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E/ESCWA/NR/86/5
10 April 1986

ORIGINAL: ENGLISH

UNITED NATIONS

ECONOMIC AND SOCIAL COUNCIL

ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA

REPORT ON THE INFRASTRUCTURE REQUIRED TO DISSEMINATE MATURE SOLAR AND WIND TECHNOLOGIES IN SELECTED ESCWA COUNTRIES

PART I

STATE-OF-THE-ART

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PART I

STATE-OF-THE-ART

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A- INTRODUCTION

The total commercial energy consumption in the world has been increasing rapidly during the last thirty years. It has almost been doubled due to increase in population and economic development.

The 1970's brought into focus the general realization that fossil fuel resources, especially oil and natural gas are finite in nature. In addition all countries realized that the era of cheap energy is over and that they should explore the possibilities of using other sources of energy as well, establishing thereby an appropriate energy mix to meet their demands for sustainable development.

The need for the realization of the appropriate energy mix, has strengthened the need for the development of the use of New and Renewable Sources of Energy "NRSE". The resource base of "NRSE" is extremely large with an infinite potential for renewal. The annual amount of solar radiation received at the surface of the earth is about 1.2×10^{18} kwh, while the global wind energy resource base was estimated to be 1.200×10^{12} w. Also, the dry weight of all living bio mass (plant matter) on the earth's land surface has been estimated as nearly of 2.40×10^{9} dry tons with a primary production rate of 171×10^{9} dry tons 1/.

Most of ESCWA's countries are enjoying favourable solar and wind resources. They are extended from earth's equater to almost 40^{o}N latitude, in an area of very high solar insolation that varies between 350 to 700 cal/cm^2. Meanwhile quite a portion of its territories enjoy high annual average wind speeds, which vary between 3.5 to 7.5 m/sec.

It is, however difficult to estimate how much of the resource base can be technically and economically exploited. Estimates of possible contribution of "NRSE" to the overall future energy supply of the region is highly dependent on the development plans, associated total energy needs, the availability of various energy resources, as well as the-state-of-the-art of the NRSE technologies.

In view of the fact that solar and wind are major resources in ESCWA's countries, this part of the report is devoted to the description of the-state-of-the-art of both technologies.

1/ Essam El Hennawi & Asit K. Biswas "Renewable Sources of Energy and the Environment, TY Cooly International Publishing Ltd. Dublin

B- SOLAR ENERGY TECHNOLOGY

The energy radiated from the sun has its origin in the thermonuclear reactions within the star. The solar energy reaching the earth's surface, is equivalent to more than 150,000 million MW, which is over 10,000 times the world's total installed generating capacity.

Although, the sun radiates energy in different wave lengths, the majority of that energy is at very high frequencies "short wave lengths". Visible light makes up 46% of sun's total energy, fourty nine percent is in the infrared band which we experience as heat and the remaining portion is in the ultra-violet band.

The solar constant, which defines the amount of radiation or heat energy reaching the outside earth's atmosphere is (1.94 cal/cm^2/min). However as shown in Fig (B-1) about 35% of solar radiation is reflected back into space, while part of the remaining portion will be scattered in all directions as it interacts with air molecules and dust particles. In addition carbon dioxide and ozone in the atmosphere absorb about 10 to 15% of the incoming radiation 2/.

Because of the earth's tilt and rotation, the length of the atmosphere that solar radiation passes through will vary with the time of day and month of the year, and seasons are created as shown in Fig (B-2).

Solar radiation reaching earth's surface was first used by ancient Egyptians. The Giza pyramids are the first solar passive buildings in the world. Meanwhile the use of solar energy for space heating continued to advance in Europe until the eighteenth century, when the industrial revolution used coal intensively, and solar use was declined.

Late of the 19th century (1870-1930), solar applications had moved out of the shadow of emperical investigations to assume the new role of energy and resource machines. This period is symbolized by the industrial growth of the solar hot water applications in Southern U.S., as well as the development of mechanical processes driven by the sun. These industrial primatives were purely new machines of simplest type for accomplishing work. Among prototypes of this period are 3/ :

2/ Duffie & Beckman "Solar Energy Thermal Processes, John Wiley & Sons, New York, 1978

3/ Jeffrey Cook "Six Evolutionary Phases Towards Solar Architecture. Thermal Applications of Solar Energy In Buildings, Proceedings of the Solar World Congress, Perth, Australia, 1982.

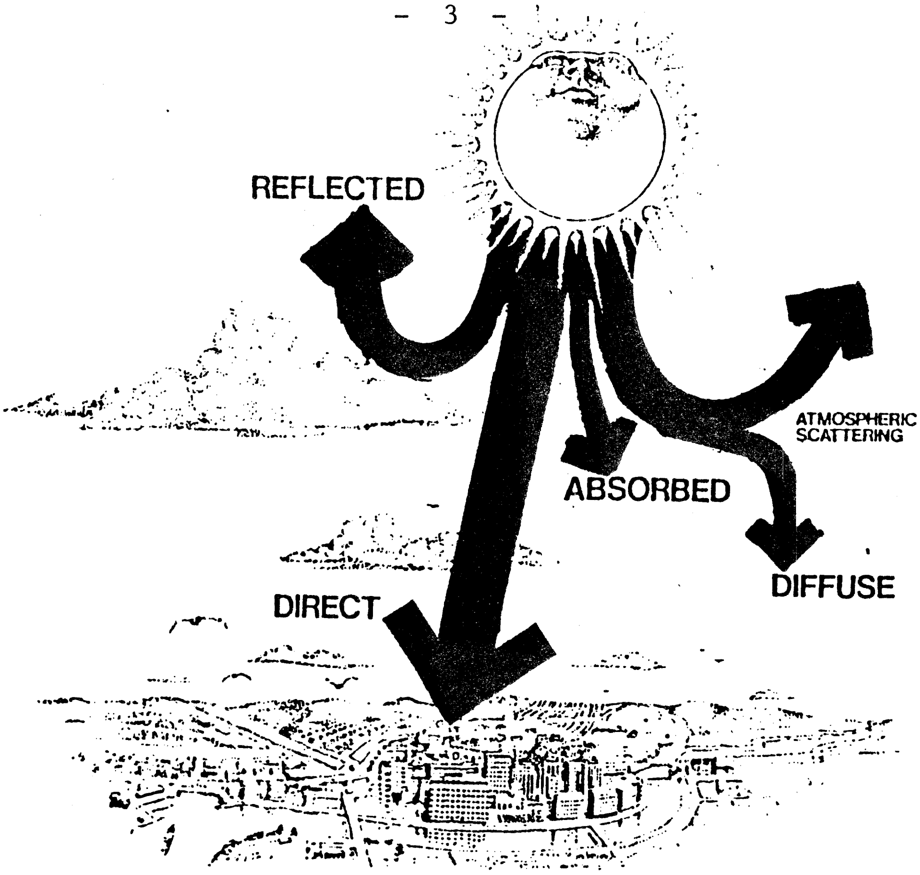


Fig B.1: What happens to solar radiation intercepted by the earth's atmosphere.

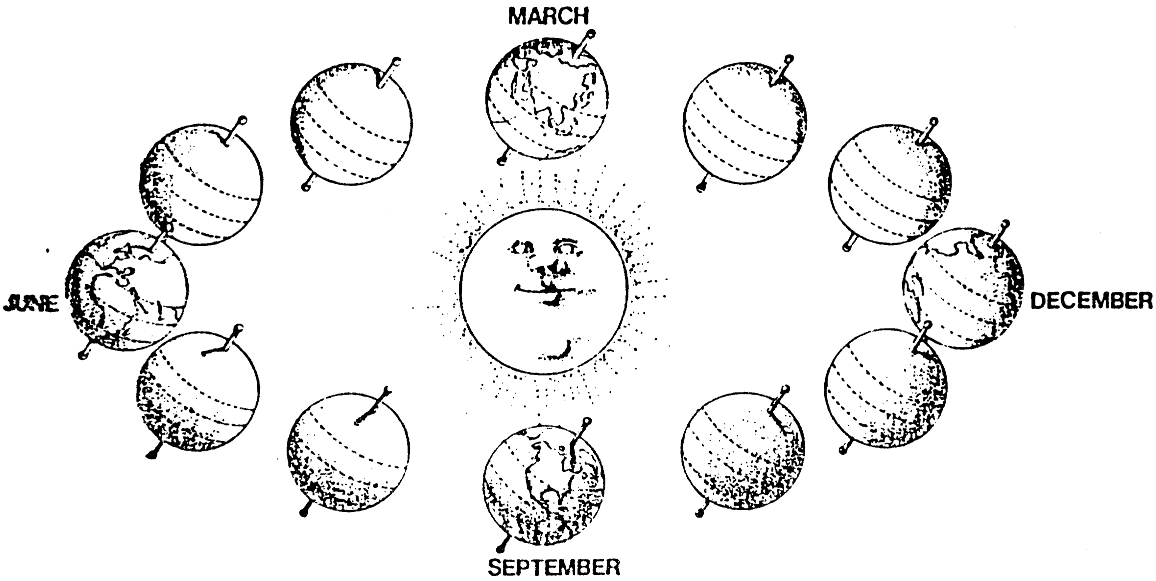


Fig. B-2: The earth's tilt remains constant.

- Flat-plate collectors using a baffled flow system and a heat exchanger loop of water heating were used substantially in Arizona during 1920's.

- Solar concentrators, were used to produce steam for use in pumping applications. In 1901 a system of (65 m^2) producing steam at (150 psi) was built in Arizona, while in 1913, a large solar engine was built by Frank Shuman at Maadi, Egypt. This pump used 1200 m^2 of parabolic hrough collectors to produce about (37 kw) steam for irrigation.

Most of the activities in the solar field during the period 1933-1963, were directed towards the development of bioclimatic building concepts. A number of demonstration buildings were built, and successfuly performed with climate for man's comfort.

In response to world energy crisis in 1970's; the different solar applications were reconsidered, the goal was to"put the sun to work" within a fuel based society. Moreover, direct conversion of solar energy to electricity using photovoltaic cells was created and developed. Solar energy has been effectively in use, for a wide variety of applications using both thermal and electrical solar technologies namely :

1- Solar Thermal Technology
2- Solar Photovoltaic Technology

B.I. SOLAR THERMAL TECHNOLOGY

There are basically two distinct approaches to the thermal utilization of solar energy, Active systems and Passive systems.

In general, active systems employ hardware and mechanical equipment to collect and transport solar heat. Flat-plate or focusing collectors and heat storage unit are often the major elements of the system. Water or air, naturally or pumped circulated through the collector, absorbs heat and transports it to the storage unit. This heat is then supplied to the end use application by a mechanical distribution system.

Passive systems, on the other hand, collect and transport heat by non-mechanical means. The building structure or some elements of it is the system in this case, passive system operates on the energy available in its immediate environment.

1. Technology Description

The design and operation of a solar thermal active system is basically dependent upon the type of solar collector used and storage system. Solar collector is the device used to convert solar radiation into heat for a particular use. The appropriate technology for solar collection varies according to the requirement of each specific application, however they may be classified to 4/ :

- Operating temperature range : low, medium or high temperature
- Working fluid : air, water or other fluids
- Design features : flat, focusing or multiple concentration.

Throughout this part active solar collections will be analyzed according to the operating temperature range, however the design features and type of working fluids will be elaborated. Meanwhile passive systems will be described according to its heat gain mechanism.

1.1 Active Solar Thermal Technology

A substantial number of different kinds of solar collectors have been in use, the temperature at which energy is used for any heating application is most important factor in assessing the solar collector option. The application required temperature largely dictates which type of collector is most appropriate. Fig (B-3) shows the operation temperature for each solar collector type. All these collectors are described hereinafter. The performance of each collector type will be discussed in part 1-2.

1.1.1 Low Temperature collectors

Low temperature collectors are those collectors with working temperatures below 90°C, such as flat-plate collector, solar ponds and simple solar stills.

a- Flat-Plate Collectors

The most commonly used solar collector is the flat-plate collector , used for heating water or air up to 90°C. Operating temperatures above 70°C diminish the relative efficiency of the system. They are simple, durable and capable of collecting both direct and diffused radiation.

A flat-plate collector consists of the following basic components shown in Fig (B-4) :

4/ M. Kudret Selcuk "Fundamentals and Collectors of the Past and Present" Proceedings of the International Symposium Workshop on Solar Energy, Cairo June 1978

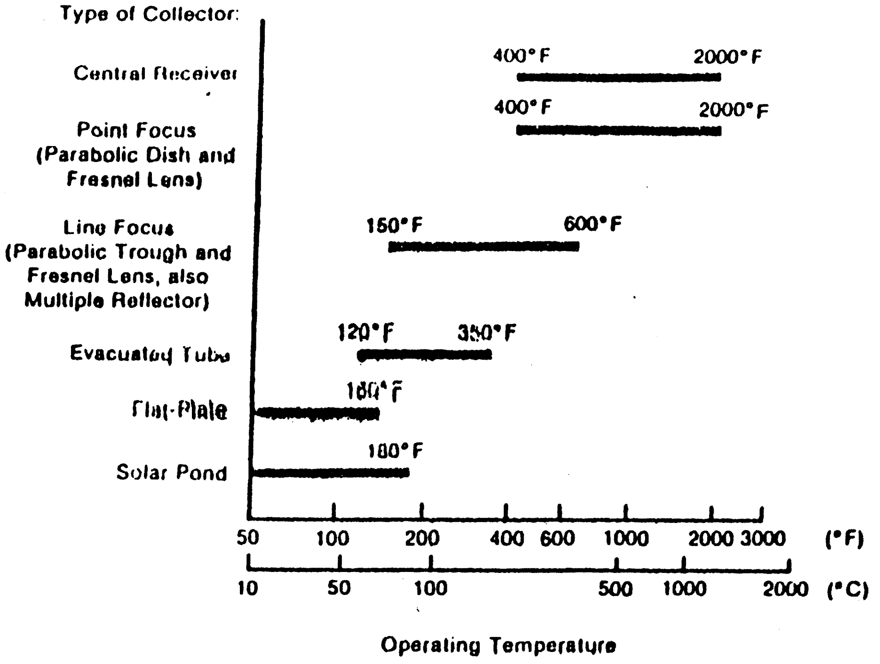


Fig (B-3) **Operating Temperatures for Various Types of Collectors**

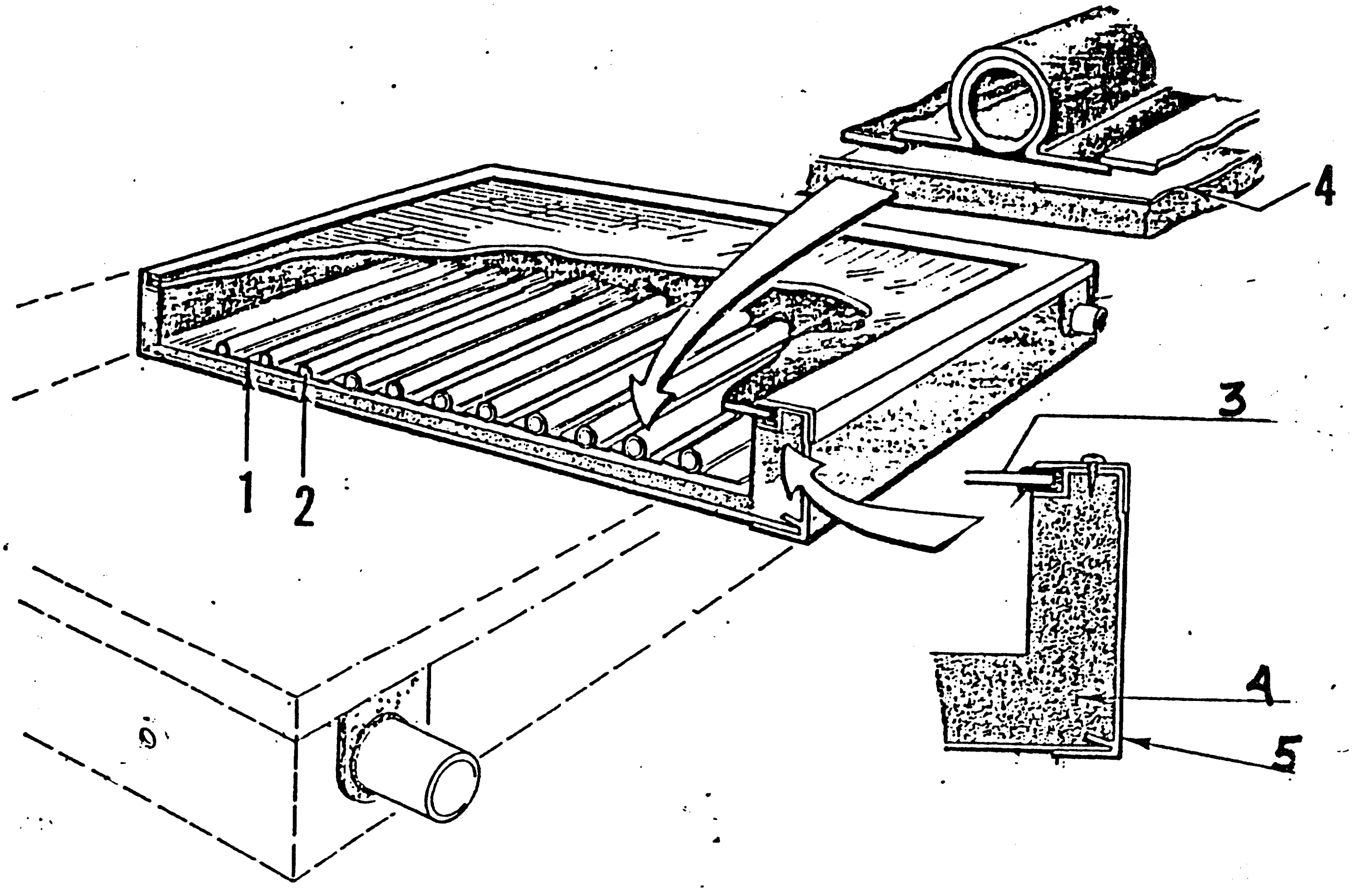


Fig (B-4) Fiat - Plate Collector Configurations .

- Absorber plate : usually copper, steel, aluminum, or plastic, surface covered with flat black paint or a selective surface to maximize absorption and minimize reradiation.
- Flow passages : liquids usually flow through tubes that are attached to, or an integral part of, the absorber plate. Air flows above or below the plate, and heat transfer surface area is maximized by means of fins, slots or metal screening.
- Cover plate(s) : one, two, or three transport cover, made of glass or various plastic materials, to reduce convective and radiative heat losses to the outside air.
- Insulation : to reduce heat losses from the back and sides of the collector, typically fiberglass or isocyanurate.
- Enclosure : a box to hold collector components together and protect them from the weather.

In a typical liquid collector, tubes can be routed through the collector in parallel paths from an inlet to outlet header, or a single tube can be routed in a serpentine fashion. The latter eliminates header leaks, but increases pressure drop. The flow passages should be easy to drain, copper has the highest conductivity and corrosion - resistancefor plate material, however it is more expensive.

Air collector absorber does not need high conductive material, as air flows on the entire surface. An air system eliminates freezing, boiling, and leaks are much less than liquid system. However, fan power is significant, large ducts are required, and greater storage volume is needed.

Flat-black paint is the most commonly used coating, with absorptance "α" between 0.92 and 0.96, however it has high emittance "ϵ". So called selective surfaces with high short wave α and low long wave ϵ , thus they retain more heat. Black chrome is the most popular selective coating, where $\alpha \simeq 0.92$ to 0.98 and $\epsilon \simeq 0.1$. Selective surfaces improve performance but increase costs.

Collector cover is normaly glass with transmittance higher than 0.85, glass is opaque to any long wave radiation lost from collector. Multi-glass covers may be needed if ambient temperatures are very low. The enclosure should have an aperture area more than 85% of the gross area, it should withstand stagnation conditions, weather conditions and cyclic heating and cooling.Fig (B-5)a,b shows variety of liquid and air flat-plate collectors.

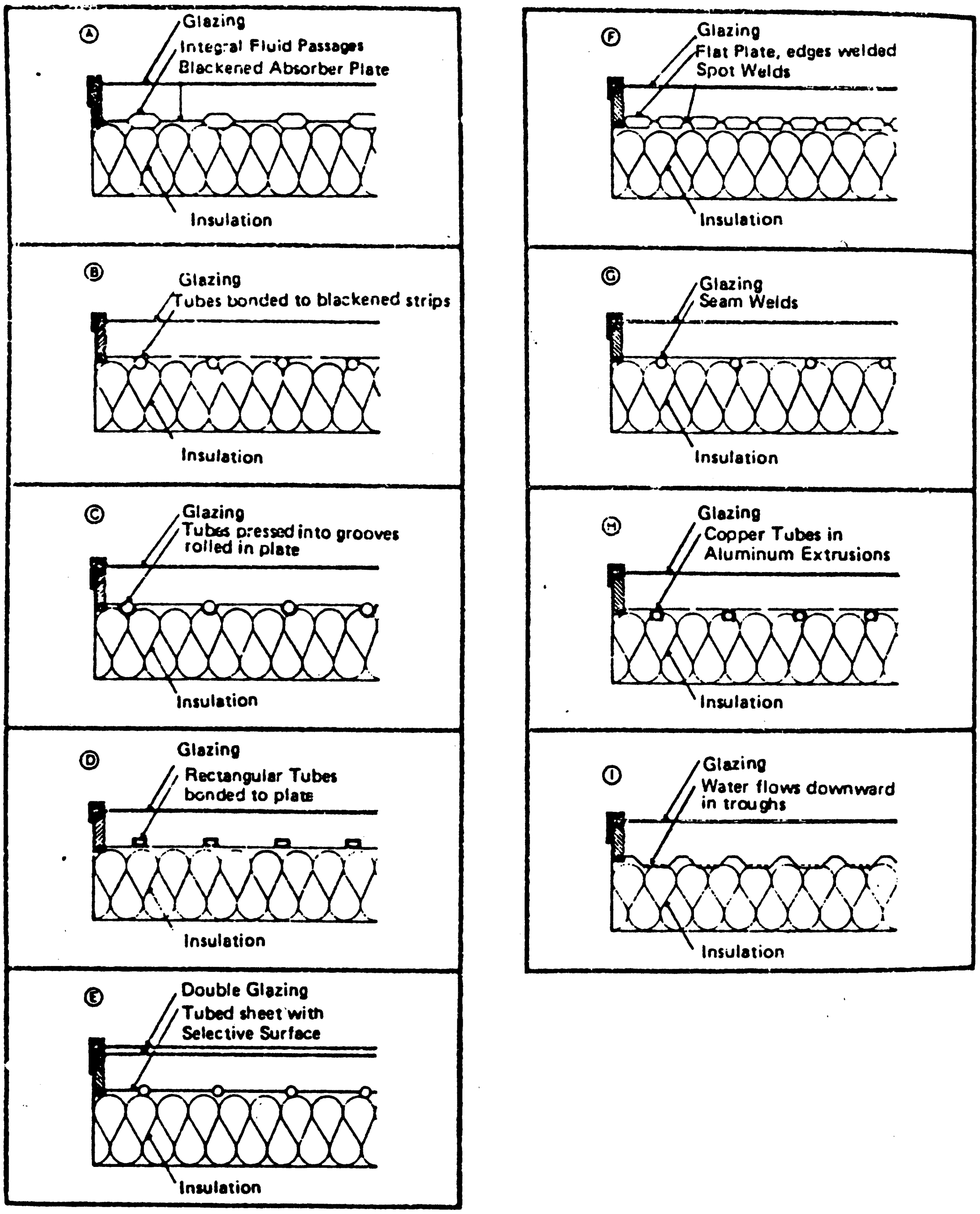
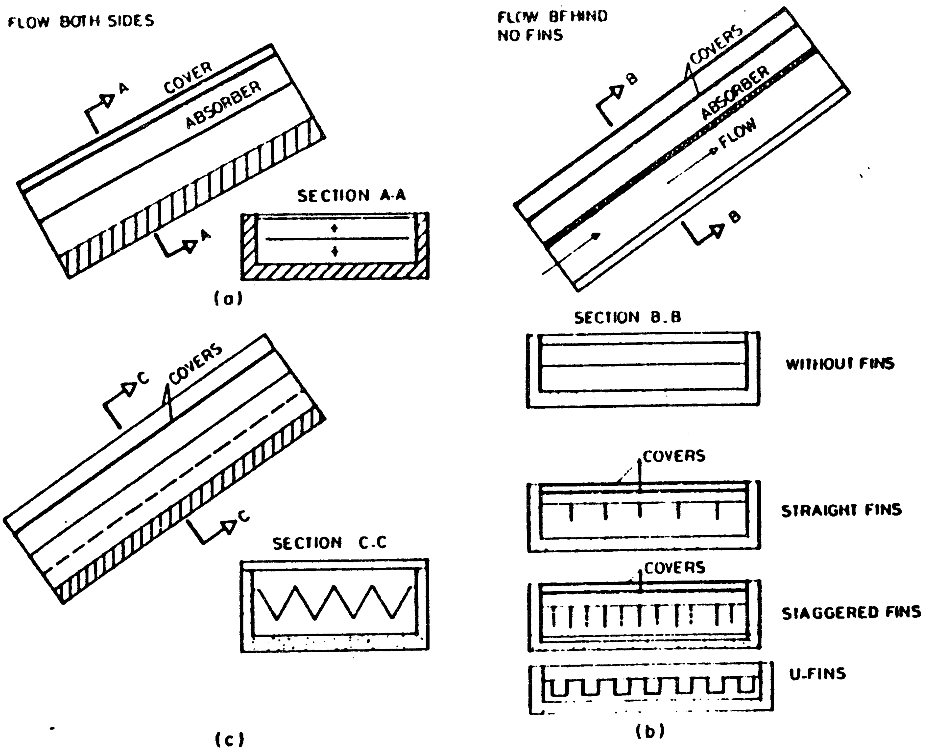
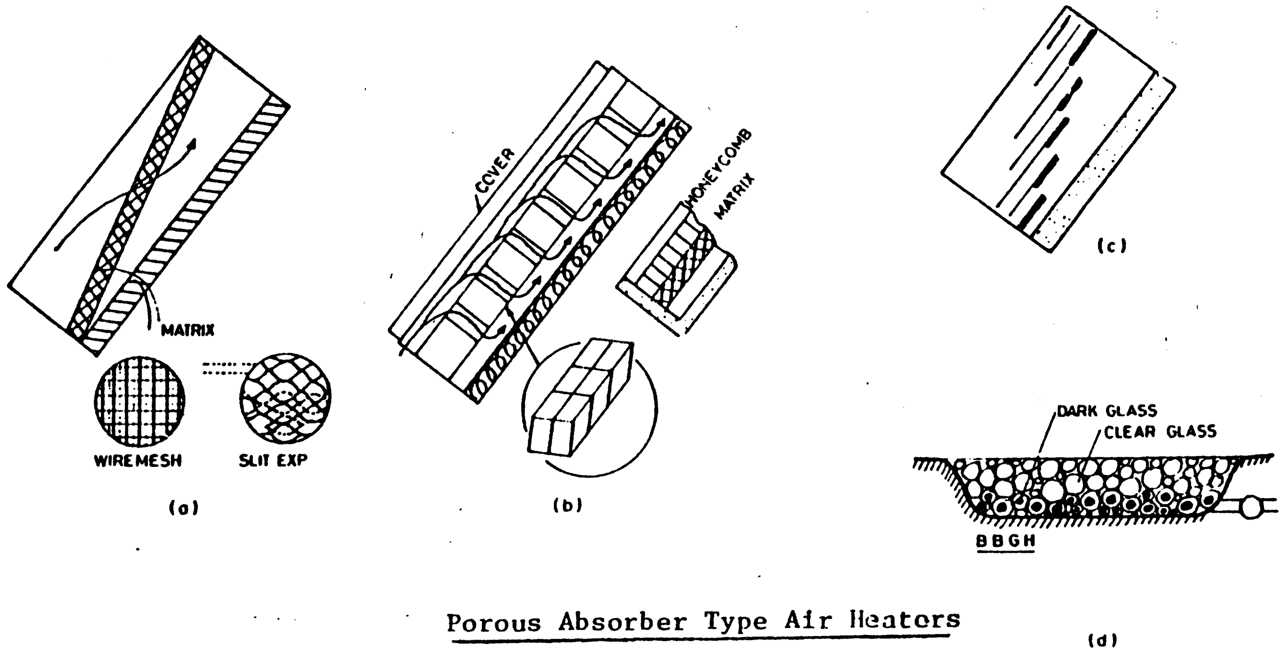


Fig (B-5),α types of solar liquid collectors



Nonporous Absorber Type Air Heaters

a) Flow on both sides of absorber
b) Flow behind the absorber
c) Vee corrugated absorber



Porous Absorber Type Air Heaters

a) Porous matrix type absorber
b) Transpired absorber
c) Overlapped glass plate air heater
d) Broken bottle glass air heater

Fig (B-5),b Types of Solar Air Collectors .

b- Solar Ponds

Salt-gradient solar ponds and shallow solar ponds, the two basic types, are among the least expensive kinds of solar collectors. Fig (B-6) shows the structure of a pond.

A salt-gradient solar pond emplys a salt concentration gradient to suppress natural convection. Water heated by solar radiation holds more dissolved salt than cooler water. The salty, heated water is also heavier, thus, it remains at the bottom of the solar pond. Sunlight penetrating through the top layers of the pond is absorbed at the bottom and trapped by the non convecting gradient layer which acts as an effective thermal insulator against conduction. In practice, a salt gradient solar pond consists of three layers or zones :-

- a surface convecting zone of low salinity water, typically 20 to 40 cm thick
- a non convecting or salinity-gradient zone beneath the surface zone, in which salt concentration increases with depth, typically 1 to 1.5 m thick, and
- a storage zone at the bottom of the pond of uniformity high salt concentration that stores heat and is typically 1 to 3 m thick, depending on the system application.

A salt gradient solar pond can provide heat at temperatures in excess of 90^{o}C, such a pond provides built in thermal storage from summer to winter. Shallow pond collectors consist of inflatable bags of water supported by insulated footings. When insolation conditions are favourable, water is pumped from an underground storage tank into collectors. The water inside the collectors absorbs solar radiation and can attain temperature up to 60^{o}C.

c- Solar Still

Solar stills using green house effect are well known, since a century at least. Fig (B-7) shows a schematic of a single solar still, where these functions are performed in the same apparatus. Solar rays are used to heat the saline water in the basin, the vapor condensate on the transparent cover and the distilled water is collected at the fresh water trough. Daily yield of a solar still is low (3 to 6 litres per square meter of basin), but not far from the upper limit allowed by a daily insolation of 6.5 kwh/m^2. This energy would be capable of evaporating grossly 12 liters of water, the usual yield of 4 to 6 lit/m^2 corresponds to a collection efficiency between 35 to 50%.

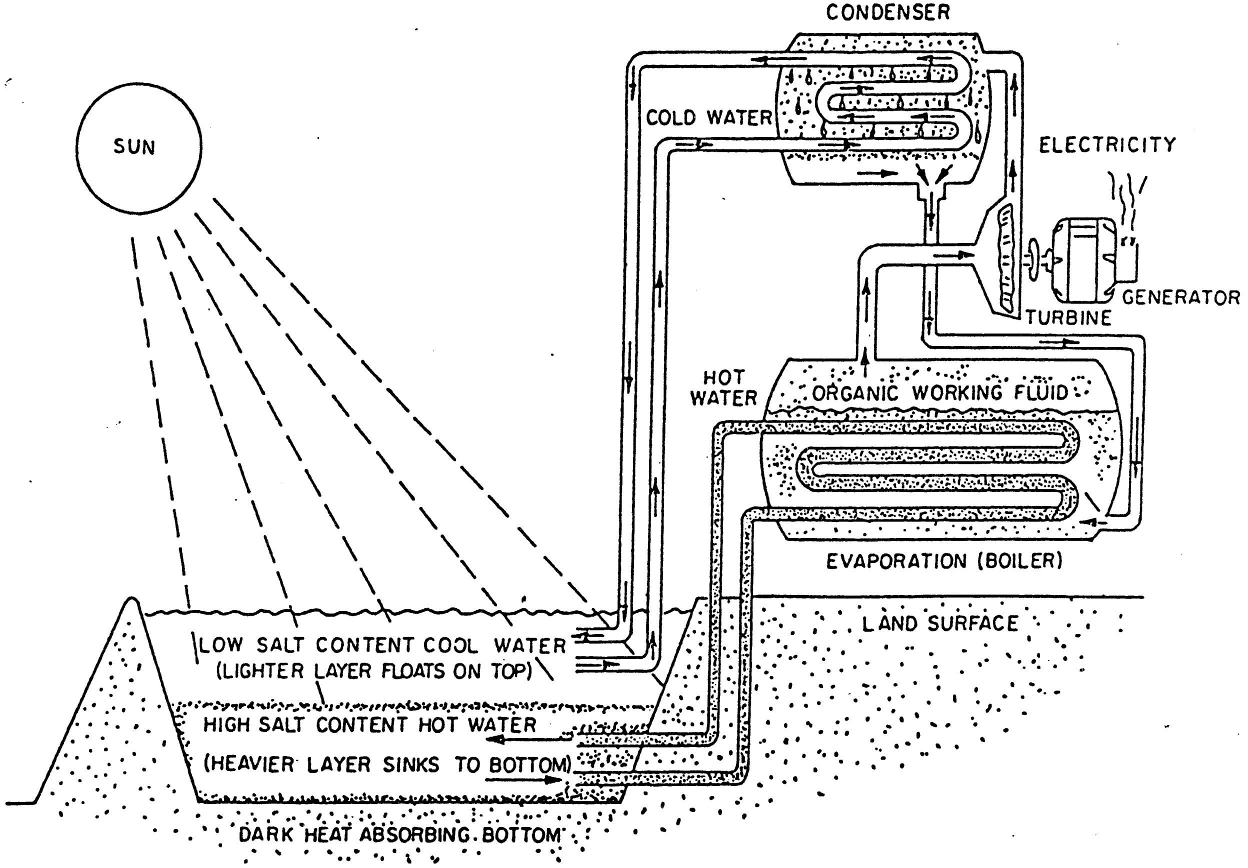


Fig (B-6) Schematic Diagram of Heat Extraction and Power Generation from a Solar Pond

Different design modifications has been introduced to simple stills, cascade design, finned back sides to increase condensation and external condensation. However each approach is improving the performance slightly, but no break through can be expected from this process 5/.

Solar stills are simple and cheap, its technology is well suited for capacities up to some cubic meters per day. Its practical designs require only the proper choice of materials. This technology is suitable for small communities at desert areas.

1.1.2 Moderate Temperature Collectors

Over 20% of the industrial processes are using energy at moderate tempertures between 90°C - 300°C, used in some drying processes, low pressure steam and other applications. A variety of solar collectors work at this temperature range, mainly evacuated tube collectors, parabolic trough concentrators, compound parabolic concentrators "C.P.C" and solar flat plate boosters.

a- Evacuated-Tube Collectors

One way to reduce convective heat losses is with a vacuum between the glazing and the absorber surface. However, because a vacuum would cause a typical flat-plate collector to collapse, this technique is used in conjunction with a tubular design. Vacuums on the order of 10^{-4} torreliminate both convection and conduction losses, thus evacuated tubes can work at high temperatures up to ≃ 175°C. Like flat-plates, they can collect both direct and diffuse solar radiation and do not require tracking. Also it is much less susceptible to wind-induced losses than other types of collectors, in addition vacuum ensures greater stability and a longer life for selective coatings 6/.

There are various types of evacuated tube collectors on the market, Fig (B-8) shows an example of it. A V-reflector or C.P.C can be used with the evacuated tubes to provide a certain degree of concentration.

Evacuated tube collectors operate much better that flat-plate at high incident angles. They are fragile, and glass breakage has been

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5/ A. Maurel "Desalination and Solar Energy", first French-Egyptian Solar Week, March 1980

6/ SERI reprot "Design Approaches for Solar Industrial Process Heat Systems", SERI/TR-253-1356, August 1982

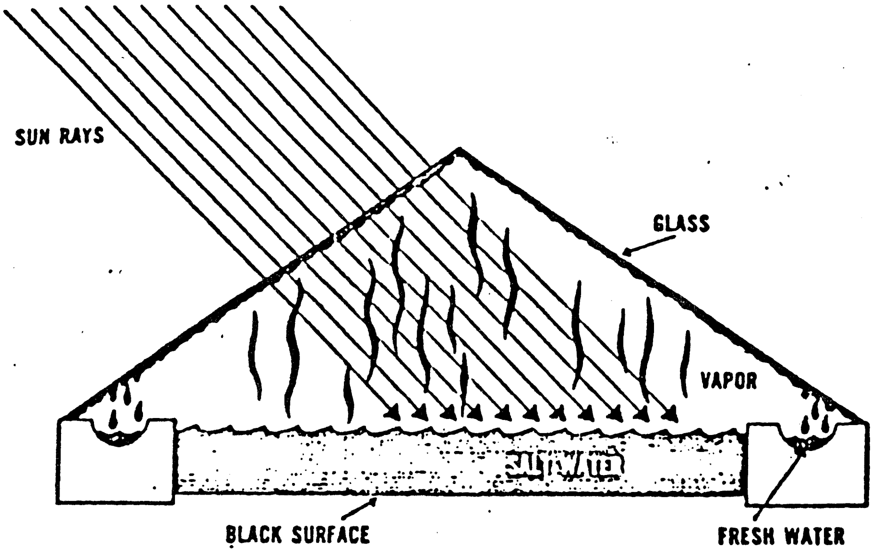


Fig (B-7) Schematic of a Single Solar Still

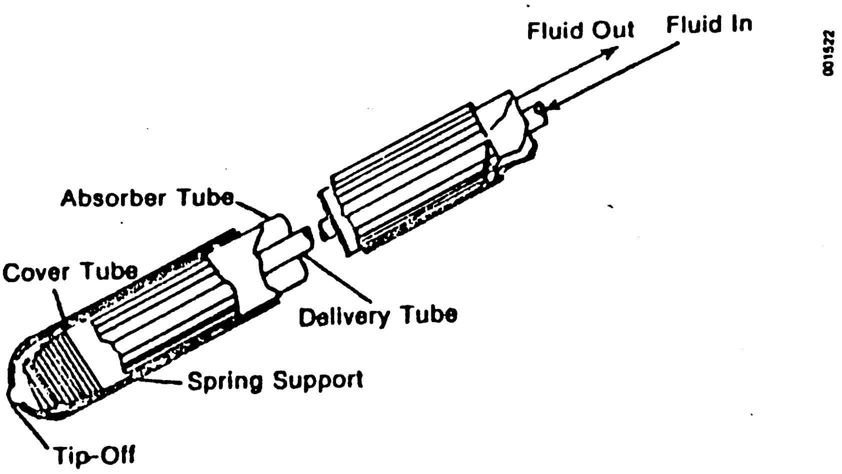


Fig (B-8) Concentric Glass Evacuated - Tube Collector a problem, shocking a stagnant collector with cold water has caused the breakage in most cases. Field experience has shown that borosilicate glass is more durable than soda-lime glass for non-drainable evacuated tube collectors.

b- Parabolic Trough Collectors

Parabolic troughs are the best-developed line focus concentrating collectors and have been used in several IPH and power generation systems. They can operate at temperatures up to about 300°C, as the result of optical concentration effected by the parabolic- shaped concentrator. Optical concentration reduces the absorber area and the associated thermal losses, however tracking is required and the diffused component is lost. A noteworthy advantage of parabolic troughs is the low pressure drop associated with single fluid passage. In addition the minimal overnight thermal losses from the collector receiver with its selective coated absorber tube, surrounded by a cylindrical glass tube that reduces convective losses from the absorber.

Three major types of reflectors have been used for parabolic troughs: polished aluminum sheets, aluminized plastics and silvered glass. Aluminized plastic films are the most widely used with specular reflectance of 0.80 to 0.86 when new, however they lose their reflectance rapidly by scratching airborne particles.

Parabolic troughs are usually installed so that their axes of rotation are oriented either north-south or east-west. Seasonal variations in collector output far north-south oriented trough can be quite large.

c- Stationary Concentrators

A vriety of stationary concentrators have been developed during the last decade, it utilize reflector non-imaging surfaces to funnel solar radiation on an absorber surface rather than concentrating it. The most commonly used stationary concentrators are, compound parabolic collectors (C.P.C) 7/, solar flat-plate boosters, and the multi reflector collectors 8/. Most of them utilize cover plate and collect diffused as well as direct radiation.

7/R. Winston "Principles of Solar Concentrations of Novel Design", Solar Energy Journal, vol 16, 1974.

8/D.P. Grimmer, Augmented Solar Energy Collection using different Types of Planar reflective surfaces, SEJ vol 21, pp 497-501, 1978

A compound parabolic concentration design shwon in Fig (B-9) and developed by Winston in 1974, consists of two half-parabolic reflectors with an absorber located at the bottom of each. If oriented east-west, a trough with a low concentration ratio requires only seasonal adjustment. Its reflective surface does not need to be highly specular; thus, it can be more readily tolerate dust and degradation. It offers a wide acceptance angle at low concentration ratios, but it requires larger amount of reflector surface.

Similarly, solar flat-plate boosters are flat reflectors shaping trapiziodal channels with absorber tube at the bottom. It is quite similar to "C.P.C", but are simpler and have wider acceptance angles. Concentration ratios between 1.6 to 5 can be obtained using different apex angles 9/.

In addition a variety of collectors that utilize a Fresnel lens have been developed with line focus and point focus characteristics. Line-focus Fresnel lens collectors can operate to about 290°C. Point-focus Fresnel lens collectors can operate at temperatures in excess of 600°C, and should be categorized as high temperature collector.

1.1.3 High Temperature Collectors

The use of the solar energy for producing power and high temperature processes heat requires very high concentration collectors. Many types of concentrating collectors have been developed, however the commonly used concepts are, parabolic dish collectors and center tower receiver facilities shown in Fig (B-10). These collectors have very limited applicability for ESCWA's countries in the short term.

a- Parabolic Dish Collectors

The concentrators for parabolic dish collectors are shaped in paraboloids of revolution, this permits a higher concentration of direct solar radiation. Good thermal efficiency can be achieved because of the small receiver area, compared with the aperture area. Temperatures up to 1100°C can be supplied, however they require two axis tracking of the sun. In addition the field piping layouts necessary can cause relatively larger thermal losses.

9/ K.H.Khalil, A.I.Hegazi "A Channelled Solar Flat-Plate Booster" Proceedings of the International Solar Society Congress, New Delhi, India- January 1978

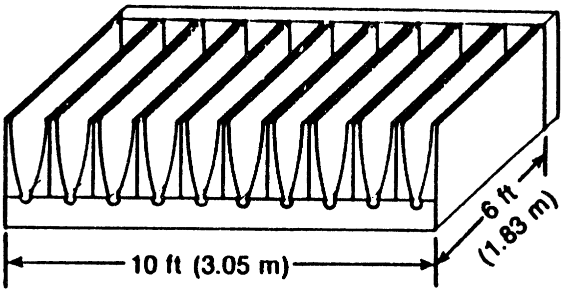


Fig (B-9) a , Compound Parabolic Trough C.P.C.

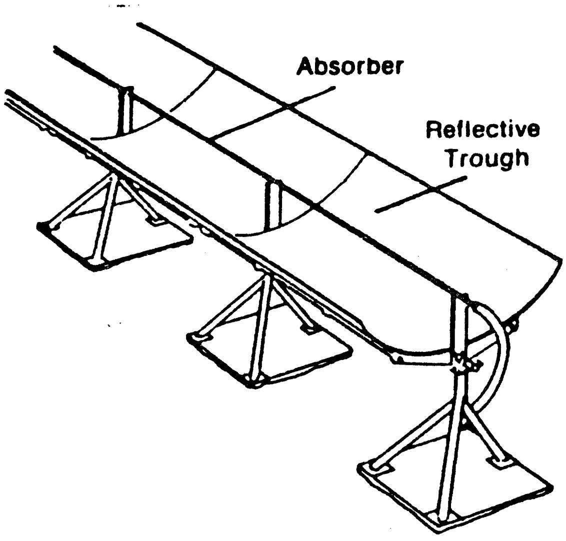
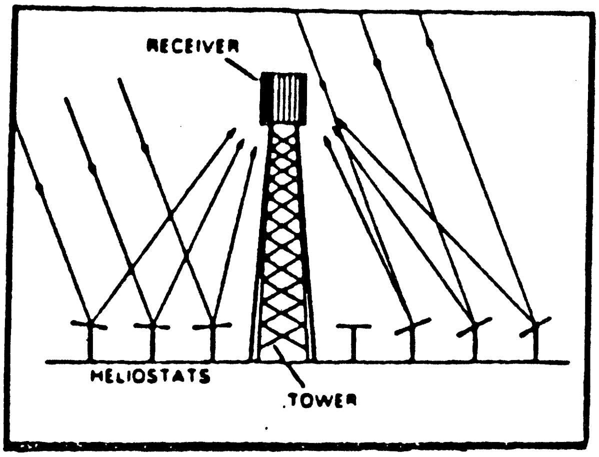


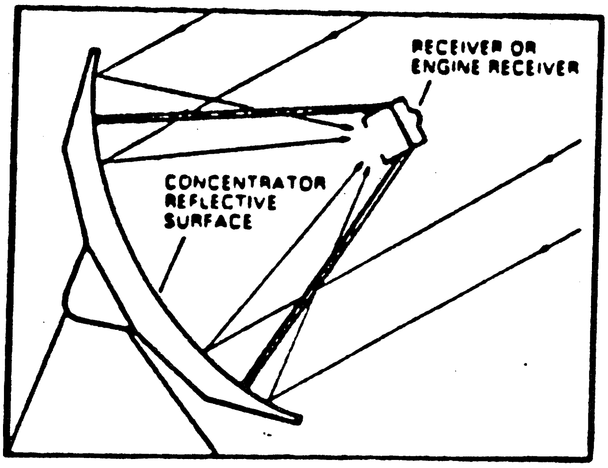
Fig (B-9)b , Typical Parabolic Trough Collector

b- Central Tower Receivers C.T.R

By mounting a receiver on a tower surrounded by a field of carefully aimed individual reflectors (heliostats), very high energy concentrations and, thus high temperatures can be achieved. Because all of the energy is transmitted to one central receiver in the form of light, piping losses associated with distributed receivers are eliminated. Drawbacks include tower support costs, two axis tracking requirements, highly accurate (and costly) heliostat optics, and exclusive use of direct insolation. Central receivers are still under development, and most of the development to date has been applied to electric power plants. The largest "C.T.R" facility is the Solar One "10 MW" facility at Barastow, California.



CENTRAL RECEIVER



PARABOLIC DISH

Fig (B-10) High Temperature Collectors

1.2 Passive Solar Technology

Passive solar systems are defined as the system in which the thermal energy flows by natural means such as radiation, conduction and natural convection. The system collects, stores and transports heat by non-mechanical means.

There are two main applications for passive solar systems, building climatization and protected agriculture. In all cases system configurations will be dependent on climatic conditions, solar radiation availability and the system requirement. They are classified according to the following concepts 10/ :

1.2.1 Direct Gain Passive System

This concept is mainly used for solar heating of buildings, it uses solar radiation directly to heat the living space where heat is absorbed by a thermal wall or mass strategically located in the space. In the direct gain concept shown in Fig (B-11), the space becomes a live-in solar collector, heat storage and distribution system all in one. It comprises two main elements :-

a- Thermal Mass

The two most commonly used materials for heat storage in passive systems are masonry* and water, either individually or in various combinations.

The thermal mass should be designed carefully to suite the environmental conditions, its area should be at least 40 to 50% of the building floor area with not less than 4" thick. The colours of floor and walls should be used to achieve the adequate heating or cooling rates.

b- Glazing "Windows"

The solar window should be carefully designed to admitt appropriate sunlight to keep the space at comfort conditions. In temperate climate with minimum ambient temperatures up to 10°C, window size should be 10 to 20% of the floor area 11/. In hot climates recessing on windows can reduce wind effects and protect the window from hot summer sun.

10/ Edward Mazria "The Passive Solar Energy Book, Rodable Press, Emmaus, Pa, 1980

* Masonry are concrete, brick and adobe materials

11/ A.I.Hegazi "Passive Solar Systems", Presented in the German-Egyptian Solar Week, Cairo, 1981

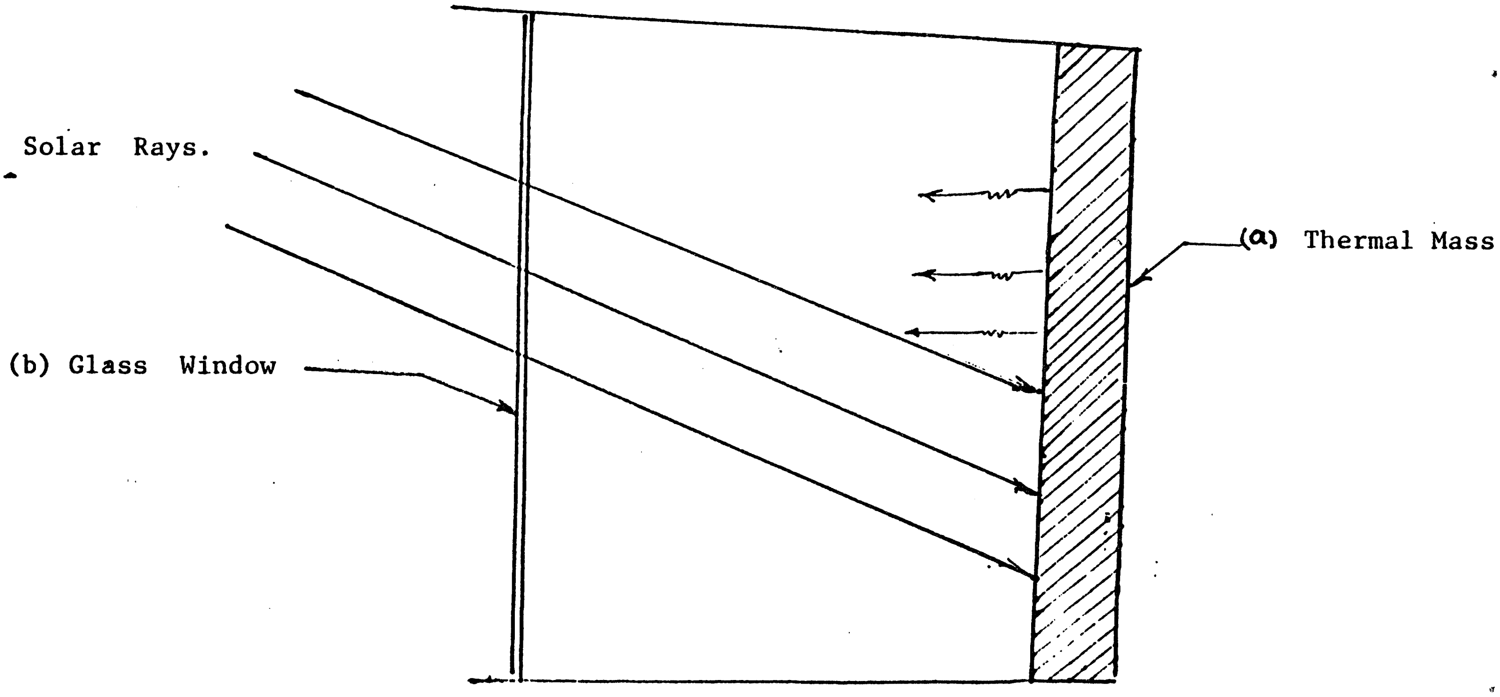


Fig (B-11) Direct Gain Passive System

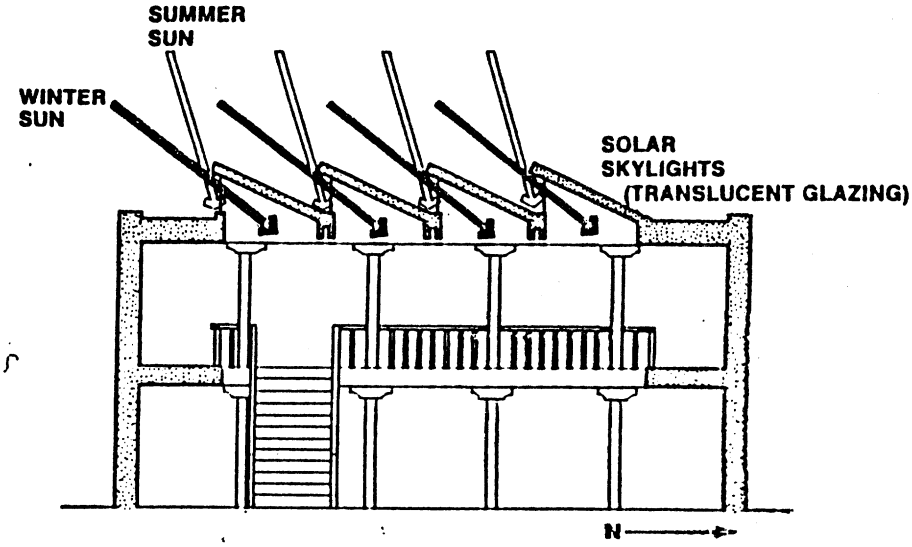


Fig.(B -12) Skylights and Clerestories

Also sky lights and clerestories can be used to avoid summer rays with high altitudes, see Fig (B-12).

1.2.2 Indirect Gain Passive System

In the case of thermal storage walls, Fig (B-13), the wall fabricated from masonary or water is placed about 4" behind the south facing glass to conduct the absorbed heat to the living space.

Vents may be added to the wall to permit heat distribution by natural convection from the exterior face of the wall.

b- Roof Ponds

In a roof pond system, thermal mass is located on the roof of the building. In case of water ponds enclosed in plastic bags and supported by a roof, it is equally used for winter heating and summer cooling as shown in Fig (B-14).

1.2.3 Greenhouse Passive System

Green house passive systems are used for both agriculture applications and space climatization. It is used basically for environmental control, in agriculture applications green houses are used to adapt the required temperature for the plant in addition to reduction of water evaporation in hot arid climates. They help to increase the productivity of land between six to eight folds if properly designed. A number of designs were developed to suite different climatic conditions and plant requirements [see Fig (B-15)] 12/.

An attached green house for a building can help in winter for heating the interrior space and for space cooling by evaporative cooling in summer. As shown in Fig (B-13), it is essentially a combination of direct and indirect gain passive systems. Basically, sunlight is absorbed by the back wall in the green house, converted to heat, and a portion of this heat is then transferred into the building 10/.

There are many possible variations that allow for design flexibility in attached green house applications. For examplé, active systems such as fans can be used to insure that a greater percentage of heat is extracted from the green house to heat adjoining spaces.

12/ A.A.M.Sayigh "Solar Based Agriculture Systems for the Middle East", International Symposium - Workshop on Solar Energy, Cairo, 1978.

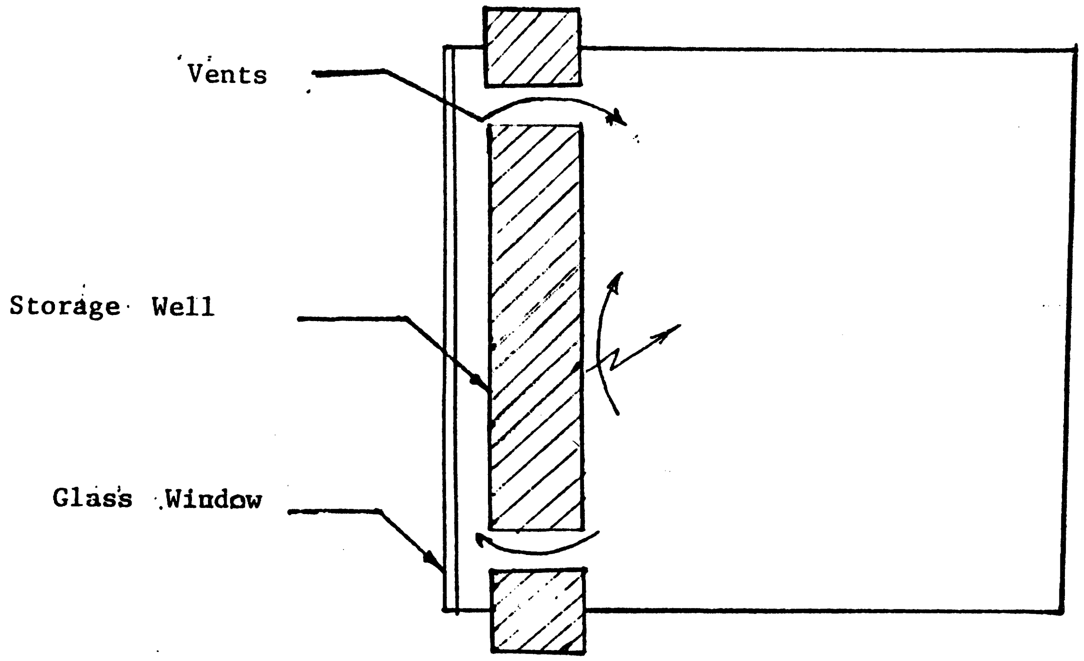


Fig (B-13) a Indirect Cain Passive System

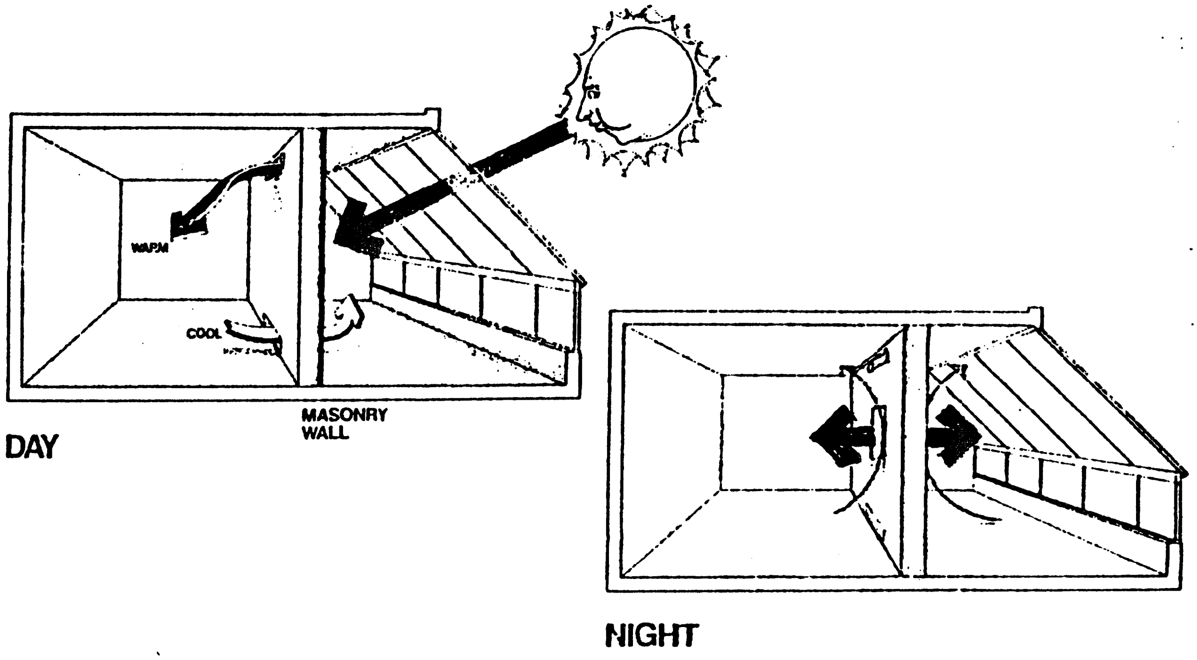
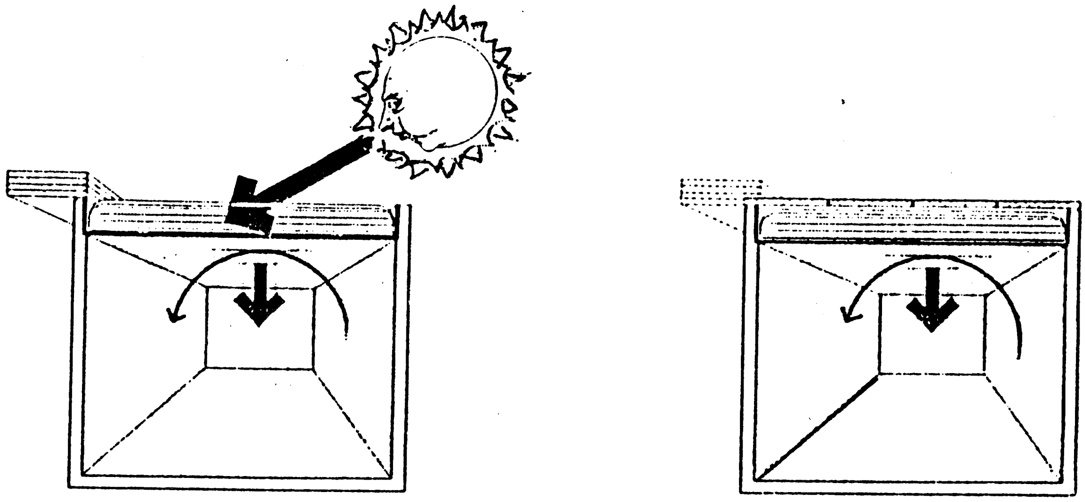


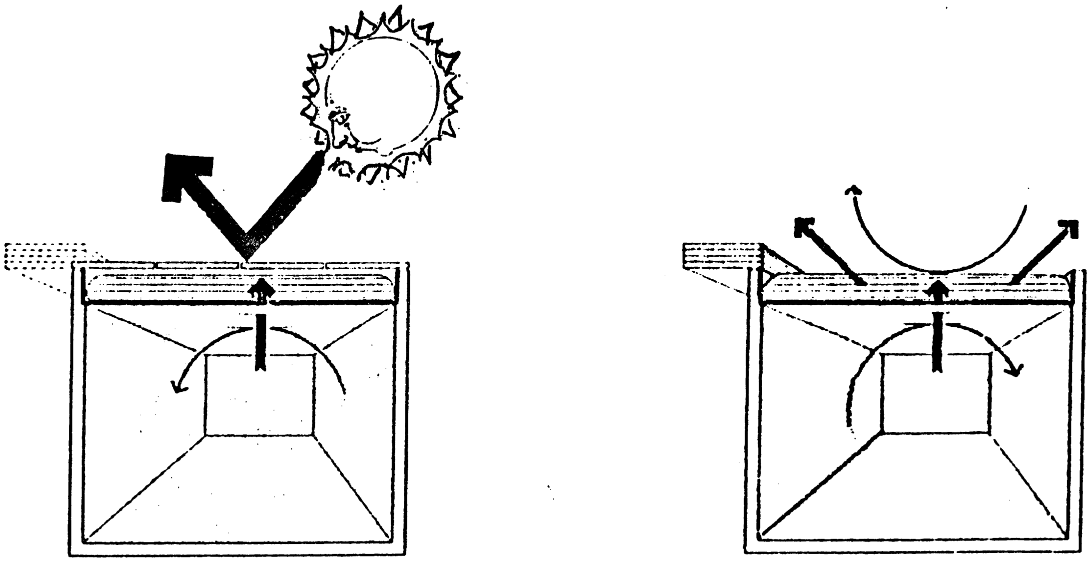
Fig (B-13) b. Indirect Cain Attached Greenhouse



DAY

NIGHT

HEATING CYCLE

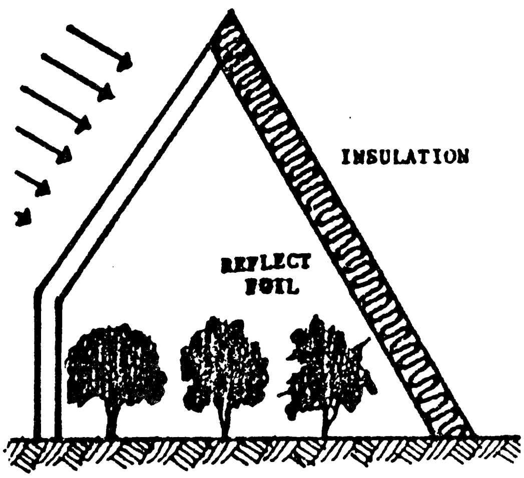


DAY

NIGHT

COOLING CYCLE

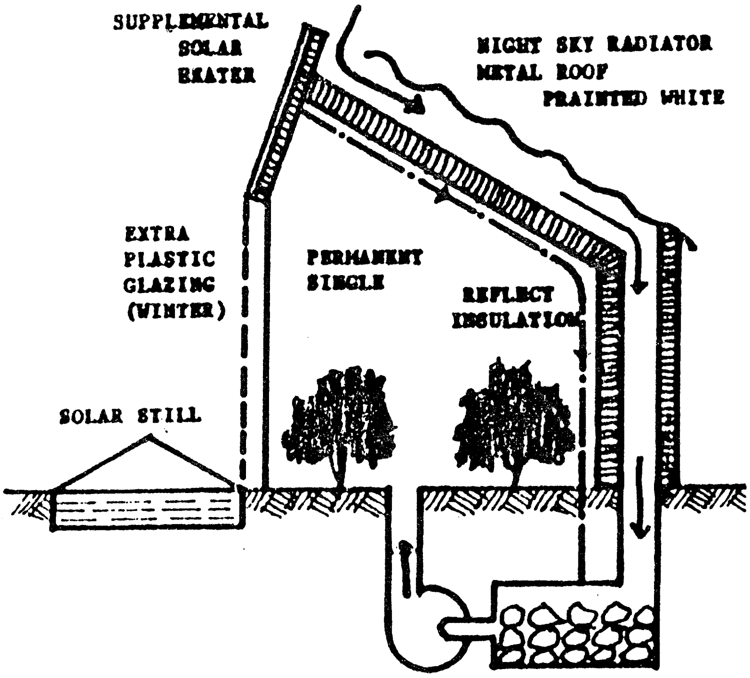
Fig (B-14) Indirect Cain Roof Pond.



LATITUDES ABOVE 45°

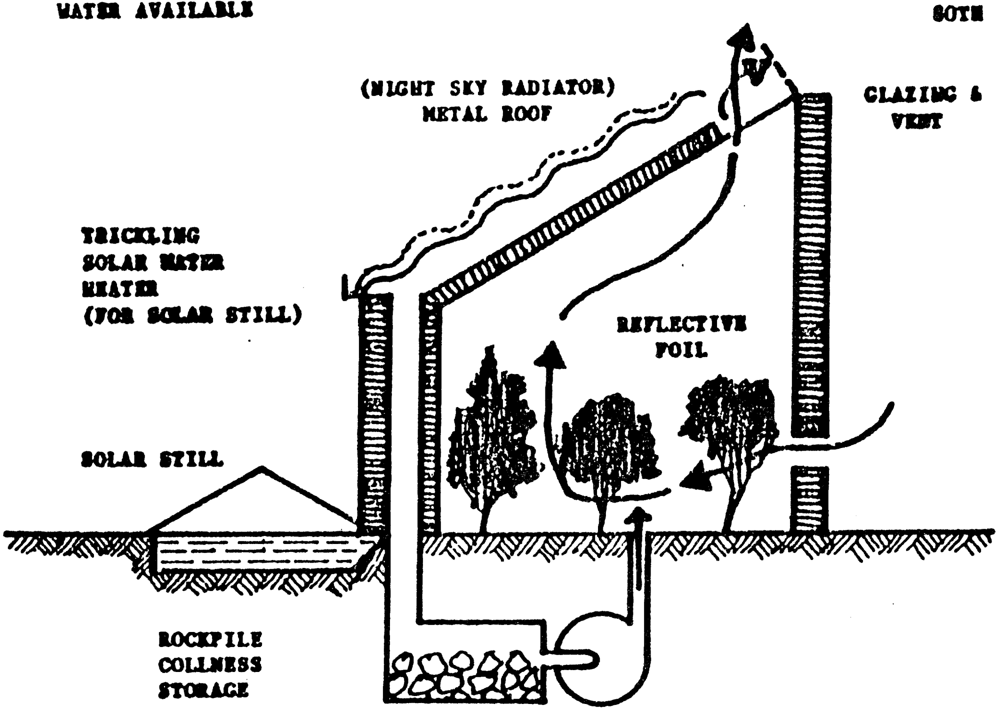
NO COOLING REQUIRED
(BRACE RESEARCH INST.
DESIGN)

MOSTLY ENOUGH FRESH
WATER AVAILABLE



LATITUDE 35 - 45°

BOTH HEATING AND
COOLING



LATITUDE 20 - 35°

NO HEATING REQUIRED

Fig (B - 15) Greenhouse Shapes For Various Climates

1.3 Solar Thermal Storage

In most solar-thermal system applications, the time pattern of solar heat availability from a collector array is a poor match to the pattern of heat demand for useful load. In such cases, utilization of the solar heat potentially available from the collector array is improved dramatically by the provision of some heat storage capability within the solar thermal system.

Direct storage of heat*, may be achieved either as, sensible heat associated with the ordinary working fluid without phase change, or as latent heat associated with the phase change of a chemically-well defined substance.

Both types of thermal energy storage can be used on either an annual or short-term storage. Short-term storage allows the solar energy collected during the day to be used at night, and laso allows energy to be collected on days when the plant is shut down, such as weekends and holidays.

1.3.1 Solar Sensible Heat Storage "S.S.H.S"

The use of'SHS' is basically associated to the low temperature solar applications (110°C) using either water or air as heating fluids. However 'SHS' is also used with high temperature applications "above 250°C", such as storage for power generation plants ....etc. 13/

Low temperature 'SHS' are mainly, hot water storage or hot air to heat solid rockbeds.

a- Hot-Water Storage

Hot water storage systems are mostly used with 'DHW' and 'I.P.H' applications, solar heating and cooling projects as well as low temperature mechanical or electric energy generation. Four possible configurations for hot water storage are shown in Fig (B-16). All four configurations illustrate direct systems that incorporate process water passing through the collector array. According to the requirement of each specific application, a heat exchanger could be placed between the collectors and the storage tank, and the appropriate system can be determined. Details of system design, modeling, cost and economic evaluation is given in 6/, 13/.

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* Without intermediate conversion to another energy form

13/ William C. Dicknson "Solar Energy Technology Handbook" Chapter 23.

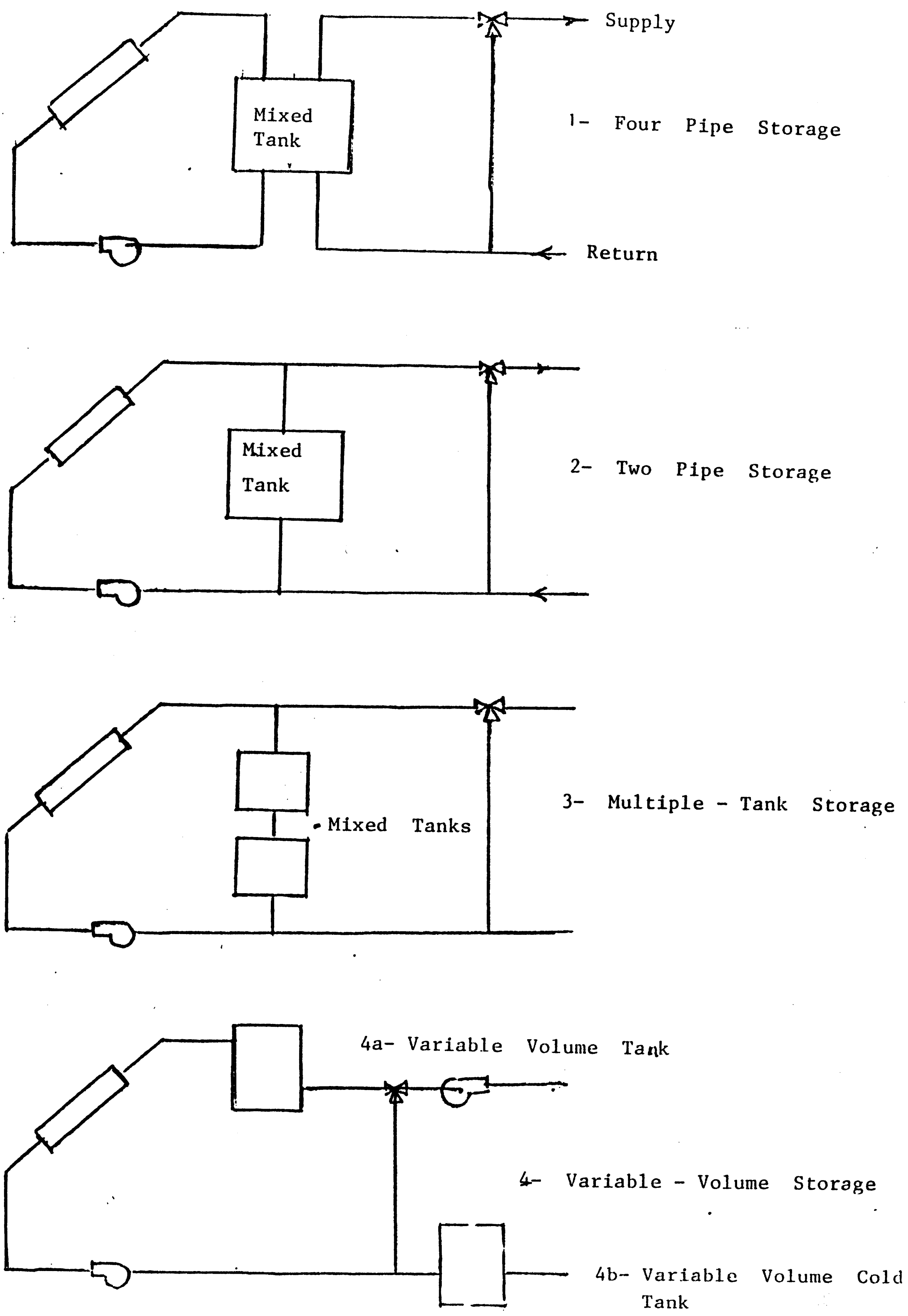


Fig (B-16) Sensible Heat Storage Configurations .

b- Rockbed Storage

Rockbed storage is mostly used with solar heating applications in buildings, either with active or passive designs. In the latter heat can also be stored in a thermal wall, which is made from masonary material or water as shown in Fih (B-17). In all cases heat is stored during daytime in the rocks and re-radiated by night. For detailed information see references 10/ and 13/.

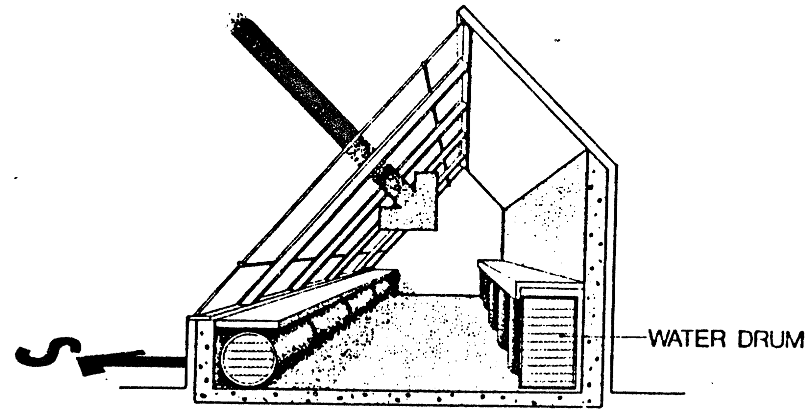
c- Storage For Steam Systems

for solar steam systems, hot water storage systems would also be appropriate if unfired boiler is used. The collector fluid would be oil, and the load supply and return would connect to the unfired boiler. Oil is used because of the high pressures that would be encountered with water storage. To maximize performance, a thermocline bank can be included that incorporates a mixture of oil and rocks however this technology is still in the development phase.

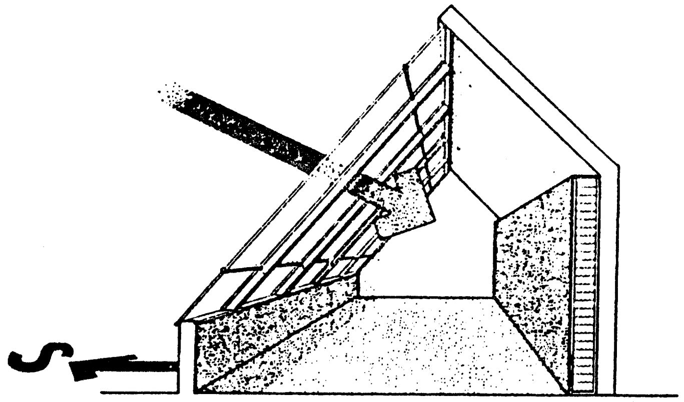
1.3.2 Phase-Change Storage Systems

Storage of thermal energy by means of phase-change materials 'PCMs' is simple in principle. It is characterized by the higher heat storage capacity per unit mass of storage material, as well as being appropriate for high temperature applications. This is due to the fact that latent heat of fusion is relatively large compared to that which is absorbed as sensible heat.

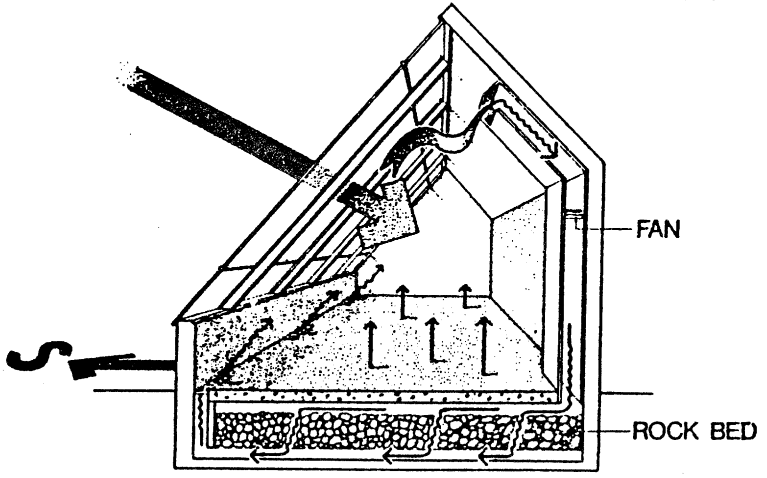
The concept of solar energy storage for practical applications by means of 'PCMs' is relatively recent. Different materials are in use, water, rock and PCM (salt hydrates). Details of these systems are given in Chapter 26 of reference 13/.



MASONRY-ADDITIONAL MASS



INTERIOR WATER WALL



ACTIVE ROCK STORAGE

Fig (B-17) Types of Thermal Mass Storage

1.4 Solar Thermal Systems Performance

The performance of a solar system is affected mainly by collector performance in active systems, and by the integrated performance of specific design in case of passive systems.

1.4.1 Solar Thermal Collectors Performance

Annual performance of a solar system is highly dependent of the performance of the solar collector, which can be evaluated using both collectors instantaneous efficiency and process load characteristics.

The instantaneous performance of a collector is normally expressed in terms of its efficiency, which defines how much of incident radiation on collector surface is actually converted to useful thermal energy. It is defined as

$$\eta_c = \frac{\text{Energy collected}}{\text{Available irradiation}} = \frac{q_a}{I_a}$$

and is expressed as follows :-

$$\eta_c = F_R\tau\alpha - F_R UL\ \left(\frac{T_{f,i} - T_a}{I_a}\right) \text{ ------------------(1)}$$

where :

FR : Collector heat removal factor
τ : Optical transmissivity of glass cover
α : Absorptivity of collector surface
UL : Collector overall heat loss coefficient (W/m^2K^{-1})
$T_{f,i}$: Inlet fluid temperature ^oC
T_a : Ambient temperature ^oC
I_a : Available irradiance on collector plane (W/m^2)

Equation (1) applies to all types of collectors, however the value of "Ia" would vary among them. For flat-plate collectors and evacuated tube collectors, the global irradiance on the collector plane should be used. For parabolic trough and concentrating collectors, I_a stands for direct radiation only.

In addition, since heat loss coefficient variation with temperature can be significant for high temperature collectors, a second order efficiency equation is sometimes used (Tabor 1980). In this case η_c would be expressed as follows :

$$\eta_c = F_R \tau\alpha - F_R U_{L,1} \frac{T_{f,i} - T_a}{I_a} - U_{L_1}^{2} \frac{(T_{f,i} - T_a)^2}{I_a}$$

Fig (B-18) presents typical solar-noon instantaneous efficiency curves, according to ASHRAE standard for testing procedure No. ANSI/ASHRAE 93-77R, which is the most commonly used testing procedure. The recent version "under revision" is developed for both flat-plate, evacuated tube and concentrating collectors.

It can be seen clearly that flat-plate collectors over-perform evacuated tube at low temperature below 80°C, and the latter exceeds flat-plate efficiencies at higher values of (DT/I), due to the reduced heat loss. Evacuated tubes are used for applications at 80°C to 150°C.

Parabolic troughs usually exhibit even smaller heat losses, in fact it shows higher efficiency thn that of other types of collector, however this is based on direct radiation only.

Variation in optical efficiency should also be accounted for to predict collector performance closely. Optical performance can vary with the angle of incidence, thus correction factor (incident-angle modifier) account for this variation, and are generated with standard collector performance tests are expressed as follows :

$$K_{\tau\alpha} = 1 - bo\,\left(\frac{1}{\cos\theta} - 1\right)$$

where :

bo : a constant dependent on the collector's optical properties.
θ : angle of incidence on collector plane.

Fig (B-19) shows the variation $K_{\tau\alpha}$ with incident angle for different types of collectors.

The choice of an appropriate collector for a specific solar application is of prime importance for adequate system performance. The dominant quantities which govern the choice are :

- The average collector operating temperature
- The performance characteristics of each collector type, described simply by an optical efficiency and an overall heat-loss coefficient.
- The average annual direct normal and total horizontal irradiance at the site.
- Capacity cost "total installed system cost divided by annual collected energy" and running costs.

Table (B-1) shows a typical range of liquid collector performance characteristics.

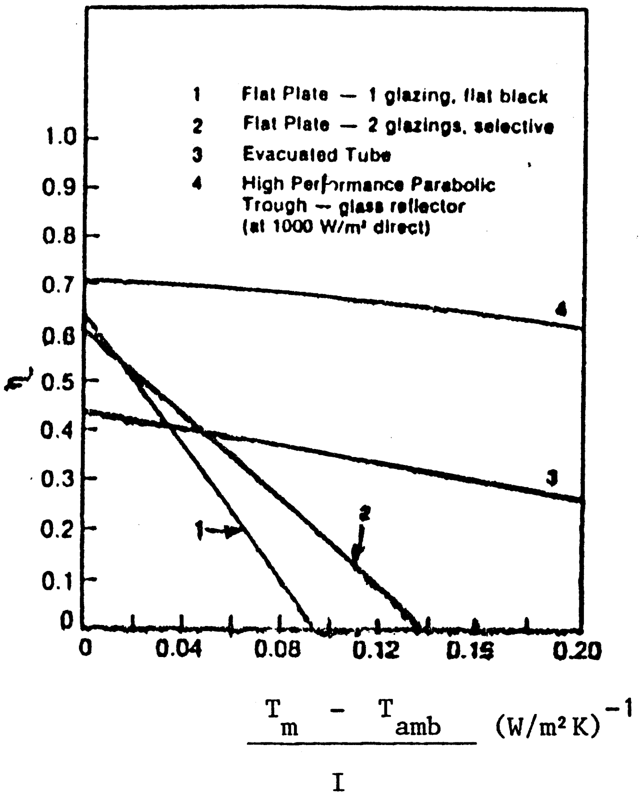


Fig (B-18) Typical Instantaneous Efficiency for Collectors

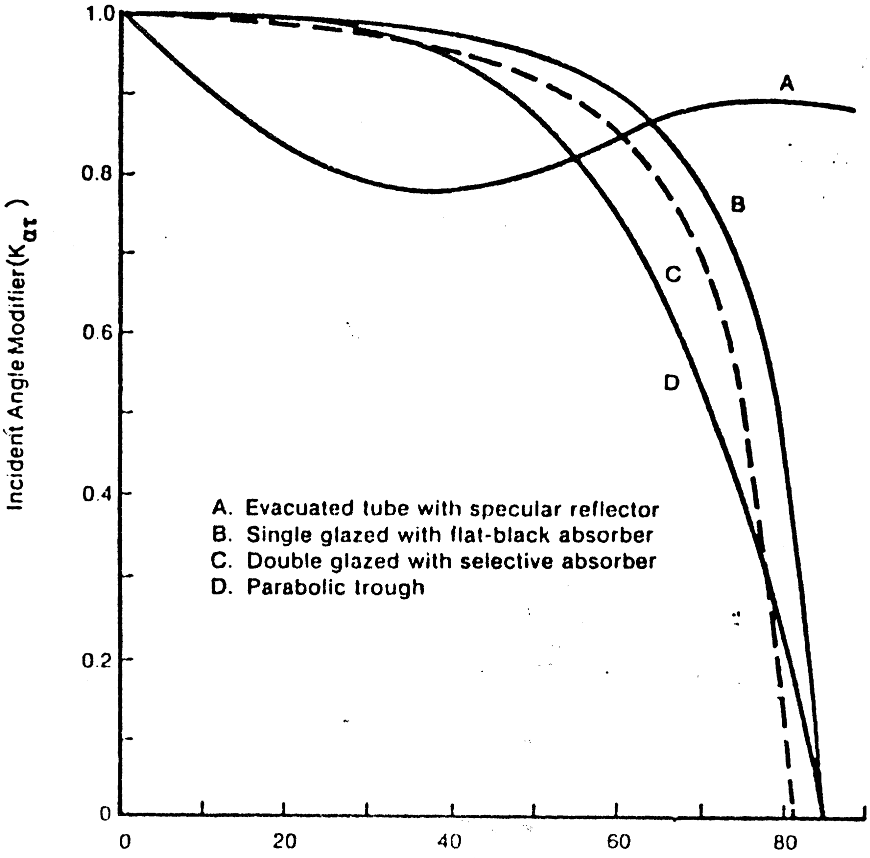


Fig (B-19) Incident Angular Modifier

Table (B-1) Solar Collector Performance Factors

Collector Type	$F_R(\tau\alpha)_n$	$F_R U_L$ (W/m² °C)
1. Liquid heater, steel absorber		
(a) Single-glazed ordinary lime float glass	0.71	5.21
(b) Single-glazed ordinary lime float glass with 5 cm additional back insulation	0.73	4.49
2. Liquid heater, single low-iron glass		
(a) Steel absorber, black selective paint	0.75	6.36
(b) Copper absorber, black selective paint	0.75	6.36
(c) Steel absorber, black chrome coating	0.84	4.49
(d) Copper absorber, black chrome coating	0.84	4.49
3. Liquid heater, unglazed (for pools), black plastic	0.76	14.76
4. Liquid heater		
(a) Fiberglass-reinforced plastic cover, aluminum absorber	0.62	7.38
(b) Fiberglass-reinforced plastic cover, aluminum absorber/copper flow tubes	0.58	4.77
(c) Fiberglass-reinforced plastic cover, copper absorber	0.64	6.08
(d) Fiberglass-reinforced plastic cover, aluminum absorber	0.54	4.32
5. Liquid heater, copper tubes in steel absorber, black chrome on bright nickel coating, double low-iron glass cover	0.78	3.41
6. Liquid heater, copper tubes in aluminum absorber, thermal paint coated		
(a) Single water-white glass	0.76	6.64
(b) Double water-white glass	0.76	5.00
7. Liquid heater, copper absorber, single cover, black paint coated	0.56	5.51
8. Heater, polycarbonate single glazing		
(a) Liquid, aluminum absorber, steel flow tubes	0.73	4.94
(b) Air, steel absorber	0.74	5.51
9. Liquid heater, acrylic glazing, black paint coating		
(a) Aluminum absorber	0.74	7.04
(b) Copper absorber, aluminum flow tubes	0.76	7.72
10. Air heater, steel absorber sheet coated with black chrome on bright nickel, single low-iron glass cover	0.56	4.88

Other factors should also be considered, including collector materials durability in working conditions, maintenance and replacement costs for each collector type and availability of appropriate man power for system operation and maintenance.

1.4.2 Performance of Passive Systems

The performance of a passive solar system is quite dependent on its integrated design concept, materials used and specific site climatic conditions. Thus its performance have not been standerdized yet. Recently the American Society of Heating, Refrigerating and Air-Conditioning Engineers 'ASHRAE' initiated "the passive energy systems design and analysis" report, which is not yet finalized. Most of existing performance data for specific buildings are measured experimentaly. Two examples are given hereinafter for heating and cooling passive systems.

Fig (B-20) shows a well-known example of passive heating buildings, the Trombe house in Adeillo, France, and its predicted performance during December. Results from studies show that approximately 70% of this building yearly heating needs are supplied by solar energy, with an average efficiency of (36%) 10/.

The earliest example of a residence with a roof pond system is the experimental building in Atascadero, California. The roof of this building is constructed of ribbed steel which spans between concrete block walls spaced at 12-foot intervals. Transparent plastic bags, filled with water are placed on the steel deck to form the roof ponds. The house has been 100% solar heated and naturally cooled since it was occupied in 1973. Fig (B-21) shows its performance both in winter and summer.

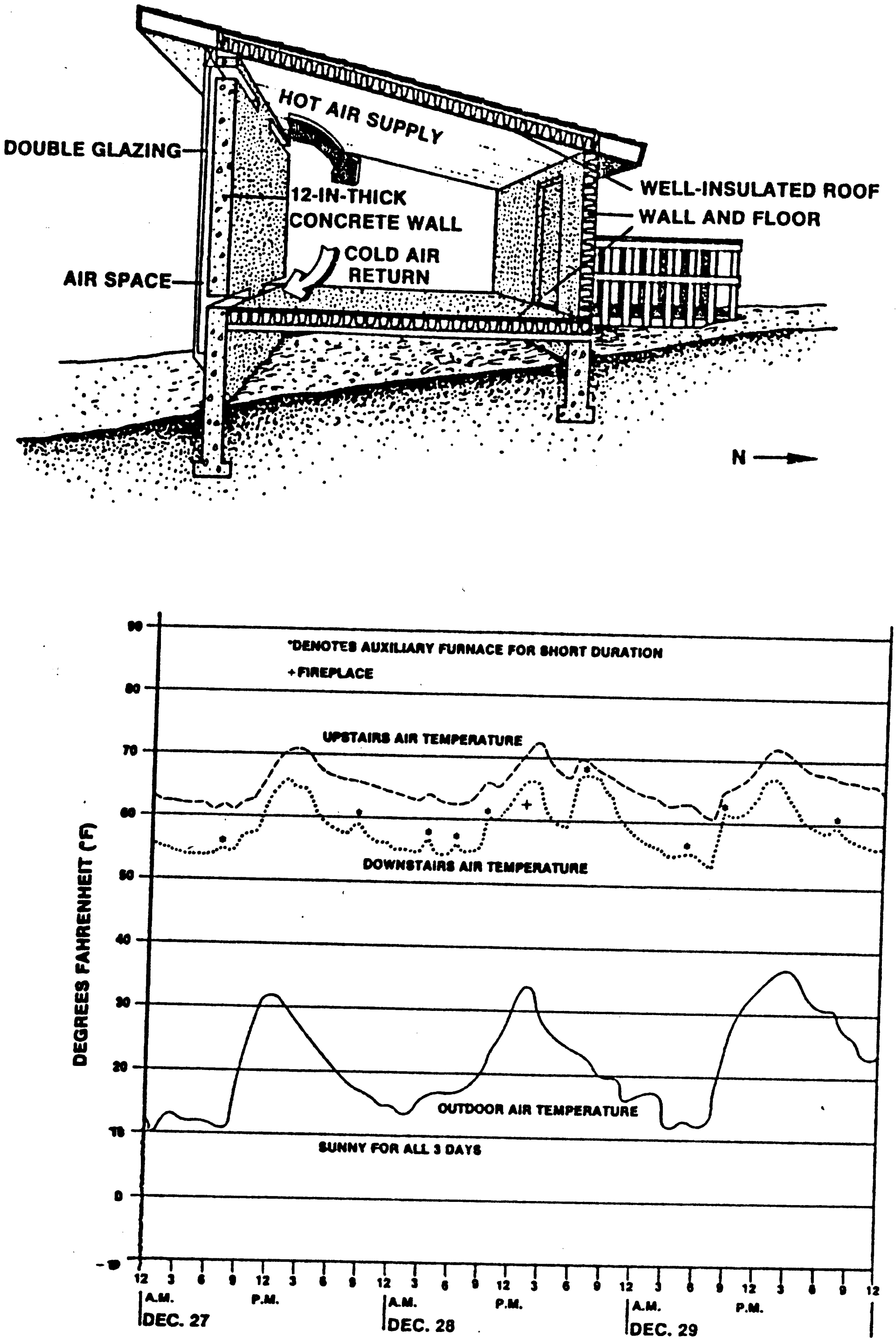
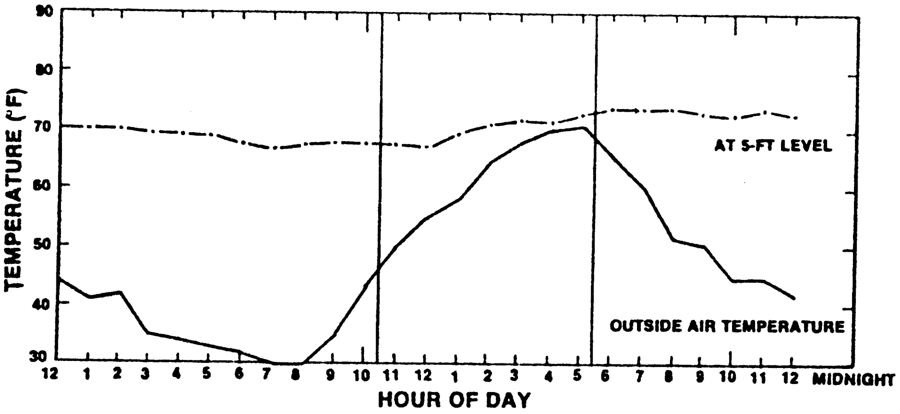
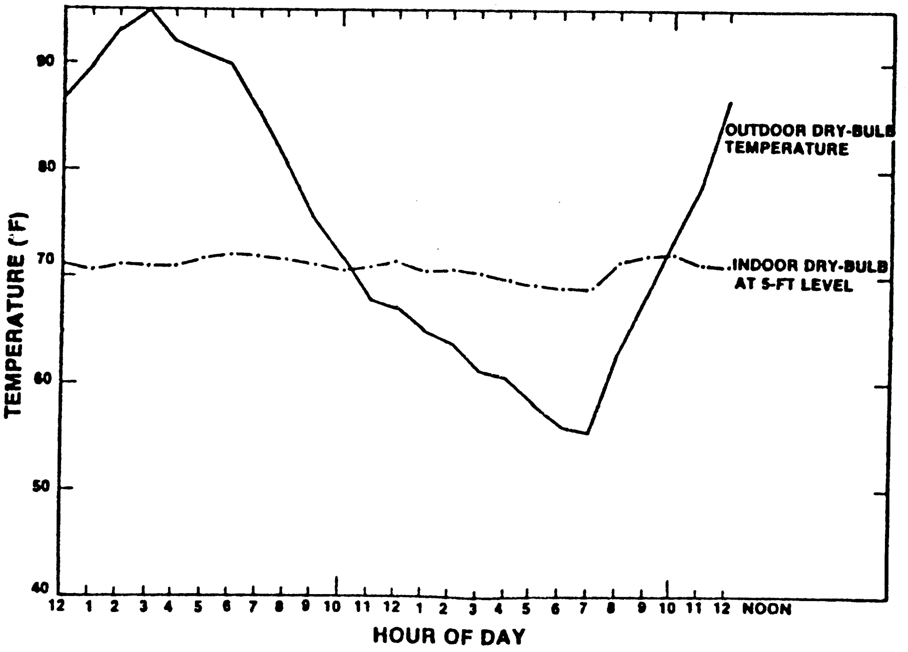


Fig (B-20) Trombe House Section and Performance



TYPICAL HEATING DAY—FEBRUARY 24



TYPICAL COOLING DAY—AUGUST 23

Fig (B-21) Heating and cooling temperature profiles, Skytherm System, Atascadero, California.

Source: R. P. Stromberg and S. O. Woodall, *Passive Solar Buildings: A Compilation of Data and Results.*

2- APPLICATIONS OF SOLAR THERMAL TECHNOLOGIES

Solar thermal technologies are used for a wide variety of applications in rural as well as urban areas. The solar thermal system would highly depend upon the specific application requirement particularly the temperature level. These applications include heating, cooling and mechanical and electrical power supply for domestic, industrial and agriculture sectors.

2.1 Domestic Hot Water

The domestic hot water "D.H.W" solar systems are the best known and commonest application of the flat-plate solar collectors. A solar water heater consist of one or several collectors, storage tank, circulation and control systems and in some cases an auxiliarly heating element. They may be classified according to the size as single or collective systems or to the type of circulation for the heating fluid, thermosyphon or forced circulation systems.

The circulation in thermosyphon solar water heater is exclusively by natural means, due to the density difference of heat water. It is almost used for single family heaters in area where freezing problems are limited. Fig (B-22) depicts the configuration of the system.

Circulating pump systems shown in Fig (B-23) , have the highest efficiency. They are most common for large installations (collective systems), and for closed loop single heaters for freeze protection systems. However mechanical energy is necessary and maintenance is more frequent than with other systems.

In addition simple models of solar water heaters made of plastic and polymer materials are developed for use in swimming pools and other limited temperature applications below 35°C. Additional detailed information are given in part III of this study.

2.2 Industrial Process Heat Applications "IPH"

The industrial sector is the largest energy user in developed and some of the developing countries, direct thermal energy use which represents a significant potential market for solar energy applications.

There are several advantages for using solar energy for (I.P.H) including, total impact on the nation's energy would be greater than other domestic applications, industrial loads are almost constant and

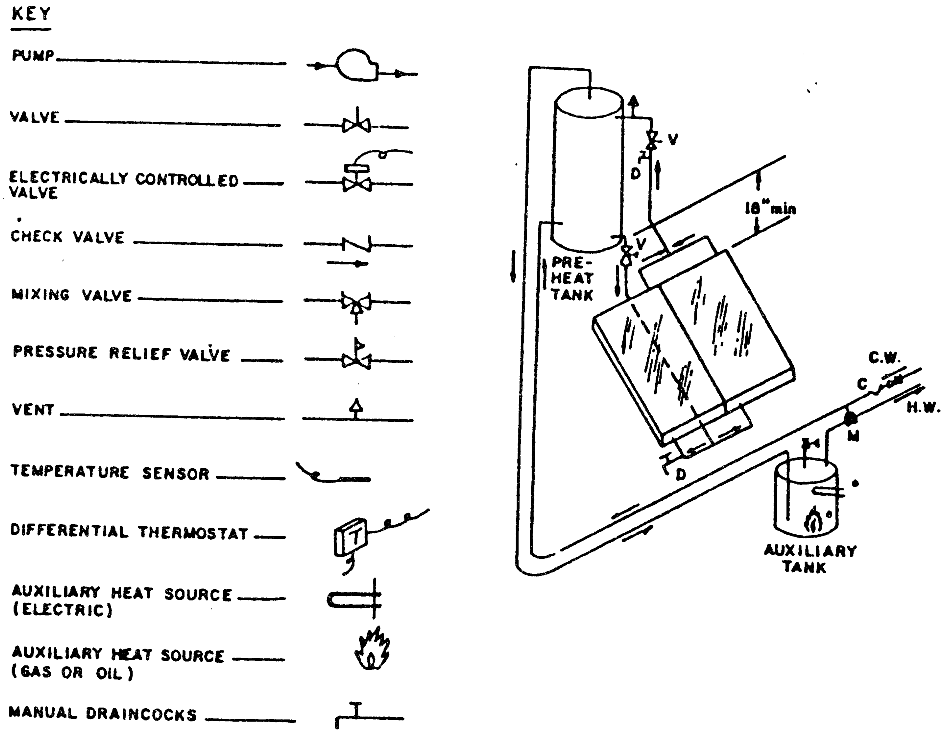


Fig (B-22) Thermosyphon Solar Water Heater

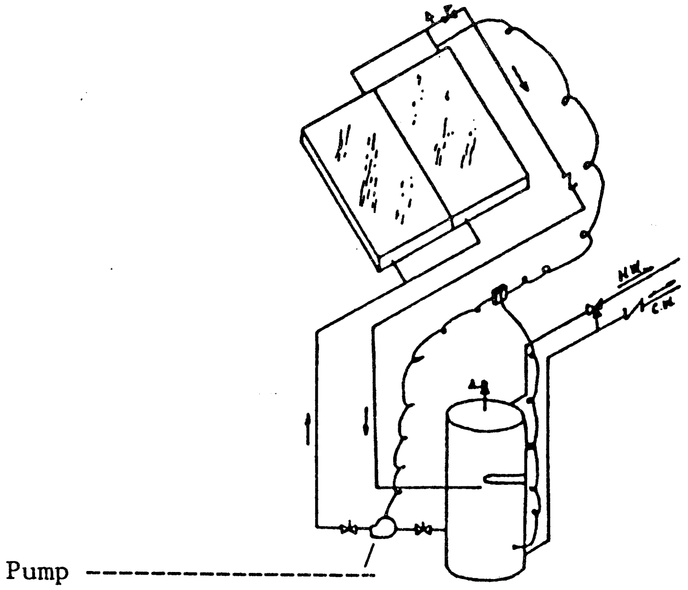


Fig (B-23) Forced Circulation Solar Water Heater installation and maintenance crews are usually available at the plant.

The suitability of solar energy in a particular application depends on, process temperature, climate, economics and available space. The market suitability is fully discussed in part III.

Three main areas of solar thermal application in industry are, process hot water, drying/dehydration and process steam .

2.2.1 Process Hot Water

Heated water is used in large amounts at temperatures between 50°C and 100°C for cooking, washing, bleaching, and anodizing, in addition to preheating of boiler feed water. These applications accounts for about 5% of industrial energy consumption, but it could be supplied by higher temperature waste heat. Collective solar hot water systems are used for these applications either using open or closed loop systems according to process conditions. An example of IPH hot water system is shown in Fig (B-24). This particular system supplies (120 gal/min) of hot water in the range of 55°C to 83°C to the York Building Products concrete block curing plant, using $(829) m^2$ of multiple-reflector linear concentrators.

2.2.2 Drying and Dehydration

The agro-industries are the main consumers of industrial hot air for crop drying, however hot air is also used for drying cloth or metalic products to at tempertures below 170°C. The two most common ways to supply solar-heated air are (1) to heat the air directly in the collectors and (2) to heat a liquid in the collectors and then use a liquid-to-air heat exchanger. An example of the first type of system is shown in Fig (B-25) 61 .

Simple solar driers have been demonstrated in different countries, for use by farm owners or in a limited industrial scale. Table (B-2) summarizes the specifications and requirements of the different solar driers for various climates.

2.2.3 Process Steam

Steam is used in industry, 80% of this process steam at temperatures below (175°C) and can be supplied with solar collectors in three ways :-

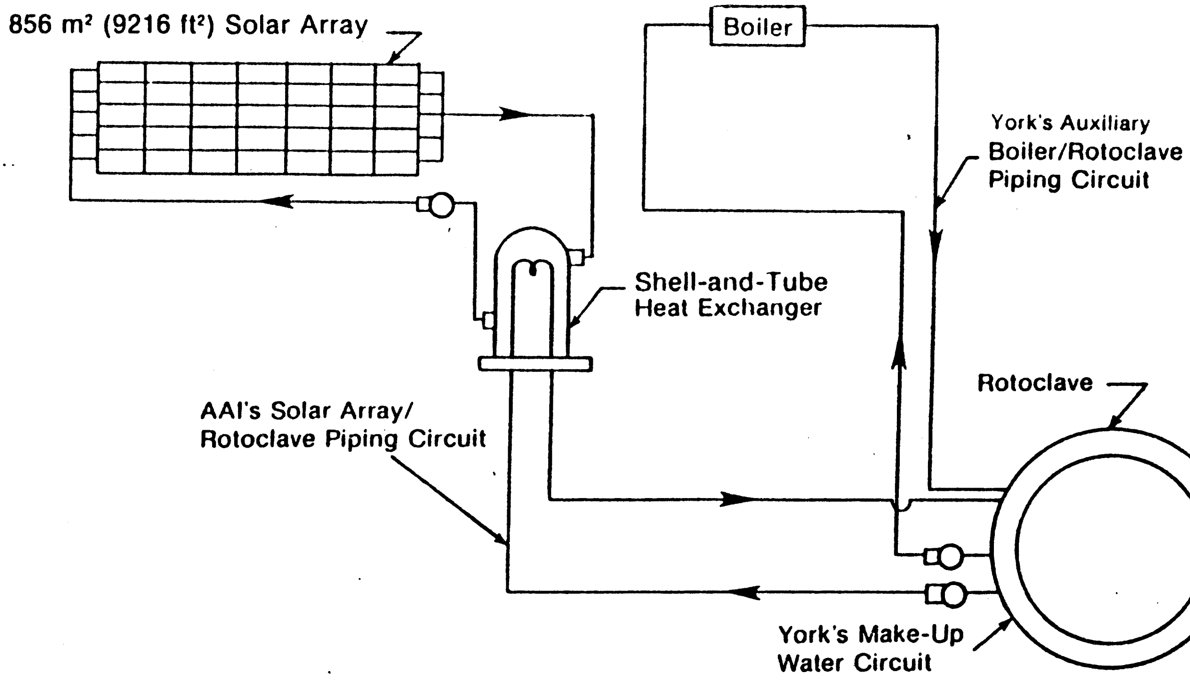


Fig (B-24) York Building Solar Hot Water System

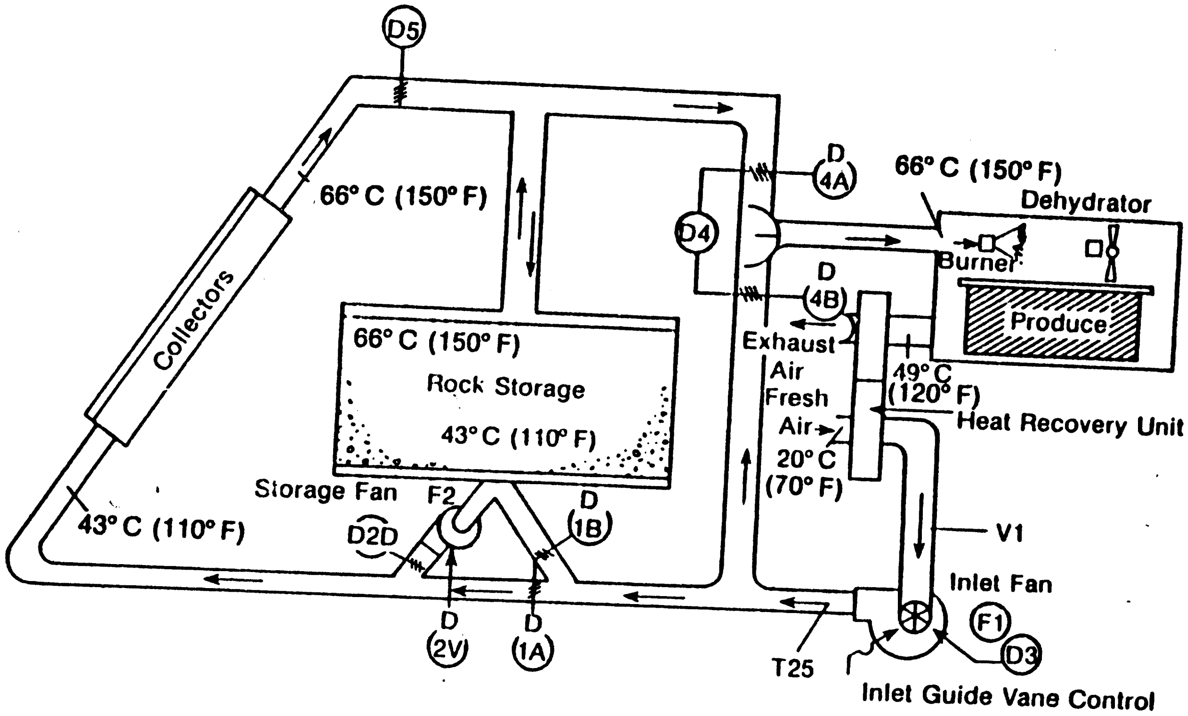


Fig (B-25) Lamanuzzi and Pantalev Food Solar Air System.

TABLE (B-2) SOLAR DRIERS FOR DIFFERENT CLIMATES

DRIVER TYPE	CLASSIFICATION	TYPICAL PRODUCT	CLIMATIC REQUIREMENTS	COUNTRIES WHERE USED	VENTILATION TYPE	CAPACITY	DRYING TIME	DRYING TEMPERATURE
Direct Mode	Aeration driver	Grains Groundnuts	Arid, low rh, high temp.		Fan forced through draught	200 kg	10 hrs	ambient
	Tray driver	Coffee, Beans Cocoa, Maize, Tao	No rains during drying time	Brazil, Colombia Phili, Pines, Nepal	Natural convection through draught	150 kg 10 trays	8-9 days	15-20°C above ambient
	Cabinet driver	Fruits, vegetables	Arid or semi-arid zones with good radiation	Bangladesh, Brazil Colombia, India, Indonesia		15-20 kg/m²	3-4 days	20°C above ambient
Indirect Mode	Bin type	Grain, maize wheat, barley etc...	Warmer humid with average solar radiation	Egypt, FRG, Italy, India, Indonesia, Korea	Fan forced through draught/cross draught	300 kg	2-3 hrs	30°C above ambient
	Tunnel or continuous belt driver	Food dehydration	Good radiation dry climate	Cyprus, Greece	Forced through draught	180 kg	1 day	70°C
Mixed Mode	Shelf type	Fruits, vegetables	High solar insolation in tropical humid or cool weather constant	Australia, India, Indonesia, Nigeria Syria, Turkey	Natural/forced through draught	14-15 kg/m²	1-4 days	60-80°C
	Wind ventilated driver	Cassava, cubes grapes, fruits, vegetable	Arid, low rh high wind velocity	Syrian Arab Republic	Wind driven fan			40-60°C

- Using a high transferring fluid in the collectors and transferring the heat to an unfired boiler.
- Circulating pressurized water in the collectors and flashing it to steam in a flash tank.
- Boiling water in collectors.

The first type of system is shown in Fig(B-26) where a fluid is heated to 246^{o}C using 900m² of parabolic trough collectors. The hot fluid is used to boil water in an unfired boiler, supplying steam at (125 psig). Also Fig (B-27) shows a system of the second type. 14/

Although steam is used widely in industry to transport heat, it is probably better to combine solar energy with hot water. If hot water supplies heat to a process, solar collectors can be used without unfired boilers and without the disadvantages of flash systems. Thus, if solar energy is being considered for a new plant, some consideration should also be given to using pressurized hot water in place of steam .

Table (B-3) shows examples of IPH, demonstration systems in the USA using different systems .

2.3 Solar Water Desalination

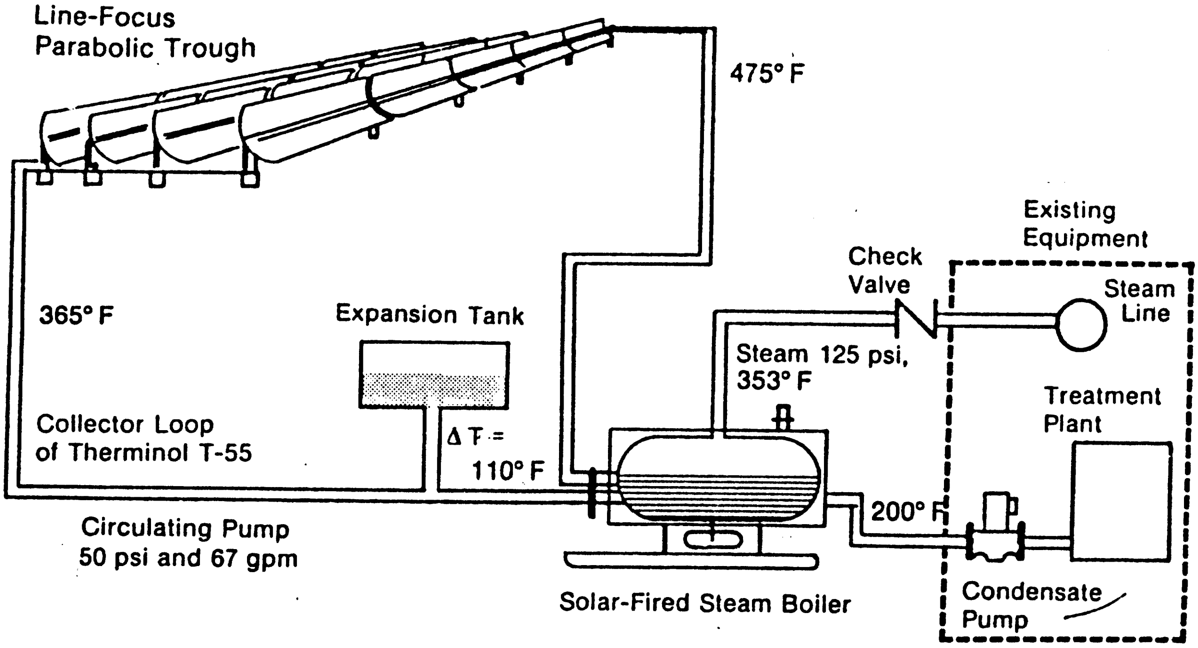
All around the world, there are huge amounts of saline water the potability of which is impaired due to the high content of total disolved solids. Fortunately arid regions suffering lack of fresh water are mostly enjoying long sunshine hours, which can be used to produce fresh water from saline water. Different processes are used for saline water thermal desalination. Table (B-4) shows how much energy is consumed in various types of desalination processes15/. These processes are :

a) Distillation Processes
   - Flash type distillation
   - Single or multiple effect distillation
   - Vapour compression distillation

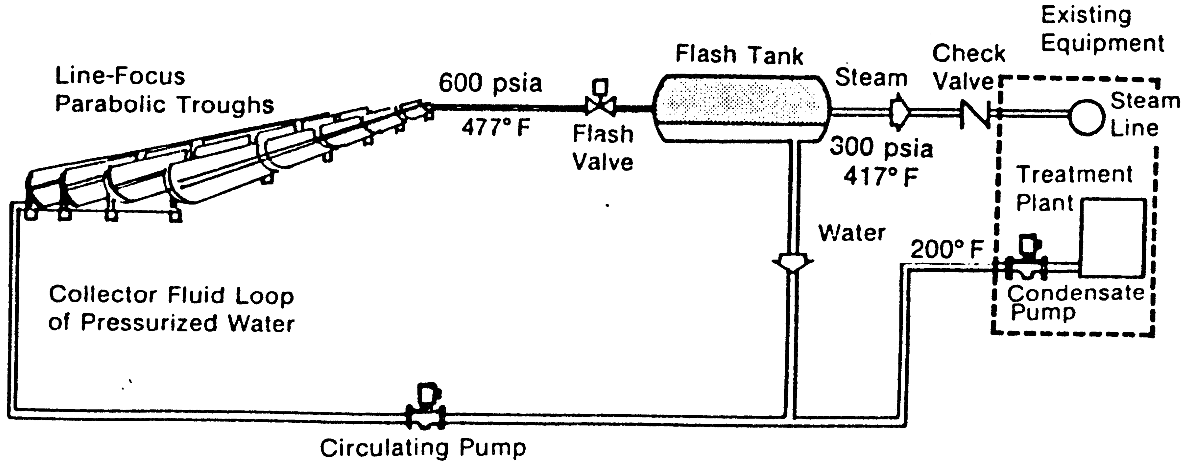
b) Membrane Processes
   - Reverse Osmosis

14/ Orin L. Muray "Solar IPH in Mid America,A Mdsec Study", Industrial Solar Associates, USA. Proceedings of AS/ISES 1980, Phoenix,Arizona

15/ A. Maurel, "Desalination and Solar Energy" First French-Egyptian Solar Energy Week, March 1980.



Fig(B- 26) Solar Steam Production Using an Unfired Boiler



Fig(B- 27) Solar Steam Production Using a Flash Tank

Table (B-3) Solar Industrial Process Heat Projects in the United States

	Company	Location	Process Application	Process Temperature (°F)	Collector Type	Collector Manufacturer	Size of Array (ft^2)	Status	Funding
HOT WATER SYSTEMS									
1	Sweet Sue Kitchens Inc.	Athens, Ala.	Preheat boiler feedwater	130	Pon	NAv	16,560	IDs	Gov
2	American Linen Supply Co.	El Centro, Calif.	Preheat boiler feedwater, wash water	200	PTr	JD	12,150	IDs	Gov
3	Aratex Service Inc.	Fresno, Calif.	Heat process water	120-160	Pl	NAv	6,720	Opr. 9/77	Gov
4	Iris Images	Mill Valley, Calif.	Film processing	75-100	Pl	NAv	640	Opr. 8/77	Gov
5	Stauffer Chemical Co.	Oxnard, Calif.	Chemical processing	125	Pl[a]	NAv	38,000	IDs	G/P
6	Jhirmack Enterprises Inc.	Redding, Calif.	Preheat boiler feedwater	160-200	Pl	NAv	6,750	Opr. 7/80	PFi
7	Campbell Soup Co.	Sacramento, Calif.	Can washing	180-195	PTr, Pl	ACX, SG	7,335	Opr. 11/77	Gov
8	Caterpillar Tractor Co.	San Leandro, Calif.	Heat wash water	235	PTr	SK	50,400	IDs	G/P
9	Salz Leathers Inc.	Santa Cruz, Calif.	Tanning and finishing	85-160	Pl	NAv	35,200	IDs	G/P
10	Barkley Meat Co.	S. Lake Tahoe, Calif.	Sanitation	180	Pl	NAv	2,500	Opr.	PFi
11	Anheuser-Busch Inc.	Jacksonville, Fla.	Beer pasteurization	140	ETu	OI	4,600	Opr. 2/78	PFi
12	Dana Corp. Spicer Clutch Div.	Auburn, Ind.	Parts washing	130	Pl	REV	936	Opr. 5/77	PFi
13	Oscar Meyer Corp.	Perry, Iowa	Meat processing	185	NAv	NAv	40,320	IDs	G/P
14	Sohio Petroleum Co.	Grants, NM	Uranium-ore processing	140	Pon	NAv	6,780	Tst	Gov
15	General Extrusion Inc.	Youngstown, Ohio	Solution heating	160-180	Tu	GSC	4,400	Opr. 9/77	PFi
16	York Building Products Inc.	Harrisburg, Pa.	Concrete-block curing	135	MRe	AAI	9,216	Opr. 9/78	Gov
17	Nestle Enterprises Inc.	Santa Isabel, PR	Juice pasteurization	210	ETu	GE	50,000	IDs	G/P
18	Riegel Textile Corp.	LaFrance, SC	Heat dye-beck water	190	ETu	GE	6,680	Opr. 6/78	Gov
19	Coca-Cola Bottling Co.	Jackson, Tenn.	Bottle washing	NAv	ETu	OI	9,480	Opr. 9/79	PFi
20	Tyson Foods Inc.	Shelbyville, Tenn.	Poultry processing	129-140	ETu	OI	53,430	IDs	G/P
21	Mary Kay Cosmetics Inc.	Dallas, Tex.	Sanitizing	140	Pl	SEI	1,000	Opr. 10/79	PFi
22	M & M Mars Corp.	Waco, Tex.	Heat water for cafeteria[b]	NAv	NAv	NAv	NAv	NAv	NAv
23	Easco Photo	Richmond, Va.	Film processing	115	Pl	SUN	NAv	Opr. 7/78	PFi
HOT-AIR DRYING SYSTEMS									
24	Gold Kist Inc.	Decatur, Ala.	Preheat dryer air	180	Pl	SR	13,104	Opr. 5/78	Gov
25	Lamanuzzi & Pantaleo Foods Inc.	Fresno, Calif.	Drying	143	Pl	TRW	21,000	Opr. 8/78	Gov
26	Gilroy Foods Inc.	Gilroy, Calif.	Preheat dryer air, boiler feedwater	194	ETu	GE	5,950	Opr. 9/79	Gov
27	Western Alfalfa Corp.	Lawrence, Kan.	Preheat dryer air	400	PTr, Pl	HX	NAv	IDs	Gov
28	LaCour Kiln Services Inc.	Canton, Miss.	Lumber drying	180	Pl[a]	CMC	2,520	Opr. 11/77	Gov
29	U.S. Gypsum Co.	Sweetwater, Tex.	Board drying	900	Hel	BOE	222,043	IDs	G/P

[a] With reflectors.

[b] Expansion for process use under way.

Table(B-3) Solar Industrial Process Heat Projects in the United States (Concluded)

	Company	Location	Process Application	Process Temperature (°F)	Collector Type	Collector Manufacturer	Size of Array (ft^2)	Status	Funding
THERMAL-LIQUID HEATING SYSTEMS/DIRECT-FIRED PROCESS HEATING									
30	Ergon Inc.	Mobile, Ala.	Heat thermal liquid	130-190	PTr	ACX	20,160	IDs	Gov
31	Atlantic Richfield Oil & Gas Co.	Bakersfield, Calif.	Heat thermal liquid	560	Hel	NOR	181,120	IDs	G/P
32	Valley Nitrogen Producers Inc.	El Centro, Calif.	Direct process heating	1600	Hel	MD	633,360	IDs	G/P
STEAM SYSTEMS									
33	West Point-Pepperell Inc.	Fairfax, Ala.	Fabric drying	320	PTr	H	7,512	Opr. 9/78	Gov
34	Provident Energy Co.	Mobile, Ariz.	Produce refinery steam	700	Hel	MD	712,352	IDs	G/P
35	Exxon Corp.	Bakersfield, Calif.	Oil recovery	500	PTr	NAv	254,208	IDs	G/P
36	Exxon Corp.	Bakersfield, Calif.	Oil recovery	567	Hel	MMC	432,000	IDs	G/P
37	Petro Lewis Corp.	Bakersfield, Calif.	Oil recovery	500	LiF	GAC	340,800	IDs	G/P
38	Home Laundry	Pasadena, Calif.	Produce steam, preheat wash water	360	PTr	JD	6,496	ICn	Gov
39	NL Industries Inc.	Newberry Springs, Calif.	Hectorite drying	372	PTr	JD	10,240	IDs	Gov
40	Tropicana Products Inc.	Bradenton, Fla.	Ice-block thawing	300	ETu	GE	10,000	Opr. 12/80	Gov
41	Dow Chemical Co.	Dalton, Ga.	Latex manufacturing	366	PTr	STC HX	9,930	ICn	Gov
42	Bleyle of America Inc.	Shenandoah, Ga.	Produce steam, heat water	750	PTr	GE	49,382	ICn	Gov
43	Hilo Coast Processing Co.	Pepeeko, Hawaii	Sugar-cane processing	400	PTr	SK	50,400	IDs	G/P
44	Stauffer Chemical Co.	Henderson, Nev.	Chemical stripping	368	PTr	STC HX	10,592	IDs	Gov
45	Southern Union Co.	Hobbs, NM	Produce refinery main steam	375	PTr	SK	10,080	ICn	Gov
46	Gulf Mineral Resources Co.	San Mateo, NM	Uranium-ore processing	366	Hel	MD	232,439	IDs	G/P
47	U.S. Steel Chemicals Co.	Haverhill, Ohio	Polystyrene processing	373	PTr	SK	50,000	IDs	G/P
48	Ore-Ida Foods Co.	Ontario, Ore.	Produce steam	417	PTr	STC HX	9,520	ICn	Gov
49	Bates Container Inc.	Ft. Worth, Tex.	Produce steam	370	PTr	SK	34,720	IDs	G/P
50	Lone Star Brewing Co.	San Antonio, Tex.	Produce steam	353	PTr	SK	9,450	ICn	Gov
51	Johnson & Johnson	Sherman, Tex.	Produce process steam	345	PTr	ACX	11,520	Opr. 1/80	Gov

Source: Kenneth Brown. 1981 (Nov.). Power Magazine. Vol. 125 (No. 11).

Legend to Table 2-3

ETu - Evacuated tube
G/P - Shared government and private financing
Gov - Government financed
Hel - Heliostat
ICn - In construction
IDs - In design
LiF - Line focus
MRe - Multiple reflector
NAv - Not available
Opr - Operational

PFi - Privately financed
Pl - Flat plate
Pon - Shallow pond
PTr - Parabolic trough
Tst - Test only
Tu - Tube

MANUFACTURERS

AAl - AAl Corp.
ACX - Acurex Corp.
BOE - Boeing Engineering & Construction Co.
CMC - Chamberlain Manufacturing Co.
GAC - General Atomic Co.
GE - General Electric Co.
GSC - General Solar Corp.
H - Honeywell Inc.
HX - Hexcel Corp.
JD - Jacobs Del. Corp.
MD - McDonnell-Douglas Corp.

MMC - Martin Marietta Corp.
NOR - Northrup Inc.
OI - Owens-Illinois Inc.
REV - Revere Copper & Brass Inc.
SEI - Solar Enterprises Inc.
SG - Solargenics Inc.
SK - Solar Kinetics Corp.
SR - Solaron Corp.
STC - Suntec Corp.
SUN - Enthone Inc. Sunworks Div.
TRW - TRW Inc.

Solar desalination processes, that are in use today are mainly solar stills and reverse osmosis membrane processes. Solar stills were discussed before, thus only reverse "R.O" system is shown in Fig (B-28) associated with its operating conditions.

The present situation of the solar desalination is the following :

1- If the demand is low (lower than 20m³/day) the basis stills appear to be good choice when there is an adequate insolation for an isolated community, and especially when there is a limited availability of skilled manpower to operate more sophisticated plants. The draw backs of solar stills are the lack of an economy of scale and the requirement of large surface area.

2- If the demand is higher than 20 m³/day, it is advisable to associate solar and conventional resources together as follows :-

- For sea water (3500 ppm) multistage flash associated with flat-plate or concentrating collectors can be promissing.
- For brackish water (more than 1000 ppm) reverse osmosis systems are the best solution.

2.4 Solar Thermal Electricity Generation and Mechanical Work

Solar thermal conversion involves the production of shaft power and of electricity via a thermodynamic-cycle. A variety of methods are used to generate mechanical or electrical energy from solar thermal energy. However it is quite difficult to realise technologically and economically satisfactory solar systems.

An important consideration for any system that is to produce mechanical energy is the overall system efficiency. It is determined by the product of the thermodynamic cycle efficiency "in a typical case, about 70% of the Carnot efficiency", and the collection efficiency of the solar system. This consideration of system efficiency has the important result that collectors for solar thermal electrical power production must operate at high temperatures with good collector efficiency or they must be extra ordinary cheap per unit area. However flat-plate collectors and solar ponds are used to generate electricity as well as high temperature systems.

2.4.1 Low-Temperature Systems

a- Flat-plate collectors are used to produce mechanical or electrical energy by thermodynamic cycles based on fluids with sufficiently low

TABLE (B-4) ENERGY CONSUMPTION OF DIFFERENT DESALINATION PROCESSES

DESALINATION PROCESSES		ENERGY CONSUMPTION			TOTAL ENERGY		
		THERMAL Kcal/m³	+	ELECTRICAL Kwh/m³	Kcal/km³	xx	KG OF FUEL/m³
Distilation	Single effect	550 000	+	-	550 000		55
	Flash ratio = 8	70 000	+	3	77 500		7.75
	Flash ratio = 14	40 000	+	5	52 500		5.25
	Vapour compression	0	+	16	40 000		4
Reverse Osmosis	Sea water	0	+	12	30 000		3
	Brackish water x	0	+	3	7 500		0.75
Electro-dialysis	Brackish water x	0	+	3	7 500		0.75

X Brackish water at 2000 - 3000 ppm
XX Hypothesis 1 kkhc = 2500 keal (R 35%)

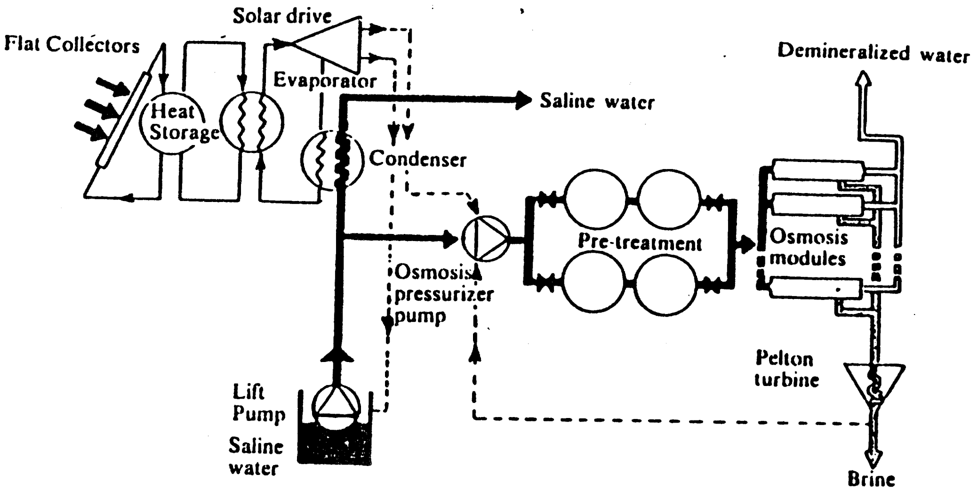


Fig (B-28) Schematic Diagram of Solar R.O.Plant

Nominal Operating Conditions

Salt water flow	5 m^3/hr
Salinity	2 g/1
Fresh water output	2.5 m^3/hr
Operating pressure	12 bar
HP pump efficiency	74%
Turbine efficiency	71%
Recovery ratio	50%
HP pump energy consumption	0.88 KWh/m^3
Power rating	2.2 KW
Turbine energy recovery	0.21 KWh/m^3
Power rating	0.5 KW

boiling temperatures (e.g freons). Many systems of this type, have been built and tested around the world for a variety of applications like water pumping, decentralised electric power.

An obvious disadvantage of such systems are their low efficiences, which range from 1% up to 2%, due to which large and therefore expensive collectors areas are required.

Information from system tests under real conditions up to now does not support very optimistic future expectations.Especially lifetime and maintenance will probably remain severe limitations above all in decentralised remote applications. Due to these problems, a tendency away from flat-plate systems towards photovoltaics for present remote small power systems and towards photovoltaic, solar ponds and concentrating high temperature systems for eventual future larger power applications 16/ .

b- Solar ponds are used similar to the flat-plate collector systems described above. An important difference is that they replace relatively expensive collectors by the pond, which depending on soil conditions etc. may be much cheaper. Another advantage is that they include a relatively large body of water, which acts as appreciable heat storage capacity and may allow almost continuous operation.

On the other hand there are also some difficulties one of these is the maintenance of an appropriate salt concentration gradient, which causes an upwork diffusion of salt. Thus salt has to be added continuously at the bottom and to be removed at the top, either by the addition of new salt or by recycling. The salt consumption of non convective ponds is remarkably large and may influence pond economy, besides wind driven disturbances cause thermal losses and thus reduce the efficiency.

Solar pond research has been done in several countries (US, Australia and Israel). A 150 kwe peak power nonconvective pond has been built at Ein Bokek, close to Dead sea. Its pond area is 7000 m². Energy conversion is performed by an organic rankine cycle and a turbogenerator. A larger plant (5MW) is under development.

16/ G. Lehner, University of Stuttgart "Solar Energy Applications for Electricity Genration and Mechanical Work", Proceedings of Solar World Congress, vol 3 Perth, Australia, 1983.

c- Solar Thermal Pumping

A number of manufactured have small-scale solar thermal pumping systems under development Fig (B - 29), and several have prototype field installations under test. The french company, Sofretes, is the only manufacturer who installed a significant number of small-scale solar thermal pumps. Table (B-5) shows examples of these pumps, however it did not prove to work efficiently 17/.

A number of large scale pumping systems have been built world wide using high temperature collectors, mainly in USA. Table (B-6) shows examples of these systems.

2.4.2 High Temperature Systems

High temperature systems using concentrating collectors can be realised in many different ways, usually achieved by mirrors. A wide range of different temperatures can be obtained by an appropriate choice of the degree of concentration, which depends on the type of mirrors and tracking applied, including parabolic troughs, parabolic dishs and Central Tower Receivers C.T.R.

Some of the most important distributed collector systems with rated powers from 50 KW up to 1MW are summarized in Table (B-7). Most of the systems use parabolic troughs, two of them use parabolic dishs at Kuwait and Shenandoah. Fig (B-30) shows components of central receiver systems realised up to now from 0.5 to 10 MW and they are tabulated in Table (B-8), in which cavity receivers seems to be more popular than external receivers. In general, steam turbines are applied, an exception is the five piston motor used in the Almeria-plant.
Some of the problems observed today for these systems include :

- Distributed collector systems having larger tubing losses than expected.
- Degradation of mirrors associated with dirt cleaning requirement.
- Stability of heliostates under storm conditions.
- Degradation of selective absorber coatings.
- Stresses due to frequent changes of temperature and power, resulting in material problems.
- In several cases the energy output is much smaller than expected.

In general solar thermal power generation are still in developing stage, and it may not compete with photovoltaic power generation.

17/ "Intermediate Technology Group Ltd Report", Testing and Demonstration of Small-Scale Solar Powered Pumping System, UNDP project No. GLO/78/004.

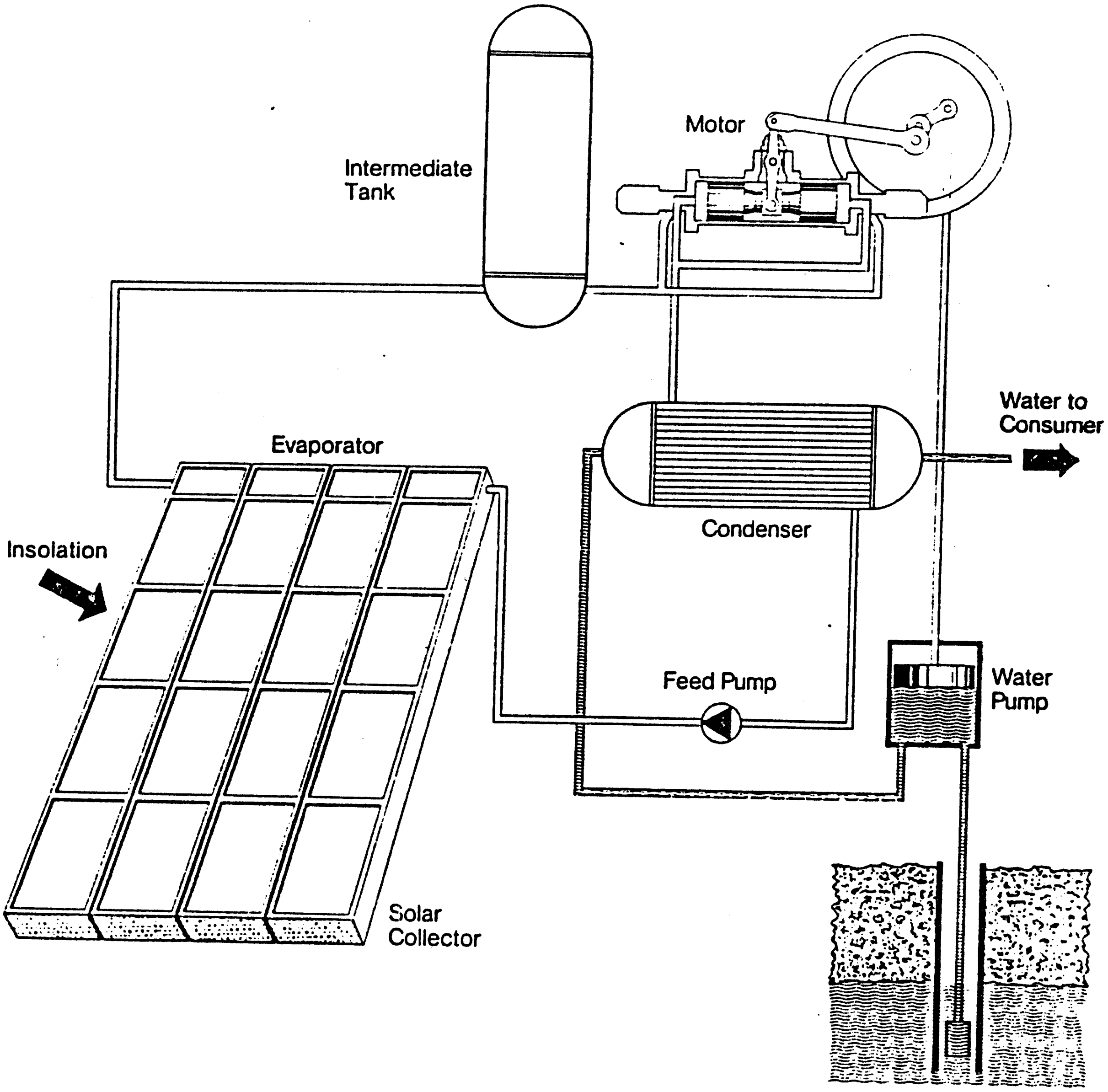


Fig (B-29) Schematic of Solar Thermal Pump

TABLE (B-5) EXAMPLES OF SMALL THERMAL PUMPING INSTALLATIONS

LOCATION	YEAR INSTALLED	COLLECTOR AREA (m^2)	DELIVERY FLOW RATE (m^3/hr)	WATER HEAD (m)	OPERATING HOURS (h)	APPLICATION
Abu Dhabi	1976	90	4	35	5 - 6	Small irrigation system
Algeria Annaba	1977	77	9	10	5	Demonstration and techning
Brazil Icolima Campos (Ceara)	1977	75	5	20	5 - 6	Drinking water supply
Cameroun Makary Logone Birnt	1976 1979	70	3	20	6	Live stoke watering irrigation
Cape verde Islands San Domingos	1979	70	3	35	5 - 6	Village water supply
N'djamena	1978	180	20	32	6	water supply + power + refrigeration
Madagascar	1977	77	7 - 8	15	5	village water supply
Gedral (San Luis Potosi)	1975	80	4	20	5 - 6	small irrigation system
Sudan, Soba	1977	112	5 - 7	25	5 - 7	village water supply

TABLE (B-6) LARGE-SCALE SOLAR IRRIGATION SYSTEMS USING PARABOLIC TROUGH COLLECTORS

LOCATION	POWER KW	COLLECTOR MANUFACTURER	COLLECTOR AREA m^2	OPERATING TEMPERATURE °C	DELIVERY FLOW RATE m^3/h	WATER HEAD m	DAILY OPERATING TIME h	APPROX.* COST £
Willard New Mexico	19	Solar Kinetics Inc.	624	163	202	25-31	5 - 7	220,000
Cilabend Arizona	37	Suntec/ Hexcell	554	138	2280 (peak)	3.7	5 - 7	110,000
Coolidge Arizona	150	A curex Corp	4550	287	317	115		

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* Approximate cost of pump including assembly, installation and check out but excluding development costs

TABLE (B - 2) DISTRIBUTED COLLECTOR SYSTEMS

SYSTEM;PLACE;COUNTRY; NOMINAL;POWER;(KW)	MIRROR TYPE;APERTURE (m^2); NO OF TRACKING AXES	HEAT TRANSFER MEDIUM; THERMO DYNAMIC FLUID	TYPE OF ENGINE; COOLING	GROSS ELECTRIC POWER (KW_e); PARASITIC POWER (KW_e)	NET EFFI-CIENCY	REMARK
SF 50;Getafe;Spain;50	3 types of parabolic troughs;582 (gross) 1,1,2	Thermal oil; water/steam	1 stage screw expander; water	30 3	5.4	electricity process heat
Dire; Mali; 50	flat plate collectors; 3248 (gross); 0	water; Freon 11	3 screw engines; water	51	2	multi purpose,education
Vignola;Corsica;France 100	segmented mirrors ("Fresnel-mirrors"); 1175 (gross); 1	Thermal oil ("Gilotherm pw"); Freon FC-75	2 turbines; water	91 6.4	9	grid connection
Step 100,Meekatharra; Australia; 100	parabolic troughs; 918 (net); 2	Thermal oil ("Transcal N") water/steam	2 stage screw engine; air	100 16	7.7	Hybrid diesel/solar
SSPPP;Sulaibyah;Kuwait; 100	parabolic dishes; 1025 (net); 2	Thermal oil ("Diphyl);toluene	turbine; air	129,4 31	13	electricity desalination
Sonntlan;Las Barrancas; Mexico; 100	parabolic troughs; 3305 (net); 2	Thermal oil ("Transcal N") water/steam	2 stage screw expander; seawater	117 17	6.5	modified to process heat
Stip;Coolidge;Arizona; U.S 150	parabolic troughs;2108 (net); 1	Thermal oil ("Caloria HT-43"); toluene	1 stage turbine; water	103 28	4	irrigation
STES;Shenandoah;Georgia; U.S. 400	parabolic dishes;4386 (gross); 2	silicon oil ("S-800"); water/steam	4 stage turbine; air	500 100	14.5	electricity process heat
DCS;Almeria;Spain;500	2 types of parabolic troughs;5172 (net); 1.2	thermal oil ("Santotherm 55"); water/steam	7 stage turbine; water	577 77	10.1	grid connection
Unit 2,Nio;Japan;1000	plane heliostats + parabolic troughs; 9820 (net); 2,0	water/steam (one loop)	8 stage turbine; seawater	1000 160	9.6	grid connection

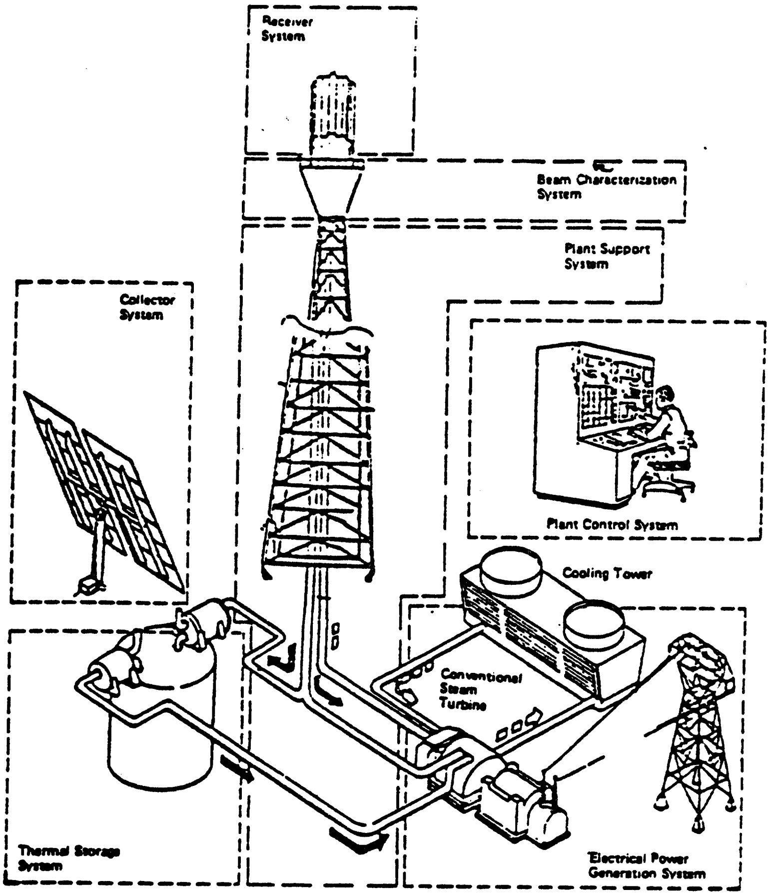

Fig (B-30) System schematic of Barstow C.T.R. system

TABLE (B - 8) CENTRAL RECEIVER SYSTEMS

SYSTEM;PLACE;COUNTRY; NOMINAL POWER (MW)	NO OF HELIOSTATS; REFLECTIVE AREA (m²)	TYPE OF RECEIVER;HEAT TRANSFER MEDIUM;THERMO-DYNAMIC FLUID	ENGINE COOLING	GROSS ELECTRIC POWER (KW_e); PARASITIC ELECTRIC POWER (KW_e)	NET EFFICIENCY	REMARKS
CRS;Almeria;Spain; 0.5	93 3655	cavity;sodium;water/steam	5 piston-engine;wet	599 99	16.5	in operation
Unit 3;Nio;Japan; 0.8	807 12912	cavity;water/steam (one loop)	turbine; wet	1000 200	8.5	in operation
Eurelids;Adrano;Italy; 1	Two types 70 + 112 6216	cavity;water/steam (one loop)	turbine wet	1200 200	16	in operation
CESA-1;Almeria;Spain 1	300 11400	cavity water/steam; water/steam	turbine dry/wet	1200 200	12.5	in operation
Themis;Targasonne; France; 2.3	301 10740	cavity;molten salt (Hitec); water/steam	turbine dry	2500 200	20.6	in operation
Solar 1;Barstow;U.S. 10	1818 72538	external;water/steam (one loop)	turbine wet	12000 2000	15.3	in operation
CES-5;Lenino;Russia;5	1600 40000	external;water/steam (one loop)	turbine			
GAST 20	2000 104000	cavity; gas	turbine		20	in stydy

2.5 Space Heating/Cooling

Application of solar energy to space heating/cooling is increasing rapidly mainly for heating applications in countries with temperate climates, where residential energy consumption constitutes a large proportion of total low-temperature energy use. Two different systems are employed :

- Active systems, in which flat-plate or other types of collectors replace conventional heat sources.
- Passive systems, where natural means are used as described in The term "bioclimatic architecture" has been used for this approach.

In both cases, possibilities to minimize energy needs of the building should be investigated before the design and installation of the solar system.

2.5.1 Active Solar Space Heating

In active systems collectors capture solar energy when available and transfer it to heat distribution or storage facility. An auxillary heating system (electric, oil, etc) is generally provided Fig (B-31). Both water and air collectors are used, where air systems are most applicable to heating, but they generally collect energy at lower temperature. Liquid systems are widely used for space/water heating, they can provide energy at sufficiently high enough temperatures to power chillers for space cooling 18/.

Heat storage capacity of active solar systems is presently limited to just few hours or days, to overcome this limitation, interseasonal storage methods are being developed to store heat for 3 to 6 months. The collector efficiency decreases with the increase of fluid temperature, thus system operating temperatures must be as low as possible. One solution being tried out is to use heat pumps in association with the solar collectors.

2.5.2 Active Space Cooling and Refrigeration

In hot, sunny regions of the earth, the prime requirements is often for space cooling and air conditioning, rather than heating, in which case solar energy can be used as the heat source for the cooling system. Several techniques are available which include :

18/ Solar Energy For Buildings Handbook, prepared for the U.S., D.O.E contract No. DE-AS05-77ET20170

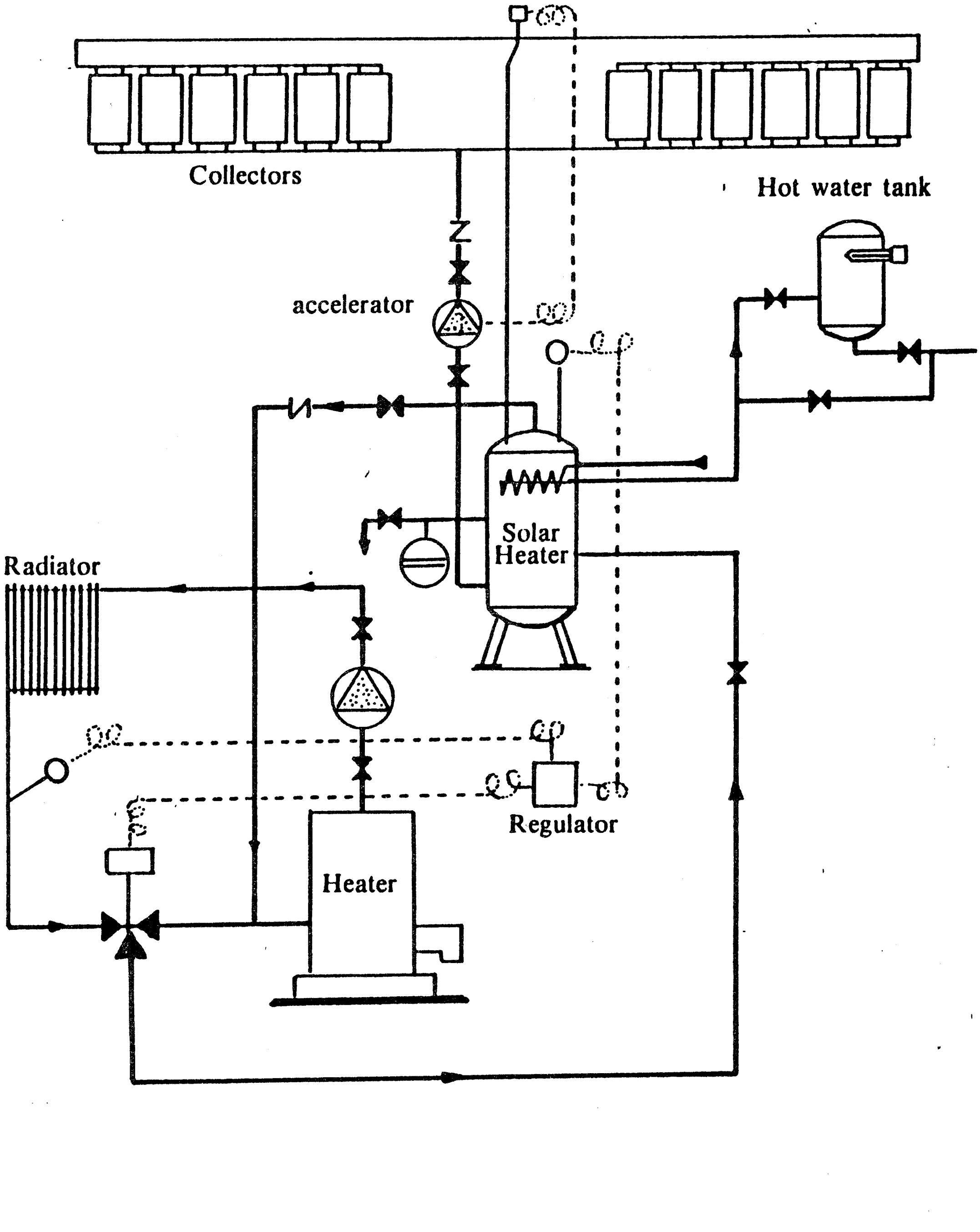

Fig (B-31) Solar Heating System With Oil Heating Backup.

a) Absorption and adsorption systems, which are the most common, consisting of two main types

- systems using an ordinary liquid absorption cycle, with water-ammonia or water lithium bromide usually chosen as the absorber - refrigerant mixture. The solar source temperature must be high to obtain a good coefficient of performance. See Fig (B-32)

- systems using a solid absorption or adsorption medium. In the latter case, the adsorber (e.g. zeolite) has a very light lattice for good adherence of the molecules of refrigerant fluid (typically alcohol), which are later desorbed under the influence of solar heat ;

b) Conventional compression systems, in which the compressor is driven by a solar thermal or photovolatic motor;

c) Evaporative cooling systems, where air is circulated over a wet medium, giving up heat to evaporate the water. Such systems have been experimented in the United States and Australia;

d) Cooling based on nocturnal radiation to the sky, where a heat-transfer fluid is circulated through a heat exchanger such as a roof top basin of water which is uncovered at night and covered during the day.

Relatively few experimental solar space cooling systems have been built to date. Although generally successful, they indicate rather high costs compared to standard compression cooling. Most have involved supplying a solar heated absorber-refrigerant mixture. Required operating temperatures for standard absorption systems are obtainable with the more efficient flat-plate collectors and with evacuated tubular collectors; therefore an ordinary commercial air conditioner can easily be used in a solar cooling system, with the solar-heated fluid substituting for the normal heat source.

Solar refrigeration is closely related to solar space cooling and air conditioning. Its main potential applications are food preservation and storage of biological and medical products. Experiments are being conducted in several countries, including the United States, Syrilanks, France and U.S.S.R., based on absorption cooling cycles and conventional compression cooling cycles using solar-powered motors. A good example is a 25 m³ Aswan cold store for fish (storage capacity 4 tons) built in Egypt with french assistance. However, most development work aims at household refrigerators/freezers and small-scale production of ice.

2.6 Solar Cooking

Many types of solar cookers have been developed, Fig (B-33) shows a number of designs, which can be classified into two categories :

- Concentrating collectors : where heat at the focus directly heats up either a vessel containing the food, or the food itself.
- Ovens and food warmers : which are basically insulated boxes with transparent covers in which the solar energy is collected directly or after reflection from a special surface.

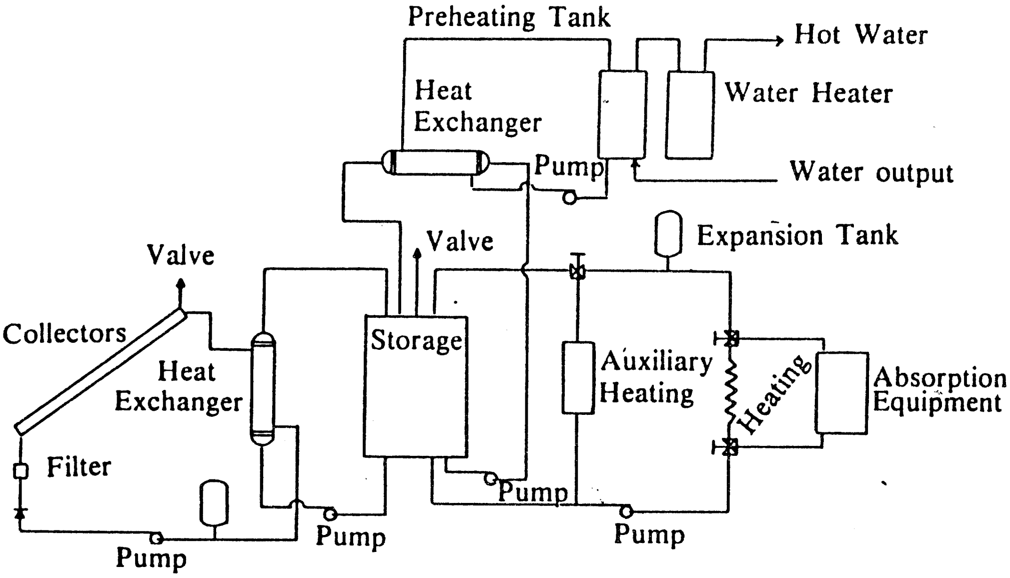

Fig (B - 32) Space Heating And Cooling System.

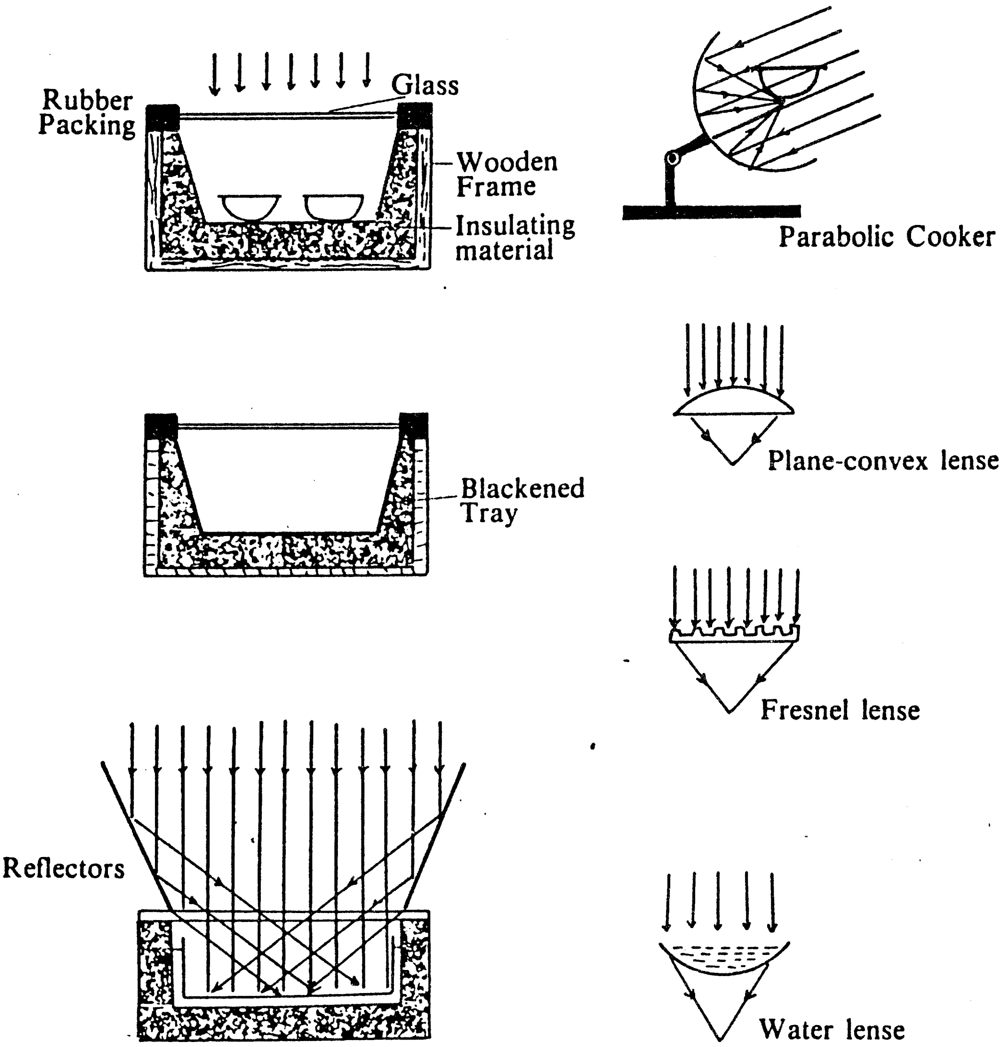

Fig (B-33) Solar Cookers Configurations

3. Current R & D Thrust

Most of the current R & D development in the solar thermal field is related to collectors improvements as well as the improvement of the cost/performance ratio of different systems.

One recent improvement to the flat-plate collectors involves treating the glass cover to reduce reflections, an increase of 4% in performance can be achieved by this method. A honey comb structure between absorber and glass cover reduces both convective and radiative losses, but would decrease optical efficiencies and conduct heat to the glass cover if not appropriately designed. Planar reflectors in front of collector raw increase incident radiation, but may cause higher shaded areas.

To improve E.T. collectors performance, R & D activities are trying to increase its optical performance, develop higher quality selective coating and reduce costs by making longer tubes.

A number of improvements to parabolic troughs are under development. Three of the most promising are silvered-glass reflectors, evacuated receivers and antireflection-coated receivers. Although a number of well designed commercial products and systems are available. Improved foundation techniques, advanced receiver structures, advanced drives trackers and control systems, are needed to bring the trough technology to a final state of development.

For parabolic dish thermal systems, development of a technically and economically feasible energy transport system, to carry the heat energy collected by each dish concentrator in the field of concentrators to a central collection point for end use and/or storage, is the most critical technical problem. In dish-electric systems where thermal transport is not a problem, R & D is needed to develop more efficient and reliable heat engines.

For central receiver systems development of high temperature components that can provide system operating temperatures of greter than 538°C is needed. The components include receivers, heat exchangers and components for energy storage and transport.

Also, current R & D thrusts for solar thermal technology includes development of innovative solar thermal concentrating concepts, research on system automation for stand-alone and remote applications; and development of efficient high - temperature heat transfer fluids.

4- Economic & Market Viability

Solar thermal technologies are widely applicable in different areas, however its economic and market viability is quite dependent on the state-of-the-art, resource availablility, the potential replicability of a specific application and the alternative energy sources.

4.1 Domestic Hot Water

Solar "DHW" systems have had a long varied history, sales peaked in 1920 at $ 100 for a 40-ft² collector and a 40-gal storage. Sales decreased in the late 1920s with the advent of cheap natural gas heaters.

In today's age of renewed interest in solar energy, solar "DWH" system are again prominent in the sales of solar systems. There is a wide variety of system types and configurations marketed by a alrge number of companies worldwide today. In U.S.A and Japan a present-day solar water heater cost between $ 1000 and $ 3000 installed depending on collector size (4 to 8 m²) and the system type. The cost would also vary according to the material and labor cost at each specific country, cheaper collectors can be produced in developing countries.

In spite of the present reduction in oil prices, sales of solar water heaters continue to increase in many countries. Table (B-9) shows the solar collector sales of 1984 in U.S. for different sectors and/or applications at low temperatures 19/.

A recent report 20/ shows that solar domestic hot water systems used at California for water and space heating, displaced one third to one half of natural gas and electricity otherwise needed. It also states that the average solar savings ratio (SSR) varies according to system type around a value of 0.48 for a typical household DHW usage of (65 gal) for single family systems. The average multi family household show SSR of about 0.32 due to the reduced requirement of (40 gal) hot water usage. Fig (B-33) shows the predictions of such a report.

19/ Biggest Firms Totally Dominate Solar Collector Market, an article in solar energy intelligence report, August 19, 1985.

20/ "Solar Water Heating in California", a report by the state public utilities commission, November 1985.

TABLE (B-9) LOW TEMPERATURE SOLAR COLLECTORS, 1984 SALES IN US M$

	BY END USE			BY SECTOR	
END USE	METALIC	NON-METALIC	SECTOR	METALIC	NON-METALIC
Pool heating	278	3.447	Residential	312	3,407
Hot water	71	227	Commercial	64	602
Space heating	28	200	Industrial	3	57
I.P.H.	0.0	0.0	Agriculture	0.0	34
Agriculture	3	226	Others	-	-
Others	0.0	0.0			
Space cooling	0.0	0.0			
TOTAL	380	4.100	TOTAL	380	4.1

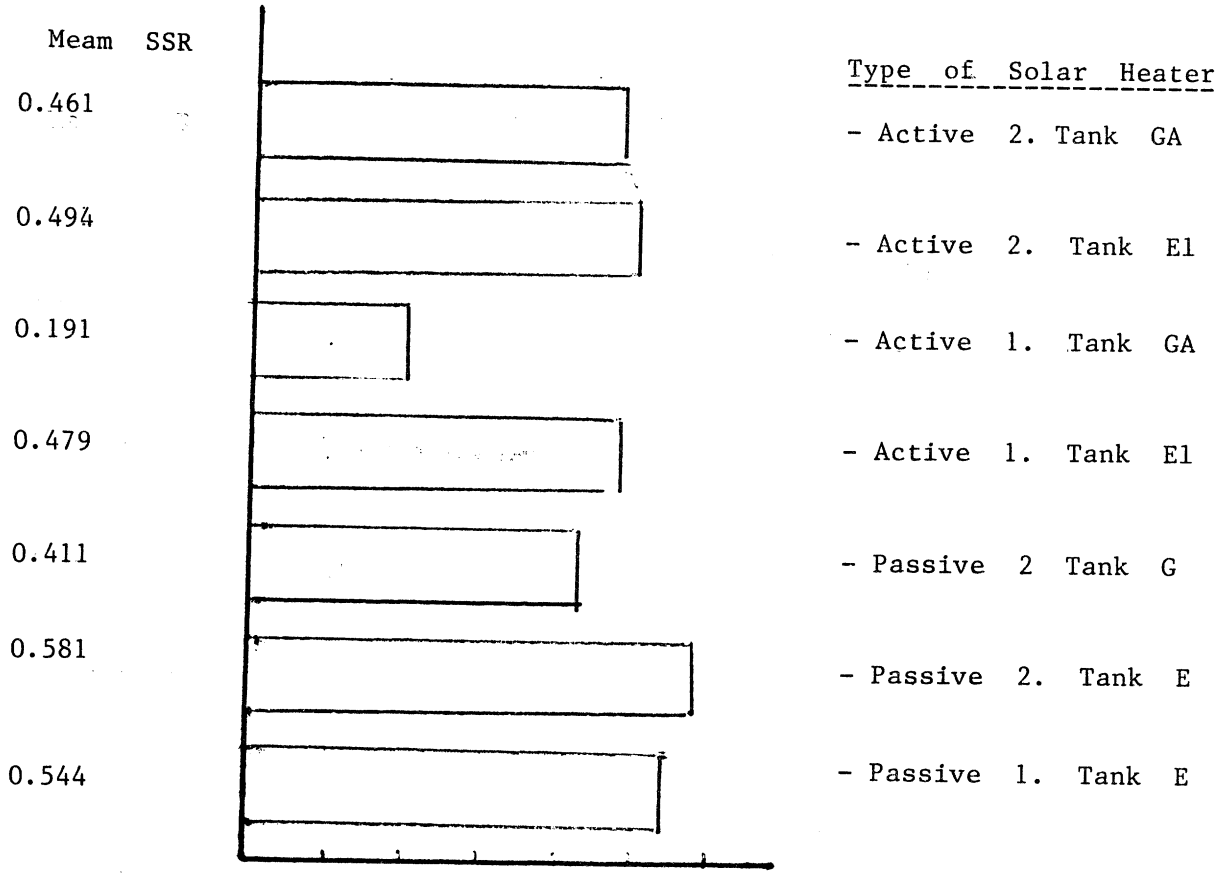

Fig (B -34) Solar Savings Ratio From Different Type of Solar Systems

4.2 Industrial Process Heat

The use of solar I.P.H. systems comes up against more obstructions than in the sector of household techniques. On the top of these obstructions is the fact that capital flowback of 4-5 years are required in industry and potential of energy conservation is more economical.

In many countries the industrial processes operating in temperature ranges below 270°C where solar systems can be used are over 40% of the I.P.H. requirements.

However, currently solar thermal technologies for moderate and high temperature, are too costy to be competitive with conventional energy sources. Advanced components and systems with improved efficiency and lower cost are currently being developed by the solar thermal research and development community.

Parabolic trough and evacuated tube technologies have the most potential for being economically competitive in the near term (1985-1990). Total installed systems cost of parabolic troughs are about $ 750/kwt, expected to reach $ 400/kwt by 1990. This trend is making mid temperature industrial process "150 - 300°C" potentially competitive with fossil fuel.

Presently although sales of low temperature hot water for industry is slightly promoting, medium temperature collectors sale is dropping 4 to 10% from 1983 sales level 19/. Table (B-10) shows sales of 1984 I.P.H. collectors in U.S.A.

Solar drying applications to agriculture are increasing, due to their simplicity and cost effectiveness in most cases. Table (B-11) shows cost of drying systems for different products 21/.

4.3 Solar Desalination

In the range of 50 to 500 m^3/h, fresh water can be produced at a cost of 1 to 1.7 $\$/m^3$, with a benefit of the order of 5% as compared with fossil-fired desalination. This cost is already fully competitive. Fig (B-35) shows cost of fresh water production using different technologies 22/.

21/ , Solar Drying of Agriculture products, sun world/vol 8/ no 1, 1984.

22/ C.Mustacchi "Solar Desalination Design, Performance and Economics", Sogesta, 1980

TABLE (B-10) I.P.H. SPACE HEATING SOLAR COLLECTORS SALES, 1984 IN US *

APPLICATION	MEDIUM TEMPERATURE		SPECIAL		OTHERS
	AIR	LIQUID	CONCENTRATION	E.T.	
Hot water	324	8.050	149	66	44
Processes stam	335	189	4	0.0	0.0
Agriculture	0.0	0.0	0.0	0.0	0.0
Space heating	1.369	742	0.0	31	-

* Solar Energy Intelligence Report, August 1985

TABLE (B-11)

COST OF SOLAR DRYING*

PRODUCT	DRIER	COST PER UNIT DRYING wt.US$/kg	COST OF DRYING PER UNIT DRY wt.US$/kg
Raw paddy	Indirect mode Bin drier	0.428	0.031
Maize	Indirect mode Chamber type	0.152	.0059
Potatoes	Mixed mode Chamber drier	0.136	.0055
Cassava	Mixed mode Chamber drier	0.374	.056
Cocoa	Direct mode Cabinet drier	2.95	0.011
Coffee	Direct mode Tray drier	3.32	0.0021
Tobacco	Indirect mode Drier	3.31	0.167
Timber	Solar kiln	244/m³	7.3/m³

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* Extracted from the Sunworld/Volume 8/Number1/1984/13

The solar plant overall investment would be 30-50% higher than a conventional plant because of the solar collectors cost. Solar desalination is very convenient, provided the limitations in available fund is overcome and that no heat storage is considered.

Below 50 m^3/hr basin stills provide a convenient solution, while above that higher technologies would be more competitive. Development in solar collector technologies and membranes are enhancing possibilities for economic solar desalination particularly using R.O. system for brackish water.

4.4 Electricity Generation and Mechanical Work

Solar thermal power generation systems are basically dependent of the development of medium and high temperature solar collectors, as well as the development of thermal machines.

Solar thermal systems providing 25 Kwe to 10 Mwe have been successfully operated in various countries including the United States, Japan, Australia, Spain and Italy. A final use being studies for solar thermal systems is the production of transportable fuels and chemicals from renewable feedstocks. This technology has been investigated on a laboratory scale and several candidate processes have been identified. However, it will take many years to fully develop it on a commercial scale.

Current costs for parabolic dish systems range from $ 8500/kwt to $ 1800/kwt. Both capital and operating costs will have to be reduced considerably to make this technology option economically viable in the near future. Lower manufacturing, field installation and O & M costs and increased parabolic dish system efficiency are expected to reduce system costs to about $ 1300/kwe and $ 470/kwt by 1995.

Central receiver systems are technically feasible, however, the cost of energy from initial plants is higher than the cost of energy from existing fossil plants. Heliostats comprise approximately 50% of the central receiver system cost. Central receiver plant costs are currently about $ 4600/kwe and $ 1300/kwt. Cost is expected to come down to about $ 1600/kwe and $ 460/kwt by 1995.

Parabolic dish system and central receiver systems are not economically viable yet. Both technologies require continued research and development to reduce costs and increase efficiencies. Solar thermal systems are most attractive in regions with good direct solar radiation over 1600 kwhr/m^2/yr.

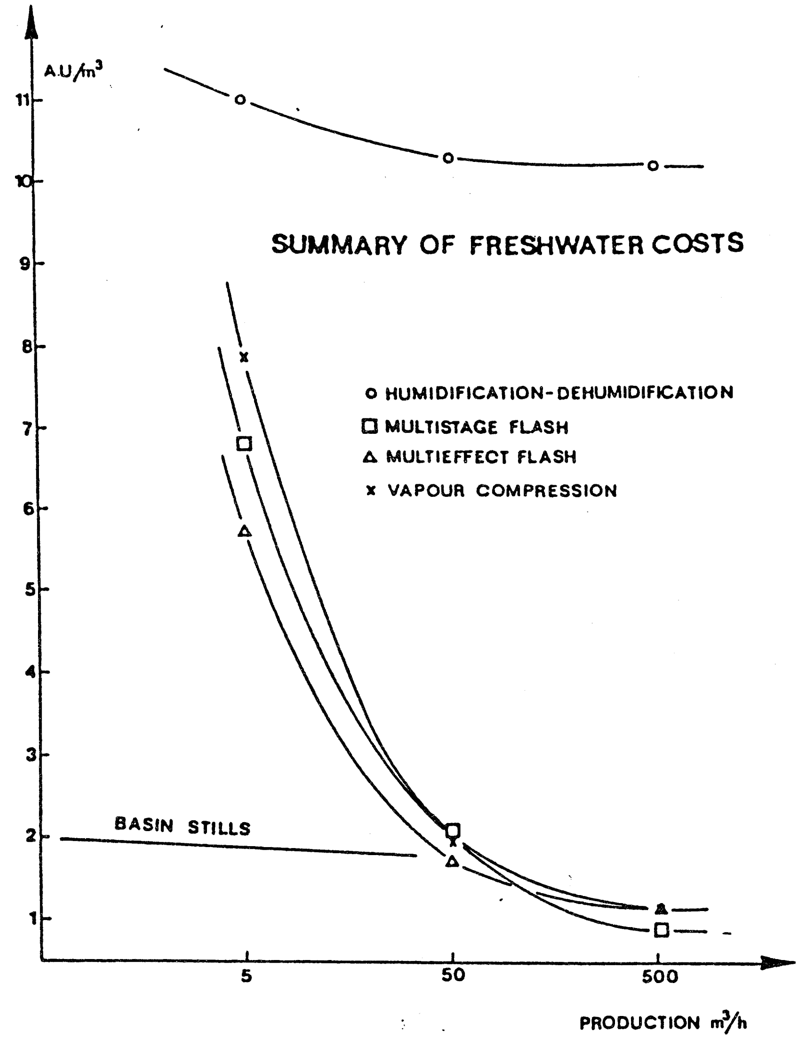

Fig (B-35) Costs of Fresh water Production.

4.5 Space Heating/Cooling

Passive solar approach to space heating and cooling proved to be effective if appropriately designed using local materials. In most cases over 70% of the heating loads were eliminated associated with better building performance in summer.

Advancement has been achieved in the field of active cooling of buildings using absorption chiller. Improvement in evacuated tube collectors enhanced the possibilities of an economical space cooling systems. However, it is clear that very substantial reductions are required in the price of solar advanced collectors before economic viability can be obtained 23/.

23/ R.Schmid, E. Mannik "Performance Comparison of Flat-Plate and Evacuated Tubular Collectors Used in the Sydney University Solar Cooling and Heating Project" Proceedings of Solar World congress, Perth, Australia, 1983

5. Relevent Status In ESCWA's Region

The ESCWA's region falls in an area of very high soalr insolation, associated with wide remote areas where cheap conventional energy reseources are not available. In view of the previous fact and the ambious development plans, that most of ESCWA's countries have, appropriate contribution of solar thermal technologies to these plans should be emphasized. The present and future status of solar energy use is highly dependent on the following :

5.1 Solar Energy Resource Availability

The available solar energy varies widly between ESCWA's countries, however it is always favourably available. The south-west area of Saudi Arabia enjoy the extremely high insolation of 600 to 700 cal/cm²/day. Areas of very high insolation (between 500 to 600 cal/cm².day) enclosing Upper Egypt and most of Saudi Arabia. The rest of ESCWA's region enjoy high insolation between 400 to 500 cal/cm².day excluding Lebanon and Northern Syria where insulation is below 400 cal/cm².day 24/.

Based on the intensive availability of solar energy, most of solar thermal applications can be adapted to use in ESCWA's countries. However, additional efforts should be given to the appropriate assessment of solar resource using direct and satelite measurement. The latter needs an integrated regional effort to be supported by the UN system.

5.2 Potential of Appropriate Applications

Due to geographical social and development considerations in the ESCWA's region, an appropriate application would satisfy one of the following regional needs :

- Development of small rural communities, particularly desert communities
- Extension of urbanization
- Supply of fresh water needs for bedwin communities and urban areas
- Satisfy energy requirements for industrial development with emphasize of small and agro-industries
- Space climatization since climate in most of the region areas can be classified as arid-hot climate which is consuming much energy to satisfy comfort.

24/ ECWA report entitled "Solar Energy in the Arab World" document no. E/ECWA/NR/WE.1/4, Dr. Ali Kettani.

In view of these needs, water heating, agro-industrial applications, space climatization and small scale power generation are appropriate applications for solar thermal technologies in ESCWAS regions. Needs are almost identical except for I.P.H. needs which may be more needed in industrialized countries of the region such as Egypt, Iraq and Jordan to different extend. However solar drying can be used everywhere in the region for native agriculture products.

5.3 In country Capabilities and Relevent Experience

Intensive activities and applications has been implemented within ESCWA's region. A number of institutions are active in each country covering the following progressive development stages :

1-	Studies and Planning	"S&P"
2-	Research and Development	"R&D"
3-	Development and Demonstration	"D&D"
4-	Demonstration and Commercialization	"D&C"
5-	Commercialization and Industrialization	"C&I"

Although most of the region countries are active in the field, their activities for using each technology are in different development stages. Table (B-12) summarize the status of the development and use of each technology in the region. Details are given in EKWA report by Dr. Kettani, but tables include recent information.

We conclude that incountry capabilities are strong in ESCWA's region for the development and utilization of solar thermal technologies.

Institutional structure seems to be not too far from being appropriate. However, efforts should be complementing and integrating each other.

TABLE (B-12) THE USE OF SOLAR THERMAL TECHNOLOGIES IN ESCWA'S COUNTRIES

SOLAR THERMAL TECHNOLOGIES

Tech.	Resource	Low Temp.								Passive		
Country	Assesment	F.P	S.P	S.S	E.T	P.T	S.C	P.D	C.T.R	D.G	I.G	G.H
Bahrain	x	-	-	-	-	-	-	-	-	-	-	-
Egypt	x	1-5	1-2	1-3	2	2	2	2	1	3	3	4
Iraq	x	1-3	-	3	1-3	2	2	-	-	-	-	4
Jordan	x	1-5	2	3	2	-	-	-	-	-	-	5
Kuwait	x	1-3	-	2	2	-	-	1-3	-	-	4	3
Lebanon	x	3-4	1	3	-	-	-	-	-	-	-	-
Oman												
Qatar	x	4	-	3	1-3	1-3	-	-	-			3
Saudia Arabia	x	2-3	-	3	N.A	N.A	N.A	3	-	3	3	2
Syria	x	4	-	2	N.A	N.A	N.A	-	-			2
U.A.E.	x	3		2	N.A	N.A						
North Yemen	N.A.											
South Yemen	N.A.											

Technology Status 1- S&P 3- D&D 5- C&I
2- R&D 4- D&C

Legand

A- Technologies

1- Low Temperature L-T
- F.P - Flat-plate
- S.p - Solar pond
- S.S - Solar stills

2- Moderate Temperature M.T
- E.T - Evacuated Tube
- P.T - Parabolic trough
- S.C - Stationary concentrators

3- High Temperature Collectors H.T
- P.D - Parabolic Dish
- C.T.R- Central tower receiver

4- Passive Systems
- D.G - Direct gain
- I.G - Indirect G
- G.H - Green house

B-II SOLAR PHOTOVOLTAIC TECHNOLOGY

The photovoltaic "PV" technology is the basis for the direct conversion of sun light into electricity. A photovoltic energy system consists of the components necessary to convert sunlight into a useful end product, DC or AC electricity for pumping, refrigeration, lighting, communications ....etc.

There is an extensive R & D programmes in many countries to develop new technologies for PV cell production and for the development of system design.

1- Technology Description

In a "PV" system, Fig (B- 36), groups of cells are mounted and interconnected to form modules (collectors), which in turn are connected into arrays. Power generated by the arrays is fed into a power conditioning system, which "conditions", the power for interaction with the loads and/or utility grid, by controlling the magnitude of the voltage and type of current 1/.

PV cells are solid-state devices made from semi-conductor materials such as silicon. A basic PV cell Fig (B-37), consists of two semi-conductor layers: the top is doped such that there is an excess of negative charges (n-type material), the bottom is doped such that there is an excess of positive charges (P-type material). The two layer's region of material refferred to as the p-n junction. When light strikes such a cell, electrons are freed and electric current is generated.

One of the most important characteristics of a 'PV' cell is its conversion efficiency. Cell efficiencies are limited by the material of semi-conductor used which limits the maximum efficiency. It is also limited by material defects and higher practical operating temperatures. Table (B-14) shows the current efficiencies for various materials .

1.1 PV Arrays

1.1.1 Cell Types

There are basically three generations of PV technology : ingot, ribbon and thin films. The current PV market is dominated by first generation technology - ingot cells. Second generation technology has just recently entered the marketplace, while third generation technology for the power market is mostly in the laboratory stages.

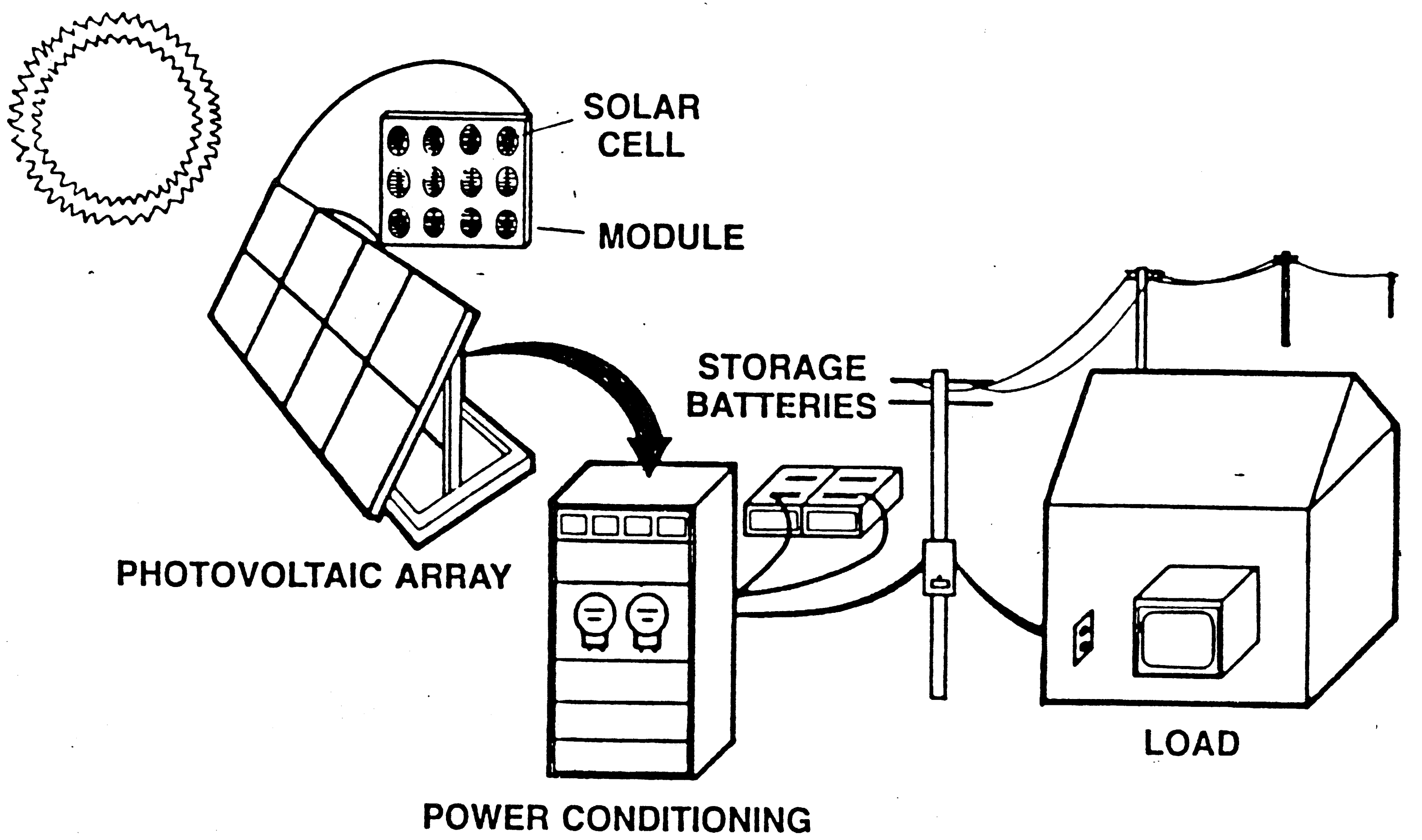

Fig (B - 36) Photovoltaic System .

TABLE (B-14) CURRENT LABORATORY CELL EFFICIENCY (UNDER NO CONCENTRATION)

Single Crystal silicon ingot	19%
Polycrystalline silicon ingot	17%
Silicon ribbon (single-crystal/polycrystal)	17% / 15%
Amorphous silicon	11.5%
Other thin films	11%

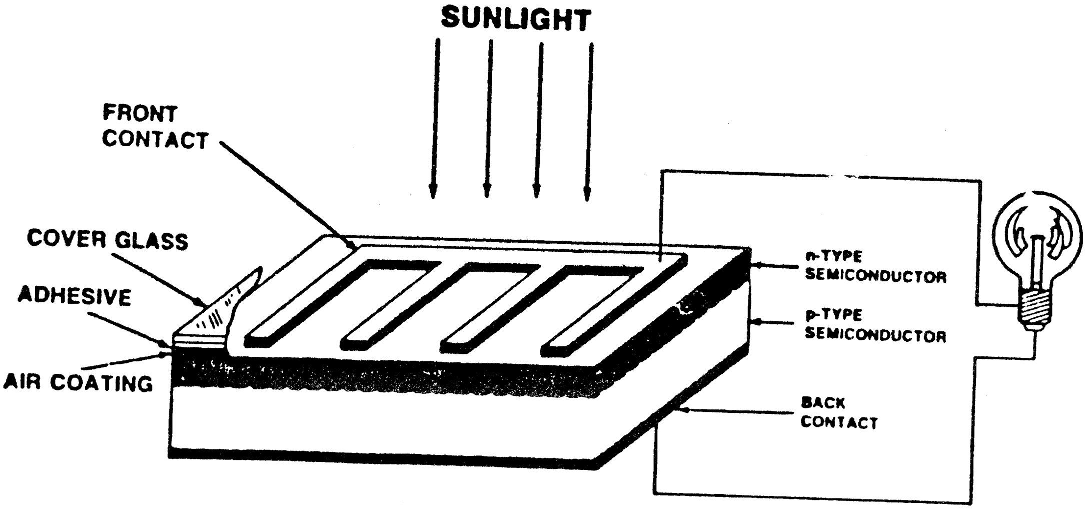

Fig (B- 37) Basic Photovoltaic Solar Cell

First generation technology consists primarly of single-crystal silicon cells cut from cylindrical ingots. A second type of ingot cell is made from polycrystalline silicon that is cast in the form of a cubic ingot. However, due to the large material losses incurred through the slicing of ingots into wafers; the incompatibility of ingot growth to automated production processes; and the impossibility (based on inherent electronic properties of silicon) of attaining a high enough conversion efficiency to compensate for these factors, systems based on this technology will not meet long term cost goals (cost-competiveness in U.S. electrical utility market). In light of this fact, new generation technologies have emerged.

Second genration technology involves the automated production of polycrystalline silicon material in the form of a ribbon. Ribbon growth results in more efficient use of silicon feedstock and a potentially higher rate of throughput; thus far, however, this technology has exhibited lower performance characteristics than ingot cells.

While not as commercially advanced as silicon ingot and ribbon cells, thin-film cells are of interest due to their potential for much lower fabricarion costs. They have the advantage of low material requirements (thin-film cells are less than one-fifth the thickness of silicon ingot cells) while lending themselves to large scale, continuous-processing techniques; however, thin-film devices have relatively low efficiencies and in some cases are unstable.

The most advanced thin-film material is amorphous silicon (a-Si). This material is the only third generation technology to have penerated the marketplace. It has done so mostly as small cells in consumer products, for which efficiency is a minor concern. The first a-Si power module was just recently introduced (in November 1984) by ARCO Solar. Other thin films such as cadmium telluride (CdTe), copper indium diselenide ($CuInSe_2$) and gallium arsenide (GaAs) are still in the research stages.

A promising concept for thin films is multiple-junction cells. These cells consist of different thin films layered on top of each other. Each material absorbs a different region of the solar spectrum and thus results in a higher total conversion efficiency than possible for any one material.

1.1.2 Modules "Collector" Types

There are two categories of PV collectors : flat-plate and concentrator. The majority of currently installed systems use flat-plate modules. Flat-plate collectors consist of cells that are interconnected and packed in planar modules. They collect both direct and diffuse radiation.

Concentrator collectors offer an approach to PV power generation that reduces the need for lowering the price of high-performance cells. By using configurations that focus direct light into cells, such as parabolic troughs and fresnel lenses, the cell area required to generate a given output can be reduced by as much as a factor of 1000. However, the cells require some type of cooling, since the high concentration of sunlight raises the operating temperatures of the cell, thus decreasing conversion efficiency.

In areas where the direct component of radiation is high (i.e. where there are clear skies), concentrator collectors should be given serious consideration. The basic trade-off between flat plate and concentrator collectors is as follows. Concentrator systems offer a higher energy density alternative that flat-plate systems (flat-plate systems are approximately 10% efficient while concentrator systems are about 14% efficient), use less costly silicon, but require tracking mechanisms and active or passive cooling. Flat-plate systems, although their power output is enhanced when they track the sun, can be effective when fixed but use much more silicon per unit of power produced. Table (B-15) shows the characteristics of some of the "PV" concentrator.

1.1.3 Support Structure Types

In a PV system, type of support structure is directly related to the type of module and the required tracking region.

Flat-plate modules are mostly mounted on a fixed structure, except in limited cases. Concentration PV systems require tracking mechanism and control. However the current development and commercial concentrators use Freonel Lens.

1.2 Storage System

Of the many possible energy storage systems available, chemical storage of electrical energy via batteries is the most practical and cost-effective method of storing energy in conjunction with a PV system. In this sense, batteries act as a load to the PV system and as a source to the other loads. 25/

The selection of a battery for a PV system is dependent on discharge rate, depth of discharge in each cycle, remoteness and temperature on site.

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25 / Solarex, Report on "Guide to Solar Electricity" 1980

Table (B - 15)

Photovoltaic Concentrator Systems

Characteristic	System					
	Spectrolab	General Electric	Martin-Marietta	RCA	MIT	Argonne
Optical system	Parabolic trough	Parabolic trough	Circular Fresnel	Circular Fresnel	Paraboloidal dish	Compound parabolic collector
Tracking system	Two-axis, azimuth elevation	Two-axis, azimuth elevation	Two-axis, azimuth elevation	Two-axis, polar-declination	Two-axis, polar-declination	One-axis, seasonal adjust
Geometric concentraion ratio	25.2	34	39	423	>200	9.2
Optical efficiency	← 0.75 to 0.85 →					
Concentrator size	3.17 m^2 1.28 X 2.48 m	22.3 m^2 2.44 X 9.14 m	0.37 m^2 0.3 X 1.22 m	0.37 m^2 0.61 X 0.61 m	0.29 m^2 0.61 m diam.	5.83 cm^2 1.91 X 3.05 cm
Cell type and size	Silicon 3.2 X 5.0 cm	Silicon 3.5 X 4.0 cm	Silicon 5.5 cm diam.	Silicon 0.56 cm diam.	Silicon 4.3 cm diam.	Silicon 0.25 X 2.54 cm
Cooling system	Passive	Active	Passive	Passive	Active	Passive

* Source : Ref 13.

Lead-acid batteries have been the predominant type used in PV applications. This is due to the much higher cost associated with nickel-cadmium batteries, although they may have better performance characteristics[26].

1.3 Power Conditioning System

Power generated by the arrays is usually fed into a power conditioning system, where power is conditioned such that it is compatible with the loads or the utility grid, as applicable. Compatibility is based both on the magnitude of the voltage and the type of the current. The actual components that make up power conditioning system (the combination of inverters, converters, controls and regulators) vary according to application. Example of possible power conditioning systems are given in Fig (B-38).

Each PV system should have an adequate set of instrumentation and controls necessary for operation and performance monitoring.

1.4 Photovoltaic-System Performance

The performance of a "PV" system is a mainly function of its array efficiency, which in turn is a function of the cell efficiency. In addition to cell efficiency the storage characteristic and efficiency are highly affecting the system performance.

Fig (B- 39) shows the typical variation of voltage with current for a solar cell under constant illumination at constant temperature. This curve is normally developed using the set up shown in Fig (B- 40). The curve designates Voc "open circuit voltage", V_{mp} (max-power voltage), Isc "short circuit current" and I_{mp} (max-power current).

The fill factor of a solar cell is defined by :

$$\text{Fill Factor} = \frac{I_{mp} \times V_{mp}}{I_{sc} \times Voc} = \frac{P_{max}}{I_{sc} \times Voc}$$

Typical fill factors are 0.7 to 0.78, the designers strive to increase it to minimize internal losses.

The efficiency of a solar cell is defined as the fraction of the incident radiation that is converted to usable electric power by the cell. It is function of material composition, the geometry of the cell, quality of the semi-conductor.

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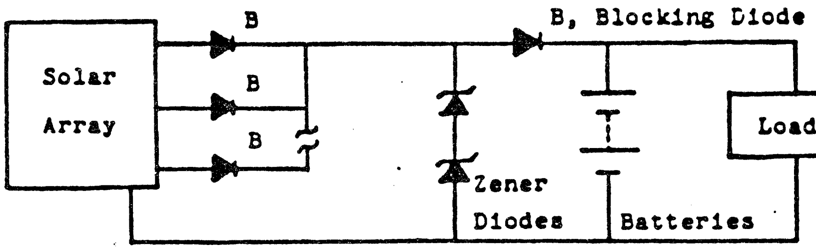
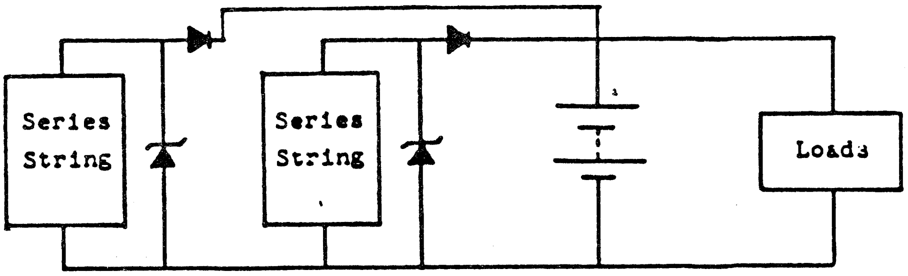
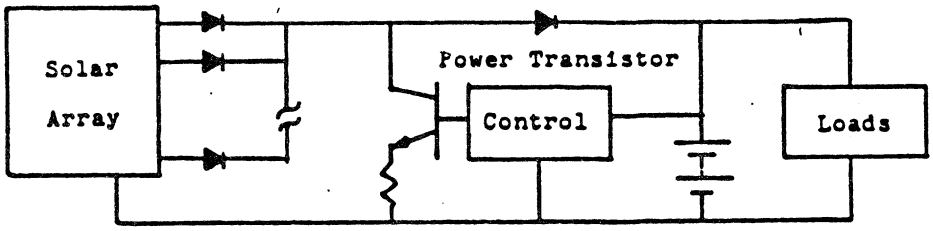
[26] Meredian Corporation, "Photovoltaic Technology Reference Notebook" prepared for USAID, Cairo, 1985.



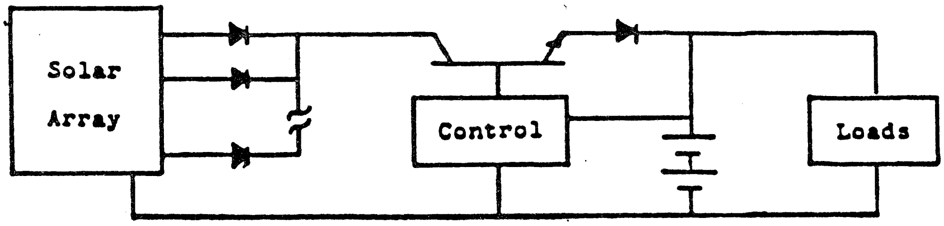
(a) Array,Passive, Shunt Regulation



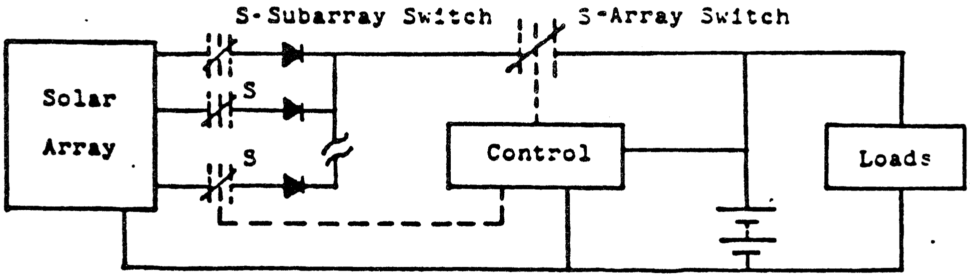
(b) String (or Subarray),Passive,Shunt Regulation



(c) Array, Active, Shunt Regulation



(d) Array, Active, Series Regulation



(e) Array (or Subarray), Active, Series Regulation

Fig (B- 38) Possible Power Conditioning Systems

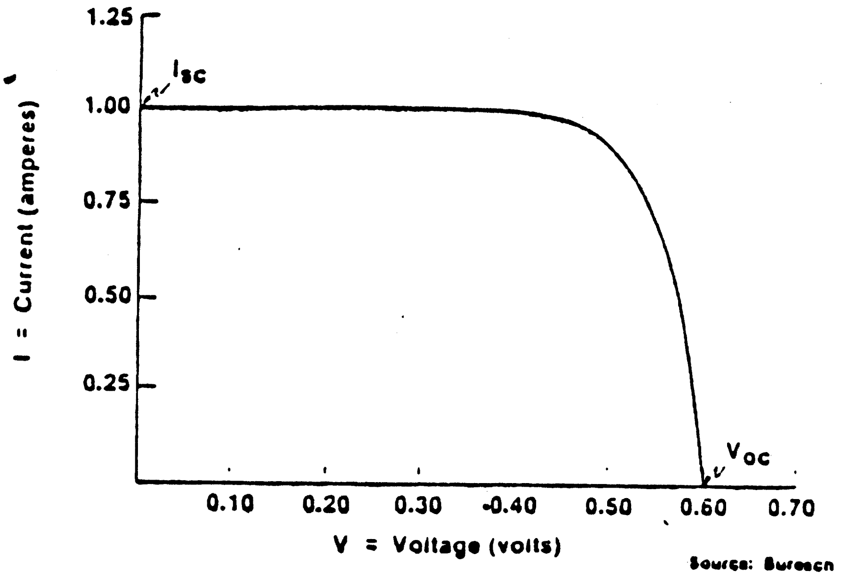


Fig (B - 39) Current - Voltage Characteristic for a Solar Cell

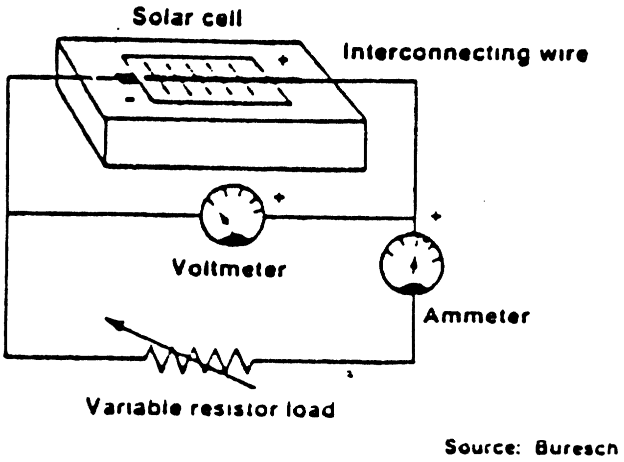


Fig (B - 40) Setup For Testing PV Cells.

Current production methods yield crystalline silicon cells that have efficiencies between 10% and 15% 27/.

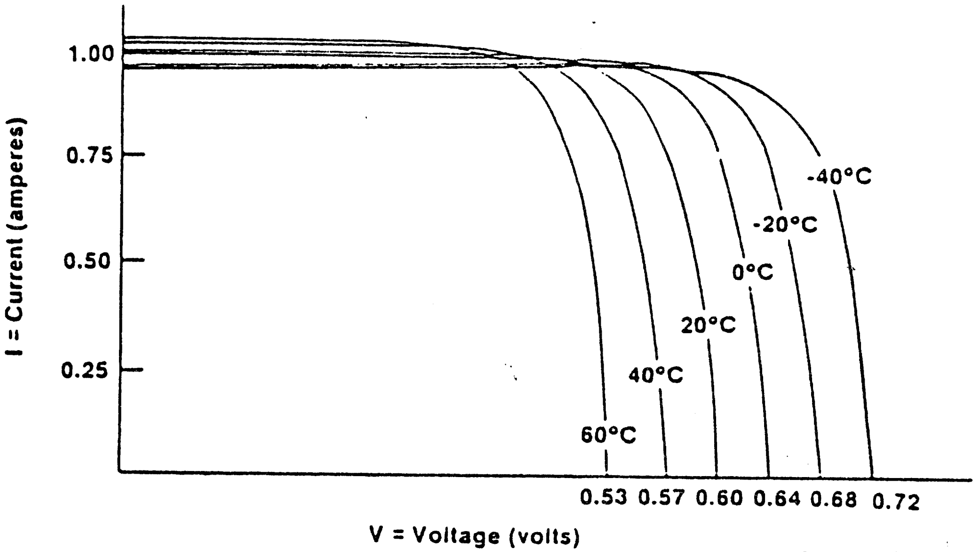
The cell performance is too sensitive to temperature, Fig (B-41) shows that reduced operating temperature are significant for achieving higher performance. The efficiency of a single crystal silicon cell of 12% efficiency would drop by 0.05%/°C cell temperature rise 28/.

Solar cell panels consisting of series parallel interconnected solar cells, its voltages are established on the basis of the application and the electrical insulation capabilities of the basic panel or concentration designs. Table (B- 16) shows the characteristics and performance of a group of solar cell modules.

27/ David Adler "How silicon solar cells work", Sun world, vol 4 No 1, 1980

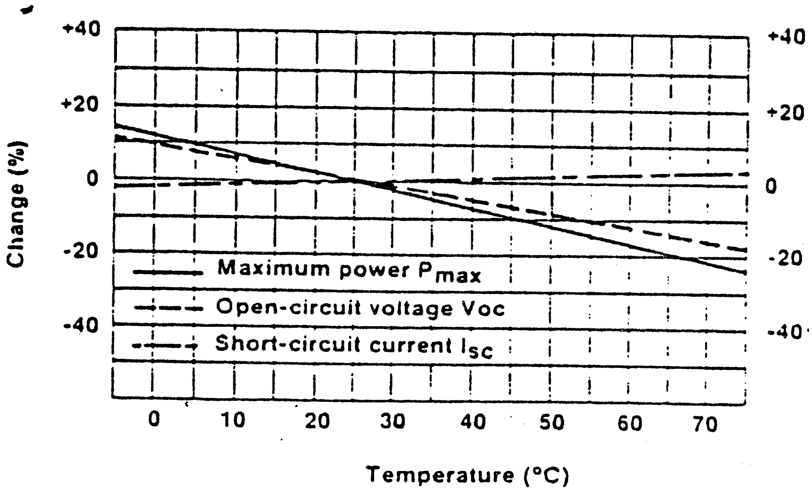
28/ Aaron Kirpich "Electric Power Generation, photovoltaics" Solar Energy Technology Hand book, Chapter 37, page 317.

Effect of temperature on cell response



Source: Buresch

Effect of temperature on cell voltage, current and power



Source: Solarex

Table (B - 16)

Characteristics and Performance of Cell modules

Design Characteristic	Module Supplier: Sensor Technology	Solarex	Solar Power	Spectrolab
1. Overall dimension (mm)				
Length	582	581	1168	1168
Width	289	581	389	388
2. Weight (kg)	1.50	4.08	7.57	6.12
3. Number of solar cells	44	42	40	120
4. Solar cell diameter (mm)	55.9	76.2	101.6	50.8
5. Total solar cell area (m^2)	0.1080	0.1915	0.3243	0.2432
6. Module area (m^2)	0.1682	0.3376	0.4544	0.4532
7. Overall module packing factor (Item 5 ÷ Item 6)	0.64	0.57	0.71	0.54
8. Nominal operating cell temperature, NOCT (°C)	42.9	47.1	46.0	41.1
9. Electrical performance at the standard operating conditions[a]				
(a) Maximum power (W)	10.4	18.7	31.3	28.5
(b) Voltage at max. power (V)	18.7	16.3	16.6	17.3
(c) Open-circuit voltage (V)	23.4	22.4	22.0	21.9
(d) Short-circuit current (A)	0.59	1.44	1.98	1.88
10. Areal specific power output (W/m^2 module area) (item 9a ÷ item 6)	61.8	55.4	68.9	62.9

Source: Based on data from Ref. 13

[a] Standard operating conditions are module irradiation of 100 mW/cm^2 and cell temperature equal to the NOCT.

2- Applications of Photovoltaic Technology

Photovoltaies is a practical energy source for any application requiring electricity. Its suitability for a specific application at a given location will depend on many factors, both economical and logistical. The applications presently being used or tested world wide can be classified as :

2.1 Stand-Alone applications
2.2 Grid-Interactive
2.3 Consumer Products
2.4 Power satellites

2.1 Stand-Alone Applications

A stand-alone system is an independent power generating system that is the sole source of power for local electrical loads. They may or may not include storage systems. The majority of current PV applications are of this type. They can be remote applications where power is otherwise unavailable or unreliable, or they can be applications where owners prefer to exist autonomous of the utility. Typical stand-alone applications are :

2.1.1 Water Pumping

Many rural electricity systems being installed have a water pumping capability, however many more water pumping system are typically required to support the large number of farms. As a result a completely independent market has been created for PV water pumping.

There are two principal types of PV-powered water pumping systems available today. These include :-

- Deepwell or tubewell systems that are used to provide clean and safe water for human or animal drinking and washing, or for irrigation.
- Surface supply systems that are used to provide water for irrigation or for animal consumption.

Commercially available PV-powered water pumping systems can supply water from surface sources with head depths from 0 to 1 meter or from wells as deep as 120 meters. Typical flow rates range from 5 cubic meter per day to more than 250 cubic meters per day. For even greater flexibility, both d.c and a.c systems are now available.

P.V systems provide a simple and economic alterations to the diesel systems for all types of water pumping and provides the same amount of power without requiring any fuel or extensive maintenance - major diesel cost elements.

Modularity of the PV-system also shows the use of a new and more efficient type of irrigation--drip irrigation. Because diesels are not typically available in small sizes, drip irrigation could not be used previously for small farms.

Smaller, portable PV system are also especially useful in areas where large numbers of small fields are to be surface water irrigated. Again, portability is not generally available with a diesel system.

Using a PV system is also beneficial where animals are the principal power sources for pumping water, it can avoid the "milk and meat loss" associated with the use of farm animals as the power source. Table (B-17) shows typical available PV pumping systems.

2.1.2 Communications

The use of PV system to provide critical power for communication systems is currently the most common PV application. Fully accepted by the world wide communication industry as a simple, viable, high quality, reliable and economic source of power, PV systems have been installed to provide critical power for :

- Microwave repeaters
- UHF and VHF radio repeaters : remote and mobile telephones, police and taxi communications
- Mobile radio systems : emergency medical communications
- TV and satellite repeaters and ground stations
- Educational TV systems
- Supervisory control systems : interusion detection, highway call boxes, storm warning signs, fire alarm systems, dangerous material detectors
- Situation and environmental monitors

The range of uses for PV-powered communication systems is also extremely broad. The total number of new PV communication installations of all types is now approaching 10,000 per year worldwide 26/. These sites provide power for voice, video and/or digital data communication. Operational environments range from deserts in the Middle East and hot, humid mountain tops in south east Asia to the very edge of the Arctic circle. Load power from several watts to several thousand watts has been supplied both economically and reliably.

TABLE (B-17) PV pumping systems

LOCATION	YEAR INSTALLED	PHOTOVOLTAIC POWER W	DAILY OUTPUT m^3	HEAD m	APPLICATION	MANUFACTURER/ SUPPLIER
ABU DHABI						
Al Ain		600	40	15	livestock	PG
?		600	16	25	livestock	PG
ALGERIA						
Bou Saada		600	46	15	Agricultural Institute	PG
ECUADOR		600	50	10		PG
FRANCE						
Corsica	1975	600	16	25	irrigation	PG
Corsica		600	16	25	irrigation	PG
Tours	1974	400	15	20	demonstration	Briau
Montpellier	1979	27kW			irrigation	PG
INDIA						
Orissa (3 units)	1979	240	~5m^3/h	~5	irrigation	SEI
Hyderabad	1979	240	~5m^3/h	~5	demonstration	SEI
Delhi	1979	240	~5m^3/h	~5	demonstration	SEI
Sahibabad	1979		~2m^3/h		demonstration	CEL
IRAN						
Tehran	1976	800	10-12	43		Briau
Tehran	1976	800	10	39		Briau
IVORY COAST						
Yamoussokro		900	19	35	college	PG
LIBYA						
Tripoli		1300	34	30	farm	PG
Tripoli		1800	42	40	equipment	PG
Tripoli		1300	34	30	supplier	PG
Benghazi	1978	800	15	18		
MALI						
Koni	1977	900	40	18	irrigation	PG
Mopti		2600	24	30		
Wabasso	1977	900	30	24	village	PG
San	1979	1800	25	30	hospital	PG
Tominian	1977	1300	70	25	village	PG
Yangasso	1979	1300	56	25	village	PG
MAURETANIA						
Gavak		3900	600	7	food	PG
N'takat		900	58	15	co-operative	PG
MEXICO						
-		1800	29	50		PG
-		1800	29	50		PG
-		600	29	12	irrigation	PG
Guerrero		600	25	18		PG
-		120				PG
-		120	3m^3/h	1	university	PG
-		120	3m^3/h	1	demonstration	PG
NIGERIA						
Kano		600	24	20	irrigation	PG
OMAN						
Muscat		320	10	15		Briau
PAKISTAN						
Islamabad	1979	240	5m^3/h	5	demonstration	SEI

PG : Pompe Guinard "France"
SEL : Solar Electric International "USA"

2.1.3 Rural Electrification

PV rural electrification systems represent a relatively new application, but they are possibly more significant in terms of future growth potential. About 2500 new PV-powered rural electrification systems were installed worldwide in 1983 and the amount is doubling annually. These sites range from one module systems for individual isolated homes to complete electricity generation and distribution systems (i.e. mini-utilities) for rural villages. Early sites were typically rated at 2 Kwp or less, but recent sites have been implemented up to 350 kwp.

PV rural electrification systems would provide primary power for lighting, water pumping, communications, and/or medical refrigeration for remote settlements in developing regions; power for similar systems for remote homes; and power for forest lookout or park facilities.

The largest rural electrification system installed to date is a 350 Kwp system in Saudi Arabia. It provides 700 villagers in 3 towns with power for lighting, televisions and radios, water pumping, farm irrigation and other domestic uses.

A significant driving force behind the past and projected growth in rural electrification applications is the development of special d.c. functional components for use with PV power systems. These components include water pumps, lights, medical refrigerators, desalination and water purification systems, evaporative coolers, television sets and other entertainment devices. New inventor system to provide more efficient a.c. power further extend the list of available functional devices by providing power for a.c. components, such as clothes washers, which are already widely available.

Further rural electrification systems will include mini-utilities that will supply power for rural settlements, thus helping to provide the advantages of progress and urbanization to rural areas. Such systems have already been proven in demonstration applications, and negotiations for commercial system installations are now in progress. PV, therefore, is a prime candidate for supplying power to both small villages or medical center sites, as well as to enter communities.

2.1.4 Corrosion Protection

Traditional corrosion protection systems have depended on either the availability of utility power or on other approaches that are expensive. The develpment of the PV alternative has given these industries a new, economical and effective solution to this corrosion problem.

In this application, the PV systems supply power for electrical circuits called cathodic protection (CP) systems. Electrical current from the PV array is used to counteract natural corrosive currents generated when metallic devices are buried in the ground. These protection circuits are used on many wellheads, pipelines, bridges, storage tanks, and other metallic structures. Approximately 1000 new PV-powered CP systems are now being installed worldwide every year. Typical power ratings for these systems range from 70 Wp to 2.5 KWp. Because the modular nature of the PV system allows users to customize systems for many different corrosion protection requirements, the use of PV for this application is expected to increase significantly in the future.

2.1.5 Navigation Aids

Aids to navigation (navaids) provide essential transportation safety information for air and sea traffic. Almost all navaids are located at remote sites where they are exposed to severe weather and corrosion-causing environments. Because human lives and valuable cargo depend upon the proper operation of these systems, their reliability is critical. Photovoltaic systems are an economical and reliable solution to the power source problem for these applications. Many thousands of PV-powered navaids have been installed around the world, and more than 5000 new sites are being added every year. Fully functional and operating systems over 10 years old have demonstrated the highly reliable nature of the PV alternative in the extremely corrosive and demanding navaid environments.

Buoy-mounted PV systems typically provide power for warning lights, fog horns, or a combination of both signals. The PV ratings for these systems range from a low of 7 Wp to a high of 200 to 250 Wp. If communication or telemetry functions are included, system size may increase. Similar warning light systems are used to signal aircraft of major geographic and man-made obstructions. Larger PV power systems, up to 2.0 to 3.5 KWp, are used for lighthouse applications. In all of these cases, photovoltaics has been proven to be less expensive than the more traditional energy sources .

2.1.6 Railroads

The use of PV systems for railroad applications is one where reliability is also essential. In this case, the PV systems supply power for track circuits and crossing gates, which provide critical protection for both humans and cargo. The track circuits monitor the location and direction of any operating trains on a given railroad network. Using this key information, railroad system controllers can coordinate railroad traffic to ensure safe operation of the network. Crossing gates ensure the protection of the general public. More than 1000 new PV-powered track circuits or crossing gates are now being installed worldwide each year.

2.2 Grid Interactive

This type of system consist of one or more power generating systems that feed into an electrical transmission and distribution network that provides power to a large number of widely dispersed loads. Grid-interactive systems have been applied most commonly in the U.S. Applications range from small residential systems to multi-megawatt central station plants for utilities.

Although PV technology as a source of utiltiy network power is not yet economical in all areas of the world, progress made to date has proven that the application is feasible. A number of utility-interactive applications have thus been identified and implemented. This list includes :

- Individual residences
- Schools
- Small residential communities
- Commercial centers and office buildings
- Utility sub-station generation
- Central station utility generation

Practical utiltiy system components have already been developed and used in demonstration projects as well as in true commercial applications. Various system integration concepts are being tested by numerous utilities that are also funding major programmes in PV development. These developments offer not only the practical utility-scale use of PV systems, but also flexibility in the way PV technology can be implemented. With proper storage backups, PV systems can even be used as a source for independent mini-utilities, eliminating the need for costly utility extensions (which in the U.S. can range from 15,000 to 50,000 dollars per mile). The technology, therefore, not only offers a supplemental source to utility power, but also could supply an independent utility netwrok of its own.

Several utility PV applications ranging from 100-Wp sub-station power systems to 7.5-KWp residential systems to 6.5-MWp central station power systems are in operation or under construction. The initial phases of a planned 100-MWp central station plant are also currently under construction. AC line-inter-tied inverters and control systems have been designed and manufactured for this wide-range of application sizes as well as for larger ones planned for the near future 29/.

2.3 Consumer Products

Next to the remote system market, consumer product applications represent the only other currently profitable photovoltaic market. They represent truly, off-the-shelf PV products. Consumer products include items such as calculators, radios, watches and small toys.

2.4 Solar Power Satellites

Another possible future development is the use of solar power satellites, which are the subject of a great deal of research in the United States and some other countries. These satellites would be placed in a geosationary orbit, being equipped with enormous solar cell arrays (many tens of square kilometers). They will beam the collected solar energy to earth in the form of microwave or laser beams for reception by large antennas, and then conversion to electricity (U.S.DOE, 1978). The feasibility, lead times, fabrication, launch and operating costs for such satelite systems have been carefully envaluated (Gilasen, 1979); the earliest possible date for a full-scale commercial use has been given as 1996.

Besides the technical and financial difficulties encountered in such a land,water, oxygen and hydrogen resources and other raw materials for the satellites, launch vehicles and ground facilities, noise pollution due to the large number of launches necessary (because of their vast size, the satellites would be sent up in "bits and pieces" for in space assembly); air pollution and effects of microwave beams and rocket-emitted products on the ionosphere and stratosphere; etc. Nonetheless, there seems to be no real technical or scientific barrier to construction of power satellites, and they could represent a promissing future solution to the challenge of large-scale electricity production, from renewable sources of energy.

29/ Photovoltaic Residences, Sun world, vol 6/No 3, 1982

3. R & D Thrusts

The key thrusts of PV R & D are to reduce the cost and raise the efficiency of systems so they can be competitive in a wider variety of applications. PV systems can be divided into the modules and the balance of system (BOS).

3.1 BOS R & D

BOS technologies are so well developed that additional significant improvements are unlikely to come from fruther research. Advancements in these areas will come from better designs, achieved through increased experience, and mass production. Thus, current research is directed toward improvements in the modules.

3.2 Module R & D

The majority of current PV research is directed toward improvements in the modules. There is a constant trade off between the cost and efficiency of the cells, the technologies that are most developed, so far have involved the most expensive processes.

3.2.1 Single-Crystal Silicon

It is the most stable and highest efficiency silicon material used in commerical PV applications. R & D efforts continue at increasing efficiency and reducing costs. A recent report stated that, module efficiency will rise from 11-12% to 15-16% in 1995, while prices fall from $ 6.5 per peak watt to $ 3/WP (system prices will be about twice that) 30/.

3.2.2 Cost Polycrystalline Silicon

Cost polycrystalline silicon cells are less efficient than single-crystal cells, however costs are less. R & D concentrates on improving efficiency. By 1995, these modules will cost about $ 3/WP and will be 15% efficient.

3.2.3 Silicon Ribbon

They offer a more automated production process, however, once again, manufacturing cost reductions have been at the sacrifice of further efficiency. R & D efforts are to resolve generic growth impediments and performance-limiting characteristics. Module prices could decline from

$ 7.5/WP in 1985 to $ 2-3/WP by 1995 , while efficiency rises from 10% to 14% - but only if larger production lines in the 10 Mw per year range are built 30/.

3.2.4 Concentrators

Concentrator technology offer the opportunity to use much smaller cells, and generate more power per unit area. R & D in this area involves increasing concentration ratios and heat dissipation from the cell, developing improved tracking mechanisms and producing lower cost collectors.

3.2.5 Amorphous Silicon

Amorphous silicon (A-Si) technology is probably the most publicized PV material of recent years, it use 100 times less silicon than single crystall cells. Therefore, its potential for inexpensive products is very high, while it has the lowest efficiency and stability of any of the more mature PV technologies. Efficiencies will rise from 5% of today to 10% and prices will fall from the present's $ 5.0 - 6.5/WP to only $ 1.66-2.5/WP.

3.2.6 Other Options

Other options for PV technology are still in preliminary research stages. Gallium arsenide (GaAs) is looked at with promise as a thin-film material in stacked cells. In single-crystal form. GaAs alloys have yielded the highest efficiency of any material to date and are extremely stable. However, it is more expensive and has only been used experimentally for space applications.

30/ Edward Stirewalt, "Five PV Technologies Viable in 1995, Solar Energy intelligence report, vol 11, No. 49, December 1985

4- Economic and Market Viability

A technology is considered "ready" when it can first compete economically in a given market. This is as opposed to being "mature" - the point at which no further product development is necessary. Some of the PV technologies are ready for certain markets, but none are considered mature.

Remote stand-alone applications represent a market for which PV is ready. Types of applications include navigational aids, communications, rural electricification, water pumping and cathodic protection systems.

Although demonstration projects are still being conducted to verify system performance in different remote environments, PV systems for remote applications are essentially past the demonstration stage. The major manufacturers offer turnkey systems and some packed systems for these applications. Since remote systems applications represent one of the two profitable PV markets (the other one being consumer products), certain firms have targeted their PV activities to specific applications (e.g. water pumping, navigational aids, etc.).

The world leader in photovoltaic systems technology and production has traditionally been the U.S. In the past eight years, more than 75% of the peak capacity in the world has been installed by U.S. firms. More recently, however, the U.S. leadership position has decreased from an 85% market share in 1980 to 62% in 1983. This decrease can be largerly attributed to Japan's aggressive activities in consumer product applications. Exhibit A.19 shows world shipments by geographic region.

TABLE (B- 19) PHOTOVOLTAIC SHIPMENTS (MW)

	1980	1981	1982	1983
U.S.	2.8(85%)	4.0(75%)	4.6(60%)	9.6(62%)
Japan	0.1(2%)	0.5(9%)	1.5(19%)	3.3(21%)
Europe	0.4(12%)	0.8(15%)	1.5(19%)	2.4(15%)
Other	0(1%)	0.1(1%)	0.2(2%)	0.3(2%)
Total	3.3(100%)	5.3(100%)	7.8(100%)	15.6(100%

Table (B-19) shows the leading manufacturers world wide for different PV technologies.

Until about ten years ago, PV cells had been developed primarily for space satellite applications. High conversion efficiency was the primary concern, and costs were not a major factor. For terrestrial

TABLE (B-) TOP PRO OF DIFFERENT PV TECHNOLOGIES *

TECHNOLOGY COUNTRY	SINGLE CRYSTAL	SEMICRYSTALLINE	RIBBON	CONCENTRATIONS	AMORPHOUS
USA	- ARCO - SOLAREX - SOLEC	SOLAREX	Mobil solar Westinghouse Energy material Shell	United energy Intersol Entech	ARCO SOLAREX Energy construct Spire/Ploroid Chronar
Japan	- Sharp - NEC - Narobine	-	Hoxan	-	Sharp
West Germany	-	Wacker Telefunken	-	-	-
Brazi	- Heliodinamica	-	-	-	-
Italy	- Helios	Semix	-	-	-
Idia	- CEL	-	-	-	-

* Developed from "Five PV technologies Viable in 1995, Solar intelligence report, Dec 1985

applications, however, expense has been the critical barrier to widespread utilization of PV.

Typically, 50 to 75% of PV system costs can be attributed to the modules. The remaining costs, or the balance of system (BOS), include all subsystems and components exclusive of the cells and modules that are needed for a fully functional system.

Today, PV module prices range from 5 to 12 dollars per week. The range reflects the quantity of modules purchased. The $5/Wp price represents ARCO Solar's bid for Phase II of the Sacramento Municipal Utility District's (SMUD-II), 1-MWp project. In the small-to-medium-size range, prices start at approximately $7/Wp.

Installed system prices range from about $10 to $30/Wp, depending upon the location and the particular application. The lowest price, $10/Wp, is for the 1-MWp, SMUD-II project. At these prices, PV is cost-competitive for many remote applications, but not for utility-interactive systems. At remote sites, PV is in competition with the extension of utility lines (which in the U.S. can cost $20,000 per mile), diesels (high O & M and fuel costs) and batteries (high initial costs).

5- Relevent Status in ESCWA's Region

PV technologies have a good potential for application in ESCWA's region, due to the wide spread availability of remote sites lacking water, energy and food resources.

5.1 Solar Energy Resource Availability

This item was described with solar thermal technologies.

5.2 Potential of Appropriate Applications

Most of "PV" applications are appropriate for the needs of ESCWA's region, since a wide variety of remote areas are existing in the region.

Water pumping for livestock, drinking water and irrigation represents a top priority for desert areas. In addition these isolated communities are in bad need for stand-alone lighting, clinics and desalination system. In some cases grid-interactive system can be considered.

There is an essential need for a detailed market survey for the potential of PV applications in the ESCWA's region, which would identify how far a PV industry is needed or not in the region.

5.3 Incountry Capabilities and Relevent Experience

Although, huge number of demonstration projects has been installed in ESCWA's region, the real indepth experience related to PV technologies seems to be limited. Table (B-20) identifies PV projects in the region, which are described in details by Kettani 24/. The following indicate the main fields of relevent experience in PV technologies :

1- Design and analysis capabilities are existing in different nation institutions particularly in Egypt, Jordan and Saudi Arabia.

2- The two technologies demonstrated are the single crystal silicon and frenel lens concentrators.

3- Most of PV applications has been demonstrated including water pumping, lighting, communication system, desalination and clinical refrigerations.

4- Industry is not yet started, with the exception of the Egyptian/Dutch and Egyptian/French projects for the assembly of solar PV panels.

Table (B - 20) PV ACTIVITES IN ESCWA'S REGION.

Country	S & P	R & D	Demonstration & Evaluation						Industry	
			Pumping	Desalination	Lighting	Communication	Refrigeration	Rural Elec.	Assenb-ly	Manufacturing.
Bahrain					N.A.					Not Started
Egypt	X	X	X4 *	X2	X25	X15	X3	X2	X	
Iraq	X	X								
Jordan	X		X			X100	X		X	
Kuwait		X								
Lebanon	X									
Oman						X				
Qatar					X **					
Saudia	X			X	X			X		
Syria				N.A						
U.A.E.					X					
North Yemen			X							
S. Yemen				N.A						

* No of demenstration Units

* Navigation & beacon are classified under Liefrting.

N.A. Information is not availab

G- WIND ENERGY TECHNOLOGY

Wind is created primarly by the sun's unequal heating of earth's surface and by the rotation of the planet. Wind energy was used by ancient Egyptians as long as 5000 years ago to propel boats, however, the earliest known windmills were located in what is today Eastern Iran and Western Afghanistan from about 200 BC[1].

By the eighteenth century, windmill technology was the highest technology both in Britain and Holland. The British and Dutch windmills of the eighteenth and nineteenth centuries were advanced and complex as a result of centuries of technical innovation, some of them produced (40 kw) or more. Windmills with greater power than (40 kw) were not produced until 1930's, when its use went into deline until quite recently. In recent years "since mid 1970's" there has been a major revival of wind energy system development and commercialisation.

Wind energy conversion system "WECS", convert the kinetic energy available in the wind to mechanical energy. Since kinetic energy is measured in units of mass and velocity squared the final theoretical power available is propotional to the wind velocity cubed and expressed as follows :

$$P = \frac{1}{2} \rho A V^3 \text{ ------------------ } 1.1$$

where P is the power available, ρ is the air density "$\simeq$ 1.2 kg/m^3", A is the swept area and V is the free stream velocity.

However, the fact that the flow must be maintained limits the amount of energy which can be extracted, to 0.593 of the theoretical available power. This fraction was derived by Carl Betz in 1927[2] thus :

$$\frac{P_{max}}{A} = 0.593 \frac{\rho V^3}{2} \text{ ------------ } 1.2$$

The wind speed at a site increases dramatically with height. This fact is called wind shear, it can be expressed as :

$$\frac{V_1}{V_2} = \left(\frac{h_1}{h_2} \right)^a \text{ -------------- } 1.3$$

where "a" is the surface friction coefficient, which varies between (0.1) to (0.4) according to the increase in surface roughness. Since most

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[1] Wind Technology Assessment Study. Intermediate Technology Power Ltd, Reading, Berts RE7 3PG, UK, World Bank Project GLO/80/003, Feb,1983

[2] World Meteorological Organization, Meteorological Aspects of the Utilization of Wind as an Energy Source WMO No. 575 (Geneva,1981),P.46.

wind turbines are installed on moderately rough surfaces,"a" is most commonly taken equal to $(\frac{1}{7})$ and equation (1.3) is reffered to as the $(\frac{1}{7})^{th}$ law.

Estimates of the available and recoverable annual average powers per square meter of the swept area, has been studied and given in a previous ECWA report 3/. The available power density has varied between 70 w/m^2 at Jeddah, Saudia Arabia and 236 w/m^2 at Ras Rukan, Qatar, while recoverable power density is between (79) and (98) w/m^2 for the same locations.

1. TECHNOLOGY DESCRIPTION

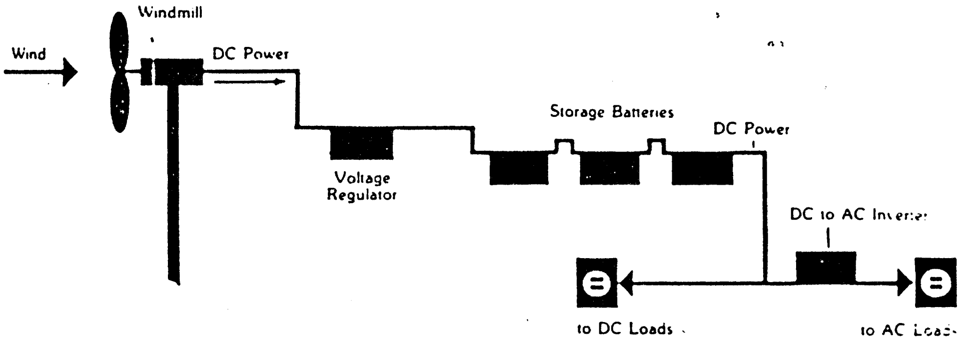
Since the latest revivel of wind energy technology development, a variety of wind turbine systems appropriate for installation in different rural and desert communities are available either commercially or in the form of prototypes. The mechanical motion generated by wind energy, can be used directly or it can be converted to electric power both for stand - alone and grid-connected applications. The system components vary according to the final produced energy form. Fig (C-1) shows a number of possible wind energy system configuration.

The following is a brief description of the available wind turbine technologies, and its status as reffered to different end use applications. Storage systems and other complementary components are discussed in part II of the study as related to the development of the WECS component inventory .

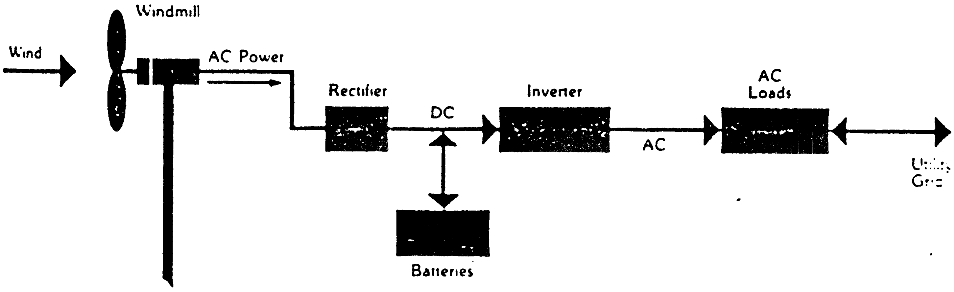
Wind machines may be classified by the manner in which they transfer kinetic energy from the wind to WECS blades. The first type uses drag forces, while the second operates as a result of lift forces. Lift forces act perpendicular to the local wind directions, while drag forces act parallel to it.

In a drag-type machine, kinetic energy is converted to mechanical energy in a vertical rotating shaft, while a lift-type machines use aerodynamic forces generated by wind flowing over an airfoil shaped rotor. Since lift-type machines can rotate faster than the wind speed and produce higher torque than a comparable drag-type machine, the most modern machines operate on the lift principle 3/.

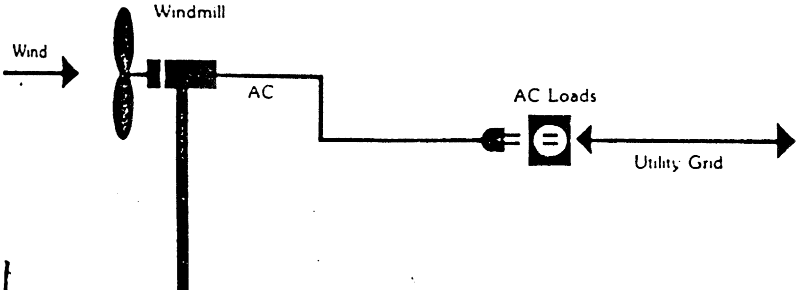
3/ ECWA "Report of Wind Energy in the Arab World" E/ECWA/WG, 1/6, January 1981, Dr. M. Saleh



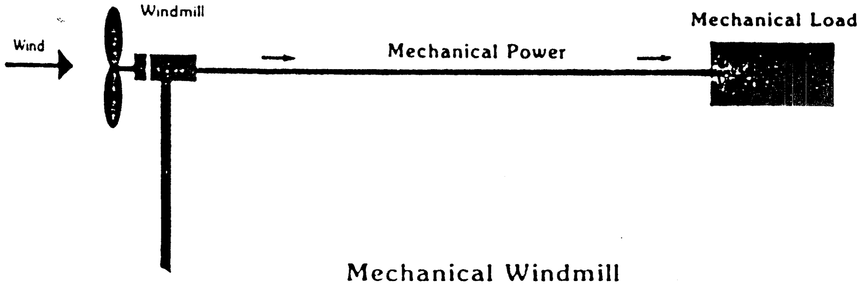
DC Generator Windmill



Variable Frequency AC Generator Windmill



Induction Generator Windmill



Mechanical Windmill

Fig (c - 1) Possible wind Energy System Configuration .

Both drag and lift-type wind machines are generally classified into horizontal axis and vertical axis types. Both types contain five common basic subsystems :

- An energy conversion device in shape of blade or rotor
- A drive train, usually including a gear box and a generator to transmit torque, to the load
- A tower
- Turbine supporting systems including controls and cables
- Balance of station subsystems, such as ground supports, interconnection equipment....etc.

1.1 HORIZONTAL-AXIS WIND TURBINES

Horizontal-axis wind rotors are normally designed to maximize lift forces in order to obtain maximum power output. The category represents the vast majority of successful wind machines, either ancient or modern.

Fig (C-2) shows a variety of configuration far horizontal-axis wind machines including the classical windmill "American Multi Bladed type". This type has a typical wheel size range from 2 to 3.5 m with about 18 - 20 fans per wheel. The curved sheet steel blades produce both high starting torque and probably double the efficiency of any preceeding type of windmill 1/.

The modern-high speed horizontal-axis wind turbine with proper airfoil shaped blades work exactly like a multi-bladed fan, but with far fewer blades. They are mainly used for electric power generation with maximum power coefficient of about o.5 3/.

To save in the weight of windmill fiberglass, wood and aluminium are used successfully nowadays for the manufacture of the rotor blades 4/ .

In a horizontal-axis wind machine, it is essential to have the plane of rotation of the blades perpendicular to the wind direction. Some type of control mechanism is required so that the wind machine can track the direction of winds. This control is refferred to as "Yaw"

4/ Wind Energy Technology Reference Notebook, a report prepared by Meredian Corporation for USAID, July 1985

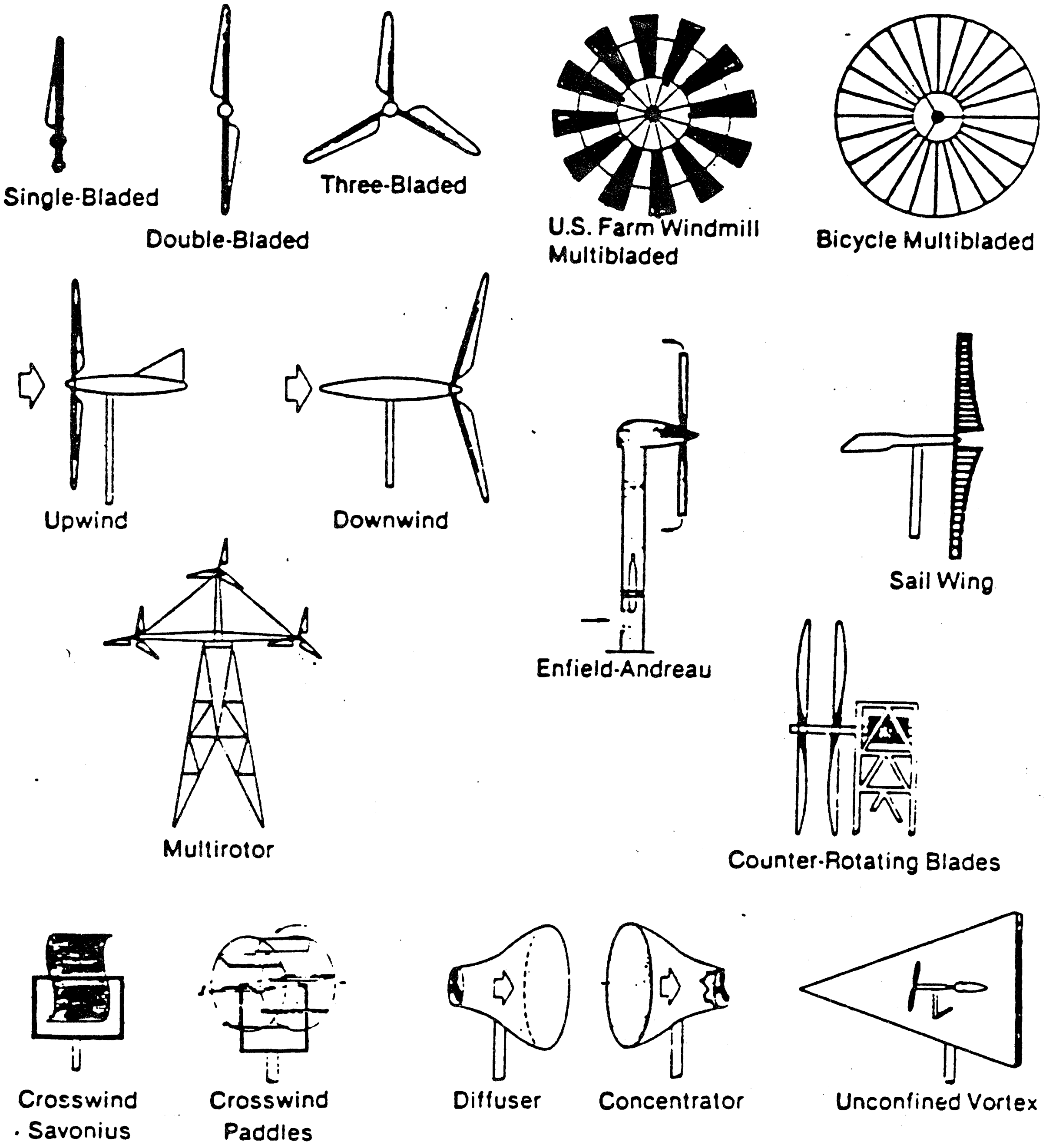


Fig (c - 2) Configurations of Horizontal - Axis Wind Turbine control and is usually a tail vane or a servo operated system. In addition, this machine requireshigh-speed cut out controls to prevent turbine damage or catastrophic failure 4/.The rotor, shaft, gearbox, generator and controls are usually housed on top of the support tower.

1.2 VERTICAL-AXIS WIND TURBINES

The earliest windmills were of the vertical axis type and used drag forces as a means of propulsion; they turn slowly and relatively inefficient and are today categorised as "Panemones". This type of device relies on a difference of drag between diametrically opposite sides of the rotor.

The axis of rotation of a vertical-axis wind machine is perpendicular to both the surface of the earth and the wind stream. It does not need to be turned according to the direction of wind stream i.e they need no "Yaw" control system.

Fig (C-3) shows different configuration of vertical axis wind machines, including both drag type and lift type machines. All the panemone devices rotate with their extremities moving slower than the wind; the ratio of the speed of the extremities, or tips of a windmill rotor to the speed of the "freewind" is known as the "tip-speed ratio" of the windmill. Drag devices always have a tip speed ratio of less than one.

The so-called Savonius rotor developed in 1920's are cup rotors, where the cups are large enough to partially overlap each other. It is more efficient than the traditional panemones, but significantly less efficient than the traditional panemones. One or two Savonius rotors have been commercially manufactured. They are easy to be manufactured, but however it does not scale up well and any such practical machine have been very small. In addition they have a low power coefficient less than 0.15 1/.

Darrieus-type rotors are lift devices with air foil blades, they have relatively high power outputs than a comparable drag-type vertical axis machine. Meanwhile they are characterised by having low or even

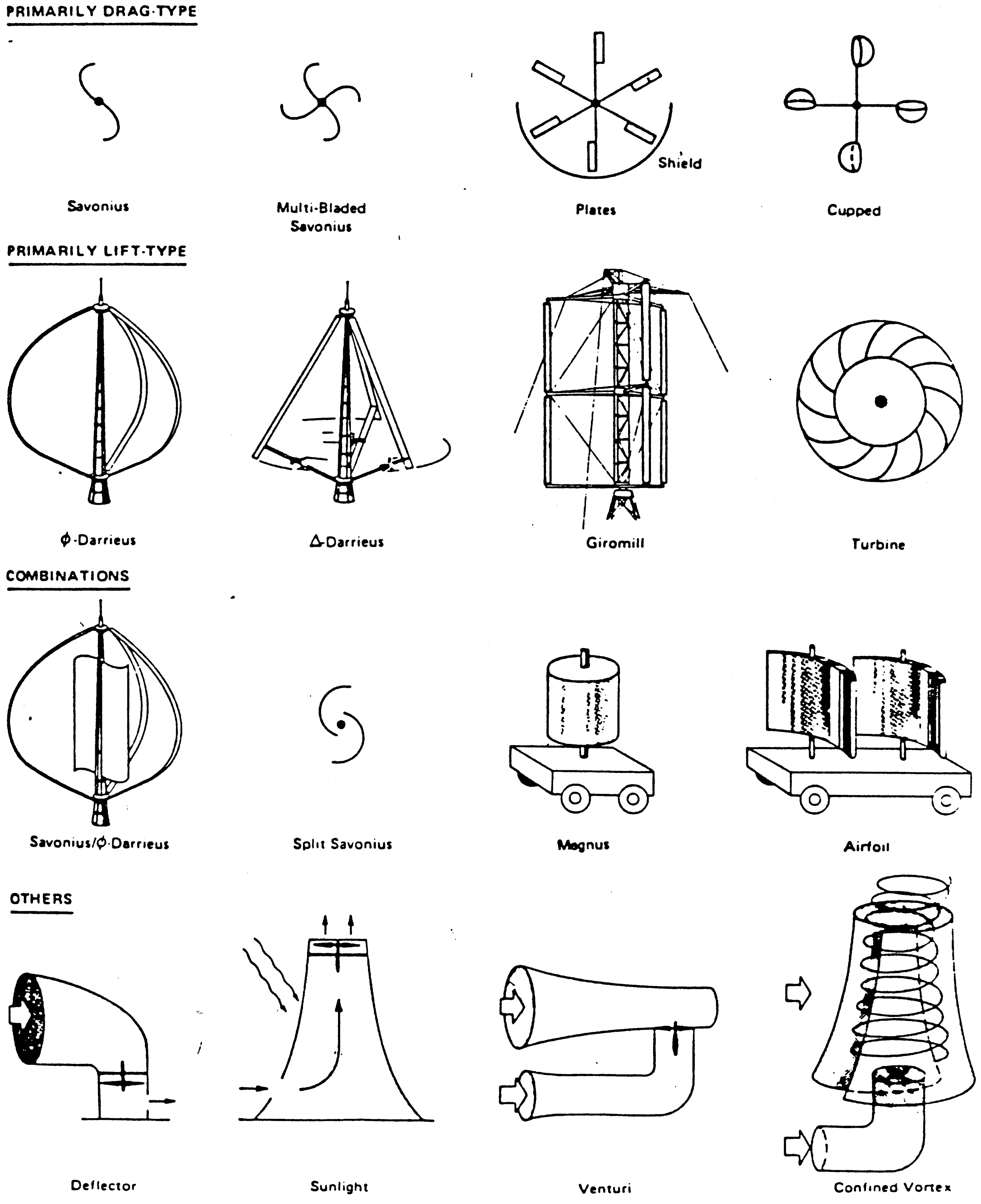


Fig (c-3) Configurations of Vertical - Axis Wind Turbines.

zero starting torque. They require an external power source to start up. Darrieus rotors usually have Cp between 0.2 to 0.35 1/.

Prototypes of Darrieus machines are developed with straight, but inclined blades, but it has much lower efficiencies, although its fabrication is much easier.

Various other concepts has been developed with straight blades, the two principal types are the variable geometry vertical axis wind turbines (VC-VAWT), which is currently under development as a large scale (20 m) machine in the U.K. The other straight bladed (VAWT) is the so-called " Gyromill" developed in U.S.A. with its blades hinged so that their pitch angle can change to reduce the speed of rotation, and over speed can be effectively prevented. They have almost identical Cp to the Darrieus rotors.

In a vertical-axis machine the gearbox, generators and controls are located on the ground, below the turbine and the central shaft. There are several vertical-axis machines that are similar in design and size, ranging from 100 to 300 kw.

1.3 WIND TURBINES PERFORMANCE

The recoverable wind turbine power is theoretically proportional to the cube of wind speed. Each machine is characterised by; a cut in speed which the turbine begins spinning, a rated speed when the power output remains constant for increasing wind speed, and a cut-out speed where the machine should shut down to avoid damage possibilities.

In a low rated wind speed machine, the rated output of the machine is lower but energy is extracted from the more frequent low wind speed bands giving a steadier power output and possibly a greater total output over a given time period 4/.

The operating wind speed for the majority wind machines range from (2.2 - 5.4 m/s) for cut in, and from (18-27 m/sec) for cut out speeds. The efficiency of most commercial machines is limited by the design of the rotor and control system. Because wind speed normally increases with height, tower has a considerable effect on machine performance.

Attention should be given to the actual test data for the performance of any wind machine, rather than the manufacturer performance data. A comparison between two sets of wind machine performance is given in Fig (C-4), Fig (C-5), based on data obtained from Rocky Flat testing part 5/. It shows that the manufacturer performance data are much higher than the actual test data, in addition the changing of the tail orientation "appropriate control"resulted in an increase in power and a reduction in cut-in speed, however power output still does not match the manufacturer's performance curve.

The recoverable power is not the only requirement for an optimum wind rotor, other factors should be considered. Since the primary requirement from a practical wind energy conversion system is that it should be as cost-effective as possible, the key requirements are :

1- Starting torque and running torque should fit the load and so should the normal speed range.
2- Appropriate and cheaper manufacturing requirements to achieve an adequately constructed machine.
3- To maintain an optimum coefficient of power Cp for maximum cost-effectiveness. In general reasonably high Cp value in the 0.3 area are necessary for modern machines 1/.
4- Optimize the "solidity" of the rotor to fit the requirement of the system.

The relative merits of different types of rotor are summarized in table (C-1). In addition Fig (C-6) shows a group of performance curves relating turbine power output, rotor diameter and annual energy production 4/.

2. WIND ENERGY TECHNOLOGY APPLICATIONS

There are in reality two primary and potentially very wide spread end uses of importance to developing countries namely; water pumping and small electricity generation. However wind farms grid connected applications are highlightened lately. Also mechanical wind energy systems are used for other applications than pumping, but in a very limited scale.

5/ Rockwell International Corporation "Sencenbaugh - Model 1000-14 Wind Turbine Generator,Performance report,D.O.E. contract No. DE-AC04-76DP03533, July 1978

ROCKY FLATS WIND SYSTEMS TEST CENTER
MACHINE NAME: SENCENBAUGH
LOAD CONFIGURATION: CONTROLLED LOAD

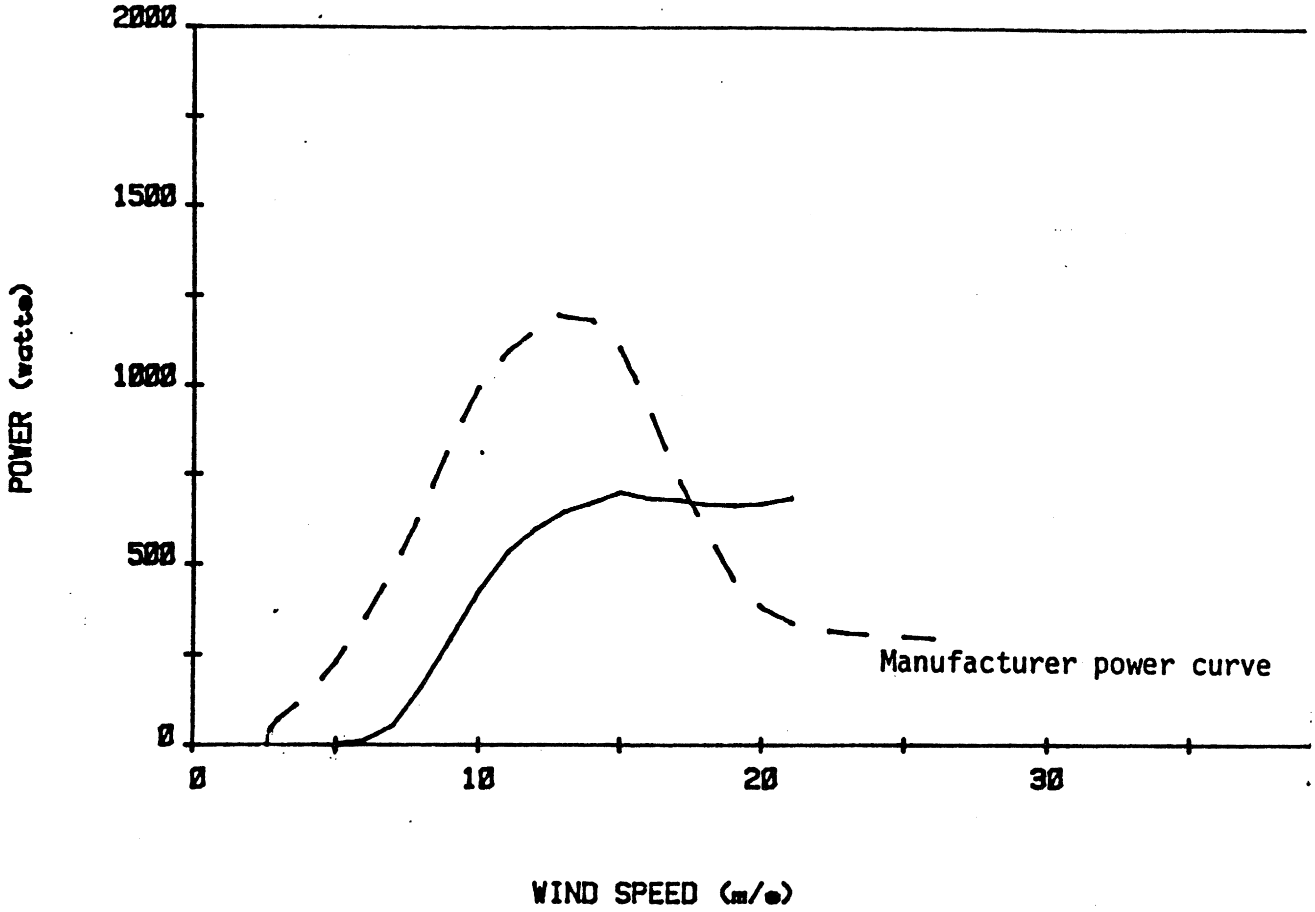


TABLE I

ESTIMATED ANNUAL ENERGY PRODUCTION
(Using A Rayleigh Wind Distribution)

Average M/S	Wind Velocity MPH	Annual Energy Output (KWH)
5.36	12	694
6.25	14	1,087
6.70	15	1,287
7.14	16	1,484
8.04	18	1,854

Fig (c-4)_ Wind Machine Testing Performance

ROCKY FLATS WIND SYSTEMS TEST CENTER
MACHINE NAME: SENCENBAUGH
LOAD CONFIGURATION: CONTROLLED LOAD - ADJ TAIL

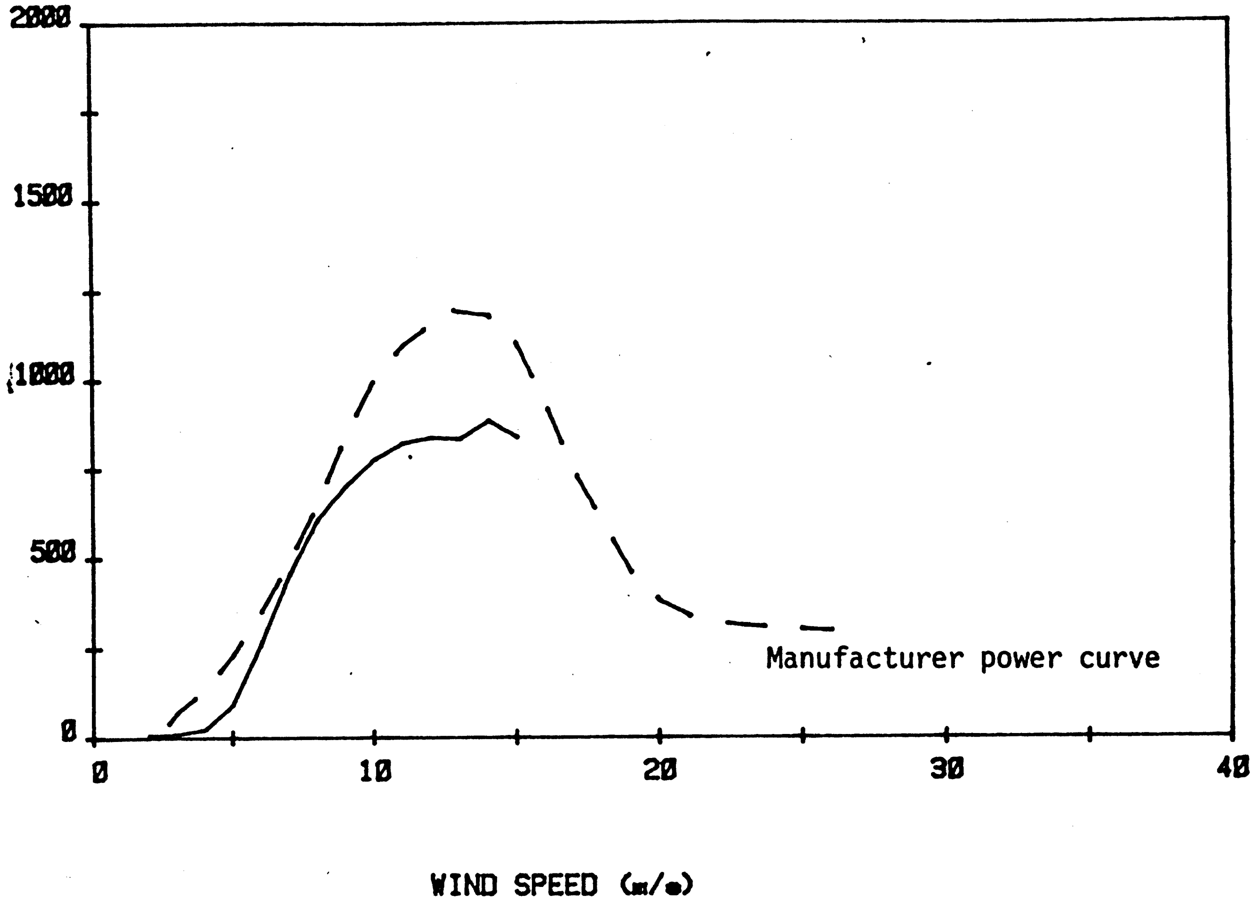


TABLE II

ESTIMATED ANNUAL ENERGY PRODUCTION
(Using A Rayleigh Wind Distribution)

Average M/S	Wind Velocity MPH	Annual Energy Output (KWH)
5.36	12	2,030
6.25	14	2,598
6.70	15	2,839
7.14	16	3,049
8.04	18	3,365

Fig (c-5) Wind Machine Testing Performace

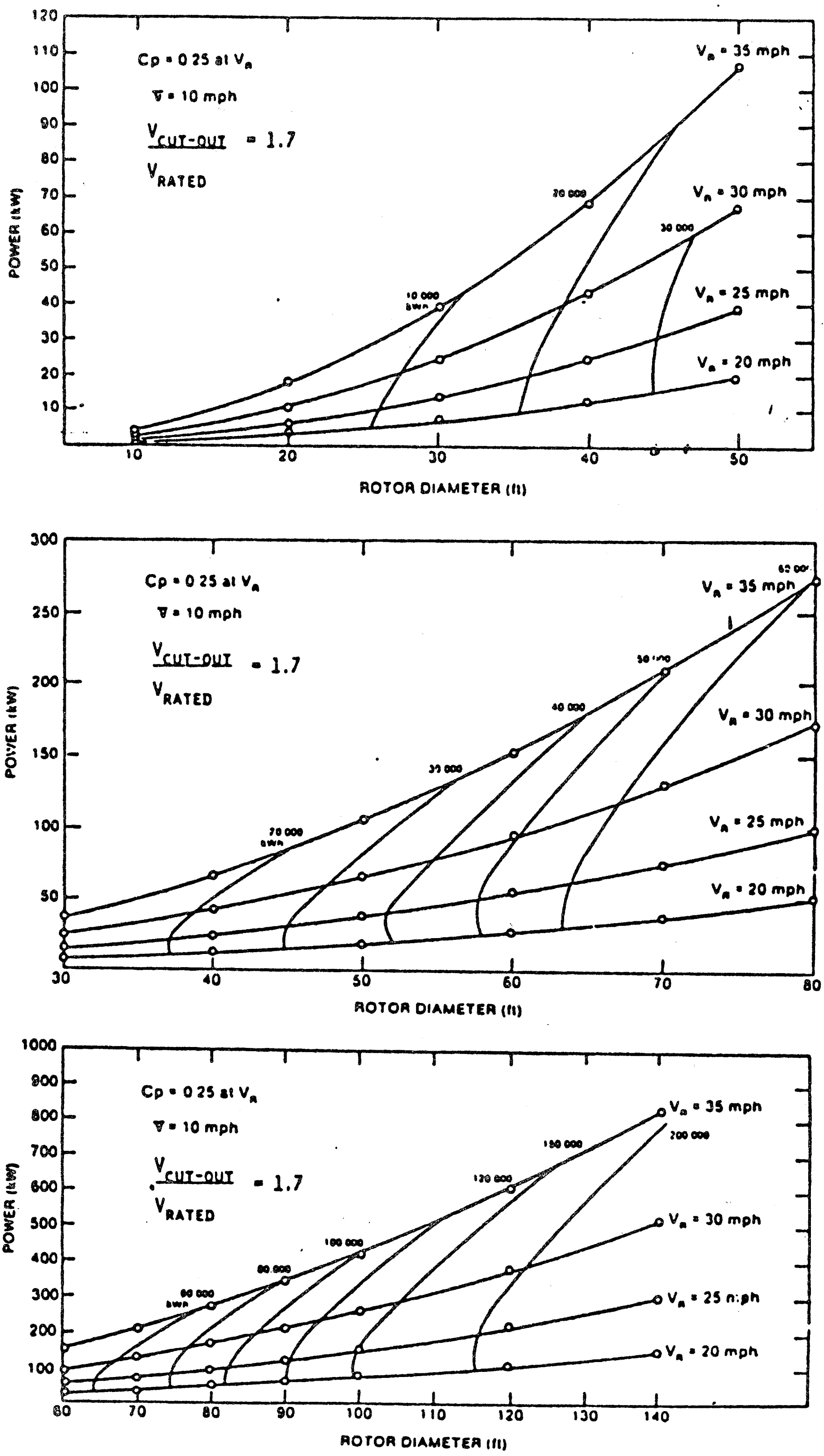
TABLE (C-1) COMPARISON BETWEEN DIFFERENT ROTOR TYPES *

TYPE	PERFORMANCE CHARECTERISTIC	MANUFACTURING REQUIREMENTS	Cp	SOLIDITY
Horizontal Axis				
Cretan sail or flat paddles	medium starting torque & low speed	simple	0.05 to 0.15	50%
Cambered plate fan (American)	high starting torque & low speed	moderate	0.15 to 0.30	50 to 80%
Moderate speed aero-generator	low starting torque & moderate speed	moderate	0.20 to 0.35	5 to 10%
High speed aero-generator	almost zero starting torque & high speeds	precise	0.30 to 0.45	under 5%
Vertical Axis				
Panemone	medium starting torque & low speed	simple	under 0.10	50%
Savonius rotor	medium starting torque & moderate speed	moderate	0.15	100%
Darrieus rotor	zero starting torque & moderate speed	precise	0.25 to 0.35	10 to 20%
VGVAWT or Gyromill	zero or small starting torque & moderate speed	precise	0.20 to 0.35	15 to 40%

* Source : Wind Energy Technology Assessment Study, International Technology Power Ltd, Reading Berks RG7 3PG, UK, World Bank project GLO/80/003

Fig. (C-6).

CURVES RELATING TURBINE POWER OUTPUT, ROTOR DIAMETER AND ANNUAL ENERGY PRODUCTION



Set of curves rated power, rated wind speed and annual energy production to rotor diameter. System Cp = 0.25 at V_R; V = 10 mph; a Rayleigh distribution is assumed.

SOURCE: Moment, R.L. Performance and Size Estimating for Wind Systems. Rockwell International Corp., Golden, CO., Department of Energy Contract DE-AC04-76DP03533, February, 1983.

2.1 WATER PUMPING APPLICATION

Water pumping is the only widely used mechanical applications for wind machines. There are three basic categories of mechanical wind pumps commercially available in addition to the electric wind pumping systems, there are :

a) Traditional Multi-Bladed Farm Wind Pump

The vast majority of wind pump in use are of such type with horizontal axis invariably with rotor upwind of the tower. It is almost in small sizes of about (5m) diameter and characterized by being material-intensive, but they are also very reliable. robust and need little maintenance.

b) Modern Light-Weight Farm Wind Pumps

Are conceptually similar to traditional farm windmill, but are much lighter and simpler, they have comparable and better performace than traditional designs. This type is not suitable for heavy duties, they tend to run at high speed and have less pump rod pull. They can be better used for good wind sites with low pumping heads.

c) Low Cost Wind Pumps

Those are mostly "on-site" built systems, using as far as possible cheap locally available materials, they are in intensive use in developing countries. Naturally the efficiency is very poor and time life is short.

d) Wind Electric Pumping Systems

They are primarily electricity producing wind mills connected to motor-pump sub system. They are a higher technology than mechanical wind pump therefore their reliability and system life are as yet unproven.

However they have numerous advantages, the main one being that the wind turbine can be located remote from the water source. They are more efficient than mechanical systems and are likely to be particularly competitive with them where large outputs of water are required at low to medium pumping heads.

Generally windmill water pumping is used for livestock, human water supplies and irrigation. These applications have wide spread market in developing countries, particulary in desert areas where water is the major need 1/.

Although the power available in the wind is proportional to the cube of the wind speed, the power output in the case of a wind pump only increases linearly with wind speed. This is because the efficiency (coefficient of performance) of a wind pump changes with wind speed 1/. Fig (C-7) shows a typical efficiency curve for a wind pump together with the resulting instantaneous power output. It should be clear that the maximum efficiency do not coincide with maximum instantaneous power. It should be noted that the total system efficiency in terms of energy capture for a conventional wind pump in a wind regime varing significantly over the season, will typically involve the product of the following efficiency factors; rotor efficiency, wind regime matching efficiency, cyclic torque matching efficiency and mechanical pump efficiency. This product would vary slightly around (4%).

In case of small wind generator, the energy capture efficiency will, typically be made up of rotor efficiency, wind regime matching efficiency, generator and wiring efficiency and battery charge/discharge efficiency. The average product of the energy capture efficiency in this case is about 10%.

In practice the actual figure can be due to inaccurate optimisation, imperfect utilisation ....etc. Details for optimization of these governing factors has been discussed in the "Wind Technology Assessment Study" performed by the Intermediate Technology Power Ltd. UK.

A list of commercialy available mechanical wind machines is shown in table (C-2) 6 .

2.2 WIND ENERGY SYSTEMS FOR ELECTRICAL OUTPUT

This is a much less widespread end use at present than water pumping, especially in developing countries. However it is of considerable potential importance in moderately windy regions (i.e. with meanwind speeds 4.5 to 5 m/s). The main end-uses are for lighting, power radio receivers, desalination, remote farms, as well as the recently developed grid connected systems. There are two main types of electricity-generating systems.

1/ Detailed information can be obtained from this reference

6 / Rockwell International "Commercially Available Small Wind Systems and Equipment, Aug, 1979

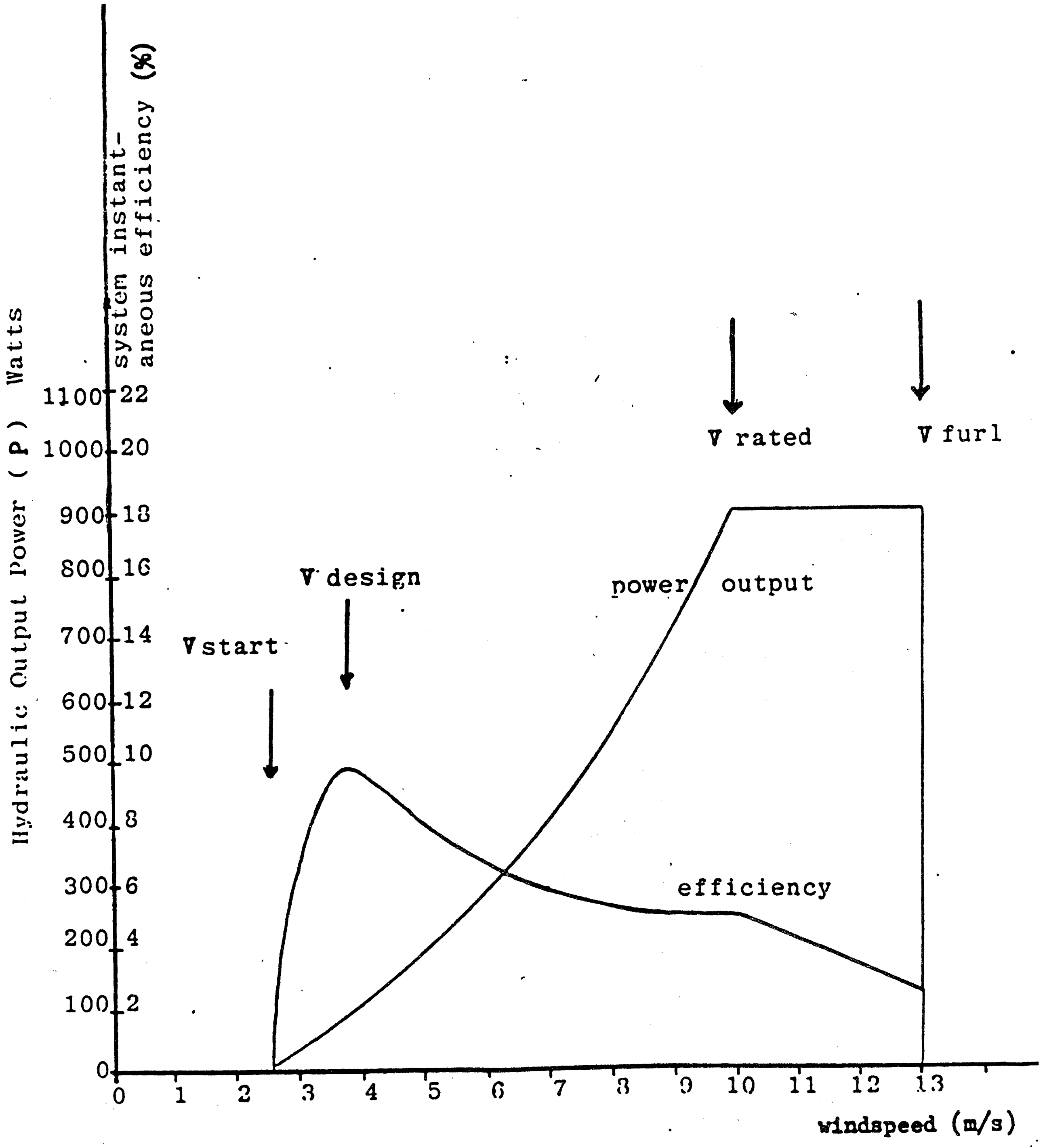


Fig (c-7) Typical Efficieny of & Power output For a Wind Pump

TABLE (C-2) COMMERCIALLY AVAILABLE WIND MECHANICAL MACHINES *

NAME &	MODEL	CAPACITY (m^3/hr)	ELEVATIONS (m)	ROTOR DIA. (m)	RATED WIND SPEED m/s	CUT-IN WIND SPEED m/s
Aeromotor	702-16	6.44	30.43	4.88	9	4
Aeromotor	702-14	3.97	29.87	4.27	9	4
Dempster	14 ft	no data	available	4.27	6.7	2.2
Aeromotor	702-12	2.76	29.87	3.66	9	4
Dempster	12 ft	2.38	32.93	3.66	6.7	2.2
Heller Aller	Baker 12	2.27	30.48	3.66	6.7	3.15
Aeromotor	702-10	1.78	30.48	3	9	4
Heller Aller	Baker 10	1.74	30.48	3	6.7	3.15
Dempster	10 ft	1.35	31.1	3	6.7	2.2
Aeromotor	702-8	1.23	28.66	2.44	9	4
Heller Aller	Baker-8	0.946	30.48	2.44	6.7	3.5
Dempster	8 ft	0.94	32.62	2.44	6.7	2.2
Bowjon	8 ft	0.91	15.24	2.44	6.7	2.7 - 4.5
Heller Aller	Baker-6	0.57	30.48	1.83	6.7	3.15
Dempster	6 ft	0.49	28.96	1.83	6.7	2.2
Aeromotor	702-6	0.49	28.96	1.83	9	4
Sparco	D	0.22	3.99	1.27	8	2.2
Sparco	D	0.22	10	1.27	8	2.2

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* The table is a summary of the major charecteristics of some mechanical wind machines. The data are arranged according to pumping capacity (m^3/hr) with an approximately 31 meters head elevation

2.2.1 SMALL WIND ELECTRIC SYSTEMS

Small wind energy systems vary in size farm few watts up to 100 kw, rotor sizes range from 3 m to 39 m. Currently, small wind generators can produce either ac or dc power and can be used as stand alone systems or inter connected with an utility network. Power transmission for this type is almost in the form of gears, although pulley belts and direct-drive systems have also been used. These systems are used in windy locations in conjunction with a diesel generator set as a fuel saving device. The current state of the art in interfacing wind and diesel systems is still somewhat experimental and unproven.

System efficiency cannot be generalized for this category as it is highly dependent upon the specific application and incorporated system components. Table (C-3) is a matrix of principal windmill types and a list of actual and potential applications which they might be applied to 1/. In addition table (C-4) shows the characteristics of some of the commercially available electrical output wind machines 6/ . There is a growing interest particularly in Denmark and US for the use of wind turbines in the 2-100 kw range coupled directly to the grid wind farms has been progressing in the U.S. and a number of European countries. In 1982 60% of the installed capacity of windmills world wide were in wind farms 7/ . This activity has grown to such an extent that one of the most successful manufacturers of (50 kw) turbines, Carter Wind Systems Inc., has two year order book for their machines.

2.2.2 LARGE WIND ENERGY ELECTRIC SYSTEM

Large wind energy systems are defined as any system with a rated output of over 100 kw. The largest vertical axis machine available at US is a 500 KW Darrieus one. The larger (over 1 Mw) machines are all of horizontal axis machines. Cut-in speeds are higher than those of smaller machines (5.4 to 6.3 m/sec). Rated wind speeds is also higher and are usually between (11.2 to 14 m/sec).

System performance of these machines has been impressive. While failures have occurred in component of several systems, overall performance has equalled or exceeded most manufacturer's exceptions.

7/ Robin sacks "Market Status and Projections : Wind and Photovolterics" RETSIE, 83 Proceedings Sept, 83.

TABLE (C-3) WIND EBERGY CONVERSION SYSTEMS AND END USES *

KEY TO RATINGS
1. Well proven & production
2. Limited use &/or proved
3. Under serious development
4. Being researched/promising
5. In need of investigation
6. Unlikely but possible

END-USES	CONVERSION SYSTEMS HORIZONTAL AXIS				VERTICAL AXIS						STORAGE METHODS									
	Low speed<2m dia	Low speed>2m dia	high speed<2m dia	high speed>2m dia	Darrieus	Cyclic pitch change	Variable Geomtry	cross flow	Savonius	Panemone (crag)	storage impossible	storage essential	standby engine	electric batteries	water tank or pond	hydraulic accumulator	air vessel	thermal	flywheel	
a) pumping water																				
shallow walls & from rivers (irrigation)	1	1		2		5	3	6	6	6			•		•					A
borehole (water supplier)	1	1		5		5	4	6	6				•		•					A
dewatering	1	1		5		5	5	6	6				•							C
saltworks (brine)	1	1											•							C
pumped storage system		5		5	5	5	5													D
desalination (circulation)	5	5					5		5				•		•					?
marine propulsion		5		5			4		6				•							B?
fish ponds (aeration	2	2	2	2									•		•		•			C
b) other pumping																				
desalination		5		5			5					•	•			•	•			B?
refrigeration or ice production		5		5			5						•					•		B?
heating (horticultural)		5		4			5									•		•		C
working (pnoumatic/hydraulic)		5		5	5		5	5				•	•	•					•	D?
c) electricity generation																				
lights and electronics (up to 200W)	1		1	1			1	6				•	•	•						A
lights and small motors (200-1000W)	1		1	1	3	1							•	•	•					A
ac power/invertor/battery (1-5 KVA)				1	1		3					•	•	•						A
ac power diesel standby (5-199 KVA)				1	1	3	3					•								A
ac power/grid feeding (100KVA)				2	2	2	2				•									A
d) mechanical drive																				
milling grain		2		5			5	6											•	C
sawing timbor		5		5			5													D?
workshop drive		5		5			5					•	•				•		•	C
bird scaring	2		2	2					1	2	•									A
STATUS OF SYSTEM in production & use	•	•	•	•	•	x	•		•				•	•	•	•	•			
under development																				
not very promising								•	•											

* Source : "Wind Energy Technology Assessment Study"
International Technology Power Ltd., Reading
Berks RG7 3PG, UK World Bank Project GLO/80/003

POTENTIAL MARKET
A : widespread
B : good
C : limited
D : unpromising

TABLE (C-4) CHARACTERISTICS OF COMMERCIALLY AVAILABLE WIND ELECTRIC MACHINES*

NAME AND MODEL NUMBER	SIZE (RATED kw)	ROTOR DIA. (m)	NO. BLADES	RATED SPEED (m/s)	CUT-IN SPEED (m/s)
Energy Development Co. (USA)-445	45.000	12.2	4	11.2	2.2
Dominum Aluminum Fabricators (Canada) VAWT 35 x 35 (vertical axis)	37.00	11.2	2	14.8	5.8
Grumman Energy System (USA) Windstream 25-B	20.00	7.62	3	12.9	3.6
Energy Development Co. (USA)-440	20.00	11.6	4	11.2	2.2
Wind Power systems INC USA Storm Master	18.00	10.0	3	10.7	3.6
Millville Windmills (USA) 10-3-IND	10.00	7.6	3	11.0	4.0
Independent Energy Systems, Inc. (USA) Skyhawk	4.000	4.6	3	10.1	3.1-3.6
Aerowatt S.A (France)4100 FP7G	4.100	10.0	2	7.2	3.1
Dakota Wind & Sun, Ltd. kw	4.000	4.3	3	12.0	3.6
Dynergy - 5 meters (vertical axis)	3.300	4.6	2	10.7	4.4
Product Development Institute (USA) Wind Heat System (Prototype)	3.000	4.15	3	12.0	5.4
Kedco, Inc. (USA) 1620	3.000	4.88	3	11.1	4.9
North Wind Power Company (USA) Eagle 3 kw - 32 V	3.000	4.14	3	12.2	3.6
Altos, The Alternate Current (USA) BWP - 12A	2.200	2.4	24	17.1	3.6
Pinson Energy Corporation (USA) C-2E *	2.000	3.66	3	10.7	3.1
American Wind Turbine, Inc.(USA) 16 feet	2.000	4.7	48	9.0	4.5
Dunlite Electrical Products (Australia) 81/002550 (Standard Model)	2.000	4.10	3	11.0	3.6
Kedco, Inc. (USA) 1610	2.000	4.88	3	10.0	4.4
North Wind Power Co.(USA)Eagle 2kw-110v	2.000	4.2	3	10.0	3.6
Whirlwind Power Co. (USA) Model A	2.000	3.0	2	11.2	3.6
Entertech Corp. (USA) 1500	1.500	4	3	9.8	3.6
Aero Power System,Inc (USA) SL 1500	1.43	3.05	3	11.2	2.7
Kedco, Inc. (USA) 1600	1.200	4.88	3	7.6	3.1
Aerowatt S.A. (France) 1100 PF7G	1.125	5.09	2	7.2	3.1
American Wind Turbine,Inc.(USA) 12 feet	1.000	3.5	36	9.0	4.5
Dunlight Electrical Products (Australia) 82/002550 (High Wind Speed Model)	1.00	3.1	3	16.5	6.3
Sencenbaugh Wind Electric (USA) 1000	1.000	3.65	3	10.3	2.7
Aerolectric Co.(USA)C-9/C-90 Wind Wizard	0.600	2.75	3	11.6	4.0
Winflo (Canada) Wingen Mod 500	0.500	2.0	3	11.2	3.0
Power Group Int'l Corp(USA) Hummingbird 4000	4.0	4.3	3	10.0	2.7-3.6
Aerowatt S.A (France) 300 FP7G	0.350	3.26	2	7.2	3.1
Winco-Devision of Dynatechnology(USA)1222H	0.200	1.83	2	10.3	3.1
Zephyr-Wind Dynamo Tetrahelix S	0.007	0.61	2	11.2	5.4

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* The table summarizes the major charecteristics of some commercially available wind machines which produces electrical power. The data are arranged according to power output

Power coefficients of (0.4) have been achieved. Capacity of 30-40 percent have been achieved, and availability is projected to be at least 90%.

Comprehensive activities are taken by different US manufacturers and testing institutes as well as other international companies. Five (2.5 mw) machines are constructed by Boeing Engineering through a contract with (DOE), three of them are installed since 1983 under testing.

A recent report stated that, West Germany's 3mw Growian I wind turbine designed by MAN is being written off after less than two years of use. Operation and construction costs have more than trebled as a result of a series of technical problems 8/.

Commercially available WTGS, over 100 kw capacity available in the United States are listed in table (C-5) 9/ , however it should be clear that very little potential exists for the use of such wind machines in developing countries, unless advanced electricity grid is available.

3. CURRENT R & D THRUST

R & D activities in the early phases of the wind technology programme were driven by three main concepts : technology developed for the aviation industry could be borrowed directly; that wind can be characterized as a steady homogeneous flows and that major improvements in cost-effectiveness would be achieved through advanced engineering, economics of scale, and mass production.

Although basic research for wind machine was not stressed, it has been advanced significantly since 1974, further improvements are required if wind energy is to be competitive with grid-supplied power from other sources. Table (C-6) shows the status of surrent state of the art technology relative to the long term goals and helps define the challenges for research and development.

Developing these opportunities for improving wind technology requires research in two parallel areas. The basic science of wind turbine dynamics, advanced components and system research. Wind turbine dynamics includes studies in atmospheric fluid dynamics, aerodynamics and structural dynamics. Advanced components and systems research includes research on advanced concepts, supporting research,

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8/Judith Perera "West Germany Scrops Wind Turbines", World Solar Markets,vol 16, No 8, August 1985

9/ Patrick Quinlan "Current Status of large Wind Turbine Technology" RETSIE,1983 Proceedings, Sept. , 1983

TABLE (C-5) LARGE SCALE COMMERCIALLY WIND TURBINES & GENERATORS *

MANUFACTURER	TYPE	RATED KW	TOWER HEIGHT (m)	ROTOR DIA (m)
Carter Wind Systems	HAWT	200	13	8
DAF Indal Ltd.	HAWT	500	41	25
WTG Energy Systems	HAWT	200,600	not available	
Westinghouse	HAWT	500	28	38
Energy Science, Inc.	HAWT	200	not available	
Flow wind Corporation	HAWT	120 170 250	not available	
Forecast Industries	HAWT	185	29	18
California Energy	HAWT	120 300	not available	
Danish Wind Technology	HAWT	340	32	31
Windmaster	HAWT	100 150	not available	
WECS-Tech Corporation	HAWT	100,150	not available	
Polenko	HAWT	100,300	not available	

* Source : Patrick Quilan "Current Status of Large Wind Turbine Technology" RETSIE, 83 Proceedings, Sept, 83

TABLE (C-6) TECHNOLOGY STATUS AND TECHNICAL GOALS (1984 DOLLARS)

	CURRENT TECHNOLOGY	TECHNICAL GOALS
Annual energy production and installed coasts (per m³ of swept rotor area)	Ranging from 300 kwh at \$ 600/m² to 200 kwh at \$ 1100/m²	Ranging from 900 kwh at \$ 50/m² to 1500 kwh at \$ 750/m²
Annual operation and maintenance costs availability	2 ¢/kwh with 85% to 95%	0.5 ¢/kwh with 90% +
Life expectancy		
- Major fatigue-related parts	5 years	30 years
- Balance of the primary structure	20 years	30 years
30 year levelized cost of electricity	10 ¢ to 15 ¢/kwh	4 ¢/kwh

applied technology testing, and multimegawatt systems. These activities are aimed at reducing technical barriers and developing the technology base that will lead to major improvements in machine cost, performance and lifetime. This area will involve not only R & D on individual components such as advanced airfoils and generators, but also systems analysis and testing to ensure that designs are optimized from an overall systems point of view.

4. ECONOMIC AND MARKET VIABILITY

4.1 WIND PUMPING

It is estimated that about 750,000 wind pumps were in regular use world-wide in 1983 (compared with over 6 million in the USA alone in the 1930's). Most of these are in Australia , South Africa, the USA and Argentina, are used for livestock and ranch water supplies. Current world production of wind pumps is uncertain but is probably less than 5000 units per year from about 50 manufacturers world wide. The immediate potential market must be in the 20,000 to 40,000 unit bracket simply if the existing world wind pump population is to be replaced by wind pumps instead of other options 1/.

Typical system costs and performance data for the range of available mechanical wind pumps from different countries is shown in Table (C-7) 1/ The wide variety shown in system cost and performance is a result of the wide technical variation and the differences in labor cost.

Wind pumps are characterized by the high cost of towers compared to system cost (35%), while the cost of windmill itself is about 40% only.

The economics of all wind energy systems are extremely sensitive to mean wind speed. It has been found that the basic requirement for wind pumping to be economic is a mean wind speed in excess of 3.5 m/sec in the most critical month. The appropriate size of units that could offer energy for deserts irrigation pumping is (5 - 10)/kw for each 10 hectares, depending on the irrigation period. In the future, 100 kw units may be used for each 100 hectares. In addition, appropriate size range for ECWA's region has been analysed *, results are presented in table (C-8).

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* More detailed information is available in references 1 & 3

TABLE (C-7) SYSTEM COST & PERFORMANCE FOR MECHANICAL WIND PUMP*

ROTOR		MANUFACTURER		COST DATA			PERFORMANCE		
DIAMETER ft/m	RATED WIND SPEED km/hr	TRADE NAME	NATIONALITY	M/C COST (local)	TOWER COST (local)	TOTAL COST $Equiv	OUTPUT m³/hr	HEAD m	η%
6/1.83	28	Aermotor	USA	830	1300	2130	1.2	14	6
	14.58	C & S Varcoe	Australia	660	614	1259	0.5	22	29
	22.5	Hayes	New-Zealand	499	143	479.1	0.425	20	6
	16	Newark	UK	2400		3500	0.9	15	27
	10	Thai U.S.A.	Thailand	18500		813.19	0.5	6	24
	29	Windkraft	W. Germany	8646	870	3890.43	10	2.5	7
16/4.88	29	Sthn Cross	Australia	$ 760	$ 310	1070	1.575	28	5
	22.5	Agro Aids	India	14000	$ 300	1843.99	2.4	21	5
	20	Local Mfg	Ethiopia			1000	4.5	2.74	2
10/3.05	28	Aermotor	USA	2200	1385	3585	1.8	30	7
	11.7	Climax	RSA	R1079	R925	1712.36	0.0997	58	10
	16	Newark	UK	3000		4550	1.29	30	27
	28	Aermotor	USA	8210	2805	11015	1.8	110	10
24/7.32	12	Merin	Pakistan	R_s 55000		4557	1.72	70	35

* Source : Wind Technology Assessment Study Intermediate Technology Power Ltd., Reading Berks RG7 3PG, UK, World Bank. Project GLO/80/003, Feb,1983

TABLE (C-8) PROJECTED SIZES AND ENERGY* COSTS FOR WIND PUMPING IN SITES IN ESCWA'S REGION

COUNTRY	SITE	LOCAL FACTOR	INSTALLED kw TO IRRIGATE 10 HECTARES	ENERGY COST (mills/kwh)
Bahrain	Muharrap	0.322	4.73	72 - 178
Egypt	El Salloum	0.292	5.22	59 - 148
	Alexandria	0.24	6.37	72 - 180
	Hurghada	0.474	3.65	36 - 91
Kuwait	Al-Ahmadi	0.354	4.31	65 - 162
Lebanon	Bekaa	0.29	6.1	83 - 207
Qatar	Doha	0.237	6.44	97 - 242
	Ras Rakan	0.393	3.88	59 - 146
	Halul Island	0.371	4.1	62 - 155
Saudia Arabia	Dahran	0.24	6.37	96 - 240
	Las Tanura	0.221	6.9	105 - 260
	Taif	0.237	6.44	96 - 240
	Yanbo	0.257	5.13	89 - 223
	Jeddah	0.195	7.8	118 - 295
U.A.E	Das Island	0.257	5.93	89 - 223
	Jebel Dhanna	0.247	6.17	93 - 233
	Sharjah	0.268	5.68	86 - 214

* Source : ECWA "Report of Wind Energy in the Arab World"
E/ECWA/WG. 1/6, January 1981, Dr. M. Saleh

4.2 WIND ELECTRIC SYSTEMS

There are no more than a few thousand wind generators of small capacity in use world-wide, and the annual production rate of machines under 10 kw rated power is estimated as being in the region of 3000 units from about (80) manufacturers world wide 1/.

Improvements in the technology and the fiscal incentives introduced both by US and Danish Government have resulted in a considerable market for grid connected wind turbines. Grid connected wind turbine market is many times larger than that of the small, stand-alone systems that dominated sales prior to 1973. Most of the wind machines installed in the last three years have been in wind farms in US, where they are producing power for sale to electric utilities.

It is estimated that, in 1982 world wide wind turbines installed reached (75 mw) 7/, while in 1983 there where over 3,600 wind turbines with a total capacity of about 120 mw in operation at US. A significant portion of this capacity is installed in wind farms in California 10/ . The average turbine size for wind forms is increasing, but today multi-mw wind turbines are not readly commercially available.

Improvement in the cost, performance, and lifetime of wind machines have already reduced the cost of wind-generated electricity more than tenfold during last decade. However, if wind turbines are to be competitive world wide the cost of wind generated electricity will have to be reduced from (10-15¢/kwh) to - 4 ¢ kwh (in constant 1984 dollars). Achieving this goal will require simultaneous improvement in the cost, performance, and lifetime of both horizontal - and vertical - axis machines. Fig (C-8) shows the projected costs large WECS. A recent report published in the Solar Energy intelligence report 11/ stated that if prices come down to $ 1,100 per kilowatt in 1990, according to projections a market of 21,000 Mwe could be reached. The report based its assumptions on wind farms of 100 or more horizontal, axis, multi-megawatt turbines.

10/ Robert L.San Martin "Renewable Energy Status and Potential", RETSIE, 83 proceeding, pg 45, Sep 83

11/ Utility Market for Windmills could reach 21,000 Moe in 1990, Solar Energy intelligence report, Oct 1985 page 336

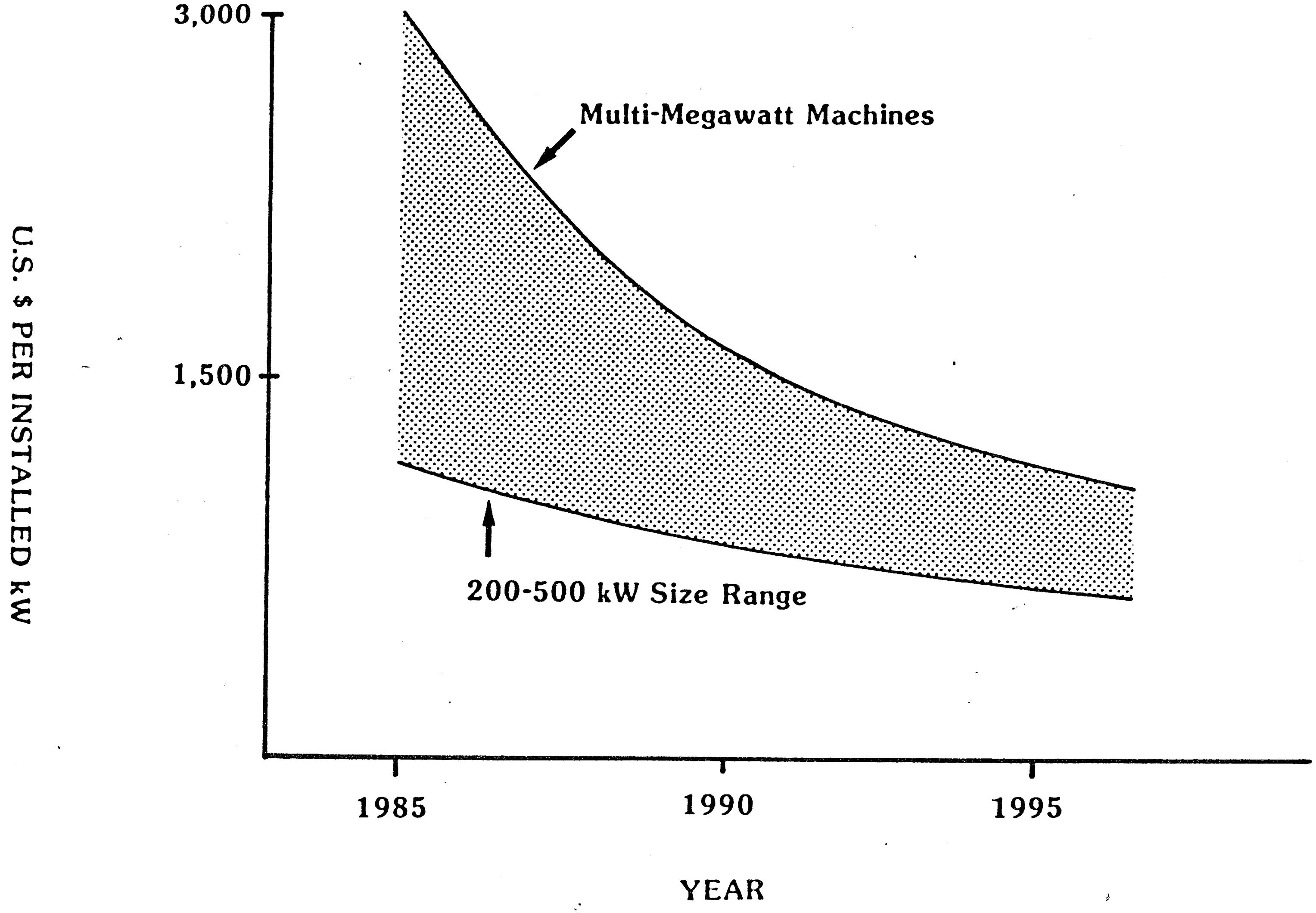

Fig (c-8) Projected Costs of large WECS.

5. RELEVENT STATUS IN ESCWA'S REGION

The potential possibilities for wind energy utilization in ESCWA'S countries (in view of the present state-of-the art) is directly related to :

5.1 Wind Energy Resource Availability

Most of ESCWA'S countires, with the exception of Egypt, do not have appropriate assessment of their wind energy resources; a fact which may necessitate the development of a regional programme in this area. However, using available meteorological data, a preliminary evaluation of wind resourses has identified reasonable average wind speeds in the wind regions of most of the ESCWA's countries 3/. These wind speeds vary between a minimum of 3.5 m/sec at the Jordanian coastal areas to 7.5 m/sec at Hurghada, Egypt. Table (C-9) summarizes these results. Since studies 1/ showed that, wind resources with higher average annual wind speeds than (3.5 m/sec) can be utilized economicaly for water pumping and small scale electricity generation; some of ESCWA's countries would have a promising potential for the utilization of wind energy technologies.

5.2 Potential of Appropriate Applications

Rural areas development is a vital need in ESCWA's countries, meanwhile the majority of its territories are arid regions, where water and energy supplies are limited. In addition most of ESCWA's countries do not have centeralized energy systems extended to its arid rural area, nor it can be done economically.

In view of these facts wind power can be a prime contender for decentralised applications in remote areas in the region, and would have a prime importance in the development of these areas.

Although the potential for water pumping and small scale electricity generation is the dominating; the possibility of a large scale electricity generation may not be ignored. Egypt is working for the development of East-Owinat area, where a potential of reclaiming 6 million acres of desert land exist using fresh under ground water. Wind farms may be an appropriate solution if the resource potential approved to be sufficient * Similar potentials can be investigated in other countries

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* Wind speeds higher than 6m/sec are recorded on site

TABLE (C-9)

AVERAGE ANNUAL WIND SPEEDS AT WINDY SITES OF ESCWA'S REGION

COUNTRY	BAHRAIN	EGYPT	IRAQ	JORDAN	KUWAIT	LEBANON
V(m/sec)	≃ 6.1	4.5 to 7.8	N.A	3.5* to 4.8	5 to 6.5	4.0 to 4.9

COUNTRY	OMAN	QUATAR	SAUDI	U.A.E	SYRIA	YEMEN
V(m/sec)	N.A	5.3 to 7.3	4.8 to 6.5	5.3 to 5.6	3.5*	N.A

* Studies showed that in Jordan , mean windspeeds higher than 3.5 m/sec are prevailing on more than 56% of the Jordanian terretories, and more than 85% of the Syrian terretories.

mainly on the Red Sea and Gulf coastal areas, for Saudia settlements *, Jordanian and Egyptian arable land; wind farms can be grid-connected for both Jordan and Egypt.

The realization of such potential possibilities should depend upon a well designed plan of action to assess and evaluate wind resources, investigate and project the actual potential needs and initiate the necessary industrial infrastructure.

5.3 In Country Capabilities and Relevent Experience

Limited attention has been given to wind energy utilization in ESCWA's region, however scattered activities and a number of small projects has taken place in Kuwait, Lebanon and Saudi Arabia for wind pumping systems. In addition only two wind electric generators were installed and tested in Yemen (18 kw) and Syria (2.1 kw). Egypt is the only country which has almost completed wind resource assessment for the whole country, installed hundreds of small multi-blade wind pumps in the early 1960's and developed manufacture capabilities. Research plans in the area of wind energy utilization are considered by a number of scientific institutions in Egypt, Kuwait, Saudi Arabia and U.A.E. Indoor and outdoor wind machines testing laboratories are expected to be in operation within two years in Egypt within the context of the Egyptian Renewable Energy Development Organization (EREDO). The ESCWA's region does surly have considerable R & D institutional capabilities, but very limited industrial infrastructure, while additional details are available in previous ESCWA's reports 3/.

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[*] A 5000 settlements and 765,000 hectares of arable land depending mainly on underground water, are existing in Saudia Arabia