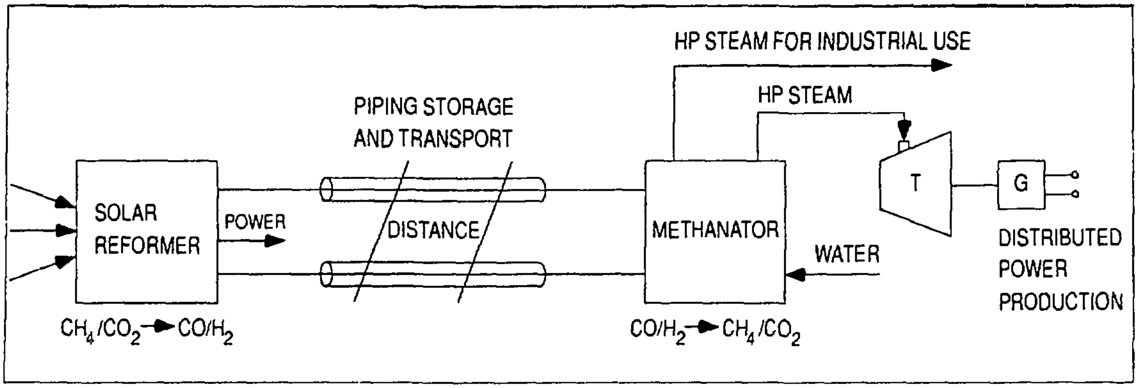


Fig. 18. Chemical energy storage and transport system

been built for the Visitor's Center in the Sde Boqer Test facility. Initial calculations indicate that this system has the potential to be economical. Moreover, it is possible to integrate a solar panel with a back-up biomass combustion system. The simplicity, easy installation and low operating cost could be useful at small combined facilities in remote locations.

Another approach to space heating is solar air heaters. Unlike water heaters, this kind of units is not commercially available, although it seems that quite efficient collectors can be produced at a low cost. Several designs of solar air collectors, which significantly reduce the heat convection losses, including reflective-fins and capillary-tube structures, are being tested at the Technion (Fig. 19).

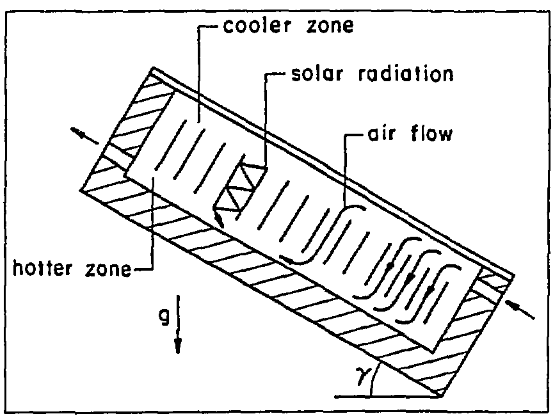


Fig. 19. Reflective-Fin or Capillary-Tubes for solar air heater

3. Research in Solar Thermal Electricity Production and Desalination

As mentioned under Utilization of Solar Energy, Section 6, the Luz Company worked to improve collectors, tracking systems, structures, coatings, production and treatment methods. Moreover, Luz tested a new concept, in which direct steam generation occurs in the collector itself. This approach would eliminate the use of thermal oil and steam generator, thereby increasing the overall efficiency and reducing the cost of the system. Further experiments were planned in the Sde Boqer Test Center.

Another approach to thermal electricity production is the salt-gradient Solar Pond investigated and developed by Ormat/Solmat. In this pond, a salinity gradient (and therefore a density gradient) is created and continuously maintained. The density of the water-salt solution increases with depth. The heat is "trapped" in the bottom layer and temperatures of 85-90°C can be reached there. The top layer has relatively low salinity at temperatures near those of the ambience. The hot bottom brine is withdrawn for the extraction of thermal energy by low temperature turbine. The organic fluid chosen provides the optimization of overall efficiency. The power module consists of an evaporator, a vapor turbine coupled to a generator, a condenser and a feed pump (Fig. 20). Several test facilities of increasing scales have been built with different combinations of solar pond size and power block capacity. A 5 MW Solar Pond power plant was constructed in Beit Haarava at the Dead Sea shore and was operated at partial capacity for a certain period of time (Fig. 21). The project showed the capability of a solar pond to act as a large collector, including its own built-in storage, and demonstrated the technological feasibility. A solar pond power plant can be built, properly maintained and operated for many years. Also, such a plant can be coupled into a grid, supplying either peak or base-load electricity. The size of the pond and the power module can be tailored to match the power profile required. Currently, however, a power plant based on a solar pond does not seem economical, mainly due to its low thermal efficiency. The Ormat organic vapor low-temperature turbine, developed for solar ponds, has been used in several countries for power production from geothermal sources.

Another concept for solar thermal electricity production is that of a central receiver located on a Solar Tower, coupled with a gas turbine, as mentioned here in Section 1. A ceramic receiver (Fig. 22) heats pressurized air to about 1000°C. The hot air is expanded through a gas turbine, which drives the generator. An experimental 250 KW Ormat gas turbine is now installed at the Weizmann Institute Solar Tower to test this method. Israel Electric Corp. is also participating in the project.

The Ormat Company is also examining several desalination processes, using heat and electricity provided by a solar pond (Figs. 23 & 24). As mentioned above, water shortage is a severe problem in Israel, so large scale desalination will be needed in the near future.

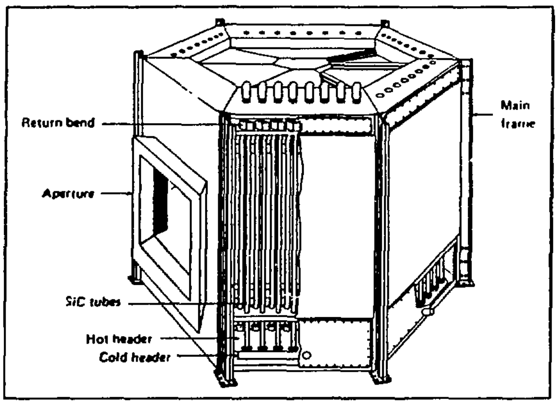


Fig. 22. Artist's sketch of the ceramic receiver

Other methods of desalination, based on the extension of the solar still concept (evaporation and condensation under a transparent cover), are being studied at Ben-Gurion and Tel Aviv Universities (Fig. 25).

4. Additional R&D Projects

Another concept of a solar pond, based on the use of fresh water, has been developed by Arel Energy Ltd., a subsidiary of Argaman. This pond is created by covering the surface of the water with special thermal diode panels, comprising a transparent polycarbonate encased within a glass box. The panel transmits solar radiation downward, but prevents upward heat losses that would normally be caused by natural convection and radiation. The depth of the pond can be tailored to provide storage for daily, weekly or seasonal cycles. The thermal diode solar pond can store energy in the form of hot water at 60-90°C. The energy is suitable for commercial space heating, absorption refrigeration cycle, hot water supply, greenhouse glazing, etc. Today, several units of up to 400m^2 surface area are in operation.

A very brief summary of additional current R&D projects on solar thermal processes, methods and equipment is given below, listed by research centers.

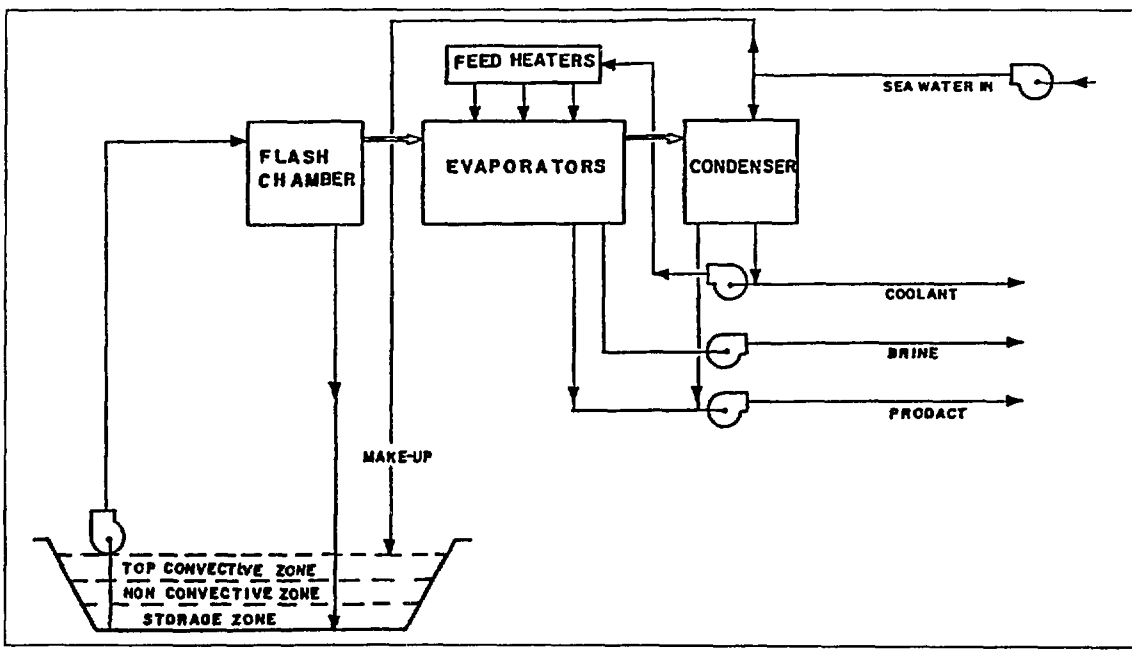


Fig. 23. Dual purpose M.E.D. solar pond plant

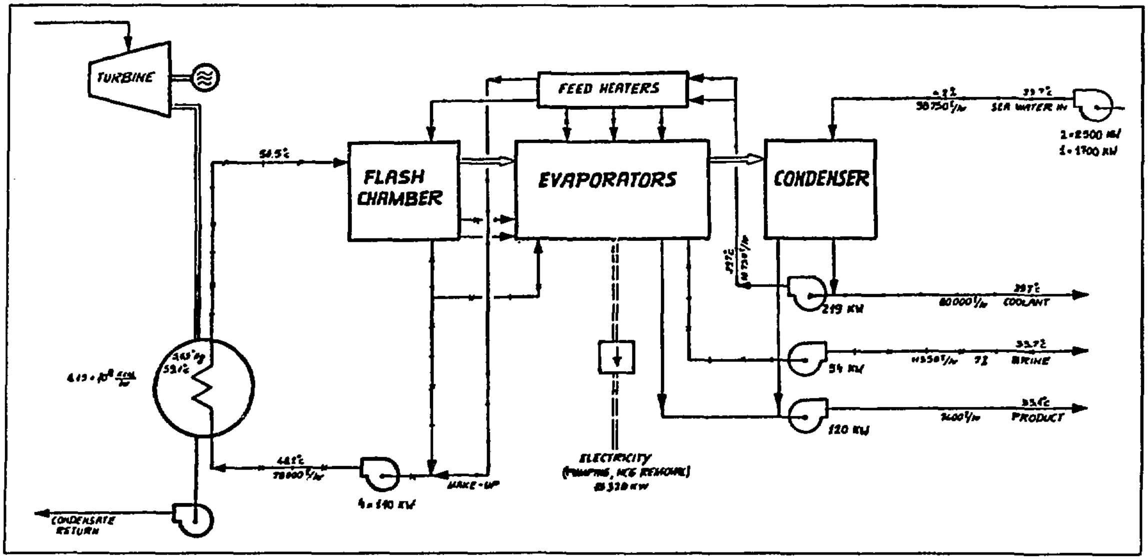


Fig. 24. Ormat dual purpose M.E.D. sea water plant

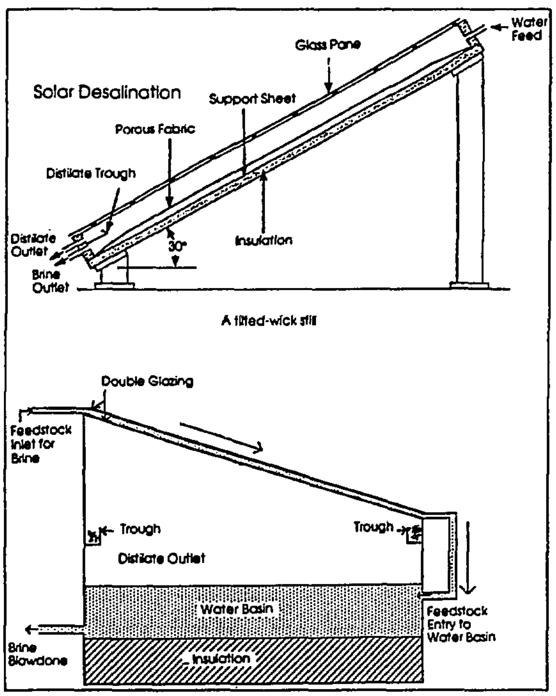


Fig. 25. Above: A tilted-wick still
Below: A simple double-effect solar still

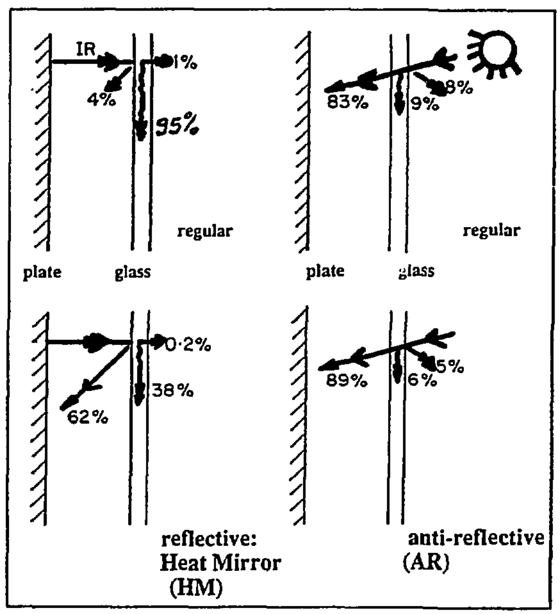


Fig. 26. Glass radiation properties and improvements by coatings

- Technion and Rafael: Improvement of intermediate and high temperature sytems — concentrators, evacuated collectors, reflective heat mirrors and various selective coatings, anti-reflective for solar radiation (Figs. 26 & 27).
- Ben-Gurion University (BGU): novel concentrators; hybrid systems; radiation measurement methods (equipment and data analysis); stochastic modeling; orientation of collectors and efficiency determination methods.
- Tel Aviv University (TAU): Improved thermosyphon configuration; thermodynamic analysis and system optimization; phase change materials for solar pipe energy storage; ejector cooling.

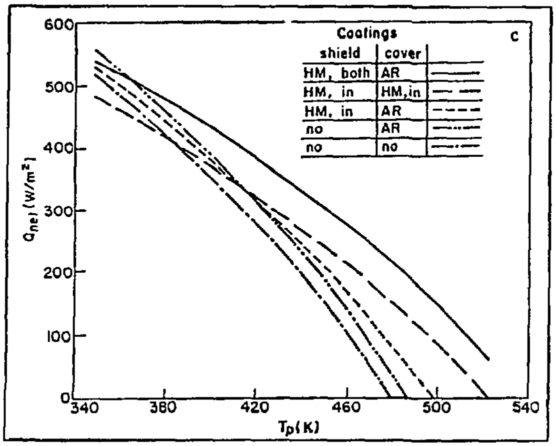


Fig. 27. Effects of heat mirror and anti-reflective coatings (HM, AR)

- In the 80's, research programs were also carried out at the Hebrew University in Jerusalem in such areas as fluorescent glass solar concentrators, storage of thermal energy in phase change materials, improving the electronic properties of amorphous silicon, hydrogen production by solar radiation and photo-chemical reactions.

5. Photo-Voltaic Systems

As mentioned under Utilization of Solar Energy, Section 7, solar cells are not manufactured in Israel on a commercial basis. However, R&D projects on materials, coatings and production methods are carried out in all the universities mentioned above, in the Jerusalem Technical College and in industry. Paz, for example, is testing the concept of increasing cell array efficiency by using side-mirrors, which reflect additional radiation onto the solar PV panels. Other projects include combined thermal and PV systems, as well as irrigation applications. A group at TAU is investigating satellite electric power and solar radiation on Mars. Finally, a group at the Sde Boqer campus of BGU developed the PV-ISRAEL software to design photo-voltaic power production systems.

6. Passive Solar

Passive solar principles, together with other means of energy conservation in buildings, can be incorporated in the design stage to save energy without compromising comfort. The principles of passive solar include conservation, orientation, materials, windows, shading, illumination and many others. The R&D projects have included numerical simulations, computer aided design and promotional programs. Researchers have found that passive solar features, which add 10-20% to the construction cost, can save 60-80% of winter heating expenditures. Energy saving of 20% can also be achieved through proper building orientation and placement of windows. Two groups at the Technion (Architecture and Civil Engineering) and one at the Sde Boqer campus of BGU have developed the principles for more efficient buildings and have issued guidelines for planners. The guide covers existing buildings, new constructions and regional planning, especially in desert areas. A Climatic Atlas of Israel for planners, which includes data from 40 weather stations, has also been completed. A number of "solar houses" have been built in Israel, employing these principles (Figs. 28 & 29).

Regulatory efforts have focused only on rules for thermal insulation of residential and public buildings. Unfortunately, the scope of regulatory efforts has yet to be extended to cover the thermal mass of buildings and regional planning based on climatic factors. As a result, passive solar principles are not yet implemented on a large scale by architects and civil engineers. It is believed that government incentives and legislation could change the picture, similar to the success in implementing solar water heating, as described under Utilization of Solar Energy, Section 1.

EDUCATION

The rapid R&D progress and the large scale utilization of solar energy in Israel has been supported by educational programs all over the country. All universities offer teaching and training curricula in solar energy and related areas on both undergraduate and graduate levels. Theses on a variety of solar energy subjects have been written, including experimental and theoretical studies, numerical simulations and optimizations, technical and economical evaluations.

The Ministry of Energy and Infrastructure has been conducting numerous educational programs, including courses, workshops, conferences, promotion in the media and consulting in advisory offices.

The Israeli Section of the International Solar Energy Society (ISES) holds various workshops and conferences, providing information on local and international activities. Israeli experts in solar energy participate in the international solar energy conferences and present the latest developments in the international journals.

SUMMARY

The presentation attempted to describe, briefly, the achievements and advancement of solar energy in Israel, both in utilization and R&D.

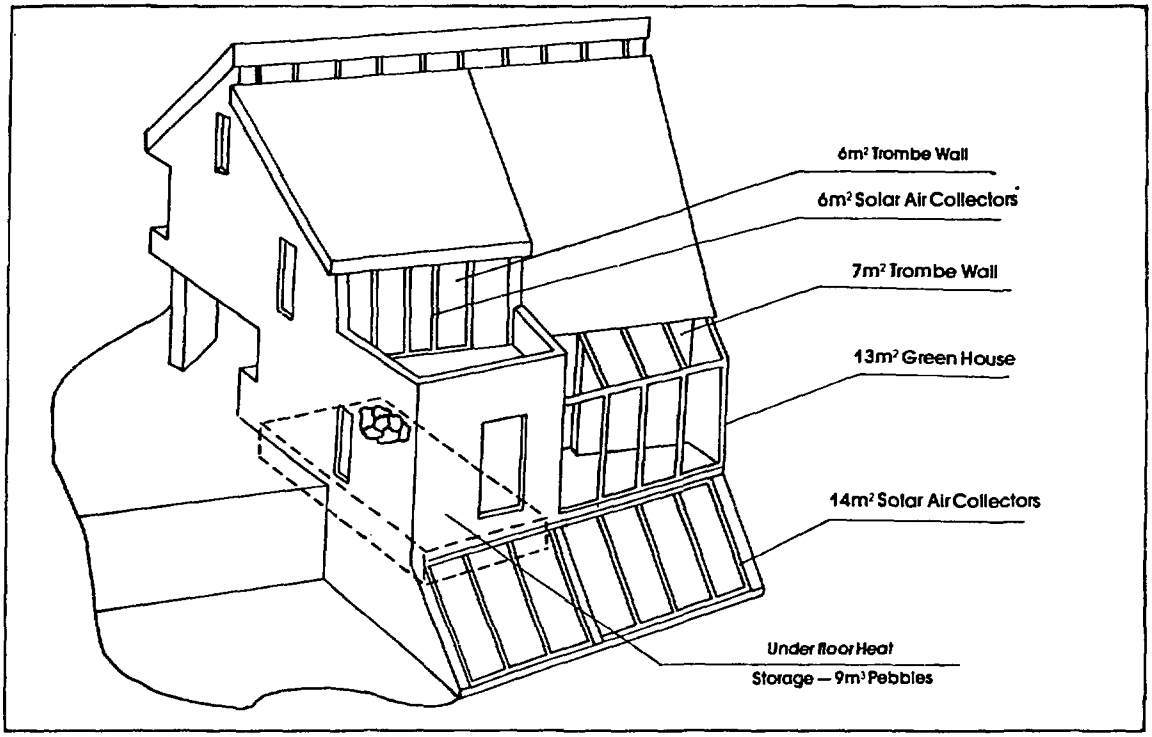


Fig. 29. Passive Solar in Jerusalem

As mentioned above, solar energy supplies over 3% of the energy consumed in Israel, which makes this country the world's largest solar energy user per capita. Solar energy has the potential to supplement or replace conventional energy in a variety of applications, such as water and space heating, cooling of buildings, steam production in industry and electricity generation.

Israel is among the world's leaders in the application and development of solar energy. A strong capability exists to supply a variety of solar energy technologies. About $38 million have been invested between 1979-1990 in a number of industrial scale solar demonstration facilities (Table 1) throughout the country. Most of them are still in operation. Local industry provides systems for DHWS, concentrating collectors and equipment for solar power utilization, exporting complete panels and systems. Different projects are at various stages of development, including some at or near commercialization.

Advanced R&D is being carried out in various universities, research institutes and in industry, encouraged by the Ministry of Energy and Infrastructure.

Ser. No.	Description	Location	Year of start-up	Capital invest $1000 *
1	Solar roof & collectors heating swimming pool	Weizmann Institute	1979	80
2	Herb drying	Maon District	1979	50
3	Water heating for kibbutz laundry	Kibbutz Geval	1980	16
4	Cooling by absorption in hospital	Tel Hashomer	1980	462
5	Water heating in an industrial process	Kefar Sava	1981	9
6	Hydrosolar greenhouse	Tiral Yehuda	1981	25
7	Fruit drying	Rishon-Le-Ziyyon	1981	37
8	Sanitary water heating	Jabotinsky boarding school	1981	4
9	Sanitary water heating	Haifa University	1981	8
10	Sanitary water heating	Bet Yona	1981	20
11	Sanitary water heating	Eshkol Regional Council	1981	25
12	Sanitary water heating	Tel Aviv University	1981	35
13	Sanitary water heating	Senior citizens home at Be'er-Sheva	1981	42
14	Sanitary water heating	Naval school at Akko	1981	35
15	Water heating (addition)	Haifa Univrsity	1982	69
16	Sanitary water heating	Kibbutz 'En Gev	1982	9
17	Sanitary water heating	Iskar Blades Plant	1982	8
18	Sanitary water heating	Technion - Israel Institute of Technology	1982	67
19	Sanitary water heating	Senior Citizens home at Ramat-Gan	1982	22
20	Water heating in student's quarters	Haifa University	1982	45
21	Sanitary water heating	Beit Hachayal at Be'er-Sheva	1982	4
22	Sanitary water heating	Girls' Institute at Bene-Beraq	1982	18
23	Solar passive homes	Ir-Ganim	1982	6
24	Water heating for dairy farm	Kibbutz Giv'at Hayyim	1982	2
25	Sanitary water heating	Kibbutz Alumot	1982	8
26	Water heating in restaurant	Kibbutz Dovrat	1983	7
27	Sanitary water heating	Senior Citizens Center at Akko	1983	34
28	Water heating for swimming pool	ILAN — Disabled Sports Center	1983	50
29	Water heating for communal kitchen	Dovrat Hostel	1983	6
30	Water heating for communal kitchen	Kibbutz Nir Yizhaq	1983	2
31	Water heating for dairy farm	Kibbutz Usha	1983	2
32	Water heating for hotel kitchen	Elat	1983	22
33	Storage for space heating	Jerusalem	1984	12
34	5 MW solar pond demonstration	Bet ha'Arava	1984	21000
35	Water heating for dairy farm	Kibbutz Ma'agan Mikha'el	1984	8
36	Water heating for plating process	Ra'ananna	1984	51
37	Water heating for hotel kitchen	Elat	1984	30
38	Sanitary water heating by solar pond	Kibbutz Ma'oz-Hayyim	1984	50
39	Water heating for hotel kitchen	Jerusalem	1985	15
40	Steam for communal kitchen	Kibbutz Nir Eliyahu	1985	35
41	Sanitary water heating	Giv'at-Shemuel	1985	14
42	Sanitary water heating	Kibbutz Alumim	1985	16
43	Swimming pool heating	Mizpe-Ramon Municipality	1985	20
44	Photovoltaic lighting systems	Natural Reserve Authority	1985	17
45	Water heating for hotel kitchen	Elat	1986	27
46	Village electrification by photovoltaic systems	Mizpe Kelil	1986	271
47	Water heating for communal kitchen	Elat	1986	27
48	Various small remote photovoltaic systems	Hundreds; dispersed	1987-90	810
49	Demonstration project—photovoltaic—by Paz	Sede Boqer Test Center	1987	180
50	Hydrosolar greenhouse	Giv'at Khen	1987	25
51	Hydrosolar greenhouse	Kefar Bialik	1987	20
52	Sanitary water heating in boarding school	Giv'at Washington	1987	35
53	Sanitary water heating in boarding school	Kefar Batya	1987	40
54	Sanitary & community kitchen water heating	Kibbutz Shefayim	1988	42
55	Solar pond for greenhouse heating	Bet ha'Arava	1988	76
56	School dormitory heating by solar pond	Petah Tiqwa	1989	27
57	Demonstration project — heat — by Luz	Sede Boqer Test Center	1989	783
58	Solar tower for R&D	Weizmann Institute	1989	12000
59	Demonstration project — steam — by Paz	Sede Boqer Test Center	1989	720
60	Water heating for guest house	Kibbutz Kefar-Blum	1990	58
61	Water heating for communal kitchen	Kibbutz Netiv-haLamed-He	1990	46
62	Steam and hot water for hospital	Hillel Yaffe Hospital	1990	750
63	Demonstration project — PV — Israel Elec. Corp.	Sede Boqer Test Center	1990	220
	Total			**38654**

* Cost at the time of investment.

Table 1. List of industrial scale solar installations in Israel

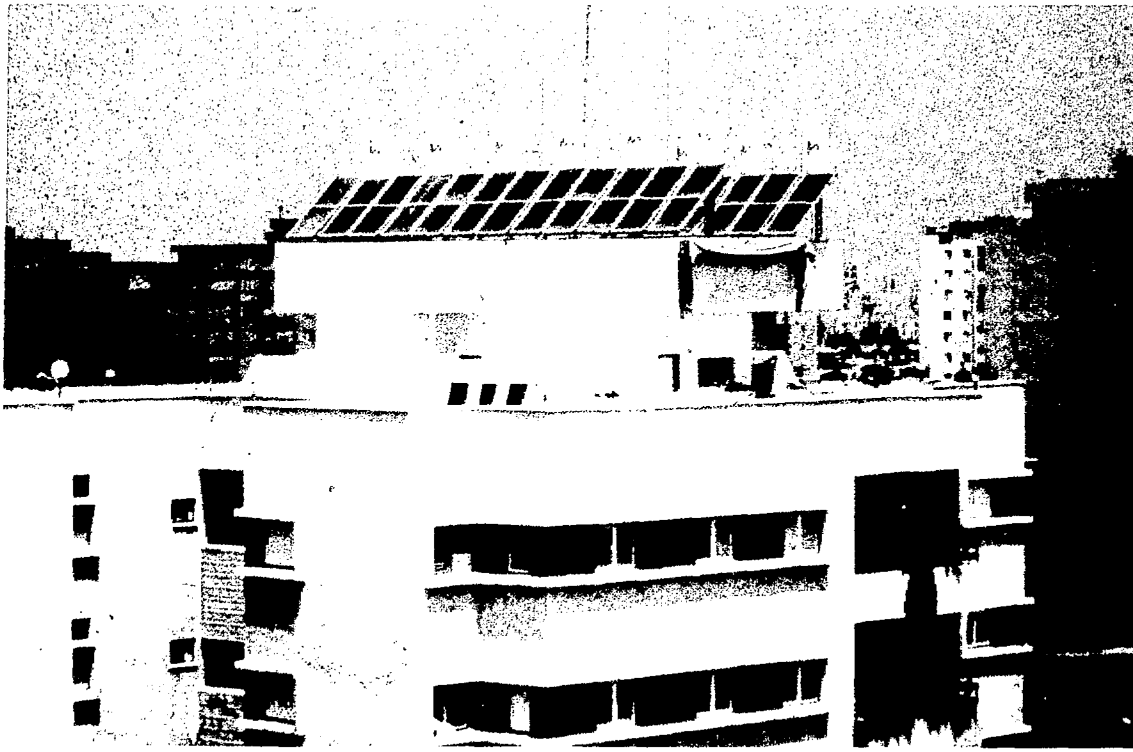
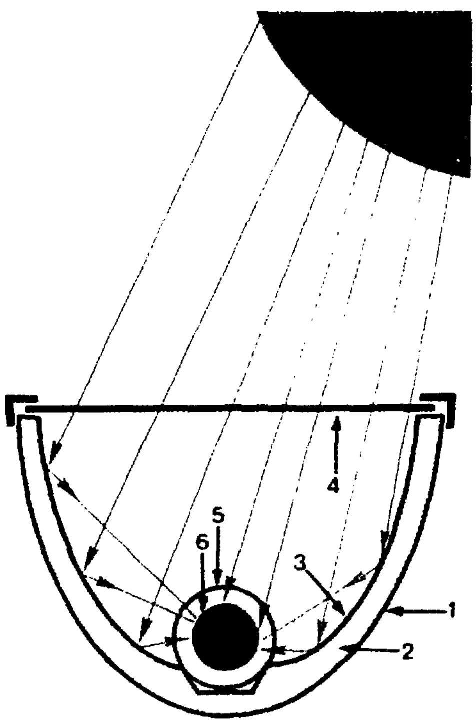


Fig. 1. Roofs covered with DHWS system



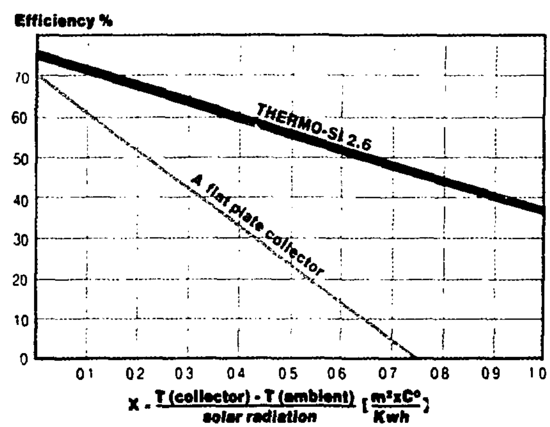


Fig. 5. Efficiency diagram of Thermo-Si Collector

Fig. 4. Cross section of Thermo-Si Collector

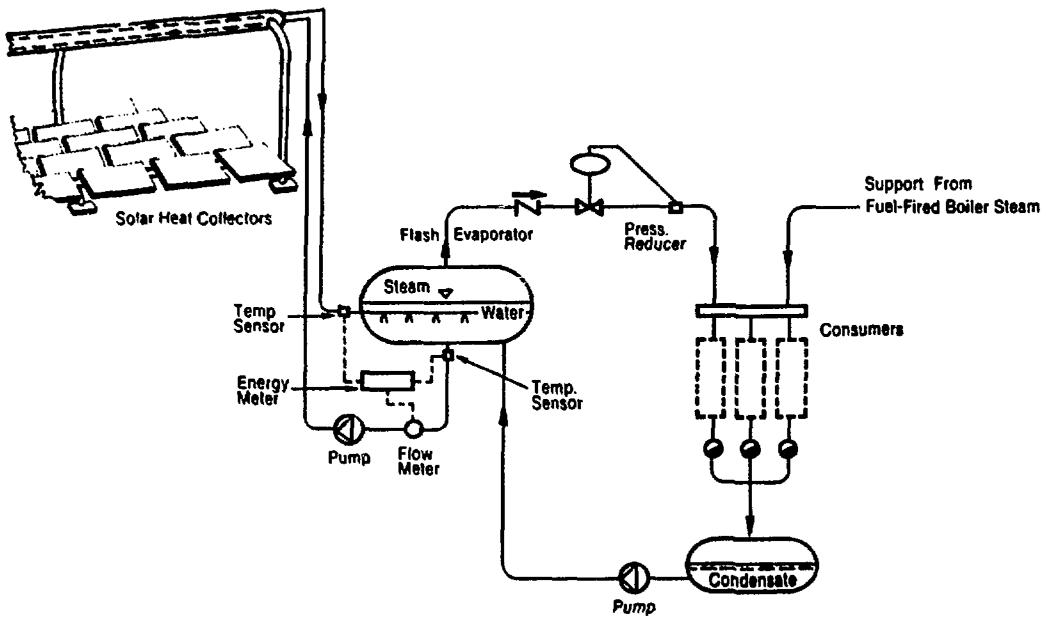


Fig. 6. Schematic diagram of CS 112 solar steam generating system

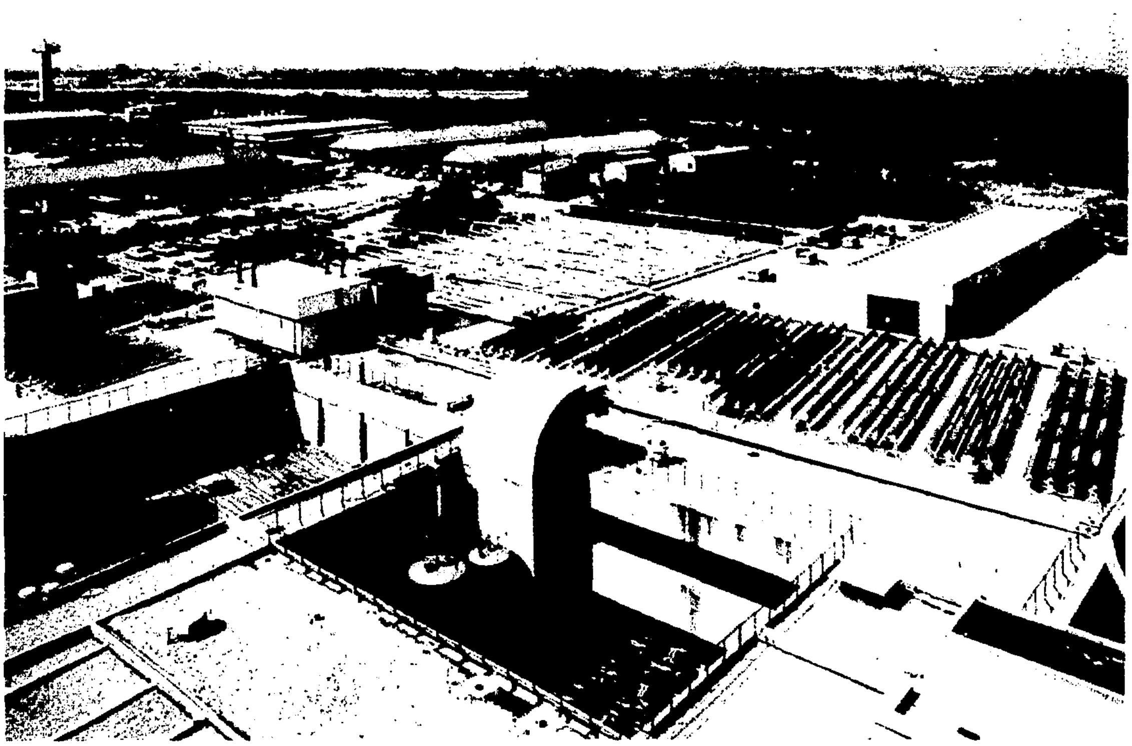


Fig. 7. Hot water and steam supply unit at the Hillel Yaffe Medical Center

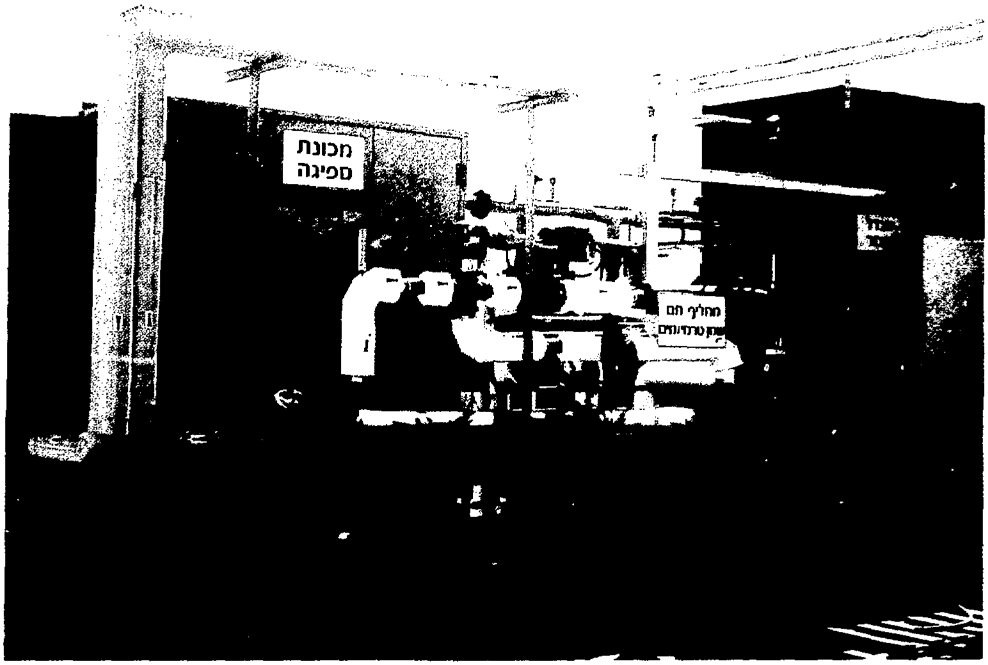


Fig. 9. Pazgal Absorption 40 RT Machine including Circumferential Equipment

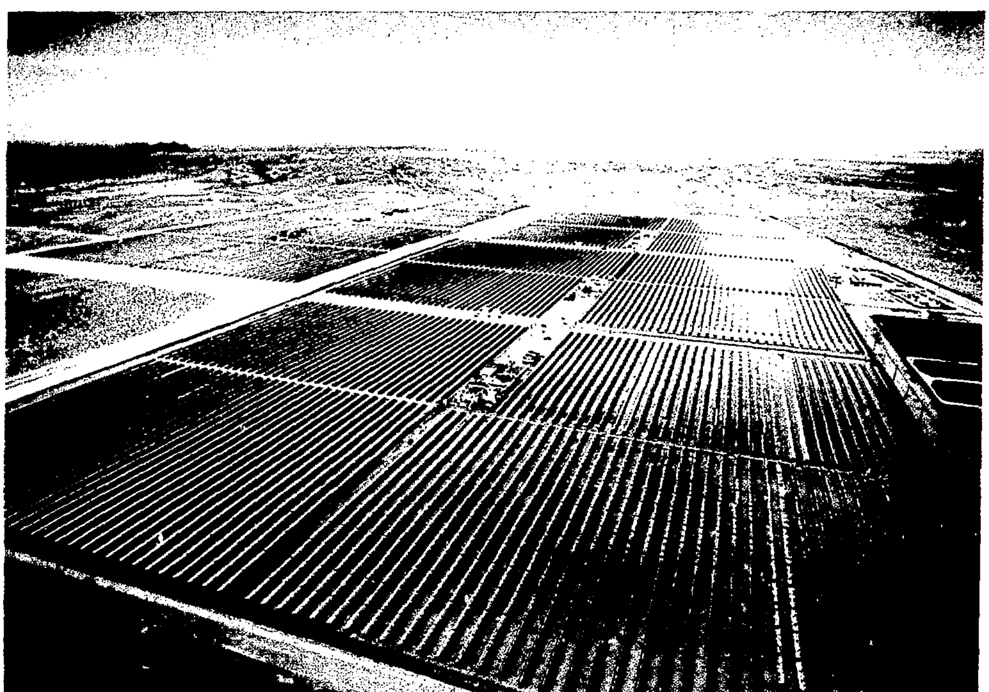


Fig. 10. Aerial view of SEGS plants, Kramer Junction, California

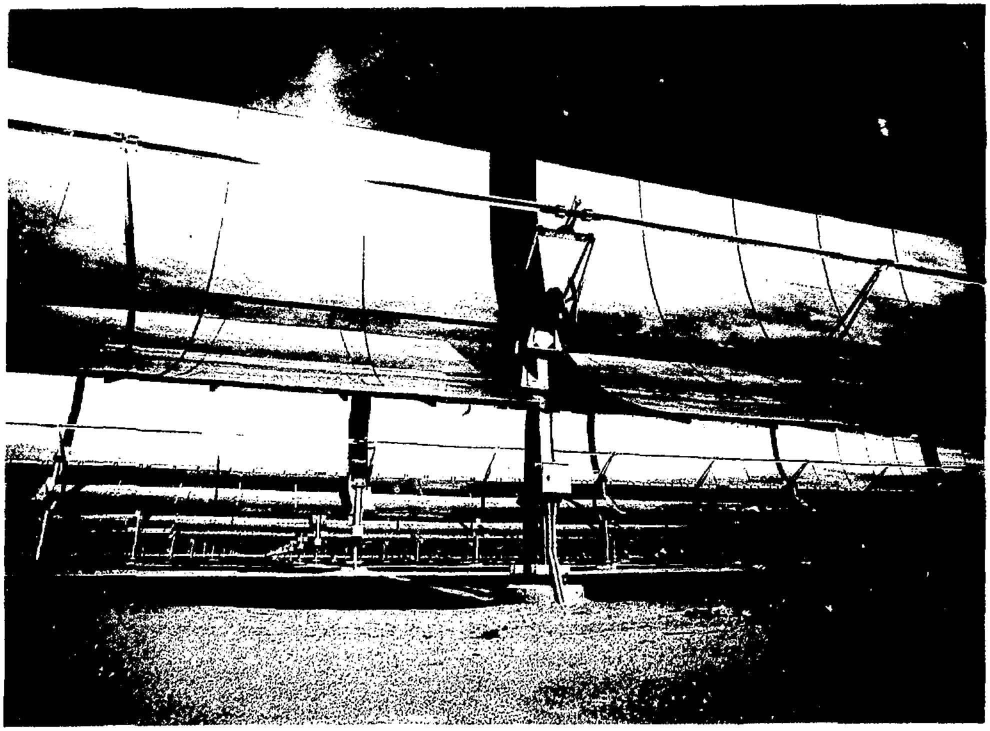


Fig. 11. Collectors, Kramer Junction, California

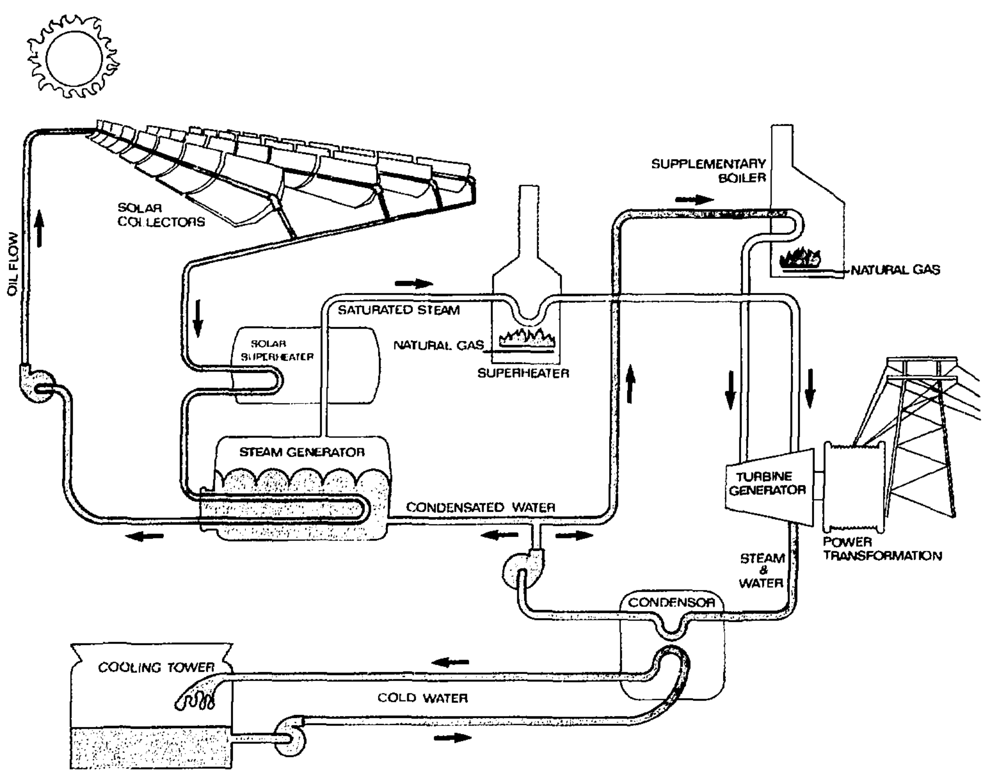


Fig. 12. The Schematic Luz System - SEGS VIII-IX-X-XI-XII

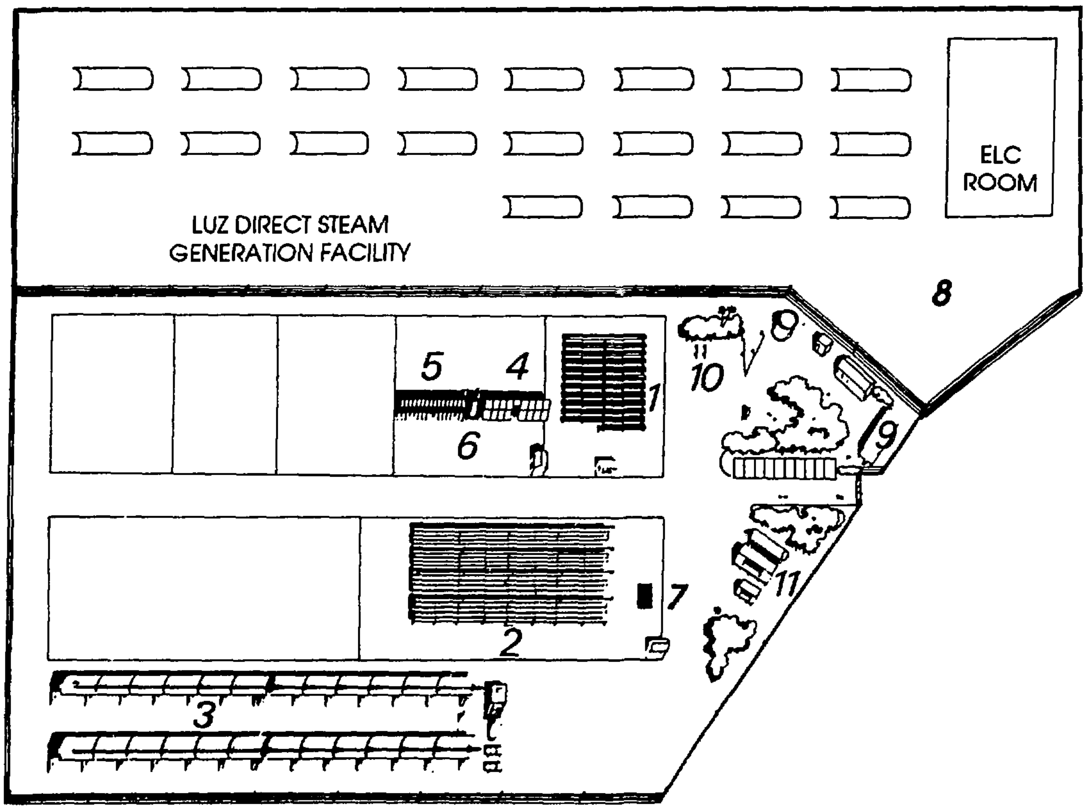


Fig. 14. List of existing and planned installations:
1. *Photovoltaic — by Paz Oil Co. (operating)*
2. *Solar Thermal — by Paz Oil Co. (operating)*
3. *Solar Thermal — by Luz Industries Israel (operating)*
4. *Two-axis photovoltaic system — by Israel Electric Corp. (IEC) (operating)*
6. *Base for future photovoltaic program — by IEC*
5. *Photovoltaic solar modules testing facility — by IEC (operating)*
7. *Cooler Absorber — by Pazgal (operating)*
8. *Solar Thermal Direct Steam — by Luz Industries Israel (planned)*
9. *Central data logging and processing — computerized systems*
10. *Meteorological Station*
11. *Visitors' Center*

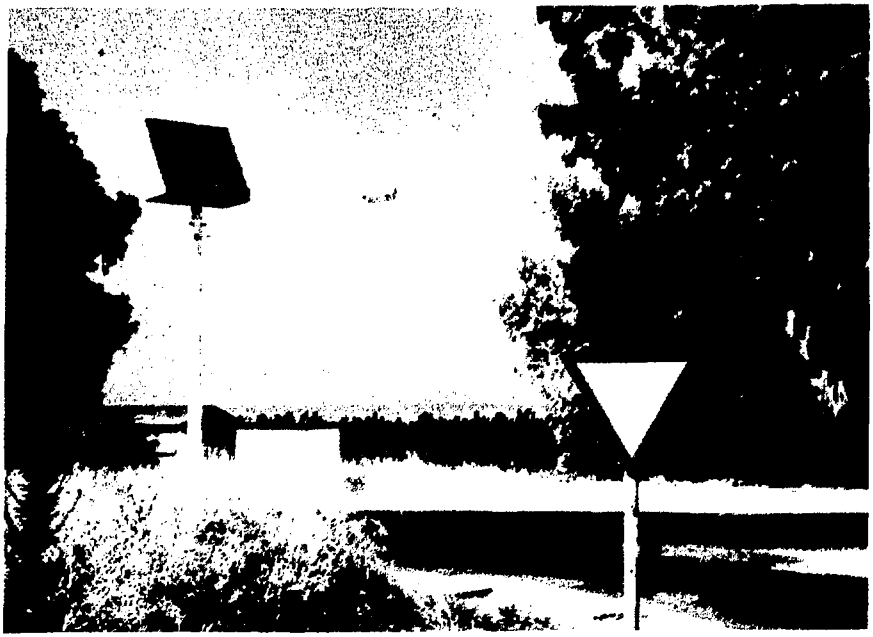


Fig. 13. PV Unit - Commercial Utilization

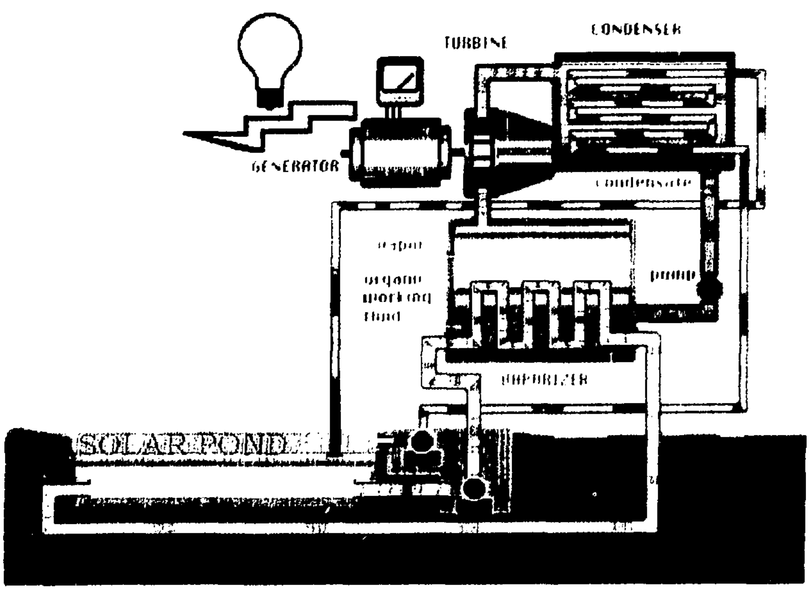


Fig. 20. Schematic diagram of Ormat Solar Pond Power Plant

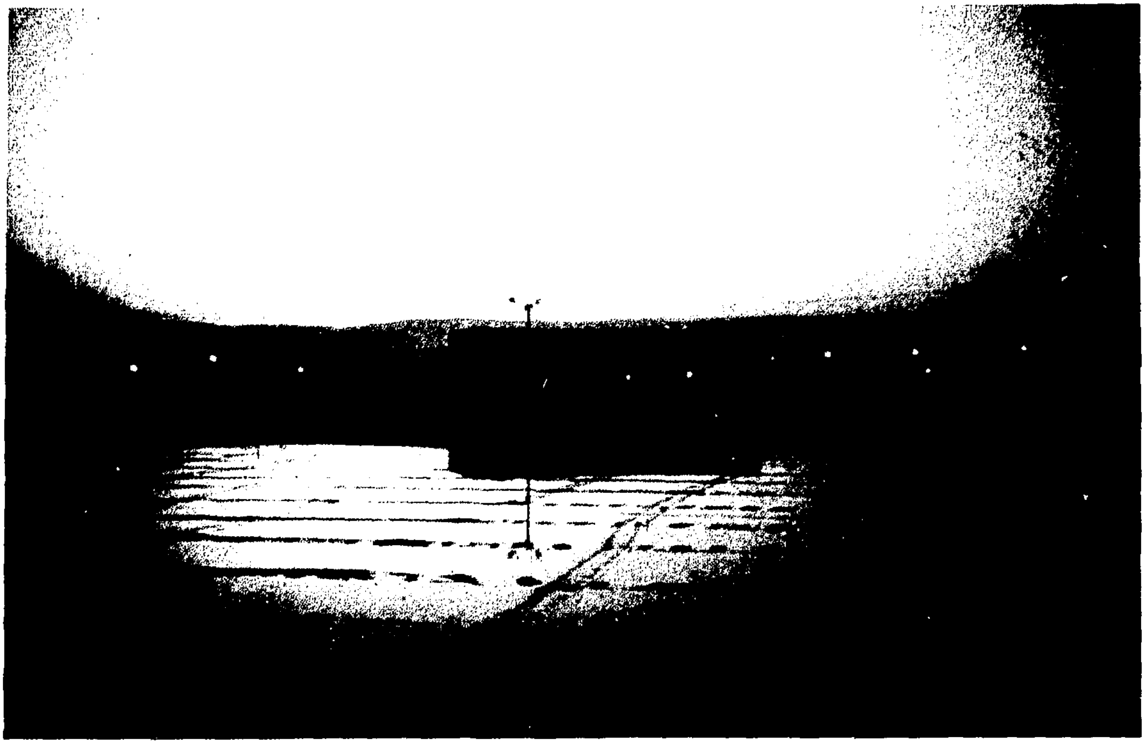


Fig. 21. Ormat Solar Pond Power Plant in Beit Haarava. Aerial view.

Fig. 28. A House in the desert