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5453

# SOLAR ENERGY (5453) (List of Contents)

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# COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH
## NEW DELHI

# STATUS REPORT ON SOLAR ENERGY

( September 1978 )

Division of Research Coordination & Industrial Liaison
CSIR, Rafi Marg, New Delhi.

## STATUS REPORT ON SOLAR ENERGY

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We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche.

## /STATUS REPORT ON SOLAR ENERGY/

### Introduction

Solar Energy has attracted worldwide attention- both for traditional use in home and industry, and scientific research on its applications in modern uses such as refrigeration, photovoltaic cells, and power generation. According to an AdHoc Advisory Panel of the Board of Science and Technology for International Development, National Academy of Sciences, solar energy offers significant possibilities to a developing country for many reasons: it is widely available in adequate intensity in these regions, useful applications of solar energy are now being made, energy is a critical requirement to meet the growing needs of these countries vis-a-vis the fast depleting agro-mineral resources and lastly because conventional sources of energy are not widely available. Most of the developing countries, including India, are characterised by arid climates, dispersed and inaccessible population, abundant labour and limitations on capital, faced with high investments on conventional power establishments and transmission problems. The panel concludes that solar energy is a resource that has the capability to meet energy requirements substantially beyond the applications now being made, and this potential can be realised only with further R &D.

A significant aspect of the subject is that most of the problems in utilisation of solar energy are "Energy problems", not solar and solutions to the energy problems require consideration of alternative sources of energy and their exploitation. The whole approach recommended by the Panel is that of tackling the energy problem as a whole through specialised and a cohesive study. This would enable assessment of the total nature and extent of energy needs and development of suitable means and devices to exploit appropriate sources of energy.

### Characteristics of Solar Energy

Solar energy is electro-magnetic radiation from a source (the sun) at an effective temperature of about 6000°K. Outside the earth's atmosphere, the average intensity of solar radiation is 1.36 kilowatts per square meter on a plane perpendicular to the direction of the radiation. The maximum intensity is about 1.2 kilowatts per square meter; zero intensity occurs on the average for about one half of the time. Integrated daily energy on a horizontal surface on good days in low latitudes is 6 to 8 kilowatt hours per square meter.

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The result is a radiation intermittent and variable in its availability, with typical clear-sky intensity of a little over 1 killowatt per square meter. The spectral distribution of the radiation is very roughly one-half visible, one-half near infrared, with a very small amount of ultraviolet. Solar radiation is further distributed between beam radiation which reaches the receiver in a direct line from the sun, and diffuse radiation which reaches the receiver after being scattered by clouds, dust, and molecules of the atmosphere. On very clear days, solar radiation might be 90 per cent beam; on cloudy days it is 100 per cent diffuse.

## Solar processes and Devices

Solar processes are based on either of two basic concepts i.e. of flat-plate collectors or focussing collectors. Flat-plate collectors, as the name implies, consist of flat, blackened surfaces to absorb (beam and diffuse) solar radiation. Transporent covers and back-insulation may be provided to reduce or control losses from the plate. On the plate, absorbed solar energy is converted to a desired form of energy, usually heat, and means are provided to remove that energy, usually as heated water on air. Flat-plate collectors are generally operated in fixed position. Ponds or basins of water used in evaporation or distillation are, in effect, horizontal flat collectors. The present upper limit of the temperature of operation of these collectors is about 100°C.

The second concept is that of the focussing collector. The basic element is an optical device, e.g., a parabolic reflector, to focus the beam component of solar radiation on a receiver smaller than the reflector. The result is higher energy flux which allows collection of energy at higher temperatures. Energy flux ratios (i.e. ratios of intensity of radiation on the receiver to intensity of the beam solar energy incident on the optical system) may range from 2 or 3 at the low end, to 10,000-20,000 at the high range. At any but the lowest of these ratios, some degree of "sun tracking" is required to orient the system to allow for the changing direction of the in-coming beam radiation.

All practical solar energy systems now in use are based on flat-plate collectors, the only exceptions are solar furnaces, which are in reality laboratory instrument. Materials, costs and operational problems have been major difficulties with focussing systems.

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The intermittent nature of the energy supply dictates that storage of collected energy, or of other products of the solar process(such as product water from a solar still), must be provided if output from the process is to be available during period of no radiation.

A review of the present status of solar energy application indicates that those recently put into most widespread use have been based on carefully engineered equipment, usually factory produced, and in some cases for community scale use. Small scale application of "homemade" devices has not been widely made.

## Applications

The applications(other than on space-crafts) enjoying most success today are (1) solar evaporation; (2) solar water-heating with factory manufactured heaters; (3) solar distillation on a small-community scale, which is now in an advanced "Pilot-Plant" state of development; and (4) solar drying, particularly of crops. Beyond this there have been many experiments, some enjoying a high degree of technological success, but their economic and social feasibility is doubtful or has never been established. These experiments have concerned space (comfort) heating and cooling, refrigeration and ice making, desalting of water, cooking, pumping of water, production of salt, drying, hot-air engines, lighting, solar furnaces, horticultural systems, growth of bacteria to produce methane, and photochemical conversion.

## Solar Evaporation

This has been a historical, traditional method of obtaining salt from sea water or brines. The basic concept is simple: In areas where evaporation exceeds rainfall a shallow pond of brine is exposed, resulting in evaporation of water and ultimately in crystallization of salt. Solar evaporation is used in many developing countries- India, Pakistan, Mexico, Colombia, Chile etc. It is also an important industrial process in the United States. Modern developments have been concerned with improved pond construction and harvesting techniques.

There appears to be little further research on traditional solar evaporation processes that cannot as well be done by the industries using the process. The suggestion has been made,howdver, that further studies of "Solar ponds" might lead to,improve salt production and by-products of power or distilled water.

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## Water Heating

This application has long been used in southern Florida, and has more recently been developed and applied in Israel, Japan and Australia. There is now an established solar water-heater industry in Australia with a production of about $ 1 million per annum. In Niger production of solar water-heaters is being undertaken, and small scale manufacture may be undertaken in several other countries. In India, the National Physical Laboratory had carried out work in this area.

The main elements of a solar water-heater are a flat-plate collector and an insulated storage tank. Water circulates through the collector, is heated, and is held in the tank for use when needed. In Australian practice the absorbers (collectors) for house-hold scale use are typically 0.8 to 1.6 square meters, with a 300-liter water-storage tank, optionally fitted with a thermostatically controlled 1-kilowatt electric booster, producing about 180 liters of hot water on a good day. Domestic installations employ thermosiphon circulation, which aloows the water to recycle through the absorber without pumps, but large commercial and industrial plant delivering some thousands of liters of hot water per day use forced circulation with thermostatic contol.

Water-heater technology is well established, and the needed development is largely to adapt the technology to use materials and manufacturing capabilities of the country in question. Hot water for hospitals, schools and other instutitons, and for famillities, could become much more widely available with these developments. The nature of equipment is such that it can be manufactured in developing countries, and adapting it to their conditions seems to be straight-forward.

## Solar Distillation

This is a process now in the "Pilot-Plant" stage of devolopment, the basic method being to admit solar radiation through a transpatent cover to a shallow, covered brine basin; water evaporates from the brine, and the vapour condenses on the covers which are so arranged that the condensate flows therefrom into collection groughs and thence into a product-water storage tank. The idea was first applied at Las Salinas, Chile, in 1872 in a plant supplying drinking water for animals used in nitrate mining and transport. The Las Salinas plant reportedly operated for 30 years. Modern developments in solar distillation have been directly at using new materials and designs for economical and durable construction, to reduce product water cost.

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Solar distillation is used on a small commercial scale to supply small towns and motels in isolated areas in Australia and small communities in the Mediterranean basin and the caribbean. The process must still be regarded as experimental, but small community-scale stills are near to extensive commercial application. Durable designs have been developed in the Units States, France, Spain, and Australia which require little day-to-day attention and operate with minimal maintenance.

In addition some experiments have been done on small family-scale distillation units, for possible use on Pacific islands and for emergency use.

Designs are now available for solar stills that are serviceable and that can be used with a reasonable degree of confidence. Further research in this application would involve further adaptation of existing technology to the specific needs of developing countries, through design modifications to allow use of locally available materials and locally manufactured components. Studies of this type could improve the economics of solar distillation, widen the areas in which it might be useful, and thus contribute to the solution of water-supply problems, particularly for small communities in good climates. The Central Salt & Marine Chemical Research Institute has carried out extensive work on these.

## Solar Drying

A traditional and widespread use of solar energy is for drying, particularly of agricultural products. This is a process of substantial economic significance in many areas. The customary technique is to spread the materials to be dried in a thin layer on the ground to ecpose it to solar radiation and wind. In recent years innovations have been adopted, particularly for fruit drying, in which fruit is placed in carefully designed racks to provide controlled exposure to solar radiation and wind, and to improve material handling. Improved process control and product quality have resulted.

Other experiments have centered on crop drying, using either solar-heated air in more or less conventional air dryers, or a combination of direct and air drying by placing the materials to be dried in flat-plate collector-dryers. Development of solar drying can conceivably benefit from further development of collector-dryor combinations, and flat-plate air heaters and energy-storage systems to supply hot air to dryers. Design and control of these processes, for the particular crops or other materials to be dried, are areas of research that could lead to more practical application in developing countries which could result in improved utilisation of food supplies

Contd....6/

Solar process applications in Experimental stages.

All other solar processes are in experimental stages of development and have not been used in developing countries (or elsewhere) of any basis other than as experiments. The present status of several processes and the observations of some of the major problems associated with them are noted.

Space Heating

This is not a primary problem in most developing countries, but providing comfort-heating in some areas would improve living conditions. Much traditional architecture has evolved, in part, to control or minimize temperature fluctuations in the structure. This has been done by designing openings to control admission of solar radiation and designing the heat capacity of the structures of minimize undesirable low (or light) temperature. However, traditional building methods have not always been followed in times of growing population; and there are modern scientific developments that can be applied to building design to control temperature somewhat under extremes of both high and low temperature. Thus space-heating in developing countries represents a limited problems, but one which may be improved the application of well-established principles.

Research and development efforts in solar heating have been aimed almost entirely at applications in the temperature climates of industrialized countries. About 15 experimental solar houses have been built and operated with the heating system comprised of the collector, a heat storage unit, and appropriate heat distribution and control system. Extensive economic studies have also been made, but are applicable to developed economies.

Solar heating in developing areas presents a set of problems which have received relatively little attention. Of several possible approaches, the first involves design of the structure to utilize fenestration, shading, insulation, selective paints etc., to minimize heat needs. A second approach is to devise heating systems that can operate with no mechanical energy for fluid circulation. Systems have been proposed and studied (e.g. the Altenkirch solar house) using only natural circulation; there may be other possibilities worth considering for application to small residences. A third approach is to adapt solar heating systems (with mechanical circulation) that have been developed for applications in developed economies, perhaps for use in large buildings, particularly in urban areas, where there are significant annual heating loads to be met.

Contd ....7/

## Air-conditioning or Comfort Cooling.

This process has received some attention for application in temperature climates by operating absorption coolers with solar heat; and other methods may be possible. Those studies, aimed primarily at United States and Australian Application, are still in early stages. Technological feasibility appears to be assured; economic feasibility is now under study. As with space heating, there are opportunities to use building design to increase comfort.

Designing air conditioning systems for use in developing nations again presents a different set of problems, of both potential utility and design. It has been suggested that air-conditioning of factories and offices would significantly improve the productivity of people working in them; and there is also the prospect of applications to residences. There are also technological problems of system design for operation without mechanical power, and for solar operation of other types of cooling processes. Building designs to minimize needs for cooling may be productive. The best methods of obtaining cooling with solar energy in developing countries are far from clear at this time, and the immediacy and extent of needs for air-conditioning are not known.

The Central Building Research Institute has carried out extensive work in these fields.

## Solar Refrigeration.

Closely related to air-conditioning, solar refrigeration is intended generally for food preservation (or storage of biological and medical materials). There have been experiments in the United States, Ceylon, France, the Soviet Union, and elsewhere on solar-operated coolers, using absorptionncooling cycles, most of which are aimed at house-hold scale food coolers, or small-scale ice manufacture. A single experiment in Mexico with a solar-operated, house-hold-scale cooler was unsuccessful; the machine was simple in its design but overly complicated in its operation, and was not usable by the people for whom it was intended.

There are many possible refrigeration cycles and systems that can be considered for solar refrigeration. It has yet to be established what may be the best scale on which to operate solar refrigeration for developing countries; community-scale systems may offer advantages of large scale, reduced educational requi ements for users, and (if appropriate) the possibility of distributing ice to smaller users(i.e. house-hold). Thus

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there are substantial number of open questions regarding solar refrigeration, and the application has the attractive possibility of better utilization of available food-stuffs if refrigeration could be successfully provided.

Conversion to Mechanical or Electrical Energy.

This conversion remains an elusive, yet intriguing problem. Thermal conversion systems using heat engines and focussing collectors are one approach; perhaps the most difficult problems are the substantial difficulties of cost and long-term operation of focussing collectors which hare received attention but are far from solved. Another approach is to use flat-plate collectors with heat engines operating at lower temperature (and this lower efficiencies). There are experiments on solar power now under-way which are based on flat-plate collectors.

A tremendous investment has been made in photo-voltaic conversion process for use in space. The costs of the convertors which convert solar to electrical energy, is now very high by ordinary terrestrial standards(from 100 to 500 times the cost of electrical energy from conventional sources). In developing countries there may,however, be applications in communications, which require power in very small quantities.

The possible applications of successful development of economic solar-energy conversion to needs for mechanical or electrical energy are wide; for example, pumping of irrigation or stock water and cooling by mechanical refrigeration. Therefore, several lines of study, of a more long-range nature, appear to be justified, although the difficulties inherent in the problem must be recognized. First, more development work on focussing collector systems and their materials of construction might be productive and should be undertaken. Second, studies designed to raise the practical operating temperatures of flat-plate collectors would, if successful, help to solve solar power problems. There may be energy-storage and engine research which should be coupled to the collector studies. Third, further research and development in solar cells might, in the long run, reduce their cost and widen their areas of application, although the prospects of generating electrical energy at the same costs as energy from conventional processes is an activity best carried out by very well equipped laboratories of industrialized country. Identification of

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the nature and extent of needs for electrical and mechanical energy in particular areas, and the economic and social considerations that will affect the utility of solar power systems, are needed to plan development activities properly.

Solar Cooking

The application appears to be simple in its technology and significant in its advantages if it can be successfully applied. Efforts to design and introduce successful solar cookers have been carried on for many years, with cookers of two types. One is based on concentrating the solar energy by a reflector into a cooking vessel, and is the analog of a surface heating unit. The other is a solar oven which depends on some concentration of radiation, combined with the green-house effect, for trapping heat within a small space in which the food is placed. Both approaches have been developed to a degree of satisfactory technical performance for providing for at least partial cooking needs of families. However, extensive field trial efforts in India, Mexico, and Morocco have so far not resulted in social acceptance of these devices. After an initial period in which some degree of utility has been shown, the users revert to their traditional methods of cooking.

Solar cookers depend on focussing collectors, and their successful long-term utility will depend on solving the materials and operational problems of focussing collectors- as well as the social and economic problems that have deterred acceptance in experiments to date. It is possible that energy-storage or heat-transfer techniques to permit indoor or evening cooking might help solve some problems of social acceptance.

Biological Processes.

Conversion of solar energy to useful materials, foods, or fuels in a sense represents an extension of agricultural practice. Study of algae growth has been doing on for some years with limited production in Japan. Water hyacinth has been proposed as another plant having relatively good ability to use solar radiation in photo-synthesis to produce plant materials and sea-weeds may represent other possibilities. The resulting plants could provide fuel( directly or through fermentation to produce methane), useful protein, or plant fibre.

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## Work in India

Considerable research and development has been carried out in India in the following institutions.

Some feasibility studies have also been reported from Central Mechanical Engineering Research Institute and Tata Research Laboratories, Jamshedpur besides National Physical Laboratory where work on solar heaters was carried out and the Solid State Physics/ /Laboratory where solar cells have been developed.

1) Central Building Research Institute, Roorkee.

The main activities on solar energy at the Central Building Research Institute, Roorkee centred round

i) Analysis of solar radiation for Indian cities.

ii) Design of flat-plate collector.

iii) Domestic solar water heater.

iv) Large size solar water heater.

v) Low cost solar water heater.

vi) Solar air heaters.

vii) Solar space heating.

### Analysis of Solar Radiation

For a correct assessment of the feasibility of using the sun's energy, it is necessary to know the total radiation on the earth's surface at that place. Data for direct solar radiation for all Indian latitudes for assumed standard atmospheric conditions of 300 dust particles per C.C., 15 mm of precipitable water, 2.5 mm of ozone and at a atmospheric pressure of 760 mm of mercury, have been computed and are given in a special (priced) publication of Central Building Research Institute.

The Institute has a meteorological observatory where they record hourly values of total and diffused solar radiation on horizontal surface, the average hourly rainfall, hourly values of dry and wet bulb temperatures, maximum and minimum temperatures of the day, ground temperature at a depth of 40 cms and 80 cms, average hourly wind speed and direction and atmospheric pressure.

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Solar radiation on various planes for all the orientations are measured under various sky conditions (overcast and clear) and are computed with the computed values. It is observed that even under overcast sky conditions the usual assumption of isotrophy of sky radiation is not valid.

A method has been developed for the computation of average hourly total and diffused solar radiation on horizontal surface from the actual measured sun-shine hours data which is available for about 100 stations.

Designeof Flat-plate Collector

A flat-plate solar energy collector was developed and is optimized to give maximum efficiency per unit of cost. Expressions for various parameters, such as plate efficiency factor, heat removal efficiency factor, effective transmissivity absorptivity product, overall heat loss co-efficient from collector plate to outside air, etc. which effects the performance of the flat-plate collector, are derived.

Generalized performance curves for various configurations and operating temperatures of flat-plate collectors for a number of Indian citites are obtained. Expressions are also derived for arriving at optimum absorber size for various phaces.

A formula for the optimum tilt of flat-plate collector which takes into account, the direct and diffused solar radiation and also the variation of transmittance of glass cover with angle of incidence, is derived.

Domestic solar water heater(140 litres capacity).

A theoretical model for predicting the thermal performance of natural circulation type solar water heater is developed and validated for clear as well as cloudy weather. With the help of this model, a prototype solar water heater(140 litres capacity) capable to meet the requirements of an average Indian family of five persons is developed and its performance has been studied for a number of years under actual conditions with different draw-offs during the day time. The heater is licenced to the following two firms:

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1. M/s M.S.J. Jain Engrs. & Co.
   Khanjarpur, Roorkee (UP).

2. M/s Bihar Impest Engrs. Ltd.
   17, Ganesh Ch[illegible] Avenue,
   Calcutta-13.

The estimated price of these units including immersion heater and safety thermostat is Rs. 800/-.

**Large size solar water heater: (600 litres capacity)**

A large size solar water heater capable of meeting intermittent demands of hot water in hospitals, hostels and kitchens is developed at this Institute. The system is fully automatic and is capable of heating 600 litres of water upto 50°C in winter months. A differential circuit developed at the Institute controls the mean tank temperature. This heater has also been licensed to the above two firms. The total cost of this heater with six absorbers and having auxiliary heating system works out to be Rs. [illegible]/-.

**Low cost solar water heater**

A low cost solar water heater ([illegible] litres capacity) comprising a flat shallow tank which performs the dual function of absorbing heat and storing the heated water is developed and studied for its performance. Various design and operating parameters are optimised with the help of the theoretical model developed for the purpose. The heater is found to be very useful for daytime use as there is no provision for overnight storage. It is estimated that the cost of manufacturing of such a heater would not be more than Rs. [illegible]/-.

**Solar air heaters**

A systematic study on various types of solar air heaters for room heating purposes, has been made under various operating and climatic conditions. In this study various design parameters, such as the effective transmissivity-absorptivity product, overall heat loss coefficient, plate efficiency factor, heat removal efficiency factor, etc., are brought out. Cheap solar air heaters of the corrugated type of construction have been fabricated and tested to supply hot air upto 30°C above ambient with an overall efficiency of 60 per cent, and another type upto 50°C above ambient with an efficiency of 40 per cent.

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Solar Space Heating

For heating a room by solar energy an integrated storage cum radiant heating panel system with the flat-plate collectors using water as a storage medium has been developed. The performance of this system has been studied by heating a test room in winter months at [illegible]. The results were found to be encouraging and the room temperature could be maintained between [illegible] to [illegible]°F over a 24 hour period. Based on the experimental observations, design methods for arriving at the absorber size and storage [illegible] for various heating requirements are developed.

D. [illegible]

The annual average intensity of solar radiation in [illegible] is [illegible] calories per square centimeter per day. The part of this energy [illegible] be utilised in various applications like solar distillation for pure water, solar [illegible] for better concentration of the energy, solar [illegible] for rural lighting, [illegible] for [illegible], [illegible] food stuff, solar hot air engine for small power in villages, [illegible] controlled green houses for green vegetables.

The investigations [illegible] refer to (i) [illegible] Solar [illegible], (ii) Solar Distillation, (iii) Solar Pond, and (iv) other investigation. A detailed report is given in Annexure-[illegible].

The principal [illegible] [illegible] [illegible]

[illegible]

Contd......[illegible]

In the other fields of solar energy applications [illegible] proposed for this institute. The project has been divided into four sections [illegible] (a) Solar cells for rural lighting [illegible] development of [illegible] [illegible]

[illegible]

[illegible]

(i) [illegible]

(ii) [illegible]

(iii) [illegible]

(iv) [illegible]

(v) [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] of [illegible] heated [illegible] with identical [illegible] heated and [illegible] huts. [illegible] heated hut and [illegible] and electrically heated [illegible] from the [illegible] of [illegible] of electricity [illegible]

[illegible] heated [illegible] tried.

[illegible]

[illegible] have been [illegible] of [illegible]

(ii) [illegible]

(iii) [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

or [illegible] structures. Such stills can provide 3-8 litres/m² of distilled water per day. It would be possible to [illegible] about [illegible] litres of distilled water per day from an area of [illegible]. This water can also be used for potable purposes.

**Solar operated desert survival kit**

[illegible]

**Solar water heaters**

[illegible]

**Solar [illegible]**

[illegible]

**[illegible]**

[illegible]

Contd....[illegible]

Detailed report from
Central Salt & Marine Chemicals Research Instt., Bhavnagar.

1. [illegible]

The Principal Solar Radiation Station at Bhavnagar (Lat. 21° 45', Long. 72° 10'E) is one of the 13 principal radiation stations in the country. The station was established with the initiative of this Institute and Indian Meteorological Department, Poona gave all the required instruments and the station started functioning from April 1957. The station houses [illegible] (one having [illegible] arrangement), [illegible] and [illegible] recorder. With these instruments global or total radiation intensity, diffuse radiation intensity, direct solar radiation intensity at normal incidence (measured at [illegible] and [illegible] hours [illegible]) are measured along with number of bright sunshine hours. Apart from this data station also [illegible] record of maximum and minimum temperatures, dry and wet bulb temperatures, evaporation rate, wind velocity etc. [illegible] a [illegible] was obtained on loan from [illegible] Meteorological Department and used for measurement of [illegible] radiation intensity during [illegible].

The enclosed [illegible] gives the values of global and diffuse radiation intensities alongwith number of bright sunshine hours, monthwise from April 1957 to December, 1971. Table 1 gives the maximum and minimum values of global and diffuse radiation intensities during last [illegible] years alongwith no. of bright sunshine hours in those months.

This station will continue to collect data till 1970 to complete a period of [illegible] years of collection of solar radiation data. These data may be taken as representing those of [illegible] region.

[illegible]

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | May | [illegible] | August | [illegible] | July | [illegible] | December | [illegible] | May | [illegible] | August | [illegible] |
| [illegible] | May | [illegible] | August | [illegible] | July | [illegible] | January | [illegible] | May | [illegible] | August | 96.7 |
| [illegible] | May | [illegible] | August | [illegible] | July | [illegible] | December | [illegible] | May | [illegible] | August | [illegible] |
| [illegible] | April | [illegible] | August | [illegible] | June | [illegible] | December | [illegible] | May | [illegible] | July | [illegible] |

## 2. Solar stills for distillation of sea or saline water to produce pure water, their special applications and cost estimate.

In nature, owing to the heating with the incident solar energy, water from oceans, lakes and rivers is evaporated and the vapours are carried by wind to the regions sufficiently cold and are precipitated resulting in rainfall. This phenomena of solar distillation is imitated on small scale in the solar stills using very simple construction. The saline water to be evaporated is kept in black bottom containers (trays) covered with a tight enclosure of glass cover ( glass has high transmissivity and lower absorptivity) and they are absorbed on the black bottom of the still (black absorbs maximum radiation) and heat the saline water. Water vapour thus formed move upwards towards the cooler covers (cooled by breeze or wind) and get condensed on the underside of the glass sheet. This condensed water slides on the sloping sheets and is collected in the channels provided at the lower edge of the cover.

This technique as a source of fresh water supply depends on steady availability of high solar energy and of course needs a saline water source. Such situations exist in arid (deserts) and semi-arid regions in the world. First large capacity plant based on this principle was built in Las Salinas in Chile in [illegible] with a daily capacity of [illegible] m3 (about [illegible] gallons/day) with a surface area of [illegible] m² (51,100 ft²) and was operating for 40 years. Research contributions mainly from U.S.A., USSR, Algeria, Australia and Greece in recent years, are responsible for popularisation of this method in locations lacking both fresh water and power but rich in sunshine and underground saline water. Due to the adaptability of this technique to treat saline water irrespective of high salt contents (up to say 70,000 ppm total dissolved solids) plants have been constructed in Australia, Greek islands, India, Tunisia and other countries. Table 1 indicates some of the high capacity solar distillation plants operating in the world.

The production from the solar stills depends mainly on the solar radiation intensity. Humidity has no effect on production. A gentle wind is favourable and the production increases with increasing ambient temperature. Amongst the design variables, depth of the saline water in the stills and the slope of the cover have some effect on production. Lower slopes and lower depths increase the productivity (expressed as litres/m²/day). The peculiar problems of this technique are about suitable material of construction, sizes of units, type of construction etc. A major problem is regarding leakage of vapours. All these problems have been tackled by numerous experiments in different countries and during the study in this Institute.

Pilot Plant studies

In India, parts of Gujarat and Rajasthan states have very dry and hot climates and they have abundant saline water resources. With thin population there the requirements are low and technique of solar stills is suitable for meeting water needs in such isolated areas. This Institute started work on desalination in 1964 and priority was given to the work on solar stills. Laboratory experiments were done using smaller units of surfce areas of 0.316 $m^2$ (3.4 $ft^2$). A solar still with a surface area of 3.21 $m^2$ (34.5 $ft^2$) with an angle of $10^o$ was fabricated and with this still productivity of 4.9 litres/$m^2$/day (0.1 gallons/$ft^2$/day) was obtained. After these experiments, need was felt for constructing pilot plant to study effect of different design variables as depth and cover angles and also to study the possibility of use of indigenous materials.

The pilot plant set up by the Institute has 10 stills covering an area of about 350 $m^2$ (3760 $ft^2$). The stills with lengths of 16.75 m (55 ft) and widths of 2.36 m (7'-9") and 1.67 m (5'-6") have been constructed having depths of 15 cms (6") and 30 cms (1 ft). Two smaller units with lengths of 4.57 m (15 ft) and width of 2.36 m (7'-9") with a surface area of 10.1 $m^2$ (109 $ft^2$) and depth of 5 cms (2") are set up. Angles used are $10^o$, $15^o$, $20^o$ for symmetrical stills and $10^o$-$20^o$ and $20^o$-$40^o$ for unsymmetrical stills. Considering the applicability of these units on large scale the operation has given a good experience and it is observed that lengths of 16.75 m (55 ft) are quite suitable and glass cover angle of $20^o$ is better from yield as well as maintainance point of view. To bring down breakages of glasses, it is seen that widths less than 2.36 m (7-9") are convenient. The plant is now dismantled.

Plastics can also be used in place of glass. But the presently available plastics in India namely (PVC) polyvinyl chloride and polythene are not suitable for the purpose because of their very short life and therefore glass is the choice.

In order to find out relationship between production and incident solar radiation, Principal Radiation Station has been set up with the help of Indian Meteorological Observatory and the data collected at the station has helped in correctly arriving at thermal efficiencies of solar stills. Data collected for one year at the pilot plant showed that the annual average efficiency of energy utilisation is about 30% which means that at places with 500 cal/$cm^2$/day as annual average productivity will be about 3 litres/$m^2$/day. The productivity will be higher in summer and lower in winter months.

The quality of the product water is as good as distilled water and the cost of (distilled) water from solar stills is negligible when compared to the market price of distilled water. Thus there is a good scope for these stills to function as distilled water units for laboratories and experimental stations. Also petrol pumps on highways can install these units and can supply this water even free of charge to their customers as the cost of this distilled water in no case will exceed a few paise/litre. Institute possesses designs for both permanent and portable type of units for this purposes. A solar still with a capacity of 80 litres/day of distilled water was constructed on the terrace of Baroda Engineering Research Institute for routine use in 1968 and it is performing satisfactorily.

Looking into the growing popularity of solar stills for supplying distilled water in quantities of 5 to 10 litres/day a unit was fabricated and tested. In construction of this unit materials like wood, asbestos cement sheets, aluminium tee, aluminium channel were used as shown in Fig.4. For bottom a thick black polythene film spread on insulating layer was used as liner and water depth of about 2 to 3 cms was maintained. The unit has outer dimensions of about (8 ft x 4 ft) 2.45 m x 1.22 m having an average capacity of about 7 litres/day and glass sheets are fitted at an angle of 20°. In the unit operated in the laboratory the plastic film lasted for more than one year. Table 1 lists some of of the units supplied by this Institute for obtaining distilled water and all of them are reported to be giving satisfactory service. In this unit it is necessary to change the plastic film once in a year ( if required)and to see that all the joints are properly sealed.

Table 1

| Location | Capacity litres/day | Year of Installation |
|---|---|---|
| Dept. of Biosciences, Rajkot. | 7 | 1969 |
| Kirti College, Bombay | 7 | 1970 |
| Steel Cast Corporation, Bhavnagar. | 7 | 1970 |
| Drug Testing Laboratory, Bhavnagar. | 7 | 1971 |
| Bhavnagar Motor, [illegible], Bhavnagar. | 10 | 1971 |

A survey was undertaken to find out the water requirements and the cost of water supply in salt works in the arid regions of Saurashtra and Kutch which indicated applicability of solar stills for salt works where they have to spend as high as Rs.11/m$^3$ (Rs.50/1000 gallons) whereas the cost of water by solar stills is about Rs.4.4/m$^3$ (Rs.20/1000 gallons), moreover the discharged concentrated brine from solar stills can be processed in the salt works for salt production. This Institute has prepared suitable designs of solar stills for the salt works.

The applicability of this technique is best suited for arid regions where the stills will produce water throughout the year without much interruption. On cloudy days the productivity is low. But clean glass covers offer a good surface for rainwater collection. Thus if proper provision is made for making this water flow through suitable channels and if sufficient storage is provided, this collected rainwater will not only give additional water for use but also improve the economy of the technique. In the normal design, a provision is made for such rainwater collection with a limited additional capacity to store water. Such combination of rainfall collection and solar distillation has advantages over either only rainfall collection or only solar distillation. Places with rainfall distributed throughout the year are better placed for the combined unit than those with heavy rainfall in a few months every year. Such combination has a possible application for lighthouses.

Department of Lighthouses and Lightships, Ministry of Trnasport, Government of India, spends Rs.77/m$^3$ (Rs.350/100 gallons) for supply of water to small group of workers in some lighthouses. Normally on all the lighthouses, rainwater is collected on the flat roofs of the staff quarters and is stored for use. But due to insufficient storage capacities, water shortage is felt. Construction of solar stills directly on the roofs (using roof slab as the bottom of solar stills) slightly affects the rain water collection, but gives a continuous a source of water with solar stills. The solar stills according to Institute's design have been constructed and put into operation since August 1968 at Navinar Lighthouse near Jamnagar. These stills have a surface area of 57.2 m$^2$ (615 sq. ft) with production of 130 litres/day. But these stills were not constructed on the roof to avoid risk of affecting the slab due to corrosive sea water and somewhat heavy structures.

Staff at the lighthouse maintains a record of the output and their department has been kind enough to supply dats to us. Complete data from the begining upto December, 1970 was sent by them and is plotted in Fig.5. In 1969 the daily water consumption values were also given for a few months and from that it seems that their daily water requirement is met through solar stills. Department has also expressed satisfaction about the performance of the stills. The lower outputs have been attributed to the leakages in glass joints.

## Cost estimates

Normally estimates will vary with types of stills constructed. Generally for all estimates, efficiency of solar energy utilisation is assumed as 30% and with the value of average annual radiation intensity, the calculated productivity is taken as the basis for calculation of surface area required for solar stills. On the basis of the cost of construction (per unit surface area) of still having facilities of rainwater collection and adequate facilities to collect rainwater and having a water supply tank, total investment is calculated. Twenty years' life and 4% rate of interest are assumed to amortise the plant. 1% of the investment is taken as operation and maintainance charges and operating labour is taken as one unskilled labour permanently employed and an additional 100 man-days per year per 930 $m^2$ (10,000 $ft^2$) area. It is also assumed that 80% of 30 cms (12") rainfall is collected and this quantity is added up in the total production.

As mentioned above, the solar stills are suitable to meet the needs of isolated small communities not having any source of potable water and power. In order to assess the advantages of solar stills over the conventional piping system specially laid to supply very small quantities, certain calculations were made by us which are shown in Fig.2. It is evident from the data that even though the cost of water by solar stills is very high, it has advantage over conventional piping system provided the fresh water source is more than 24 kms. (15 miles) away from the point of actual use and the daily requirement is less than 22.25 $m^3$/day (5000 gallons/day). The data is plotted on the basis of costs existing in 1966-67 and since then the prices have gone up. The estimated construction cost of solar stills in 1966-67 was Rs.65/$m^2$, (Rs.6.05/$ft^2$) which is now about Rs.90/$m^2$.

## Design considerations

Two types of constructions have been adopted in designing the basins of large solar still plants. One type provides for a single large water basin covering the whole still area (i.e. pond type construction as adopted in pilot plant of Office of Saline Water (OSW), U.S.A., at Daytona Beach and at Las Marinas in Spain). In the other type, the distillation plant is divided in many units with varying lengths but having restricted width (bay type construction as in Australia, Greece, etc). In the pilot plant constructed by this Institute, second type of construction was used as this plant was meant for experimental studies. Pond type construction works out cheaper than bay type construction. Stills at Navinar Lighthouse are having pond type construction. Fig.3 shows the construction details of the pilot plant at this Institute.

In the initial construction, glass to glass joints were sealed by cotton adhesive tape which worked satisfactorily for about an year. These were replaced by Tarplastic manufactured by M/s. Shalimar Tar Products Ltd. This material is quite suitable.

Other problems faced in the operation of solar stills were regarding deposition of silt on the bottom (but this can be considered as local problem at Bhavnagar) and growth of algae. But they are minor in nature.

Basedon the experience gained on the pilot plant of solar stills (now dismantled) following conclusions are arrived at for permanent installation.

In the absence of availability or butyl rubber sheets at reasonable price in the country and short lives of jute impregnated asphalt mat liners and black plastic film (thicker ones) it is necessary to adopt complete concrete or brick masonary flooring suitably plastered and coated with black asphalt coatings (these are now introduced by M/s. Wessix Engineers in market) for bottom of solar stills in permanent installations. In the pilot plant width of individual still was taken as 5½ ft and 8 ft. This was found to be larger for 3 mm. thick glasses particularly with lower cover angles. Hence this is now reduced to 120 cms (say 4 feet). In the pilot plant pre-cast items were used for top ridge, bottom supports combined with rainwater gutter and ridge supporting pillars. It appears that their long life can only be assured by better workmanship and proper precautions taken during casting. At times these items caused difficulty in glass fixing as was experienced in stallation at Baroda. In the pilot plant the bottom supports combined with rainwater gutter were made out of brick masonary for two solar stills and they proved to be equally good. Due to availability of suitable aluminium 'tee' sections and angles, in the new designs they will be adopted as central support and glass supports at the end walls. Concrete pillars will be replaced by wooden pillars on which Central 'Tee' support will be fixed. All these modifications are incorporated in the new design and complete details are prepared for a unit of 25 litres/day capacity.

On examining the reports on performance of various large scale installations we find that vapour leakage is one of the major and most important problem affecting the performance of solar stills during its operation. Use of silicone sealant in Australian solar stills proves to be a solution to this problem. But its adoption in India is difficult due to high cost. One has to continue using asphaltic sealing materials and inspecting and maintaining the sealed joints at regular intervals.

The product water is very pure and the productivity of this technique is nearly independent of salt content of raw feed water. To drink tasteless water is difficult and it is necessary to add some salts to give taste. Drinking water specifications limit salt content or TDS (total dissolved solids) to be 500 ppm and acceptable maximum is 1000 ppm. Thus if this technique is used to treat saline water with salinity very much less than that of sea water, addition of raw water to product water will give additional amount of water quite suitable for drinking purpose.

With all the experience gaines, this Institute is now in a position to give suitable designs for combined system of rainfall collection with solar distillation or alone for solar distillation for production of drinking water or distilled waster for various capacities. In future designs, new ideas will be incorporated.

The maximum capacity of individual plant is likely to be limited to about 22.5 $m^3$/day (5000 gallons/day) to meet good quality drinking water needs in many villages. The villages lack in skilled labour but the technique is very simple and solar stills are easy to maintain. Although due to high initial investments this technique does not offer immediate attraction yet on the whole it may be economical in many areas where concerned authorities have to spend huge sums for providing the water. One always considers the cost of production of the water by the technique but forgets many a times, gravity of problem of water supply and what is actually spent in case of bad needs. It is pertinent to mention here that this technique is widely used for supplying water in Australia, in Greek islands, Spain and Tunisia. This is because in Australia in many regions they have no other method suitable for those regions to supply water and if they will not do it those very hot and arid regions (Western and Southern Australia) will not develop even though they are rich in minerals (for example there are gold mines in Western Australia). In desertic regions of Sahara in Tunisia where water is so scarce that small pools, after tains, on the roads are sources of water for daily use who will rule out solar distillation as a solution with all its simplicity within the reach of unskilled persons. Under such situations naturally cost of water is a minor consideration. In Greek islands and in Spain (at Las Marinas) Government was spending quite a lot for supplying water through ships. Now although the cost of water for the installation at Las Marinas works out to about Rs.6.9/$m^3$ (*F4.60/$m^3$), this is much below the cost incurred by Government previously for supplying water. Greek and Spanish Governments have decided that the communities using water from such installations will only bear the operation charges, and hence habitants at Las Marinas pay only Rs.1.13/$m^3$ (F.0.75/$m^3$).

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* 1 F = Rs.1.5

## Table 1

**List of large solar stills as in [illegible]**

| [illegible] | [illegible] m² (ft²) | Year of installation. | Capacity* in m³/day @ 3 lits/m²/day (gallons/day) | Cover material | Status * |
|---|---|---|---|---|---|
| Muresk (Western Australia) | 418 (4500) | [illegible] | 1.2[illegible] (275) | Glass | Operating |
| Coober Pedy (Sounthern Australia) | 3640 (39,000) | [illegible] | 10.[illegible] ([illegible]) | Glass | * |
| Caiguna (Western Australia) | 41[illegible] (4,500) | [illegible] | 1.[illegible] (275) | Glass | * |
| [illegible]elin Pool (Western Australia) | [illegible] (6,750) | [illegible] | 1.[illegible] (41[illegible]) | Glass | * |
| [illegible] (Greece) | [illegible] ([illegible],000) | [illegible] | 6.4[illegible] (1,4[illegible]) | Plastic | Being converted to stretched frame design. |
| Salamis (Greece) | [illegible] (4,100) | [illegible] | 1.14 ([illegible]) | * | Uncertain |
| Patmos (Greece) | 8,000 (86,000) | 1967 | 24.00 (5,300) | Glass | Operating |
| Kimolos (Greece) | 2,510 (27,000) | [illegible] | 7.[illegible] (1,[illegible]) | Glass | * |
| Las Marinas (Spain) | 1,070 (11,500) | [illegible] | 3.[illegible] (710) | Glass | * |
| Mahdia (Tunisia) | 1,300 (14,000) | [illegible] | 3.90 ([illegible]) | Glass | * |
| [illegible] (Tunisia) | 440 (4,740) | [illegible] | 1.[illegible] ([illegible]) | Glass | * |
| Petit St. Vincent (W.Indies) | 1,710 (18,400) | 1967 | [illegible].90 (1[illegible]) | Glass | * |

* Actual capacities will be different. For example, in Tunisia average yields of 5 litres/m²/day have been reported.

## 3. Solar Pond

### Scope

As the conventional sources of energy such as fossil fuels are fast exhausting, the scientists all over the world are working more and more on suitable methods of utilizing solar energy available in arid and semi-arid regions. The solar ponds are such devices to utilize the solar energy more efficiently. The solar pond principle is based on the elimination of convection currents in shallow bodies of a low solution of salts, resulting in the heating of bottom layer. This could be achieved by imposing a density gradient throughout the depth of the pond in such a way that each layer is progressively heavier than the one above it.

### [illegible]

Temperature and density gradients in the solar pond system are to be maintained at all times as any reversal will completely upset the system. Diffusion of salts in the system is remarkably low process and therefore the pond can stand for weeks together without losing its stability on this account. It is known from the hydrodynamic studies that where vertical density gradient exists, flow of fluids can take place in different layers with almost no mixing of layers thus extraction of heat is possible at any layer.

### [illegible]

The Negev Arid Zone Institute, Israel has studied the solar pond system and succeeded in getting bottom temperature up to 100°C. Solar pond work was also carried out at Chile where they used semi-circular ponds instead of rectangular shaped ponds for better performance.

### Scope of the present work

The data available on the working of solar pond at Israel were scanty and that the working of their solar pond was discontinued due to leakage started in the pond, and as such further results were not made available. The present study has been therefore taken up to collect comprehensive data, at the same time considering the valuable work conducted at Israel.

The size of the solar pond was maintained at 40 x 30 metres and was located close to our humidification and dehumidification plant of water desalination wherein it was proposed to meet the required supply of heated sea water for the operation, initially, and at a later stage to the flash distillation unit of desalination.

The present solar pond was filled in April 1971 and

[illegible]

1. [illegible]

2. [illegible]

3. [illegible]

4. [illegible]

5. [illegible]

**[illegible]**

1. [illegible]

2. [illegible]

3. [illegible]

[illegible]

1. [illegible]

2. [illegible]

3. [illegible]

4. [illegible]

5. [illegible]

**[illegible]**

1. [illegible]

2. [illegible]

3. [illegible]

# [illegible]

1. [illegible]

[illegible] the project [illegible]

a) [illegible]

b) [illegible]

c) [illegible]

d) [illegible]

2. [illegible] of the Project

3. [illegible] of the project.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

**6. Studies to be undertaken with an indication of their magnitude and methodology.**

In the direct conversion of solar radiation to electricity, quite a few methods and materials are known to have been used, of which photovoltaic cells of silicon give a fairly higher conversion efficiency as high as 15 per cent. These have been used in quite a few countries as sources of light and power for remote and isolated regions, for unattended light houses, for light buoys at ports, for radio telemetering stations, for terrestrial uses and satellite stations and so on. These cells are durable and capable of withstanding many years of continuous outdoor use, and can charge the long life Nickel-Cadmium batteries for storing electrical energy. A solar stack with Nickel-Cadmium battery is easier to build for low voltage and high currents. Kits can be made of a solar stack of 5 watt capacity, a storage battery of 2.4 volts 20 amp. hr., two lamps and portable lantern, with long life of solar stack and batteries. In it, can be provided supply for a 4.5 volt transistor radio. It may be assumed that normally, the village house for lighting purpose is a kerosene lamp of say, 5 candle power (C.P.O.), and portable lantern of say, 1 C.P. It is reasonable to state that in such a house, whiter and brighter light may be in demand with the lamp of intensity of say 25 C.P. and a portable lantern of 1 C.P., the need for a transistor radio operating on 4.5 or 6 or 9 volts, and 2 [illegible] can be connected in series parallel to provide the required voltage and current for lighting and transistor radio. As an example, - the intensity of solar radiation in a typical sunny village = 600 Cal/cm²/day - 750 watt/m² (approx); area of the module = 30 cm²; conversion efficiency = 10 per cent; the power output per module - 0.30 watt (approx.) For 5 watts, the number of modules [illegible] - 16 (approx). For charging 2.4 volts Nickel-Cadmium batteries, 2 modules would be in series and 8 such limbs in parallel giving a total number of modules as 16.

It is proposed to use during the five-year period of experiments in a sunny village, the modules of silicon solar cells together with the Ni-Cd batteries in the form of kits. The number of such kits for an experimental village of say, 100 families has been estimated. This experimental period of five years may be termed the first phase of such a developmental study involving an expenditure of Rupees 3.625 lakhs and it is expected that during the course of this five years period, sufficient data and experience will be at our disposal to extend such applications to other villages in India in future. In between, preparation of cheaper and more efficient kits is to be undertaken.

(b) A prototype machine to produce ice in blocks will be suitable for commercial sale to fisherman, butchers, dairy-men etc. Such a machine would raise income preserve food in the unelectrified regions of a country. The power source is evidently sunshine. For ice production, the best system seems to be solutions of sodium thiocyanate in liquid ammonia. The physico-chemical characteristic and engineering data have been developed. For a machine of 75 kg/day of ice, one skilled person is enough, and the capital expenditure is about Rs.4000/-. Locally available materials can be used. Sterile water for drinking comes out as by-product. The coefficient of performance of such a machine is about 0.3 under conditions of 45°C ambient.

(c) Development of solar air engine is of considerable interest and importance for irrigation providing energy to small scale idustries vital to the regeneration of rural economy.

Exploratory studies indicate that a good approach is through many focussing collectors of say 6 feet in diameter and small stirling hot air engines of 0.2 KW power. A 6-foot parabolic mirror can intercept 2½ KW of solar radiation and deliver 1½ KW of heat to a small target. It may operate a stirling engine at 15 p.c. efficiency, giving about 0.2 KW of mechanical power. Five such small engines, and focussing collectors costing about Rs.2000/- could produce one KW of mechanical power.

(d) Air-inflated, controlled environment "Green Houses" wherein desalinised water is used to provide arid zones with fresh vegetables. At the Environmental Research Laboratory of the University of Arizona in Tucson, crops are grown in controlled enviroment air-inflated plastic Green House in an area of 4 x 4600 ft. Such crops are tomato, cucumber, radish, spinach, carrots, squash, egg plants, peppers, lettuce, cabbage, beet, chill, water melon etc. Control of humidity to almost 100% it it is by the use of desalinised water for the Humidification-dehumidification plant indicating indigen-ous development of this technique of desalination and control of carbon dioxide it is from the exhaust gas of generator. The crops are seeded directly into sand. The basic approach has been to provide water and green vegetables and some fruits for the arid regions. The larger scale Puerto-Penasco (Mexico) Green House, designed on the basis of Arizona experiments is in operation since quite a few years producing various vegetables in the arid region. The nicely plastic coverings of the Green Houses, apart from maintaining control of humidity, carbon dioxide etc. also shields the plants from extreme heat and light, sandstorms and insects. Recently, the results of the experiments and experience have been extended to the Shaikhdom of Abu Dhabi, a highly arid region of the Arabian Peninsula south east of Kuwait and the state has started producing much expected green vegetables and water required there. The rate of production there is soon going to be enhanced.

Such type of "Green House" has got immense possibilities in some of the arid regions of India. More basic data are required for Indian condtions.

Annexure 2

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[illegible] [illegible] solar [illegible] [illegible]

[illegible] & [illegible]
[illegible] of the [illegible] of flat plate solar collectors for [illegible]

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Design data for heating [illegible] by means of [illegible] [illegible] for utilization of solar energy.
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Solar [illegible] design for [illegible]
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**[DEPARTMENT OF SCIENCE & TECHNOLOGY]**
**([N.C.S.T. Secretariat])**

[NCST] Document No. 142/[illegible]

**[Panel of Experts for Alternative Sources of Energy]**

At the last meeting of the NCST it was decided that a panel of experts to identify potentials in alternative non-conventional sources of energy, i.e. solar, wind, air, geothermal and [illegible] should be drawn up and submitted at the next meeting for consideration. It is suggested that the following experts could be nominated to form the panels for examining each one of the alternative sources of energy.

**[Solar Energy]**

1. Dr. M.C. [illegible] - Chairman.
   Director (Energy)
   Planning Commission, Delhi.

2. Representative from [illegible], Delhi.

3. Dr. Gupta, Defence Laboratory, Jodhpur, Def. R&D Org.

4. Dr. R.L. [illegible],
   Assistant Director,
   [illegible], Bhavnagar.

5. Representatives from other associated CSIR laboratories such as NPL, [illegible], [illegible] etc.

6. Dr. A.K. [illegible],
   Solid State Physics Laboratory,
   Def. R&D Org., Delhi.

7. Representative from [illegible] Research.

8. Representative from [illegible], [illegible].

9. Representative from TIFR, Bombay.

[illegible] has already been requested for a status paper on Solar Energy.

**[Wind Energy]**

1. Dr. [illegible] - Chairman
   [illegible]
   Indian Statistical Institute,
   Delhi.

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2. [illegible]

3. Representative from IIT, Delhi.

4. Representative from [illegible]

## Air Survey

—Chairman

1.

2. Representative from NAL, Bangalore.

3. Representative from Meteorological Department, Delhi.

4. Dr. A. Krishnan [illegible], Jodhpur.

5. Dr. S.K. Gupta, [illegible], Bhopal.

6. Representative from [illegible], Delhi.

## [illegible] Survey

—Chairman

1. Dr. M.R. Srinivasan, Chief Project Engineer, Indian Atomic Power Project, Kalpakkam.

2. Shri B.A. Subramanian, Director, [illegible], CWPC, New Delhi.

3. Representative from University of Roorkee, Roorkee.

4. Shri M.L. Gupta, [illegible], Hyderabad.

5. Representative from IIT, Delhi.

6. Shri [illegible], [illegible], IIT, Kanpur.

7. Shri V.S. Krishnaswamy, Director, Engineering Geology, Southern Region, Geological Survey of India, Hyderabad.

## [illegible] Survey

—Chairman

1. Brig. K.K. Mehta, Director, Electronics Def. R&D Org., Delhi.

2. Representative from [illegible], Hyderabad.

3. Dr. [illegible] Singh, Jt. Director, Min. of Prod. [illegible] (Electronics), Def. [illegible], Delhi.

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4. Representative from [illegible], Delhi.

5. Shri C.M. Joseph, Add. Dir., Signals & Telecom., RDSO, Lucknow-5.

6. Shri R.I. Mitra, Director(Standards) Electrical Traction & Rolling Stock, RDSO, Lucknow-5.

7. Shri R. Vasant [illegible], Dy. Dir. (P.T.) Telecom., Research Centre, Delhi.

8. Representative from CWPC, Delhi.

In the first instance, a status paper on each of the alternative sources of energy would be requested from the 'best-placed' institution/laboratory (marked with an asterisk above), except for Solar Energy, on which status paper has already been requested from CSIR. A meeting of the Panels would then be convened by the various Chairmen to review/discuss the status papers. The Chairmen will be requested to submit a summary on their respective Panels to the Integration Committee for consideration. The Integration Committee at its meeting will review the summary papers with the various Panels, and formulate its recommendations, for consideration by NCST. It is suggested that the Integration Committee would consist of the following members -

1. Shri [illegible], Member, NCST - Chairman
2. Shri S.B. Vinod, Jt. Secretary, Min. of Irrigation & Power, Delhi.
3. Vice-Chairman, CWPC, Delhi.
4. Shri D.R. Bal[illegible], Chief(Power), Planning Commission, Delhi.
5. Shri Baldev Singh, [illegible] Division, CSIR, Delhi.
6. Prof. C.S. Jha, IIT, Delhi - Chairman, Planning Commission Task Force on R&D for Power Development.
7. Shri S.K. Bhatia, Director, BHEL, Bhopal. (Member-Secy. Planning Commission Task Force on R&D Power Development).

NCST may consider and approve the composition of the Panels and the Integration Committee.

(P.J. [illegible])
NCST COORDINATOR

45 [redacted]

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# Sun Could Brighten Long-Term Energy Picture For U.S. Economy

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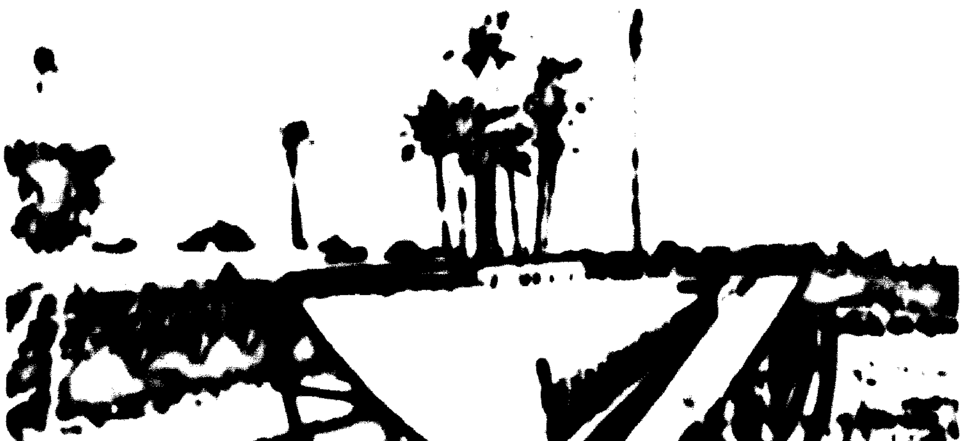

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this country, a California firm made solar water heaters from around the turn of the century until competition from cheaper natural gas forced them to drop production in the mid-[illegible]. Solar water heaters are common today in Israel, are standard equipment in many homes in Northern Australia, and have been bought by more than a million Japanese for their homes.

In short, the technology is here; what is needed is a major effort to develop economic applications that are competitive with currently available energy prices.

Three broad applications of solar energy have been identified:

- The heating and cooling of residential and commercial buildings (research has tended to concentrate in this area)
- The chemical and biological conversion of organic materials to liquid, solid and gaseous fuels.
- The generation of electricity.

A panel of experts, formed at President Nixon's request, reported that by the year [illegible] solar energy could provide at least [illegible] percent of the heating and cooling for buildings in the United States, more than [illegible] percent of the methane and hydrogen needed for gaseous fuels, and greater than [illegible] percent of the country's electric power needs. The panel stresses that all this could be done with minimal effect on the environment and at a substantial saving of fossil fuels.

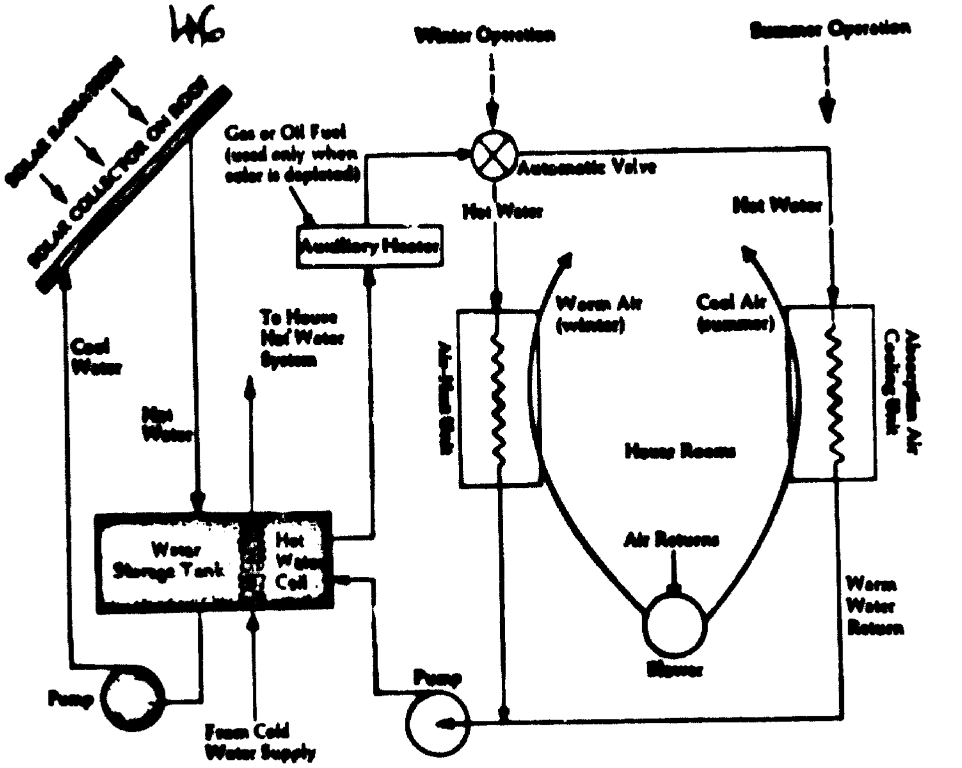
## Funding Jumps

[illegible]

Solar energy becomes much more competitive once you throw in the rising prices of fossil fuels and their health and safety impact on the environment. The costs of distributing the fuels are also eliminated.

Economic studies have shown that solar heating already is less expensive than electric heating in a wide variety of U.S. climates, and in a few locations it is competitive with gas or oil heat. These same studies demonstrate that solar heating, even without supplemental savings from cooling, can be a practical alternative to conventional heating. The Solar Energy Panel concluded that residential heating and cooling could be in widespread public use within a decade.

Approximately 20 experimental solar heated homes have been designed, built and operated in the U.S. Various combinations of collector types, heat storage techniques, heat transfer media, and auxiliary energy supplies have been used. Workable heating systems have evolved, however, they are not fully engineered, either from the standpoint of selecting the best systems or optimizing the design of these systems. In addition, solar-powered air conditioning systems, which have been operated in several laboratories, must be designed into and combined with the solar heating system.




**MAKE YOUR OWN**—*Schematic diagram outlines a solar installation for home or factory which heats in winter and cools during the summer.*

## How it's done

Solar energy is trapped by a rooftop collector facing the sun at an elevation 15 degrees greater than the latitude. Collectors fall into two categories, flat plate and focused. Flat plate collectors are usually preferable since they can utilize diffuse solar radiation and, consequently, perform effectively on cloudy and overcast days. They can also be maintained in a fixed position. While focused collectors can generate much higher operating temperatures and thus are capable of higher efficiencies, they must follow the sunlight and be kept clean.

Solar radiation is transmitted through the glass plates covering the face of the collector and then absorbed by a blackened metal sheet at the rear. Tubes carry the heating element—usually water, air or some other gas—through the intervening space. As the metal sheet warms up, the water or gas is heated to temperatures of 100 to 200 degrees Fahrenheit, depending on conditions. Heat losses are minimized by rear insulation and the overlying glass covers.

The system also includes an insulated storage tank for the heated material, and an auxiliary power supply unit for those periods when the sun fails to appear for several days. The solar system is not totally self-sufficient, because in addition to the periods when the sun doesn't shine it still needs a pump to keep the water circulating or a fan to blow the air. Overnight heating is no problem, because the storage tank accumulates enough heated matter during the day to last through the night, and another day or two for that matter.

Current efforts are concentrating on adapting solar heating to conventional systems in existing homes—"retrofitting" in the parlance of the trade. Depending on which expert you're talking to, the cost of "solarizing" a home today could cost anywhere from [illegible]. Incorporating solar heat into a newly-built home "generally runs about twice as much as an oil-fired hot water system and three to four times as much as an electrical resistance system," says Dr. James E. Hill of the National Bureau of Standards. Estimates also vary on how long it would take a solar system to pay for itself in lowered fuel costs, but six to ten years are the most frequently mentioned periods.

Several small operations have recently begun marketing solar energy components for the home, "but I don't think the nation will be affected by people like this," says Hill. "It will take people like General Electric and Westinghouse before there is any real impact." He expects some of the major U.S. firms to begin marketing combined systems, in which the conventional capacity will be strictly auxiliary, within three to five years.

In a temperate, sunny, central U.S. location, a house with 1,[illegible] square feet of floor area could get about three-quarters of its heating and cooling needs from a [illegible] to [illegible]-square foot collector and [illegible] gallons of hot water storage. Careful house design, incorporating effective use of insulation, roof and wall orientation and window arrangement, can lower the heating and cooling requirements further.

Solar energy use is being explored at the National Bureau of Standards, where solar collectors mounted on the roof of a townhouse will collect and store the sun's energy for cooling and heating purposes. The townhouse experiment is designed to produce standard test procedures for solar systems.

The townhouse will be equipped with "state-of-the-art" systems manufactured by commercial firms presently considering the production of solar heating equipment. This house has been studied extensively over an 18-month period and its thermal characteristics are better understood than those of any other such structure. It has been moved to a site on the NBS grounds and will be tested with its conventional heating equipment before beginning operation as a "solar house" this spring.

Scientists at the University of Delaware are working on a test house which would be the first to convert sunlight into both heat and electricity. "If mass produced, this system wouldn't add to the cost of a house," says project director Dr. Wolfgang Boer.

## Refrigeration, too

Research in the refrigerator driven by solar energy has been insufficient to permit immediate residential usage, according to Dr. Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology. "The ammonia-water absorption refrigeration system is considered to be in the forefront of development," she says, "although current research is also being directed toward a lithium bromide and water system. In concept, the refrigeration system is identi-

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Roger N. Schmidt, manager of Honeywell's solar energy programs, describes progress to date. "A trough concentrator focuses the sun's energy onto a coated heat pipe, which transfers the thermal energy to one end with a thousand times the effectiveness of a copper bar. The heat is used to generate steam for electric power production or is stored for later generation of electricity. Each 40-foot long, 10-foot wide collector is a single module which lends itself to volume production and can be easily placed and maintained in the solar field. Computer simulations have verified technical feasibility of these collectors—the key element in the solar power system.

"Therefore, engineering efforts have been directed toward questions of economic feasibility," Schmidt continues. "For example, there were serious concerns on the availability of suitable surface coatings for the concentrator and receiver. Under the current program, concentrator surface materials are being tested in Florida, Arizona and Minnesota. Preliminary results have been favorable.

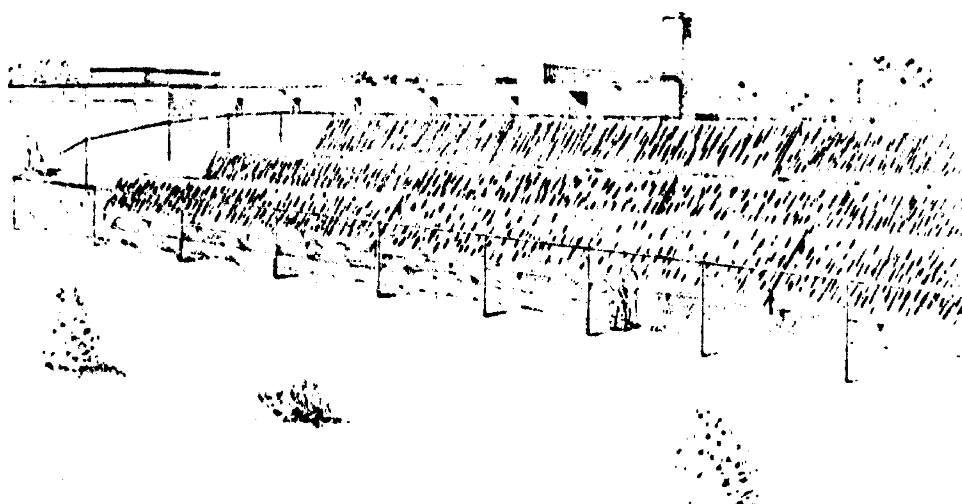
"Honeywell has made independent cost estimates for a solar steam generating plant to be built and operated late in the 1980's. Our estimate of initial cost in 1973 dollars is approximately $1000 per KW installed based on present materials and on volume production techniques. This estimate is in reasonable agreement with other independent estimates and is at least twice the cost of current light water nuclear plants.

"We are encouraged by this estimate" says Schmitt, "because we foresee that the corresponding costs of alternate systems with their environmental controls will increase significantly by the late 1980's. It is also possible that the $1000 per KW estimate may be lowered through additional engineering development and new volume production techniques."

## Photovoltaic process

Photovoltaic conversion is based on use of the photovoltaic effect on a semi-conductor such as silicon in devices which are commonly called solar cells. The process involves absorption of light which then generates an electrical current which can be collected on contacts applied to the surfaces of the semi-conductor. The theoretical efficiency of this conversion process is 25 percent but it has not been reached.

Solar cells made from silicon have supplied essentially all of the power used by spacecraft. Their performance and reliability in space are well established. For earthbound energy applications, solar cells are in use in the U.S., Great Britain, Japan and other countries in the form of small "packaged power" systems to energize transistor radios, harbor and buoy lights, highway emergency call systems and microwave repeater stations. However, because of the very high cost of solar cells, large photovoltaic systems for terrestrial applications have not been built, although the technical capability exists.



TOMORROW—*This experimental solar heating system is being installed in a suburban Minneapolis junior high school by Honeywell under a National Science Foundation contract. When operational, it is expected to save 12,500 gallons of fuel oil annually.*

## Harnessing the wind

Solar energy sustains the winds. On an annual basis, the winds are remarkably repeatable and predictable. It is calculated that the power-generating potential in the winds over the continental U.S. and the Aleutian Arc is considerably greater than our present installed capacity. The kinetic energy of the moving air can be extracted by an aeroturbine or similar device. A wind energy conversion system for large-scale power production would incorporate a storage capacity, to allow for the times when there is no wind blowing during peak energy demand periods.

Sixty years ago, wind power serviced small generators throughout the world. In the 1940s a 1300-kilowatt wind energy converter was built and operated for a year in Rutland, Vermont. Steady improvements directed toward large-scale applications were made through the 1950's, but the availability of large amounts of cheap fossil fuels made the further development of wind power unnecessary.

However, recent events have prompted a reevaluation of the merits of wind power, and several large scale wind power systems with 2000-kilowatt aeroturbines have been proposed. These units would be located one-eighth to one-quarter of a mile apart and linked together to form an integral system.

Cost estimates for large scale wind power systems indicate they could compete with today's fossil and nuclear power plants.

Between the Tropics of Cancer and Capricorn, where the intensity of incoming solar energy reaches its peak, 90 percent of the earth's surface is water.

The Gulf Stream carries 1000 to 1500 million cubic feet per second of near tropical sea water through the Gulf of Florida, in a stream about 30 miles wide. It is possible to modify a conventional energy conversion system to convert some of the energy contained within the warmer water into electricity. The conversion efficiency would be quite low—around 2 percent—and the cost of such a facility is expected to be about double that of large conventional power plants. A collection system of units moored on one mile spacings along the length and across the breadth of the Gulf Stream is thought capable of an annual energy production about ten times the present electricity generation in the United States.

## Feasibility shown in 1929

The proof-in-principle of the generation of electricity using a vapor cycle operating between the warm surface and cold depths was demonstrated in 1929. A technical and economic feasibility study of a 400,000-kilowatt central power station based on this concept is under study.

The knowledge is there and in most cases the equipment is there for full-scale development of solar energy. To date the only thing lacking has been any real sense of urgency that would justify the very substantial sums involved.

Perhaps the energy crisis will supply that sense.

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# Solar Energy: Conversion and Utilization

by DR. ERICH A. FARBER
Professor & Research Professor of Mechanical Engineering
Director, Solar Energy & Energy Conversion Laboratory
University of Florida

Widespread concern with our energy situation and crisis, and what meeting the ever increasing demand of this energy does to the environment through pollution, prompted the writing of this paper. It presents the over-all activities of the Solar Energy & Energy Conversion Laboratory of the University of Florida rather than the technical details of one particular investigation.

The laboratory has looked into old methods of converting solar energy into the forms of energy needed, has used the present state of the art, and has pioneered in many areas of solar energy utilization.

It is obvious from all surveys and reports that we are using our fossil fuels at a tremendous and ever increasing rate so that in the not too distant future these supplies of energy, so vital to our present growth of civilization, will be depleted. For this reason it is of utmost importance that we look for other more permanent sources of energy and learn to use them before the dire need arises. Solar energy is readily available, well distributed, inexhaustible for all practical purposes, and has no pollution effects upon the environment when converted and utilized.

Our present usage of energy can be compared to a family or group living off their savings, stored in a bank, and being steadily depleted. This process cannot go on very long unless some "income" is added to the savings.

In the field of energy the most abundant "income" is solar energy. This incoming energy was, usually in very in-efficient processes and over millions of years, converted into our fossil fuels. With these savings rapidly disappearing we will have to learn to use this income, in the form of radiant energy, directly by converting it into the forms of energy needed.

This conversion from solar energy into the desired forms should be done in the fewest possible steps and along the most direct route. This procedure will insure the most efficient way of doing this and will keep the equipment necessary simplest.

Solar energy has certain characteristics. It is intermittent, only available during the day on a particular location on the surface of the earth. In spectral character it approximates a black body source of about 10,000F, modified by gaseous layers of both the sun and the earth atmosphere.

It arrives on the surface of the earth both as direct radiation and diffuse radiation. The former portion can be concentrated if desirable.

A knowledge of the specific properties of materials under solar irradiation will then allow the collection and, or concentration and absorption of this energy.

If night time operation or operation during bad weather conditions is necessary or desirable the storage has to be provided. For many applications this is not necessary. The energy could be stored in conventional manner as potential energy (pumped water, etc.) as heat in hot water storage tanks or rock bins, as chemical energy utilizing chemical processes, the latent heat or heat of fusion, etc.

In other words the technology has been developed to convert and utilize solar energy, the economics and sociological acceptance has still to be worked out in many cases. These problems vary from region to region and therefore take on a local character to be worked out by the potential users.

To be most effective, local materials should be used in fabricating by local methods and labor fitting the economics and habits of the local civilization.

With this introduction of a general nature the paper will now go into some of the work done by one group and the best way to do this is to take you on a tour through the Solar Energy Laboratory of the University of Florida in the United States of America.

## UF Solar Energy Laboratory

The University of Florida Solar Energy Laboratory is one of the largest laboratories of this kind and a tour through it will give an idea what such laboratories look like and the kind of work which is carried out in them. The work carried out at this laboratory is supported by work and persons all over the world and proper credit should be given to them. Fig. 1 presents the entrance, within the gate to the laboratory and two of the four buildings.

Stepping around these two buildings one can see some of the equipment of the laboratory which will be discussed in more detail in the paper and the following illustrations. Fig. 2 shows this equipment with engines of various types in the foreground, behind them collectors and concentrators of various types. On the left of the picture are a small solar air-conditioning system and two solar water heaters, a solar still and parabolic concentrators. Further visible are a solar power plant, a solar still, the solar furnace and solar calorimeter to investigate the solar properties of materials. In the background partially visible is a five ton solar air-conditioning equipment.

## Solar Properties

The first step in utilizing solar energy is to find materials which will withstand the exposure necessary in the equipment to be built. To do this we take some of these materials and expose them under rather realistic operating conditions to the weather and the sun. Fig. 3 shows different plastics exposed to the environment, stretched over cans which are filled with water or sand or wet soil, etc. If these materials deteriorate after a short time the investigation is terminated.

Those materials which, however, withstood this exposure test satisfactorily are then investigated in our Solar Calorimeter as to their reflection, absorption and transmission characteristics under actual solar irradiation.

The Solar Calorimeter, Fig. 4, can be oriented into any desired position, it can be made to follow the sun, it can simulate severe winter conditions or extreme summer environments. It is further instrumented with many, many thermocouples to be able to obtain complete heat balances. This instrument, the only one of its kind, it constantly used to investigate new types of materials such as glasses with tinting or coatings, laminated glasses and plastic materials, venetian blinds, thermopane windows, plastic bubbles for aircraft, fabric used for clothing, curtains and draperies, water cooled venetian blinds, etc.

With the properties determined a selection can be made to obtain the best results in any desired application.

## Solar Water Heating

In Fig. 5, five different flat plate collectors used for water heating are presented. They consist of a box with glass or plastic covers (one or more) with a metallic absorber element inside, which contains the water. This water is circulated to the small water storage tanks shown above. These absorbers can be compared with each other when exposed to the sun under identical conditions and for the same length of time.

Some of the absorbers have copper plates with copper tubes soldered into them, others are two flat plates riveted, crimped or welded together. The most efficient unit found consisted of two thin flat copper plates fastened together on the edges and providing a water space of about 1/4 inch, with one glass cover and one inch of styraform insulation behind the plates. No plastic materials were found to be as good as glass since none of the ones we could find had the characteristics of glass, namely letting through the short wave radiation but not the long wave radiation. This characteristics of glass allows it to be used in the design of a solar trap.

Fig. 6 presents a typical Florida Solar Water Heater. It consists of a sheet metal box, 4 feet by 12 feet, covered by a layer of glass. Inside the box is a copper sheet with copper tubes soldered to it in sinusoidal configuration and connected to an 80 gal. water storage tank. This system, rather common, is found satisfactory for a typical American family of 4 with automatic washing machine, etc. Under the copper sheet is one inch of styraform insulation. For satisfactory operation the bottom of the hot water storage tank must be above the top of the absorber to provide circulation without a pump.

Fig. 7 shows actual installations of this type in an apartment house in Florida with each apartment having its own unit to provide the needed hot water.

These standard units may be damaged if used in freezing temperatures and for this reason we developed a dual circulation system which eliminates this problem. It consists of two tanks one inside the other, the outer tank being connected to the collector and this system is filled with an antifreeze solution. The heat is then transferred from this solution through the wall of the inner tank to the water to be used. Since in this system the primary circuit operates at atmospheric conditions (the outer tank can just have a lid on it) the collector can be constructed much cheaper and lighter, for example patterned after the most efficient design mentioned earlier. Insulation covers the outside tanks.

## Swimming Pool Heating

Another type of heater which has interested many people in Florida is a swimming pool heater as shown in Fig. 8. It is one of the simplest ones and least expensive. It consists of a galvanized sheet, wrapped into plastic. The sheet is painted black (flat) like all the other absorbers. Water from the pool can be fed to these absorbers by the filter pump and then running down the front and back of the metal plate drains back into the pool. It usually takes a collecting surface equal to the pool surface for raising the water temperature in the pool 2 degrees F. These absorbers can be constructed to form the fence around the pool which is in many localities required by law, and in addition can provide privacy.

## House Heating

If the objective is to heat a house rather than water it can be done by hot water circulated through base-board pipes in a conventional hot water heating system. Frequently it is, however, more convenient or desirable to heat a building by hot air. Fig. 9 shows such an air heater, made up of overlapping aluminum plates, painted black on the portion exposed to the sun. About 1/3 of each plate is showing the other 2/3 shaded by the plate above. They are put into a glass covered box. The air will enter this unit on the bottom and then streaming between the hot plates will pick up the heat and leave on top as hot air. The circulation can be produced either by free or natural circulation or by a fan.

All the above mentioned col-

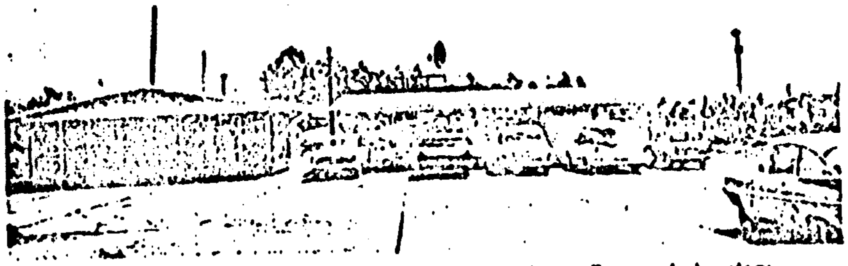


Fig. 1. Entrance to the University of Florida — Solar Energy Laboratory.

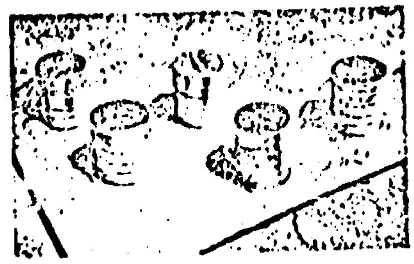


Fig. 3. Exposure Test of some Plastic Films.

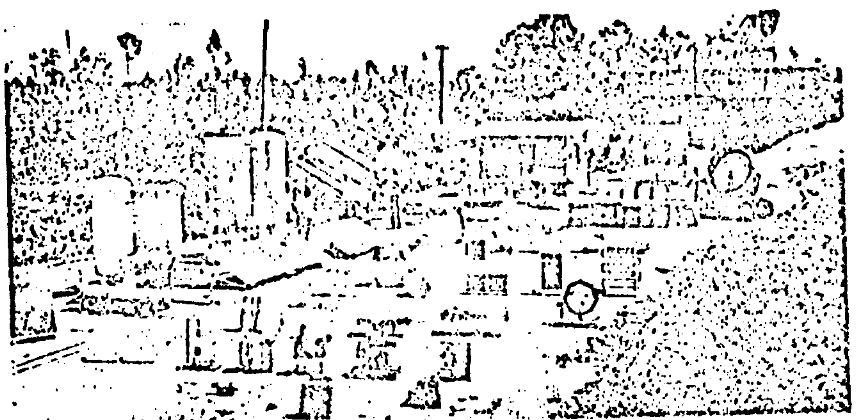


Fig. 2. View of some of the Solar Energy Conversion Equipment in the Laboratory.

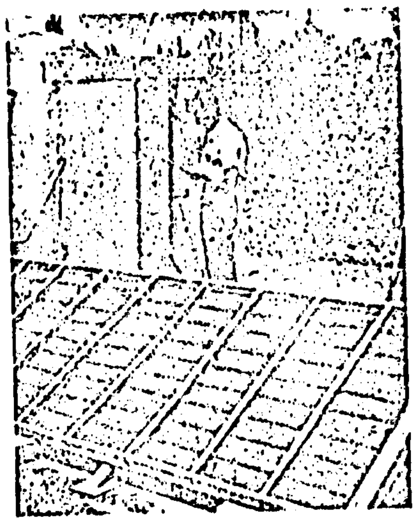


Fig. 6. Florida Solar Water Heater.

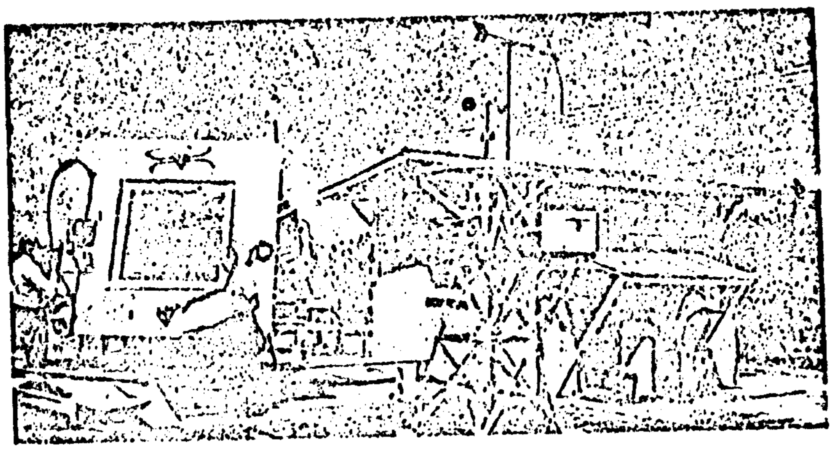


Fig. 4. The Solar Calorimeter.

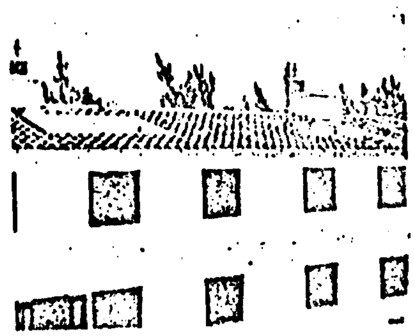


Fig. 7. Solar Water Heaters in Apartment House.

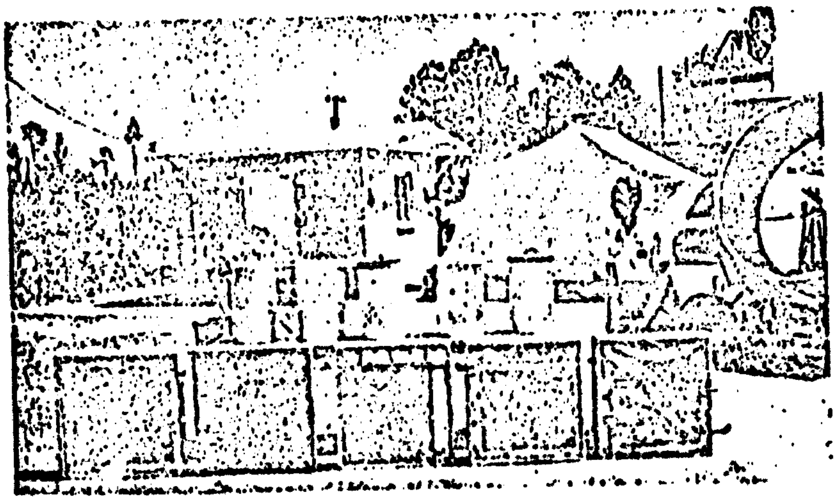


Fig. 5. Experimental Flat Plate Collectors.

Fig. 8. Swimming Pool Solar Heater.

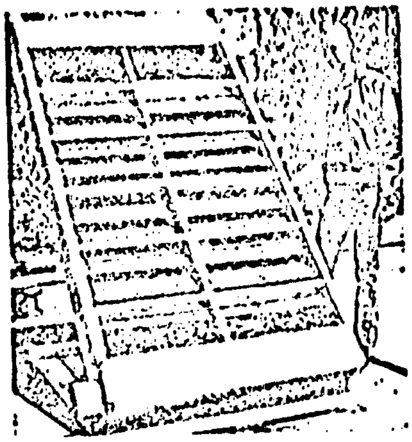


Fig. 9. Solar Air Heater.

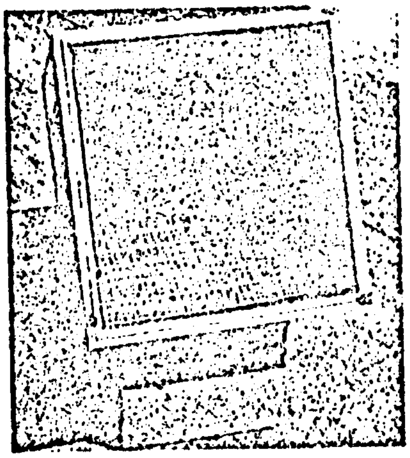


Fig. 10. Solar Oven.

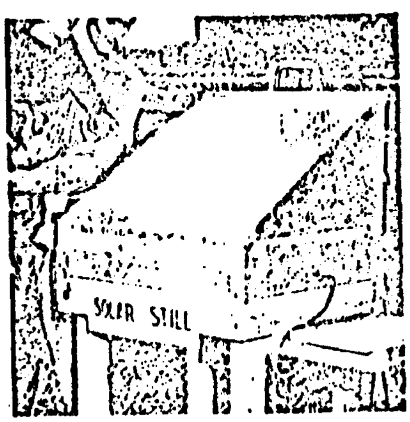


Fig. 11. Small Solar Still.

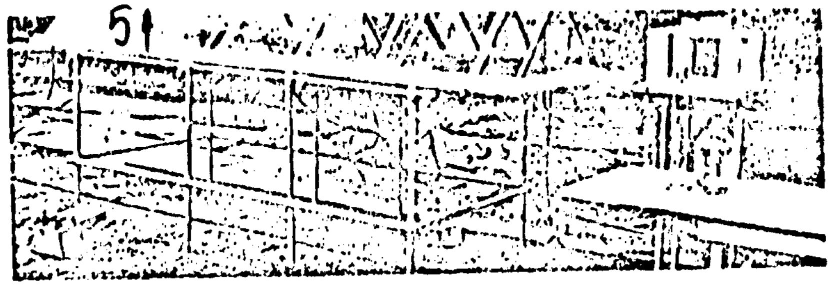


Fig. 12. Larger Solar Still, also able to Collect Rain Water.

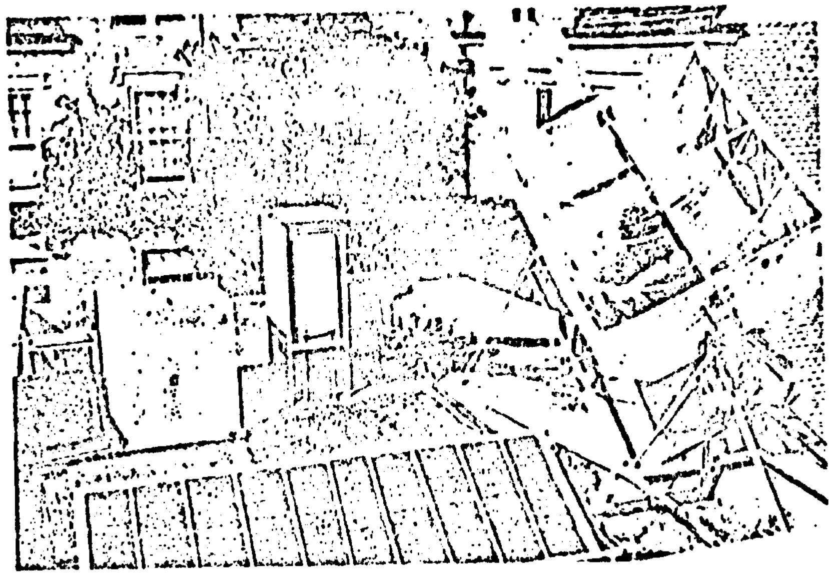


Fig. 13. Refrigerator, Driven by Solar Energy.

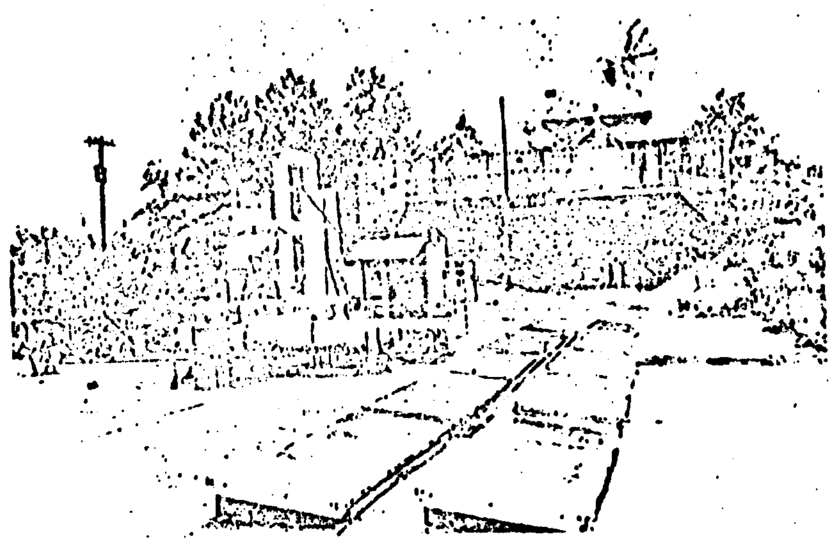


Fig. 14. 5 Ton Solar Air Conditioning System.

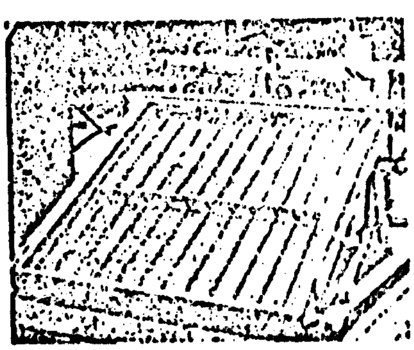


Fig. 15. Small Solar Refrigeration System, Front.

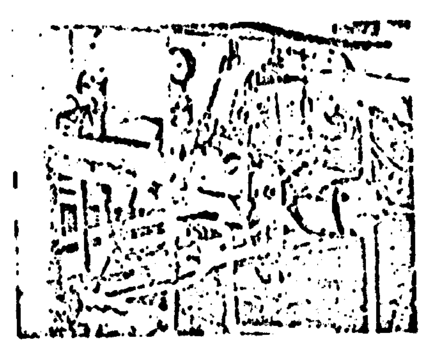


Fig. 16. Small Solar Refrigeration Systems, Back.

lectors are ideally facing South and inclined with the horizontal at an angle equal to the local geographic latitude plus 10 degrees. This gives a little higher collection efficiency during the winter when the days are shorter.

The air heater could be designed forming the wall of a building, let us say the East wall where it could produce hot air the first thing in the morning to take the chill out of the building the first past of the day.

## Solar Baking

Another application can be a solar oven, Fig 10, essentially a glass covered box facing into the sun. Cooking and baking temperatures can easily be reached with such a device. Periodic (about every 15 minutes) reorientation, due to the movement of the sun, is required. Flaps can be added as shown in Fig 25 to provide some degree of concentration and thus bringing the things to be cooked up to temperature quicker. Very little heat is actually required for the cooking process, only a certain temperature for the required length of time. If one of these ovens is to be used in the late afternoon or early evening, the walls could be made thick, of clay or other materials which can store appreciable amounts of heat and thus remain warm long after the sun has gone down.

## Solar Distillation

One of the major problems in many parts of the world is fresh water. Solar energy can with very simple equipment convert salt or brackish water into fresh and pure water. Fig. 11 shows a simple solar still. A metal box with slanting glass facing South. Inside the box is a pan on short legs, painted black and holding the bad water. The sun shining into this pan heats the water in the pan and vaporized it. The vapor or steam then will, when coming in contact with the cold surfaces of the box, both the glass and the metal, condense forming the fresh which runs down the sides in the form of droplets. This fresh water can then be collected for future use. About ½ lb. of water can be produced at an average per square foot per day.

Another larger still is shown in Fig. 12. The pan is covered by glass at about 45 degrees which forms most of the condensing surface. Glass is much better than plastic since it forms film condensation letting the solar energy through without much difficulty. Plastics in general produce dropwise condensation, each droplet forming a little crystal which reflects much of the incident solar energy. This larger still is also designed to be able to collect rain water and in some areas such as Florida this can double the output of the still.

The best orientation of the still depends somewhat upon the angles of the glass but is generally East-West or somewhat NE-SW.

## Solar Refrigeration and A/C

Another phase of our work is the use of solar energy for solar refrigeration and air-conditioning. At a number of international meetings it was pointed out that famine could be prevented in much of the world if the food which is raised during certain parts of the year could be preserved from spoilage, and thus preserved for use during the rest of the year. This requires refrigeration and for remote areas, or areas without electricity, solar refrigeration may well be the answer.

Some of our early work along these lines was to heat oil to rather high temperatures by concentrating solar energy and then circulating the hot oil around the generator of an ammonia absorption refrigeration system. Fig. 13. This picture is somewhat out of order since all the applications thus far dealt with solar energy in its natural state without concentration but it was put in here since it was actually our first attempt. We believe, however, that solar refrigeration without concentration holds much more promise since nonconcentrating devices can also utilize the diffuse portion of solar radiation, thus function even on cloudy days.

A number of small units have been built and then a 5 ton unit shown in Fig 14. Flat plate collectors heat water which is then circulated to drive out the ammonia from the water in the generator of the system. This ammonia vapor is condensed and then expanded, providing the cooling effect by evaporation. After having done its work the ammonia vapor is reabsorbed in the ammonia absorber of the system into the water to repeat the cycle.

Fig. 15 and 16 show a smaller version of such a system with some improvements. The main one, of combining the solar collector and the ammonia generator into one unit, thus eliminating the primary fluid and reducing the heat losses by providing a more direct path for the solar heat to get into the system and do its work. This small 4 x 4 foot unit can produce 80 lb. of ice on a good day.

It should be pointed out again that all the applications mentioned so far did not require concentration of solar energy, and therefore could utilize the diffuse portion of solar energy and even work on cloudy days.

The solar air-conditioning or refrigeration systems have an added advantage, that the demand and supply are in phase. When the sun shines hottest the need for refrigeration and air-conditioning is greatest.

## Solar Energy Concentration

For some uses, however, higher temperatures than can be obtained with flat plate, non concentrating collectors, are needed. If this is the case, then concentration is called for. Many different methods can be used for concentration, the simplest ones stationary in design but not as good, and the better ones requiring methods which allow them to follow the sun. Fig. 17 shows a simple high temperature absorber. It consists of a number of parabolic troughs oriented horizontally and with a pipe running down the focal line of the parabolas. The system of parabolic troughs is inclined at about the local latitude. Depending upon the diameter of the pipe adjustment may or may not be needed during the year. The solar energy is reflected by the parabolic surfaces upon the focal pipe which painted with a good absorbing paint (flat black) absorbs this energy and transmits it to the fluid inside the pipe. This device can easily produce hot water, steam or hot oil.

Some energy is lost during the early morning and the late afternoon hoors with the above method of converting solar energy to heat because of shading, but the simplicity and stationary design have considerable advantages, both economically and do not need much attention.

## Solar Power Plant

If better efficiency is desired, then cylindrical parabolas can be used which are allowed to follow the sun. In the simplest form they can be made as shown in Fig. 18 of a single parabola with a pipe at the focal line. This particular absorber is used to produce steam to operate a small steam engine, which in turn drives a small generator and lights up a light bulb, thus demonstrating what a solar power plant could look like. The 2 x 5 foot absorber is the equivalent of 500 watts of electrical heat.

A large cylindrical parabolic absorber is shown in Fig. 19 having dimensions of 6 x 8 feet with a glass covered focal tube. The glass cover reduces the losses from the heated tube. Depending upon the needs, different diameter tubes can be used. Copper has been found best, again painted with a good absorbing high temperature paint. This absorber is mounted on a rotating axis parallel to the earth axis. It is adjusted to face East in the morning and then, by an electrically driven worm gear reduction unit is made to follow the sun all day. Where electricity is not available, a heavy weight with a clock work timing unit can be used as well. The construction of such a large device must be rather rigid since wind loads in windy areas, may make it difficult to keep the unit directly facing the sun and to keep it from oscillating.

This unit has been used to produce steam for the operation of a fractional horsepower steam engine, to provide 800F oil to operate a solar refrigerator, etc.

Other methods of concentrating solar energy are lenses both of glass and other materials (including liquid lenses), but they are not widely used because of their cost in large sizes and their weight. However Fresnel lenses, specially made from plastic sheets, with groves cut or embossed so as to focus the rays, can be produced rather inexpensively are unbreakable and can be of large size and light weight. The lense shown in Fig. 20 is of this type and can produce temperature of 2000F.

A very effective way of concentrating solar energy is to take flat pieces of reflecting materials (for better results they can even be slightly curved) such as mirrors or reflecting metal surfaces, and oriented in such a manner as to reflect the solar radiation on one spot. Front surface reflecting mirrors are giving better performance than, for instance, back silvered mirrors where some of the energy is absorbed in the glass. Very large concentrators of this type have been built with thousands of these mirrors used in some of the large solar furnaces in the world.

## Solar Cooking

A few concentrating panels of this type are shown in Fig 21, where three of them concentrated upon a board will make this board flash into fire. Such mirrors can also be set up in a different pattern like the one shown in Fig. 22 where the mirrors are set up into a circular pattern, heating the fluid in the jar at the focal region of the device.

If higher concentration, and thus higher temperatures, and smaller focal regions are desired then either small mirrors are needed or continuously curved surfaces can be employed. In this manner excellent concentrating mirrors even of optical quality can be made but they are very expensive and there is a practical limit to the size of these configurations.

Two such mirrors of fair quality are shown in Fig. 23, the one on the left being strong enough to hold its shape by being properly formed, the one on the right being supported by ribs from wood in this case which are cut out forming parabolas. Then thin highly reflecting metal sheets are held loosely to these ribs to allow for expansion when the metal sheets are slightly heated thus avoiding distortion. This type of construction is especially important in large sizes. This type of construction was also used in the large parabolic cylindrical concentrator mentioned earlier.

The two concentrators of Fig. 23 were used as solar cookers where only a moderate amount of concentration is needed and too good a concentrator may burn holes into the containers used if great care is not taken. So, not too good a quality, is more desirable for this application.

If such concentrators are used for solar cooking it may be desirable to design them for easy portability, thus either in sections which can be collapsed for moving, or of coated cloths of an umbrella design which can be folded when not in use. This type is shown in Fig. 24.

An oven and a cooker of moderate concentration are shown in Fig. 25. The flaps on the oven can be adjusted to regulate the degree of concentration needed. An oven of this design will shorten the cooking and baking time by bringing the food up to the desired temperature faster than the type mentioned earlier.

Higher concentration, than the surfaces previously discussed can provide, is needed for high temperature work solar engines, etc. For this purpose the geometry has to be more perfect. Fig. 26 shows various mirrors of rather high quality giving high degrees of concentration with the ultimate reached in the solar furnace, Fig. 27.

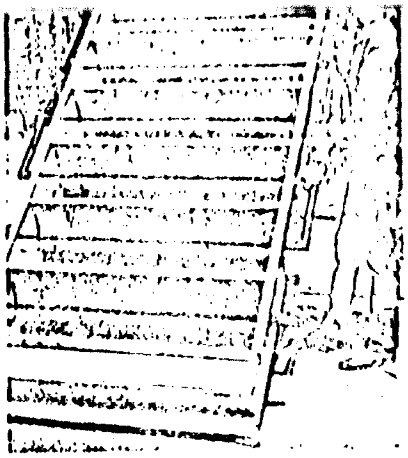


Fig. 17. Stationary High Temperature Absorber.

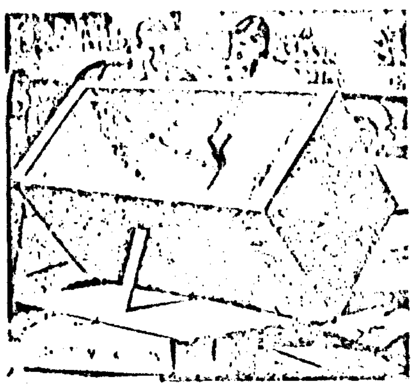


Fig. 18. Solar Steam Boiler of Solar Steam Power Plant.

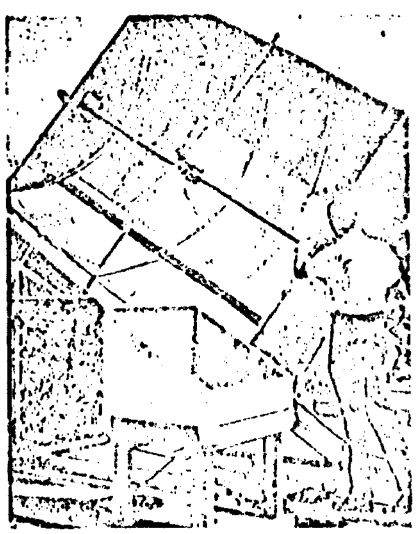
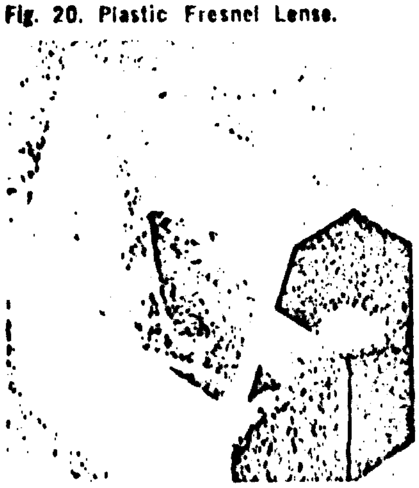


Fig. 19. 6 x 8 Cylindrical Parabolic Absorber.

Fig. 20. Plastic Fresnel Lense.



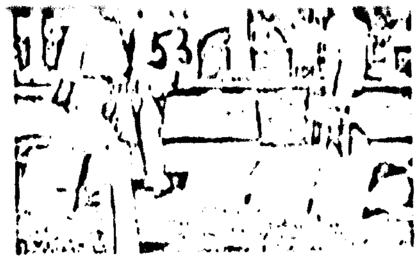


Fig. 21. Solar Concentrating Panels.

Fig. 22. Solar Cooker.

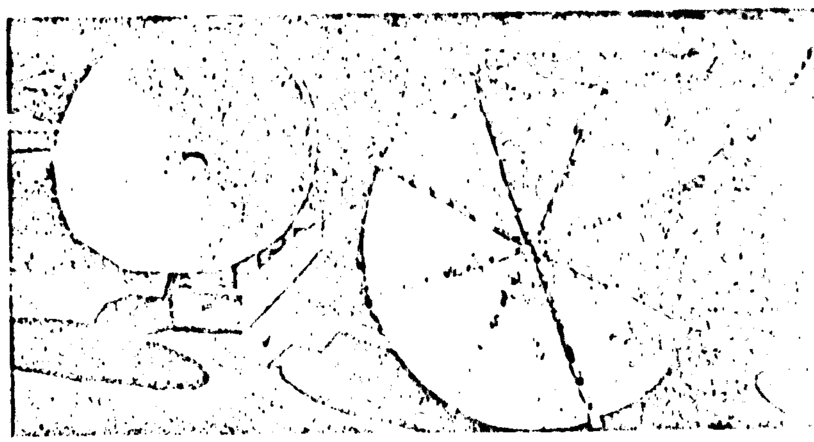


Fig. 23. Parabolic Solar Concentrators.

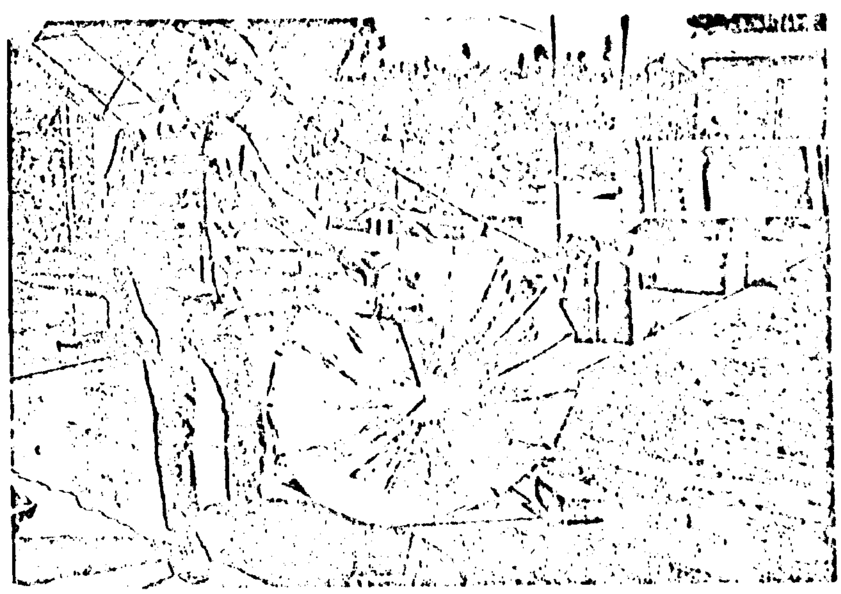


Fig. 24. Collapsable Solar Cooker.

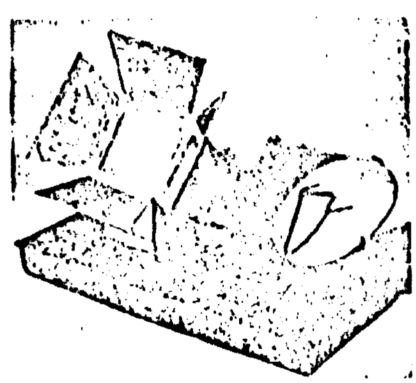


Fig. 25. Solar Oven and Solar Cooker.

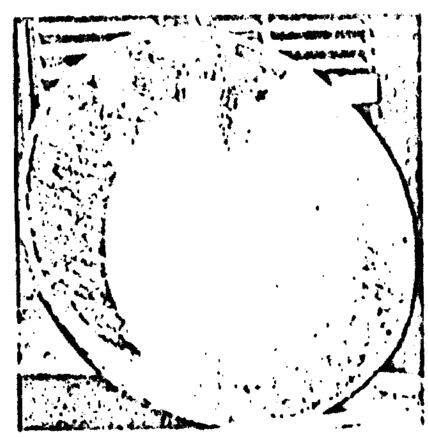


Fig. 26. Concentrating Mirrors.

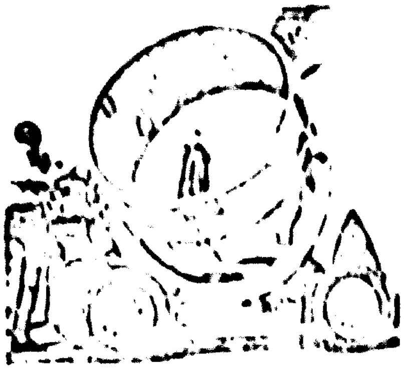


Fig. 27. 5 Foot Solar Furnace

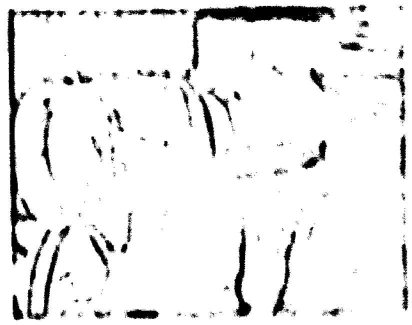


Fig. 36. Hot Air Engine Operated by Solar Energy

Fig. 31. Steam Engine Operated by Solar Energy (1/4 horse power)

Fig. 28. Calcium Oxide Target Irradiated in Solar Furnace

Fig. 32. Solar Steam Power Plant (see also Fig. 18).

Fig. 37. 1/3 Horsepower Closed Cycle Hot Air Engine

Fig. 29. Calcium Oxide Crystal.

Fig. 33. Solar Steam Power Plant (see also Fig. 21).

Fig. 38. Pumping Water with Solar Energy

Fig. 34. 1/4 horsepower Closed Cycle Hot Air Engine.

Fig. 30. Small Steam Engine.

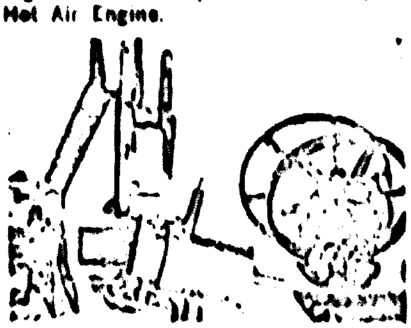


Fig. 35. Dis-assembled Closed Cycle Hot Air Engine.

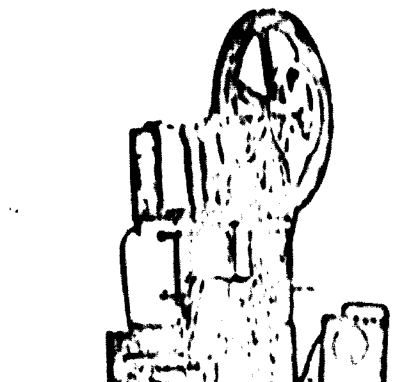


Fig. 39. 1/2 Horsepower Closed Cycle Hot Air Engine.

Fig. 40. Open Cycle Hot Air Engine

Fig. 38. Solar Cells

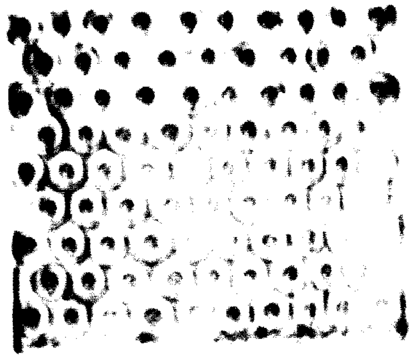


Fig. 39. Solar Cells

Fig. 47. Sewage Digesters Heated by Solar Energy

Fig. 41. Solar Pump

Fig. 42. Solar Turbine

Fig. 46. [illegible]

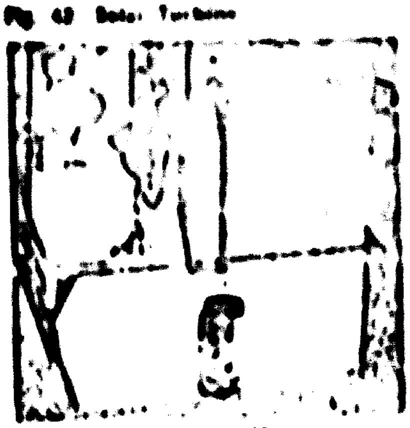


Fig. 43. Solar-Gravity Motor

Fig. 44. Solar Thermo-Phase Shift Reciprocating Engine

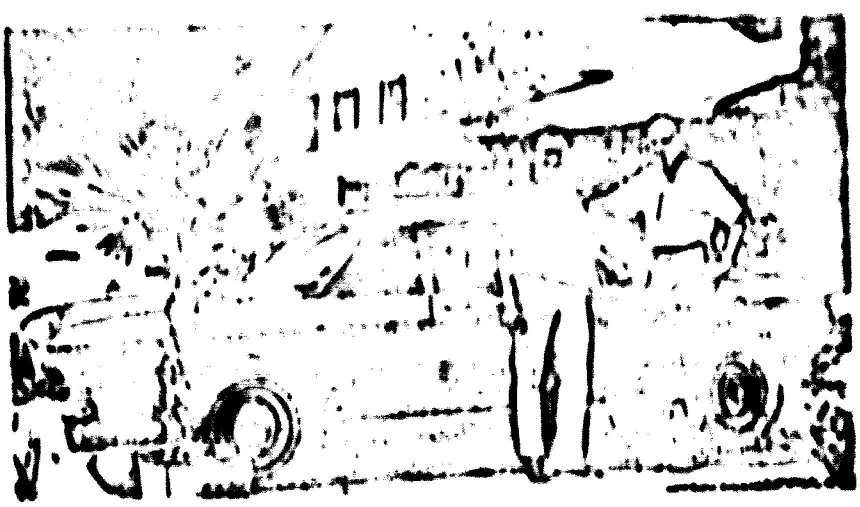


Fig. 45. The Solar House.

## Solar Furnaces

[illegible]

## Mechanical Power

[illegible]

We believe however that hot air engines [illegible] greater [illegible] mechanical [illegible] power requirements. They are relatively quiet and only need [illegible] of [illegible] [illegible] engines can be operated [illegible] during the day and [illegible] at night by other sources of heat [illegible] coal oil or it can be [illegible] by the heat produced from the burning of waste products such as trash [illegible] ding etc.

## Closed Cycle Hot Air Engines

There are two basic types of hot air engines, the closed cycle type [illegible]

[illegible]

Fig [illegible] shows another use of the closed cycle hot air engine in operation and in Fig 38 it is pumping water out of a ditch. The [illegible] with this engine is actually [illegible] than needed but was used since it available. It is an old mirror from the solar furnace which has been polished so many times that the reflecting surface is no longer very good for engine operation the concentrator [illegible]

## Solar Pump

[illegible]

[illegible] liquid to be transported. The pul[illegible] action can be smoothed into steady flow if an air chamber is provided past the top check valve.

## Solar Turbine

Another method of converting solar energy into mechanical energy is by means of a turbine, a model of which is shown in Fig 43. A vertical chamber with a turbine [illegible]

## Solar Gravity Motor

[illegible]

## Solar Thermo Phase Shift Reciprocating Engine

[illegible]

[illegible] quite noisy sounding like a small gasoline engine and can be adjusting the pressure on the end of the bellows be made to run at different speeds several hundred cycles per minute if desired.

## Conversion to Electricity

If electricity is desired as the form of energy to be used it can be produced by converting solar energy into [illegible] energy and then driving a conventional electric generator. More conveniently the solar energy can be converted directly into electricity by one of the many solid state devices normally referred to as solar cells

Though the space programs great strides have been made in the photovoltaic conversion field utilizing silicon as the most common material. Two photographs some concentrators are shown in Fig. [illegible] and [illegible].

Thermoelectric conversion has also been investigated in our laboratory using certain semiconductor materials as couples, thermocouples as well as thermionic conversion but not a great deal of energy was spent in these areas.

## Sewage Treatment

Another project of interest is application of solar energy to sewage treatment. One phase of this work provided solar heating for sewage digesters. By heating these digesters and controlling the temperature for optimum efficiency considerably more sewage can be handled by a given size plant. Many plants buy very expensive covers and collect the sewage gas and then burn it to heat the fluid in the digesters. Many of these plants even buy fuel and all this becomes a very expensive operation. Solar heating of these digesters proved relatively inexpensive by being able to use plastic sheets glued together to form an air mattress type cover floated on top of the digester. This in many cases provided enough of a solar trap to keep the digester at good operating temperatures in our region. As a matter of fact one winter with rather severe and prolonged freezes all the bacteria in the unheated digesters died and action stopped completely until they were reseeded. During this same period the solarly heated digesters survived and the bacterial action, even though slowed down during the extreme cold spells, picked right up again when the temperature of the digesters increased. The basic problem of heating here is the same as for swimming pools.

If the digester is designed more like a solar still in addition to the digestion fresh water can be produced by distillation and the remaining sludge used for fertilization.

## Transportation

The Solar Energy and Energy Conversion Laboratory has an Electric Car which one of the staff members drives to work regularly to obtain operating and performance data under high traffic density conditions. This car, Fig. [illegible], has [illegible] 6 V Lead Acid batteries. These batteries can be charged by converting solar energy either by Solar Cells or by a solar engine generator system. This method would make it a truly non polluted transportation system.

## Solar House

The Solar House, originally the out house of the Mechanical Engineering Department of the University of Florida has been in operation for quite a number of years under actual occupancy conditions. A graduate student couple lived in the house and various heating systems, air conditioning systems, hot water systems, washing machines, dryers, lighting systems have been studied fully instrumented.

This house is now being converted step by step into a Solar House, where all the energy requirements will be met by converting Solar Energy into the various forms needed.

A true and realistic comparison can then be made with conventional methods on both a technical and economic basis.

## Closure

The above discussion with a number of illustrations, and we believe that pictures can tell a story much better, covers much of our work but by no means all of it. It presents the range of activities in our laboratory.

When solar energy utilization is contemplated its availability and amount of supply, the requirements, the availability of materials and labor, as well as the economic considerations should be analyzed on a regional or local basis since large variations can occur from place to place on a global scale. The devices discussed here and shown may have different degrees of applicability in different areas.

As an example we recommended one time for an Army Post in Chile to spread steel pipes on the sandy ground and to hook them together into a number of parallel circuits to provide the hot water they needed. They had steel pipe, the sun, and the sandy land. To recommend to them the Florida type solar water heater would have been the wrong thing to do since they did not have copper sheets, copper pipes and hot water storage tanks. Their problem was solved with local materials, under local conditions, and produced the desired results.

In closing I would like to say that solar energy, its conversion and utilization will not solve all our problems but it will be a great step in the right direction, by supplying needed energy wherever it can, without having adverse effects upon the environment and at the same time conserving our fossil fuels which can do much more for us than provide heat. The chemicals they contain can be used as preservatives, in medication, etc., so that the indiscriminate use of these resources for energy is unwise and a loss to future generations.

## Acknowledgements

The Solar Energy and Energy Conversion Laboratory of the University of Florida was used as the basis for this paper but credit must be given to the many laboratories around the world and individuals who are engaged in the effort to utilize solar energy for the betterment of mankind and their work supports ours through ideas and results as our work is helpful to them.

Thanks must be given to the faculty, students and staff of our laboratory who have over the years had an important part in advancing the state of the art of solar energy utilization and who have provided knowledge and results for others to build on. ΔΔΔ

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# The Generation of Pollution-Free Electrical Power From Solar Energy

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*Projections of the U.S. electrical power demands over the next 20 years indicate that the U.S. could be in grave danger from power shortages, undesirable effluents, and thermal pollution. A pollution free method of converting solar energy directly into electrical power using photovoltaics on the ground shows that sunlight falling on about 1 percent of the land area of the 48 states could provide the total electrical power requirements of the U.S. in the year 1990. By utilizing and further developing some NASA technology, a new source of electrical power will become available. Such a development is attractive from conservation, social, ecological, economic, and political standpoints. While the cost of producing solar arrays by today's methods prohibits their use for large scale terrestrial plants, the paper suggests how the cost may become acceptable, especially as conventional fuels become scarcer and more expensive. Some of the desirable reasons for developing methods to convert solar energy to electrical power are: to conserve our fossil fuels for more sophisticated uses than just burning; to reduce atmospheric pollution by 20 percent; to convert low productive land areas into high productive land areas; to make the U.S. less dependent upon foreign sources of energy; and to learn to utilize our most abundant inexhaustible natural resource.*

## Introduction

The rapid advancement in the American standard of living is reflected in the drastic increase in the nation's electrical power demands. In 1938 the U.S. had an electrical power installed capacity of approximately 26 million kw. Thirty yr later (1968) there were 226 million kw of capacity installed [1].[1] The actual installed capacity and the projected requirements [2] for the next twenty years are shown in Fig. 1. Clearly, the electrical power demand across the U.S. is doubling every 10 yr and in some areas, such as Washington, D. C., the requirements are doubling every 8 yr.

Fig. 1 shows that the principal method of power generation is the burning of fossil fuels and shall continue to be so for at least the next 20 yr. Nuclear power generation is projected to increase from something around 3 percent today to about 40 percent of our needs by 1990. While hydroelectric installations represent about 15 percent of the U.S. capacity in 1970, they will account for only about 7 percent of the U.S. demand in 1990. The U.S. has run out of suitable sites for hydroelectric installations. Other conventional methods of power generation, such as internal combustion and gas turbine facilities, will probably play only an auxiliary or emergency power supply role.

Except for hydroelectric installations, the other means of generating power produce undesirable by-products of $CO_2$, CO, nitrous oxides, $SO_2$, fly ash, water vapor, and large amounts of waste heat which must be vented into the atmosphere or dumped into rivers or lakes. Since the best of the fossil and nuclear fueled installations are between 30 and 40 percent efficient, about 2 kw of thermal energy must be dissipated for each kilowatt of electrical power generated. Also, the disposition of vast amounts of nuclear waste must be taken into account as this method of power generation becomes more and more prominent.

There are serious questions concerning the advisability of continuing to produce electrical power at the expense of our environment and the wholesale exploitation of our irreplaceable natural resources, such as natural gas, oil, coal and nuclear deposits. Perhaps the time has come for a reappraisal of other methods of generating electrical power if only to supplement our present methods so that the rate of increase in use of our irreplaceable natural resources will be slowed.

## NonConventional Methods of Producing Electrical Power

Examining other methods for generating electrical power requires the need to restrict it to processes which will not seriously affect the ecology. Tidal action might be harnessed in some regions of the U.S. and the world but this would be so restricted as to add little to the U.S. generating capacity. World-wide potential generating capacity is estimated to be 64 MKW [3].

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[1] Numbers in brackets designate References at end of paper.

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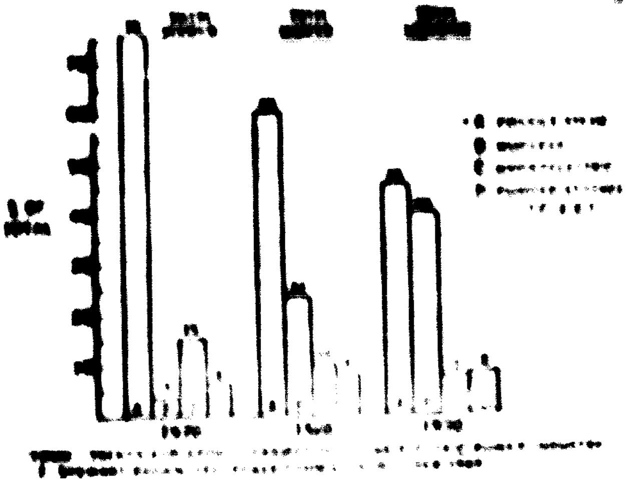


Fig. 1 Electric requirements and supply for U. S.

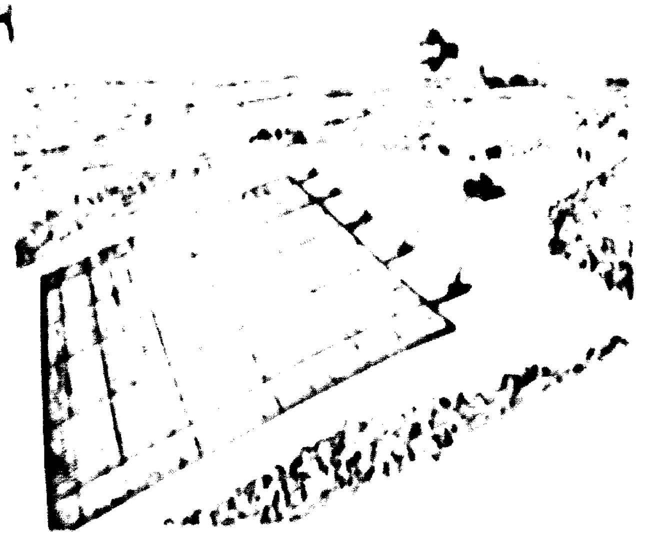


Fig. 2 One sq mi terrestrial solar power plant

Wind power in certain regions has promise but in the heavily populated locations of the U. S. the velocity and consistency is highly variable. Geothermal power has interesting possibilities and is particularly favorable in certain regions, especially along the west coast of the U. S. Some power plants are already in operation in the U. S. and other places in the world. About 0.8 MKW is installed and should reach 1.3 in 1971 world wide [3]. It is, however, a polluting process in the sense that thermal energy is being removed from the earth's interior faster than by natural processes. Therefore extensive use of this method would introduce substantial amounts of heat into the surface environment.

Perhaps the most abundant source of energy available to man is solar energy. It is entering the earth's atmosphere at a density of 130 watts/ft² which means that over every square mile 3.6 × 10⁶ kw potential energy is available during the sunlight hours. Solar energy is an absolutely clean "fuel," has no by-products and for all practical purposes is inexhaustible. Its interception and partial conversion to electrical power would not cause thermal unbalance since the energy is arriving at the earth in any event.

Various methods of using solar energy for heating hot water, warming buildings, drying foods, recovery of salt and other chemicals, as well as agricultural processes, are well known. However, its direct conversion into electrical power has been restricted to outer space applications where over 90 percent of the U. S. unmanned space vehicles are solar powered. Photovoltaic, thermoelectric, thermionic, and dynamic processes have been investigated as means of generating electrical power from sunlight in the U. S. space program but the method which proved most practical was the photovoltaic (solar cells).

Let us now turn our attention to the consideration of using solar cell processes for conversion of solar energy into commercial quantities of electrical power.

## Conversion of Solar Energy on the Ground

Fig. 3 shows the WH/ft² of solar energy falling on a horizontal surface at 40 deg N latitude on the east coast of the U. S. under various seasonal and weather conditions [4]. The power available was considered when the solar illumination was sufficient to develop useful power in the array. At no time was there sufficient illumination on the cloudy winter day to generate significant power. Table 1 summarizes the total KWH available under the various conditions measured for a ground power station 1 mi square in size.

Table 1 Incident energy/power available, 40 deg N latitude, sea level

| Season and type of day | Incident solar energy | 5 percent conversion | 7 percent conversion | 10 percent conversion |
|---|---|---|---|---|
| | Kilowatt hours per square mile per day | | | |
| Clear summer day | $17.3 \times 10^6$ | $0.86 \times 10^6$ | $1.21 \times 10^6$ | $1.73 \times 10^6$ |
| Clear winter day | $6.5 \times 10^6$ | $0.33 \times 10^6$ | $0.45 \times 10^6$ | $0.65 \times 10^6$ |
| Cloudy summer day | $3.5 \times 10^6$ | $0.17 \times 10^6$ | $0.24 \times 10^6$ | $0.35 \times 10^6$ |
| Cloudy winter day | nil | nil | nil | nil |

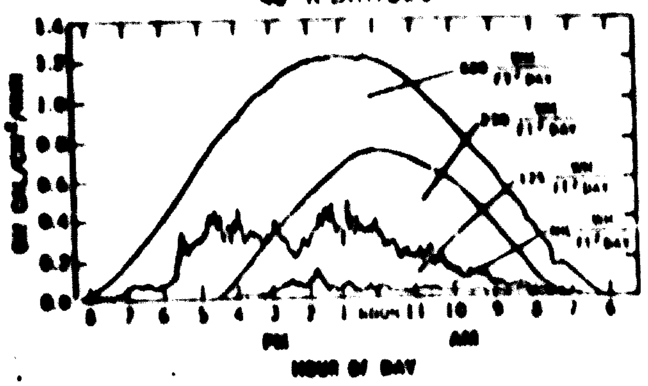



Fig. 3 Solar insolation at sea level on various days

A fully electrically equipped modern 1730 ft² air conditioned home along the east coast of the U. S. averages about 1300 KWH per month from May through September to operate its electrical equipment. This same house in the October through April period requires about 700 KWH per month, exclusive of heating. Thus a square mile of solar array, as illustrated in Fig. 2, during the summer months, assuming 60 percent sunshine hours at 7.0 percent conversion efficiency, could produce enough power to accommodate about 18,000 homes. This same power station during the winter months with about 50 percent sunshine hours and lower intensities could accommodate about 10,000 homes.

By providing an electrical storage system for the station as illustrated in Fig. 3 around the clock power would be available. Using lead acid storage batteries similar to those installed in telephone exchanges, a storage capacity of 2.6 KWH/ft² can be obtained. A 1 million KWH storage capacity would require

Fig. 4 Mean monthly percentage of possible sunshine for selected stations

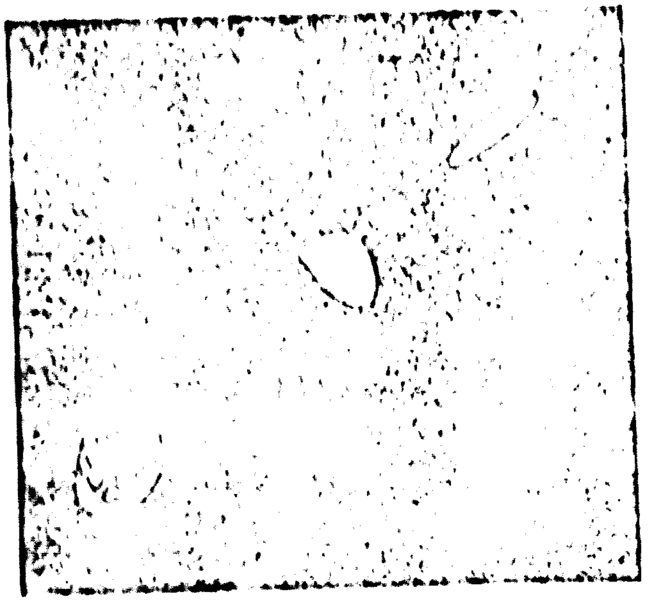


Fig. 5 Solar power satellite station

about 600,000 ft³ or a building approximately 115 ft × 115 ft × 30 ft high. This storage could provide around the clock power to the 10,000 homes in the winter time for 4 full days, should this be necessary or it could be used to handle peak power demands.

The entire electrical power requirements for Washington, D. C. and Prince Georges County, Maryland (PEPCO) for 1969 were 1.1 × 10[illegible] KWH/yr [5].

Fig. 4 shows the mean monthly percentage of possible sunshine in various parts of the U. S. If a terrestrial solar power station was built in the Washington, D. C. area it would require an area of about 73 sq mi to produce PEPCO's 1969 needs. The total area serviced by PEPCO is about 545 sq mi so it requires about 1 sq mi to service about 7.5 sq mi in the Washington, D. C. area.

If the same power station was located in the sunny southwestern U. S. where the possible sunshine hours average nearly 70 percent year around, then PEPCO's needs could be generated in a region of about 53 sq mi.

Enormous land areas in the arid parts of the U. S. are low productive regions. Many thousands of square miles could be made highly productive, "harvesting a crop" of electrical power for sale in the areas where it is vitally needed. Not only would the land become more productive and valuable but the U. S. would become less dependent upon foreign import of energy resources. Considerable savings of our irreplaceable natural fuels could be made and a big step toward relief from atmospheric and thermal pollution would be accomplished.

It is estimated that the total U. S. electrical power needs for 1990 will amount to some 6.6 × 10[illegible] KWH/yr. Assuming the 7 percent conversion efficiency as before and 70 percent sunshine hours in the southwestern U. S., about 31,500 sq mi of solar array could generate our nation's total needs. This represents barely 1 percent of the land area of the 48 states.

If ways could be found to intercept the solar energy entering our upper atmosphere [6], then over 3 MKWH of power could be generated during the summer months and over 2 MKWH during the winter each and every day from a 1 sq mi station. To provide the annual consumption of Washington, D. C. and Prince Georges County, Maryland would require about 15 sq mi of array at 80 per cent transmission efficiency. While such a station would be above the weather and benefit from 100 percent possible sunshine hours every day, there are major problems to be overcome in supporting such a power station and of transmitting the power to the ground.

The ultimate method of generating vast quantities of electrical power would be from a series of synchronous satellites [7] illustrated in Fig. 5 beaming the microwave power back to earth to be used wherever needed. A satellite with an area of about 6¹/₄ square miles could generate the total power requirements of Washington, D. C. and P. G. County, Maryland. The losses of converting the DC power to microwave frequencies, transmitting through 22,300 miles and reconverting to useful power on the ground are considered to be 20 percent. Table 2 summarizes this comparison.

Table 2 Comparison of solar power generation on the ground, upper atmosphere, and in synchronous orbit, assuming 7 percent conversion efficiency

| Location & condition | Area to provide Pepco production 1.1 × 10[illegible] KWH/YR (1969), sq mi | Area to provide total U. S. requirements 6.6 × 10[illegible] KWH/YR (1990), sq mi | Area ratio |
|---|---|---|---|
| Ground, Wash. D. C. 50% sun | 73 | ... | 11.7 |
| Ground, S. W. U. S. 70% sun | 53 | 31,500 | 8.5 |
| Upper atmosphere 100% sun 80% transmission eff. | 15 | 9,000 | 2.4 |
| Synchronous orbit 100% sun 80% transmission eff. | 6¹/₄ | 3,700 | 1 |

## Conventional Electrical Power Costs

Most commercial power stations are amortized over a 30 yr period. Typical cost of generating 1 million KW of electrical power for 30 yr by conventional methods [8] are shown in Table 3. The least expensive method, obviously, is hydroelectric where most of the cost is tied up in the installation. The wide variation of cost, ranging from $170–$[illegible] per installed KW is related to location, where some may be in rugged isolated terrain and require the relocation of roads, railroads, and towns. The big advantage of hydroelectric installation is the zero "fuel" cost.

Natural gas is the cleanest and at present least expensive type of fossile fuel generating plant. It is also the first fuel which is likely to be depleted since these reserves are indeed seriously limited. At present it costs about $[illegible] per installed KW to build, maintain, and operate a plant for 30 yr at 1964 prices. Perhaps manufactured gas can be produced from coal or shale but it will cost more than natural gas.

**Table 3 20 yr cost of installation, maintenance and fuel for power stations (1960).* 1 million KW installation**

| Type | Installation | Nonfuel | Fuel | Total |
|---|---|---|---|---|
| | Millions of dollars | | | |
| Hydroelectric | 150-470 | 20-120 | ... | 170-500 |
| Gas fired | 150 | 32 | 281 | 463 |
| Oil fired | 175 | 37 | 304 | 516 |
| Coal fired | 100 | 47 | 387 | 534 |
| Nuclear fueled | 200 | 152 | 301 | 653 |

* Based on FPC "Hydroelectric & Steam Power Plant Construction and Annual Production Expenses" Report, Nov. 1969.

Oil and coal fired installations are quite comparable in cost, ranging from about $516 to $534 per installed KW, and they will probably be the major fossil fuels used to generate electrical power for the rest of the century. No charges for the deterioration to our environment are accounted for in the costs shown in Table 3.

It still costs about 1¼ times as much to generate electrical power with nuclear energy than with natural gas, but as the fossil fuels become less abundant and more expensive to retrieve, it is expected that the fossil and nuclear fueled plants will cost about the same to operate.

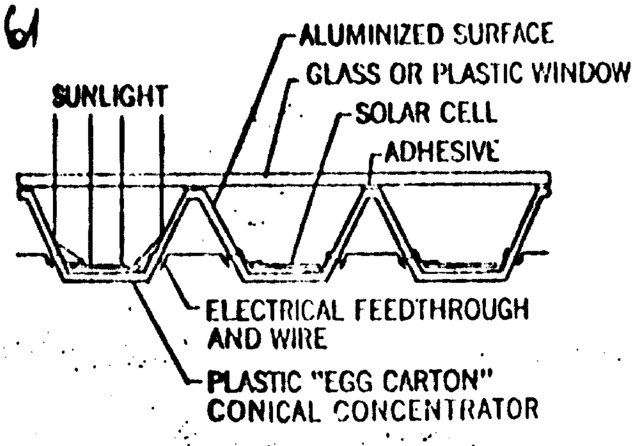
## Solar Electrical Power Costs

Today the direct conversion of solar energy into electricity is very expensive and confined to those applications where conventional processes are impractical. Solar cells have found wide application on long life unmanned spacecraft. The solar cells manufactured for the space program are subjected to stringent specifications and high quality control measures, both of which involve expensive hand operations. Further, the demand for solar cells is quite small, amounting to some 2 million devices per year with a total market value of between 6 and 8 million dollars. Also, the demand is sporadic.

This involves numerous start-ups and shutdowns of the production line, resulting in considerable waste in manpower and materials. Finally, no standard design has been agreed upon by the users, forcing the manufacturers to rely heavily on many hand operations simply because it is economically unfeasible to invest in automation.

Because of all this, oriented space solar arrays, like the large Apollo Telescope Mount illustrated in Fig. 6, cost about $2,000,000 per KW. A recent study [9] has shown that cells for terrestrial applications can be made now for about $15,000 per KW using

**Fig. 6 Apollo telescope mount with "Skylab"**




G. RALPH HELIOTEK

**Fig. 7 "Egg carton" concentration design**

existing silicon solar cell manufacturing methods, by relaxing the stringent space cosmetic and performance specifications, changing the cells' shape for better utilization of the single crystal silicon, and automating many of the processes for large scale production. By using simple concentrators, as illustrated in Fig. 7, which would require fewer cells to generate the same electrical power, the cost would be nearer to $10,000 per KW.

The next big step in cost reduction would be the utilization of inherently inexpensive processes, such as evaporation or deposition on long sheets of substrate. Thin film solar cells made of cadmium sulphide in 3 × 3 in. sizes might be mass produced for $2,500 KW.

Fig. 8 illustrates a process where many thousands of sq ft of solar array might be produced at costs around $50 per KW under space simulated conditions or $.50 per sq ft. Thus a square mile of array would cost about $14 million. Construction of the necessary ground support structure and conductor might amount to $1.00 per sq ft or $28 million per sq mi. Batteries for a 1,000,000 KWH storage facility might cost $10 per KWH or $10 million when purchased in large quantities, and the necessary buildings and switching gear might add another $20 million over a 20 yr period, including two battery replacements.

Since the solar array is a direct energy conversion system and has no fuel costs associated with it, its operating costs should be considerably less than any of the dynamic systems, perhaps as low as $1.00/ft² over 20 yr or $28 million per sq mi, which would include 2 array replacements. Table 4 shows that a 1 sq mi solar array power station, built after techniques are developed to produce low cost solar arrays and batteries, would

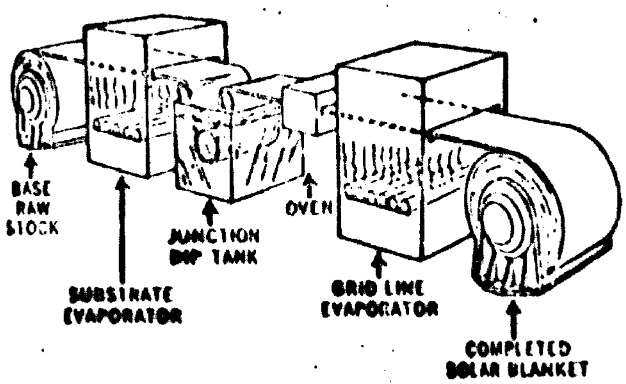



**Fig. 8 Solar array manufacturing**

cost about $100 million to build, operate and maintain over a 20 yr period. A solar array in the sunny southwestern part of the U. S., using a 70 percent sunshine factor, would generate at least $2.1 \times 10^9$ KWH/mi² yr. If the power were sold for 3¢/KWH, about twice today's rates, the gross return over a 20 yr period would be $\$1.26 \times 10^9$/mi². Subtracting the installation, maintenance and operating costs of $\$1.0 \times 10^8$/mi² leaves about $26 million net income per sq mi over 20 yr. This land is then producing a "crop" which yields about $2,000 per acre per year. Farm land yielding such a net return is considered premium.

**Table 4 Cost of 1 sq mi solar array power station**

| | |
|---|---|
| Solar array @ $0.50/ft² | $\$14 \times 10^6$ |
| Site construction | $\$28 \times 10^6$ |
| Storage and switching facility | $\$10 \times 10^6$ |
| Maintenance of storage facility (2 replacements in 20 yr) | $\$20 \times 10^6$ |
| Maintenance and operation of station (2 array replacements in 20 yr) | $\$28 \times 10^6$ |
| Total 20 yr construction maintenance and operating | $\$100 \times 10^6$ |

## Major Problems to be Solved

Before the large scale terrestrial use of solar energy to generate electrical power can take place, the cost of solar arrays must be reduced in cost between 3 and 4 orders of magnitude. The unautomated jewelry techniques presently used for making solar cells must be replaced by massive automated techniques using abundant low cost materials.

Instead of the 7 percent efficient arrays considered in this paper there is definite promise of doubling this performance within the next 5 to 7 yr by improving the solar cell material and better controlling the process.

Methods of constructing large area arrays on the ground from materials that can withstand many years of sunlight and weather must be developed. Large scale production of UV resistant plastic sheets, for example, would be required.

Development of large scale batteries, capable of long life and deep cycles, is needed to solve the 24 hr per day requirement. While the batteries will be operated at an ideal environment condition, they must have high storage density and be made of abundant and inexpensive materials. They should be constructed from materials that, after being formed, can be reprocessed time and again so as to eliminate the need for complete replacement of materials.

## Reasons for Converting Solar Energy Into Electrical Power

Following are some reasons why development should be started immediately on the conversion of solar energy to electrical power.

1 To conserve our irreplaceable natural resources such as gas, oil, coal, and nuclear ore so they can be used for more valuable purposes than just burning.

2 To make, considerable progress toward reducing atmospheric and thermal pollution which are having serious detrimental effects on our environment.

3 To make many thousands of acres of our sun rich land more productive and valuable in producing a marketable "crop" of electrical energy.

4 To make the U. S. less dependent upon foreign sources of energy.

5 To learn to utilize our most abundant and inexhaustible natural resource, solar energy.

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# REPORT ON THE USE OF SOLAR ENERGY

# FOR WATER PUMPING IN ARID AREAS

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This report has been compiled following work by Professor MASSON of DAKAR University.

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## 1°/ - SOLAR ENERGY : PROBLEMS OF ITS USE

The solar energy received at ground level is considerable (up to 1 K Watt/m2 in clear weather) and one wonders why its direct conversion into conventional energy is not more widespread, after decades of research and experiment.

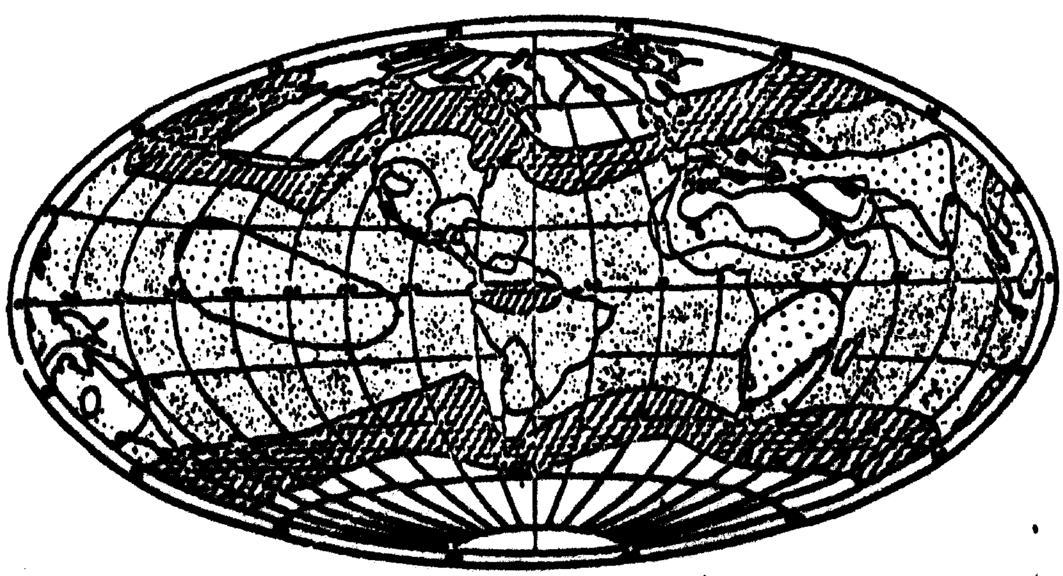
The reasons can be summarized as follows :

solar energy apart from its 3 major advantages (free, unlimited production, distribution independant of distances and obstacles) presents characteristics which can condemn it when the techniques and fields of application of its use are not thoroughly adapted to those characteristics.

The criteria which we think entirely condition the use of solar energy are the following :

1°/ - knowing that the suns's rays are very attenuated in cloudy weather, we must certainly (at least in the present state of capture techniques) adapt techniques to give priority to the needs and conditions of dry countries generally having clear skies for a large proportion of the year. Desert regions (for example the Sahara, the high Brazilian plateaux, Middle-East countries).

2°/ - knowing that solar energy is periodic, it should be applied to needs which are also periodic, not posing complex energy storing problems, for which water pumping and refrigeration are the best examples, noting that in both cases, the maximum need corresponds to maximum production intensity.



Area receiving more than 2.300 kwh per year.
Area receiving between 1.860 and 2.300 kwh per year.
Area receiving between 1.400 and 1.860 kwh per year.
Area receiving between 930 and 1.400 kwh per year.
Area receiving less than 930 kwh per year.

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3°/ - knowing that sunlight is dispersed, capture media must be realistic, and not necessarily be simply the result of laboratory logic (see paragraph 2 on different solar capture techniques).

4°/ - in short, knowing the present worldwide distribution of wealth and need, it is the developing countries which present the maximum useful solar area. Solar energy production and use research, as an instrument of development, must consider the overall limitations, and the economic resources and needs of these countries.

We should add that within these countries, we are more concernend with their rural areas than with the small industrial areas. This leads us to briefly define the chosen area of heliotechnical installations as being an area of sharp climatic limitations, generally rich in rapid erosion factors, badly supplied, inaccessible, inhabited by natives with an archiac way of life, and lacking modern technical qualifications.

It's in the light of these limitations that we are going to examine the range of solar material existing today.

## 2°/ - CONVENTIONAL TECHNIQUES IN SOLAR ENERGY CONVERSION

At present, the techniques for converting solar energy to usable energy are the following :

a) - direct conversion of solar energy into electrical energy -

Silicon solar cells can be used for this.

It can be considered for an energy received of : 1 KW/m2, with a 36 x 48 panel comprising 64 silicon cells, it is possible to obtain 8 watts, i.e. to obtain 175 hp would need 138 panels, (a surface of : 25 m2).

At first glance, this solution appears very attractive. However for the moment, it is much more expensive than engines, which are the subject of this survey.

Direct conversion of solar energy into electrical energy is, in the immediate future, limited to the space industry.

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b) - conversion of solar energy into mechanical energy using a high temperature thermic cycle -

Using these techniques, parabolic mirrors concentrate their rays on black bodies positioned at their focal points, the calories thus produced feed a conventional thermodynamic system to achieve a high thermodynamic output. Solar ovens are the most widely known application of this principle.

But these systems present problems which render them practically useless except in very special situations :

- the concentration requires parallel rays, and thus a complete absence of cloud, which is very rare.

- it also requires constant and precise mirror reorientation, thus requiring very complicated features, which are very difficult to maintain.

  (the collector - adjustment unit, which is often enormous, is particularly vulnerable to wind).

- the reflecting surfaces must be maintained in good condition, and perfectly clean, which necessitates great care.

## 3°/ - A DIFFERENT RESEARCH DIRECTION : LOW TEMPERATURE ENGINES AND PLANE COLLECTOR PUMPS

In short, conventional collectors, even those which are theoretically satisfactory, do not lend themselves to use in uncivilized areas where it would be preferable to install them.

For this reason it appeared necessary to totally change heliotechnical installation conception towards strength, simplicity and reliability which are the only characteristics allowing such an installation.

These options resultin the choice of a low temperature thermic cycle similar to refrigerator cycles.

Solar engines using this principle, work with temperatures no greater than 70°, which simple collectors or plane collectors, produce easily.

Low temperature solar engines, as they have been studied for the last ten years at l'Institute de Physique Météorologique de DAKAR, under the direction of Professor MASSON, and in close relationship with Etablissements Pierre MENGIN de MONTARGIS (France), have been especially designed for water pumping.

These solar pumps, although still prototypes, are not merely laboratory instruments. They are already used for agricultural, pastoral, and communal purposes, and are accessible to the population.

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Today, they total (particularly the SEGAL pump) several thousands of working hours and of cubic meters of water pumped. They are individually described later. Let us just say that at present, 4 prototypes are working in Africa, a 5th is being built, and 7 others planned.

4°/ - <u>MAIN PRINCIPLES OF A PLANE COLLECTOR SOLAR PUMPING STATION</u>

Plane collector solar pumps comprise essentially :

1°/ - A battery of insulators intended to heat the water circulating in a closed circuit by thermo-siphon, and which can also be used as a roof (see solar architecture theory later).

2°/ - A solar engine converting the sun's calorific energy into mechanical energy, by means of a low temperature thermic cycle.

3°/ - A hydropump intended for exhaust, comprising a hydraulic press situated close to the solar engine, and a hydraulically controlled piston pump at the bottom of wells.

<u>Access to the latter is very easy, because the well pump control is hydraulic, and therefore the solar engine can be installed more than 50 meters from the wells</u>.

<u>NOTE</u> -

This hydro-pump can be replaced by any other type of pump, particularly, for large installations, conventional vertical pumps which are indispensable.

4°/ - A pumped water storage reservoir.

**PATENTS** -

The low temperature engine has been the subject of various patents in France and abroad.

Channeled type collectors are also patented.

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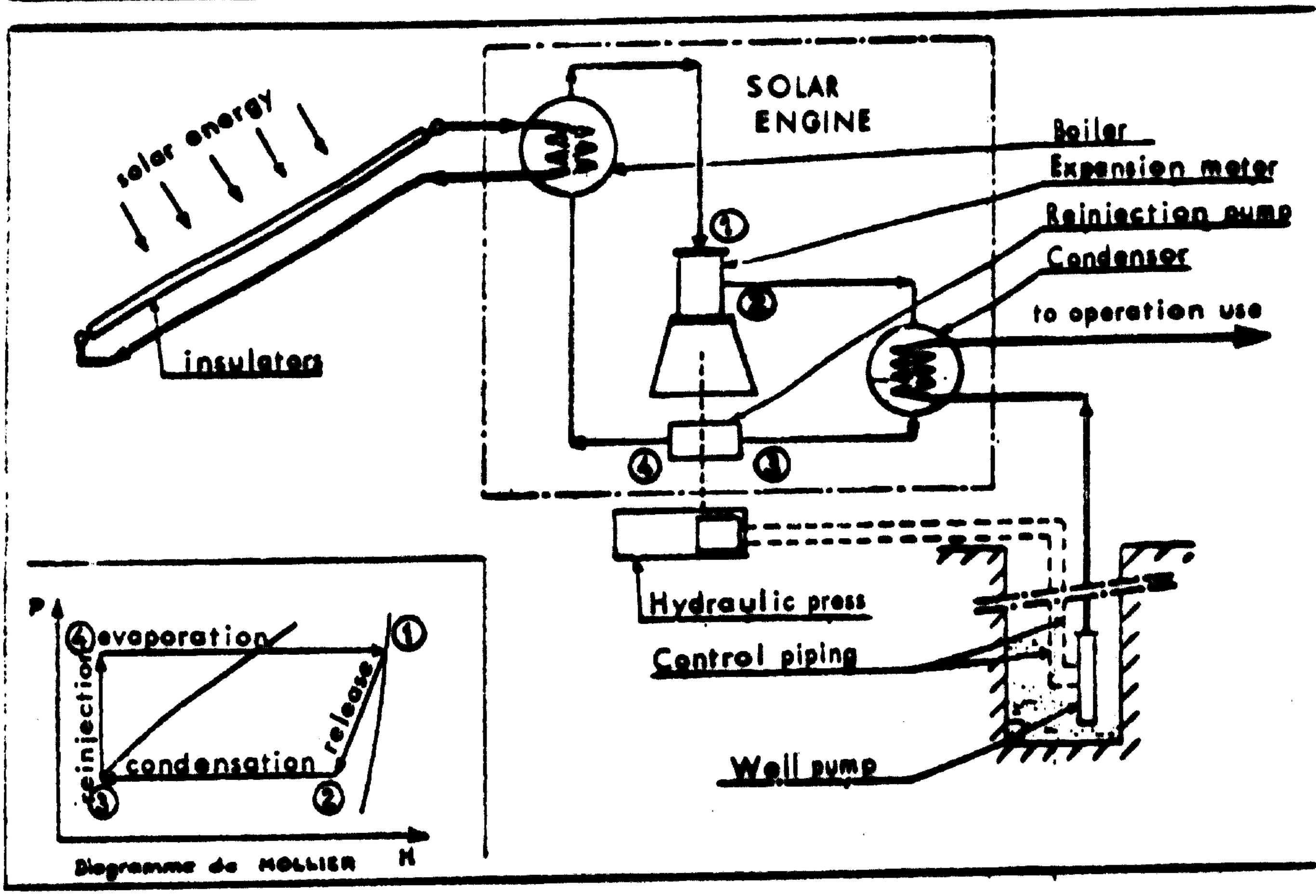
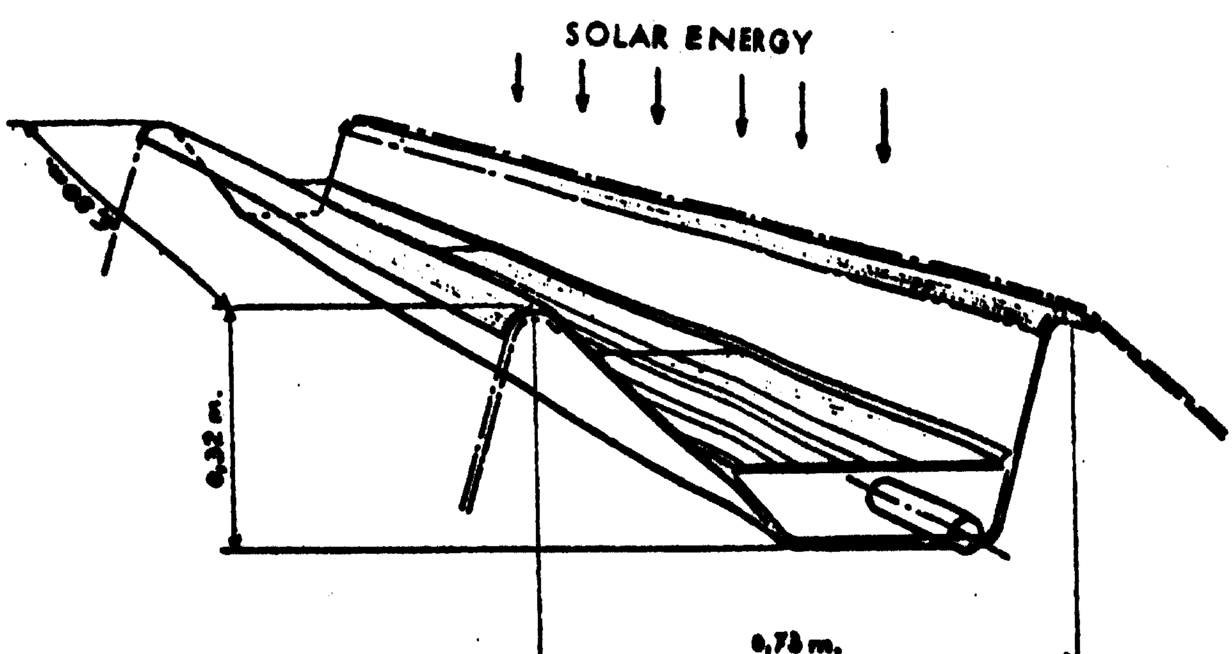
## SOLAR ENGINE WORKING PRINCIPLE

( Patented cycle)




Channeling

## 5°/ - TECHNICAL POSSIBILITIES

At the moment, we are limited to fairly low power, mostly because African wells in desert areas generally work at the rate of 8 to 10 m3/ hour, but this technique is not limited in power, and one can envisage very large assemblies.

To find applications other than deep pumpint in which solar features would be competitive, a comparative economics calculation must be performed. We are thinking particularly of low rise irrigation projects, which probably constitute one of the most profitable applications. And although research, up to the present time, has for financial reasons been limited to pumping, it is certain that the same machines, will, in the near future, produce refrigeration and electricity.

- for refrigeration, it is sufficient to expand a part of the low pressure liquide and to couple a compressor to the engine.
- for electricity, one could easily design larger assemblies, using air condensers cooled by running water, which eliminates necessity of water pumping, and allows the motor to drive a generator, which together with the motor forms a sealed assembly.

It is also possible, when close to a large mass of water (river, swimming pool, reservoir) to use this water with normal condensers. But at present, these techniques are meeting electrical storage problems.

## 6°/ - PRESENT APPLICATIONS AND SOLAR ARCHITECTURE

We have shown since the introduction in which direction we are carrying our development and research, and the target to which they are directed.

While developing these principles, we can arbitrarily list the following uses :

### 6-1/ - Village hydraulics -

The main need of isolated villages and oases is water.

These villages often have wells, but manual pumping occupies a large proportion of the time of the population to the detriment of other work. In addition, it is hard work, often performed by children to the detriment of their education.

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For this reason well mechanization is very important, providing it is running parallel with population reorganization and production development programs.

Solar pumps are well adapted to this problem, by their working qualities, and by their absence of operating costs, once the installation investment has been agreed.

Collectors show particular benefits in this kind of program, roofs which allow a real assembly, integrated with the village, to be achieved.

The principle of this solar architecture differs from most of the more well known examples, which are generally luxury residences in rich countries : U.S.A. , Australia, and where solar energy only brings additional luxury comfort.

The integrated assemblies examined by us (of which l'Ecole de CHINGUETTI will be the first example built in Africa) are mainly social installations or agricultural buildings, the aim of which is to participate in the necessary village modernization providing the more essential services, comfort and security of solar roofs, and this at a reasonable price.

Apart from education buildings, these are dispensaries, markets, and agricultural cooperatives and sheds which constitute the integrated assembly priority programs. Rural residences are also very suitable, and have been the subject of advanced research, but the absence or lak of funds available for rural residences has led us to only mention them in passing. As far as the tourist considerations are concerned, particularly Sahara expeditions, these would constitute different, but extremely interesting, programs.

6-2/ - Pastoral hydraulic -

This is a basic application, because nomadic tribes lose part of their weight through lack of water in the dry season.

It is therefore wise to plan automatic wells on their routes, to supply the water holes.

Solar pumps resolve this problem (this was tested for the first time at BOSSEY-BANGOU, with the ONERSOL pump).

Economically, one could say that bovines, fed normally with water and reaching 50 Kg live weight at slaughter, at 50 francs CFA (in 1970) i.e. 2.500 francs CFA per head.

A pump of the ONERSOL type could water simultaneously more than 1.000 head.

This application is the most immediately profitable, and could be linked with a village hydraulic problem.

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## 7°/ - PRESENT ACHIEVEMENTS

Remember that the group of achievements presented here are the result of university-industry collaboration.

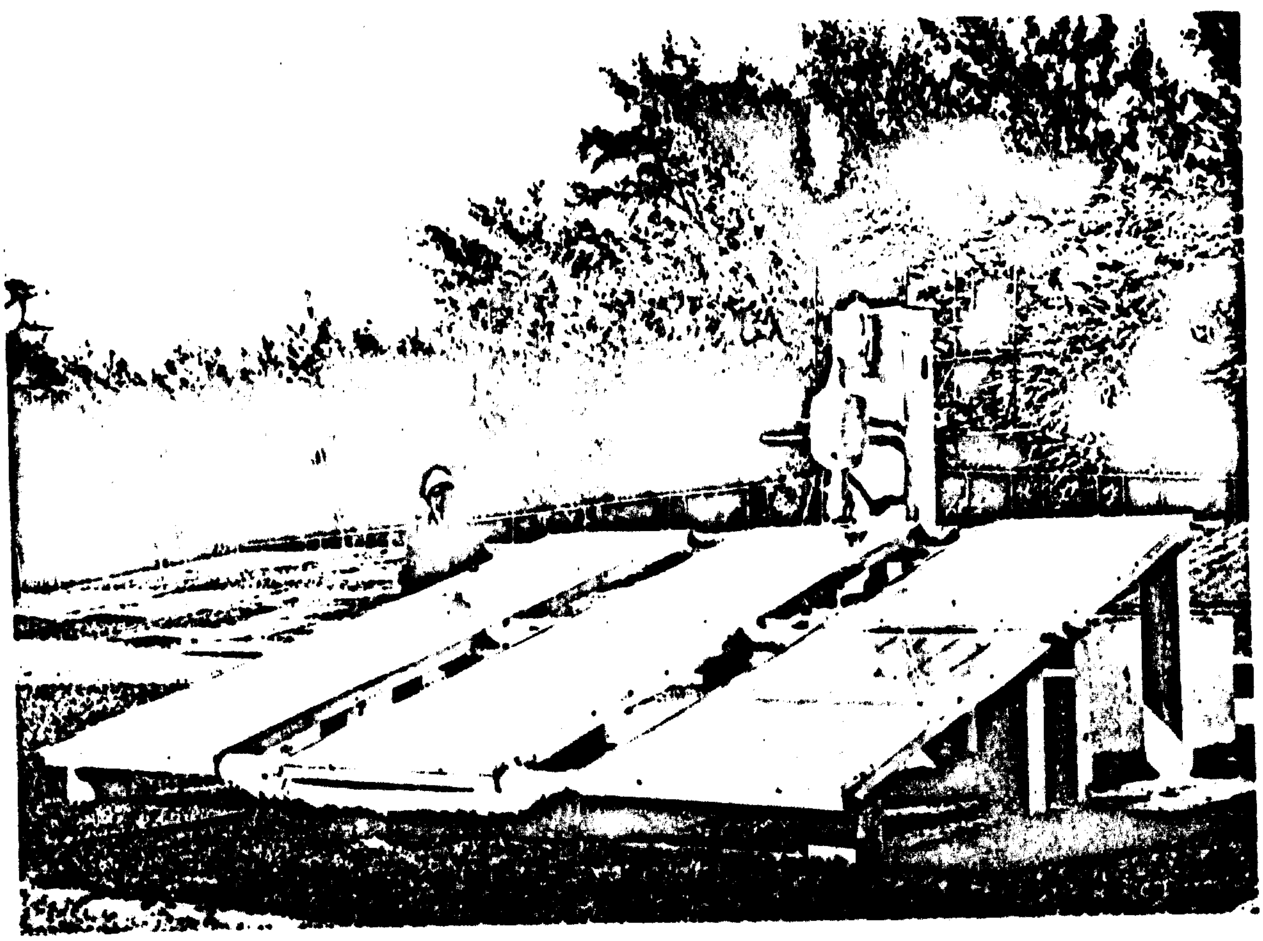
The various projects undertaken together have resulted in the following achievements :

(we are not referring to strictly experimental prototypes without application possibilities, such as : SECRA : 6 m2 and I.TEC : 300 m2).

a) - NADJE pump -

Technical characteristics :

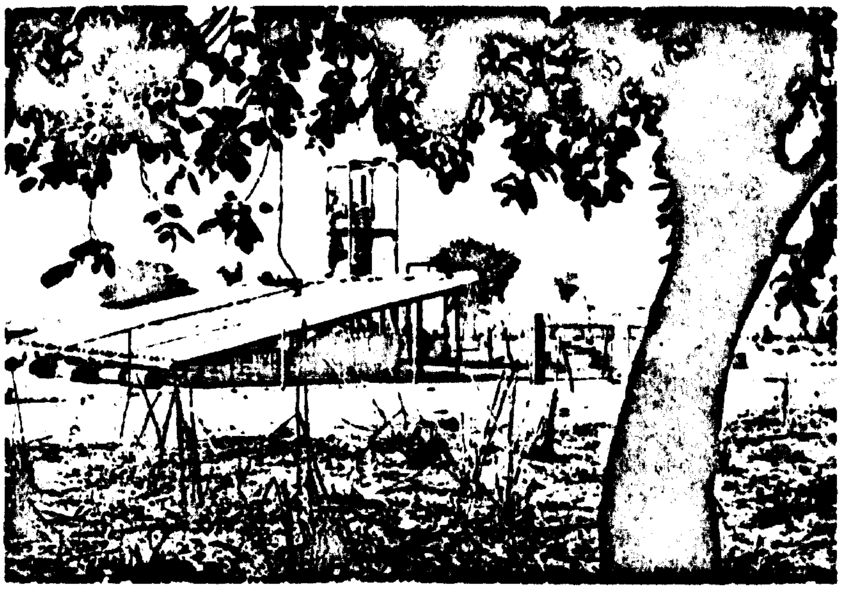
- collector area ........................ 12 m2
- rate .................................. 1,200 l/h.
- pressure height ....................... 15 m.
- working times ......................... 5 to 6 hours
- date operational ...................... 1966
- location .............................. Institut de Physique Météorologique de DAKAR (Sénégal).



b) - The ONERSOL pump

Technical characteristics :

- collector area ........................ 60 m2
- rate .................................. 6 to 7 m3/h
- pressure height ....................... 12 m.
- working time .......................... 5 to 6 hours
- location .............................. Office de l'Energie Solaire à NIAMEY (Niger) Village de BOSSEY-BANGOU



This pump met with a certain number of operational difficulties, as it was the first prototype sent to the operational location without the final detailed perfection.

This pump is now operational.

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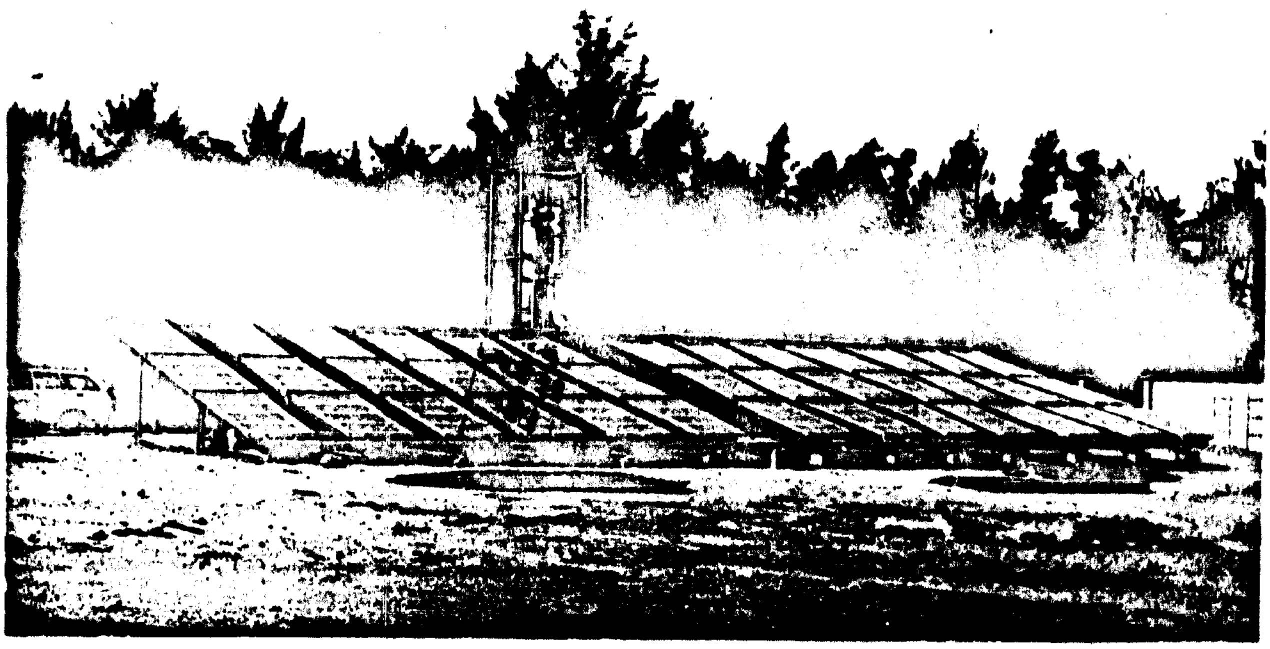
c) - **The [illegible] PUMP** -

**Technical characteristics** :

- collector area ............................ 80 m2
- rate ...................................... 6 m3/h
- pressure height ........................... 25 m.
- working time .............................. 5 to 6 hours
- date operational .......................... 1968
- location .................................. Institut de Physique Météorologique de DAKAR (Sénégal).



This pump is the reference prototype. It has been working uninterrupted, for almost one year.

It is going to be taken out into the bush between now and the end of the year.

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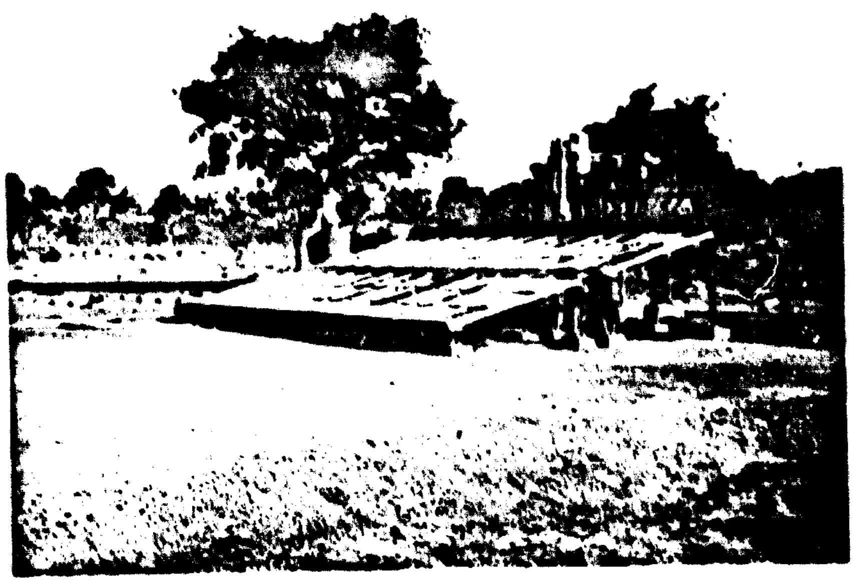
c) - The OUAGA pump -

Technical characteristics :

- collector area ........................ $30\ m^2$
- rate ................................. $2\ m^3/h.$
- pressure height ...................... 20 m.
- working time ......................... 5 to 6 hours
- date operational ..................... 1971
- location ............................. Ecole Inter-Etat d'Ingénieurs de l'Equipement Rural OUAGADOUGOU (Upper Volta).



This is an instructional pump which is used to test equipment, and it is on this that we are experimenting for the first time with commercial butane thermic cycles.

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e) - The CHINGUETTI pump -

Technical characteristics :

- collector area .............................. 88 m2
- rate .......................................... 8 to 10 m3/h
- pressure height ............................ 20 m.
- working time .............................. 5 to 6 hours
- date operational ......................... beginning of 1973
- location ...................................... CHINGUETTI (Mauritania).

This pump will bring water to about 2.000 people.

It will offer a place which can be used as a school.

It is the first integrated assembly and is the result of cooperation between heliotechnicians and architects.

It is also the first application of "solar channeled" collector panelled roofs.

The channeling comprises continuous, shaped roof panels as shown in the diagram on page 5.

The various panels are connected to each other, and are self-supporting.

They have been used for a number of years in economic construction, and have now been produced in Africa.

Their adaptation to the function of solar collectors consists merely of changing the base, this gives fairly economical collectors:

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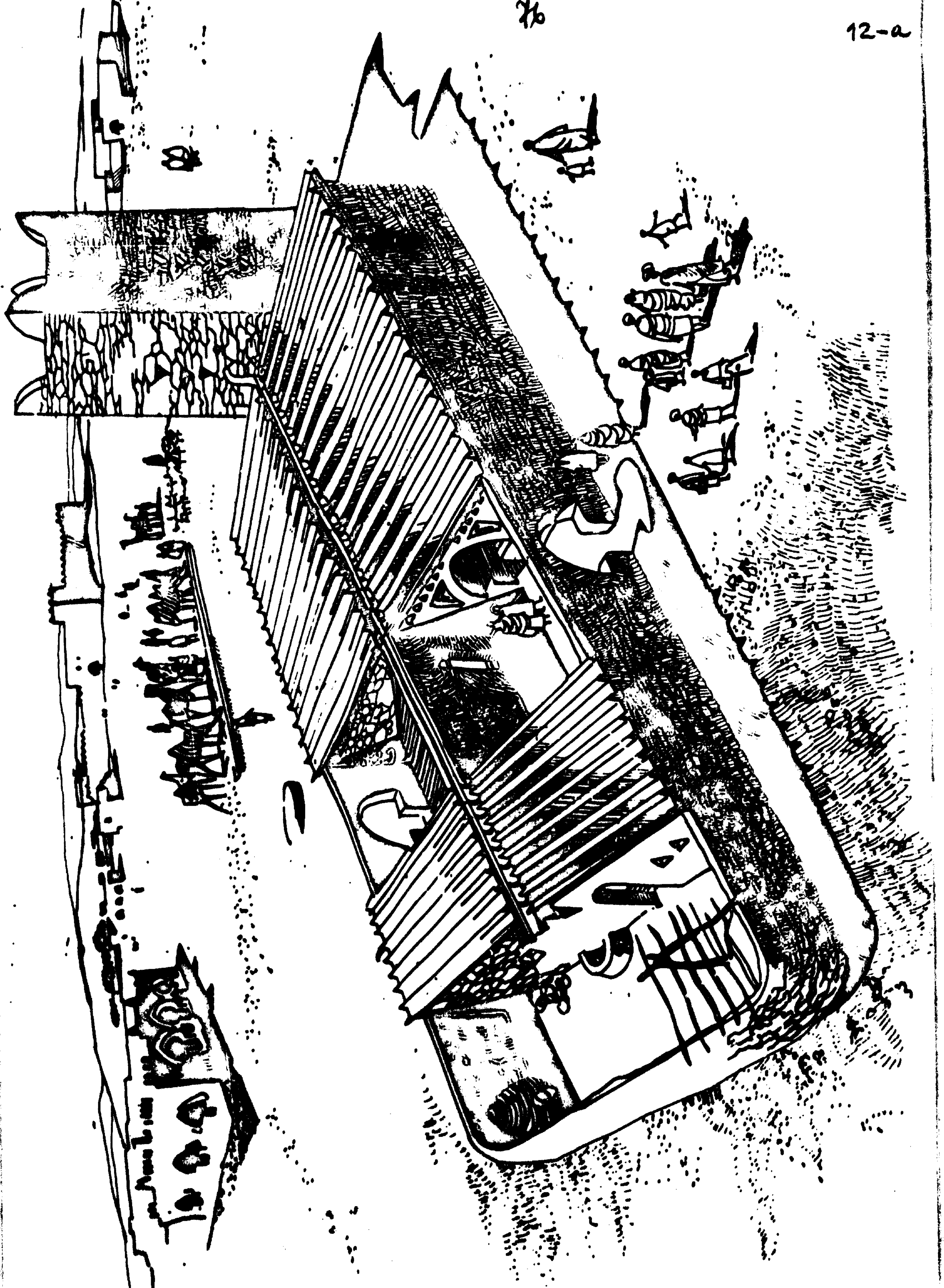

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## PUMP PROJECTS

a) - A 5 pumps project (equivalent to the SEGAL pump)

Technical characteristics :

- active area .............................. 85 m2
- rate ...................................... 8 to 10 m3/h.
- pressure height ......................... 20 m.
- working time ............................ 5 to 6 hours.

These projects are being studied with the Sénégal République.

The pumps will serve small communities of about 250 people and 500 to 600 animals.

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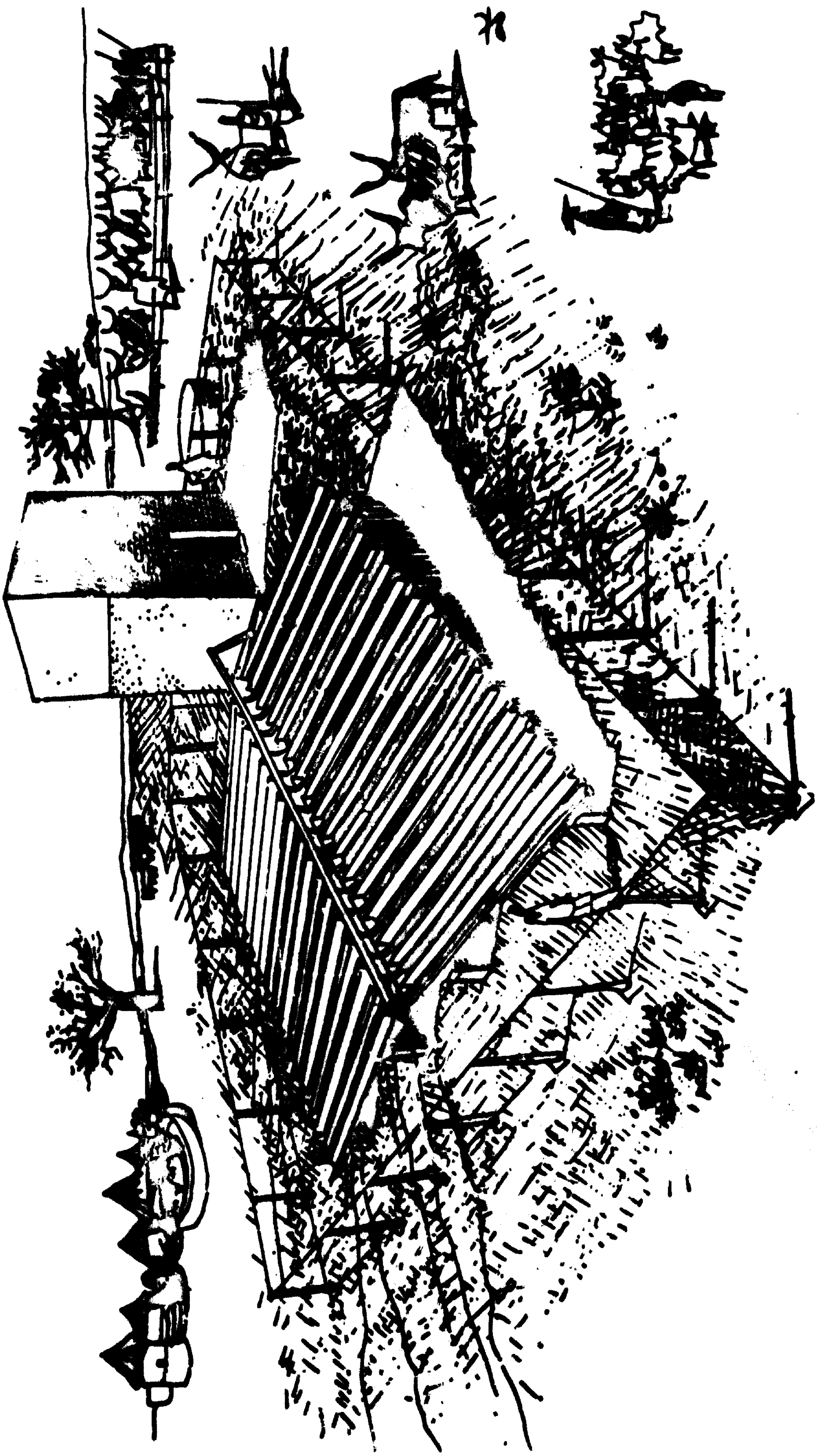

b) - A NIAMEY hospital -

Technical characteristics :

- active area .............................. 60 m2
- rate .................................... 5 m3/h.
- pressure height .......................... 40 m.
- working time ............................. 5 hours
- location ................................. Lazaret Hospital.

This is an existing isolation center, which will now be provided with sufficient water.

The project consists of installing a channeled collector on the roof, which at first, will bring water not only to the hospital but also to the surrounding area. The project will then be (depending on sufficient funds) to continue the survey to provide electricity for the hospital and medical supply refrigeration.

This will be a hospital group prototype, which could be reproduced anywhere in tropical Africa.

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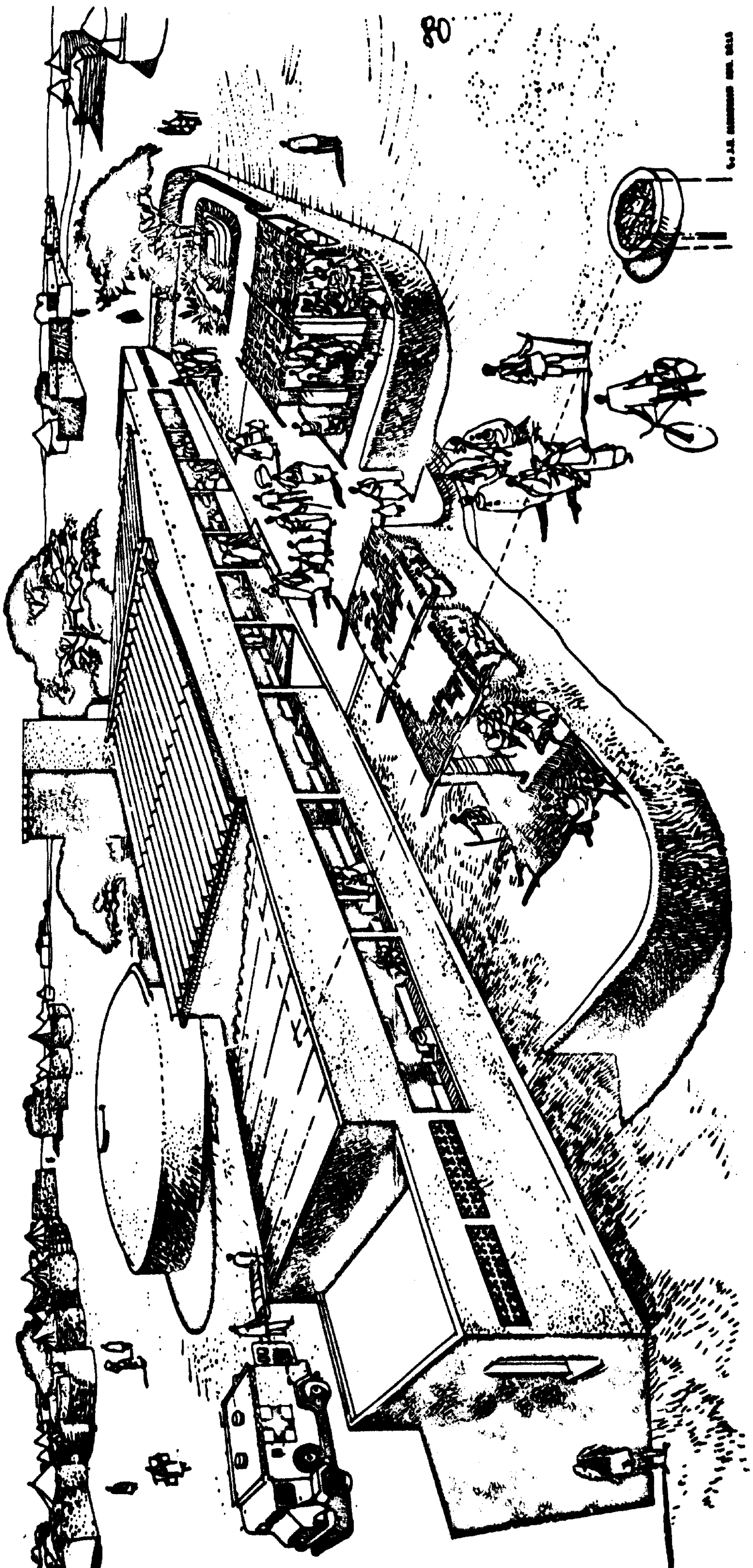
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c) - an irrigation pump -

Technical characteristics :

- active area .............................. 350 m2
- rate ..................................... 21,5 m3/h (6 l/s)
- pressure height .......................... 30 m.
- working time ............................. 5 to 6 hours.

When the heights to be raised are not very great, larger assemblies could be planned for the irrigation of isolated areas.

At present, a project of this kind is being studied at the request of the Ministère de l'Hydraulique de la Wilaya des Oasis, in the Algerian Republic.

We have designed a solar pump to resolve problems posed by water supply to small operations and cooperatives around Oasis.

A finance request for this project has benn made.

This assembly would irrigate several hectares of desert area.

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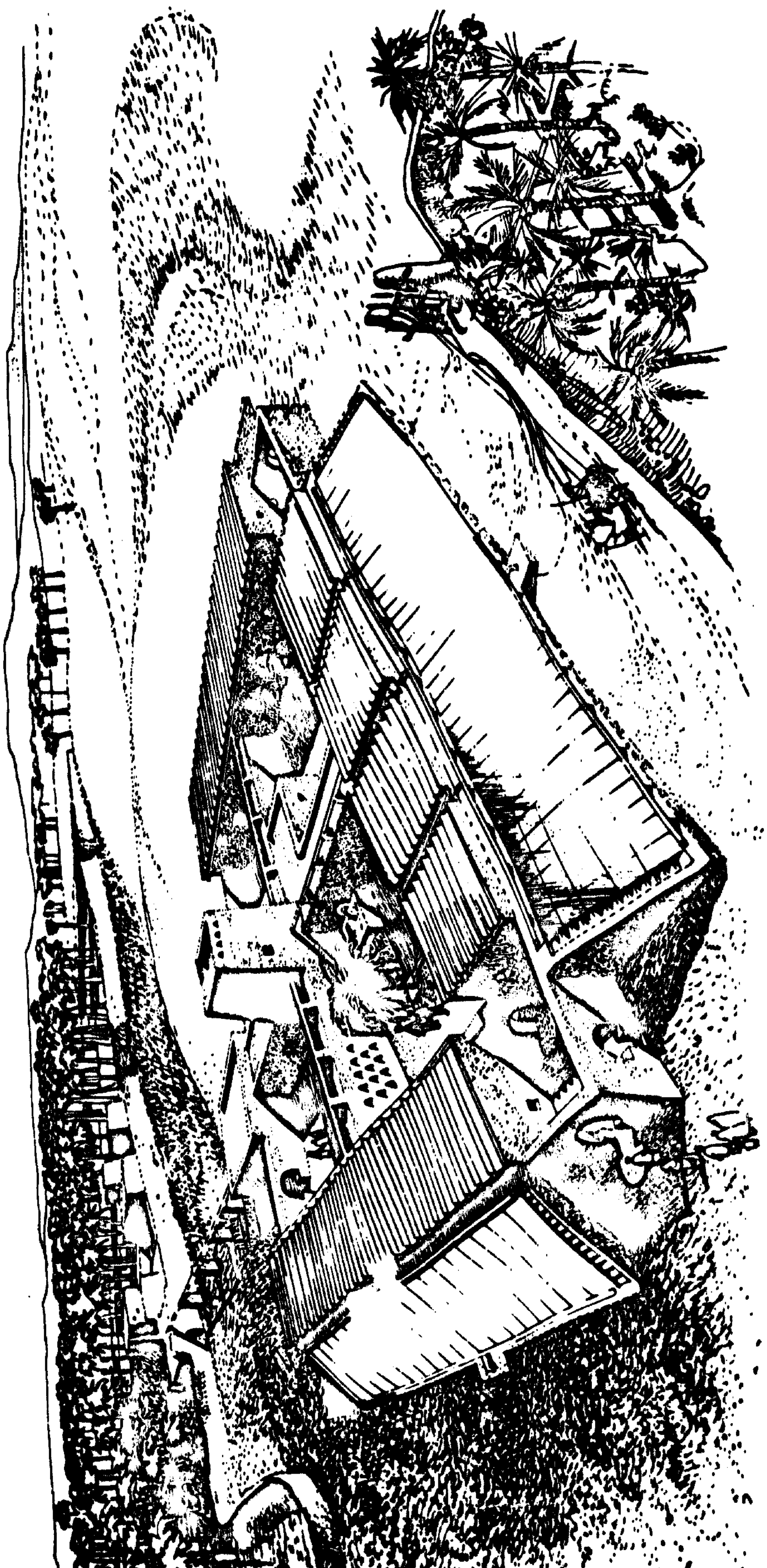

d) - Tourist centers (CARAVANSERAIL)

Across the Sahara, the problem of a journey in stages is a direct application of this procedure, which also applies to isolated tourist centers.

The water reserve (swimming pool for example) gives condenser cooling and the assembly could easily produce the electrical energy necessary for the functioning of the center.

Consequently, there are no obstacles to this kind of operation, to create entirely autonomous tourist centers.

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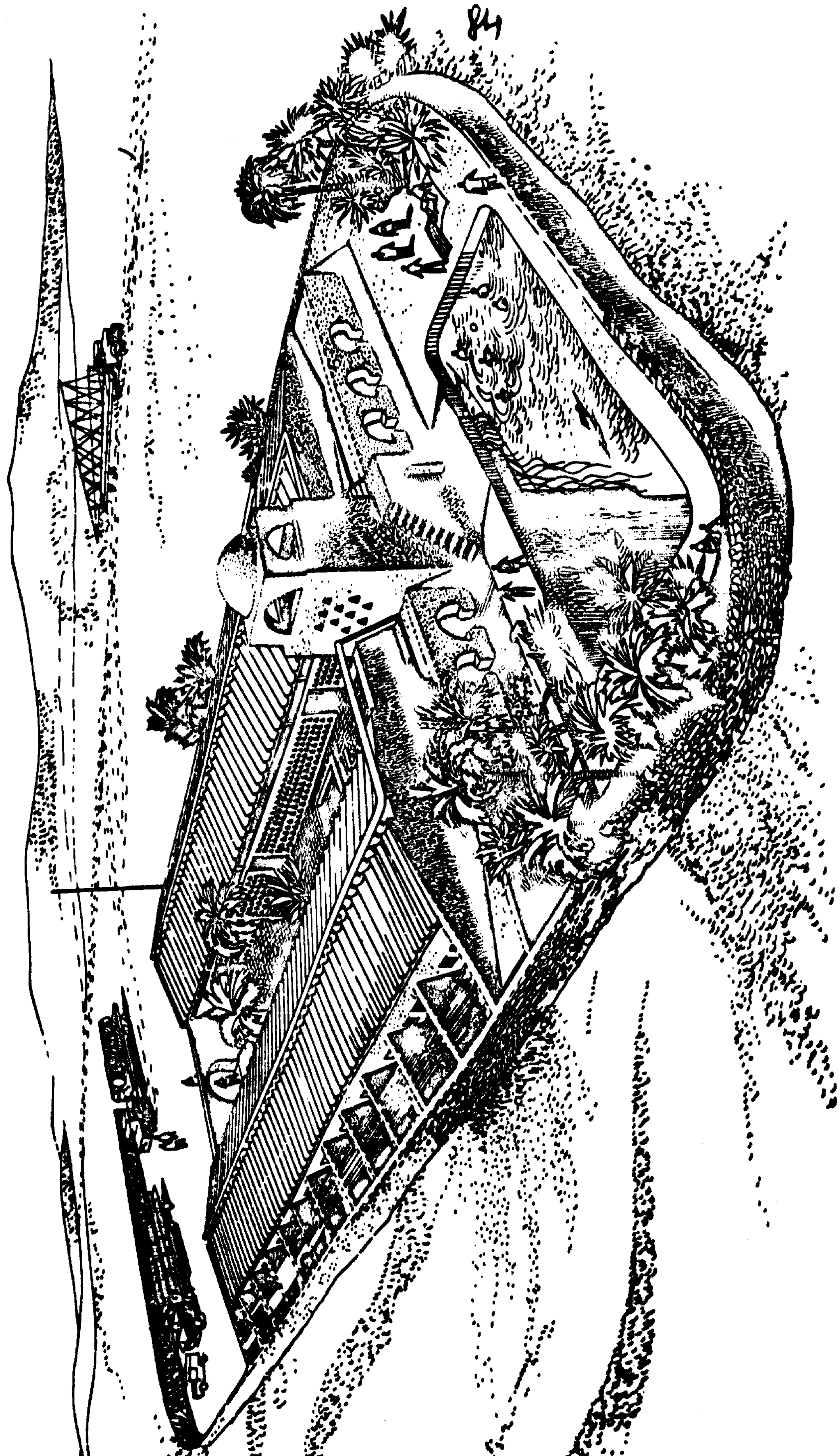

## 8°/ - CONSIDERATIONS ECONOMIQUES

Il est très difficile de faire dès maintenant une analyse économique comparative, compte tenu du fait que ces moteurs solaires commencent seulement à être fabriqués au stade industriel, et qu'on les compare avec des moteurs Diesel fabriqués depuis des années, en grande série.

Cependant, on peut dégager des grandes lignes des niveaux de prix, et ainsi positionner les moteurs solaires par rapport aux moyens classiques.

Prix actuels des moteurs solaires -

a) - Nous donnons des prix approximatifs dans l'état actuel des choses, c'est à dire au stade des prototypes, et dont l'ensemble est fabriqué en France.

Prototypes (FOB port d'embarquement français).

| TYPE | Débit | HMT | Puissance à l'arbre | Surface couverte | Prix HT FOB |
|---|---|---|---|---|---|
| NADJE | 1 m3/h | 20 m | 0,15 CV. | 15 m2 | 55.000 |
| OUAGA | 2,5 " | 20 m | 0,3 CV. | 30 m2 | 94.000 |
| ONERSOL | 6 " | 16 m | 1 CV. | 60 m2 | 139.000 |
| SEGAL | 6 " | 25 m | 1,3 CV. | 88 m2 | 145.000 |
| * MIFERMA | 6 à 8 | 25 m | 1,5 CV. | 80 m2 | 170.000 |
| ALGERIE | 42 " | 30 M | 13 CV. | 700 m2 | 505.000 |
| IRRIGATION | 1.700 " | 9 m | 90 CV. | 3.000 m2 | 2.000.000 |

Base : JUIN 1972

A rajouter : le transport et montage sur place.

* partie pompe solaire seulement.

Cette station est comparativement plus élaborée que les autres (moteur de secours, etc ...) compte tenu de l'endroit où elle est installée.

b) - réalisations futures -

Dans l'avenir, il faut chercher à fabriquer le maximum d'éléments sur place : c'est à dire le collecteur (c'est déjà le cas de celui de CHINGUETTI) les tuyauteries de liaison, et probablement, le condenseur et échangeur.

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En dehors de celà, après les premières réalisations, et sous réserve d'un certain nombre de commandes, les prix devraient baisser de façon très sensible.

DEUX CAS SE PRESENTENT :

a) - ensembles non intégrés -

(pompe pour elle-même, sans autres applications).

| - puissances de références ......... | 0,15 | 1 | 1,5 | 10 |
|---|---|---|---|---|
| - débit .............. | 1 m3/h. | 6 m3/h. | 10 m3/h. | 65 m3/h. |
| - Hmt (références) .. | 20 | 20 | 20 | 20 |
| - surface de collecteur (m2) .......... | 15 | 60 | 80 | 550 |
| **Fait sur place :** | | | | |
| - insolateurs ....... | 5.000 | 25.000 | 38.000 | 200.000 |
| - charpente ......... | 1.500 | 5.000 | 6.000 | 10.000 |
| - condenseurs ....... | 3.000 | 5.000 | 6.000 | 12.000 |
| - tuyauteries ....... | 3.000 | 4.000 | 4.000 | 10.000 |
| - peinture - calorifugeage ........... | 1.000 | 3.000 | 3.000 | 5.000 |
| TOTAL FAIT SUR PLACE | 13.500 | 42.000 | 57.000 | 237.000 |
| **Fait en France :** | | | | |
| - échangeur .......... | 4.900 | 15.000 | 17.000 | 45.000 |
| - moteur ............ | 6.000 | 6.000 | 15.000 | 30.000 |
| - fluide ............ | 310 | 500 | 500 | 1.000 |
| - pompe de puits .... | 2.000 | 6.000 | 6.000 | 20.000 |
| - transport ......... | 1.000 | 2.500 | 2.500 | 6.000 |
| TOTAL IMPORTE, hors droits de douane .... | 14.210 | 30.000 | 41.000 | 102.000 |
| TOTAL ............ | 27.710 | 72.000 | 98.000 | 339.000 |
| **A titre indicatif :** | | | | |
| - prix par m3 d'eau pompé sur 10 ans d'amortissement, sans tenir compte du taux d'intérêt de l'argent....... | 1,56 Fr/m3 | 0,68 Fr/m3 | 0,56 Fr/m3 | 0,30 Fr/m3 |

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Ces prix sont donnés pour une hauteur manométrique de référence égale à 20 m.

Pour l'irrigation, cette hauteur est souvent inférieure, par exemple dans le projet (irrigation 1.700 m3/h).

On arrive au niveau prototype, à un prix de revient par m3 de : 0,07 Fr. (sans tenir compte du taux d'intérêt de l'argent) et dans un avenir proche, ce prix pourrait être abaissé dès les 5 ou 6ème réalisations de ce genre à : 0,05 Fr/m3.

b) - dans les ensembles intégrés -

Ces prix sont encore plus favorables, car le collecteur s'amortit en tant que toiture, et de plus, l'énergie du moteur peut être utilisée à d'autres tâches que le pompage.

Il est très difficile de comparer avec des stations classiques, car il y en a très peu dans les régions isolées, mais on peut dire d'après les renseignements de l'O.F.E.D.E.S. du NIGER d'une part, et du Ministère de l'Hydraulique du Sénégal d'autre part, qu'une station de 10 m 3/h. par exemple revient à 2 millions CFA par an d'amortissement, y compris les frais d'entretien et de gardiennage.

Si l'on compte une durée d'amortissement d'une dizaine d'années, on arrive dans les prix d'investissement des pompes solaires, mais surtout il y a des régions où les moteurs Diesel sont pratiquement inutilisables, comme dans le Sud-Algérien par exemple (rapport ci-joint).

Cette étude économique est très succincte. Elle ne sert à apporter que des ordres de grandeur qui prouvent que même dans les premières applications, l'énergie solaire est utilisable.

C'est surtout après un certain nombre de réalisations que l'on pourra juger de l'économie réelle de ce genre de station.

Mais on peut dire d'ores et déjà que cette technique apporte le développement dans des régions où les moyens classiques sont inopérants.

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## ORGANIZATIONS HAVING FINANCED RESEARCH AND PROJECTS

1°/ - Institut de Physique Météorologique de DAKAR -

for : - SECRA prototype and the evaluation and improvements on the prototypes existing in Sénégal.

2°/ - D.G.R.S.T. -

for : - the ITTEC prototype and development of thermic exchanger.

3°/ - Fonds d'Aide et de Coopération (FAC)

for : - the SEGAL and ONERSOL prototypes, as well as the production of the engine itself, and butane tests.

4°/ - Ministère de l'Industrie - (FDES contribution to Ets MENGIN)

for : - development and financing of all existing applications.

5°/ - ANVAR -

for : - engine mechanical development.

6°/ - MIFERMA - (Mines de Fer de Mauritanie) -

for : - the order for the first experimental integrated assembly. (CHINGUETTI).

7°/ - Etablissements Pierre MENGIN -

for : - study, research and development of various prototypes.

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For any information concerning this survey, write to :

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## SOLAR WATER-RAISING INSTALLATION INCORPORATING PHOTOCONVERTERS AT THE OVEZSHIKH WATERING POINT IN THE TURKMEN SSR

N. S. Lidorenko, B. V. Tarnizhevskii, B. Ya. Rodichev, G. B. Levitskii and S. Khandovletov

Geliotekhnika, Vol. 6, No. 2, pp. 52-55, 1970

UDC 662.997:663.634

A solar power installation incorporating photoconverters was constructed in April 1969 at the Ovezshikh watering point in the Bakhardenskii region of the Turkmen SSR. The system was developed at the All-Union Institute for Current Sources (VNIIT) for water raising purposes. This was the first practical Soviet solar installation based on the principles of direct conversion of solar energy into electric power to be used in agriculture.

This solar power installation (SPI) is essentially similar to that described in [1] (as far as concentrators, steering equipment, etc., is concerned). The main differences are in the design of the photoelectric battery which is the main part of the installation. The modifications were introduced in the light of practical experience with the first SPI designs of 1965. It is important to note that prolonged operation of these first solar power installations forms an essential stage in the development of practical installations because no such experience was available prior to 1965.

The initial experience with the first SPI's showed that the photoelectric batteries were not adequately protected from atmospheric effects and this reduced their output power [2]. Moreover, the water cooling system for these batteries turned out to be very inconvenient in practice, and could not be used at temperatures below the freezing point. Experimental and theoretical studies of the temperature distribution within the photoelectric cells showed that in the case of concentrated irradiation [3] it is quite satisfactory to use air cooling of the batteries if they are provided with suitable cooling fins.

In the new designs the battery is in the form of a finned radiator with the battery mounted on the irradiated surface. The battery is protected with glass which is in intimate contact with the entire surface. In view of the increased weight of the battery it was necessary to modify the design of the steering frame. The air-cooled photoelectric battery of this design was constructed in 1967 and was used in the solar power installation built near Ashkhabad at the Experimental Base of the Physicotechnical Institute, Academy of Sciences Turkmen SSR.

Measures which have been taken to protect the photoelectric battery from atmospheric effects have been found to be very effective: there has been no change in the output power during the first two years of operation. Repeated measurements of the electrical parameters showed that they remained constant.

The Ashkhabad installation was transferred after two years of operation to the Ovezshikh cattle watering point. In accordance with the designs provided by Soyuzvodproekt in collaboration with the Physicotechnical Institute, Academy of Sciences Turkmen SSR, and VNIIT, a solar energy system was assembled for the raising and distillation of water [4]. The ground water has to be distilled in this locality because of its high mineral content (up to 30 g/l).

The figure shows the arrangement of the water-raising equipment, the system of pipes, reservoirs, and so on (in vertical projection) together with an indication of the various heads of water and heights. Electric pump 2 is mounted inside well 1 at a height of about 0.8 m above the static water level. This pump raises the saline water through pipe 3 into reservoir 4 which has a capacity of 50 $m^3$. It then flows under gravity through pipe 5 into solar still 6. The distillate produced in the still again flows under gravity through pipe 7 into collector 8 which has a capacity of 10 $m^3$. The distilled water is forced by electrical pump 9 along pipe 10 into tanks 11 and 12 which have a capacity of 250 $m^3$ each.

Floating maximum-level indicator 17 is placed in tank 8 at level −1.4 and a similar minimum level indicator 18 is placed at mark −1.9. In saline-water tank 4 the maximum level indicator 19 is placed at mark 2.6.

From tanks 11 and 12 the distilled water flows freely along pipe 13 into mixing tank 14, which also receives saline water from tank 4 along pipe 16. The two media are mixed in the required proportions and the mixture flows freely into their final water trough 15.

All the reservoirs are made of reinforced concrete. The large volume of the tanks collecting distilled water is dictated by the annual variation in the output of the solar still.

The solar power installation is mounted on one of the distilled-water reservoirs. One of its functions is to supply the two electric pumps which raise the water from the well and then transfer the distilled water from the distillate tank. Provision is made for the alternate operation of the two pumps.

The system operates as follows. When the insolation is $E > 300$ W/m$^2$, the irradiance probe produces a signal which switches on the control system and the search for the sun and sun-tracking begin. As soon as direct solar radiation is intercepted with $E = 400\text{-}500$ W/m$^2$ the power probe produces a signal which switches

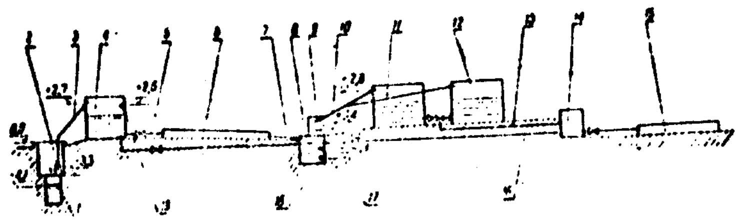

Diagram illustrating the arrangement of the Ovezshikh system. The notation is explained in text.

on the motors.

The first to be switched on is the pump 9 which transfers water from collector 8 whenever the water level in this collector is higher than that of probe 17. If the maximum level probe is not closed then pump 2 is switched on. If the water level in the distillate collector rises above probe 17 then pump 2 is switched off and pump 9 comes into operation and continues to pump until the minimum level indicator 18 produces its signal. At this point pump 9 is switched off and pump 2 is switched on again. The maximum level indicator 19 shows when the saline water in tank 4 reaches a level of 100 mm below the end of pipe 3. This probe switches off pump 2 as soon as there is any danger of overflow.

Three trucks were necessary to transport the solar installation and the water-raising equipment from Ashkhabad and Ovezshikh. The supporting metal construction was assembled manually while the steering frames which carry the mirrors and photoelectric batteries were raised with a manually operated winch.

'Kama' pumps operating in conjunction with VRV-150 d.c. motors (27 V, 11.5 A, shaft power 150 W) were used as the water-raising equipment. The pump used to raise saline water is made of titanium whereas the other pump is made of stainless steel to prevent rapid corrosion. The pumps are connected into the system as a whole in such a way that they are protected from flooding when the motors are suddenly switched off for a period of any duration (for example, as a result of cloud cover).

Tests have yielded the following data: the electric power output is 420 W for an insolation of 800 W/m$^2$, air temperature of 17°C, and wind speed in the range 2.5-3.5 m/sec. The optimum voltage is 27 V, the short-circuit current is 21.6 A, and the emf is 42.4 V. When the pumps are supplied by the entire installation the consumed power is found to be 360 W. The output of the saline-water pump is 2.5-2.6 m$^3$/hr while the output of the distilled water pump is 2.6-7 m$^3$/hr. The power balance of the installation is described in greater detail in [5].

Experience has shown that the pump is in fact too fast for the well. Four to five hours of continuous operation of the pump is found to empty the well completely. In order to prevent the complete emptying of the well and dry operation of the pump, attempts were made to operate the pump from 2/3 of the output of the solar battery (the battery mounted on one of the three steering frames was switched off). However, even in this case the pump output was about 2.2 m$^3$/hr at 260 W.

The first stage of the solar still (600 m$^2$) is nearing completion, and when it is ready the entire system will become operational and will be transferred to the agricultural authorities.

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20 December 1969

All-Union Scientific-Research Institute for Current Sources

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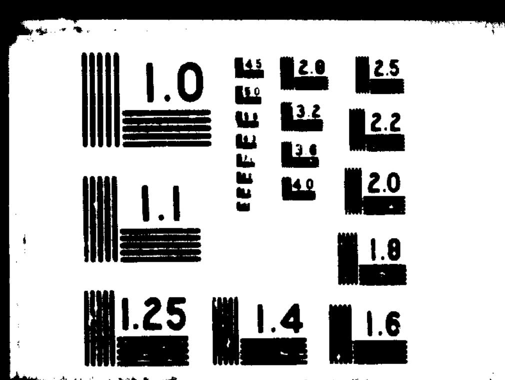

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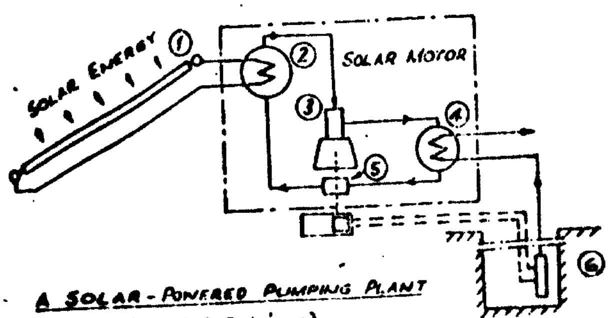
# A SOLAR-POWERED PUMPING PLANT

Over the past few years the University of Dakar in West Africa has developed a solar-driven pump for use in remote arid areas.

The principle of operation can be seen from the diagram. Water leaving a solar heater (1) at about 70° C (160° F) is used to vaporize a secondary fluid in a heat exchanger (2). The vapour, at a pressure corresponding to its temperature, is expanded in an engine cylinder (3) and then exhausted to a water-cooled condenser (4). The condensate is returned to the heat-exchanger by a small direct-coupled feed pump (5), thus completing the closed working cycle.

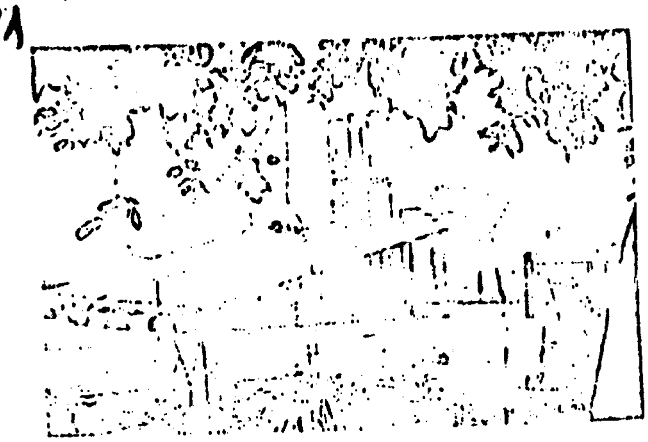
The water pump (6) is also driven by the engine. Its discharge passes first through the condenser tubes and then to an elevated storage tank, from which it is reticulated to the points of consumption.




A SOLAR-POWERED PUMPING PLANT
(after P J. Schéma)

The system uses a flat-plate type of solar absorber, operating on natural circulation. No external power source is required, and once the system is up to pressure in the morning the engine can be started with a quarter-turn of its flywheel. It will continue to run as long as adequate solar energy is being received. In Dakar, for example, the daily operating period is about five hours.

Pumps of this type are in service in Senegal, Haute-Volta and Niger, while a large installation is being built in Mauritius. Output is a function of the absorber area, which in present installations ranges from 6 $m^2$ (65 sq ft) to 300 $m^2$ (3230 sq ft). Typically, a system with an 88 $m^2$ (950 sq ft) absorber can deliver water at the rate of 5 $m^3$/hr (22 US gpm) from a source at a depth of 35 m (115 ft).



Further information on the solar pump can be obtained from Prof. H. Masson, Université de Brazzaville, Brazzaville, République du Congo.

FROM ISES NEWSLETTER No 3 1973

TECHNOLOGICAL DEVELOPMENTS SECTION

TECHNICAL INFORMATION SERVICE

NATIONAL RESEARCH COUNCIL
CONSEIL NATIONAL DE RECHERCHES

CONCEPT OF MAGNETIC MOTOR PUMP DIRECTLY POWERED BY SOLAR HEAT

New Scientist(US), Sept.21,'72, p.487

D. Landel

SERVICE DE RENSEIGNEMENTS TECHNIQUES

***This simple magnetic device, developed by Moscow engineer Alexander Presnyakov, converts solar heat directly into mechanical power. The rim of the wheel is made from an alloy with a Curie temperature of 65° to 100°C. This is the temperature at which the material becomes non-magnetic. When the temperature of the ring reaches this point, the large permanent magnet near the inside of the rim will attract the next section which is still cool enough to remain magnetic. The rim continues to revolve in this way as long as the part over the magnet is heated. Presnyakov hopes his invention will be of use as a pump for raising well water among other applications***

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# STUDIES ON HOT-AIR ENGINE RUN WITH SOLAR ENERGY CONDUCTED AT THE NATIONAL PHYSICAL LABORATORY, NEW DELHI, AND A CRITICAL REVIEW OF ITS PRESENT STATUS

by

M.L. KHANNA

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# STUDIES ON HOT-AIR ENGINE RUN WITH SOLAR ENERGY CONDUCTED AT THE NATIONAL PHYSICAL LABORATORY, NEW DELHI, AND A CRITICAL REVIEW OF ITS PRESENT STATUS

by

MOHAN LAL KHANNA*

## SUMMARY

During the fifties some work on the use of a hot-air engine for lift irrigation was conducted at this laboratory, the details of which have so far remained unpublished. But several subsequent workers have referred to this work while describing hot-air engines developed by them.

A small hot-air engine, coupled to a small reciprocating water pump, was mounted at the focus of a parabolic reflector and trials were made for pumping water from different depths. Mention may be made of two concentrators: one with an effective aperture of 11.6 sq ft and depth of 2.25 ft and the other of 28.3 sq ft effective aperture and depth of 4.5 ft. Main difficulties encountered with big size metal reflectors were in the construction of large reflectors with the desired focus-spread, heavy supports, turning mechanism, counter-balancing with heavy weights, etc.

Later, another larger capacity hot-air engine was used with plane-glass-mirror concentrators, which were used to concentrate solar energy.

A hot-air engine, developed by Messrs Philips, Eindhoven, was obtained for operation with solar energy. The heating system, designed for burning kerosine oil, was removed and concentrated solar energy was made to fall on the metal alloy plate, which formed part of the engine. The engine could be made to run at its rated r.p.m. when coupled to the generator.

A heat exchanger or regenerator is the heart of a hot-air engine. Its performance below the expected theoretical level and the sources of the efficiency or losses of a hot-air engine are critically reviewed keeping in view the work done so far by different groups on hot-air engines operated with solar energy.

## 1. INTRODUCTION

In 1860, Robert Stirling had his invention of a hot-air engine patented. The engine is a simple but elegant machine with advantages of being quiet in operation, requiring little effort in maintenance and being of use over wide ranges of temperature. However, the hot-air engine remained in the background, because the steam engine and the internal combustion engine were developed almost simultaneously. After a century, interest in the hot-air engine is being revived. The potentialities of the Stirling cycle have prompted several investigators [1-13]** in recent years to re-examine this cycle. During the fifties some work on the possibility of using a hot-air engine as a prime mover run with solar energy for lift irrigation was conducted in this laboratory; the details of this work have so far remained unpublished. However, many subsequent workers [14-18] have referred to this work while describing hot-air engines developed by them. In the present paper, studies on a hot-air engine run with solar energy conducted in this laboratory have been described in detail. The present status of the hot-air engine has also been critically reviewed.

Studies conducted in this laboratory on a solar operated hot-air engine may be divided into two parts, viz. the equipment used to concentrate solar heat onto the engine and the hot-air engine itself. These will be considered separately.

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* The author is a Senior Scientific Officer, National Physical Laboratory, New Delhi, India.

** Numbers in brackets refer to references listed at the end of the paper.

## 2. CONCENTRATORS

Experience gained in the development of different designs of solar cookers [19,20] was of great help in the design and construction of large size metal concentrators used in concentrating solar heat. The first metal parabolic reflector with a wide aperture and low depth constructed with m.s. rods and thin tin-plated m.s. sheets was similar to the reflector used by Ericsson and was suitably mounted on a turning mechanism. Its gearing device at the base facilitated seasonal adjustment, while the daily adjustment was made by turning the reflector around an axis passing through the focus. This arrangement enabled the direct solar radiation incident on the tin sheet to be focussed onto the bottom of the cylinder of the hot-air engine mounted upside down along the axis of the paraboloid. The hot-air engine could be made to run at its rated r.p.m. under no load but could not provide sufficient power to run even a small reciprocating water pump through a leather belt.

After conducting some trials, another reflector was designed. This consisted of three parts, viz. lower portion, middle portion and upper portion adjacent to the aperture rim. Each portion was prepared by beating a copper sheet along a curved surface and by matching it to a template of the requisite contour. The thickness of the copper sheet was so chosen that it gave rigidity to the reflector surface thereby avoiding the formation of distorted and diffused focus-spread. Each portion had its own paraboloid surface, but the focal length of each portion was equal. This ensured that when the three portions were brazed to one another, the overall parabolic metal reflector formed gave a sharp uniformly illuminated focus-spread of the required design. The three portions of the reflector are seen in Fig. 1. The copper surface was bright chromium-plated and the concentrator had an effective aperture of 12.6 sq ft and depth of 2.25 ft.

The apex of the reflector was so cut as to facilitate proper mounting of the engine with its cylinder length lying along the reflector axis. The engine was coupled to a water pump through a leather belt as shown in Fig. 2. The rest of the engine was protected against heat by using a thick asbestos sheet. It was observed that solar heat concentrated by the three portions of the metal reflector raised the cylinder bottom temperature and minimized side heating considerably. This was made possible by keeping the cylinder bottom slightly below the focus-spread. This also helped to add a heat storage portion to the bottom of the cylinder for its smooth running during the passage of clouds and shift in the focus-spread.

For collecting solar energy from a larger area and for obtaining still higher temperatures at the focus-spread another concentrator was prepared and mounted on the turning mechanism. It had an effective aperture of 28.3 sq ft and depth of 4.5 ft with a focal length of 9 in. The copper surface was bright chromium-plated. The hot-air engine, used with the two reflectors described above, was mounted with its cylinder length lying along the reflector axis. The overall weight of the reflector and the engine assembly became so heavy that need was felt to use a heavy weight to counter-balance the assembly. For solar radiation to fall normal to the aperture surface, the movement of the assembly became unstable and unmanageable. Mounting of the engine inside the reflector in an inverted position also created difficulties in engine lubrication. Major difficulties encountered were in the construction of reflectors with a large effective aperture and the desired focus-spread, heavy supports, turning mechanism, counter-balancing with a heavy weight, etc. This led us to give up further experimentation with metal concentrators and to use plane glass mirrors mounted on wooden frames capable of concentrating solar energy at a distance depending on the construction of the frame. These concentrators were designed and constructed in this laboratory, and most of the difficulties mentioned above were overcome.

The design, construction and use of 3 ft by 3 ft and 6 ft by 3 ft glass-mirror concentrators, employing 9 in by 9 in plane glass mirrors, have been discussed earlier in connected with the use of solar energy in concentrating cane and palm juices to a thick syrup or masa [12,22]. The size of the focus-spread was nearly $9\frac{1}{4}$ in by $9\frac{1}{4}$ in. Similarly mirrors of 2 in by 2 in and 4 in by 4 in sizes were used in the construction of plane-glass mirror reflectors with different sizes of the focus-spread. Mirrors were secured to the curved bar surface with metal wire instead of screws and washers.

These reflectors were used in experiments on the hot-air engine.

## 3. HOT-AIR ENGINE

A small open-cycle hot-air engine was dismantled from an old kerosene oil-operated fan and was overhauled. Its wornout parts were replaced and suitable modifications were carried out before its use. It operated at an average speed of 250 r.p.m. Heat at the cold end was dissipated through large thick fins cast along with the body of the engine. To give smooth and continuous running, a $1\frac{1}{2}$ in thick hollow disc, which formed the 'false bottom', was slipped over the bottom of the expander cylinder. The disc was made of copper sheet and the empty space was filled with dry sand. It formed a perfect fit and ensured complete contact between the metal surfaces. The entire cylinder length of $8\frac{1}{2}$ in including the 'false bottom' was enclosed in a pyrex glass tube closed at one end and of slightly larger diameter. Both these arrangements helped to raise the temperature of the hot end and to realise uninterrupted and steady running of the engine.

Coupled to a small reciprocating water pump, this engine was suitably mounted with the three metal reflectors described above and used for experiments on pumping water from different depths. The coupled unit developed about 1/16 h.p., and not 1/8 h.p. as stated by Jordan [16].

Later, another hot-air engine of nearly double the capacity of the one used earlier was procured, modified and mounted in the vertical position on an iron tripod stand (Fig. 3). It was used with plane-glass-mirror concentrators. Coupled to the water pump, the engine developed about 1/8 h.p. A small cylindrical parabolic metal reflector was placed behind the cylinder to help heat the hot end of the engine [17] uniformly and thereby ensure its smooth running (Fig. 3).

An excellent hot-air engine, developed by Messrs. Philips, Eindhoven [3,22] became available. This engine was developed with the object of providing a small generator to power a radio set. A re-examination of the Stirling cycle as a hot-air engine resulted in a 1 h.p. engine, whose regenerator or heat exchanger is the heart of the machine and consists of a neatly wound mass of copper wire 0.008 in in diameter. The heater system of the engine is designed for burning kerosene oil and is in the form of a cylindrical head of 8 cm. diameter with an exposed surface area of 50 sq cm. Two units of this hot-air engine developed by Messrs. Philips [3,22] were obtained directly from the manufacturers for operation with solar energy.

The kerosene oil burner of one of these engines was removed and the metal alloy plate of the engine was exposed to the concentrated solar energy. The engine operating with solar energy is shown in Fig. 4. The arrangement of the plane-glass-mirror reflectors in a semi-circle and the solar energy concentration on metal alloy plate capable of withstanding extremes of temperatures are seen clearly in Fig. 4. Using an adequate number of mirror reflectors with an effective concentrating surface area of 8 sq m., which area could not be obtained with a single metal concentrator described above, the engine unit, coupled to a 200 watt generator, could be made to run at its rated r.p.m. and generated the rated capacity of 200 watts. But the high efficiency inherent in the Stirling cycle could not be realised in practice due to some of the reasons discussed below.

## 4. REVIEW OF DEVELOPMENTS IN THE FIELD

The Stirling cycle has been studied and thoroughly investigated by several workers [1-11]. Kohler [23] has recently critically examined the hot-air engine cycle by establishing its losses or sources of inefficiency, which fall into four categories, viz. mechanical loss due to friction, insulation losses, non-ideal heat transport, etc. Improvements have been effected in the new designs of the engine so as to further reduce the losses encountered in the first two categories, whereas non-ideal heat transport losses need further thorough study.

In the regenerator or heat exchanger, heat must be absorbed and an equal quantity of heat rejected during each cycle. Heat transfer being non-ideal, part of the heat not absorbed by the regenerator is carried along with the gas into the cold space. To overcome this difficulty, it is suggested that the hot-air engine should operate at a fairly low operating speed (200 - 300 r.p.m.) instead of the nominal speed of 1500 r.p.m., as specified by the manufacturers [24]. John Ericsson [25] built a large sized hot-air engine operating at 12 r.p.m., which could propel a marine ship. Farber and Prescott's recent work [11] on pressurised and non-pressurised hot-air engines has shown that high efficiency can be achieved when operating at 200 r.p.m. or less.

Complications inherent in the analysis of the operation of the hot-air engine cycle make it difficult to correctly evaluate its performance. Extreme compactness and high efficiency of the machine (to be realized through careful control in manufacture and assembly) are two major considerations that come into play.

By reversing the cycle to produce a refrigerating machine, the Philips engine acts as a refrigerator to produce liquid air and liquid nitrogen and also liquefies hydrogen successfully. Philips [1,23] have been able to manufacture liquid air or gas machines. In the hot-air engine, the expansion phase occurs at a temperature above the ambient temperature, while in the refrigerating machine the expansion phase occurs below the environmental temperature. Secondly the efficiency of the Philips engine increases with fall in temperature (Fig. 5 [23]). It is evident from Fig. 5 that the Philips engine based on the Stirling cycle has high efficiency at extremely low temperatures. The lower curve represents the performance of a small machine built for laboratory use and the upper one that of a large industrial machine. At high temperatures the engine efficiency, as depicted in the curves, falls considerably.

Difficulty is encountered in the efficient transfer of heat across the cylinder head. An engine of improved design, made at the Battelle Memorial Institute, is provided with a transparent window of quartz in the cylinder head to focus solar radiation directly inside the hot-air engine. Such an engine, operating with focussed radiation from an electric lamp, was demonstrated by Finkelstein and Eibling at the U.N. Conference held in Rome in 1961 [5,9,14].

The conclusions arrived at independently by Farber [11], Eibling [5,8,9] and Philips workers [10,23] are vital to further progress in the field. The lack of success with a solar-operated engine is due to such factors as intermittence and low intensity of solar energy itself, inadequate engine development, prohibitive collector cost, competition from I.C. engines, etc. But there is evidently an urgent need for a small engine for the less-developed but sun-rich countries for such applications as water pumping, lighting, grinding of cereals and other purposes, but not characterized by such exacting demands as continuity of operation and energy storage. As stated earlier [26], efficiencies of the order of 15 to 20% might make hot-air engines practical in these countries.

The experimental studies described in this paper are the results of team work, to which Dr. M.L. Ghai and Mr. B.S. Pandher have contributed. Dr. K.N. Mathur obtained the Philips engine for trials with solar energy and guided the experimental work described above. The author acknowledges his grateful thanks to all of them. Thanks are also due to the Director, National Physical Laboratory, New Delhi, for permission to publish this paper.

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Fig. 1 - Hot-air engine, coupled to a water pump and mounted inside the metal solar energy concentrator, seen pumping water from a depth of 16 ft.

Fig. 2 - A close up view of the hot-air engine, as coupled to a reciprocating water pump and shown in Fig. 1.

Fig. 3 - Plane-glass-mirror reflectors concentrate solar energy on the bottom of the hot-air engine mounted vertically.

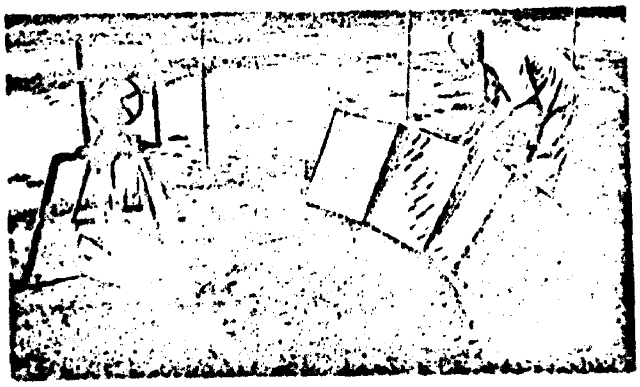

Fig. 4 - Philips hot-air engine, after suitable modifications is shown operating with solar energy concentrated by means of plane-glass-mirror reflectors arranged in a semi-circle.

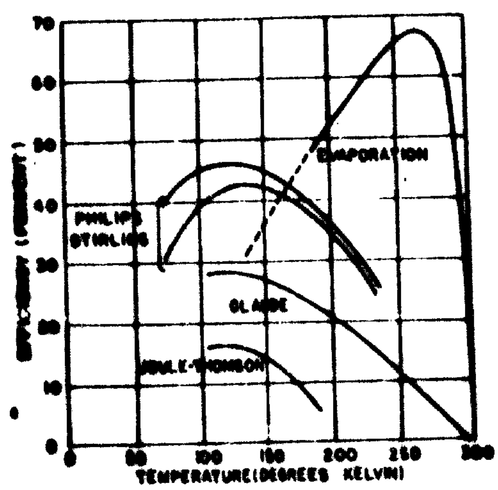


Fig. 5 - Refrigeration efficiencies of various proccsses in the temperature range of 50° and 300° Kelvin, reproduced reproduced after Kohler (23).

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# SUPERCHARGED AND WATER INJECTED SOLAR HOT AIR ENGINE

by

E.A. FARBER

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# SUPERCHARGED AND WATER INJECTED SOLAR HOT AIR ENGINE

By

E. A. FARBER*

## SUMMARY

This paper, one in the series on the development of fractional horsepower Solar Hot Air Engines, describes further changes and improvements of a previously discussed engine.

The addition of a simple adjustable checkvalve allows the engine to supercharge itself by drawing in air during the below atmospheric pressure part of the cycle. The same device can be used to draw in water instead of air.

The performance of the engine is thereby improved giving higher power output, increasing it for air injection up to about 8 percent and for water injection up to as much as 19 percent.

## 1. INTRODUCTION

The hot air engine development at the Solar Energy Laboratory of the University of Florida was started over a decade ago. The main emphasis in this development has been on fractional horsepower engines of simple design and low cost construction. Portions of this development have been described in previous papers (9, 10, 11, 14)+, some of the work is as yet unpublished.

Different investigators have made improvements in the original Stirling Engine, from simple designs to very complex ones, resulting in highly efficient engines such as the General Motors Stirling Engines (1). These engines have conversion efficiencies even higher than today's best conventional heat engines.

The present paper follows two earlier papers, the first (9) of which described a simple hot air engine made from a lawn mower and presented its performance. The second (10) presented a somewhat improved design for solar energy application and discussed the performance due to pressurization of the engine. The use of pressurization required tighter seals which increased the friction losses and necessary maintenance.

The present paper discusses self-supercharging of the engine by allowing it to draw in air or water during the below atmospheric pressure part of the cycle.

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*The author is Professor and Research Professor of Mechanical Engineering and Director of the Solar Energy and Energy Conversion Laboratory at the University of Florida, Gainesville, Florida, U.S.A.

+Numbers in brackets refer to references listed at the end of the paper.

The following pages cover engine design, engine performance and results of theoretical investigations. They are necessarily approximate since these engines have complex cycles with the amount of working fluid and its composition varying throughout the cycle.

## 2. DESIGN AND OPERATING PRINCIPLE OF THE ENGINE

The operation of the engine can be understood by referring to Figure 1 which presents a schematic diagram of the important parts of the engine. Figure 2 shows the hot air engine.

A displacer cylinder is mounted on top, having an inside diameter of 2 3/4 inches and an internal length of 10 1/8 inches. A displacer moves with an outside diameter of 2 11/16 inches and a length of 8 inches inside this displacer cylinder. This diameter and a 2 inch stroke leave enough clearance, both radially and at the ends, to allow it to move freely in the displacer cylinder.

One end of the displacer cylinder is designed to be heated by gas, oil, solar energy, etc., the other to be cooled by air or a water jacket (circulating or non-circulating). The displacer motion is controlled by a 1/2 inch rod entering through a sleeve bushing. The present improvements were suggested at least in part by the difficulty of keeping the bushing gas tight without introducing unnecessary friction.

The displacer cylinder is connected by a 3/4 inch pipe nipple to the power cylinder with a piston diameter of 2 3/8 inches and a stroke of 1 1/2 inches.

The linkage between displacer and power piston allows timing of the engine. For normal operation the displacer leads the power piston by about 100 degrees.

The operation of the engine depends upon the alternate heating and cooling of the working fluid. When the fluid is heated the pressure increases pushing the power piston down. When the working fluid is cooled, the pressure in the engine decreases, allowing the power piston to be returned by the energy stored in the flywheel.

The alternate heating and cooling of the working fluid is accomplished by moving the working fluid back and forth between the hot cylinder.

The performance of the engine is furthermore improved by regeneration along the displacer and the displacer cylinder walls. In these walls heat is stored during part of the cycle to be released and used during another.

## 3. OPERATION, NORMAL AND WITH FLUID INJECTION

Since the engine is started with atmospheric pressure inside, the pressure will dip below atmospheric during part of the cycle.

a. Normal Operation: During normal operation of the engine this dipping below atmospheric pressure, during part of the cycle, is enhanced by leakage of the working fluid (air) through the displacer rod bushing, out - during the high pressure part of the cycle and in - during the below atmospheric pressure part of the cycle.

Efforts have been made to prevent or minimize this leakage but it was found quite difficult to do this without increasing the friction losses considerably. For this reason two alternative methods were developed and they are described below.

b. Air Injection: A small adjustable bal. check valve was installed as shown in Figure 1 which made it possible for fresh air to enter the system quickly during the below atmospheric pressure part of the cycla. This simpla addition allowed the engine to operate with a larger average amount of working fluid resulting in higher power output.

c. Water Injection: When the inlet to the small adjustable ball check valve was dipped into water, water was injected into the system rather than air. This allowed larger amounts of fluid to be added to the system, since it was added in the liquid phase, resulting in even greater increases in power output. Another advantage of water injection (or other liquids) is that it enhances the heat transfer at the hot end greatly.

## 4. PERFORMANCE OF THE ENGINE

Normally this engine is operated with a 5 foot diameter surplus search light mirror which gives solar energy concentration better than actually needed. For the purpose of this investigation, a comparison of performance due to different modes of operation, the engine received its heat from a natural gas-compressed air torch, adjusted for constant output. The engine was operated normally and the speed (rpm) and power output measured. Then the check valve was opened and adjusted so as to give the highest power output for this speed.

After these tests the inlet to the check valve was dipped into water, allowing water to be injected instead of air. The check valve had to be closed some during this step since otherwise too much water was injected, lowering the engine performance. Again the best combination of settings was determined for the same speed.

The above procedures were repeated for a number of different speeds including that for maximum power output.

Figure 3 shows superimposed the indicator diagrams for normal operation, air injection and water injection at 200 rpm. The actual amount of air injected could not be determined easily but the water injection amounted to 0.096 lb/min. In all cases it was made certain that, before data was recorded, steady state conditions had been reached and could be maintained.

Figure 4 presents the power output, normalized with respect to the maximum value for normal operation. This method of presenting the three modes of operation allows comparison and indicates the degree of improvement.

Figure 5 is a plot of the conversion efficiences, normalized with respect to the maximum value at normal operation.

## 5. DISCUSSION OF RESULTS

The check valve seems to be a simple solution to a problem which has given considerable difficulty, how to reduce or eliminate the leakage losses without complicating the design of the engine and without introducing undue friction.

In the work described here the below atmospheric pressure part of the cycle was used to introduce additional working fluid to make up for the leakage losses of the high pressure part of the cycle.

When air was used as the "injected" medium, increase in power output became as much as 8 percent. The even greater increase (up to 19 percent) with water injection is principly due to two factors:

a. More water could be added to the system than air, under otherwise identical conditions.

b. The heat transfer to the working fluid was increased due to the liquid to vapor phase change.

The heat input to the engine was kept constant at all times during these experiments and the power output was determined for different speeds and optimum injection.

Theoretical calculations indicate that the average amount of working fluid in the engine during normal operation is about 0.0024 lb. The working fluid temperatures vary from about 900 R to 1800 R. Measurements of the displacer wall temperatures indicate that the hot end of the engine reached 2200 R and the cold end (water jacketed) about 600 R, but satisfactory operation is obtained at more moderate temperatures.

In these experiments the amount of fluid drawn into the system, during the below atmospheric pressure part of the cycle, depends upon the conditions in the engine and is thus self acting and controlling. There exists a definite maximum of fresh fluid which can be drawn in for a certain design and operating condition. This amount can, however, be increased by using a positive pressure or absolute displacement type of injector, allowing above atmospheric pressure operation throughout the cycle.

Pressurization as described in an earlier paper (10) can increase the output of the engine by considerable amounts and the most efficient engines which have been built to date are pressurized.

A further improvement of the performance of an engine with liquid injection could be brought about by valving which would allow, first, a certain amount of liquid to be injected and at the end of the power stroke the discharge of some of the working fluid. This procedure could increase the heat transfer at the hot end, utilizing the phase change phenomena, and could, for otherwise similar conditions, increase the engine speed and thus the power output.

Engines of the above type could be classified as "Hybrid" since they combine the basic Stirling with other cycles.

## 6. CONCLUSIONS

Based upon the foregoing work described in this paper the following conclusions can be drawn:

1. Self-acting air or water injection can considerably improve the performance of the simple hot air engines of the type used here.

2. Water injection is more effective because it allows larger quantities of fluid to be injected and it increases the heat transfer at the hot end of the engine through phase change.

3. Engines of the type described here can be classified as "Hybrid" since they combine the advantages of the Stirling cycle with those of others.

## 7. ACKNOWLEDGEMENTS

The help, advice, and constant interest of Professor Emeritus Ford L. Prescott is deeply appreciated and without his efforts in building and modifying the various engines this work would not have been carried out.

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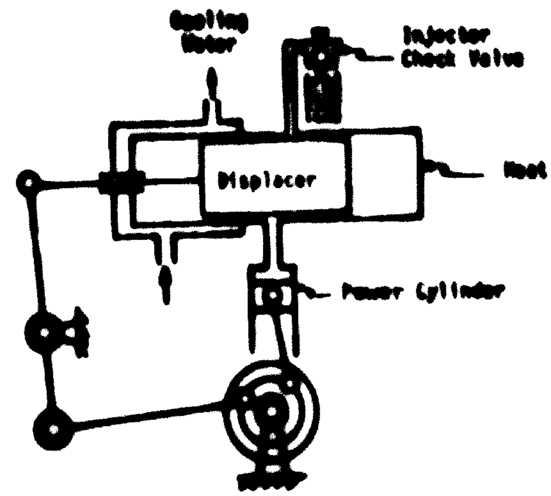


Fig. 1 Schematic Diagram of the Engine

Fig. 2 The Solar Hot Air Engine

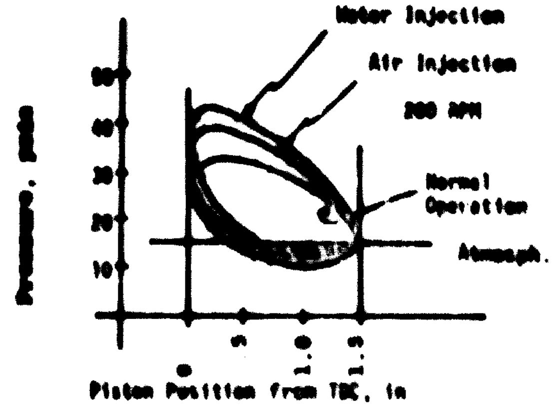


Fig. 3 Indicator Diagram, Normal, Air Injection, and Water Injection Operation

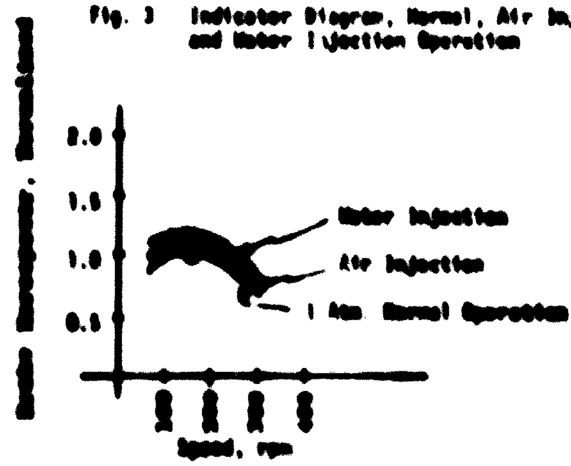


Fig. 4 Relative Power Output of Normal, Air Injection, and Water Injection Operation

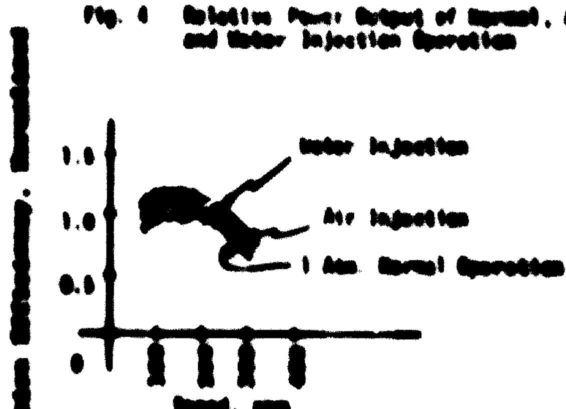


Fig. 5 Relative Conversion Efficiencies for Normal, Air Injection, and Water Injection Operation

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# TECHNICAL NOTE

## Operating Experiences with Solar Stills for Water Supply in Australia*

R. N. MORSE, W. R. W. READ and R. S. TRAYFORD†

(Received 10 August 1969)

### INTRODUCTION

Solar stills are now producing water for motels and a small township on a commercial basis. In addition, full-size prototypes have been operating on an experimental basis at field stations since 1963. These are widely separated on the Australian continent and have produced more than a million gallons of fresh water.

Details of the various installations are given in Table 1.

Table 1

| Location | Size (ft²) | Date installed | Water supply | Function |
|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | | | |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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*[illegible]
†[illegible] Australia

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top ridge. The installations at Muresk, Coober Pedy, Caiguna and Hamelin Pool are of this type, and it is these that provide the bulk of the operating experience to date.

## WATER PRODUCTION

From Fig. 1 it may be seen that production varies from [illegible] Imp. gal ([illegible] U.S. gal)/1000 ft² day for the best summer month down to 10 Imp. gal/1000 ft² day for the worst winter month. This low figure, however, increased to [illegible] Imp. gal/1000 ft² day for the improved Mark II design operating at the same time and on the same site. The improvement was attributed to the more vapor-tight construction and led to the predictions that the Mark II still would produce [illegible] per cent more than the Mark I over a whole year. This turned out to be incorrect, there being no significant difference in the summer production for the two designs.

An effect which has not been fully explained is a gradual reduction in output over a period of years for all stills. At first it was thought to be due to [illegible] salt and clay deposits reducing the solar absorption when compared with the original black polythene sheet base. This apparently is not the reason since after cleaning out the still there is no significant change in output, as may be seen from Fig. [illegible], which shows the relative performances before and after cleaning (when compared with other stills of the same design which were not touched).

This steady drop in production is not easy to measure because of changes which have taken place in the various stills, but it seems to be about 10 per cent per annum.

It is probably due to an accumulation of a number of small faults:

(a) A pinhole leak in the polythene base is hard to detect, but it increases the thermal losses from the base and reduces output for the particular area affected.

(b) Slight changes in grade can cause a distillate channel to overflow into the saline trough. At Coober Pedy it had been found that [illegible] out of [illegible] were not producing any water for this reason.

(c) Glass leakage due to storm damage, if not quickly repaired, can have lasting effects. It takes a long time to dry out the ground under a still after it has become wet. The increased moisture content, as well as increasing the thermal losses, [illegible] which interfere with the flow in the channels, [illegible] the stability of the still and [illegible] the proper channels.

(d) Individual stills tend to develop vapor leaks.

## OPERATION AND MAINTENANCE

[illegible]

(a) [illegible]

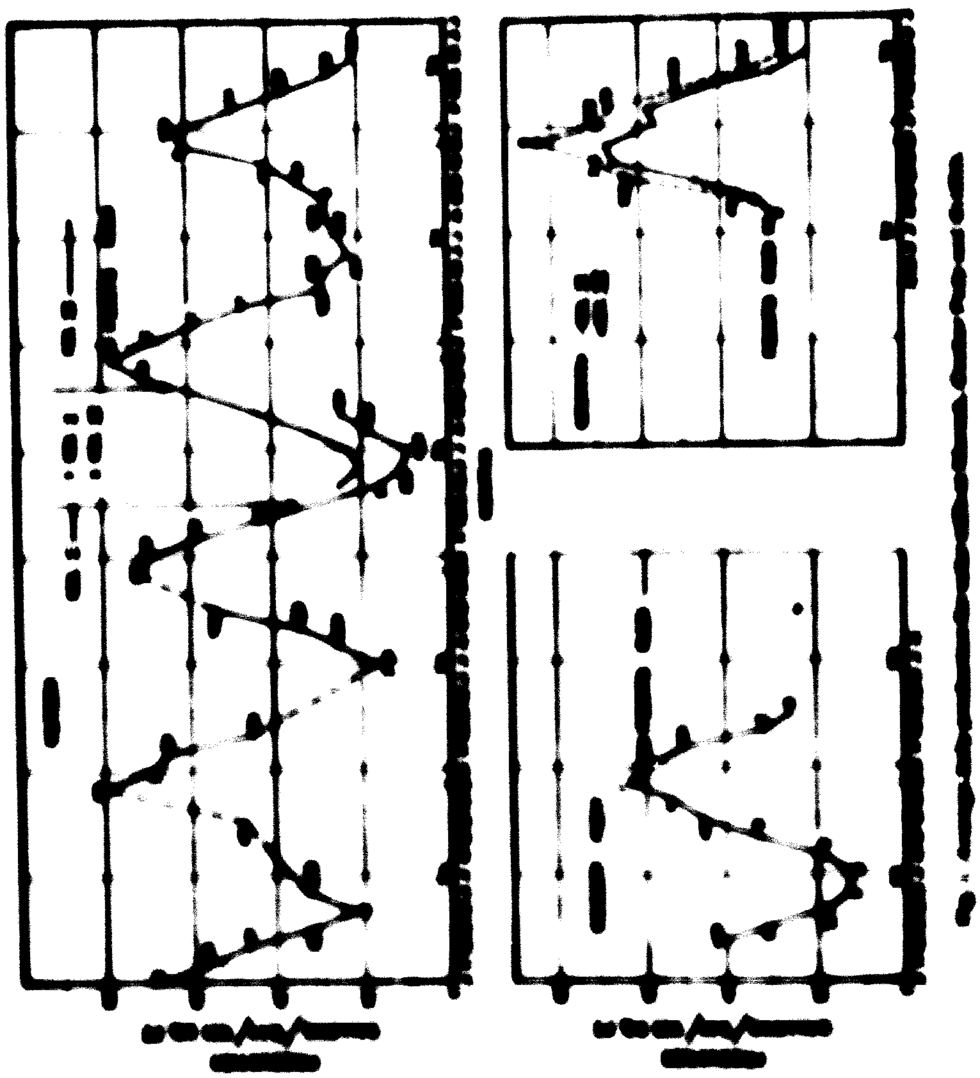
(b) [illegible]

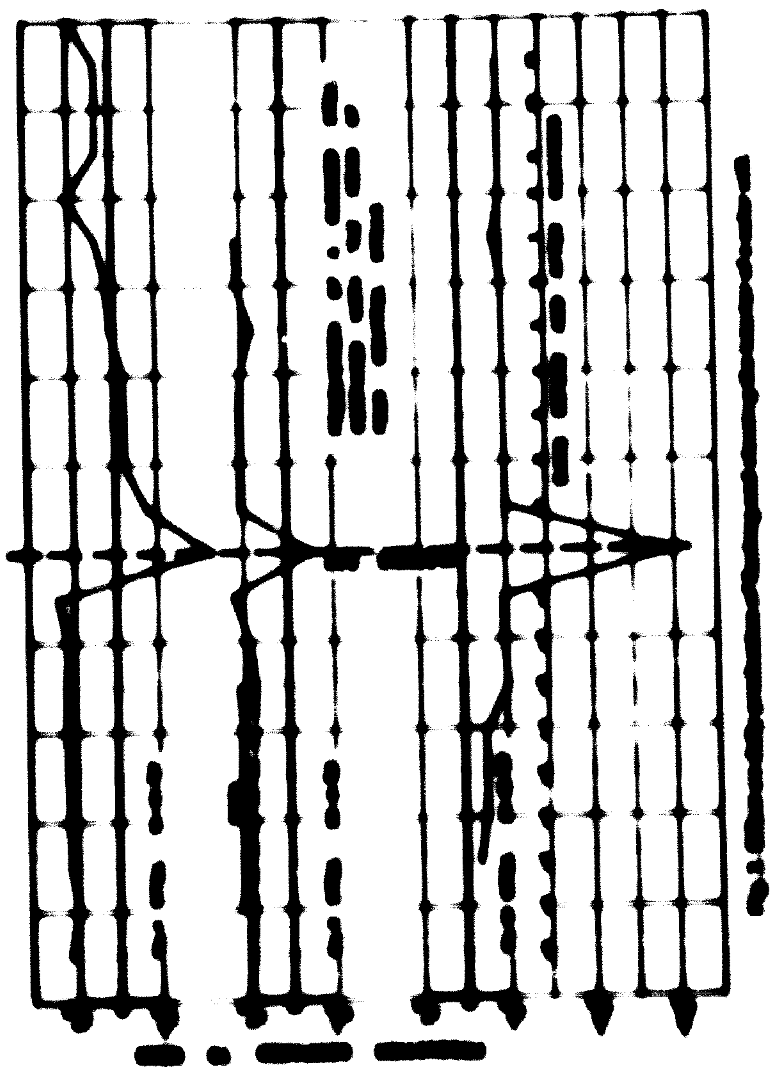
(c) [illegible]

(d) [illegible]

(e) [illegible]

[illegible]





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maintenance is considered to be excessive, ranging from 10 to 60 man hr/1000 ft². year. This covers both storm damage and cleaning, much of which is now thought to be unnecessary. A realistic target for essential maintenance is 10 man hr/1000 ft². year. Under Australian conditions, this is quite expensive since for a production of 15 gal/ft². year and labour at $1.00 per 1000 gal to the cost of the water. Moreover, since this is the lowest figure yet reached in service, it does highlight the importance of the problem. Operating experience in other parts of the world is thought to confirm this view.

It is encouraging to be able to report that solar stills are being found satisfactory for the desalination of underground saline water in isolated areas for human consumption. While they do not need skilled attention in their day-to-day operation, they do require skilled maintenance from time to time.

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# A Method of Solar Air Conditioning

By

R. V. Dunkle

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[illegible]

# A Method of Solar Air Conditioning

BY R. V. DUNKLE
*(non-member)**

## Introduction.

This paper discusses a method of solar air conditioning applicable in humid tropical or sub-tropical areas. Electric power requirements are limited to air and water circulation and control mechanisms, the major energy input being solar radiation. The proposed method is based on adsorption dehumidification of the air, coupled with regenerative evaporative cooling. A complete working system has not yet been built, as until now the research effort has been concentrated on the components or "building blocks" from which the complete system will be assembled.

## Reasons for Selection of this Method.

Tropical regions are, in general, subject to high insolation which is distributed fairly uniformly throughout the year (Ref. 1). Furthermore, conventional fuels are often in short supply, electricity rates are high, and operating costs of conventional heat pump systems are excessive; hence the interest in solar powered systems which may find widespread use both in Northern Australia and in other humid tropical and sub-tropical regions. The capital cost of the installation can be considerably greater than that of conventional systems and still be economically competitive because of the low power consumption.

The working fluid in the cycle is actually the air-water mixture which is circulated through the dwelling. Consequently, small leaks are of negligible importance and, since the complete system operates at, or very close to, atmospheric pressure, cheap and lightweight construction is possible. By keeping pressure drops low, electric power requirements are minimized so that full advantage can be taken of the air conditioning potential without incurring excessive costs. The air conditioning cycle is designed so that relatively large quantities of fresh air for ventilation can be introduced without a large penalty in performance, thus overcoming the "stuffiness" frequenrly encountered in air-conditioned structures. The use of a heat-mass regenerative exchanger in the cycle would enable still larger fresh air loads to be handled economically, although this is not included as an integral part of the cycle. The solid adsorbent, nominally silica gel or activated alumina, is odourless, non-toxic, non-volatile and non-corrosive. Finally, the individual components of the system are of considerable interest in themselves for other applications.

## Description of System.

The system (Fig. 1) can be visualized as consisting of three major sub-systems each composed of a number of components. The three sub-systems are :—

1. The regenerative evaporative cooling system.
2. The dehumidification system.
3. The thermal energy source.

To illustrate the method more clearly, its operation will be described for specific conditions typical of a severe day in Darwin when outside conditions are 95°F. dry bulb and 82°F. wet bulb, while inside conditions are maintained at 77°F. and 65 per cent relative humidity (68.3° wet bulb temperature). A continuous supply of 200 c.f.m. of outside air for ventilation is assumed, corresponding to a heat load of 12,000 B.Th.U./hr. on the system. The peak building load, other than fresh air, is taken to be 18,000 B.Th.U./hr. while the mean building load is 10,000 B.Th.U./hr. over a 24-hour period.

The descriptions of the sub-systems and their operation follow.

### *1.—Regenerative Evaporative Cooling System (Ref. 2):*

A schematic diagram of the system is given in Fig. 1 and the corresponding processes and state points are indicated on a psychometric chart in Fig. 2. Air is drawn from the room at a rate of 1,800 c.f.m. and delivered to the first evaporative cooler which is assumed to have an humidifying effectiveness of 80 per cent. The air leaves this cooler at 70.5°F. and 90 per cent relative humidity. Part of this air stream, 1,000 c.f.m., is diverted to point 9 via a by-pass duct controlled by a damper. This by-pass air stream then mixes with the cool air at state 8 returning from the dehumidification loop. The resultant mixture at 68.3°F., statepoint 10, is delivered to the room. It is seen that the temperature rise of air through the room is 8.7°F. under these conditions. It will be noted that in the cycle as described here no latent heat was included in the room load. If a latent heat load occurs in the building, statepoint 10 must be slightly lowered to maintain the desired conditions, which is accomplished by reducing the by-pass ratio by means of the control damper. The recirculation and mixing feature of the by-pass system results in a larger enthalpy and humidity rise of the conditioned air when passing through the building, and reduces the quantity of air circulated through the dehumidification loop. Consequently, the size and power consumption of the equipment is reduced. The by-pass feature enables humidity control to be achieved, the larger the by-pass ratio the higher the resultant humidity in the building, and the smaller the quantity of air which must be circulated through the dehumidification system. One of the major advantages of the by-pass system is that the effectiveness of the evaporative coolers, or air washers, has little effect on the overall system performance; the only significant effect is a change in the by-pass air ratio to maintain the desired conditions. For example, if the two evaporative coolers are reduced from 80 to 60 per cent humidifying effectiveness, an increase in the by-pass air rate from 1,000 to 1,800 c.f.m. will maintain the building at the original condition. To go a step further, the evaporative cooler in the return air from the dehumidification system could be eliminated completely by further increasing the by-pass ratio; however, this results in undesirably high air circulation rates.

The remainder of the air leaving the evaporative cooler passes through the spray eliminator and enters the first regenerative heat exchanger at state 2. This air stream, 800 c.f.m., flows through this heat exchanger counter to the air stream returning from the humidifier and is heated to roughly ambient temperature, 95°F. The effectiveness of each of the rotary heat generators in this cycle is assumed to be 80 per cent with equal air rates through both sides, a conservative figure on the basis of experimental units tested in this laboratory. The exchanger is assumed to have leakage and carry over equal to 5 per cent of the air flow per side, so that as a result the water content of the air decreases slightly between points 2 and 3. Fresh outside air amounting to 200 c.f.m. is drawn into the system at the suction of fan B, mixed with the air at state 3, and delivered by fan B to the desiccant bed at state 4.

*This paper, No. [illegible], was presented before a Conference in Melbourne on 7th and 8th December, [illegible], organised by The Institution's Technical Committee on Applied Thermodynamics.

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The air passes through the desiccant bed and in the process is lehumidified and heated, leaving at state 5 at 130° to 135°F. This 1ot dry air then passes through the second heat exchanger, counter o an outside air stream, and is cooled to state 6 which is about 5°F. above ambient. The water content is raised somewhat in his process due to carry over of outside air. This cooling process ıctually constitutes the heat rejection stage of the reversed thermolynamic cycle.

The warm dry air at state 6 leaving this exchanger passes back hrough the first heat exchanger where it is cooled to about 80°F., he water content rising slightly to state 7. The air stream then asses through the second evaporative cooler, also of 80 per cent umidifying effectiveness, and is cooled to state 8, about 65°F. This cool air is mixed with the by-pass air at state 9 to form the nixture at state 10 which is delivered to the building.

The heat exchanger and evaporative coolers, with the addiion of another fan at 6, form a very effective cooling system by hemselves in hot dry climates. In this case, the hot dry air at state 6 would actually be the ambient air drawn into the system, while the hot moist air at state 3 would be discharged to waste. In this case there is no need for dehumidification, and the rest of the equipment can be dispensed with.

### 2.—*Dehumidification System:*

Solid adsorbents have been proposed for the dehumidification system, although some work has been done on solar concentration of lithium chloride solutions as an alternative method (Ref. 3). Solid adsorbents were selected because they are stable, non-toxic, non-volatile, relatively cheap, and produce very dry air, and are readily regenerated with hot air. The regeneration temperature for this system will probably fall in the range between 180° and 220°F. This is below normal regeneration temperatures for silica gel and, due to a paucity of information on performance under these conditions, it has been necessary to conduct a study of silica gel beds under simulated operating conditions. This work is currently being carried out by R. C. Johnston of the Division of Mechanical Engineering, and will be reported in due course. Preliminary results indicate that satisfactory regeneration can be achieved at these temperature levels.

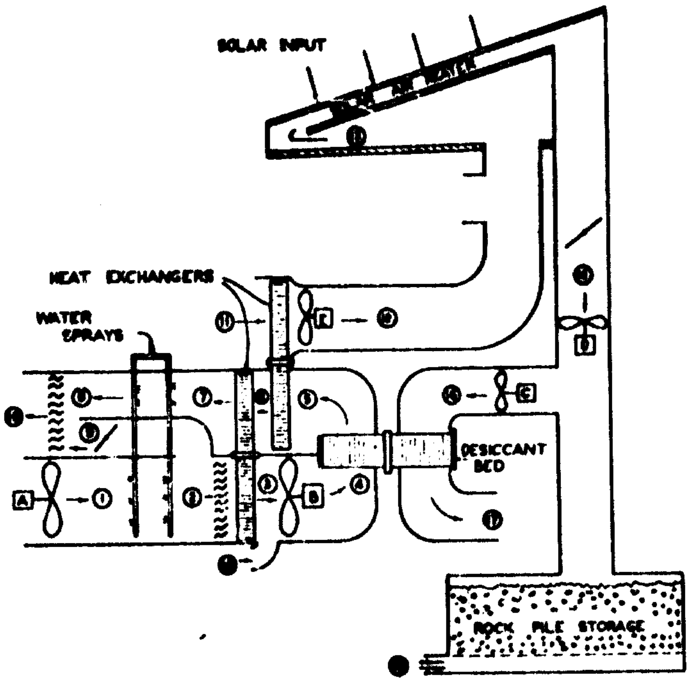


*Fig. 1.—Solar Air Conditioning System.*

A rotary desiccant bed has been indicated in Fig. 1, although it is likely that a fixed bed system with periodic regeneration via a valve mechanism will be used in practice.

### 3.—*Thermal Energy Source:*

The primary thermal energy source consists of a vee-corrugated selective surface solar air heater (Refs. 4 and 5). The air heater will deliver air, state 14, at 210°F. with a thermal efficiency of about 40 per cent. The area of air heater required is roughly the same as the roof area of the building and, in the author's opinion

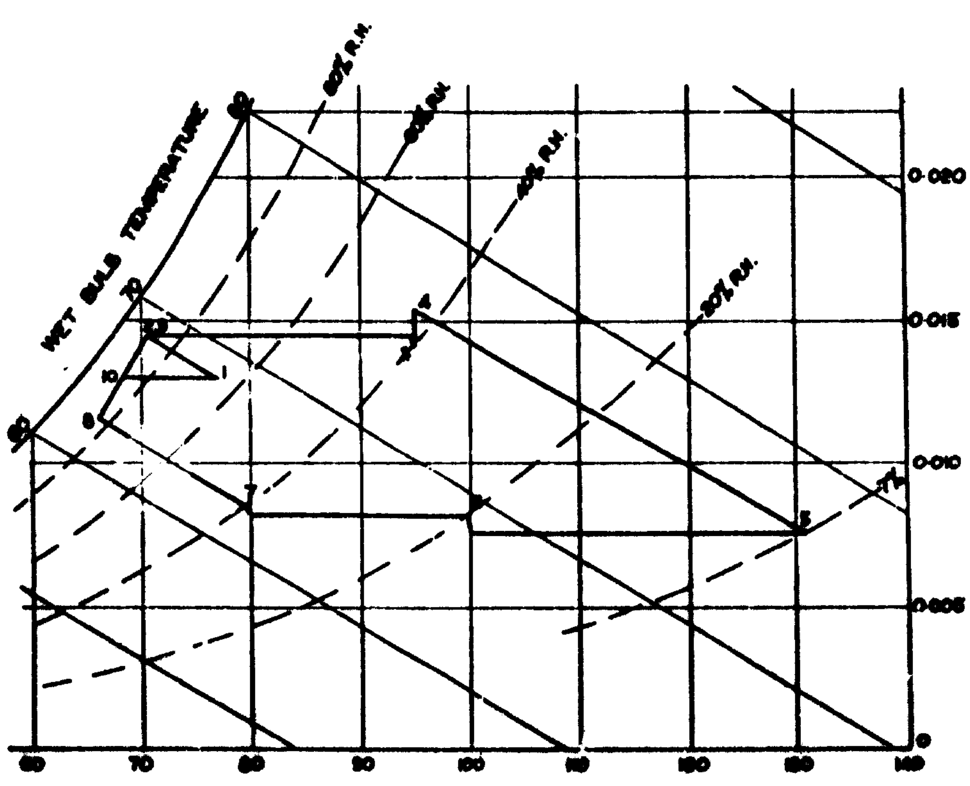


*Fig. 2.—Cycle on Psychometric Chart.*

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for economical construction, it will be necessary to integrate the solar air heater into the roof structure. However, in the case of existing structures, it may be necessary to superimpose the air heater on the conventional roof at some increase in cost. Since most tropical homes are very poorly designed and built from the viewpoint of air conditioning, it is doubtful if a solar system would find wide acceptance in the usual type of building.

The air supply at 13 to the air heater can be drawn from within the attic, thus ventilating the roof space, recovering the heat lost by conduction through the base, and reducing the heat load on the ceiling of the house. Alternatively, the air discharged from the outside air (heat rejection) exchanger at state 12 can be used as a supply of preheated air. This air stream is also slightly lower in water content than ambient due to mixing in the heat exchanger which results in slightly better performance of the dehumidifier. A third alternative is to discharge the air at 12 into the roof space and also draw the air supply to the air heater from this space, thus recovering both the rejected heat from the cycle and conduction losses from the air heater.

Due to the intermittent and variable nature of sunshine, it is necessary to have a temperature control element at the air heater outlet which varies a control valve to keep the hot air temperature at the proper level. The hot air from the air heater is delivered by fan D to the top of the rock pile thermal storage and/or the silica gel bed via fan C (state 16).

When the solar air heater is inoperative, or is supplying insufficient hot air for regeneration, heat is drawn from the top of the heat storage, outside air being drawn in at the base of the rock pile. A more comprehensive discussion of rock pile thermal storage is found in the paper by Close (Ref. 6). Suffice it to say that the rock pile acts as its own heat exchanger and that more than 90 per cent of the stored heat can be extracted from a well designed rock pile before the outlet temperature drops significantly. The size of the heat storage required depends upon the climatic pattern of the region, the size of the system, the storage temperature, and whether any form of supplementary heating is supplied for extreme conditions. A reasonably sized storage unit would appear to be one containing about 3 days' normal heat requirements. For the size of system described herein, this would be in the order of 1,500 cu. ft. of rock screenings.

Although this system has been designed specifically to use solar energy, it should be recognized that any other cheap source of low grade thermal energy could be used to power the cycle, thus eliminating the large capital costs for a solar air heater and thermal storage.

One further point applies to areas where heating is required in winter. This can readily be obtained by connecting a duct from the discharge of fan C at point 16 to the duct returning conditioned air to the room at point 10. In this manner, the air heater and rock pile can also be used for heating in cold weather.

## Power Consumption.

The power consumption of the system consists mainly of fan power requirements. The power necessary to rotate the heat exchangers, operate the controls, and circulate water is small relative to fan power. Although the estimates are tentative at the present time, approximate pressure rises, air flow rates, and power consumptions for the various fans in the system at full load are given in Table I. Efficiency of each fan-motor combination is arbitrarily taken as 50 per cent.

TABLE I.

| Fan | Pressure Rise (Inches of water) | Air Flow (c.f.m.) | Power Consumption k.W. | Power Consumption B.Th.U./hr. |
|---|---|---|---|---|
| A | 0.2 | 1,800 | 0.085 | 290 |
| B | 0.8 | 1,000 | 0.188 | 640 |
| C | 0.2 | 600 | 0.030 | 100 |
| D | 0.5 | 1,200 | 0.141 | 480 |
| E | 0.3 | 1,200 | 0.085 | 290 |
| | | TOTAL : | 0.529 | 1,800 |

Thus it is seen that to handle a total heat load of 30,000 B.Th.U./hr. only about half a kilowatt electric input is required. This compares favourably with the performance of a typical heat pump system with a coefficient of performance of 2 which would require an input of about 4.4 kW to handle this load under these conditions.

## Comparison of Regenerative Evaporative Cycle with Conventional Heat Pump.

In terms of power cost in Darwin at the present rate of 3d. per kWh, the comparison is 13.2d. per hour operating cost for the conventional heat pump versus 1.6d. per hour for the proposed system. It should be realized that these figures are very tentative, but should be of the right order of magnitude. Also, to arrive at the total cost of operating the system much more information is needed, such as capital cost of equipment, and the load distribution. At the present stage of development of the system these factors cannot be estimated with any degree of precision.

Another advantage of the regenerative evaporative system occurs under part load conditions. If the circulating fans have two-speed motors, they can be operated under low speed a large percentage of the time. The power consumption varies nearly as the cube of the fan speed so that cutting the speed in half cuts the power requirement to one eighth. Furthermore the effectiveness of the evaporative coolers, regenerative heat exchangers, and dehumidifier are all higher at lower air velocities. As a result, the overall performance of the cooling system is much higher under part load conditions. This is in marked contrast to the conventional heat pump which normally runs on an on-off basis, and the coefficient of performance is nearly independent of load.

Another factor of importance is noise, one of the most aggravating features of air conditioning systems. In the proposed system there is no compressor with its noise and vibration to contend with. However, there are five air circulating fans to create noise. Of these fans, four are separated completely, or by effective sound attenuators, from the air ducts to the building. This leaves only Fan A and the connecting ducts as the major sources of sound delivery to the building. As the pressure rise through fan A is small, by proper fan selection and duct design it should be possible to keep the noise production below an objectionable level.

## Suggested Control Method.

Although not pertinent to the theory of the cycle, a few comments will be made on the important practical problem of control. The complexity of the control system depends upon the flexibility and degree of control needed to maintain satisfactory conditions within the building.

The first element of the control systems has already been mentioned; this is the solar air heater control. A temperature sensor located at the air heater exit would actuate a modulating valve in the hot air line which would open when the air temperature rises above and close when the air temperature drops below the set point. When the control valve is completely closed, fan D also stops. No other control is needed on the hot air system.

The building itself should have both temperature and relative humidity control, although temperature control is by far the most important. The relative humidity detector should act via a modulating motor drive on the by-pass damper thus controlling the air flow at state 9. The control achievable is limited to the humidity levels reached with the valve closed and completely open, this will be discussed further in connection with the temperature control.

A four-step temperature controller is suggested to operate as follows.—

*Step* 1 : The top level would be set to produce maximum cooling when the temperature reached or exceeded 77°F. Fans A, B, C and E would be running at full speed and all sprays in the evaporative coolers would be on. The humidity control, assumed to be set for 65 per cent relative humidity, would tend to open the by-pass damper if the relative humidity in the room dropped below 65 per cent. In the unlikely event that the relative humidity fell below 65 per cent with the by-pass valve wide open, humidity control would be lost, but the conditions in the building would still remain well within the comfort range. The opposite situation is perhaps more likely to occur: under conditions of high humidity the relative humidity in the building might rise above 65 per cent with the by-pass air flow reduced to its minimum rate.

*Step* 2: If the building temperature drops slightly so that less cooling is called for, fans A, B, C and E are switched to part speed operation. As mentioned earlier this reduced the power input per unit of heat removed. The humidity control functions as in step 1.

*Step* 3: A further drop in temperature will result in shutting off all the water sprays in the evaporative cooler and the stopping of fans C and E as well as the reversal mechanism of the dehumidifier. Fans A and B will continue to operate at reduced speed. With regard to humidity control no corrective action would result if the relative humidity drops below 65 per cent during this mode of operation. If the relative humidity rises above 65 per cent, fans C and D and the dehumidifier will be called into action for dehumidification.

*Step* 4: At an appropriate temperature level heating will be called for. Under these conditions humidity control will become inoperative as not essential to comfort. When heat is called for, fan C at reduced speed will deliver hot air from the air heater or thermal storage via a duct to point 10 in the circulation system. Fans B and E will be stopped and the hot air supply to the dehumidifier closed off. When the temperature rises to the desired point the system resets to step 3 operation.

## Present State of Programme.

Although a complete solar air conditioning system remains o be designed and built, a great deal of research and development work has already been completed on the individual components. For example, numerous types of packing for both heat and mass transfer have been studied in an experimental rotary exchanger. Based on early results of these experiments a prototype fixed bed regenerative evaporative cooler, without the by-pass feature, has been built and is currently undergoing performance tests.

The air heater has passed through a period of extensive analysis to a development and testing stage, and a large solar air heater is under construction to supply the winter heating requirements for part of the Division of Mechanical Engineering. This heating system incorporates a rock pile thermal storage and should answer many of the practical problems of design and operation of such systems.

As mentioned earlier, the work on dehumidification is progressing satisfactorily, and the programme is rapidly approaching the point where the first complete system can be built.

## Conclusion.

The proposed method of air conditioning for hot humid regions using solar energy as the source of heat which has been described appears very attractive from a theoretical viewpoint. However, many practical engineering and economical problems remain to be answered before the true utility of this development can be ascertained.

## Acknowledgments.

The author wishes to thank the many willing workers in the Division of Mechanical Engineering for their help and co-operation in the many phases of this programme. In addition to those already quoted in the paper, he would specifically like to thank Mr. K. A. Robeson, B.Mech.E., A.M.I.E.Aust., for his help in the air conditioning calculations, Messrs. M. Dewhurst and J. Bannister for their aid in the laboratory, Messrs. L. Chapman and D. Norris for their work with the regenerative heat exchanger, and finally, Mr. R. N. Morse, B.Sc., B.E., M.I.E.Aust., for his close co-operation and guidance.

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## Discussion

***Mr. N. R. Sheridan (Associate Member, Brisbane Division).***—This proposal for providing complete air conditioning by relatively simple means is most interesting and, should it come to fruition, would be extremely useful in providing relatively inexpensive air conditioning. Such air conditioning would go far in assisting the development of those areas of Australia which are at present less desirable because their climate is severe. Since the proposal is obviously exploratory in nature, it is felt that constructive criticism is sought to help the further development of the idea.

On first sight, the system is complex with components of great variety. But it must be remembered that a *maximum* system is envisaged, i.e., one that can cope with any possible outside condition to produce any reasonable inside comfort condition. For particular situations, only parts of the system will be required.

Being an extension of the idea of evaporative air conditioning, the system can best be assessed in the light of present evaporative air conditioner experience. The common direct evaporative air conditioner achieves a drop in dry-bulb temperature of the outside air by exchanging enthalpy between the air and evaporating water. Provided the outside air is of sufficiently low humidity, the condition of the supply air is such that it can remove the room loads though a rather larger air rate than used in refrigerated air conditioner practice may be needed. More complicated indirect and two-stage systems have been used with some success. Of these, the Pennington system (Ref. D1) is of particular interest for comparison as it uses a rotary regenerative exchanger and rotary chemical dehumidifier in a somewhat similar circuit to the one described in the paper.

Generally, evaporative air conditioning has been confined to areas of low humidity but this system extends the method to high humidity areas. Since solar regeneration of the dehumidifying chemical is proposed, there may possibly be insufficient sunshine in certain areas of high summer rain.

In areas where it is suitable, evaporative air conditioning is a simple and effective way of achieving comfort conditions at a *minimum* cost. All too frequently, the equipment is installed as a *cheap* job with resulting dissatisfaction from failure to give comfort conditions. The remedy is good engineering of the installation, a matter which will need careful attention.

In the paper, noise is treated rather lightly as this is surely one of the problems of evaporative air conditioning where the air rates are relatively high. Fan, air transport and distribution noise will still remain a problem with this system, a problem, however, to which there is an engineering answer.

One of the biggest problems in evaporative air conditioning results from the high rate of water usage of the equipment and accompanying trouble with algae, fungi and mineral deposit. These troubles can be minimized by design but not eliminated. It will be interesting to see how the rotary heat exchangers, which are subjected to humid air and possibly water, stand up to the high humidity conditions. It would seem that the matrix with its flow passages of small cross sectional area would be particularly susceptible to clogging by these growths or deposits and that the sealing may be affected.

The normal experience with silica gel as a desiccant would indicate that the temperatures proposed for regeneration, 180-220°F.,

·e somewhat low. Also, the tendency of silica gel to powder with ıovement of the bed may make it undesirable for the rotary de-ccant bed. However, if the principle proves sound, other desic-ınts could be investigated.

One particular attraction of the proposed system is that it ıables a solar air heater to be used. The solar air heater as eveloped by C.S.I.R.O. would seem to be a most economical nd practical way of collecting solar energy. The heater is efficient, mple and should require only a minimum of maintenance.

The value of 90 per cent in the statement, "The rock pile cts as its own heat exchanger and more than 90 per cent of the tored heat can be extracted from a well designed rock pile before ne outlet temperature drops significantly", may be over-optimistic specially if storage up to three days is contemplated. Perhaps, he author would like to comment and give an idea of the expected emperature drop.

In conclusion, such an extension of evaporative air conditioning could have wide application and, though there will be many roblems of a practical nature, the system is worthy of further tudy and development.

**Reference.**

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***Mr. E. G. A. Weiss (Associate Member, Melbourne Division).***—Mr. Dunkle mentioned that an experimental unit with a capacity of 30,000 B.Th.U./hr. and an air handling capacity of 2000 cu. ft. per min. is under construction.

(1) Because of space limitations, the dimensions of the individual units such as solar air heater, regenerators and rock pile storage would be of interest.

(2) The installed cost of 2 window units with a total capacity of 30,000 B.Th.U./hr. would be approximately £500. Would it be possible to estimate at this stage the capital cost of the solar air conditioning system?

***Mr. A. F. Hall (Associate Member, Melbourne Division).***—Exploitation of solar energy is receiving increasing attention and C.S.I.R.O. is to be commended for undertaking development of a simple system in which solar energy is employed for cooling purposes.

Because of the comparative simplicity, evaporative cooling has been used to a considerable extent in remote areas in Australia where conditions favour its use and the particular requirements are not great, but two problems have been commonly experienced with such installations:

(i) In proportion to the volume of space served, air quantities are large and therefore air noise is pronounced in evaporative cooling units commercially available.

(ii) Local water supplies are often charged with mineral salts (and sometimes other matter) so that the wet pad quickly becomes fouled. Maintenance attention must be frequent and often is troublesome to arrange.

In the system of cooling under discussion both these problems might be expected to arise in many locations and comment by Mr. Dunkle as to whether these points have been considered would be appreciated.

***Mr. K. Gorman (Member, Melbourne Division).***—It is disturbing to learn of the considerable effort in skilled manpower and money being devoted to the application of solar energy to various methods of cooling.

It would appear that undue importance is being given to expected economy in operating cost which is expected to be achieved by cumbersome complex and costly devices of relatively inferior performance whereas the general experience in residential air conditioning is that the purchaser is concerned with capital cost, performance and reliability, with operating cost regarded as insignificant.

Any program to develop an alternative cooling system can only be justified by comparison with the existing method of vapour compression.

In Australia the majority of residences are in hot dry climates where daytime cooling is the problem and satisfactory conditions in reasonably insulated residences can be obtained by a refrigeration capacity between 2 and 3 tons, with a cooling power consumption for a normal summer of under 2,000 kWh costing about £20, which is relatively insignificant.

In the tropical areas the main problem is dehumidification and this is a 24-hour demand where although somewhat more power may be required, performance at night is as critical as by day, which immediately involves the storage of the cooling effect at a temperature level effective for dehumidification.

The present position in residential air conditioning is that satisfactory performance can be obtained from well developed semi-mass produced vapour compression equipment which can be installed easily in existing buildings and which have relatively low operating costs.

It is instructive to remember that a 50 h.p. solar steam engine was installed and operated in Cairo in 1913 but has not come into general use because of high capital cost, complexity of design and indifferent performance.

While the efforts and ingenuity of those engineers engaged in this project are to be greatly admired it is suggested their efforts might be directed into directions more likely to be of practical use to the country.

***The Author in Reply:***

I would like to thank *Mr. Sheridan* for his constructive comments which will prove very helpful to us. As Mr. Sheridan points out, the proposed system is complex and many problems remain to be resolved.

I agree with Mr. Sheridan that the matter of noise is extremely important and that good engineering design is essential to reduce the noise to acceptable levels. In my opinion this criticism is also applicable to conventional systems which almost invariably are much too noisy.

The problems arising from the high rate of water usage in the system and the resultant troubles with algae, fungi, and mineral deposits, are very troublesome. These problems are not serious in Melbourne where we are working, but could prove very serious in regions of poor quality water. As to the problem of clogging of the heat exchanger matrix, we expect that this will remain dry so that growths and deposits will not occur. However, there is the problem of dust accumulation. As the air flow reverses twice during each rotation of the wheel, these dust deposits tend to get blown off and we have had one heat exchanger operating continuously for over a year with very little drop in performance or visible dust accumulation.

The regeneration temperatures proposed for the silica gel are low by comparison with conventional systems. Mr. Johnston of our Division is investigating this problem in some detail and these temperature levels appear feasible. He also proposes a fixed rather than rotary desiccant bed which should overcome the tendency of the gel to powder.

I must agree with Mr. Sheridan that the 90 per cent heat recovery from the rock pile is very optimistic. This figure applied only to short term storage, the recovery from long term storage depends upon the insulation of the storage system, the temperature levels, and the effect of longitudinal conduction.

*To Mr. Weiss*: It is difficult at this stage to be precise with regard to the dimensions of the proposed system. However, it appears that the air heater area should roughly correspond to the roof area. It is possible that this can be reduced to perhaps 50 per cent of the roof area, dependent upon several factors. One important factor which could result in quite a large reduction in collector area and thermal storage size would be the inclusion of a supplementary heat source for peak loads and periods of low insolation. The proposed rock pile would have a volume of 1,500 cu. ft. and could conceivably be located beneath the building. The regenerative heat exchangers are about 3 ft. in diameter and 3 in. deep.

With regard to the cost of the system, this is impossible to estimate with any degree of precision at present, and depends to a large extent in the success in integrating the solar air heater and rock pile storage into the structure.

*To Mr. Hall*: The problem of noise is common to all types of air conditioning systems and we believe that with adequate care in design that this problem can be overcome.

The problem of deposits and fouling due to use of low grade water supplies is serious and can only be completely answered by actual experience. We are considering spray type coolers as well as the wetted pad type in the hope that maintenance can be reduced with the former.

*To Mr. Gorman*: The author is sorry to hear that Mr. Gorman is disturbed by the "considerable effort in skilled manpower and money being devoted to the application of solar energy to various methods of cooling". As yet, these efforts and sums of money are quite infinitesimal compared to those devoted to conventional air conditioning systems, and it must be pointed out that engineering research and development would come to a dead end if we only concerned ourselves with the study of conventional and established systems and techniques. Admittedly, the proposed system is complex and costly, but the goal is to develop a cooling system competitive with existing vapour compression systems as stated by Mr. Gorman. It should be mentioned that the lithium bromide-water absorption system in the United States is highly competitive with vapour-compression systems, and while the author has suggested an alternative scheme, Mr. Sheridan and Dr. Duffie are reporting on the use of a $LiBr\text{-}H_2O$ system in connection with a solar heat source.

With regard to Mr. Gorman's next point that, "In Australia the majority of residences are in hot dry climates . . .", it is pointed out in the paper: "The heat exchanger and evaporative coolers, with the addition of another fan at 6, form a very effective cooling system by themselves in hot dry climates". This point was not strongly emphasized in the paper, but it is believed that the cooling system in these areas where dehumidification is not required would be less in capital cost than the vapour compression system and have perhaps one-quarter of the operating cost.

On the next point of Mr. Gorman's, concerning humid tropical areas, I agree that performance at night is critical. However, it is not necessary to hold a cool storage for dehumidification. Dehumidification is accomplished by solid desiccant, e.g., silica gel. The desiccant bed is regenerated by hot air from the thermal storage (or other heat source), and no cold storage is necessary. It is in the humid tropics or sub-tropics where this complete system may find wide scale utilization if successful.

The next point concerning the solar steam engine is completely irrelevant.

With regard to the final comment, I would like to thank Mr. Gorman for the compliment. However, I do believe that worthwhile results can emerge from this project. Looking ahead fifteen years the population of Australia will be about 16,000,000, say 3,000,000 homes. Now, I like to assume that the standard of living will continue to rise even more rapidly than in the past 15 years and that a sizeable proportion of these homes will have some form of cooling. Taking the figure of 2,000 kWh as a typical annual power consumption for a vapour compression cooling system and assuming that half the homes are cooled by this done, the annual power consumption for cooling would be 2,000 × 1,500,000 or 3,000 million kWh. The saving of a sizeable fraction of this load, corresponding to about 1,500,000 tons of coal per year, would appear to be of practical value.

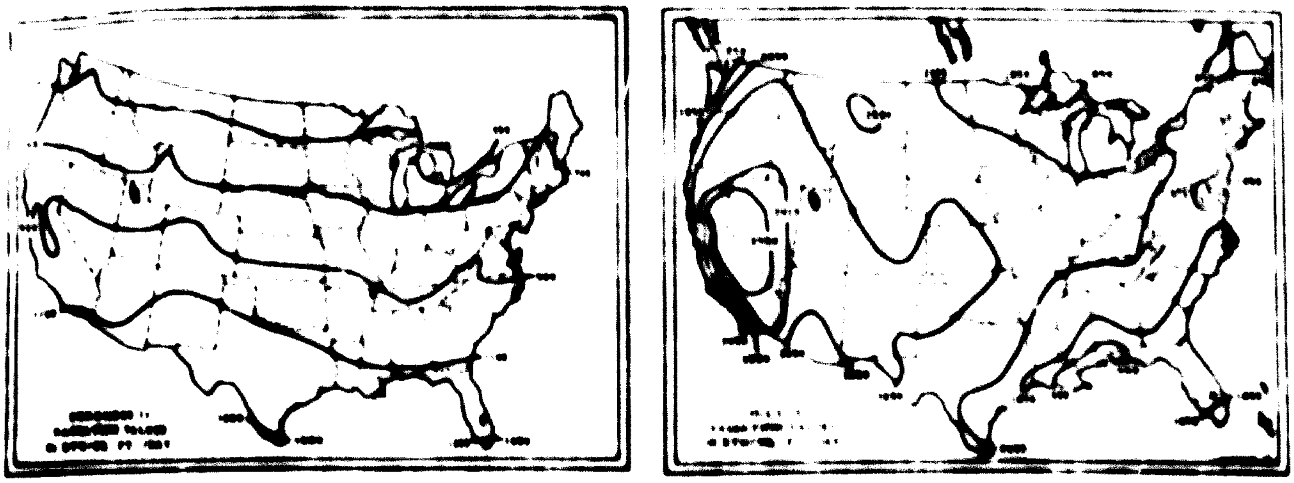


Fig.1 Availability of sunshine in the United States (Courtesy Dr. John I. Yellott, ASME Paper No. 56-F-15.)

# Solar Water Heating

## *Present Practices and Installations*

By Erich A. Farber

This paper discusses the use of solar energy for water heating. It describes present day practices, designs, and considerations in installing a solar hot-water system. It discusses the availability of sunshine, the features of solar hot water systems, types of absorbers, storage requirements, absorber size, location and position of absorber and storage tank, materials and their properties, design and economic considerations, and presents pictures of installations which have performed satisfactorily for some time.

It is almost impossible to pick up a technical magazine without being reminded of the terrific rate at which our fossil fuels are being used up. For this reason scientists all over the world are desperately looking for new fuel sources which our civilization depends upon. Nuclear energy has come just in time to give us hope and promise. Solar energy, our most abundant source of energy has not yet received the attention it should have. Its use is, however, reasonably widespread, especially for water heating, even in the United States where fossil fuels are relatively inexpensive.

This paper deals, not with solar-energy utilization of the future, but with the actual and every day use of it for heating water in homes, apartment houses, hotels, restaurants and factories.

### AVAILABILITY OF SUNSHINE

Sunshine or solar energy is reaching us day in and day out, whether we make use of it or not. Thus compared to other energy sources it is free and does not need further preparation. It is only necessary to make sure that there is enough of this energy available for a particular purpose and that the equipment to absorb it and convert it is inexpensive. Otherwise the initial cost of the installation discourages the use of it.

It is also fortunate that the inhabited parts of this planet which are lacking fossil fuels usually are the ones most blessed with sunshine. Therefore it is no coincidence that many of these parts, poor in fossil fuels, are leading in the field of solar-energy utilization.

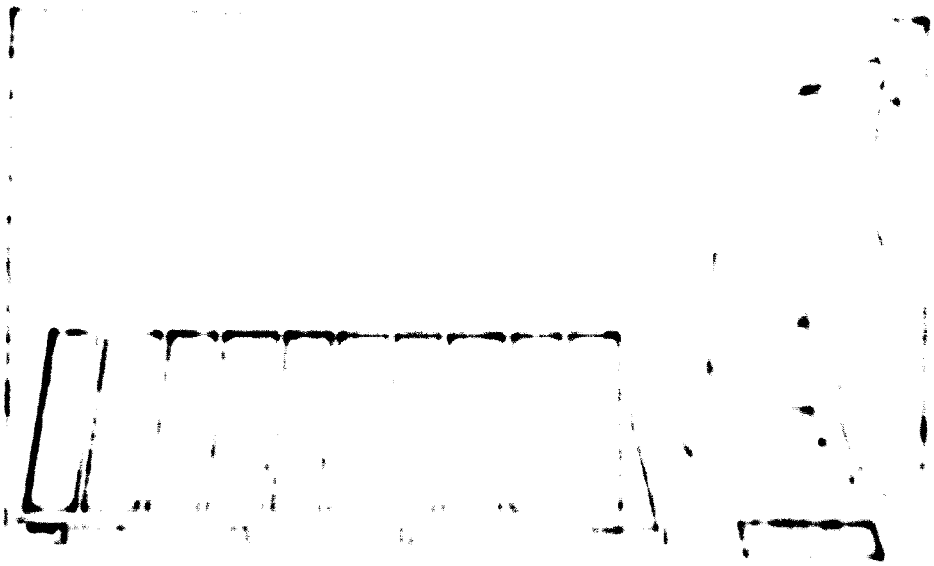


Fig. 2 Solar hot-water system

Since probably the easiest conversion of solar energy is into heat, for instance for water heating, where neither high temperatures nor expensive equipment is needed, this use is most widespread.

This paper deals primarily with the United States, which is relatively rich in fossil fuels, and especially with the states and areas where solar energy for water heating is at this time competitive with other methods.

Fig. 1 indicates the availability of solar energy in the United States, both in the summer and winter. When the areas are [illegible] where solar water heating is used in quantity, they are seen to overlap with the areas that have the longest amount of sunshine in the winter. Almost all parts have enough sunshine in the summer but many of them would have to have an auxiliary water heater during the winter when the sun does not supply enough energy through an economic installation.

SOLAR HOT-WATER SYSTEMS

General Features

Solar water heating systems consist of a unit, exposed to the sun, which is able to absorb a considerable portion of the incoming direct and diffuse energy (many of us have been sunburned on cloudy days, indicating that such energy comes to us even in bad weather), and after converting it into heat, transfers it to the water. The water being heated in this manner is then stored, sometimes right in the absorber, but more often in a separate tank. The latter design is most common in the United States, Fig. 2. The tank, placed higher than the absorber, causes the water, heated in the absorber, to flow into the top of the tank and being replaced by cold water from the bottom of the tank by free convection and no pumps are necessary.

Variations in the solar hot-water systems are usually in the design of the absorber, several of which are shown in Fig. 3.

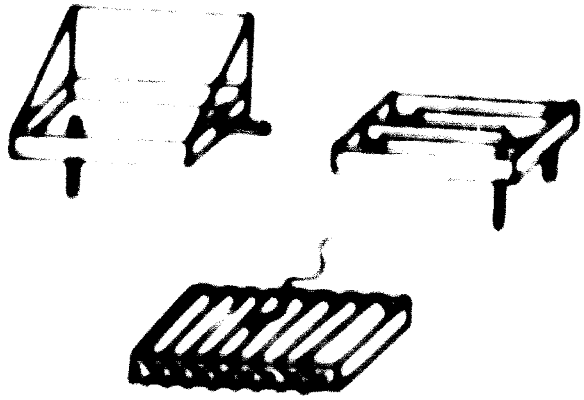
Absorber Types

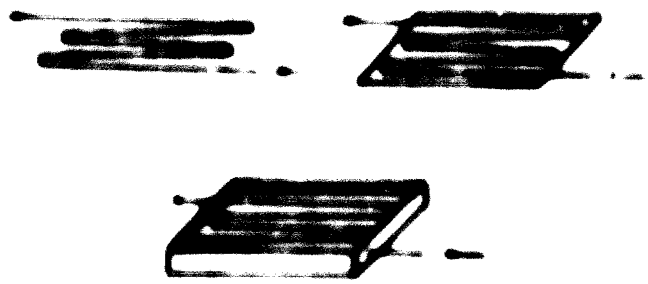
The designs of the absorber unit which are being used at this time in different parts and different countries can be put into five classes.

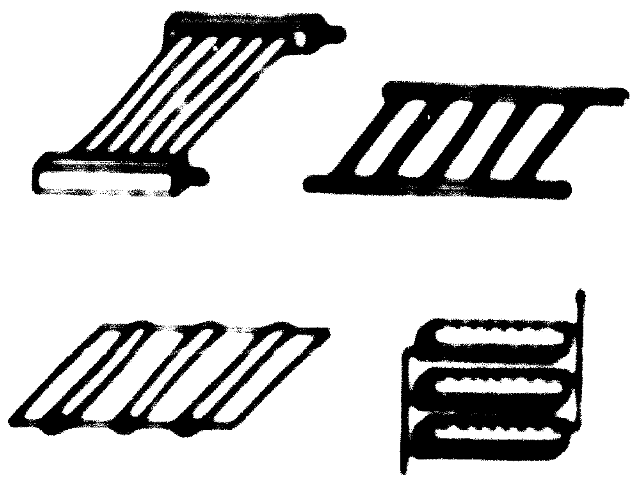
Pan Type. This type, Fig. 3(a), consists of a pan filled with water. The pan is painted with a highly absorbing paint and after converting the absorbed energy into heat delivers it to the water. The water is often stored right in this pan until it is needed, or sometimes flows slowly through this pan and to a storage tank. In the better ones [illegible] strips are often placed into the pan to give the flow of water a definite path between inlet and outlet. The pan is either open or covered by a horizontal or inclined glass sheet. Many of these units are found in the rural areas of Japan.

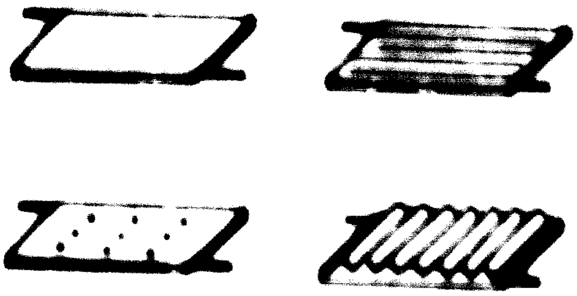
In Russia a flat pan is found which has parallel glass plates inclined so that they are essentially perpendicular to the sun. The water flows behind the glass plates which also act as guides for the flow and give in effect a double glass cover. This unit is more effective but more expensive.

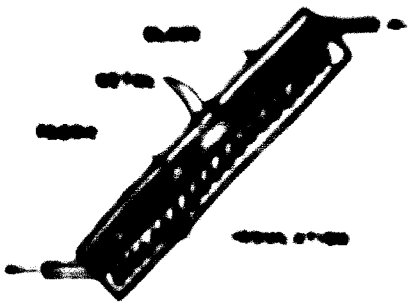
[illegible] Type. This type, Fig. 3(b),











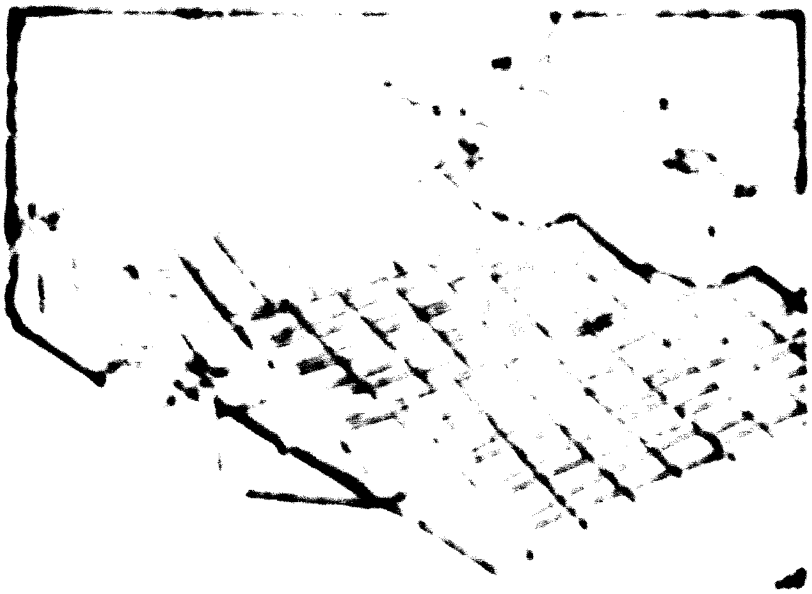


Fig.4(a) Solar hot-water installation
(Courtesy Solar Water Heater Company.)

Fig.4(b) Solar hot-water installation
(Courtesy Solar Water Heater Company.)

chamber and positioning and connecting the storage tank.

## Summary

The use of solar energy for water heating, found all over the world, is even used extensively in the United States where fossil fuels are relatively plentiful at the present time. It seems to be surprising to many that this application is not only competitive but even advantageous in many areas. It has been pointed out that many of these areas are very cold with sunshine.

Solar water-heating systems are quite similar in design since they all must have a chamber and provisions for storing the hot water once it has been obtained. In many systems the storage capacity is not large enough thus resulting in poor performance.

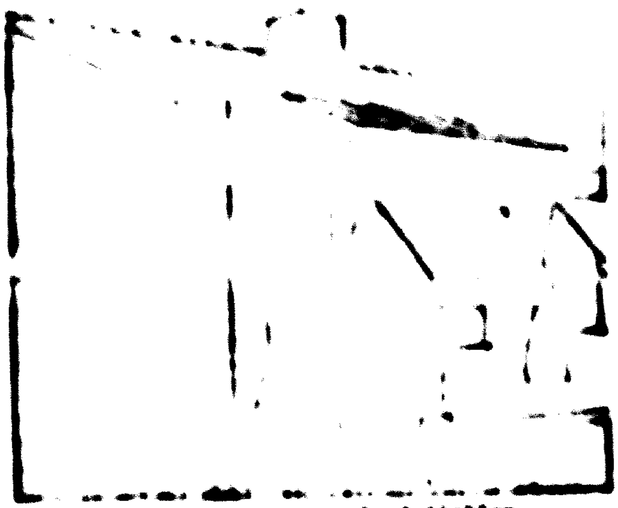


Fig.4(c) Solar hot-water installation
(Courtesy - O & L Roofing Company.)

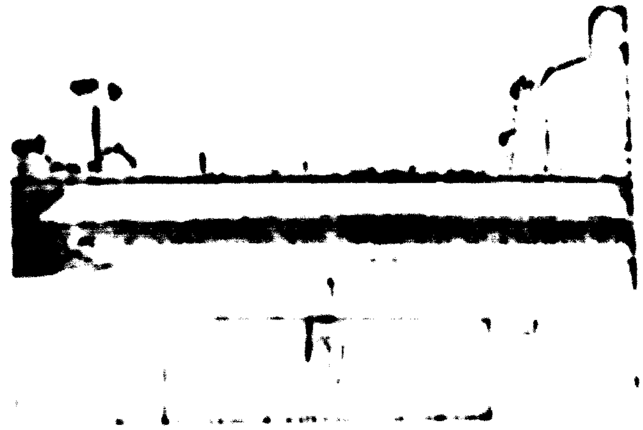


Fig.4(e) Solar hot-water installation
(Courtesy - O & L Roofing Company.)

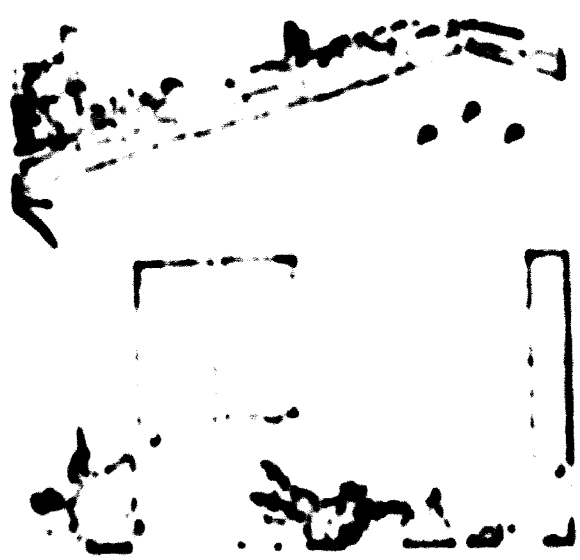


Fig.4(d) Solar hot-water installation
(Courtesy - O & L Roofing Company.)

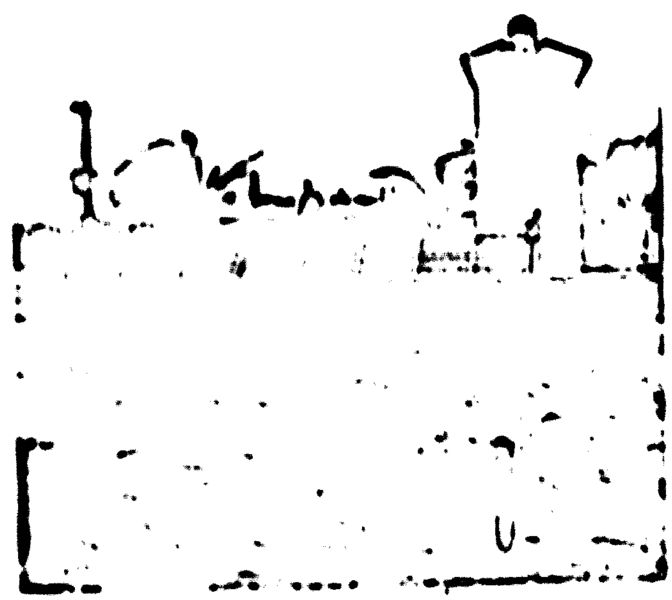


Fig.4(f) Solar hot-water installation
(Courtesy - O & L Roofing Company.)

Many designs exist for absorbers and the particular one selected is usually a compromise of the conversion efficiency and the materials available. Some designs are shown in Fig. 3.

Most absorbers are stationary and face south. They are inclined about 10 deg more than the latitude of the particular geographic location, to give better performance in the winter when the days are shorter and the air temperatures lower.

The practical design will always be a compromise between performance and cost, so that all the hot water needed is obtained at the lowest possible price. As a rough figure a homeowner hot-water heater for an average family of four in the Miami area will have cost as much

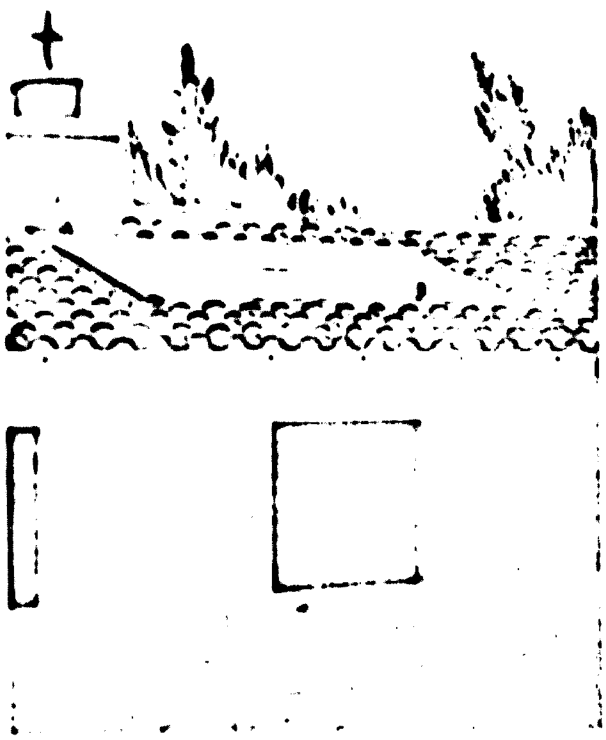


Fig.4(g) Solar hot-water installation
(Courtesy - G & L Roofing Company.)

at the end of 2½ years as a solar hot-water system. After that period the solar system will furnish the hot water free while the fuel for the kerosene system will have to be furnished and paid for regularly.

Finally, actual installations are shown which have been used for a number of years and satisfactorily supplied all the hot water needed.

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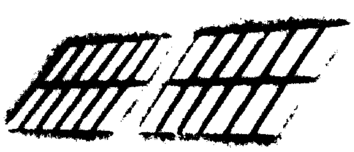
6 "Present Status of Solar Water Heaters in Japan," by Ichimatsu Yamashita, World Symposium on Applied Solar Energy Paper, Tucson, Ariz., Nov. 1955.

Fig.4(h) Solar hot-water installation
(Courtesy - Bollinger Company.)

solar ONE

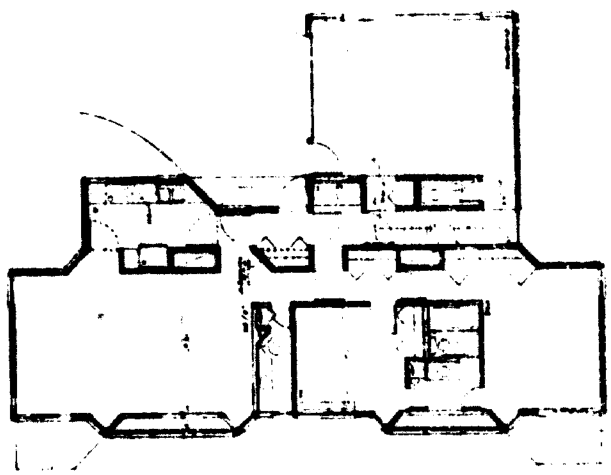


## WHY SOLAR ONE?

SOLAR ONE is the first house to directly convert sunlight into *both* heat and electricity for domestic use. Built at the University of Delaware with support from the Delmarva Power and Light Co., SOLAR ONE has been designed as an experimental structure to accumulate data from its solar harvesting system. These data will provide the basis for further development and optimization of the system and its components. This will lead to the design of certain other prototype buildings that will implement these optimized systems.

## WHAT DOES IT LOOK LIKE?

SOLAR ONE is unique in its architecture. The artist's conception on the cover shows it to have a high, interesting, 45° roofline, designed for exposure to maximum sunlight.

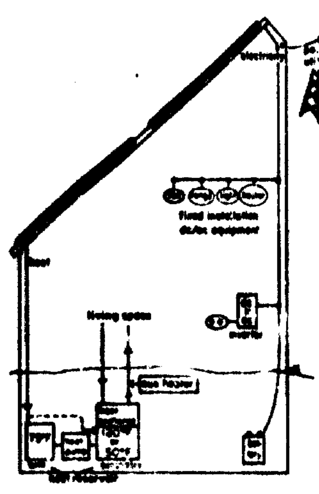


The house has a living room/dining room, two bedrooms and a kitchen as well as a garage and full basement. The upper level currently is devoted to experimental equipment but will be converted into two additional bedrooms in the future.

The roof contains a skylight which is designed to protect the solar collectors during the experimental period. Below the skylight the solar cell panels and heat collectors are located. The front of the house also contains six solar heat collectors for additional heating during cold winter days. All collectors have plexiglass front coverings.

## HOW DOES IT WORK?

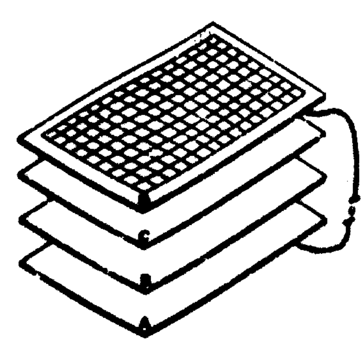
SOLAR ONE is a systemized house which converts sunlight directly into heat and electric power. When light strikes the solar panels on the roof, DC electricity is generated by the Cadmium Sulfide (CdS) Solar Cells. In addition, the sunlight heats these solar cells. Air if forced through the solar collectors and is heated by contacting the back of the hot solar cells. Additional black surface panels are provided to boost the heat further.



Ductwork conducts the hot air through a storage system containing eutectic salts. As the air passes over the eutectic salt, heat is transferred to the salt and causes it to melt at 120°F. absorbing a large amount of heat known as "Heat of Fusion." In this way heat can be stored in a much smaller volume (6 ft x 6 ft x 6 ft) than in heated rocks or water. During the evening and night hours when the house cools down, its air is circulated through the eutectic salt containers and now "extracts" this heat of fusion from the salt. The process starts over again when the sun begins to shine. When there is not enough sunshine to heat the house to comfortable temperatures, a heat pump is used to amplify the heat. In this way solar energy can be utilized for house heating even during cloudy winter days.

During the summer, the heat pump is used as an air conditioner and will operate predominately during night hours to freeze another eutectic salt. During day hours house air is circulated through these eutectic salt containers, extracting "coolness" from the salt and cooling the rooms. Night hours are used to freeze the salt since it is easier to cool during night time and more electricity is also available from power utilities.

The use of Cadmium Sulfide Solar Cells and the generation of electricity as well as heat is what distinguishes SOLAR ONE from other solar structures that have been built in the past. The Cadmium Sulfide (CdS) cell is relatively simple in its design. As shown in the illustration, a CdS cell is composed of four basic parts:



A metal foil substrate (A) forms the base electrode upon which (B) cadmium sulfide is vacuum evaporated as a thin film. Then a layer of copper sulfide ($Cu_xS$) (C) is electroplated onto the CdS (both films together are thinner than a human hair). A metal grid electrode (D) is then placed on top of the first three. Light passes through the metal grid and activates a current flow in the film sandwich, which can be picked up through the two electrodes. Plastic material is laminated on the entire cell to encapsulate it for protection.

Wiring conducts the electricity (e) from the CdS cells to household units such as an electric range, heaters, lights, etc. Any excess electricity that cannot be immediately used is stored in a series of batteries. The stored energy will be used especially during the hours when electricity is high in demand (afternoon hours) and will help to alleviate power shortages for power utilities.

## WHY IS IT IMPORTANT?

SOLAR ONE is an experimental house that will provide information for residential dwellings in the future; it will define how solar energy can supplement conventional energy sources and thereby help alleviate energy shortages.

SOLAR ONE is designed to obtain up to 80% of its heat and electricity from sunlight and the rest from the power utility predominantly at a time when power is available (night hours).

SOLAR ONE is designed to operate in conjunction with the power utility to prove how solar energy can contribute to "Peak Shaving" and can supply "Power on Demand" to eliminate "brownouts" and "blackouts".

SOLAR ONE has been built with contributions from the University of Delaware and the Delmarva Power and Light Company. It was designed by Harry Weese Associates with assistance by Cosentini Associates and the Institute of Energy Conversion. Further contributions from Frederick G. Krapf and Son Inc., York Air Conditioning Division of Borg-Warner, Rohm and Haas Corporation, ESB, and Alcoa Aluminum are gratefully acknowledged.

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*Traditionally, fuels available locally and nationally, such as wood and coal, have been used for domestic heating. But short-sighted policies - supported by advertising - have led to the general use of liquid fuels and gas, even in country districts where wood is cheap and readily available. The sun offers another alternative as will be seen in the following article.*

## HEATING HOMES BY SUNLIGHT

*by Félix Trombe*

A glance at power estimates shows that in many so-called temperate and cold areas of the world the sun, sky and clouds can provide a considerable amount of calories for heating purposes. A medium-sized house in these regions literally receives hundreds of kilowatt hours of heat each day on its façades and roof. This heat is completely lost through infra-red radiation and the normal heat exchange with the surrounding air.

Work has been going on for many years to find ways of using this wasted energy. Sophisticated prototypes of dwellings have been designed but, unfortunately, they are highly expensive, making heat derived from sunlight far dearer than that produced by conventional methods.

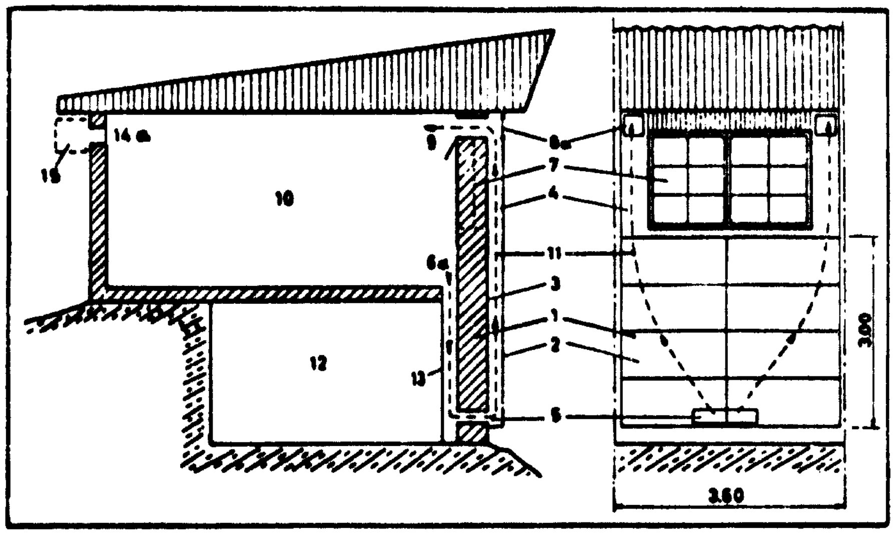
Using a somewhat different approach, the CNRS - French National Centre for Scientific Research - has come up with several designs that have been patented by ANVAR - the National Association for the Advancement of Research. Since it is not economically feasible to try to heat a house exclusively by sunlight, which appears and disappears capriciously, or to store sun-derived calories for long periods, an auxiliary power supply - such as electricity or some conventional fuel - must be provided.

A systematic study of the most economic ways of capturing solar heat has shown that the best receptor surfaces are the walls of a house, rather than its roof, particularly the south walls which receive a lot of sunlight during cold periods. Heat from the sun's rays, the sky, clouds and even energy reflected off the ground can be collected by placing vertical glass panels, built on the same principle as a greenhouse, over half or two-thirds of the south wall. This method greatly reduces the loss of heat from the walls. Moreover, the "greenhouse" walls can also be used to cool the house in hot weather.

CNRS has been conducting research in this field for the last 15 years, and has built a number of experimental houses at Odeillo, at the Mediterranean end of ...

*Prof. Trombe is director of the solar energy laboratory of the French National Centre for Scientific Research (CNRS).*

*Heating mechanism with lateral air inlet ducts.*



*1 - Accumulator wall*

*2 - Glass panelling*

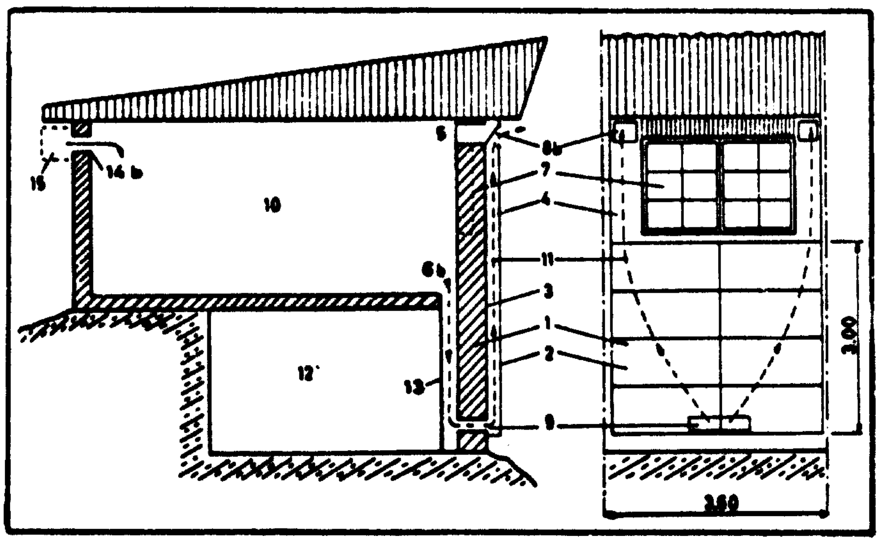
*3 - Sunlight absorbing surfaces*

*4 - Path of circulating air*

*5 - Lower aperture*

*6a- Inlet for air*

*6b- Intake of air into room*



*7 - Glazing*

*8a- Ventilator (closed)*

*8b- Inlet of warm air*

*9 - Inlet admitting warm air into room*

*10 - Room to be heated*

*11 - Circulation of air*

*12 - Garage on lower level*

*13 - Partition*

*14a- Closed inlet for conditioned air*

*14b- Inlet for conditioned air*

*15 - Air conditioner*

*These two diagrams from a patent recently taken out by CNRS-ANVAR (Trombe & Michel) show how sun-derived calories entering through the glass panels of the "greenhouse", can be used either to heat a house in cold weather or to cool it in warm. Fig.1, showing the heating system, indicates how the warm air circulates round the wall to heat the rooms inside the house. In Fig.2, the wall serves as a suction mechanism, after which the air is expelled through an aperture at the top of the greenhouse. The depression created inside the house enables cold air from the north wall or from an air conditioner to be admitted.*

*It should be noted that the accumulator area of the greenhouse is topped by lateral chimneys surrounding the apertures admitting daylight. The chimneys make it possible to increase the pressure controlling the propulsive circulation of air; their role is analogous in the greenhouse accumulator to that of the flue of a conventional fireplace. The chimney exhausts all smoke upward.*

the Pyrénées, where families have now been living for about four years. The results are quite conclusive: in countries where there are clear skies and the sun shines frequently, it can provide 75 per cent of the calories required for domestic heating, the remaining 25 per cent being supplied by auxiliary sources. In less sunny climes, the economy achieved is less spectacular but still important: a prototype house was recently built at Chauvency-le-Chateau in the cloudy east of France by architect Jacques Michel.

In each case, the cost of collecting solar calories is the yardstick for deciding whether or not to build a solar house. But in good climatic conditions the cost of a kilowatt-hour of solar heat - calculated on the initial investment involved - is two or three times cheaper than a kilowatt-hour of electricity. Sunlight, after all, is free. (UNESCO FEATURES)

*Note to Editors: Photographs are available upon request.*

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U.S.A. FIRST TO RATIFY CONVENTION ON CULTURAL AND NATURAL HERITAGE

The United States is the first Unesco Member State to ratify the Organization's Convention Concerning the Protection of the World Cultural and Natural Heritage. William B. Jones, Permanent U.S. Delegate to Unesco, presented the instrument of ratification at a ceremony held at Unesco Headquarters on 7 December.

The Convention, adopted by the 1972 Unesco General Conference, sets up a World Heritage Committee to establish a World Heritage List of cultural and natural properties, submitted by the Member States and considered to be of outstanding universal value. A State may request that a property be placed on a List of World Heritage in Danger if its conservation requires major operations because of decay, large-scale public or private projects, rapid urban or tourist development, armed conflict, or other dangers. (UNESCO FEATURES)

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UNITED STATES WILL CONTRIBUTE $1,000,000 TO SAVE PHILAE

A United States contribution worth the equivalent of $1,000,000 in Egyptian pounds is to be paid to the Unesco Trust Fund for the monuments of Nubia. The total cost of the operation to preserve the temples of Philae was estimated at US $13,700,000 of which the Egyptian government will find one-third. The voluntary contributions of Unesco Member States, either paid in or pledged to date, now amount to more than $6,300,000. (UNESCO FEATURES)

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McGill University
Faculty of Engineering
BRACE RESEARCH INSTITUTE

# How To Make
# A SOLAR STEAM COOKER

Do-It-Yourself Leaflet No. [illegible] January, [illegible]

by
AUSTIN WHILLIER

BRACE EXPERIMENT STATION
St. James
Barbados, West Indies.

# How To Make
# A SOLAR STEAM COOKER

This leaflet describes a relatively simple, yet effective, device for steam cooking of food using solar energy. The cooker has been designed for village use in areas where sunshine is abundant, and where most food is cooked by boiling. Frying and baking cannot be done in this stove.

The cooker consists of two parts that are rigidly and permanently joined to each other. The first is the solar collector, which boils water to produce steam, and the second is the insulated steam bath or steam cooker, in which the food-containing saucepan (pot) is placed. The solar collector is at a fixed tilt angle of [illegible] degrees, and is supported on a single pivot pipe that is fixed into the ground. The entire cooker is pointed towards the point of sunrise all morning, and the point of sunset all afternoon. More frequent adjustment of the collector position can be done but is not essential, except in poor weather.

The solar collector always contains water, about one cup of water being added each evening to replace the water that has boiled away. Steam is produced within an hour of sunrise and will continue to be produced for the rest of the day as long as the sun shines on the collector, i.e. almost until sunset. Thus it is possible to cook both the mid-day meal and the evening meal. Food left in the cooker will remain hot for several hours after sunset.

The solar cooker is a slow-cooking device, and is best suited for foods that require long slow boiling, such as stews, cereals and vegetables.

## FABRICATION INSTRUCTIONS

Gather the material as listed in the materials list, and paint all wood framework pieces (not the hardboard panels) with a good white undercoat paint.

### The Collector Box Framework

Assemble the rectangular collector box, and insert all the support cross braces (Part No. A11), and the two long support strips (A4) down the sides. (There is no support for the copper plate along the centre.) Fix the upper end brace (A10) inside the box.

After keeping it thoroughly wet for several hours, nail the rear panel of tempered hardboard (A5) in place.

Drill the clearance hole for the support pipe at [illegible] degrees into the 2 in. x 4 in. x 7 in. block (A12), then fix in place by screwing from inside.

Drill holes, one in each end board of the rectangular box, to clear the ½ in. water tube (B1). They should be central and 1½ in. from the bottom of the end boards.

Paint the outside of the box, sides and ends, any dark colour such as green, grey, black, etc.

### The Copper Plate and Pipe

Firmly attach the pipe (B1) along the centreline of the copper plate (B2), by partially wrapping the tube three quarters of the way round the pipe, then drawing the two tightly together with galvanised steel wire spaced at 3 inch intervals along the length of the pipe. The joint may subsequently be soldered to ensure a good bond, but although desirable this is not essential if the copper plate has been very carefully and tightly drawn up around the pipe. At the lower end the pipe should end 1 in. beyond the copper plate, leaving 6 in. of pipe clear at the upper end.

Place the insulation material (D1) in the 3 in. deep space in the bottom of the box, and cover with a layer of aluminium foil (D2). (Any loose fibrous material such as coconut fibre or even straw may be used for insulation. Sawdust is not recommended.) The material should be packed reasonably tightly

(Aluminium foil is sold in shops for household use or wrapping purposes.) Insert the pipe-plate assembly and nail the copper plate to the side mounting strips (A4). Screw the bottom end cap (B9) in place; this is removed only for draining the pipe. Give the copper plate a very light coat of flat black paint, being sure first to clean the plate. A second coat of flat black paint may be added when the first has been thoroughly dried in the sun.

## Transparent Covers

"Tedlar" is a thin polyvinylfluoride film marketed by the DuPont Company, Wilmington, Delaware, U.S.A. It has both a high transparency to solar radiation and a long life. The film recommended for this cooker is 0.004 inch thick "Tedlar" PVT clear film, which is supplied in bulk in 4 foot wide rolls for a cost of about U.S. $100.00. One roll has enough material for just over 100 cookers. If Tedlar is not available, owing to local foreign exchange restrictions, glass may be used instead for the three transparent covers. Suitable changes in constructional details should then be made.

## Inner Tedlar

Assemble the rectangular framework (A7, A8) for the two inner Tedlar layers, being sure that it fits loosely into the collector box. Wrap the Tedlar (B10) around the frame (top and bottom), fixing in place with an office-type stapler or any other suitable method.

Insert the 1/4 in. x 3/4 in. spacers (A5, A6), nailing in place, then install the inner frame with its two layers of Tedlar.

## Outer Tedlar

Fix the centre spacer (A9) in place. (This ridged centre spacer is to provide tent-like support for the outer Tedlar cover.)

Place the outer Tedlar layer (B11) in place, carefully folding the corners, and fixing around the under edge of the box. In this way the Tedlar forms a completely rain-proof cover.

Fix the 30 in. wide shield (A13) to the bottom of the box.

## Support frame for Steam Bath

Assemble the support frame (A14, A15, A16) for the steam bath, paint gloss white, then firmly screw to the underside of the collector box.

Cut hardboard undergrnace (A17) to fit and drill hole in centre to allow the pipe.

Fabricate the steam bath (B17) and solder the bottom pipe bracket (B4) in place.

Be sure that the upper horizontal areas of the steam bath and lid are slightly sloped so that all the water and condensate will drain back into the pipe.

Rivet the hinge (B14) of the lid (B13) to the outer casing. Fill the 1 in. annular space around the steam bath with insulation.

Screw the 135 degree pipe spring (B3) into the bracket under the steam bath. It must not protrude up into the bath. Place insulation into the space under the steam bath and place the steam bath in position. Join the two pipes with a short length of radiator hose (B5). Wrap the entire exposed pipe with insulation.

Paint the outer surfaces of the steam bath and lid any convenient dark colour, such as green or grey.

The bottom of the cooking pot (saucepan) should stand about half an inch above the bottom of the inside lining of the bath to allow the boiling water to pass freely into the bath from the pipe. Normally the side handles of the pot will rest on the top of the outer casing, holding the pot in the correct position. If this cannot be arranged, a light wooden or metal pot stand, 1/2 in. high, must be placed in the bottom of the steam bath. The cooking pot (B15) should be of aluminium if possible.

## Pivot Pipe

The cooker should be set up on ground that is reasonably flat. The top of the 1 in. dia. outer pivot pipe (B9) should be about 30 inches above ground level.

A built-up platform behind the unit will be needed to stand on while cooking, because the top of the saucepan will be 5 feet above the ground.

## Cooking With Two Saucepans

The same collector would supply enough steam to permit cooking with two saucepans instead of one. The steam bath would have to be enlarged so as to provide two holes for the two saucepans.

**Note: THE USE OF TEDLAR**

Since writing this report we have been informed that Tedlar earlier highly recommended as a transparent cover for solar collectors, is no longer considered suitable for use in these dry applications (that is, where no moisture condensation takes place).

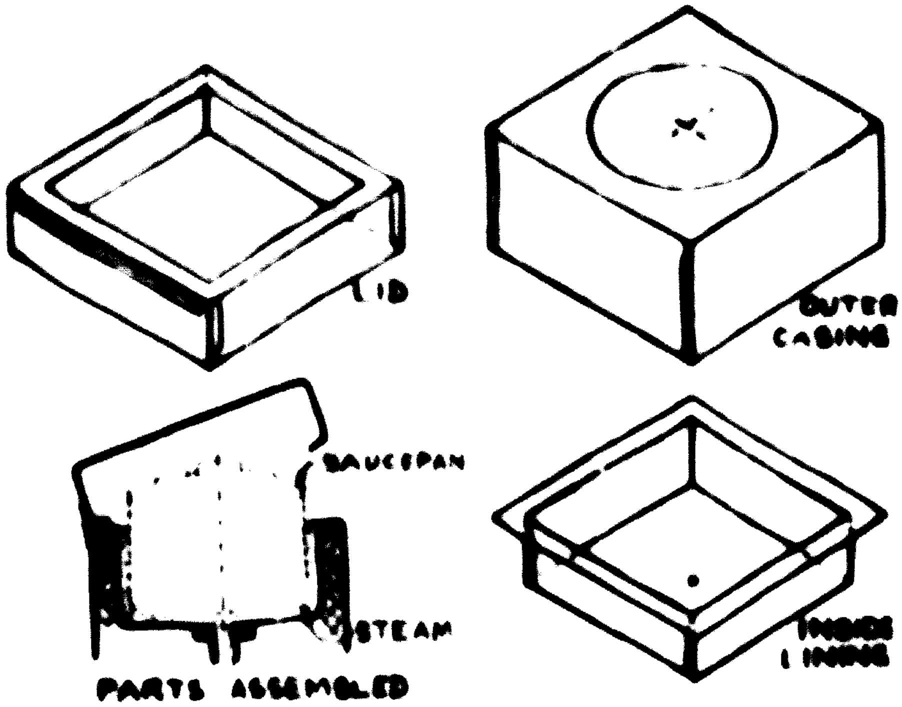
Consequently, we would advise people interested in this type of unit to adopt 1/8" or 3 mm. thick window glass (16 oz.), supported by a suitable frame, for their installations. It is recommended that a silicone type sealant be used when installing the glass.

## OPERATING INSTRUCTIONS

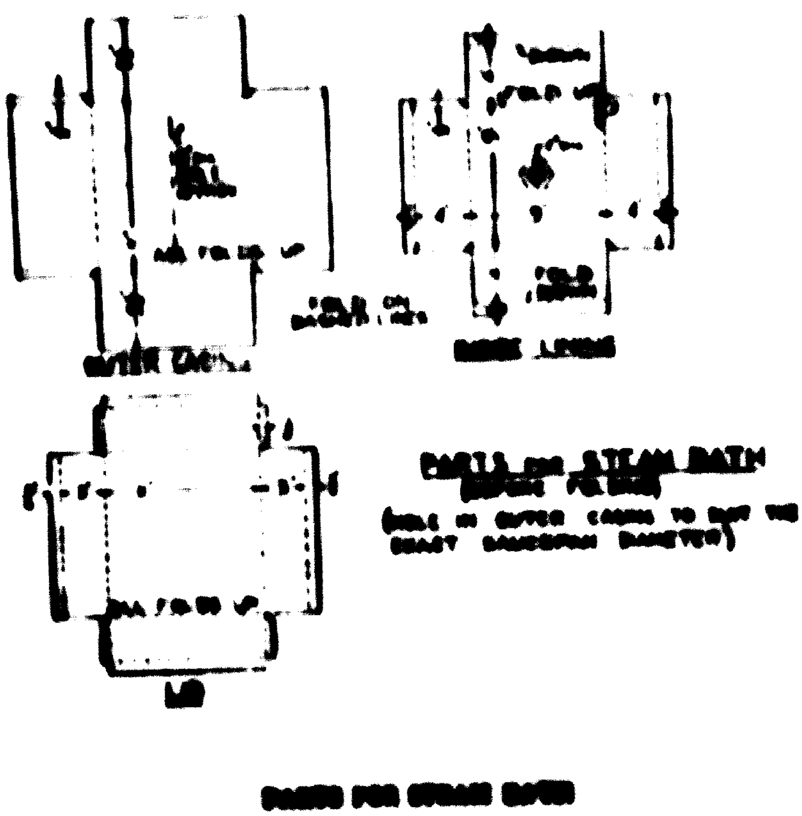
1) Never leave the unit in the sun without water in the pipe.
2) Each evening sufficient water should be added to bring the water level up to the top of the pipe.
3) In the morning the cooker should be pointed towards the position where the sun first rises over the horizon. From noontime onwards the unit should be pointed towards the setting sun.
4) It is not necessary to keep moving the collector during the day so as always to face the sun. However, in very windy or cold weather, or on days when sunshine is poor, this would be beneficial.

# Materials List for Cooker

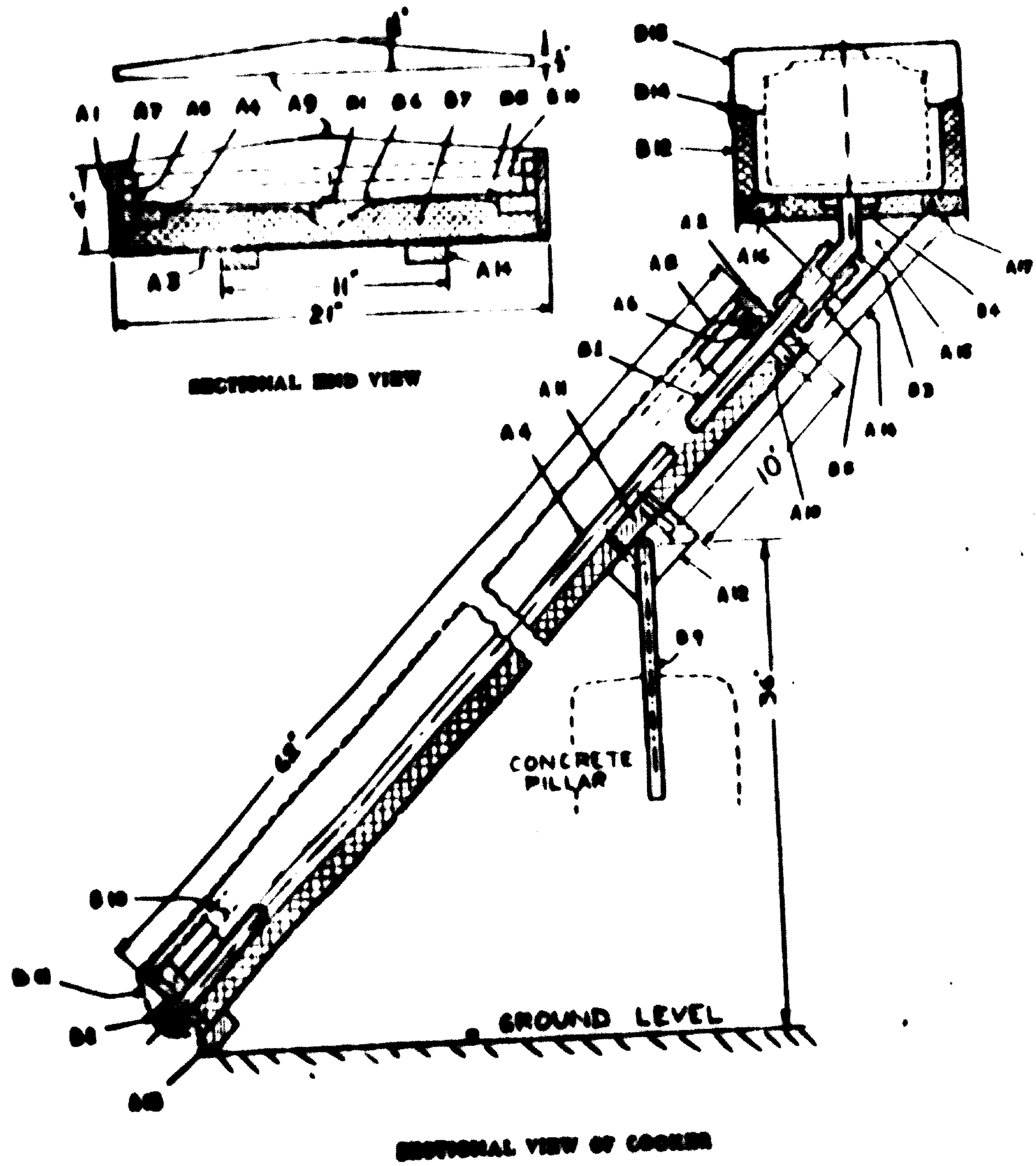
| Part No | No Off | Name and Size |
|---|---|---|
| **Wood** | | |
| A 1 | 2 | Box sides [illegible]" x 4" x 62" |
| A 2 | 2 | Box ends [illegible]" x 4" x 20" |
| A 3 | 1 | [illegible]" tempered hardboard rear panel 62" x 21" |
| A 4 | 2 | Mounting strips for copper plate 1" x 2" x 61" |
| A 5 | 2 | Spacers [illegible]" x [illegible]" x 61" |
| A 6 | 2 | Spacers [illegible]" x [illegible]" x [illegible]" |
| A 7 | 2 | Frame for inner Tedlar, sides [illegible]" x [illegible]" x 60 7/8" |
| A 8 | 3 | Frame for inner Tedlar, cross pieces [illegible]" x [illegible]" x [illegible]" |
| A 9 | 1 | Tedlar support strip, see drawing [illegible]" x 20" x [illegible]" |
| A10 | 1 | End brace (for attaching support arms for steam bath) 1" x 2" x 16" |
| A11 | 1 | Support cross brace 1" x 3" x 20" |
| A12 | 1 | Pivot block 2" x 4" x 7" (with 45° hole for pivot pipe) |
| A13 | 1 | Bottom skid 1" x 2" x 30" |
| A14 | 2 | Support arms for steam bath 1" x 2" x 24" |
| A15 | 2 | 45° wedges to support steam bath 1" x 10" on long face |
| A16 | 2 | Steam-bath platform cross-members 1" x 2" x 9" |
| A17 | 1 | [illegible]" hardboard 9" x 10" |
| **Miscellaneous** | | |
| B 1 | 1 | [illegible]" pipe 65" long, threaded both ends |
| B 2 | 1 | [illegible]" cap, screwed [illegible]" BSP (British Standard Pipe thread) |
| B 3 | 1 | [illegible]" 135° pipe spring |
| B 4 | 1 | [illegible]" pipe locknut |
| B 5 | 1 | 1" i.d. x 4" long rubber tube |
| B 6 | 1 | 0.025" copper sheet 20" x 59" |
| B 7 | 1 | Insulation 20" x 61" x 22" |
| B 8 | 1 | Aluminium foil 18" x 61" |
| B 9 | 1 | Pivot pipe [illegible]" x 12" |
| B10 | 1 | Tedlar 42" x 72" |
| B11 | 1 | Tedlar 30" x 72" |
| B 12 | 1 | Steam bath fabricated from 26 gauge, [illegible]" x 60" galvanized sheet, see drawing |
| B13 | 1 | Lid, fabricated with B12 |
| B14 | 1 | Hinge, 9" long, galvanized |
| B15 | 1 | Saucepan with lid, 8" dia. 9" deep |
| | | White undercoat paint |
| | | White gloss paint |
| | | Flat black paint |
| | | Any other dark paint |
| | | ✓16" galv. wire, 10 ft. long. |




DETAILS OF STEAM BATH




PARTS FOR STEAM BATH




SECTIONAL END VIEW

SECTIONAL VIEW OF COOKER

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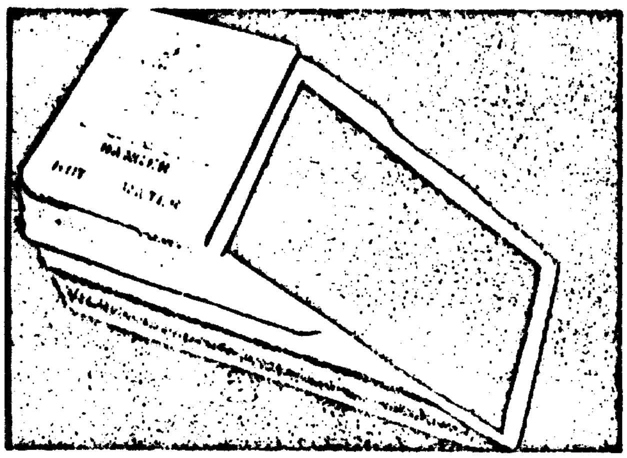
## Portable tank captures solar energy

**A new concept in solar heating** provides free hot water for small-scale needs of picnickers and campers. The water is contained in a foamed-polystyrene tank that has an aluminum-sheet, heat-exchange surface covering molded-in channels through which the water circulates by convection currents. The product is the result of more than 19 years of experimental work by inventor Frank L. Suhay, Glendale, Calif. Production and marketing commenced late last year after the granting of a U.S. patent on the principles involved. The present model has a suggested retail price of $3.98.

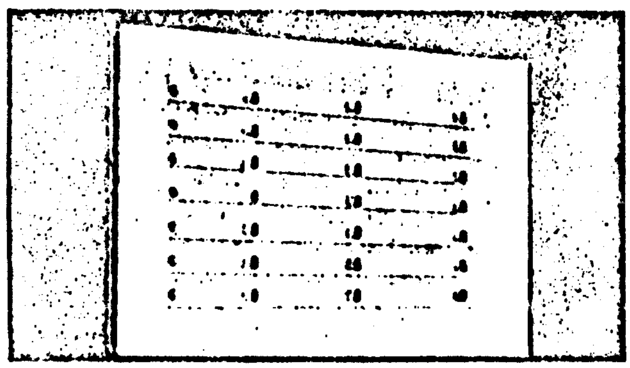
With a total weight of approximately 1 lb, the unit can absorb sufficient solar heat to raise 4 gal of water as much as 30F in from 3 to 6 hours. This amounts to approximately 1000 Btu of heat absorbed by the 1 sq ft of aluminum. The inventor claims that it would require 24 ft of 1/2-inch copper tubing to absorb the same amount of solar energy. Likewise, he points out that best performance occurs during the 9 months from early spring to late fall.

Plastics make an important contribution to the unit's weight and overall efficiency in several ways. In addition to the light weight and insulating value of the molded polystyrene bead tank, a sheet of "Mylar" film covers the heat-exchange area to provide a dead-air space that increases the heat-transfer efficiency. The various components making up the assembly are bonded together with a nontoxic polymeric adhesive.

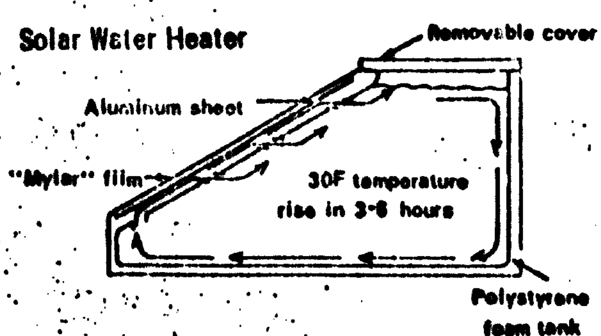
The inventor also claims ecological benefits by the elimination of fires that otherwise would be required to heat the water supplied by his solar unit. And plans are in the works to build larger units employing the same principles that could be used to heat swimming pools or provide hot water for commercial and industrial needs.



**Solar water heater** consists of three polystyrene foam moldings, a 0.005-inch-thick aluminum sheet and a 0.003-inch-thick "Mylar" sheet. All components are bonded with "Lockbond" 923 adhesive.



**Aluminum sheet absorbs solar energy and transfers heat to water in channels. Convection currents circulate water through channels in polystyrene panel (right).**



SUN-COOKED LUNCHES IN GENEVA

Cooking lunch on the roof of a Geneva block of flats is no problem for Dr. Adnan Tarcici, Ambassador to the U.N. in Geneva of the Arab Republic of the Yemen.

He does it on a portable solar cooker designed and patented by himself, reports *Development Forum*, the monthly published by the U.N. Centre for Economic and Social Information (CESI).

Dr. Tarcici, 56, was born in Akkar, north of Tripoli, in Lebanon, and as a boy was often taken on hunting expeditions in the plain between the Mediterranean coast and the mountains.

The area is hot and sunny, with few trees. Camp fires were kept going with animal dung, ignited initially by Tarcici with a magnifying glass.

But after learning how Archimedes set fire to the invading fleet in front of Syracuse - legend has it that he trained men with mirrors to focus the sun's rays on the ships' sails - he adopted the principle himself.

Forty years later, the result is a fully portable, inexpensive solar cooker - the Solnar - which opens out in the shape of a parabolic mirror, its polished aluminium concentrating the sun's heat on a central grill. It weighs only 3 kilos (6 lbs) and boils a litre of water in 8 to 10 minutes.

During a lengthy assignment in the United States, Dr. Tarcici surprised many people by using his cooker for picnic meals on country outings.

"The cooker is an extremely useful article for most developing countries which have the necessary sunshine", Dr. Tarcici says. The problem is now to mass produce it at low cost.

Looking further ahead, Dr. Tarcici, who is in touch with other solar enthusiasts in many parts of the world, as well as with several potential manufacturers of his cooker, can visualize some of the wider possible applications of sun power.

In many countries - India, Cyprus and Israel among them - the use of the sun's rays is already commonplace for heating domestic water supplies, usually by means of a rooftop installation. In more sophisticated applications, particularly if constant sunshine is not assured, this functions in conjunction with a thermostat-controlled electric immersion heater. India has also developed solar cookers.

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(UNESCO FEATURES)

THE SOLAR REVOLUTION

*by Daniel Behrman*

Changes in society as revolutionary as those wrought by the advent of steam or electricity could well be in store if the sun becomes a major source of energy.

Time and again, this forecast was heard at the international congress on "The Sun in the Service of Mankind" that filled Unesco's Paris headquarters last summer with 800 scientists from 60 countries.

If the omens are right, our world may be turned topsy-turvy. Homes that are cheap to build but costly to run because they consume great quantities of fuel for heating, cooling and hot water, could become obsolete, giving way to houses that hoard the sun's energy collected on their roofs. The shape of communities, too, would change if energy came not only from mines, refineries and power plants but also from the sky.

Solar energy has already made some major changes in the life of Chinguetti, an oasis in the desert of Mauritania a good 500 miles (800 km.) from the sea. There, a solar pump built by a young French engineer, Jean-Pierre Girardier, supplies drinking water to 2,000 inhabitants.

Girardier is a rare blend of industrialist and idealist. Doing his national service as a teacher in Africa, he met his mentor, the late Prof. Henri Masson, at the University of Dakar, in Senegal.

"Masson told me that Africa had sun overhead and water down below. He said: 'Look at the sun, it's hot. Look at the water, it's cold. You should be able to run an engine on that difference in temperature'.."

Back in his small factory at Montargis, southeast of Paris, Girardier studied the problem until he finally came up with a simple rugged engine that uses butane as its working fluid. Heat from a solar collector evaporates the butane which expands, driving a piston that works a pump. The cold water pumped to the surface is first used to condense the butane back into liquid form so that the cycle can start all over again.

At Dakar, one of these engines has run for three years without a breakdown. In June 1972, Girardier started to install another at Chinguetti, one of the most isolated places in the world.

A small-scale social revolution took place. Since the solar pump would replace the children who had always hauled water, Girardier and his architect,

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Georges Alexandroff, reasoned that a school had to be built for the kids who now had nothing to do. Alexandroff designed the school in classic Mauritanian style and used its roof as a collector for the heat needed to drive Girardier's pump.

Breaking the laws of economics

They are now working on two new ideas - one a tourist hotel in the mid-Sahara, the other a big pumping station that would supply irrigation water. They seem to be breaking all the laws of economics because the solar engine is much more expensive than a diesel of equivalent power.

Girardier has a ready [illegible]wer to that objection. His installation runs to about $40,000, but the Mauritanian government estimates that it costs from $5,000 to [illegible]0,000 a year to maintai[illegible] and fuel a diesel installation in a remote spot like Chinguetti, where oil has to be trucked across the desert from the coast.

Solar energy is beginning to look like an economic proposition to industrialists operating on a much bigger scale than Girardier. Twenty-five of the 500 leading firms in the United States are supporting a project by Arthur D. Little Inc., one of the biggest of American 'think tanks', to look at prospects for solar heating and cooling of buildings.

Dr. Peter Glaser, vice-president and head of engineering sciences at Arthur D. Little, declared in Paris that the market for equipment could run to $1,000 million over the next ten years. Glaser has also advanced a much more ambitious plan to put a solar power station 12,000 miles (about 20,000 km.) out in space where the sun always shines. Power generated by solar cells would be beamed by microwave transmitters to a receiving station on earth.

Averting the energy crisis

Optimism was expressed at the conference in a message from Dr. Wernher von Braun, father of space flight, now working with an industrial firm in the United States. He said:

"I am confident that solar energy can be developed to meet significant portions of our future energy needs and thereby help to avert the coming energy crisis. The solar industry is in its infancy today, much as the space industry was so many years ago when I first started dreaming of rockets to the moon.

"I believe we are at the dawn of a new age, one which might be called the 'Solar Age'."

That age is already at hand for researchers like Harold R. Hay of Los

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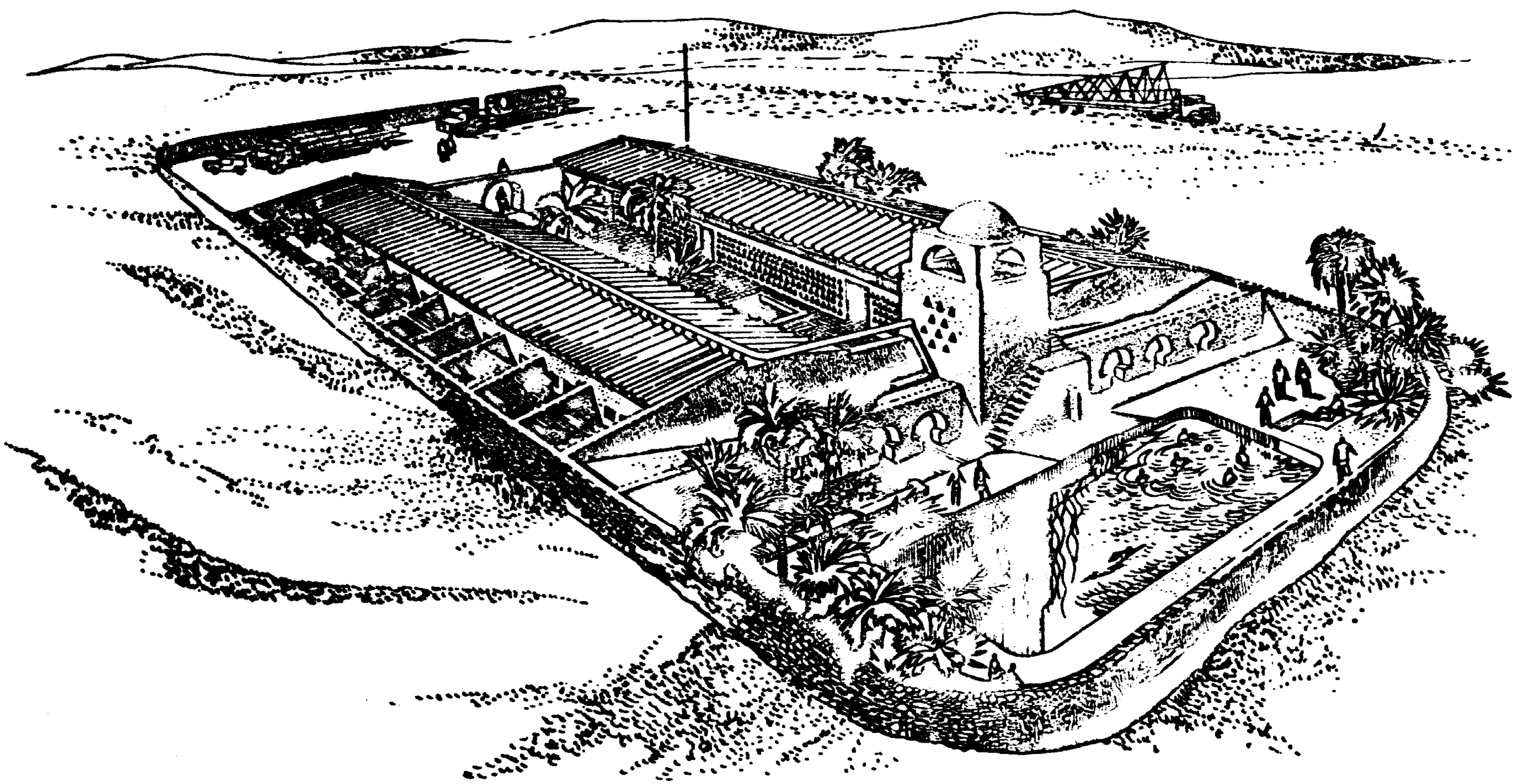

*This tourist hotel for travellers through the Sahara - complete with swimming pool - is one of the designs that solar energy engineers have come up with to increase the prosperity of arid regions. The roof of the main building is covered with solar energy collectors and the pool also serves to cool the solar engine's condenser.*

Angeles who has built a 'solarchitecture' house in Phoenix, Arizona. He has succeeded in heating and cooling the house with a roof pond eight inches (20 cms.) deep. Moveable panels allow the pond to warm up by day during the winter, and shield it at night to keep the heat in. In summer, the pond stays covered by day, but at night the panels open to let the heat out.

Such housing runs counter to the trend of huge high-rise buildings standing in lonely grandeur amidst a desert of parking lots. Hay has stated: "Land use and value are changing in ways that will affect, and will be affected by, on-site use of solar energy. To conserve virgin areas, new cities should be built on abandoned agricultural land and planned for lower power and fuel consumption through natural heating and cooling."

Prof. J.K. Page of the University of Sheffield in the United Kingdom reminded the congress of what he called the tragedy of architecture in Latin America which, he said, has borrowed the worst features of European designs. Glass-walled buildings in hot climates demand air-conditioning that takes electric power away from industry.

Page sees the distinctions being wiped out between town and country. Already factory farming has created 'animal cities' and even 'animal slums' in the countryside.

The next step is to bring the country into the city. Page wants to use sunshine falling on buildings to grow plants on their roofs. The carbon dioxide and moisture generated by the inhabitants of these buildings would then feed the gardens to speed plant growth, since plants thrive on the carbon dioxide produced by the human metabolism and humans breathe the oxygen manufactured by plants.

*Note to Editors: Photographs are available upon request.* (UNESCO FEATURES)

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## PERPIGNAN UNIVERSITY CENTRE OFFERS COURSES IN SOLAR ENERGY

Perpignan University Centre is offering diploma courses in solar energy with both theoretical instruction and practical experience at the solar furnace installation at Odaillo - Font Romeu in the Pyrénées. Organised with financial assistance from Unesco, the Perpignan course is intended for professors, researchers and other post-graduate students from third world countries who are interested in solar energy.

(UNESCO FEATURES)

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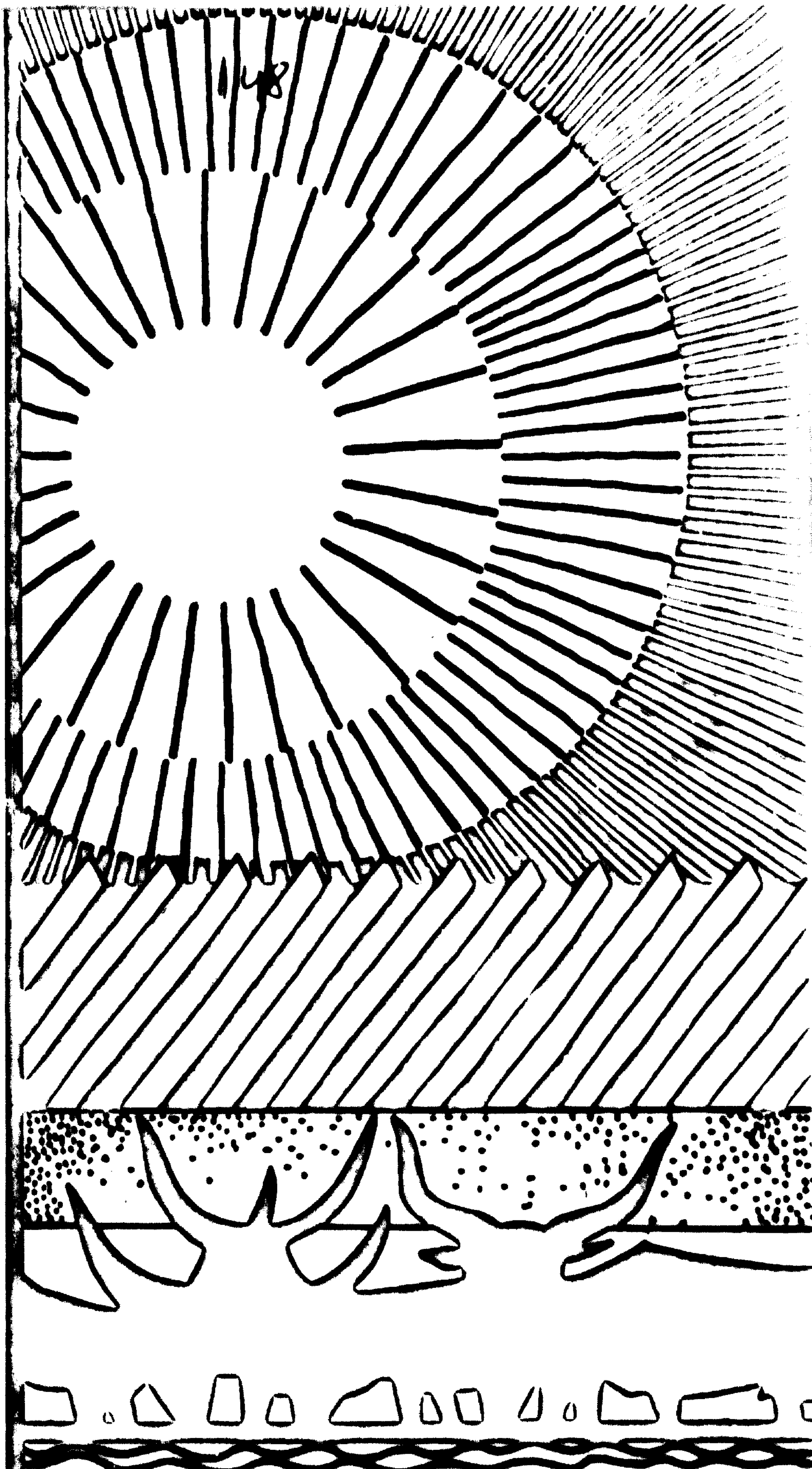
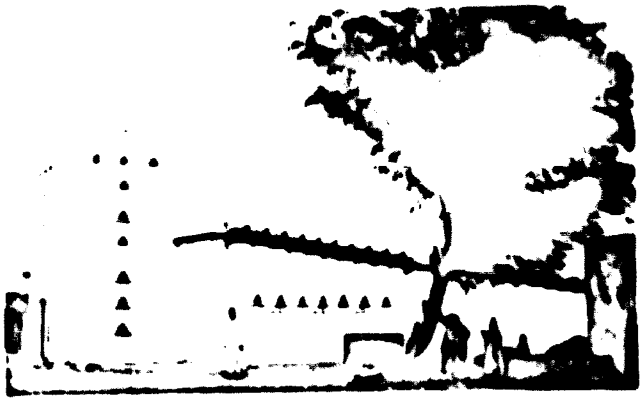


# L'ENERGIE SOLAIRE

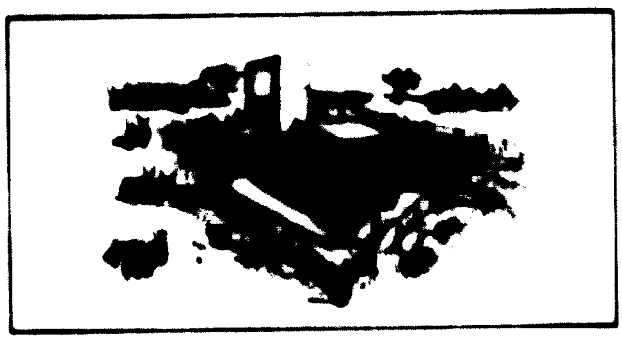
# village water supply

An integrated model of Sofretes's solar pumps is installed at Chinguetti, Mauritania. This model has been particularly designed to supply a whole village with water.
The pump is inside a building — a school building in this case. The roof collects the heat of the sun which provides the energy that is necessary to operate the pump. In a desert area, this type of pump can supply about 1,000 people with water.

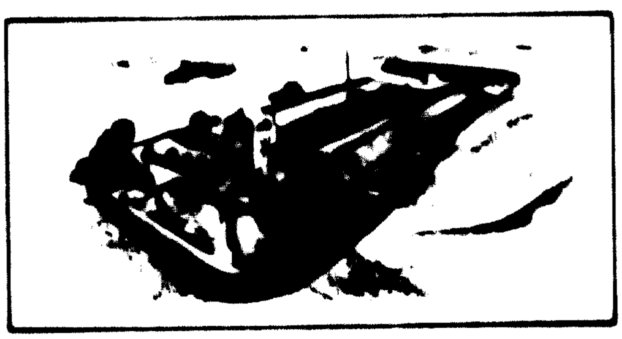


# country-side water supply

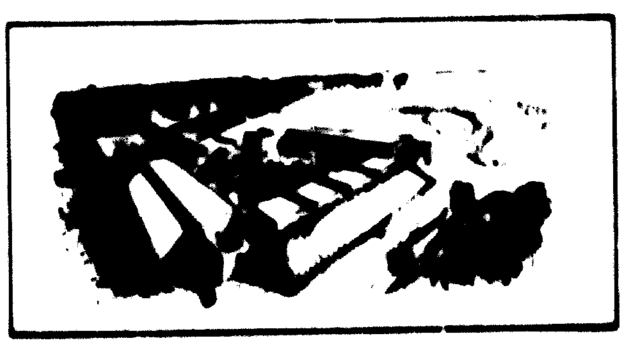
Sofretes also makes solar pumps for usage in the country-side. This model can be installed anywhere, it pumps water from wells no more than 80 meters deep, and it can provide for a cattle herd of several hundred heads daily. The presence of a specialized mechanic is not necessary: a herdsman can easily operate the pump.



# community and tourist facilities



Sofretes's solar pumps allow the construction of public buildings in desert areas. Too often, in fact, such buildings cannot be planned because the cost of water necessary to their operation is too high.
Chinguetti provides an excellent example to the solution of this problem: a solar pump connected with a development structure — a school.
However, other combinations are possible, such as medical dispensaries or administrative buildings in the country-side. This type of solution can also lead to the construction of autonomous touristic units, for a simple water reserve — e.g. a swimming pool — supplies a sufficient quantity of energy. Moreover, it will soon be possible to produce electricity and operate cooling systems.
Thus, it has become possible to consider the development of important projects, such as the Southern Sahara Agricultural Cooperative, which operates a sizeable irrigation system.



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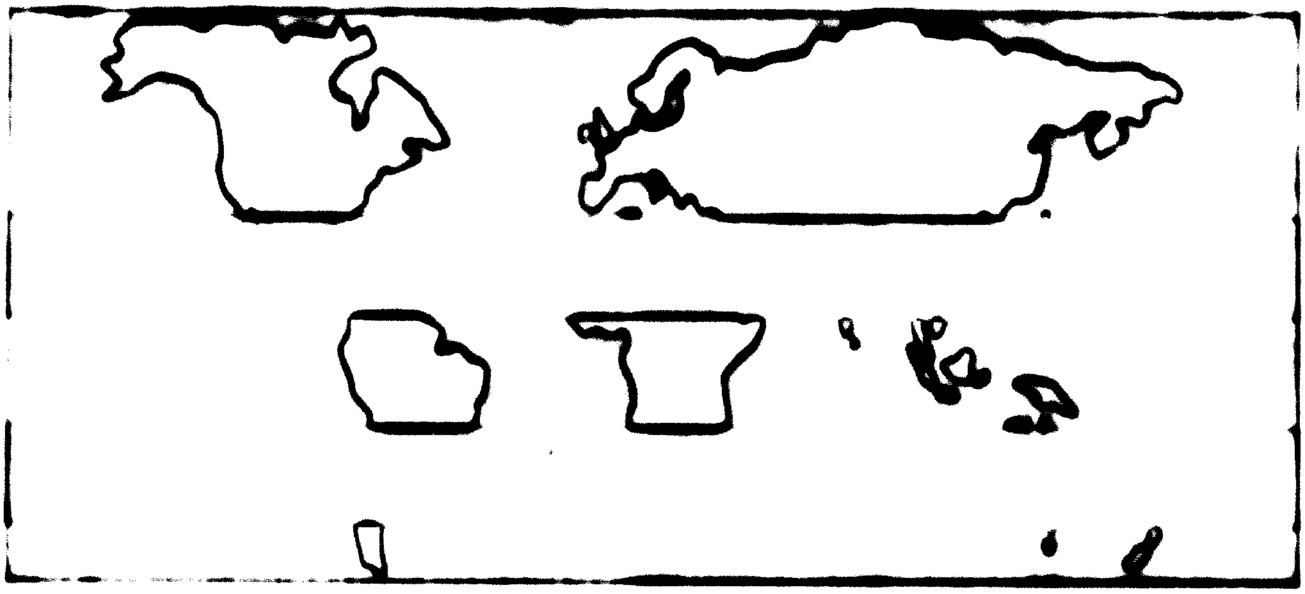

# when water means life

Water is essential to life on earth and is a fundamental factor in determining human living conditions. It favors all kinds of development processes in those areas where it is abundant and readily available. However when it is scarce and difficult to obtain, it exerts a powerful negative influence on man and nature. lack of water can determine the creation or the extension of desert areas and its scarcity hangs like a curse over peoples heads. Wherever rain does not fall in sufficient quantity — or it does not rain at all — and water is available in underground pockets, it is imperative to drill wells. This undertaking can bring about the complete transformation of an entire region or stop its dramatic decline. The Sahara is a perfect case in point. Some 2,000 years ago, there were still lakes in that area, and an impressive set of data indicate that there were agricultural settlements along its southern border. Then, the Sahara became dry. The drought was particularly severe during the last sixty years, with a short pause between 1950 and 1955. Yet, there is no lack of water in the Sahel region. Only it must be looked for without waiting for it to fall from the sky. But here lays the main problem: what sources of energy can be used and where can they be found. In most instances, when operating in arid regions, there are only two simple alternatives: either there is no water or this can be reached by employing human energy. As a matter of fact, the population of some isolated villages in the Sahel devotes most of its time to manual pumping, with highly negative consequences on its productive activities and school attendance, for this undertaking involves children as well. However, in all those areas in which the problem of water is coupled with the problem of energy, there has always been available a source of energy that can now be exploited: that is the rays of sunlight. In fact, solar energy moves Sofretes's pumps that were developed in Africa and that are now in use because of their satisfactory operational costs.

# the functioning of sofretes's solar pump

The functioning of solar pumps is based upon a type of thermodynamic cycle. The heat of the sun is captured by a flat, black surface, with progressively heating water circulating underneath. This is the hot source of the cycle. The water pumped up from the well has the same temperature as the water in the well itself, and this is the cold source of the cycle. A closed cycle, somewhat analogous to an inverted refrigerator cycle, is established between the hot and the cold sources mentioned above. The intermediate fluid keeps in motion the motor that operates the pump. This type of equipment has been designed especially for use in desert areas, and it needs practically no maintenance.

ATIONALE

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...a peu, traiter avec quelque ... à ses élèves portait sur des ...ment efficace. Il faut répondre ...le concours mutuel entre les ...ités dont disposent les pays ... par le moyen du réseau de ...mondiale. La seconde réponse, ... qui précède : invoquer l'am... ...pliqués en 1968 et 1969 pour ...vient d'être mise au point. ...n'a rien compris à la coordi... ...pas l'on se refuse à y croire ...ndpris affiché par le journal

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Paul COULBOIS,

*Professeur à la Faculté de Droit ...et des Sciences Économiques de Paris*

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Four solaire de Font-Romeu

*SCIENCES ET TECHNIQUES*

# LES FOURS SOLAIRES

par J. BOSCA

Il est admis, aujourd'hui, que la vie sur terre n'est possible que grâce au soleil. Cette omnipotence du soleil fit que, très tôt, les hommes en firent un Dieu : Jupiter, Apollon, Phébus ou Râ. Icare fit la triste expérience de sa puissance. Bien des siècles après, la NASA s'en méfie encore lorsqu'elle choisit avec soin la nature des composantes des engins O.S.O. et Pioneers qu'elle envoie dans son voisinage.

La chaleur bienfaisante du soleil a été, très tôt, exploitée. D'abord par les Egyptiens qui découvrirent l'effet de serre si utile en agriculture. Plus tard, Archimède réalisa la première concentration du rayonnement solaire au moyen de ses miroirs ardents avec lesquels, dit-on, il incendia la flotte romaine assiégeant Syracuse.

Depuis cette époque, les prototypes de machines utilisant l'énergie solaire furent nombreux. Depuis quelques années cependant, les recherches dans ce domaine se sont intensifiées ; en particulier des fours solaires de plus en plus grands et perfectionnés ont été construits.

Ce développement soudain a plusieurs causes. D'abord les fours solaires permettent aux métallurgistes et aux chimistes d'effectuer des travaux qu'ils ne pourraient faire avec les fours classiques. Ensuite l'énergie solaire est considérée par certains auteurs comme la principale source d'énergie future qui, selon eux, prendra une forme industrielle vers l'an 2000 ; elle couvrirait vers l'an 2200 le tiers des besoins en énergie des U.S.A. Remarquons que d'autres savants pensent qu'à la même époque, l'énergie tirée de la fusion des noyaux légers, réalisée par les hommes, sera la principale source d'énergie utilisée.

Beaucoup de pays peu ou faiblement industrialisés sont très ensoleillés et possèdent de vastes régions qu'ils ne peuvent mettre en valeur. Ces pays pourront, grâce au soleil et malgré le faible rendement des installations actuelles, disposer dans ces régions souvent désertiques d'une source d'énergie capable de produire de l'eau potable à partir d'eau de mer ou des eaux souterraines et développer ainsi leur agriculture.

## LES FOURS SOLAIRES.

Les fours solaires sont des appareils capables de capter le rayonnement solaire sur une grande surface et de la concentrer en petite surface, aussi réduite qu'il est possible ou souhaitable de la réaliser.

Les lentilles optiques ont une bonne concentration et un bon rendement, elles pourraient donc être utilisées.

Elles ne le sont cependant pas à cause de leur coût élevé et parce qu'il est impossible d'en obtenir de très grandes. On utilise presque uniquement des miroirs paraboliques qui jouissent de la même propriété (tout rayon lumineux arrivant parallèlement à l'axe optique du miroir est réfléchi vers son foyer), et qui peuvent atteindre des surfaces plus importantes. La température atteinte au foyer du four dépend évidemment de la surface de son miroir concentrateur ; aussi pour les grands fours solaires, il a été nécessaire de construire le miroir concentrateur en plusieurs éléments qui forment dans certains cas un paraboloïde continu mais qui peuvent être, comme à Natick (U.S.A.), des miroirs sphériques, indépendants [illegible] face [illegible]



## CONCENTRATION THÉORIQUE POUR UN MIROIR PARABOLIQUE UNIQUE.

Considérons sur un paraboloïde, une couronne élémentaire d'angle $\theta$ à la distance $\rho$ du foyer.

L'image que cette couronne donne du soleil est un disque de diamètre $d = \dfrac{\rho\alpha}{\cos\theta}$ en appelant $\alpha$ le diamètre apparent du soleil ($\alpha$ = 0,0093).

Si le miroir parabolique est de faible ouverture (l'ouverture $\theta$, est l'angle entre l'axe optique du miroir et un rayon passant par le foyer et s'appuyant sur le contour du miroir), $\rho$ est un peu différent de la distance focale $f$ du miroir et $\theta$ est voisin de 0 ; on peut donc espérer avoir une image nette du soleil. Cette image a un diamètre $d = f\alpha$.

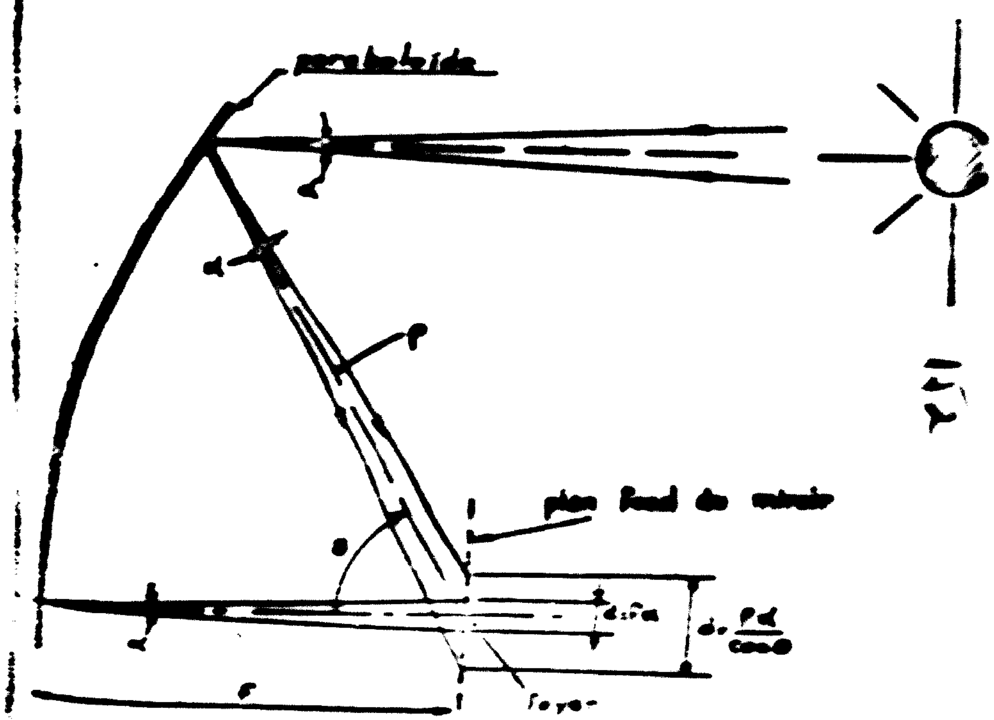


Fig. 1

L'image obtenue par un miroir de grande ouverture n'est pas nette. Elle se compose d'une tache centrale très éclairée entourée d'un anneau de lumière dont l'intensité décroît au fur et à mesure que l'on s'éloigne du centre.

La densité d'énergie dans ce disque central s'écrit après calcul :

$$e = \frac{4E}{\alpha^2} \sin^2 \Theta_M$$

en appelant E l'énergie solaire reçue sur la terre ($E = 0{,}1\ W/cm^2$). Les possibilités théoriques du four solaire sont définies par le facteur de concentration théorique $C_T$ :

$$C_T = \frac{e}{E} = \frac{4}{\alpha^2} \sin^2 \Theta_M$$

Par exemple, pour un miroir d'ouverture $\Theta_M = 60°$ et d'une distance focale de 2 m, on obtient :

— une surface de la tache centrale : $S = 3{,}14\ cm^2$

— un facteur de concentration théorique : $C_T = 33\,000$

— une densité d'énergie : $e = 3{,}3\ kW/cm^2$

— et une énergie totale : $S.e = 10{,}2\ kW$.

## INSTALLATION A MIROIRS MULTIPLES.

Nous venons de voir qu'une couronne élémentaire prise sur le paraboloïde à l'azimut Θ et à la distance ρ du foyer donne du soleil une image de diamètre $d = \frac{\rho\,\alpha}{\cos \Theta}$.

Plus cette couronne élémentaire est éloignée de l'axe optique du miroir, plus l'image qu'elle donne du soleil est grande puisque ρ et Θ augmentent et plus la concentration d'énergie dans cette image est faible. Il est donc préférable d'employer non plus une surface continue mais des surfaces indépendantes qui donneraient du soleil des images de dimensions voisines que l'on superposerait. On démontre que, si ces surfaces indépendantes étaient paraboliques, le meilleur résultat serait obtenu avec un paraboloïde continu, ce qui ne résoud pas le problème ; par contre, si ces surfaces réfléchissantes étaient des miroirs sphériques de très faible ouverture la concentration obtenue au foyer du four serait meilleure. La concentration du four solaire peut être améliorée en déformant, à volonté des petites glaces planes de faibles dimensions qui forment le miroir concentrateur.



Ces miroirs, devant constituer un système géométrique indéformable, il est nécessaire de les monter sur une charpente rigide. Pour les grands fours solaires, cette charpente a de telles dimensions qu'elle doit nécessairement être fixe ; aussi, le rayonnement solaire est-il envoyé convenablement vers l'ensemble concentrateur par un ensemble de miroirs plans appelé dispositif orienteur qui, asservi, suit le soleil dans sa course apparente.

## CONCENTRATION EFFECTIVE D'UN FOUR A MIROIRS MULTIPLES.

Que la surface concentratrice soit continue ou non, les résultats théoriques, calculés uniquement d'après des considérations géométriques, sont bien supérieurs aux résultats obtenus.

Si les miroirs sont de très bonne qualité les pertes par réflexion sont faibles, par contre on évalue à 10 % de l'énergie incidente les pertes par absorption dans le verre des miroirs, c'est donc au total 20 % du rayonnement solaire qui sont absorbés par les miroirs orienteurs et le miroir concentrateur. Les autres pertes sont dues aux images des différents miroirs qui ne se recouvrent pas exactement et aux ombres des montures des miroirs qui, du fait du grand nombre d'éléments, sont importantes. Au total, on peut dire que de 30 à 70 % de l'énergie incidente est perdue ; le rendement d'un four dépend donc pour une grande part du soin apporté à sa construction.

Pour résumer ces pertes, on définit le facteur du four (F) qui est le rapport de la concentration effective mesurée $C_E$ à la concentration calculée géométriquement $C_T$ :

$$F = \frac{C_E}{C_T}$$

En reprenant l'exemple précédent si l'on mesure la concentration $C_E = 20\,000$ on obtient un facteur du four $F = 0{,}6$.

## TEMPERATURE MAXIMALE D'UN FOUR SOLAIRE.

Pour calculer la température maximale d'un corps placé au foyer d'un four solaire on admet, par hypothèse, qu'il ne rayonne que par sa face exposée au rayonnement, et on lui applique la loi de Stéphan (la quantité d'énergie reçue par le corps est proportionnelle à la puissance quatrième de la température [illegible]

[illegible] facteur de proportion[illegible] du corps [illegible]

Dans l'exemple précédent ($C_E$ = 20 000 et E = 0,1 W/cm²) on peut théoriquement dépasser 4 000 °C ; les fours actuels sont cependant limités à 3 500 °C parce que l'hypothèse ci-dessus n'est qu'une grossière approximation.

Cette température maximale dépend de la nature et de l'état du corps chauffé ; elle est obtenue quand l'équilibre (énergie incidente = énergie absorbée + énergie rayonnée) est atteint ; par exemple : un corps qui présente au rayonnement solaire une face lisse et brillante s'échauffera moins qu'un corps de même nature présentant une surface rugueuse et noire.

Les fours solaires présentent sur les fours classiques l'avantage d'une très faible inertie thermique et le temps mis pour atteindre la température maximale d'un corps ne dépend que de sa conductibilité ; ainsi, il ne faut que quelques secondes pour fondre du fer (1 500 °C) et, un corps de très faible conductibilité peut être porté à 2 900 °C en moins d'une seconde.

## REALISATION DES MIROIRS CONCENTRATEURS.

### 1. — *Miroirs de petites dimensions.*

Les premiers miroirs employés pour concentrer le rayonnement solaire étaient des réflecteurs de projecteur de D.C.A. De nos jours, on fabrique en petite série des miroirs d'un diamètre inférieur à 2 mètres en plastique ou en aluminium.

Les premiers sont moulés d'une seule pièce et aluminés ou argentés face avant ; ils donnent en général de bons résultats. Les seconds, constitués d'éléments obtenus par emboutissage de tôles minces, ont une qualité optique très moyenne ; ils ont cependant l'avantage de ne pas être chers.

### 2. — *Miroirs de grandes dimensions.*

Le miroir concentrateur des grands fours solaires est constitué de plusieurs éléments assemblés sur une charpente rigide. Ces miroirs élémentaires sont soit prétaillés, c'est-à-dire que leur forme définitive leur est donnée avant le montage ; soit tous plans et déformés ensuite élastiquement par un moyen mécanique lors de l'assemblage du concentrateur.



Les grands fours solaires construits ou en construction dans le monde sont :

*a*) Le four solaire de l'université d'Alger à la Bouzaréah : const en 1954, il est le seul grand four dont le miroir concentrateur de de diamètre soit mobile, les miroirs élémentaires, en aluminium formé, forment un paraboloïde continu.

*b*) Le four de Sendai (Japon).

Le miroir concentrateur fixe de ce four est formé de 180 piè réparties en 7 couronnes. Ces éléments ont été chauffés au ramo sement jusqu'à ce qu'ils épousent la forme du moule du paraboloïde les glaces ont été ensuite polies et aluminées face avant :

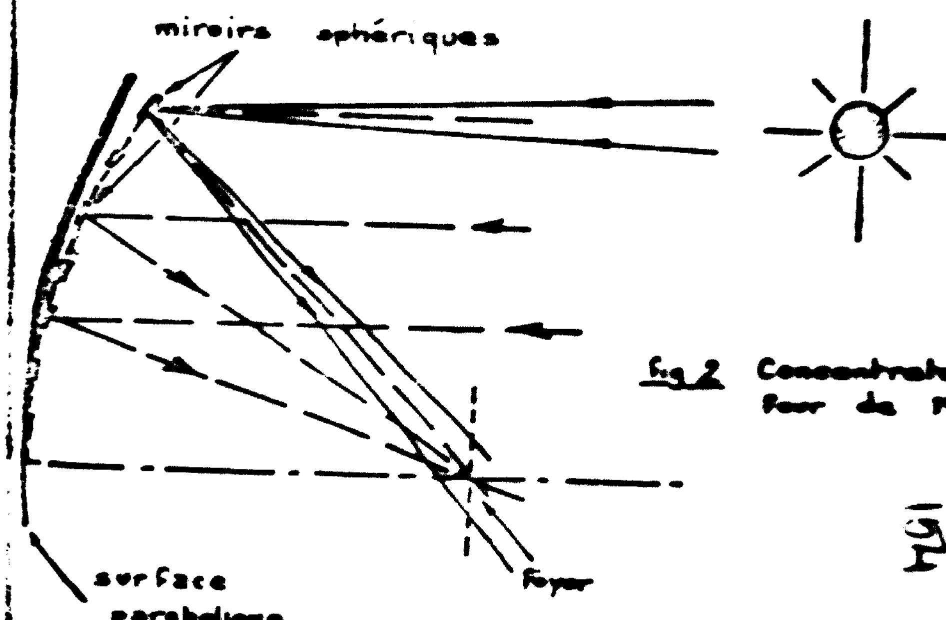


fig 2 Concentrat four de N.

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*c*) Le four de Natick - Massachusetts (U.S.A.) (fig. 2). Le concentrateur du four Natick se compose de 180 miroirs élémentaires, sphériques de faibles ouvertures. Ces miroirs prétaillés sont réglés de manière à ce que leurs images se superposent au foyer du four ;

*d*) Le four de Mont-Louis (Pyrénées-Orientales). Les 3 500 glaces de 15 cm de côté qui composent le miroir concentrateur de ce four sont planes et argentées face arrière. Elles sont déformées élastiquement

quement lors du montage par un système mécanique situé devant elles. Ce four a une puissance thermique de 75 kW ;

*e)* Le four d'Odeillo Font-Romeu (Pyrénées-Orientales). Ce four est une évolution du précédent tant par ses dimensions que par les techniques de construction employées. Son ensemble concentrateur adossé à un immeuble de 9 étages compte 9 000 glaces déformées mécaniquement par un système situé cette fois au dos des glaces pour éviter les ombres (fig. 3). Les images du soleil données par chacune des glaces se superposent dans une tache focale d'un diamètre de 25 cm. La puissance thermique disponible au foyer du four est de 1 000 kW et la température maximale atteinte est 3 500 °C ;

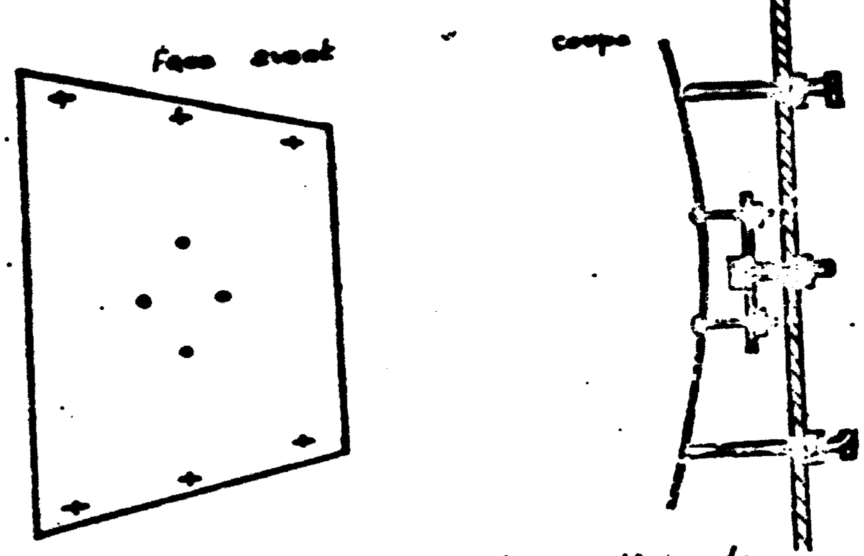


fig 5 Système de déformation des miroirs du four d'Odeillo

*f)* A Everan, en U.R.S.S., un four solaire de la hauteur d'une maison de 9 étages est en construction. A la partie inférieure de l'installation un réflecteur plan mobile réfléchira les rayons solaires vers un miroir parabolique de 10 m de diamètre situé à la partie supérieure du bâtiment. Ce four servira à la fusion des matériaux réfractaires particulièrement purs. Bien que la hauteur de l'installation soit analogue à celle d'Odeillo son miroir concentrateur plus petit ne permettra pas d'atteindre les performances du four français.



## DISPOSITIFS ORIENTEURS.

1. — Le miroir parabolique des fours solaires de petites dimensions est orientable. Il est astreint par un système d'asservissement à suivre le soleil. Le foyer de ces fours, la partie utile donc, est continuellement en mouvement et cela pose quelques problèmes d'accessibilité aux utilisateurs.

2. — Les grands fours solaires, à l'exception de celui de l'univers d'Alger, ont un miroir concentrateur fixe ; les rayons du soleil sont réfléchis par un ou plusieurs miroirs plans, mobiles de façon à lui envoyer parallèlement à son axe.

Ces miroirs plans sont mobiles autour de deux axes : un axe vertical (mouvement en azimut) et un axe horizontal (mouvement en site). Pour cela, une lunette forme l'image du soleil sur quatre cellules photoélectriques, deux pour le site, deux pour l'azimut, qui, si elles sont inégalement éclairées, provoquent les rotations convenables du dispositif.

En général, ce dispositif est un miroir unique. A Mont-Louis, par exemple, c'est un rectangle de 135 m² constitué par des glaces élémentaires de 50 × 50 cm.

Des solutions originales ont été trouvées à Sendai et à Odeillo afin de réduire le prix de revient de ces dispositifs.

L'orienteur de Sendai (fig. 4) a la forme d'un escalier ; sur l'arête de chaque marche s'articulent 34 miroirs qui forment une bande réfléchissante de 2 m × 15,5 m. Le mouvement azimutal est obtenu en faisant tourner l'ensemble de l'escalier autour d'un axe vertical ; le mouvement en site, le même pour tous les miroirs, est assuré par un système de levier.

Si le four d'Odeillo n'avait qu'un seul orienteur celui-ci aurait 2 800 m² de surface et poserait aux techniciens de gros problèmes de rigidité et d'entraînement, aussi a-t-on préféré construire sur la colline qui fait face au four 63 surfaces réfléchissantes de 6 m × 7,5 m. Ces surfaces groupées par 8 ou 9 sur des terrasses naturelles sont orientées chacune à la fois en azimut et en site.

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## UTILISATION DES FOURS SOLAIRES.

Les grandes quantités d'énergie à haute température, concentrées au foyer du four ne serviront pas à la production d'électricité par la filière vapeur d'eau, turbine, générateur d'électricité ; le prix de revient de l'installation grevé du coût élevé de l'installation optique étant

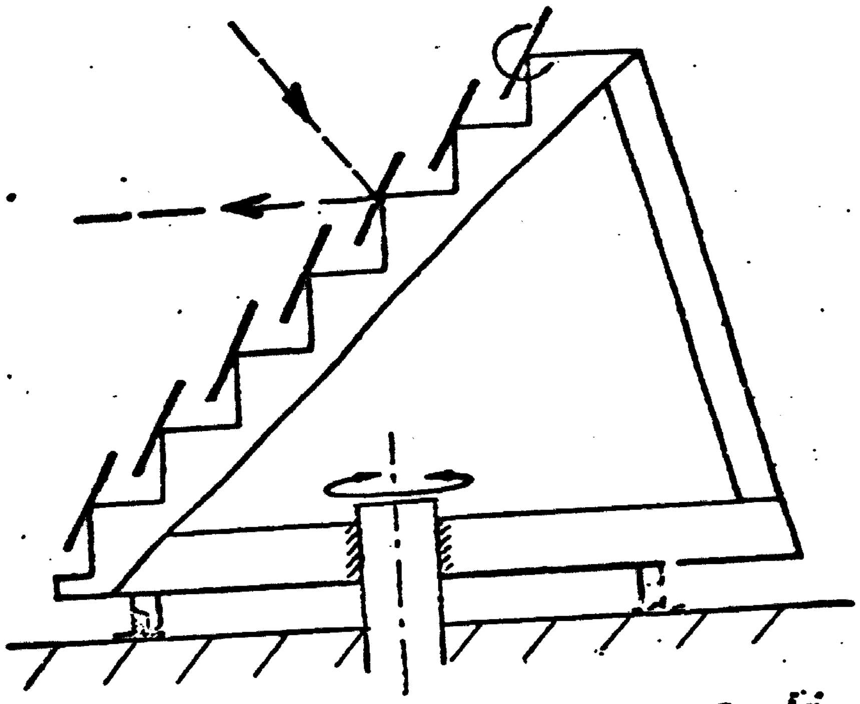

*Fig 4* orienteur du four de Sol[illegible]

trop important devant le rendement d'une telle filière. Les fours solaires ne sont employés, de nos jours, qu'en héliochimie et pour le traitement de matériaux spéciaux ou réfractaires.

1. — *Traitement direct des poudres.*

Les matériaux réfractaires en poudre sont fondus au four solaire. Deux méthodes sont employées suivant que l'on désire effectuer la fusion d'une quantité finie de poudre ou une fusion continue.

La « fusion en nacelle » consiste à faire passer au foyer du four une nacelle contenant le produit en poudre ; si le récipient est assez grand le produit fond puis se solidifie au fur et à mesure du déplacement.

La fusion dite « en baguette » permet, à partir d'une tige de métal solide et de poudre de métal, d'effectuer une coulée continue. En effet, la fusion d'une extrémité de la baguette solide provoque la formation d'un petit cratère, si l'on y fait tomber de la poudre métallique, celle-ci fond et se solidifie au fur et à mesure du déplacement vertical de la baguette.



2. — *Le frittage des poudres au four centrifuge* (fig. 5).

Lorsqu'un métal a un point de fusion très élevé ou que des métaux ne s'allient pas dans des proportions souhaitées par fusion on peut obtenir ce métal ou cet alliage sous forme frittée.

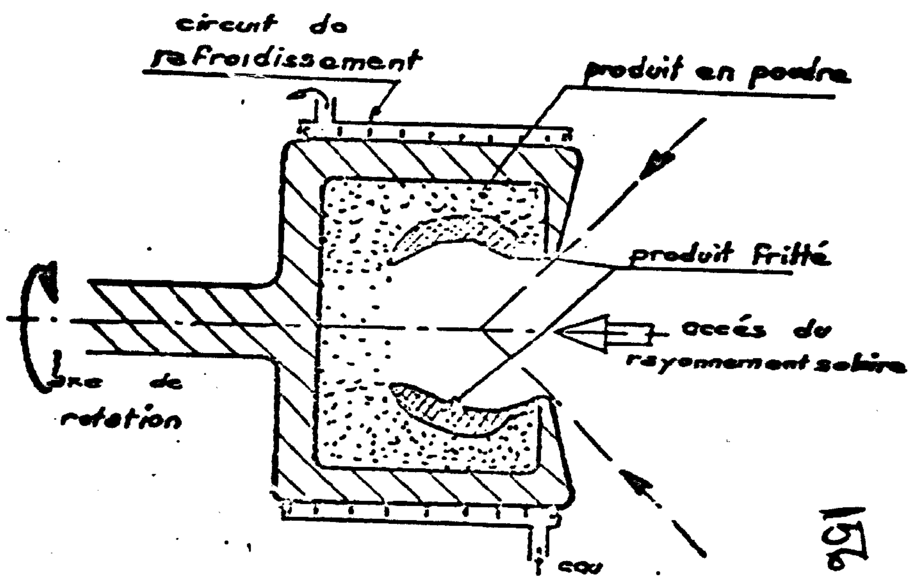


*Fig 5* Four centrifuge

Le frittage consiste à chauffer la poudre métallique en même temps que l'on exerce sur elle une forte pression. Ces deux opérations simultanées créent des soudures entre les grains de poudre, le produit se présente sous forme d'agrégat.

Dans une installation solaire le frittage est obtenu au four centrifuge. Ce four tourne rapidement et la force centrifuge exerce la pression tandis que le four solaire apporte, par un orifice, la chaleur nécessaire.

3. — La fusion propre est une application des fours solaires qui n'a pas d'équivalent dans l'industrie classique. En effet, la fusion à l'arc électrique peut donner des températures égales à celles du four solaire, mais cette fusion se fait en atmosphère de carbone ou d'oxyde de carbone et le produit obtenu est contaminé. La fusion propre utilise le fait que le verre est transparent à presque toutes les longueurs d'onde du rayonnement solaire (sauf les infrarouges) [illegible] en

plaçant le produit à traiter dans un ballon de verre dont on contrôlera l'atmosphère on obtiendra une fusion dans des conditions idéales ; cette fusion peut se faire sous vide ou en présence d'un gaz (fig. 6).

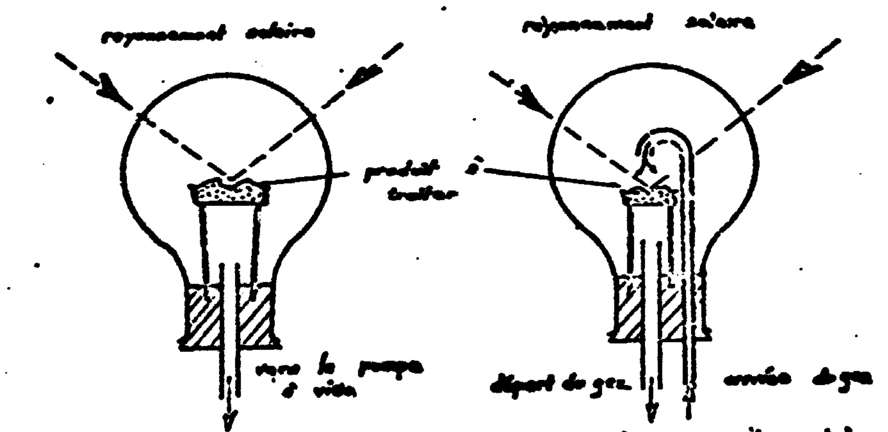


fig. 6 Fusion sous vide — Fusion sous atmosphère contrôlée

Les fusions les plus intéressantes réalisées au four solaire sont celles de l'alumine à 2 050° (pour obtenir du corindon), de quartz à 1 700°, de l'oxyde de zirconium à 2 700° et du zirconate de calcium $Zr_2O_5Ca$ qui n'a jamais pu être préparé de façon correcte en dehors du four solaire.

4. — Le four solaire de Natick, aux U.S.A., est doté d'un système permettant d'arrêter ou de laisser passer instantanément le rayonnement incident. Du fait de la très faible inertie thermique des fours solaires, le corps placé au foyer du four se trouve donc échauffé très rapidement de la même manière qu'il le serait par la boule de feu d'une explosion atomique. Cette simulation permet donc aux métallurgistes de reconnaître le comportement des matériaux dans de telles conditions.

## CONCLUSION.

L'étude précédente montre que les fours solaires sont d'une fabrication compliquée et d'un coût très élevé en regard des puissances fournies. Leur utilisation n'est donc, pour l'instant, valable que dans le cadre d'un laboratoire de recherche parce qu'ils permettent d'effectuer la fusion propre de n'importe quel matériau conducteur ou non



L'évolution des techniques contribuera à l'abaissement du coût d[e ces] installations ; les fours solaires serviraient alors à la fabrication [de] matériaux très purs et très réfractaires comme par exemple certai[ns] composants électroniques.

Quelques auteurs pensent que le développement des fours solair[es] amènera l'énergie solaire à la première place des énergies conso[m]mées par les hommes devant la houille, le pétrole et surtout l'énerg[ie] tirée de la fission des noyaux lourds. Ceci, bien sûr, si les recherch[es] sur l'énergie de fusion des noyaux légers n'aboutissent pas et si aucun[e] autre forme compétitive d'énergie ne voit le jour.

Il existe beaucoup d'autres moyens de capter l'énergie solaire san[s] concentration, sur une grande échelle et à plus basse température. On peut, par ces moyens dont les plus connus sont les photopiles e[t] l'effet de serre, conditionner des immeubles (chauffage et réfrigéra[tion]), produire de l'eau chaude, de l'eau douce à partir de l'eau de me[r] et aussi de l'électricité s'il n'existe pas, sur place, de moyens plus économiques.

J. BOSCA.

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... if we stake everything on

'If we stake everything!'
... we have enough time.'

... 1964. 'Max Born is one
... Prize in 1954', the *Bulletin*
... during the First World

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Félix Trombe

# Some aspects of the utilization of natural radiation, especially in the developing countries

**Energy** requirements vary considerably from one part of the world to another, and depend on a number of factors relating to human societies and their activities: climate, living and working conditions, basic needs of daily life, needs arising from scientific, industrial, economic and social development and so on.

In countries with a high industrial and economic potential, the energy factor is the essential basis of a continuously expanding and even more multifarious material civilization. Energy consumption per inhabitant is growing apace and the majority of human activities depend on it.

The human societies called 'civilized' from the material standpoint possess a host of mechanical, electrical, electronic, thermal and other 'slaves' which enable them to act and operate in extraordinarily diverse and effective ways.

In these countries with a high potential, the earth's reserves of conventional energy—coal, oil and natural gas—are being more and more heavily drawn upon, while the immediately available forms of energy, such as heads of water, are being used to the maximum. The present situation is extremely promising, for intensive prospecting of the soil and underlying strata of the earth reveals great opportunities for the use of coal, liquid fuel and natural gas reserves.

At the moment, there is even an overproduction of various fuels, and in certain cases new deposits are not exploited because of the uncertainty of finding markets for them.

There remain perhaps a few hundred years' supply of oil and a thousand years' supply of coal, but that is sufficient to give an optimistic touch to energy prospects, especially as nuclear energy with its enormous possibilities is appearing on the horizon.

This, of course, does not prevent keen world-wide competition and vigilant concern for these terrestrial capital reserves which, as consumption trends show all too clearly, cannot be replaced at the same rate by natural processes even now, let alone in the face of future demands.

As matters stand today, the use of the so-called 'secondary' or replacement sources of energy, which include solar energy and in which we also class



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terrestrial energy, is not, of course, a problem requiring urgent solution. It is with these forms of energy, however, that we shall be dealing in this article. For, in addition to the materially highly civilized societies which occupy only a relatively small part of the earth's surface, we must also take account of the huge majority of the world's population, spread over vast territories from the Poles to the Equator, including, in particular, what are usually called the arid zones.

In general, these peoples are poorly supplied with energy either because they have not yet developed local resources of conventional energy or because, having no such resources, they are economically unable to replace them with sufficient supplies of transportable fuel, of which, incidentally, there is considerable overproduction in other parts of the world.

Inadequate purchasing power is not alone to blame. Distance and, in some cases, the absence of economic means of transport substantially increase the price of conventional fuel delivered to certain areas.

It is from this angle that the use of substitute forms of energy should be considered. At the present stage, the use of these substitute forms for industrial purposes is out of the question except perhaps in very special cases. For example, solar furnaces, the use of which for fundamental research and for certain special applications is developing along hopeful lines, can only be introduced at this juncture in a very limited manner in certain countries with unclouded skies; they could play only a very small part in 'settlement policies' for the settlement or development of communities in the arid zones.

It is with the object of improving physical living conditions in already existing communities that the energy from natural (solar and terrestrial) radiation should be put to use.

In many regions where the sky is very clear (whether near the tropics or much farther north or south), the inhabitants suffer from extremes of heat or cold. At certain periods they lack water, especially pure water; they lack power for the operation of cottage industries, and refrigeration to preserve food and pharmaceutical products. They also lack means of transport, communication and information. To all these problems, interesting possible solutions, some more economically profitable than others depending on their practical nature, might be found in the use of energy from natural radiation.

## EXPLOITATION OF SOLAR RADIATION

### *Space heating in dwelling houses*

In many cloudless countries it is warm or hot during the day and sometimes very cold at night. Even in low latitudes—for example, in the Sahara—the winter season is cold above a certain altitude. In Afghanistan the average temperature over twenty-four hours is relatively low during the greater part of the year owing to the very low night temperatures. In the arid regions indoor comfort could be much improved if even a fraction of the solar energy accumulated during the day were to be trapped and stored.

In France, the National Centre for Scientific Research (CNRS) has been working to find an economic solution to this problem. Prototype houses have been built, with significant results.

The principle consists in capturing the solar energy received by the southern façades of these houses. As is well known, the energy from solar radiation in cloudless countries amounts to about 1 kWh./m.$^2$ on a surface placed at right angles to the sun's rays. The total energy received on a southern façade has been calculated for different latitudes (F. Trombe, A. Le Phat Vinh and Mrs. M. Le Phat Vinh). Figure 1 summarizes the readings for the northern hemisphere. For the southern hemisphere, identical curves would be found for the corresponding seasons.

An examination of Figure 1 shows that the insolation curve for southern façades in latitudes between the tropics and the neighbourhood of 60° is parallel to the curve for house-heating requirements. The sun being very high in summer, southern façades receive little sunlight; indeed, at the Tropic of Cancer they receive none at all in June. In any case, protruding roofs over southern façades protect them very effectively from the direct rays of the sun for several months of the year, sometimes even for more than six months.

In the period between October and March, which may be cold, the sun is much lower, and the amount of sunshine on the southern façades reaches its peak. Examining Figure 1, we see that the total amount of energy theoretically received during the winter solstice ranges around 7 kWh./m.$^2$/day. This is equivalent to what is received by the roofs of houses in summer when the aim is rather to get rid of the sun's heat.

The reception of solar energy on southern façades, which is particularly suitable for the heating of houses, makes it possible to capture large quantities of solar calories, amounting in cloudless countries to 80 or 85 per cent of the theoretical total (see Fig. 1). Under average conditions, a southern façade actually receives from 5 to 6 kWh./m.$^2$/day. For a single-storey dwelling this represents several hundred kWh. per day, the bulk of which can be retained indoors.

It should also be noted that a glass-surfaced façade, being vertical, costs less than a glass roof. A glass roof must perforce be weatherproof, and mechanically strong enough to support an accumulation of snow, in mountainous areas for example. Furthermore, the accumulation of snow on roofs seriously reduces the solar input and the glazed surface may cease to have a hothouse effect for extended periods of time. A further disadvantage of glazed roofs is that they supply calories only to the upper sections of the house.

On the other hand, the advantages of south-facing glazed walls are readily appreciable. The glass used can be lighter in weight and still remain comparatively weatherproof, since it does not have to withstand the direct force of atmospheric precipitations. In addition, the height of the glazing can be extended as far upwards as is desired, thus enabling multi-storeyed buildings on an east-west axis to be equipped with solar collectors.

It may be objected that southern façades should be sources of light, and that the capture of calories by means of blind surfaces could result in the

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construction of poorly-lit buildings. Experience shows, however, that in cloudless countries only one-fourth of the surface of a south wall of a room of normal dimensions is used to admit light, the other three-fourths being opaque surfaces which admit neither light nor calories.

The diagram in Figure 2 shows a unit-construction house into which is built a low thermal mass in the form of a water tank (5) running east and west across the south wall.

The solar energy passes through a glass surface (1) and heats the collectors (2) which emit warm air through the main duct situated behind a wall (4).

By means of this upward flow of air, a well-balanced temperature is obtained over the entire height (approximately 3 metres) of the living area. At night, the protective panels (3) surrounding the collectors help to prevent the air cooled by contact with the outside glass walls from descending into the living area. The water mass (5) located above the living area restores calories to that area by radiation, both directly and by reflection from the ceiling which is lined with infra-red reflecting aluminium foil.

This dwelling with a floor area of 80 square metres has a storage tank containing approximately 7 cubic metres of water giving back about 50,000 kilocalories during the night. This storage capacity is obviously insufficient, and to obtain adequate results a thick wall extending from ground to roof level would be needed. Such a wall will be incorporated in the prototype (Fig. 3) now being built at Montlouis-Odeillo (Pyrénées-Orientales) in France.

In addition, on the north, east and west sides the dwelling shown in Figure 2 has specially designed walls for the selective capture of calories. The main insulating wall is protected on the outside by an air space, an infra-red reflecting surface (9) and another heat-insulating layer (7) consisting of two thicknesses of boards, the second of these being largely decorative in function.

This wall serves as a warm air trap, discharging in the daytime the colder-than-outdoor air which it contains, and retaining at night, to some extent, the warm air accumulated during the day.

The very important role of the polished aluminium foil infra-red reflector (9) should be stressed. It is well known that radiation losses are much greater than convection losses, even at normal temperatures.

In its present form, this type of dwelling becomes a little too hot during the day (30° C.) and a little too cool at night (8° to 10° C.). But apart from this drawback, which is due to the inadequacy of the interior thermal mass, it behaves very differently from ordinary houses in Montlouis which always freeze hard in winter. It should be noted, in fact, that the mean temperature of the outer surface of a dwelling, and consequently, *a priori*, its inside temperature, may be well below the mean temperature of the ambient atmosphere, especially if there is no intake of solar energy (as in the case of north façades) and if the night sky is clear.

Finally, we should note that this type of dwelling provides warm air not only on sunny days but also on days when there is bright cloud. This is due to the direct angle of incidence of the sun's rays on its south-facing glass wall, and indoor temperature rises of over 10° C. on cloudy days are quite common.

The present programme of the CNRS includes the construction of various dwelling houses, along the lines of Figure 3, with heat storage walls to keep the temperature below the daytime outside maximum (30° C.) and take the chill of the dawn temperature (8° to 10° C.).

It should be stressed that such dwellings require no costly apparatus; for instance a four-roomed house (80 square metres total floor area) built by conventional methods costs some 65,000 French francs; the same building with incorporated solar collectors and accumulation wall as shown in Figure 3 would cost 75,000 to 80,000 francs.

The thermal kWh. thus reclaimed works out very cheaply. If we estimate the total cost of the collecting installation at 15,000 francs, covering a surface area of 64 square metres (16 × 4 m.), for a four-roomed house, we arrive at a yearly amortization rate of 750 to 800 francs.

Assuming that the installation operates for six months of the year and taking into account exceptionally warm and sunless periods, the heat energy collection would amount to 5 kWh. × 64 × 180 = 57,600 kWh. The solar kWh. thus obtained therefore costs less than 1.5 centimes, which is very cheap indeed.

### *Refrigeration*

The use of solar radiation for refrigeration is one of the most intriguing prospects for the improvement of living conditions in countries with clear skies.

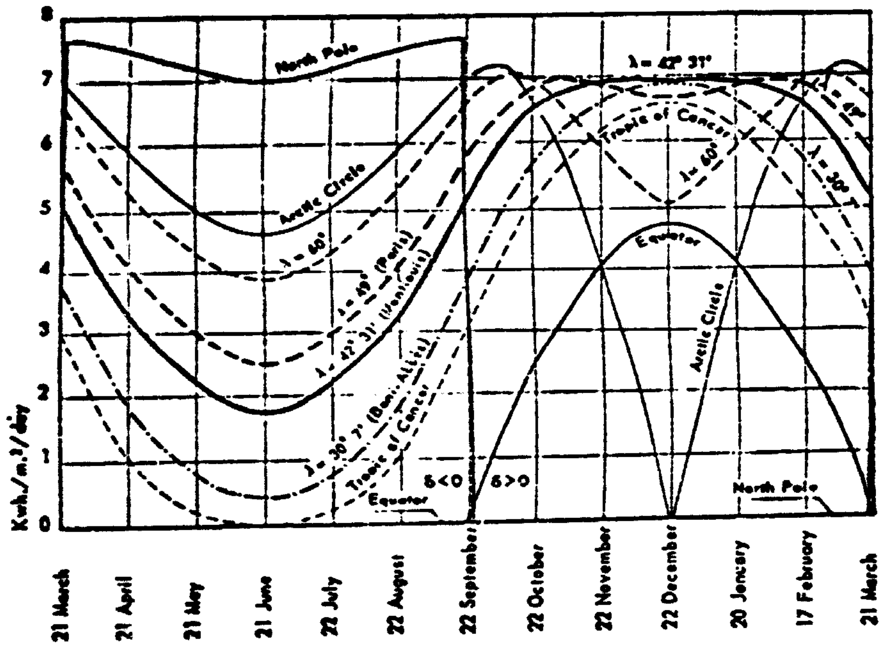
A great deal of research has been done on this subject in France, the Soviet Union and the United States. Hitherto, the cost of ice produced by solar energy has been substantially higher than the cost of ice produced by conventional methods. The cheapest ice so produced appears to be that made at the French (CNRS) plant at Montlouis which operates on the principle of direct distillation by day and expansion of ammonia gas at night. The cost per kilogram is between 0.10 and 0.15 francs. This is more than double the current price in large urban centres, for example on the African coast. On the other hand, at inland centres current prices are much higher, and here solar ice might well be competitive with that produced by conventional means. The possibilities of such production are now being investigated.

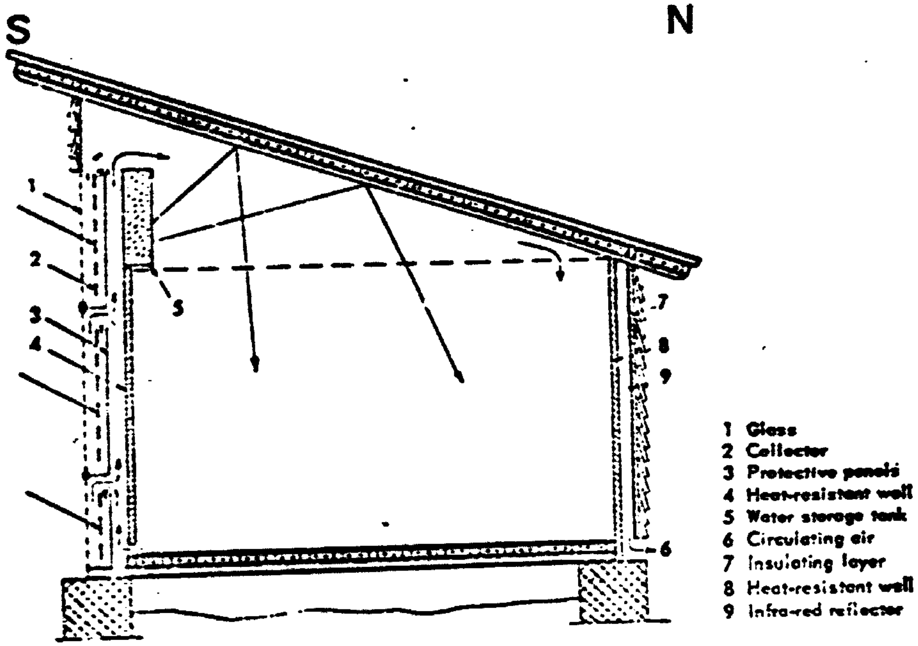
### *Water heating*

Heating water by means of the sun's rays and the hothouse principle is a highly economic operation. The hothouse is very simple, and many versions of metal and glass, or plastic, water heaters have been constructed in the United States, in Israel and especially in Japan, where hundreds of thousands of them have been installed.

### *Water distillation*

A supply of pure water is a vital necessity for any settlement area, and the absence of such supplies is the main obstacle to arid zone development.



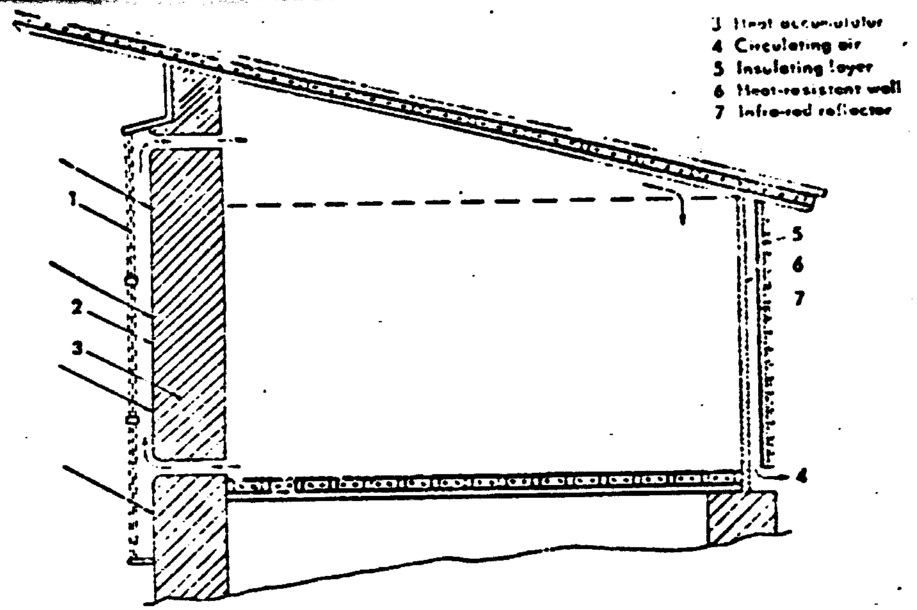




**Fig. 3. Prototype of unit-construction dwelling with solar heat collector and thick ground-to-roof storage walls (CNRS, Montlouis).**

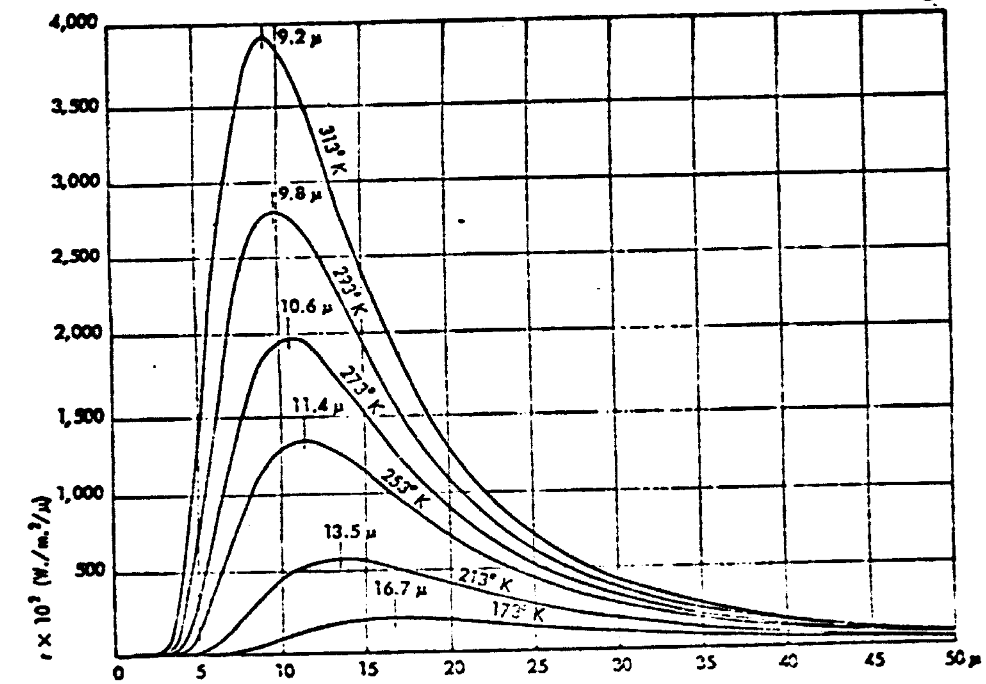



Fig. 4. Black body radiation.

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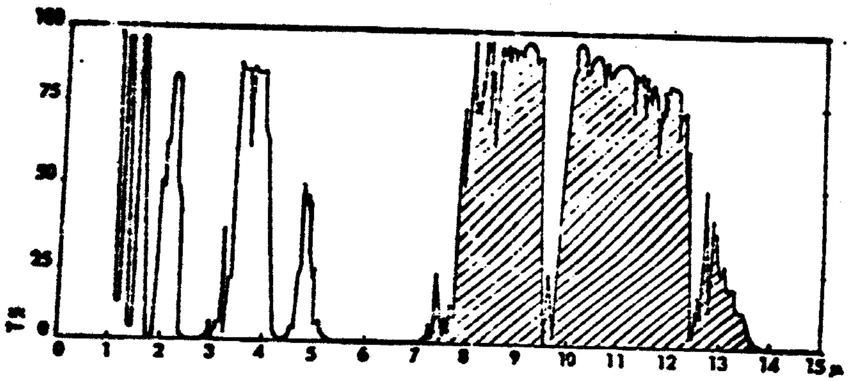


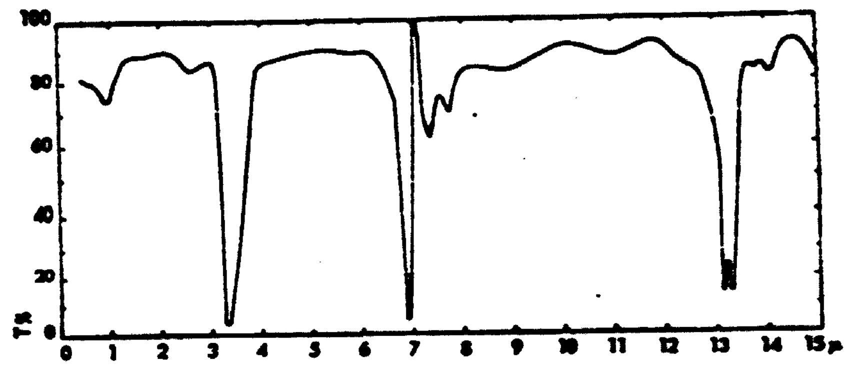


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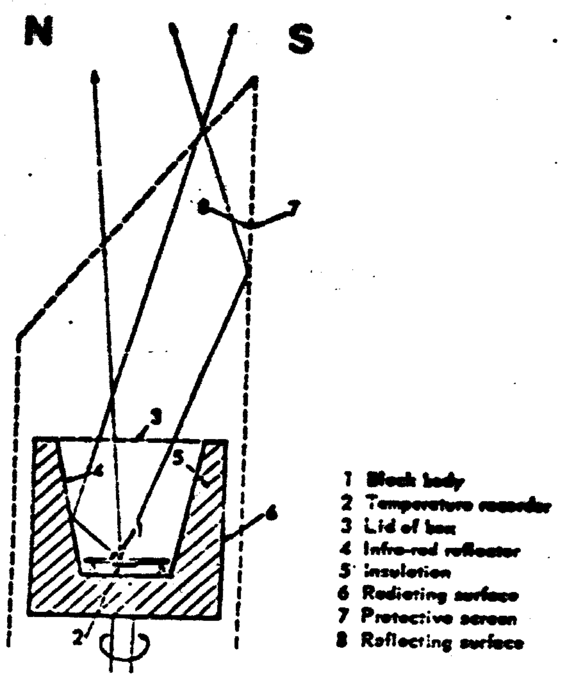
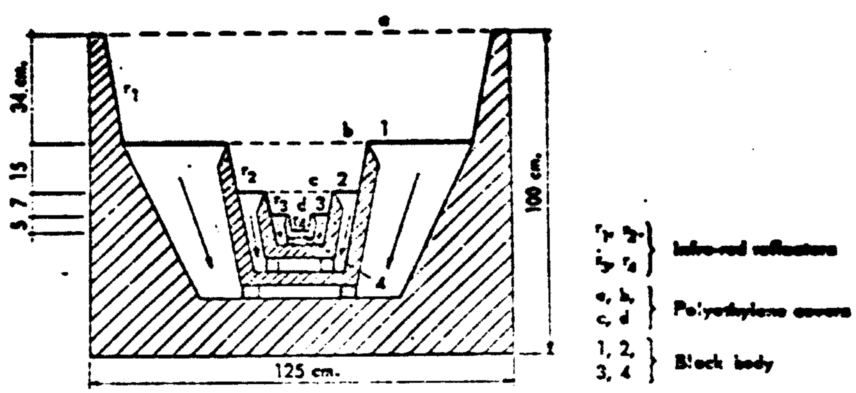



Fig. 6. Experimental localization of energy losses.



Many excellent solar stills have been developed in France, Algeria, Australia, the United States, the Soviet Union and Israel. The production of fresh water from brackish water by solar processes is fairly expensive, and it would seem to be no easy matter to lower the cost, which is about 1 to 2 francs per cubic metre.

To distil one litre of water over 600 calories are needed, which is more than is needed to smelt one kilogram of iron. As things stand at present, solar water may be very useful for human drinking purposes, but it is a little too dear for cattle and out of the question for crop irrigation. It seems that the development of small-scale solar stills is to be preferred to the establishment of large distillation plants.

### *Motive power*

A basic community requirement is some form of energy for pumping water and generating electricity.

Extensive research in France, the United States, the Soviet Union, Israel and Senegal has led to the development of various kinds of solar generators. The general conclusion is that under the present competitive conditions governing energy production, the solar engine is still too expensive and cannot compete with liquid fuel, even in remote areas. However, in view of the importance of the problem, it is essential to encourage the introduction of prototypes in various countries so as to see how they stand up to operation under actual working conditions and to devise a standard type of solar generator for which there is certainly a promising future both as a technical and as an economic proposition.

### *Other applications*

There has been much talk of devices for cooking food by solar heat in regions where there is plenty of sunshine but no other energy resources. Although those tried out in India and Latin America have not been successful, there is no reason why the effort should be abandoned. The main thing is for the manufacturers of solar cookers to discover solutions which are economic —which is certainly possible—and, above all, practical, taking due account of the customs of the populations concerned.

Another application of solar radiation which should be developed is the use of photopiles and thermopiles.

Photopiles could be used to very great advantage to feed transistor equipment used for public and private telecommunication purposes. Thermopiles could be used not only for these purposes but also for operating small-capacity refrigerators (Peltier effect) to preserve certain products, such as medical supplies.

## EXPLOITATION OF TERRESTRIAL RADIATION

It has long been known that in cloudless areas and at night the earth's surface is always colder than the surrounding air. The difference in temperature is not very high at any given moment—2° to 6° C., and in exceptional cases as much as 8° to 9° C.—but it is nevertheless responsible for widespread phenomena (extensive cooling of the earth's surface and the air during the night, dew and hoar-frost). All these are due to a considerable loss of infra-red energy by the earth to the atmosphere and to space. This loss of energy, which many experimenters since Angström and Boutaric have measured, may amount, in clear and dry weather, to more than one-third of the earth's total radiation at the given temperature: for example, the earth, considered as a black body, would radiate 316W./m.² at 0° C., whereas it would receive only about 200 W./m.² from the atmosphere. This difference of more than 100 W. is not exclusively due to the fact that the emitting atmosphere is colder than the earth (which, incidentally, is not always true): it is due to the discontinuity of the atmospheric spectrum.

Figure 4 shows black body radiation (the earth's surface is almost black) at different temperatures, as a function of the wave-length expressed in microns.

Figure 5 shows the transmission spectrum of the atmosphere and the largest transparency zone or slot between 8 and 13 μ. It is mostly through this slot that the escape of terrestrial energy takes place beyond the atmosphere into space.

An attempt was made at the Montlouis Laboratory (by F. Trombe, A. Le Phat Vinh and Mrs. M. Le Phat Vinh) to exploit this phenomenon to obtain cold or refrigeration—in other words, to localize energy losses in order to obtain regular and much larger drops in temperature than those which are to be observed in nature.

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The principles applied are extremely simple (see Fig. 6). The black body (1), the temperature of which is measured at (2), is placed at the bottom of an insulated box (5) lined on the inside with an infra-red reflecting metallic surface (4), for example, non-oxidized aluminium or a polished gilt surface. The outer wall of the device is of the same nature as the emitting surface (1), for example, oxidized aluminium or glycerophthalic paint containing titanium oxide (rutile). The box thus prepared can be surrounded by a reflecting screen at (8) and a radiating body (like 1 and 6) at (7) for daylight tests.

A problem which arose, and which was solved only after considerable research, concerned the lid of the box (3), which has to have the same transparency zones as the atmosphere. Polyethylene 50 to 200 μ in thickness was finally adopted on account of its extreme transparency in the principal atmosphere slot (see Fig. 7).

The results obtained with this simple apparatus are spectacular: *a stable temperature drop of 14° to 30° C. in relation to the surrounding air.*

Results of this kind can be obtained either in the daytime or at night, provided that the reflecting and protective screen (7, 8) is employed and that a selective radiating substance is used as radiator (1)—a black body for infra-red to reflect the sun's rays diffused by the sky (radiation below 1 μ).

An additional 4° to 7° C. can be gained by the use of concentric boxes (Fig. 8), which serve to attenuate the losses by conduction. The temperature drop then ranges from 18° to 36° C., depending on the transparency of the sky.

In our experiments we have used a very wide variety of radiating substances: silvered glass, oxidized aluminium, any type of metal surface with a suitable coat of paint, and even a plastic surface (polyvinylchloride) presenting an emission spectrum in the 'window' zone in which polyethylene is transparent.

Had they not been repeated very many times and strictly controlled in every detail, these experiments might have met with considerable incredulity on account of the magnitude of the drops in temperature that were recorded.

Experimentally, in fact, temperatures are found which are often lower than those obtainable by calculation on the basis of the energy emitted per unit of surface at the temperature of the surrounding air, but this phenomenon is easily explained by the discontinuity of the spectrum emitted by the atmosphere.

It is quite evident that phenomena of this nature, which occur over the greater part of the earth's surface and practically dictate the climate of the earth's environment, call for thorough basic studies whose practical significance should not be overlooked.

### *Air-conditioning of houses*

It is now possible to modify considerably the average temperature of living premises in arid zones and to establish a climate in which normal living conditions can be obtained.

In addition, there is the fact that the moisture content in the very dry air of arid zones is still relatively low when the air has been cooled down to around 20° C. This means that to the radiation effect a further cooling effect can be added by saturating the air with water vapour, the air being used to accumulate cold in thermal masses instead of directly in the dwelling.

### *Cold rooms*

The exploitation of $\Delta t$ (drops in temperature) during the night period, which is relatively cold in cloudless countries, should in most cases result in temperatures in the neighbourhood of 0° C., or possibly lower than 0° C. with the application of an additional refrigeration effect produced by vapourizing water or dissolving certain salts. It would thus be possible to ensure stable temperatures of between 0° and 10° C. day and night in heavily insulated compartments constituting veritable cold rooms.

This possibility opens up very considerable prospects for the conservation of foodstuffs (meat and even fruit) which deteriorate very quickly in hot countries.

### *Energy production*

It is also important to be able to have a stable $\Delta t$ of 15° to 30° C. day and night.



Frequent attempts have been made to operate large thermal cycles with a $\Delta t$ of the same order, necessitating the use of expensive apparatus. The evidence is that radiation towards space could lead to a form of production of energy through the functioning of thermal cycles which could be very simple and which would in any case be useful for the day and night feeding of the cold source of thermopile groups.

### *Condensation*

Finally, it is not impossible that such temperature differences would enable large quantities of water to be condensed underneath the radiating system independently of the polyethylene screen.

## CONCLUSIONS

From this quick survey of the possible uses of energy obtained from natural radiation with particular reference to the developing countries, we may list a few conclusions.

1. There are applications of solar and terrestrial energy which can already be exploited economically; for instance, house and water heating can be envisaged in cloudless countries where there are long periods of sunny cold weather. Afghanistan, for example, has such a climate.

In warmer parts, such as the African regions from North Africa to the Sahel, the main problem is the production of cold. As from now it is possible to envisage applications of terrestrial radiation which could improve living conditions in dwellings and be used to preserve food.

In general, in cloudless countries with extreme conditions (hot in the day and cold at night, with great variations in average temperatures throughout the year) sources of both heat and cold are needed according to the season.

Other uses of solar heat for the distillation of water or desiccation of fruits, for example, also offer interesting possibilities. One great problem is that of providing fuel for the cooking of food which is a serious cause of deforestation in regions already poor in vegetation.

Despite many interesting attempts it has still not proved possible to introduce solar cookers in countries where there is abundant sunshine. The effort to be made in this respect is both technical and psychological, and the solution lies in convincing populations bound to ancestral methods to change their habits.

2. There are other applications which deserve attention, such as refrigeration by thermal cycles, the heat being provided by solar energy. We have seen that ice production by this method could compete, in countries where fuel is expensive, with conventional methods of production. Such economic feasibility, however, could not be achieved with individual household freezers but only with community plants producing ice for a population equivalent to that of a small village.

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3. **Other** applications of solar energy will have this importance in the future but cannot as yet be considered as paying propositions. These include the production of motive power for pumping water and generating electricity. The small individual plant is as yet much too expensive, while power production in large solar generating stations still works out at too high a cost per kilowatt. But these disadvantages should only be considered spurs to further research in this field of importance.

How can we now envisage the gradual promotion of the use of natural radiation energies?

The first step is to install publicly-operated plants with the help of governments and possibly international organizations. Little by little, thanks to such concrete examples and accumulated experience of actual working conditions, private ventures will follow.

With regard to those uses of radiation energy which, while already technically feasible, are still generally inapplicable for economic reasons, one can only hope that every effort will be made to develop devices of various kinds and that prototypes of these will be put into service in the actual locations where their future utility will be most valued. Here again international co-operation in both research and practical development will be required.



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# SOLAR ENERGY UTILIZATION

## Solar and Thermal Radiation Properties of Materials

In response to the demand for radiation coefficients for materials used by the Australian building industry, the spectral characteristics of a range of materials have been measured using a Gier-Dunkle spectroradiometer. Coefficients of reflectance, transmittance and absorptance for solar radiation, transmittance and reflectance for visible radiation and thermal emittance properties are determined for most materials. These values may be used to calculate equilibrium temperatures of surfaces under known conditions of insolation and air environment, shading coefficients of fenestrations, solar heat gain factors or other calculations which give an estimate of the thermal load on a building.

All spectral reflectance measurements are for hemispherical reflectance for an incidence angle of 20° from the normal with the sample at or near room temperature, and may be determined for radiation of wavelengths from 0.3 (ultraviolet) to 25 microns (far into the infrared). The spectral transmittance and absorptance for both diffusing and non-diffusing materials are determined over the spectral range from 0.3 to 2.5 microns and direct beam spectral transmittance characteristics are measured over the wavelength range from 0.3 to 25 microns.

Simple integration procedures have been developed so that solar, visible and thermal radiation properties may be evaluated from the spectral data. Solar radiation properties are computed for the solar spectrum corresponding to an air mass of 2, i.e. twice the mass of atmosphere which would be traversed to an observer at sea level from the sun at his zenith. Visible radiation properties are corrected for the standard visibility function of the human eye, whilst the thermal radiation properties may be evaluated for any required temperature.

Interest has been increasing recently in types of glazing and treatments for glass that reduce the solar heat gain through the fenestration. Clear window glass transmits both visible and infrared radiation in the solar spectrum; however,

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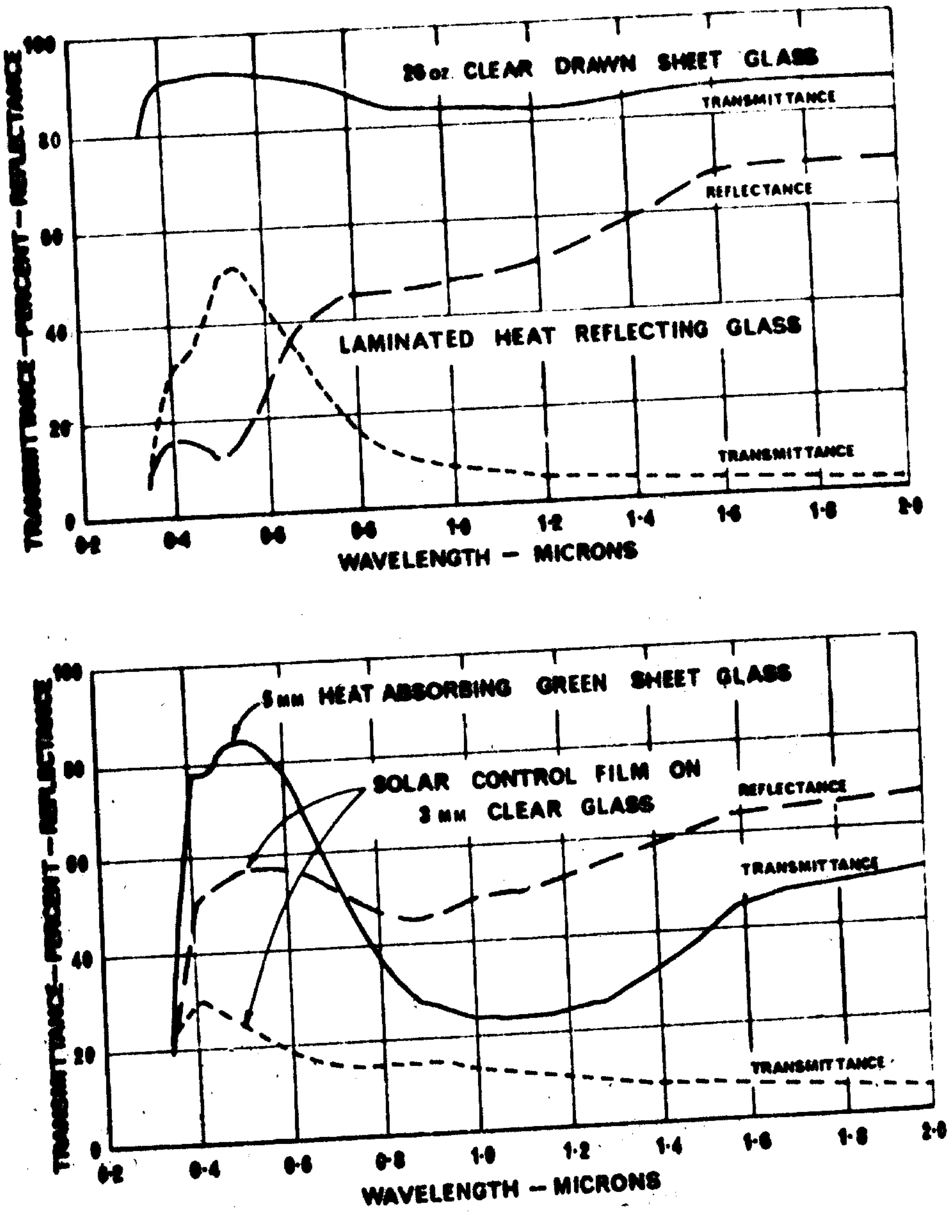


Fig. 15 - Spectral characteristics of glazing materials.

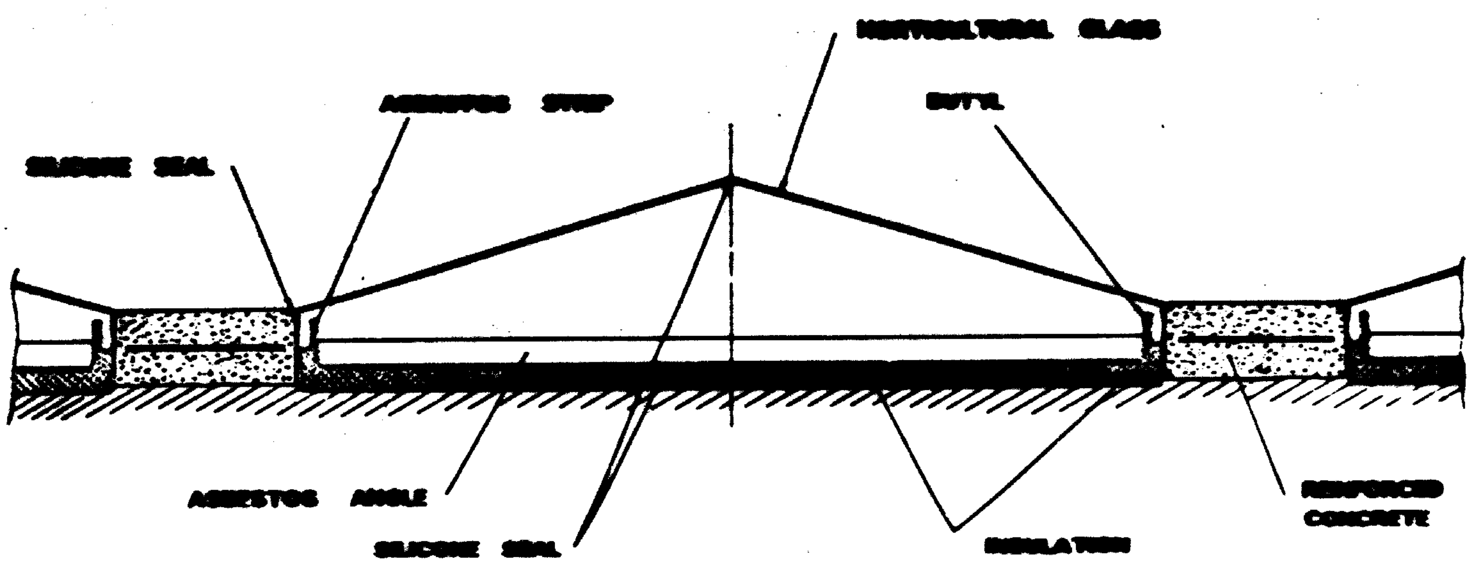


Fig. 16 - Cross-section of Mk. VI solar still.

glazing materials which transmit a large fraction of visible radiation while either absorbing or reflecting most of the solar infrared radiations are now being used in many of the large commercial buildings. Solar control films for application to existing clear glass windows are also being used.

The construction principles of the solar control films and glasses which strongly reflect solar infrared irradiation are similar; the film is in the form of a laminate, while the glasses may be either laminated or in the form of a double glazed unit with an air gap separating the two sheets of glass. In each case, a very thin metallic film of the laminate forms a semi-reflecting surface and, because of the relatively high reflecting characteristics to visible light, these systems tend to form a one-way mirror. This tendency may be reduced by an interference coating on the glass which decreases the visible reflectance.

Spectral characteristics for examples of each of the above types of glazing systems are shown in Fig. 15.

(E. A. Christie)
(P. 153)

**Solar Distillation**

In developing a satisfactory design of solar still, many factors need to be studied. Dimensional or geometrical relations to performance can usually be ascertained in a year or less, but it takes much longer to determine the most suitable materials to use, when cost, ease of installation, and durability under initially uncertain conditions are some of the variables.

The present stage of evolution is the Mark VI still, of which Fig. 16 is a cross-sectional drawing. Its glass roof spans a long basin lined with a butyl rubber membrane, between graded abutments of reinforced concrete. The saline water flows along over a descending series of asbestos-cement weir angles, which ensure that all the rubber lining is submerged except for a narrow hump along each distillate channel and a flat triangular piece inside each end. The only metal inside the still envelope is two short copper tubes for distillate outlets, and a clip holding the butyl rubber around the asbestos pipe saline outlet trap.

Stills of this type have been installed at Griffith (NSW), Coober Pedy (SA) (Fig. 17), and Muresk (WA). Thermal insulation underneath, and improved vapour tightness owing

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to complete jointing with silicone rubber sealant, have resulted in a higher distillate yield than from early Mark numbers, as graphed in Fig. 18.

At Coober Pedy, the composition of the bore water supply is such as to give fairly rapid salt precipitation. The effect of this on distillation rate is being measured by first cleaning five of the ten 500 sq ft stills, which had all become similarly affected. This was done by a lengthwise pull-through of a plastic loop, to break up the thick surface incrustation. A progressive comparison of daily yield from the two groups of five stills indicates how often this is necessary.

Also at Coober Pedy a number of level checks at marked points on the concrete edges of stills has been made periodically, using a small dumpy level and a graduated staff, to see if ground movement was occurring. Over two months no change was observed, outside observational tolerance.

At Griffith, a polyisobutylene lining was tried on one still instead of the dearer butyl rubber. Failure occurred after only nine months service.

Some theoretical work has been done in estimation of loss of performance cue to reflection from salt incrustations, and on the possible effect of adding a dye to the basin water. These investigations are still incomplete.

(W. R. W. Read, P. I. Cooper)
(P. 89, 102, 103, 110, 117, 131, 140, 144, 148, 151, Aust. Pat. 275, 448)

## Solar Air Heaters

The 300 sq ft (27 $m^2$) bank of unit heaters with its 340 cu ft (9.63 $m^2$) rock pile thermal storage, which were illustrated in the Division's 1968-69 Annual Report, have now been in operation for over twelve months. Measurements of the performance of the system under varied control conditions have been made, and the results can be summarized as follows.

Test runs, each lasting two weeks or longer, have shown that with a system discharge of 650 lb/hr (161 c.f.m. at 120° F) (0.082 kg/s (76 l/s at 49° C)), the efficiency of the solar air heater and thermal storage system is 49% and 52%, for solar heater outlet temperature settings of 150 and 130° F (66 and 54° C) respectively, when average insolations for the test periods were 1,170 and 960 Btu/ft$^2$/day (13.3 and

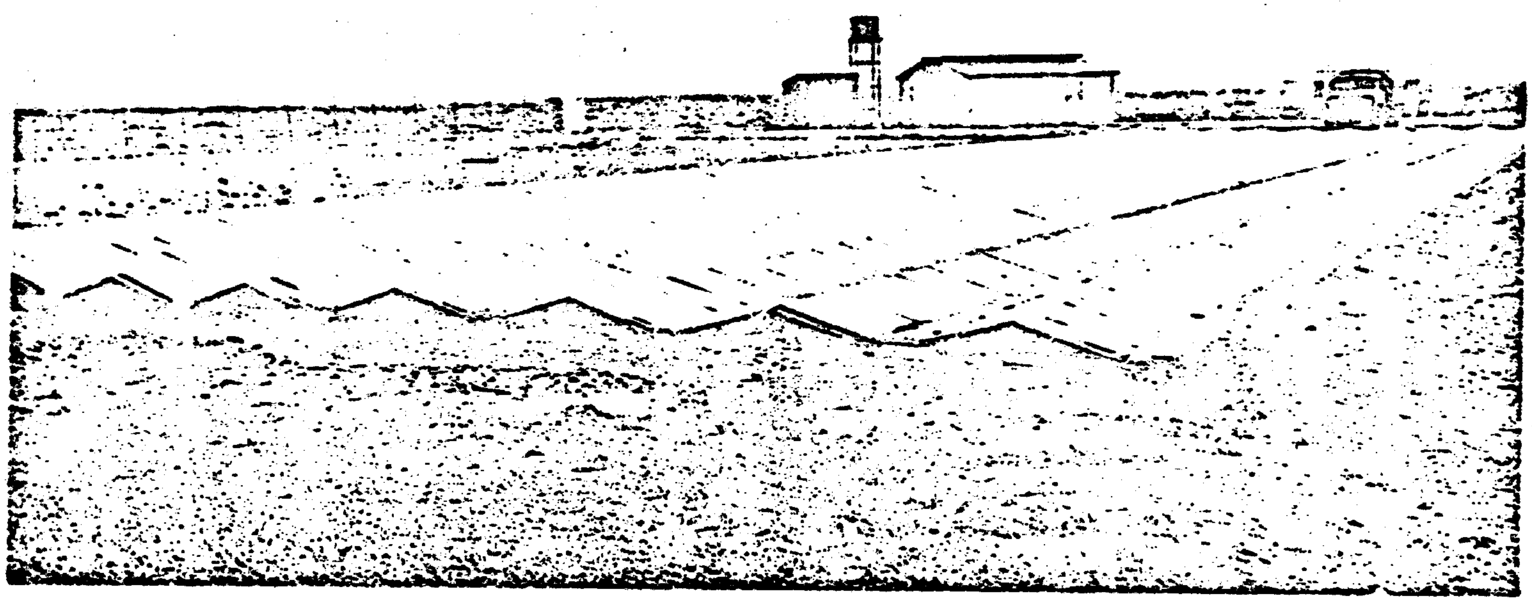

Fig. 17 - Mk. VI solar stills in operation at Coober Pedy, SA.

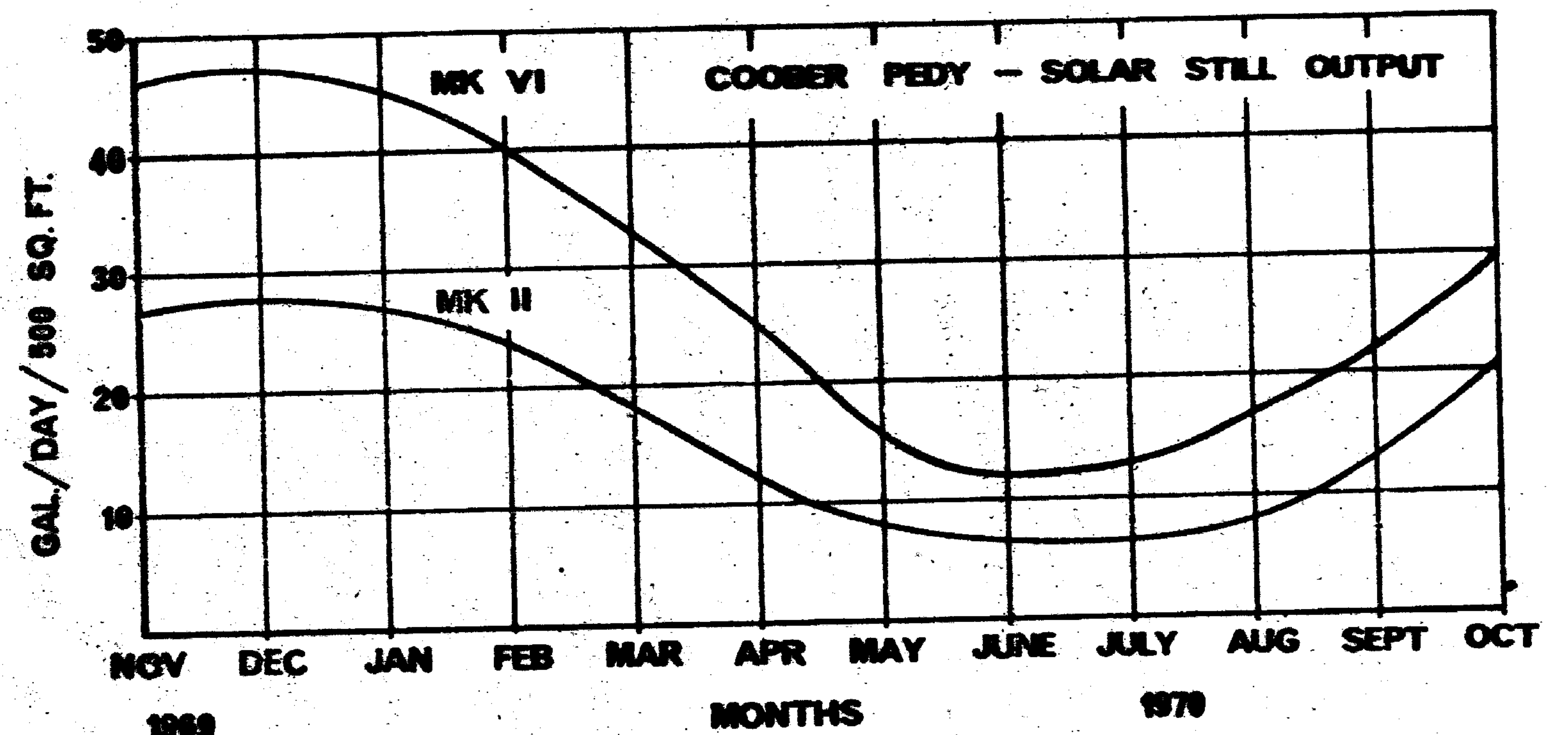


Fig. 18 - Comparative output from Mk. II and Mk. VI solar stills at Coober Pedy, SA.

10.9 $MJm^{-2}$/day) and average ambient temperatures were 64.5 and 61.5° F (18.1 and 16.4° C).

The system has also been under test with a differential control. This control allows maximum air flow in the solar heater when the temperature difference between the heater outlet and the cool end of the storage is more than a set value of 19° F (10.5° C) and stops the air flow when the temperature difference is less than 15° F (8.3° C). An initial test run of three weeks gave an efficiency of 49% at an average insolation of 75 Btu/$ft^{-2}$/day (851 kJ/$m^{-2}$/day) and average ambient temperature of 53.1° F (12.5° C).

The testing of the system and evaluation of results have not yet been concluded, but the performance has been sufficiently encouraging to warrant consideration of a number of practical applications, mainly in drying of agricultural and other primary products. From these, timber drying has been chosen for investigation and a small timber kiln has been planned, having its own rock pile and operating in conjunction with the existing solar heater.

(W. R. W. Read, A. Choda)
(P. 147)

## Utilization of Waste Heat in Solar Stills

At most of the remote motels and pastoral properties in Australia electric power is normally obtained from a diesel generator set. Only about one third of the energy in the fuel is converted to electricity, the rest being lost to the atmosphere, mainly as heat from the cooling jacket and exhaust gases.

The current research is aimed at utilization of the heat from the engine jacket to supplement that received from the sun in solar stills. Studies were made of eight possible systems, comprising two separate groups: (a) where the saline water is heated before entering the still, by using some form of heat exchanger, and (b) where the heat exchange is made within the still itself by passing hot water from the diesel through pipes inside the still basin. The former category would be used for stills already in existence, but estimates concerning cost and ease of operation favour the latter type for new installations.

Consideration of likely sizes of diesel plant in the situations mentioned suggests that suitable areas and possible outputs for waste-heat boosted stills might be in the ranges

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of 400 - 800 sq ft (37 - 74 $m^2$) giving 200 - 400 gal/day 900 - 1,800 l/day) of distillate.

A series of tests is being made on a small Mk. VI still at Highett on performance with various set rates of flow of heated and "saline" water, to obtain suitable figures for design purposes.

(W. R. W. Read, D. Proctor)
(P. 150)

Solar Measurements Programme

(a) Measurements. Routine measurements of solar energy are now being made at Muresk (WA), Coober Pedy (SA), Griffith (NSW), and Townsville (Qld), where the pyranometers are connected to integrating electronic recorders giving printed outputs of the energy received.

These measurements are used mainly to determine the efficiencies of experimental solar devices established at these locations, and to give long-term radiation data to assist in such studies as agricultural experiments and heat loads on buildings.

The results from these stations, together with those obtained at Highett, are processed by computer and sent primarily to the Bureau of Meteorology and thence to the World Meteorological Organization at Leningrad, USSR.

(D. J. Norris)

(b) Calibration of Pyranometers. A method of calibrating pyranometers in situ has been developed. A pyranometer to be calibrated is mounted near to and in the same plane as a reference sub-standard pyranometer. The outputs of the two instruments are fed to a data logging system consisting of a digital voltmeter, a scanner and a PDP8 computer. The ambient temperature is also recorded, and an estimate of cloud cover is entered manually into the computer.

The computer is programmed to calculate the calibration coefficient of the pyranometer and prints out each ten minutes the average of fifty readings, together with solar time and ambient temperature. The output from the computer is in the form of paper tape which is used for full regression analysis of the results. Correlations are determined between calibration coefficient and temperature and time. Thus temperature coefficients and variations with the sun's position may be studied.

Calibrations have been carried out of pyranometers of American, European and local manufacture on clear, cloudy and overcast days. Variations in sensitivity have been found to be less than 3% over all types of days except when rain occurs.

(D. J. Norris

(c) <u>Solar Cells for Power Generation.</u> Thin-film micro-crystalline cadmium sulphide solar cells produced by a United States firm have been tested. For those encapsulated in Mylar the output degrades up to 40% in six months; those encapsulated in Kapton (polyamide) degrade much less. However, since these cells have been designed mainly for space vehicles some consideration has been given to a new design for terrestrial applications, where the main problems are resistance to atmospheric conditions and cost per unit of power.

A recently developed silicon solar battery has been tested and, since the cadmium sulphide cells degrade so rapidly, this battery is the most economic so far produced. The cost of installing a solar battery now appears to be about $50 per watt based on an available input of 100 mW/cm$^2$.

(K. G. T. Hollands, R. V. Dunkle, D. J. Norris

(P. 14

(d) <u>Design of Instruments.</u> The pyranometer developed in co-operation with the Division of Irrigation Research has undergone small modifications in design to facilitate manufacture and to overcome minor faults that developed after several years' operation. Approximately fifty pyranometers have been built and they are in use in Africa, India, Pakistan, New Zealand and widely in Australia.

By combining two pyranometers back-to-back an albedometer has been built. This instrument is used to measure the proportion of incoming solar radiation that is reflected by the ground or any other surface.

The design of a new integrating digital recorder has been completed and tested. This recorder will enable millivolt signals from a pyranometer to be integrated and encoded in BCD for direct input to a computer.

(D. J. Norris)

(Aust. Pat. 402, [illegible])

The waste heat, radioactive emissions and disposal of radioactive wastes from light water nuclear reactor are vexing questions because of the potential environmental hazards from these three factors. They also contribute appreciably to the cost of operation of the reactors. Precautions against radioactive emissions are usually arrived at through the construction of barriers which depend on the specific design of the reactor. On the other hand, the geographic and geological conditions at the power station site strongly influence the solution of the cooling scheme needed to take care of the waste heat. These conditions also dictate the procedure of disposal and storage of the radioactive wastes.

3.3 Solar Energy

Because of the large amount of the solar energy reaching the earth's surface, there have been many attempts to exploit this energy. The use of solar energy for direct heating has encountered a certain degree of success. In Japan, commercially available units for providing residential needs for hot water appear to operate quite satisfactorily. Similar reports have been given from experiments in the U. S. where a great deal of pioneering work is being performed.

The chief incentive in using solar energy is that it is a non-polluting source of power and that there is no expenditure on fuel. There are two serious disadvantages, however, to the exploitation of this method for the production of electricity. First, solar energy is very dilute. Consequently the size of the power plant becomes inordinately large. The second disadvantage is the high cost of the capital invested per kilowatt of electricity that would be produced when direct photoelectric conversion is contemplated. To fix the ideas a few comparisons are given. A 1000 MW coal burning poweplant is projected to cost in 1978 about $360 million, i.e. 360 $/kW, a light water nuclear reactor of the same rating is expect to cost 380 $/kW, while an oil fired plant would cost the least with a corresponding figure of 330 $/kW. On the basis of improved (cadmium sulfide) cell production techniques it is conceivable to construct plants costing about $2500/kW.

Two promising but radically different approaches have been suggested recently. In one of them the energy from the sun is collected in a "solar farm". Assuming an energy conversion efficiency of about 30% (which is very optimistic), a 1000 MW can be collected over an area equivalent to a square 4 km on a side. Since the collectors do not completely cover this area, the area under the collectors is in partial shade and is hence cooler, and more apt to retain moisture. The idea of the solar farm is to utilize the space under the collectors for agricultural purposes. The high cost of the power plant could thus be advantageously offset by the availability of cooler agricultural land. The true effective cost of a solar farm in Egypt will have to be determined. Meinel[(5)] the originator of the concept of the solar farm claims that the cost of such a solar plant could be made to operate at a cost competitive with that of a gas fired plant.

The second alternative method proposed by Zener[(6)] makes use of the solar energy absorbed in tropical regions of the seas. Zener's proposal would apply to the waters of the Red Sea. In this scheme a heat engine using a Rankine cycle operating on the temperature differential between upper and lower levels in the sea is the basic conversion process. Several working fluids have been suggested (propane, ammonia, etc.). Although the system is fundamentally inefficient from a thermodynamic point of view, Zener claims that such a solar plant could be made competitive to a nuclear power plant.

# FLOW DISTRIBUTION IN SOLAR ABSORBER BANKS

by

R.V. DUNKLE and E.T. DAVEY*

## SUMMARY

The efficiency of large solar water heating installations is reduced if flow is not uniformly distributed among the individual absorber units. A theoretical analysis of the flow distribution is presented in this paper and recommendations proposed for large installations. Some temperature measurements on an experimental system are also presented.

## 1. INTRODUCTION

Solar water heaters are usually made in standard sizes, e.g. 2 feet by 4 feet, and water heating installations are usually composed of a number of standard units connected together. For small systems it is customary to connect the units in parallel. Cold water enters via the lower header of the first absorber, flows through the risers in parallel, and is discharged from the top header.

It is apparent that if inlet and outlet are at the same end of the absorber bank that flow will be "short circuited" through the first few risers with less flow toward the far end of the bank. It is not so obvious that a similar "short circuiting" effect occurs if the flow discharges at the opposite end of the absorber with the dead zone of low flow near the centre of the absorber bank.

In the region of low flow rates high absorber temperatures arise resulting in high heat losses and low thermal efficiency. Fortunately, free convection forces tend to counterbalance this "short circuit" effect to some extent when the absorbers are inclined. However, in the tropics where the absorbers are nearly horizontal, a serious drop in performance can result from this "short circuit" effect. An analysis of this "short circuit" effect and some experimental measurements of temperatures on absorber plates in a bank of 12 absorbers are given in the paper. It should be recognized that this problem of poor flow distribution arises whenever a large number of parallel pipes are connected between two common headers, and is not confined to solar water heating systems.

## 2. PRESSURE AND FLOW DISTRIBUTION IN A SYSTEM WITH MULTIPLE PARALLEL TUBES WITH COMMON HEADERS

This problem can be solved by conventional pipe line network analysis techniques, but is tedious and the inclusion of buoyancy forces is difficult. As the problem is most important in large banks with many risers, an alternative approximate analytical approach consists in the replacement of the individual risers by a distributed flow resistance between the headers, thus permitting a general analytical solution of the pressure and flow distributions which will correspond closely to the actual distributions in large installations. This could, alternatively, be visualized as replacement of the separate risers by an infinite number of risers offering the same total

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resistance to flow between the headers, but having the effect of varying the flow continuously along the headers rather than in a series of steps corresponding to the flow in each riser. Thus, the greater the number of risers in an installation the better the mathematical approximation to the real system.

The assumptions are made that flow is turbulent in the headers and laminar in the risers. This is probably a valid assumption even at fairly low Reynolds numbers in the headers due to form drag introduced by the ends of the risers projecting into the headers and the flow disturbances at the connections between absorbers. In a large system, flow in the end risers may be turbulent, but as the bulk of the risers operate in the laminar flow region, the overall picture will be little affected. In this paper the effect of density variations with temperature on the flow distribution is not treated. The density problem has been studied and is important in small steeply inclined absorber banks but is of less importance in large banks. This will be reported in a later paper.

### 3. HORIZONTAL OR ISOTHERMAL SYSTEM

The system of interest is a series of uniformly spaced parallel tubes or risers (Figure 1) joining two headers with flow into the bottom header on the left and out of the top header on the right. The absorber bank is assumed to start ($x = 0$) a distance equal to half the riser spacing before the first riser and to extend at $x = L$ half a space beyond the last riser. Due to lack of space, the derivations will not be given, only the important results being described.

The interesting result is found that two simple parameters are sufficient to describe the behaviour of the system. The first is a dimensionless pressure ratio $\beta$ which has the following form:

$$\beta = \sqrt{\frac{2\Delta p_h}{\Delta p_r}} = \left(\frac{D_3}{D}\right)^2 \sqrt{\frac{N L f v Q_T}{32\pi \mu L_3 D}} \quad \text{, note } v \ \mathrm{lb_m/ft^3} \tag{1}$$

In this equation $\Delta p_h$ represents the pressure drop in the headers if the total flow were uniformly divided between the two headers.

$$\Delta p_h = \frac{2 f v L Q_T^2}{\pi^2 g_c D^5} \tag{2}$$

$\Delta p_r$ represents the pressure drop if the flow were uniformly divided among all the risers.

$$\Delta p_r = \frac{128 \mu L_3 Q_T}{\pi g_c N D_3^4} \tag{3}$$

The second dimensionless parameter is the ratio of distance along absorber bank to total length or $x/L$. Flow distributions and pressure distributions are expressed in terms of these parameters.

**FLOW DISTRIBUTION IN TOP HEADER:**

$$\frac{Q_2}{Q_T} = \frac{1}{2} + \frac{1}{2}\,\frac{\sinh \beta \left(2\frac{x}{L} - 1\right)}{\sinh \beta} \tag{4}$$

Equation (4) indicates that the flow is zero at entrance of top header, is half the total flow at the midpoint (half of total flow in each header), and is equal to the total flow at discharge. For a large value of $\beta$, that is, pressure drop of headers large relative to risers, the flow rises very quickly near the entrance, remains nearly constant through the major part of header and then rises sharply near exit so that the centre part of system has very low flow in risers. For small values of $\beta$ the flow increases linearly in the top header, in effect due to the relatively high flow resistance of the risers.

**FLOW DISTRIBUTION IN RISERS:**

$$\frac{Q_3}{Q_T} = \frac{\beta}{N} \frac{\cosh \beta \left(2 \frac{x}{L} - 1\right)}{\sinh \beta} \qquad (5)$$

It is seen from (5) that when $\beta$ is small the flow is distributed uniformly among the risers, and the larger the value of $\beta$ the more the flow tends to concentrate towards the ends of the system. The ratio of flow in the centre riser to that in the end riser is:

$$\frac{Q_{3,x=\frac{L}{2}}}{Q_{3,x=0}} = \frac{1}{\cosh \beta} \qquad (6)$$

**PRESSURE DISTRIBUTION:**

The pressure drop in the risers is given in terms of distance from entrance by:

$$\frac{P_{1,x} - P_{2,x}}{\Delta p_r} = \frac{\cosh \beta \left(\frac{2x}{L} - 1\right)}{\sinh \beta} \qquad (7)$$

The pressure drop along the top header is given by:

$$\frac{(P_{2,0} - P_{2,x})}{\Delta p_h} = \left(1 - \frac{1}{2 \sinh^2 \beta}\right) \frac{x}{L} - \frac{3}{4\beta} \frac{\cosh \beta}{\sinh \beta} + \frac{\cosh \beta \left(\frac{2x}{L} - 1\right)}{\beta \sinh \beta}$$

$$+ \frac{\sinh \beta \left(\frac{2x}{L} - 1\right) \cosh \beta \left(\frac{2x}{L} - 1\right)}{4 \beta \sinh^2 \beta} \qquad (8)$$

This equation indicates that for very large values of $\beta$ that the pressure drops linearly with distance, that is, flow is uniformly distributed between the top headers with cross flow concentrated in the end risers, so that

$$\frac{P_{2,0} - P_{2,x}}{\Delta p_h} = \frac{x}{L} \qquad (9)$$

On the other hand, for very small values of $\beta$ the pressure drop varies with the cube of the distance along the header, or

$$\frac{P_{2,0} - P_{2,x}}{\Delta p_h} = \frac{4}{3} \left(\frac{x}{L}\right)^3 \qquad (10)$$

The total pressure drop in the top header is:

$$\frac{P_{2,0} - P_{2,L}}{\Delta p_h} = 1 - \frac{1}{2 \sinh^2 \beta} + \frac{1}{2 \beta \tanh \beta} \qquad (11)$$

To illustrate these equations, consider a bank of 6 typical solar absorbers each 2 feet by 4 feet and connected in parallel. Headers are 1 inch (0.0753 ft I.D.) and risers are ½ inch (0.0335 ft I.D.). The viscosity of water is taken as 1.6 lb/hr ft, length of header 15 feet, length of riser 4 feet, friction factor in header 0.10, and flow rate 1 gallon per $ft^2$ or $Q_T = 7.705\ ft^3/hr$. In Figure 2 the calculated pressure distribution is plotted, demonstrating the large pressure differences at the ends of the absorber bank relative to the centre section.

**DENSITY EFFECTS:**

If the flow were uniformly distributed among the risers, the effect of density variations could be neglected. If flow is not uniform, fluid temperatures are higher in the risers with low flow, and the lower density of the hot water increases the flow in these risers thus offsetting to some extent the "short circuit" effect previously discussed. These high local temperatures can significantly reduce the overall efficiency of the solar water heaters. For small banks with low velocities, the free convection effects tend to minimise the effect of the forced flow pattern. For large banks the forced flow pressures predominate and control the flow distribution to a large extent. This problem is considerably more complex than the isothermal system and will be treated in a separate paper.

## 4. EXPERIMENTAL INVESTIGATIONS

The first step was the construction of a small simulated absorber bank in clear plastic. Cold water was allowed to flow through the system and provision was made for the injection of dye into the lower end of the risers. The observed movement of the dye agreed qualitatively with the isothermal theory, in that the velocities were much higher in the end risers than in the centre ones.

The second step in the experimental investigation involved instrumentation of a forced convection solar hot water system. The tests described were carried out on twelve 4ft x 2ft selective surfaced absorbers at flow rates of 1, 1½ and 2 gal/min corresponding to approximately 60, 90 and 120 $ft^2$ of absorbers. The pump used was a centrifugal hot water accelerator. Thermocouples were attached to ½ inch risers on the absorbers in the position shown in Figure 3 and inlet and outlet temperatures were recorded. The pump was operated manually and ran continuously during the period of the readings. Comparative results and comments are given for each of the four methods used.

As the tests were carried out on an operating system, it was not possible to reproduce test conditions with different arrangements. The criteria of performance here are the temperatures measured on the absorber plates. If flow were uniformly distributed in the risers, it is expected that the measured temperature distribution would be smooth and roughly parallel to but somewhat higher than the water temperature. Any peaks and dips in the temperature distribution will be due to low or high flow rates through the respective element.

Probably the most common way of connecting absorbers is to put them in parallel. This arrangement is shown in Figure 4. The high temperatures measured in the centre section of the absorber indicate that little water is flowing up the centre risers, the bulk of the water passing through runs either up the first few risers and along the top headers, or along the lower header and up the end risers. This method is therefore not recommended for large banks. It will be noted that the temperature distribution is worst at the highest flow rate. This is because the pressure drops are larger relative to density effects at higher velocities.

An improved distribution was obtained from a series-parallel arrangement. The absorbers were connected in 3 lots of 4 and interconnected by 1 inch pipe as shown in Figure 5. In the case of the test set up clear plastic hose was used as it was thought that air may have been trapped in the upper headers particularly at the low flow of 1 gal/min. However this was not so, it was carried through in large quantities initially and after settling down the small amount of air released from the water during the heating cycle was very readily discharged.

Another suitable method of connection is a multiple parallel arrangement as shown in Figure 6. The absorbers are broken into groups containing up to 24 risers in parallel, which are then connected in a larger bank to a header system. If the headers are large enough to have a relatively low pressure drop compared to the pressure drops across the groups, then fairly even flow is assured. The analysis in this paper can be used as a guide treating each group as an individual riser as a first approximation.

## 5. RECOMMENDATIONS

The recommendations on large banks of solar absorbers are:

1. Banks of up to 24 risers in parallel are satisfactory for either natural or forced circulation.

2. For forced circulation banks with over 24 risers, it is recommended that no more than 16 risers be connected in parallel. For larger banks downcomers can be used, either a separate 1 inch pipe, or one of the absorbers can serve as a downcomer. Alternatively, the multiple parallel system can be used.

3. Flow rates of $^{3}/4$ to 1 gallon per hour for each square foot of absorber area is satisfactory and will give a reasonable temperature rise through the absorbers.

4. As the pressure drops in headers depends to a large extent on the method of construction (e.g. projection of risers into headers), it is recommended that manufacturers should check their own designs.

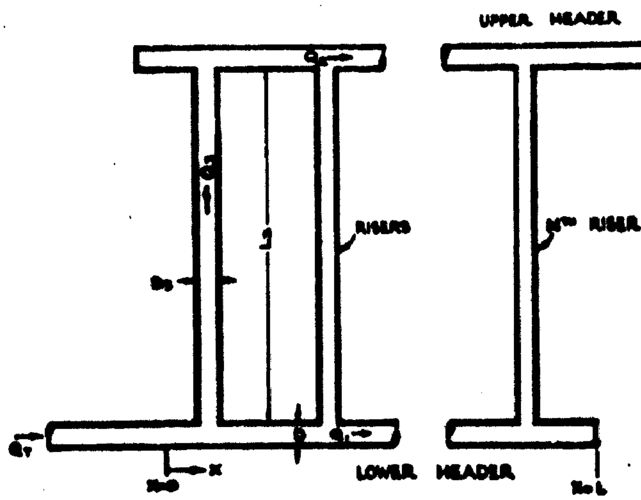


Fig. 1 - Sketch of absorber bank.

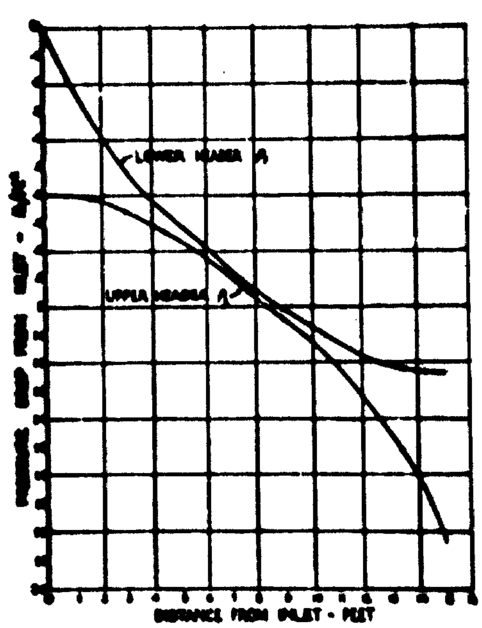


Fig. 2 - Calculated pressure distribution in isothermal absorber bank.

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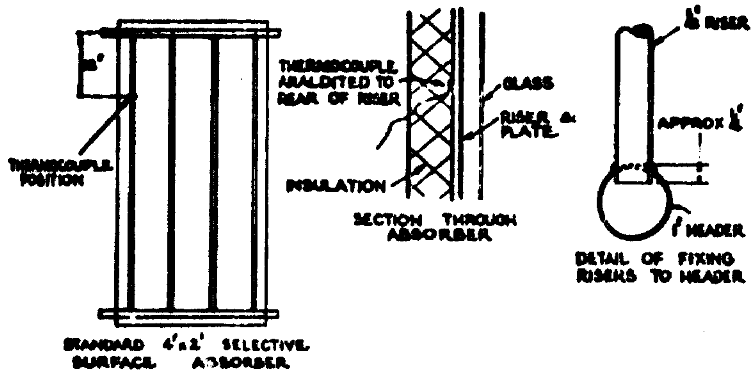


Fig. 3 - Sketch of experimental absorber bank.

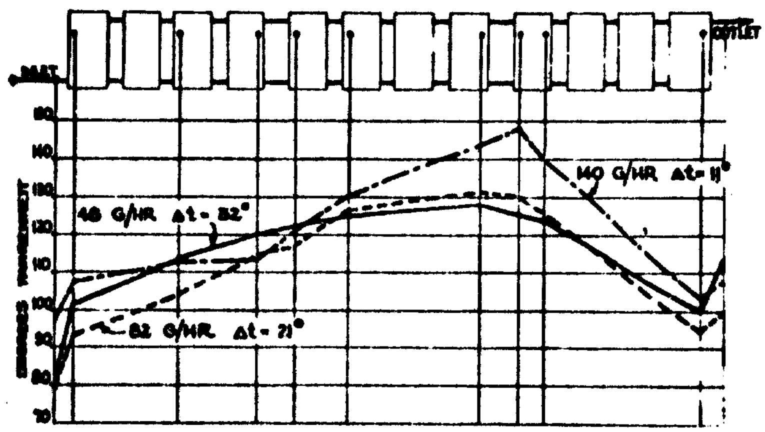


Fig. 4 - Experimental results, absorbers all in parallel.

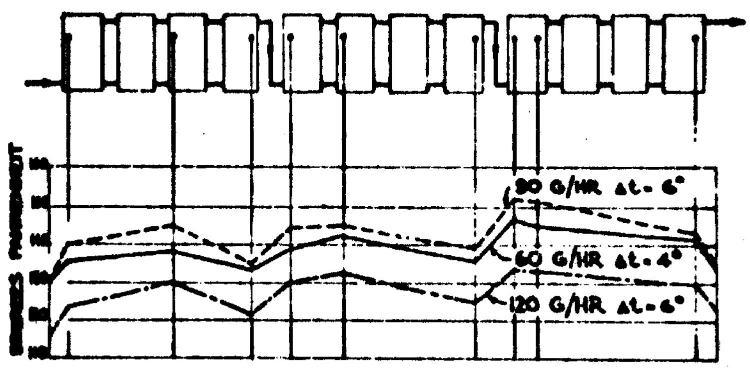


Fig. 5 - Experimental results, series-parallel arrangement.

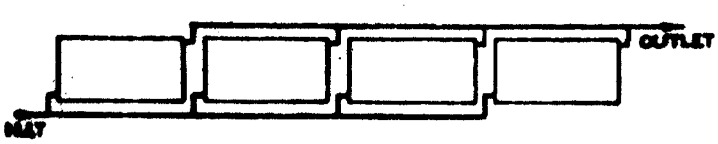


Fig. 6 - Sketch of alternative method of connecting absorbers.

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# CORRELATION OF SOLAR RADIATION WITH CLOUDS*

D. J. NORRIS†

(Received 15 February 1968)

**Abstract**—The possibility of installing solar energy devices such as novel air conditioning plants, solar desalination stills, etc. in remote parts of Australia has led to the necessity of predicting solar radiation in places where no measurements have been made. In the past good correlations of solar radiation with sunshine hours, as recorded on the Campbell Stokes sunshine recorder, have been obtained. However, when looking into the proposed regions for application of solar energy devices, it was found that very little information was available on sunshine hours recordings. It was decided, therefore, to investigate the possibility of correlations of solar radiation with reported cloud cover. Several methods of cloud classification have been examined and in no case was a high correlation coefficient found. It is considered that if cloud reports are used to predict values of solar radiation, only monthly or longer averages may be obtained with reasonable accuracy.

**Résumé**—La possibilité d'installer des dispositifs à énergie solaire tels que des Installations nouvelles de conditionnement d'air, des distillateurs solaires de dessalement, etc... dans les régions isolées d'Australie, a conduit à la nécessité de prévoir les radiations solaires aux endroits où l'on n'avait jamais fait de calculs. Par le passé, il a été possible d'obtenir de bonnes corrélations des radiations solaires par les heures d'ensoleillement, selon les enregistrements de l'héliographe enregistreur de Campbell Stokes. Toutefois, en étudiant les régions proposées pour l'application de dispositifs d'énergie solaire, on a trouvé qu'il y avait très peu d'informations sur les enregistrements des heures d'ensoleillement. Il a donc été décidé de rechercher la possibilité d'obtenir des corrélations de radiations solaires à partir de données sur les nuages. Plusieurs méthodes de classification des nuages ont été examinées et l'on n'a pas trouvé de coefficient de corrélation élevé. On considère que si les données sur les nuages sont utilisées pour prédire les valeurs des ratiations solaires, en se basant uniquement sur des moyennes mensuelles ou plus longues, il est possible d'obtenir une précision satisfaisante.

**Resumen**—Ante la posibilidad de instalar aparatos de energía solar tales como nuevas plantas de aire acondicionado, destiladores solares de agua del mar, etc.—en las zonas remotas de Australia, es necesario hacer pronósticos sobre la radiación solar en lugares que hasta ahora no han sido objeto de medición. En el pasado, se venían obteniendo buenas correlaciones entre la radiación solar y las horas de luz solar, según registradas en el heliógrafo de Campbell Stokes. Sin embargo, al investigar las regiones donde se propone emplear los aparatos de energía solar, resultaron ser muy escasos los datos de registro disponibles en materia de horas de luz solar. En consecuencia, se decidió estudiar la posibilidad de correlacionar la radiación solar con los partes de cielo cubierto; pero, después de examinar los diferentes métodos de clasificación de nubes, ninguno presentó un alto coeficiente de correlación. Se opina, pues, que, si se emplean los partes de nublados para predecir los valores de radiación solar, solamente se podrán obtener valores razonablemente exactos aplicando promedios mensuales o más largos.

IN AUSTRALIA interest is rapidly increasing in the possible utilization of solar energy for useful domestic purposes. The use of solar water heaters is already well established in the northern states and is spreading to the south. Desalination of salt or brackish water by solar stills is today entering a new phase following the successful testing of pilot installations. Research is being undertaken to apply solar heated air or water to air conditioning. Since most useful applications of solar energy will probably first come in remote areas where there is a premium paid for other fuels, a need has arisen to predict the intensity of solar radiation outside the existing network of recording stations. This network is at present associated with the centres of population and does not give a representative picture of radiation distribution over the continent.

*1967 Solar Energy Society Conference paper.

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Following much successful work overseas and in Australia on the relationship between solar radiation and measured sunshine hours, it was thought that this would be the best approach to this problem of radiation prediction. However, it was found that the network of sunshine hours recording, although more extensive than that for solar radiation measurements, does not penetrate into those climatic regions of most interest in this regard.

It therefore became necessary to look at other meteorological conditions which may aid in this prediction. Several reports have been made of the use of cloud measurements for this purpose. Therefore, correlations have been sought between solar radiation and clouds classified by type and amount. Firstly, the method proposed by Lumb [1] was investigated. He divided clouds into nine arbitrary classes and calculated regression between solar radiation intensity, $Q$, and the sine of solar elevation, $S$, within each class. He proposed the formula

$$Q = AS + BS^2. \qquad (1)$$

by substituting a factor '$f$' defined by

$$Q = 135 f.S \text{ where } 135 = \text{solar constant in mW/cm}^2$$

he derived a linear relationship

$$f = a + bs$$

where '$a$' and '$b$' are constants determined by least squares analysis of reported data.

The classification of cloud data used by him is shown in Table 1. His results appear to indicate an accuracy of prediction of better than 10 per cent.

Table 1

| Category | Criteria used for classification |
|---|---|
| 1 | Total amount of clouds $\leq$ 2 oktas |
| 2 | 3–5 oktas $C_L$ (excluding cases where showers were reported). Total amount of cloud 3–5 oktas |
| 3 | 6–8 oktas $C_H$ (excluding $C_H$7) with 0–4 oktas $C_L$ |
| 4 | 6–8 oktas $C_M$ 3 or 6. As category 1 AC/As7 with base $\geq$ 12,000 ft, with 0–4 oktas $C_L$ |
| 5 | $C_H$7 with 0–4 oktas $C_L$ |
| 6 | 7–8 oktas $C_L$ 5 or 8 without precipitation other than $ww = 80$. No rain reported at preceding or succeeding synoptic hour (Also checked by reference to synoptic charts) |
| 7 | 6–8 oktas $C_M$ 2, $C_M$ 7 (either with rain or with $C = 4$) with 0–4 oktas $C_L$; also 7 or 8 oktas $C_L$ if rain reported at next synoptic hour |
| 8 | 8 oktas $C_M$ 2 or $C_L = 6, 7$ with $ww = 50$–$59$ |
| 9 | 8 oktas $C_M$ 2 or $C_L = 6, 7$ with $ww = 60$–$69$ |

Loudon[2] proposed the assignment of transmission factors to each of Lumb's cloud categories. He applied this method to Lumb's data and found little decrease in accuracy due to this simplification.

Sharma and Pal[3] have introduced a factor which they call "clearness number" and is defined as the ratio of the measured direct solar radiation to the computed solar radiation (standard atmosphere) for the same solar altitude. They have used this con-

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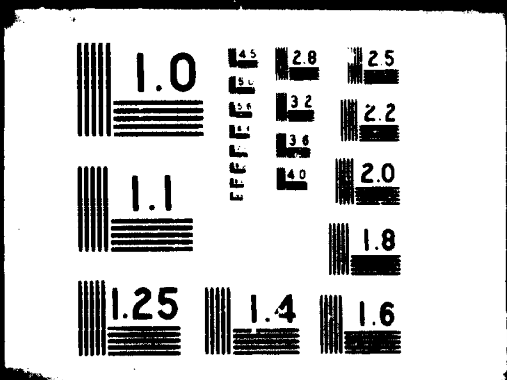

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cept, in empirical formulas, for computing direct and diffuse solar radiation on horizontal surfaces from measured values of total radiation.

Iven Bennett [4] in his paper on preparing maps of daily total radiation quotes the regression equations

$$Q/Qe = 751 + 0{\cdot}845\,Cd - 3{\cdot}56\,Cd^2$$
$$Q/Qe = 775 - 28{\cdot}97\,Cd \qquad (2)$$

where $Q/Qe$ is the ratio of total radiation to extraterrestrial radiation and $Cd$ is daily mean amount of cloud cover.

Coefficients for the linear and parabolic regression lines are given as $R^2 = 0{\cdot}646$ and 0·708 respectively. Standard error of estimation in both cases is approximately 10 per cent.

Budyko *et al.* [5], have proposed a formula relating total radiation on a cloudy day to that on a clear day by a linear expression.

$$(G+g)_n = (G+g)_0[1-(1-K)n] \qquad (3)$$

where the coefficient $[1-(1-K)n]$ is made to depend on $K$, a transmittance of cloud in the case of totally covered sky and on $n$, the mean amount of cloud in tenths.

They state that the value of $K$ depends on solar altitude and properties of clouds and is thus dependant on latitude.

In applying this formula to measured values of both $(G+g)_n$ for cloudy days and $(G+g)_0$ for clear days, they found that monthly means indicated an error of about 10 per cent, while yearly means gave errors less than 5 per cent.

## METHODS USED AND RESULTS OBTAINED FOR MELBOURNE

### *Linear regression*

Solar radiation measurements and total cloud reports for synoptic hours during 1964 for Melbourne were tested for linear regression. Correlation coefficient of $R^2 = 0{\cdot}2$ were found.

### *Method of Lumb*

When this method of classification of cloud measurements was applied to Melbourne records it was found that approximately fifty per cent of observations was not included in the classification. Results are shown in Table 2.

Table 2

| Category | *A* | *B* | *R* | *N* |
|---|---|---|---|---|
| 1 | −2·04 | 0·51 | 0·13 | 174 |
| 2 | −1·72 | 0·36 | 0·59 | 88 |
| 3 | −1·29 | 0·31 | 0·63 | 35 |
| 4 | −8·41 | 0·43 | 0·98 | 3 |
| 5 | 0 | 0 | 0 | 1 |
| 6 | −1·31 | 0·11 | 0·10 | 86 |
| 7 | 0 | 0 | 0 | 0 |
| 8 | −1·91 | 0·92 | 0·38 | 21 |
| 9 | 0·35 | 0·18 | 0·54 | 10 |

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Only in categories 2 and 3 were reasonable correlations found. The small number of samples taken indicates the number of records discarded as not fulfilling the requirements of the classification.

Following the small success found with the above method, by critically examining the International Cloud Atlas and the procedures used by observers in reporting cloud, a new all inclusive classification was drawn up. Clouds in each of the three layers, low, middle and high, were divided into classes of thin, medium and thick based on the amount of cloud present.

Once again measurements of cloud and solar radiation were applied to this classification to seek correlations within each classification using the formula proposed by Lumb. Results are shown in Table 3.

In this case no significant improvement in correlation was found over that shown by the method of Lumb.

### *Sharma and Pal's concept of clearness number*

This concept has been used to classify 3 hourly means of solar radiation into classes of 0·1 in this ratio. The cloud reports were then sorted, placing the clouds for

Table 3

| Category | *A* | *B* | *R* | *N* |
|---|---|---|---|---|
| 1 | −2·15 | 0·34 | 0·39 | 77 |
| 2 | −1·14 | 0·23 | 0·20 | 358 |
| 3 | −1·06 | 0·06 | 0·06 | 189 |
| 4 | −1·17 | 0·40 | 0·37 | 55 |
| 5 | 0 | 0 | 0 | 0 |
| 6 | −0·85 | 0·12 | 0·12 | 69 |
| 7 | −1·55 | 0·25 | 0·25 | 47 |
| 8 | −2·12 | 0·08 | 0·14 | 25 |
| 9 | −2·09 | 0·01 | 0·01 | 23 |

each corresponding 3 hourly synoptic period into the appropriate class of clearness number. Within each class a correlation was sought according to the formula proposed by Lumb relating solar radiation to sine of the solar elevation.

Correlations were found to be extremely low and it was found that various types of cloud in large amount were placed in nearly all classes.

Similar classifications were drawn up defining the transmission factor in each of the following ways:

(a) Ratio of diffuse to total radiation,
(b) Ratio of total to extraterrestial radiation,
(c) Ratio of direct to extraterrestial radiation.

In all cases the same low correlations were found as was the poor classification of some types of clouds.

### *Linear regression applied to means of several days*

Since all these above approaches failed to give the desired accuracy of prediction of solar radiation and since it has been found that on a basis of monthly mean values a good correlation exists between total cloud amounts and solar radiation, an analysis of

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daily cloud amounts was made. From the 9 a.m., 12 noon and 3 p.m. total cloud observations, a mean was taken and a number assigned to each day. This was compared with daily total radiation.

A least squares analysis based on a linear regression line was carried out for these daily values. The daily values were taken successively on two, three or more at a time and mean values obtained. A computer programme was devised to determine the number of days that must enter the mean to obtain a correlation coefficient greater than 0·85. A summary of results for a mean of ten days is shown in Table 4. No number of days less than thirty gave the required degree of correlation.

Table 4

| $R^2_{x-y}$ | $\sigma_{x-y}$ | $A$ | $B$ | $N$ |
|---|---|---|---|---|
| 0·296 | 2·25 | 7270 | −184 | 10 |

Where $y = Ax + B$; $x$ = cloud number; $y$ = solar radiation.

## DISCUSSION

In the observation and reporting of cloud, subjective assessments are relied upon. In Australia only three hourly synoptic observations are made and the reliability of the reports depends upon the skill and experience of the observer. Apart from this factor, no assessment is made of the luminance of clouds or of their transmissivity. Similarly, no report is made of which part of the sky is covered by the clouds. For example, the sky may be half covered with cloud and the sun never obscured during that period. In fact, in the extreme cases, one small cloud could obscure the sun by slowly traversing the sky and similarly a small hole in the clouds could include the sun for long periods.

As mentioned above, in the classification of clouds according to transmission factor, no matter how this is assessed, certain types of clouds fall into nearly all classes. For example, the most widespread report of cloud, stratocumulus, appears in amounts of seven eights of the sky covered with transmission factors of 0·2 to 1·0.

An analysis of frequency of occurrence of clouds over five cities in Australia has been made. Stratocumulus is the predominant cloud type reported at Adelaide, Melbourne, Sydney, Brisbane and Townsville and in most cases comprises more than twentyfive percent of all reports.

There is a rational explanation of this behaviour and this is due to clouds being observed in the past only from beneath. If seven eighths of the sky is covered with stratocumulus clouds, it is extremely difficult if not impossible to describe the middle and high clouds which are above. Stratocumulus may be accompanied by cumulonimbus clouds giving very low transmissivities or they may be accompanied by no other clouds and be themselves in a thin layer. Transmissivities may then be high. In fact it can be considered that a nearly overcast sky may have a wide range of transmissivities.

Another factor that may invalidate the classification of clouds by transmissivity is the reflection of solar radiation from the edges and sides of cloud masses. This is traditionally referred to as the 'silver lining'. Evidence has been obtained that with broken cumulus clouds reflections from them may increase the amount of radiation reaching the Earth's surface to more than that which would be received on a clear day. Occasions have been noted when in tropical regions this reinforcement has led to the intensity

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reaching the surface to exceed the solar constant for appreciable periods. In one case from Gladstone on the east coast of Queensland, an intensity exceeding the solar constant was recorded continuously for more than half an hour.

## CONCLUSION

The foregoing discussion and the reported attempts to divide cloud reports into classes of transmissivity indicate that it is probably impossible to use cloud information to predict solar radiation. This is because of the doubtful extent of the reduction in intensity of transmitted radiation and the possible increase by reflection of the total amount of radiation reaching the Earth's surface.

In order to predict solar radiation, the only method proposed is that using sunshine hours or as has been proposed by Bennett a multivariate analysis of cloud amount and sunshine hours.

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# Solar Radiation on Inclined Surfaces

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**To predict the amount of solar energy falling on inclined absorbing surfaces, such as absorbers for solar hot-water services, several formulas have been published by authors in this field. These are based on measurements of sunshine hours, cloud cover, total solar energy falling on a horizontal surface or both total and diffuse solar energy on a horizontal surface. A study of these formulas has been made and the two most likely to give accurate predictions have been tested against measured values of energy on an inclined surface. Using the assumptions made in these formulas good agreement is found for some conditions though for short period values, such as daily totals, gross errors are indicated. Since the amount of solar energy available varies greatly with climatic conditions it is suggested that more widespread measurements of solar energy falling on inclined surfaces should be made. These measurements are essential for the design of absorbers and heat storages for the increasing application of solar energy to useful purposes.**

SOLAR energy, the heat energy from the sun that reaches the earth's surface, is used at present for the heating of water, distillation of salt or brackish water, direct conversion to electrical energy, and for cooking. Other uses such as air heating have been used on a limited scale. In most cases where the maximum energy collection is required the collectors are pointed towards the sun. In some applications, such as water heating, the collector usually consists of a flat-plate absorbing surface. Since automatic tracking devices to follow the passage of the sun across the sky are expensive these flat-plate absorbers are mounted at an angle varying from zero to 90 degrees to the horizontal facing towards the equator. The optimum angle of inclination depends upon the latitude of the place of installation. This inclination can be selected to give equal energy absorption during winter and summer, to give maximum year round absorption, or to give a maximum at any desired season of the year.

To design an absorber, a knowledge of the amount of energy it will receive is necessary and since the sun does not shine every day storage of energy must be provided for any system that relies mainly on solar energy. The size of the storage is related to the size of the absorbing surface, the energy demand, and on the variations in solar energy.

A knowledge is therefore necessary of the way in which the intensity of solar energy varies with time as well as the amount that will be collected by the inclined surface of the absorber.

There exist in several countries of the world networks of instruments for measuring solar radiation and scattered solar radiation, the latter only at a small number of locations. These instruments are, in nearly every case, mounted horizontally.

For places where no measurements are being or have been made methods have been proposed for calculating the solar energy available from other climatic data. The most direct approach has been to use sunshine

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**NOMENCLATURE**

- $a$ and $b$ = Constants.
- $D$ = Diffuse radiation incident on a horizontal surface.
- $D_{60}$ = Diffuse radiation incident on a surface inclined 60 degrees to the horizontal facing the equator.
- $E$ = Solar energy falling on a surface inclined at a fixed angle to the horizontal.
- $G$ = Solar energy falling on a horizontal surface at the top of the atmosphere.
- $G_e$ = Solar energy falling on a horizontal surface at the earth's surface.
- $H$ = Total solar energy falling on a horizontal surface.
- $H_i$ = Solar energy falling on a surface inclined to the horizontal.
- $N$ = Possible hours of sunshine.
- $n$ = Measured hours of sunshine.
- $R_D$, $R_d$, $R_\rho$ = Liu and Jordan ratio for inclined to horizontal values of direct beam, diffuse and ground reflected radiation.
- $X$ = Horizontal component of solar energy in the vertical plane normal to the inclined surface.
- $Y$ = Vertical component of solar energy.
- $\beta$ = The angle of inclination of the surface to the horizontal.
- $\rho$ = Albedo of the surface reflecting onto an inclined surface.

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hours as measured at many places by a Campbell Stokes sunshine recorder. The formula relating solar energy to sunshine hours is due to Angstrom[1] and is given in the form:

$$\frac{G_0}{G} = a + b\frac{n}{N} \qquad (1)$$

Several authors have measured both solar radiation and sunshine hours to determine $a$ and $b$. Page[2] gives a summary of values shown in Table 2 of his paper. It is shown that $a$ varies from 0.10 to 0.33 and $b$ varies from 0.35 to 0.70. Claimed regression coefficients for these correlations vary from 0.45 to 0.99.

These results would appear to cast considerable doubt on the validity of this equation.

Another climatic measurement proposed for calculating solar radiation is cloud cover as estimated synoptically at weather stations[3]. Formulas based on this have not received much recognition due to the way in which cloud cover is usually reported. No reference is made to the location of cloud bodies in the sky for partly overcast skies. Where cloud cover is recorded photographically, as in a few places, some assessment of solar radiation may be possible.

To obviate the necessity for relying on other climatic data the World Meteorological Office has proposed publishing world maps of insolation with contours of equal radiation based on monthly means of solar radiation measured by the various networks. As the number of networks of measuring stations increases the value of these maps for interpolating to regions where no measurements are made will increase. Even at present the interpolations may be made with nearly the same accuracy as is probable from using correlations with other climatic data.

These interpolations and calculations from climatic data with their inherent errors are unsound bases on which to commence the calculation of insolation on surfaces equatorially inclined.

Proposals have been made of methods for calculating, from published or measured values of solar radiation on horizontal surfaces, the value to be expected on surfaces equatorially inclined to the horizontal[4, 5, 6, 7, 8, 9]. Before proceeding to a detailed discussion of these methods, the assumptions used need to be mentioned.

The total solar energy reaching the earth's surface consists of a direct beam and scattered or diffuse sky radiation. As the solar radiation reaches the top of the earth's atmosphere a part of it is scattered by the molecules of the atmosphere, part is absorbed or scattered by dust particles, ice particles or water droplets, a part is absorbed by water vapor and in the ozonosphere, and a part transmitted. The scattered solar radiation arriving at the earth's surface is usually referred to as "diffuse" radiation. One assumption that is frequently used is that this diffuse radiation largely emanates from the area of the sky close to the sun's position and that this circumsolar portion can therefore be treated as a direct beam. Another opposing assumption is that the diffuse radiation is isotropically distributed[5]. This latter assumption is used when measuring the diffuse or sky radiation. When this is done by means of shading the measuring device by an equatorially mounted ring, a correction must be applied for that part of the sky occluded by the ring. Two formulas are in use due to Blackwell[10] and Drummond[11] and both use the latter assumption that the sky radiation is isotropic. Drummond, however, regards the computation of this correction from astronomical considerations only as the starting point. He has compared, on a very extensive basis, such theoretically derived shadow-band corrections with corresponding values established experimentally (for real non-isotropic conditions, and has advocated this procedure generally.[12]

A search of the literature for reported measurements of insolation on inclined surfaces reveals that in only a few places are measurements made on other than horizontal surfaces and then only on vertical surfaces facing various azimuthal directions. These measurements have been used mainly for assessing solar heating loads on buildings for air-conditioning calculations.

Since March 1964 a solarimeter has been mounted, at Highett, at an angle of 60 degrees to the horizontal facing north and recordings of hourly and daily integrated values of insolation obtained. This has permitted a check to be made of formulas based on either of the two assumptions discussed earlier.

The formula proposed by Morse and Czarnecki[6] uses the assumption that "the diffuse radiation is not uniformly distributed over the whole sky but is largely concentrated around the sun and may therefore be approximately treated as directional radiation. This is true both for clear and bright overcast sky. For dull overcast sky conditions the maximum intensity is at the zenith but the radiation is then very low."

The formula proposed is

$$E = X \sin\beta + Y \cos\beta \qquad (2)$$

The ratio of $X$ for north facing surface to $Y$, $X/Y$, is a function of solar altitude and the authors have given a series of curves for its easy determination.

This formula has been applied to measurements of total insolation on a horizontal surface to predict values on a surface inclined at 60 degrees to the horizontal facing north. The results obtained for monthly means of daily total insolation has been compared with measured values obtained month by month. These results are shown in Table 1. Errors up to 42 percent are found and the mean error is 22 percent.

When comparison is made on a daily basis, Table 2, individual errors up to 30 percent are found and a

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TABLE 2—COMPARISON OF DAILY TOTALS CALCULATED AND MEASURED OF RADIATION RECEIVED ON A SURFACE INCLINED 60° TO THE HORIZONTAL

| Day | Measurements | | | Calculated Values | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Horizontal, BTU/ft²/day | Diffuse Horizontal, BTU/ft²/day | Total Inclined 60°, BTU/ft²/day | Equation 2, BTU/ft²/day | Error Percent of Measured Value | Equation 3, BTU/ft²/day | Error, Percent of Measured Value | Equation 4, BTU/ft²/day | Error, Percent of Measured Value |
| 1 | 1313 | 725 | 1315 | 1395 | +6 | 1302 | −1 | 1268 | −4 |
| 2 | 909 | 604 | 992 | 1053 | +6 | 968 | −2 | 820 | −17 |
| 3 | 1040 | 759 | 880 | 1087 | +24 | 965 | +10 | 669 | −24 |
| 4 | 1602 | 820 | 1582 | 1661 | +5 | 1578 | 0 | 1470 | |
| 5 | 2057 | 476 | 2146 | 2115 | −2 | 2166 | +1 | 2060 | −4 |
| 6 | 904 | 730 | 824 | 1013 | +23 | 911 | +11 | 862 | +5 |
| 7 | 1352 | 775 | 1226 | 1367 | +12 | 1288 | +5 | 1258 | +3 |
| 8 | 1222 | 698 | 1179 | 1225 | +4 | 1159 | −2 | 1106 | −6 |
| 9 | 1335 | 796 | 1228 | 1327 | +8 | 1253 | +2 | 1214 | −1 |
| 10 | 1283 | 806 | 1185 | 1263 | +6 | 1189 | 0 | 1145 | −3 |
| 11 | 1855 | 732 | 1719 | 1811 | +5 | 1795 | +4 | 1737 | +1 |
| 12 | 922 | 870 | 687 | 892 | +30 | 792 | +15 | 613 | −6 |
| 13 | 1302 | 823 | 1090 | 1249 | +15 | 1190 | +10 | 1148 | +5 |
| 14 | 1512 | 920 | 1385 | 1437 | +4 | 1382 | 0 | 1283 | −7 |
| 15 | 2054 | 553 | 2007 | 1935 | −4 | 1970 | −2 | 1989 | −1 |
| 16 | 762 | 603 | 569 | 711 | +25 | 670 | +18 | 646 | +14 |
| 17 | 1832 | 911 | 1628 | 1694 | +4 | 1677 | +3 | 1552 | −5 |
| 18 | 1149 | 929 | 889 | 1052 | +18 | 1003 | +13 | 880 | −1 |
| 19 | 906 | 936 | 717 | 876 | +22 | 826 | +15 | 652 | −9 |
| 20 | 1798 | 912 | 1562 | 1615 | +3 | 1615 | +3 | 1519 | −3 |
| 21 | 783 | 696 | 574 | 697 | +21 | 673 | +17 | 598 | +4 |
| 22 | 564 | 550 | 393 | 497 | +26 | 481 | +22 | 411 | +5 |
| 23 | 2028 | 682 | 1789 | 1769 | −2 | 1815 | +1 | 1837 | +3 |
| 24 | 1805 | 980 | 1500 | 1558 | +4 | 1582 | +5 | 1468 | −2 |
| 25 | 1869 | 913 | 1514 | 1505 | +5 | 1635 | +8 | 1559 | +3 |
| 26 | 2140 | 743 | 1895 | 1811 | −4 | 1873 | −1 | 1837 | −3 |
| 27 | 2215 | 658 | 1741 | 1856 | +7 | 1930 | +11 | 1932 | +11 |
| 28 | 1656 | 1017 | 1416 | 1373 | −3 | 1420 | 0 | 1317 | −7 |
| 29 | 380 | 371 | 285 | 312 | +9 | 323 | +13 | 284 | 0 |
| 30 | 2286 | 656 | 2091 | 1855 | −11 | 1953 | −7 | 1946 | −7 |
| 31 | 2271 | 723 | 1871 | 1824 | −3 | 1917 | +2 | 1805 | +1 |

TABLE 1—COMPARISON OF MONTHLY MEANS OF CALCULATED AND MEASURED RADIATION RECEIVED ON A SURFACE INCLINED 60° TO THE HORIZONTAL

| Month | Measurements | | | Calculated Values | | | |
|---|---|---|---|---|---|---|---|
| | Total Horizontal, BTU/ft²/day | Diffuse Horizontal, BTU/ft²/day | Total Inclined 60°, BTU/ft²/day | Equation 2, BTU/ft²/day | Error, Percent of Measured Value | Equation 3, BTU/ft²/day | Error, Percent of Measured Value |
| Jan | 2123 | 816 | 1560 | 1337 | −14 | 1595 | +2 |
| Feb | 1932 | 720 | 1643 | 1535 | −7 | 1678 | +3 |
| Mar | 1506 | 571 | 1668 | 1651 | −1 | 1588 | −5 |
| Apr | 1100 | 527 | 1463 | 1618 | +13 | 1408 | −4 |
| May | 664 | 350 | 1038 | 1286 | +24 | 996 | −4 |
| Jun | 500 | 288 | 987 | 1343 | +36 | 1042 | +6 |
| Jul | 615 | 293 | 933 | 1310 | +41 | 1022 | 10 |
| Aug | 743 | 476 | 864 | 1254 | +42 | 898 | +2 |
| Sep | 1105 | [illegible]56 | 1178 | 1381 | +17 | 1209 | +3 |
| Oct | 1463 | 754 | 1286 | 1340 | +4 | 1282 | 0 |
| Nov | 1872 | 842 | 1440 | 1293 | −10 | 1628 | +13 |
| Dec | 1677 | 925 | 1268 | 880 | −31 | 14[illegible] | +11 |

mean error of 8 percent is indicated. The high errors occur on days of high cloud cover, which are not necessarily days of low total insolation.

Liu and Jordan[8] have adopted the second alternative assumption regarding diffuse radiation, that it is isotropic over the whole sky. They have proposed a more exact and more complex method of calculating insolation on inclined surfaces. They apply well-known astronomical formulas to determine the angle of incidence of the solar beam to the inclined surface and use this to integrate the direct insolation on an inclined surface at the top of the atmosphere between the hours of sunrise and sunset. An assumption is made that the ratio of direct radiation on an inclined surface to that on a horizontal surface is the same on the earth's surface as at the top of the atmosphere.

In treating the diffuse component they assume this to be isotropic as a fair approximation and propose that the ratio of that incident on inclined to that incident on horizontal surface is given by the expression

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$$R_d = \tfrac{1}{2}(1 + \cos\beta)$$

They also include a term $R_r$ to account for the diffuse component reflected from the surface beneath the inclined surface such that

$$R_r = \left(\frac{1 - \cos\beta}{2}\right)\rho$$

The complete formula then becomes

$$H_t = (H - D)R_D + DR_d + HR_r \qquad (3)$$

Using this formula and Liu and Jordan's method of calculating these ratios, measured values of total and diffuse radiation incident on a horizontal surface have been applied to predicting total radiation incident on a surface inclined at 60 degrees to the horizontal facing north. The values obtained have been compared with measured values on a monthly and daily basis and these are shown in Tables 1 and 2.

Good agreement is found of the calculations of monthly means with measured values except for two months when the cloud cover was unseasonably high. But when daily total values are compared, errors up to 22 percent are indicated. The higher errors are again found when the cloud cover is greatest. The mean error found for daily values in the month selected is 7 percent.

The tables show that for the formula based on the direct beam assumption the errors in monthly mean values are higher than those for daily values. A reasonable explanation of this feature is that when averaged over a month the distribution of sky radiation is isotropic. This is borne out by the low errors for monthly values calculated by the formula based on the isotropic assumption. The errors for daily values are comparable for both formulas and their magnitudes for days of part cloud cover indicates that both assumptions are incorrect and that probably the sky radiation comes predominantly from some sector of sky not adjacent to the sun's position. Even on days of high cloud cover, for example the 22nd and 29th October, both assumptions give high errors. There are, however, few days when either assumption appears to be valid.

To arrive at a more exact formula for calculating the diffuse component incident on an inclined surface it would be necessary to study the anisotropy of the sky radiation. As this would involve considerable instrumentation it is unlikely that widespread studies will ever be made. Because it is far easier to measure the insolation at any desired inclination and location, the development of a method of calculation including a more exact treatment of diffuse radiation appears undesirable.

Measurements have been made at Highett of total and diffuse radiation on a horizontal surface and on a surface inclined at 60 degrees to the horizontal. Correlations have been sought and these, for total radiation, are shown in Fig. 1 for twelve months from March 1964 to February 1965. These are mostly as expected, showing a fairly uniform variation with solar declination. During October 1964 when diffuse radiation was measured on a 60-degree surface a correlation between horizontal total and inclined diffuse radiations was obtained when each was expressed as a ratio to the maximum incident radiation on a horizontal surface taken from the tables of Spencer[18]. The relationship found is

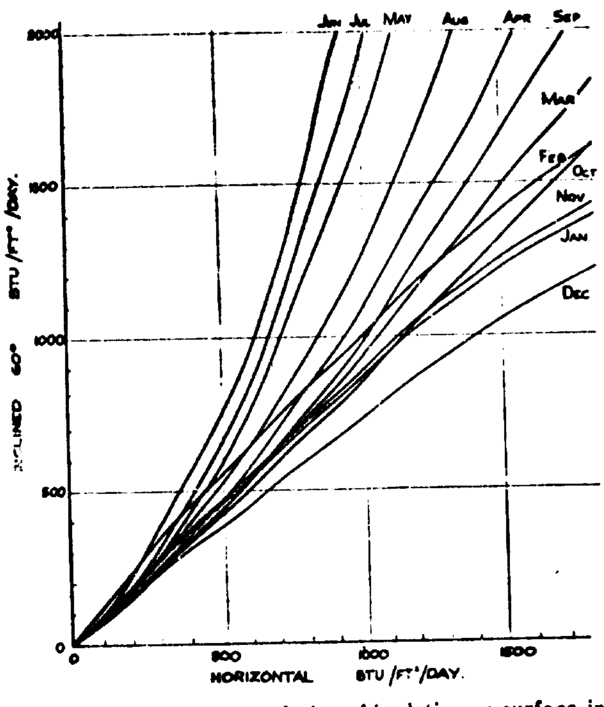


Fig. 1—Least squares correlation of insolation on surface inclined 60 degrees with insolation on horizontal surface.

$$\frac{D_{60}}{G_0} = 0.203 + 0.555 \cdot \left[1 - 0.225\frac{G_0}{G_m} - 0.641\left(\frac{G_0^2}{G_m^2}\right)\right] \qquad (4)$$

When this empirical formula is applied to measured values of $G_0$ and Liu and Jordan's method of calculation of $R_D$ is used, a prediction of the total radiation on an inclined surface can be made. The results of such a calculation are shown in Table 2. A considerably higher mean accuracy is shown, equal to 2 percent. So that such an empirical formula can be established for more general application it would be necessary to measure both total and diffuse radiation on inclined surfaces at a variety of latitudes. Again this would appear to be more costly and more painstaking than the measurement of the total radiation incident on a surface of any desired orientation and location.

The foregoing discussion has placed much emphasis on diffuse or sky radiation, as argued first by Drummond.[14] Since this component may be up to 100 percent of the total radiation received on any day its importance in the design of solar-energy absorbers and storages is more than has sometimes been assumed. The most important regions of Australia for the application of some solar energy devices are those subject to either or both north-west and south-east monsoons. They therefore experience considerable cloud cover for parts of each year. It has been noticed at latitude 28 degrees south on the east coast of Australia that maximum total radiation tends to occur on days when partial cloud cover adds to the total rather than subtracts (Figs. 2 and 3).

This increase in insolation with partial cloud cover is probably attributable to reflections from the sides of thunder clouds that are prevalent during the monsoon season. A similar effect has been noted in inland semi-arid areas of Australia[14]. Funk[15] has suggested that by this reflection the total radiation received at the earth's surface may exceed the solar constant.

This phenomenon throws considerable doubt on both hypotheses regarding the distribution of diffuse sky radiation. The manner in which this is distributed appears to be determined by the microclimate of the region in which measurements are made.

It is suggested that until such time as far more detailed examination of climatic data has been made the prediction of solar radiation from climatic data is prone to lead to gross errors. Also that the calculation of radiation incident on non-horizontal surfaces is similarly restricted.

Therefore in regions where solar devices are being used or are proposed to be used there is a need to study experimentally the radiation incident on the absorbers. This it is felt would be far more economic than estimating the energy available from available meteorological data or from using simplifying assumptions.


FIG. 2—Record of insolation on day of broken cloud superimposed on record for clear day at Gladstone, Queensland, latitude 28° S.

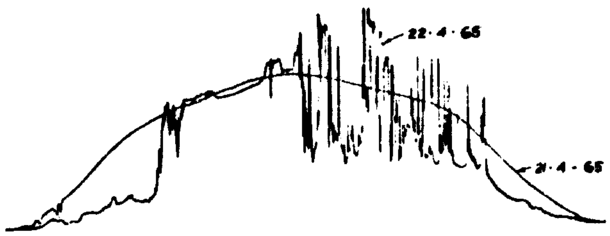


FIG. 3—Record of insolation on day of broken cloud superimposed on record for clear day at Gladstone, Queensland, latitude 28° S.

## ACKNOWLEDGMENT

The author wishes to thank Mr. R. V. Dunkle for his encouragement and assistance with some of the correlation formulas and Mr. J. Bannister for the recording and compilation of the measurements used in this analysis.

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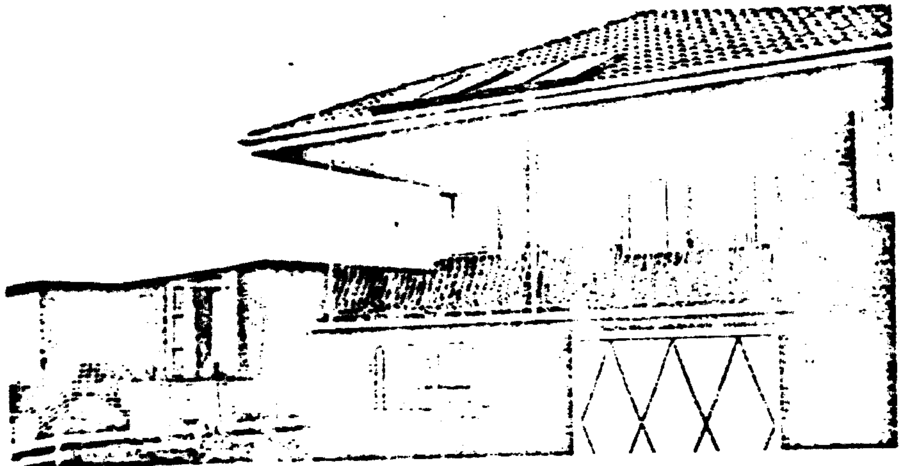

Fig. 2 - Domestic solar water heater installation - Sydney.

Fig. 3 - Absorbers roof mounted - forced circulation system - New Guinea.

# INTERNATIONAL SOLAR ENERGY SOCIETY CONFERENCE 1970

Paper No. 4/71

## SOLAR WATER HEATING IN AUSTRALIA

by

E.T. DAVEY

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# SOLAR WATER HEATING IN AUSTRALIA

by

E. T. DAVEY*

## SUMMARY

**Some twenty years ago solar water heating was developed in Australia and there are now many thousands of installations giving satisfactory service both in this country and in the islands in the South Pacific area. Because of the number of systems installed it is inevitable that there have been several which are unsatisfactory from a number of points of view. The paper outlines some of the faults experienced and gives some design and installation details.**

## 1. INTRODUCTION

Australia lies broadly in the region latitude 10°S to 40°S and ...eriences a wide variation of climatic conditions, including humid ...pics, arid tropics and temperate zones. Over the continent solar ...iation varies from an average of 1,650 Btu/ft$^2$/day in the humid ...ics to 1,800 in the arid tropics and some 1,200 in the southern ...erate regions. It is not surprising, therefore, that solar energy ...lization has become widely accepted in many areas.

There are at present 15-20 solar heater manufacturers in the country ... whilst in most cases the manufacture of solar absorbers is not a ...or part of their activities, it is nevertheless an industry in total ...th approximately $1 million a year. Australian firms have been ...erately successful in their attempts to export units to less developed ...as. It would appear, however, that freight charges, particularly on ...rage tanks, and high import duties make the economics marginal. ...angements have been made in some cases to export the tanks in knocked-...n form, completely pre-worked, thereby reducing the freight and import ...rges and increasing the local labour content, and this is considered ...e a sound approach.

## 2. ECONOMICS

One of the major factors to be considered when deciding on a solar ...er heating system, is that of economics. The biggest obstacle in ...s regard is the higher capital cost of the solar installation. ...tralian-manufactured absorber plates and storage tanks are all-copper ...ch, whilst expensive, has excellent heat transfer properties and long ...e expectancy. As yet no cheaper substitute to copper has been found, ...hough the developments in the plastics field are such that this may ... be far off.

The cost of water heated by a solar system is essentially a function ...capital cost, interest on capital and depreciation over the expected ...e of the components. Maintenance is low and in most cases can be ...lected. It is extremely difficult to generalize on the economics as ...re are a number of factors to be considered. These include the availability and price of alternative fuels, cold water temperatures, space and weight limitations in the location of the tank, siting and mounting of absorbers and the actual acceptable usable hot water temperature.

It is accepted that water at 135°F is satisfactory in the temperate zones. However, in the higher temperature regions water at 120-125°F is equally acceptable, hence a smaller absorber area or larger storage can be used. As the installed cost of a hot water cylinder is not proportional to its capacity, it is often more economic to oversize the cylinder. Additional absorber area can be added with little inconvenience if the demand increases.

Actual operating costs are given (1)* for Darwin, Alice Springs and Port Moresby and these show the advantages of the solar system in these locations. More substantial savings can be effected if the capital cost is minimized, and this is so in the case of a large number of installations where people construct and install their own absorber panels.

## 3. AESTHETICS

It was at one time considered that the angle of inclination of the absorbers should be latitude + 5°. For Melbourne (lat. 38°S) this meant 43° from the horizontal. However, with improved techniques in solar radiation measurement it has been determined (2) that absorbers placed at the angle of the normal roof (Melbourne 27°) lose very little in collection efficiency. Fig. 2 shows absorbers mounted on a normal-pitch tiled roof with the storage tank mounted in the attic space.

For areas further north, particularly where the sun moves both north and south of the location, the units should be almost flat with a minor slope to assist thermosyphon action. There would appear to be some advantage with low pitched roofs at latitude 10°S and less to place the absorbers on both sides of the ridge facing north and south. This procedure has been adopted successfully in Darwin and New Guinea, and Fig. 3 shows the absorbers of a forced circulation system mounted in this manner in New Guinea. Because of these factors solar absorbers can be integrated into the structure as roof- or awning-mounted units, and provided the economics are favourable, there should be little resistance to their more general use.

## 4. THERMOSYPHON CIRCULATION SYSTEMS

In Australia the great majority of systems installed operate on the natural circulation or thermosyphon principle, and these, in the main, give long and trouble-free service. There are, however, some basic points which should be observed at the time of installation. These fall broadly into the following categories :-

(a) Reverse flow    It has been found that reverse flow will not be of any significance provided the lower connection to the storage tank is at least 6" above the top header of the absorbers, and both the flow and return lines are adequately insulated and weatherproofed where external.

(b) Insulation    Troubles which have arisen from reverse flow have more often than not been due to poor insulation of the flow line or upper connection of the absorber. There appears to be a misunderstanding on the use of insulation and people invariably wrap it tight, thereby destroying its cellular properties and nullifying its effect. There should be at least 1" of lightly-placed insulation on both the flow and return lines to the absorbers.

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*Numbers in brackets refer to references listed at the end of the paper.

(c) Air locks  As water is heated in the absorbers air comes out of ution and will, in a properly installed system, be exhausted through system vent. All too often it has been witnessed that the top header the absorbers is installed with a slope down towards the upper connecn to the tank. This allows air to be collected in the top header, , if the reverse grade is severe enough, flow through several of the ers in the absorber will cease.

## 5. FORCED CIRCULATION SYSTEMS

In recent years there has been a noticeable increase in the number large commercial and institutional installations. This is due, in the e of institutional systems, to the fact that the higher capital expenure can usually be financed at the building stage, but very frequently ficulty is experienced in providing operating funds. For commercial the substantial benefit from depreciation of plant for taxation pures, together with the much lower operating costs, make the solar tem attractive.

The large storage capacities required make it impractical to mount tanks above the absorbers and so a forced circulation system is used. re are a number of such installations operating satisfactorily through- Australia and the nearby islands, and some of these are listed in le 1. Whilst the basic circuit is substantially the same in each case, economic considerations at the design stage often cause some minor iations. For instance, space limitations in plant rooms and manufac- e and transport costs usually determine the number and size of storage inders to be used.

TABLE 1

| | $ft^2$ | gal |
|---|---|---|
| Plant Research building - Canberra | 336 | 400 |
| Church hostel - Alice Springs | 280 | 500 |
| Church hostel - Alice Springs | 200 | 350 |
| School - Mt. Isa | 160 | 200 |
| Hotel - Fiji | 450 | 970 |
| Caravan Park - Exmouth Gulf 2 installations, each | 362 | 750 |
| Caravan Park - Broken Hill | 127 | 240 |
| Airline Staff Quarters - Darwin 9 installations, each | 256 | 400 |
| Welfare hostel - Darwin | 190 | 300 |
| Youth hostel - Darwin | 384 | 400 |
| Hotel - New Guinea | 160 | 300 |
| Hotel - New Guinea | 450 | 900 |
| School - Adelaide | 640 | 900 |
| Laboratory - Melbourne | 192 | 250 |

Figure 1 is a line diagram of a typical system, consisting of a 900 tank and 450 $ft^2$ of absorber surface, operating successfully in New ea. This system was designed in conjunction with the hot water cirtion system throughout the building and it was installed during the lding stage. This is most desirable; however, if it is not practic- e, provision should be made for the later addition of the solar plant such a way that a minimum of inconvenience and expense is involved.

t loss  It is of primary concern in any installation to keep the losses to a minimum. This is particularly so on a larger installa- where, because of the need to have hot water at the outlets within a sonable time, a building hot water circulation system is employed. ily this operates on a 24-hour basis and all too often the piping is ized, thereby imposing an additional load on the source of supply. tallation shown in Fig. 1 the building circulation ring main was sized 1½" from the tanks, stepping down in stages to a return of ¾" to the suction side of the pump. The main was vented at its highest point by means of an automatic air eliminator. A ring main so installed has a twofold advantage in that the actual material, pipe fittings, insulation and labour costs are kept to a minimum at the time of installation, and also for all time the heat loss is within reasonable limits.

Storage cylinders  Due to space allocation in the building and also because of lower costs four 225 gal insulated tanks were used, connected in a series-parallel arrangement. The tanks were sized to provide approximately two days' supply and sufficient absorbers were installed to meet the hot water requirements, plus provision for the system heat loss.

Control  The most common control used on systems of this nature is an immersion thermostat, the bulb of which is located in the top header of the absorbers at the outlet end of the bank; the thermostat is usually set to energize the solar pump at 130°F and de-energize it at 125°F. Justification can often be found for lower settings, particularly, as mentioned previously, in areas of high ambient temperatures.

Pumps  All pumps handling hot water should preferably be of all-bronze construction. The solar pump is sized nominally to give a temperature rise through the absorber bank of 15°-20°F at noon under cloudless conditions, and under these circumstances the pump delivers some 0.75 to 1 $gal/ft^2/hour$. It has been shown (3) that, in a forced circulation system with large banks of absorbers at low angles of inclination, the buoyancy effects are reduced, hence a substantial part of the absorber area is ineffective. In order to obtain peak collection efficiency from the absorber bank a series-parallel flow arrangement should be used, and this gives near-uniform flow through all risers.

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Reverse flow  A valve must be placed in the return line from the absorbers to prevent reverse circulation when the pump is de-energized. In most cases a check or non-return valve is used. An electrically-operated solenoid valve can be used to operate in conjunction with the pump switching; however, these are likely to develop faults and the more simple valve can be relied upon to give less trouble in service.

Venting  On a large installation it is as well to exhaust the air coming out of solution from the absorbers rather than let it enter the reticulation, where in all probability it would cause trouble. This is usually done by means of a vent or an automatic air-eliminator. If a vent is used its height above the absorbers must be some two feet more than the pressure drop in the flow line returning to the tank. As air eliminators have proved to be quite satisfactory in service they are recommended from the appearance point of view.

## 6. GENERAL

(a) Shading  Care should be taken to install absorbers in areas that are unshaded for an appreciable part of the day. Whilst this would appear elementary, several systems reported as being low in output have been found to have had this cause as the reason for the malfunction. In some instances in the low-latitude regions, if both tank and absorbers are roof mounted, shading can occur from the tank and this should be minimized with due consideration given to loss of efficiency if flow and return lines are excessively long.

(b) Absorber mountings  In all cases the absorber mountings should be as inexpensive as possible consistent with strength and appearance. The mounting shown in Fig. 3 is an ideal example of simplicity and is in direct contrast with that in Fig. 4, the construction of which

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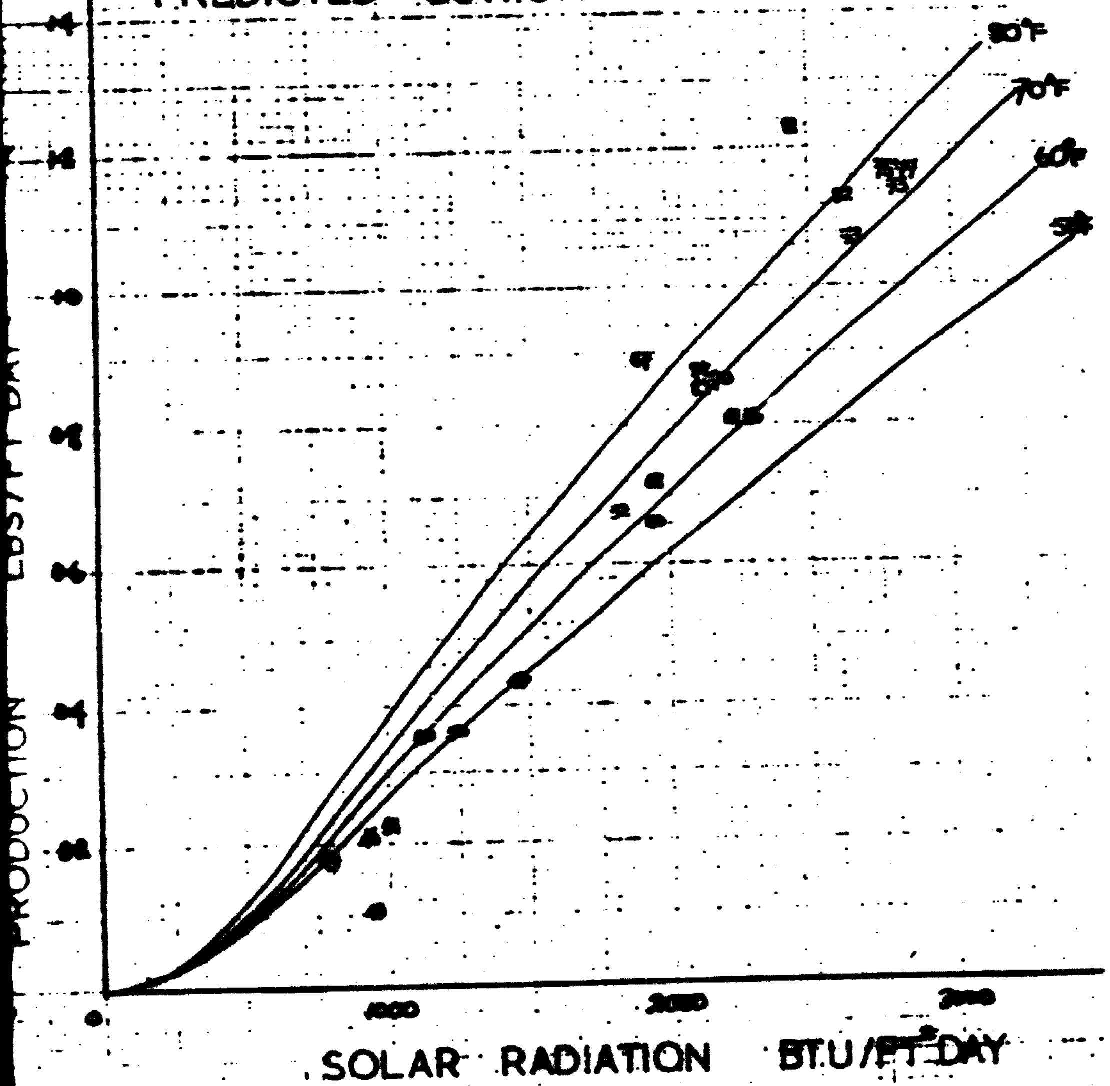
FIG. 2

PREDICTED OUTPUTS FOR MK.VI STILL




INTERNATIONAL SOLAR ENERGY SOCIETY

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1970

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Paper No. 5/55

**EFFECT OF ADDING WASTE HEAT TO A SOLAR STILL**

by

D. PROCTOR

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At the outlet end of the still the distillate from the meter box was fed into the outlet pipe seal sump. Make up sea water to the still was fed in at the outlet pipe seal sump and its flow rate controlled by means of a float valve working on the saline water level in the sump. See also flow diagram in figure 1.

Instrumentation consisted of thermostatic control on the saline feed water to the still, an hours-run meter for the heaters, thermocouples along the length of the still recording water and vapour temperatures and a distillate meter to record output. The flow was measured by means of a variable area flow meter.

## 3. RESULTS OBTAINED FROM STILL

Three daily sets of results have been chosen to give an idea of how the still performs under three different types of days. The data is listed in Table 1.

## DISCUSSION AND CONCLUSIONS

Although the solar still at Highett has been fed with waste heat from a constant heat source i.e., immersion heaters, it is more likely that the source of waste heat will be supplied at a "constant temperature" of say 180°F. In this case when the solar radiation and temperature are high either the saline water temperature will not be so high as in the immersion heater case 3 in Table 1 or because of the high ambient temperature the unit producing the waste heat will run hotter and so provide more waste heat to the still, e.g., for a unit whose cooling water circulation rate is 13.85 g.p.m. a 1°F rise in the cooling water temperature will produce an extra 2.46 kW. Hence waste heat supply sources are more likely to be variable heat supply sources.

The results obtained so far suggest that for 5.5°F temperature drop along the solar still and a saline flow of 8 g.p.m. a waste heat source at 180°F supplying heat at 166 Btu/hr ft$^2$ can be used in a 159ft$^2$ solar still. Since the normal solar still is 500ft$^2$ it would be reasonable to operate it with an 11°F temperature drop and 57% increase in the flow. On scale up balance has to be struck between increasing the temperature drop along the still which will lower the production of distillate due to lower operating temperatures, and increasing the flow which will raise production.

Figure 2 is a graph of the predicted output from a Mark VI solar still for a given solar radiation and ambient temperature and was obtained via a C.D.C. 3200 computer program. The figures superimposed on figure 2 are ambient temperatures, the centres of which mark the actual outputs obtained from a Mark VI still at the stated solar radiations. From figure 2 it is possible to compute what the output would be from a conventional solar still on days of similar solar radiation and ambient temperature for the outputs from the waste-heat still. These outputs are listed in Table 2 along with the outputs from the waste heat still.

If the outputs from the conventional solar still are taken away from the total productions of the waste heat still (assuming that the process of solar distillation and waste heat distillation are additive) then the output produced by the addition of waste heat alone to the solar still is, within the limits of experimental accuracy, independent of solar radiation and ambient temperature and is 2.66± 7% lbs/ft$^2$ day. This represents a thermal efficiency of 68% (based on a saline water temperature of 140°F). Clearly there is room for further improvement in the utilisation of waste heat.

TABLE 1

| | Time Hours. | Solar Radiation Btu/ft$^2$ | Ambient Temperature °F | Saline Inlet Temperature °F | Saline Outlet Temperature °F | Saline Water Flow G.P.M. | Waste Heat Input Btu/hr ft$^2$ | Output lbs/ft$^2$ day |
|---|---|---|---|---|---|---|---|---|
| 1) | 0 | 0 | 62.5 | 148.0 | 142.5 | 8 | 166 | 3.67 |
| | 1 | 0 | 62.0 | 148.0 | 142.5 | | | |
| | 2 | 0 | 61.7 | 147.5 | 142.0 | | | |
| | 3 | 0 | 61.0 | 146.0 | 140.5 | | | |
| | 4 | 0 | 60.5 | 145.0 | 139.5 | | | |
| | 5 | 0 | 60.5 | 144.0 | 138.5 | | | |
| | 6 | 3 | 60.5 | 144.0 | 138.5 | | | |
| | 7 | 16 | 61.0 | 145.0 | 139.5 | | | |
| | 8 | 34 | 61.5 | 145.5 | 141.0 | | | |
| | 9 | 115 | 64.0 | 149.0 | 143.5 | | | |
| | 10 | 136 | 64.5 | 152.5 | 147.0 | | | |
| | 11 | 267 | 67.0 | 159.0 | 153.5 | | | |
| | 12 | 324 | 67.5 | 170.5 | 165.0 | | | |
| | 13 | 338 | 67.5 | 180.5 | 175.0 | | | |
| | 14 | 319 | 68.5 | 184.5 | 179.0 | | | |
| | 15 | 299 | 68.5 | 185.5 | 180.0 | | | |
| | 16 | 225 | 68.0 | 184.5 | 179.0 | | | |
| | 17 | 159 | 66.5 | 178.0 | 172.5 | | | |
| | 18 | 62 | 64.0 | 170.5 | 165.0 | | | |
| | 19 | 9 | 63.0 | 163.0 | 157.5 | | | |
| | 20 | 0 | 62.0 | 156.0 | 150.5 | | | |
| | 21 | 0 | 61.0 | 149.0 | 143.5 | | | |
| | 22 | 0 | 60.5 | 144.0 | 138.5 | | | |
| | 23 | 0 | 60.5 | 141.0 | 135.5 | | | |
| | 24 | 0 | 60.5 | 140.0 | 134.5 | | | |
| 2) | 0 | 0 | 60.5 | 140.0 | 134.5 | 8 | 166 | 3.48 |
| | 1 | 0 | 60.5 | 140.0 | 134.5 | | | |
| | 2 | 0 | 60.5 | 140.0 | 134.5 | | | |
| | 3 | 0 | 60.0 | 139.5 | 134.0 | | | |
| | 4 | 0 | 60.0 | 139.5 | 134.0 | | | |
| | 5 | 0 | 60.0 | 139.0 | 133.5 | | | |
| | 6 | 3 | 60.0 | 137.5 | 132.0 | | | |
| | 7 | 22 | 61.0 | 140.5 | 135.0 | | | |
| | 8 | 63 | 61.5 | 146.0 | 140.5 | | | |
| | 9 | 81 | 62.0 | 150.5 | 145.0 | | | |
| | 10 | 161 | 64.5 | 155.0 | 149.5 | | | |
| | 11 | 190 | 64.5 | 160.5 | 155.0 | | | |
| | 12 | 198 | 65.0 | 167.0 | 161.5 | | | |
| | 13 | 256 | 66.0 | 168.0 | 162.5 | | | |
| | 14 | 241 | 66.5 | 168.0 | 162.5 | | | |
| | 15 | 221 | 67.0 | 168.0 | 162.5 | | | |
| | 16 | 188 | 65.5 | 166.0 | 160.5 | | | |
| | 17 | 152 | 63.5 | 162.0 | 156.5 | | | |
| | 18 | 91 | 62.5 | 156.0 | 150.5 | | | |
| | 19 | 21 | 62.0 | 151.0 | 145.5 | | | |
| | 20 | 6 | 61.0 | 146.0 | 140.5 | | | |
| | 21 | 0 | 61.0 | 144.0 | 138.5 | | | |
| | 22 | 0 | 61.0 | 141.0 | 135.5 | | | |
| | 23 | 0 | 61.0 | 140.0 | 134.5 | | | |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | |

Contd.

TABLE 1

| Time Hours. | Solar Radiation Btu/ft² | Ambient Temperature °F | Saline Inlet Temperature °F | Saline Outlet Temperature °F | Saline Water Flow G.P.M. | Waste Heat Input Btu/hr ft² | Output lbs/ft² day |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 60.5 | 140.0 | 134.5 | 8 | 166 | 3.70 |
| 1 | 0 | 59.0 | 140.0 | 134.5 | | | |
| 2 | 0 | 56.5 | 139.0 | 133.5 | | | |
| 3 | 0 | 55.0 | 138.0 | 132.5 | | | |
| 4 | 0 | 54.0 | 138.0 | 132.5 | | | |
| 5 | 0 | 55.5 | 137.5 | 132.0 | | | |
| 6 | 0 | 55.0 | 140.0 | 134.5 | | | |
| 7 | 12 | 58.0 | 143.0 | 137.5 | | | |
| 8 | [illegible] | 62.5 | 147.5 | 142.0 | | | |
| 9 | [illegible] | 67.5 | 153.0 | 147.5 | | | |
| 10 | [illegible] | 71.0 | 162.0 | 156.5 | | | |
| 11 | [illegible] | 75.0 | 175.0 | 169.5 | | | |
| 12 | [illegible] | 80.0 | 185.0 | 178.5 | | | |
| 13 | [illegible] | 83.5 | 192.0 | 186.5 | | | |
| 14 | [illegible] | 84.5 | 196.0 | 190.5 | | | |
| 15 | [illegible] | 85.0 | 197.0 | 191.5 | | | |
| 16 | [illegible] | 84.5 | 195.0 | 189.5 | | | |
| 17 | [illegible] | 84.0 | 186.5 | 181.0 | | | |
| 18 | [illegible] | 82.5 | 178.5 | 173.0 | | | |
| 19 | [illegible] | 78.0 | 168.0 | 162.5 | | | |
| 20 | 1 | 74.5 | 161.0 | 155.5 | | | |
| 21 | 0 | 72.0 | 155.5 | 150.0 | | | |
| 22 | 0 | 70.0 | 151.5 | 146.0 | | | |
| 23 | 0 | 68.0 | 147.5 | 142.0 | | | |
| 24 | 0 | 66.0 | 145.5 | 140.0 | | | |

TABLE 2

| Solar Radiation Btu/ft² day | Ambient Temperature °F | Output from waste heat still lbs/ft² day | Output from Solar still lbs/ft² day | Diff. in outputs lbs/ft² day |
|---|---|---|---|---|
| 1739 | [illegible] | 3.22 | 0.63 | 2.59 |
| 2365 | [illegible] | 3.70 | 1.10 | 2.60 |
| 1727 | [illegible] | 3.04 | 0.67 | 2.37 |
| 2431 | [illegible] | 3.70 | 0.95 | 2.75 |
| [illegible] | [illegible] | 3.67 | 0.83 | 2.84 |
| [illegible] | [illegible] | 3.48 | 0.69 | 2.79 |
| [illegible] | [illegible] | 3.70 | 1.05 | 2.65 |

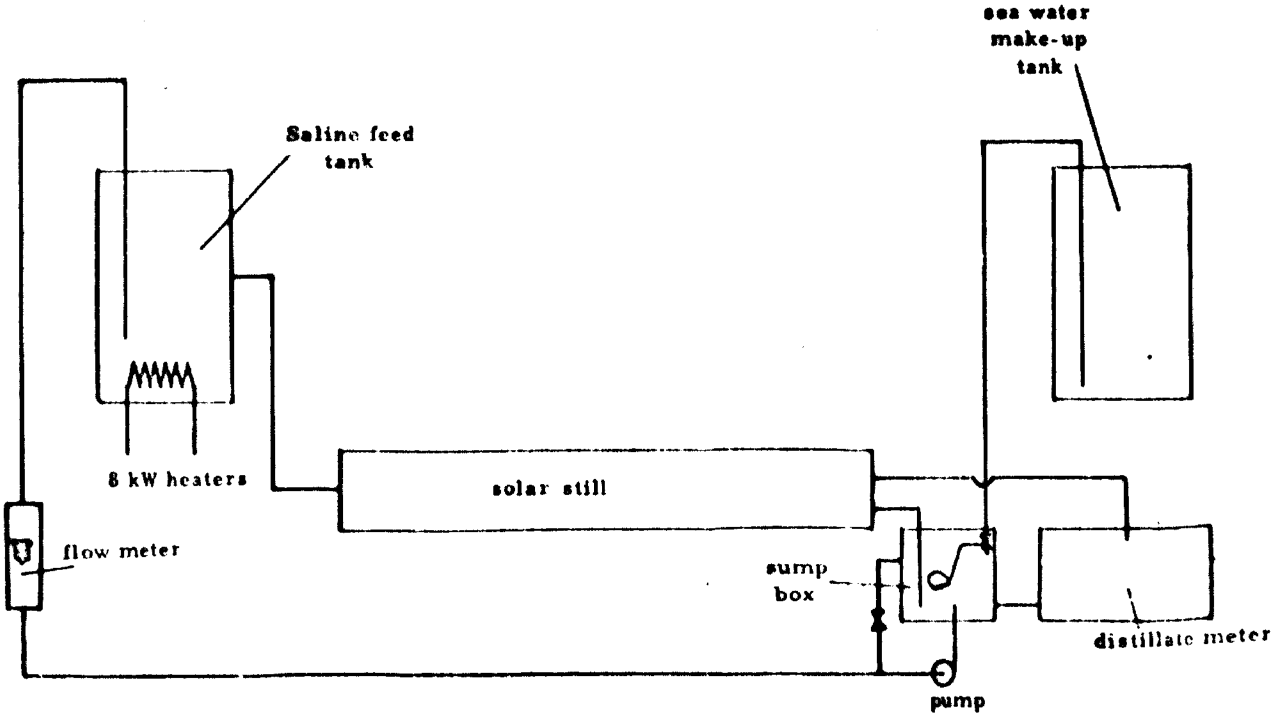


FIG. 1 FLOW DIAGRAM

(c) Freezing of absorbers. In some areas problems due to freezing absorbers at night time have arisen. For most of these locations ble glazing of the absorbers has been sufficient to prevent the urrence. However, in the more severe situations, where prolonged ls of sub-zero temperatures are experienced, the solution appears to he use of flexible butyl rubber headers which provide for the expan- and contraction due to ice formation.

## 7. CONCLUSION

In conclusion it is as well to mention that among the general public e appears to be a failure to realize that solar water heaters do, in , operate under conditions of other than clear blue skies. With her promotion on the part of manufacturers this is being dispelled, it is expected that the sales of solar water heaters will steadily ease.

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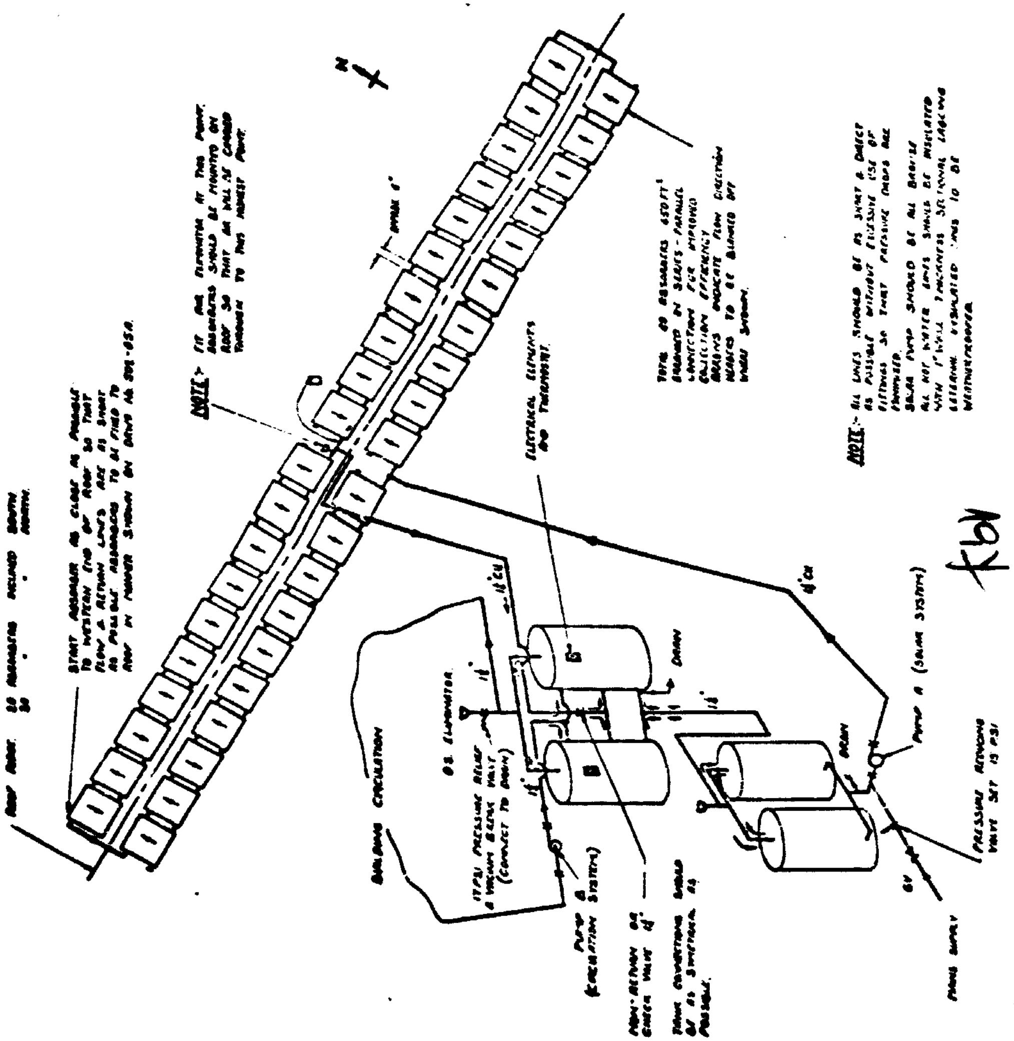

Fig. 1 - Line diagram of forced circulation solar hot water system - New Guinea.

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# EFFECT OF ADDING WASTE HEAT TO A SOLAR STILL

by

D. PROCTOR*

SUMMARY

At some of the solar still sites in Australia there is an adequate supply of useful heat which is at present being rejected to the atmosphere. It would, therefore, seem fortuitous to utilize this waste heat to improve the performance of solar stills.

Outputs from the Highett experimental waste heat still shows that adding waste heat to a solar still is a feasible proposition.

## 1. INTRODUCTION

There are several advantages to be gained from adding waste heat to a solar still viz:

(a) a reduction in the size of the solar still to produce a given output

(b) a reduction in the storage capacity required to tide the still user over the winter months

(c) less still area to maintain, and

(d) a possible improvement in the performance of the unit from which the waste heat is being abstracted.

Problems arise as to what is the best way to add the waste heat to the solar still. Either the heat is added as uniformally as practicable along the length of the still, or all at once to the inlet feed water. In the experimental system at Highett the latter system was employed because of the simple way in which the Mark VI still could be used without modifying the basic design. (The only modification was to lower the outlet pipe).

## 2. EXPERIMENTAL STILL USED

The still used was 48 ft long with an area of 159 $ft^2$. The waste heat was supplied to the feed sea water in an insulated 50 gallon tank, in the form of 8 kW immersion heaters. These heaters supplied heat at a rate of 166 Btu/hr $ft^2$ to the still (after heat losses from the tank and supply line had been accounted for). A recycle loop, 1½" diameter flexible polythene tube, was used to supply the necessary amount of saline water to remove the heat from the feed tank, the return line being underneath the still and hence insulated. The flow in the recycle line was 8 g.p.m.

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# INTERNATIONAL SOLAR ENERGY SOCIETY

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## SOLAR ENERGY RESEARCH AND DEVELOPMENT AND INDUSTRIAL APPLICATIONS IN AUSTRALIA

by

R.N. MORSE

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# SOLAR ENERGY RESEARCH AND DEVELOPMENT AND INDUSTRIAL APPLICATIONS IN AUSTRALIA

by

R. N. MORSE*

## SUMMARY

Since 1955 there has been a significant increase in research and development in Australia related to the utilisation of solar energy. A solar water heating industry has been established and solar stills are supplying water continuously for human consumption in several different areas. In addition to a considerable amount of work in CSIRO and the Universities directly related to solar energy utilisation, there is a great deal more being undertaken in the related fields of meteorology and photobiology. A bibliography is included.

## 1. INTRODUCTION

There is now an established solar water heating industry in Australia, and research and development at a number of different centres is focusing attention on the value of solar energy as a power source. In this survey the emphasis will be on industrial and domestic applications and the research which has led to these developments, although it is recognised that agriculture, forestry and salt production could be considered the most important industries dependent on solar radiation.

During the last 15 years research programmes which are concerned with solar energy measurement and/or utilization have expanded considerably, and work is now being carried out in the following centres :-

CSIRO -
Division of Mechanical Engineering, Melbourne, Griffith and Townsville
" " Building Research, Melbourne
" " Meteorological Physics, Melbourne
" " Chemical Engineering, Melbourne
" " Irrigation Research, Griffith

Universities -
Uni. of New South Wales, Depts. of Mechanical Engineering and Physics, Broken Hill College
" Queensland, Depts. of Mechanical Engineering and Architecture
" " Western Australia, Dept. of Mechanical Engineering
" " Adelaide, Dept. of Architecture
" " Sydney, Dept. of Architectural Science
Monash University, Dept. of Mechanical Engineering.

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The Australian and New Zealand Section of the Society has helped to provide a channel of communication between research workers and the industry by holding regular meetings and also by means of its publications. In 1962 it started a News Sheet for this purpose, and in 1964 this was renamed "Solar Energy Progress in Australia and New Zealand" which is produced annually.

## 2. CURRENT RESEARCH AND DEVELOPMENT

### WATER HEATING

The most widespread industrial and domestic use of solar energy is for the heating of water. Research and development at the CSIRO Division of Mechanical Engineering led to the commercial production by a number of manufacturers of flat plate solar absorbers and insulated storage tanks suitable to supply the water requirements of a typical household. Absorbers vary in size from 0.6–1.6 sq m, and storage tanks are available over a wide range of sizes, with or without electric boosting. A common size for a domestic installation is 3 sq m of absorber, with a 300 l. storage tank, and electric booster thermostatically controlled, producing [illegible] l. of hot water per day.

Selective surfaces are widely used in commercial absorbers and are produced by a simple chemical dip process on the bright copper sheet from which the absorber plate is constructed. This is comparable in cost to black paint when produced on a large enough scale and the thermal performance is appreciably better.

Domestic installations employ thermosyphon but large installations, delivering some thousands of litres of hot water per day, use forced circulation with thermostatic control.

Although numerically the domestic installation which supplies a single household is the most common, there is an impressive number of large units having capacities up to 5.0 cu m per day. These are located in South Australia, Western Australia, Queensland, Northern Territory, New Guinea and Fiji. One Darwin group of staff flats and [illegible] has 9 solar water heaters with a combined output of [illegible] cu m per day.

Large installations use standard size absorber units connected in [illegible] to provide the required area, but the connections must be carefully designed to ensure the uniform flow distribution necessary for good thermal performance.

Solar water heaters are proving to be the most economical way of providing hot water in many parts of the Continent, particularly in the north, and it is Government policy to install solar water heaters on Government houses in the Northern Territory. A small but growing export industry is developing.

### HEATING OF SWIMMING POOLS

It has been demonstrated that the solar heating of swimming pools is practicable, and design information is now available to enable solar heaters to be designed for this purpose and their performance predicted. The high temperature type of absorber used for hot water services is not necessary but is nevertheless frequently used because of its ready availability from manufacturers.

### SOLAR STILLS

Australia is the driest of the earth's land masses, having over five million square kilometres of arid land. This arid zone, however, is important economically since its contribution to the national economy is considerable. It carries about one-quarter of the sheep, one-third of the beef cattle, as well as most of the country's mineral wealth.

A great deal remains to be learnt about the water resources, particularly of the arid zone, but recent surveys have confirmed the occurrence of underground water under large areas, although it often has a high saline content, sometimes higher than sea water.

It has been the need to provide economical methods of desalination of underground water in isolated areas which has provided the main stimulus for the development of solar stills in Australia.

Significant progress has been made in three areas -

(i) Research leading to better understanding of the thermal behaviour of the still as a dynamic process.

(ii) Development of improved designs based on this work and incorporating new and more durable materials.

(iii) Operating experience for both large and small units over several years of continuous operation.

There are five installations in various parts of Australia which have been continuously supplying water for human consumption over a period of some years. The largest of these is at Coober Pedy, which is also being used by the South Australian Engineering and Water Supply Department as a testing ground for other desalting processes. A great deal has been learnt from these installations, which have produced over 10,000 cu m of fresh water, Coober Pedy alone having produced 6,500 cu m, which is believed to be more than any other still in the world.

It has been found that, in areas of high insolation, the rate of deterioration of some components was excessive. Polythene sheet, for example, which has a life of [illegible] years in Melbourne, lasted only [illegible] years at Coober Pedy and [illegible] months at Ocean Island and metal components deteriorated rapidly. In view of this, the galvanized iron and polythene construction has now been abandoned in favour of a concrete and butyl rubber design having no metal parts. On the other hand, a very successful technique has been evolved in the use of silicone to make glass-to-glass and glass-to-concrete joints using suitable formulations.

Stills incorporating a considerable amount of insulation are being tested and appear to be promising. Methods of using waste heat (e.g., heat rejected from a diesel power plant) in a still are being developed, and work is proceeding to improve the accuracy of predictions of performance under a range of operating conditions.

Research is continuing on the thermodynamic behaviour of a still as a dynamic process, in which radiation and ambient conditions are continually varying, and it is now possible to get good agreement between the measured and predicted performance of a still when all the input factors are taken into account.

Improved designs continue to be developed as a result of a better knowledge of the thermal behaviour and also because of improvements in materials technology. It is important to appreciate that this process [illegible]

...r pieces of engineering equipment, and it can be expected to continue the same way. However, when considering performance or suitability for a specific application, it should be remembered that there has been considerable progress recently and some designs thought to be satisfactory a few years ago have now been superseded. Nevertheless the ... still appears to have reached the stage where satisfactory commercial installations can be built as long as people with the necessary background and experience are employed.

## ...1 HEATING

Research on a vee-corrugated absorber with a selective surface led to the development of a successful air heater absorber in the form of a unit which can be factory-built and erected on site to provide an absorber area of any size. These are not yet commercially available but experimental installations of 15–40 sq m have been tested, using an insulated tank of 10 mm rock screenings as a thermal storage. This may be used, with or without supplementary heating, to supply a steady stream of air at 45–60°C. As a commercial proposition this system is being evaluated, and it may prove attractive where there is a year-round demand for heated air at these temperatures. Some industrial processes may be able to benefit from this development.

## ...AR CELLS

Solar cells are not used in Australia to any extent as a power source, due chiefly to the fact that the silicon cell is very expensive and the cadmium sulphide thin film cell has a very short life. Nevertheless, several groups are interested in the possibilities of direct conversion to electrical energy, both for telecommunications purposes and as a general purpose power supply in isolated areas for applications such as water pumping. It has been estimated, for example, that if a cell with a reasonable life were available for 8¢ per watt it would be more attractive proposition than either diesel engines or windmills for water pumping. At present this objective is not in sight.

## ...ILDINGS

Solar energy research and development applicable to buildings is of ... types -

(a) Work aimed at predicting the thermal load and controlling it by shading or other means.

(b) Methods of utilising solar energy to heat and/or cool buildings.

Work on prediction of thermal load is closely allied to projects in the air conditioning field with a similar objective, but only those ...lications directly concerned with solar radiation and/or sun position ... listed. A considerable amount of information is now available in this area and it is extensively used by consulting engineers and architects in the design and siting of buildings.

Although it is technically possible to heat and cool buildings using solar energy, the economic feasibility of this is open to question, ... there are several current projects aimed at an evaluation of this feasibility and the development of suitable hardware.

Cooling, utilising solar energy as the heat source for an absorption-type refrigeration system, is being tested on an experimental ... in Brisbane, and heating, using solar air heaters and rock thermal ... being tested in Melbourne. In ... an experimental

uses solar ... for heating, ... for thermal ... At ... stage it appears that this ... may have wider applications.

## AGRICULTURE AND HORTICULTURE

Some years ago a considerable effort was devoted to the development of a phytotron for research purposes, able to produce a controlled environment for the study of plants under a variety of conditions. Although at the time there was no suggestion that the techniques employed would be suitable for economic horticultural production, this is now being re-examined. It seems that, under certain circumstances, controlled environment horticulture can be profitable, and the research problems necessitate a multi-disciplinary approach in which solar energy scientists and engineers will certainly be involved.

In Canberra there is a continuing experimental research programme concerned with photosynthesis and the radiation climate for plants. This work includes a study of the microclimate in the vicinity of the plant leaf, and is leading to the development of small sensors for this purpose.

The dried fruits industry in New South Wales and Victoria at present uses simple drying racks without any supplementary heating, which in normal years and in most areas are satisfactory. From time to time, however, humid conditions so retard the drying rate that heavy losses are incurred and the possibility of a solar dehydrator for dried fruits has been examined. More work will be required, however, if this is to be a practical proposition.

## HIGH TEMPERATURE APPLICATIONS

The University of New South Wales operates a 3.7 m diameter solar furnace in Sydney and a smaller unit at Broken Hill. The 3.7 m furnace is temperature-controlled and is used as a research tool in which the atmosphere surrounding the specimen can also be controlled. The paraboloidal mirror is mounted with its axis vertical and is fixed, and a heliostat with servo-control reflects solar radiation onto the mirror. The angular aperture at the focal point is 150° and its focal length is 1.2 m. The furnace, which is rated at 5 kW, has been in operation since 1962.

## METEOROLOGY AND RADIATION MEASUREMENT

In addition to the solar radiation network established by the Commonwealth Bureau of Meteorology (about 25 stations), measurements are made at certain research centres distributed around Australia. These latter measurements are usually made for short periods and relate to specific projects. There are very few long-term records and there are still gaps in the network, especially in inland and sparsely populated areas, so it is often impossible to obtain reliable data for the design of solar installations in these areas.

Meteorological parameters, such as sunshine hours and cloudiness, are more frequently available, and studies have been made of the correlations between these and solar radiation to improve the prediction of solar radiation in remote areas.

To improve the reliability of the measurements that are being made, a programme has been initiated to standardize the calibration of the instruments used by arranging regular comparisons with reference e of the subject of simplifying solar radiation measurements, several research groups have been working on the development of pyranometers, recording recorders and data processing equipment. This has led to several types of instruments being manufactured locally on a small scale.

An instrument has been designed to measure long wave or thermal radiation and thermal balance. This has been used widely in climatology, agricultural research, and in other studies where radiant thermal energy is of interest.

Knowledge of the spectral characteristics of materials is of utmost importance in the utilisation and control of solar energy. The CSIRO Division of Mechanical Engineering has a versatile spectroradiometer which can be used to measure directional spectral reflectance of rough or specular materials from the ultraviolet (0.25 μ) to the far infrared (... μ). Direct beam transmittance can also be measured in this wavelength range, while diffuse spectral transmittance and absorptance can be measured over the wavelength range from 0.25 μ to 2.5 μ. This equipment has been invaluable in the development of selective surfaces for solar applications.

## 3. CONCLUSION

Since this short survey has had to concentrate on the industrial utilization of solar energy in Australia, it has not been possible to do justice to the considerable amount of work being carried out which is only marginally related to this objective, particularly in the fields of meteorology and photobiology. The bibliography reflects this limitation, and even those references which are included have been selected from a much larger list for which space was not available.

Again, in order to save space, the 22 Australian papers presented to this Conference have not been included, since they can be obtained from the Conference programme.

Perhaps the most serious omission from the survey is any reference to air and water pollution, which is becoming a serious problem in industrialised communities. Solar energy, being a clean source of power, obviously can contribute to the solution of this problem in the long term.

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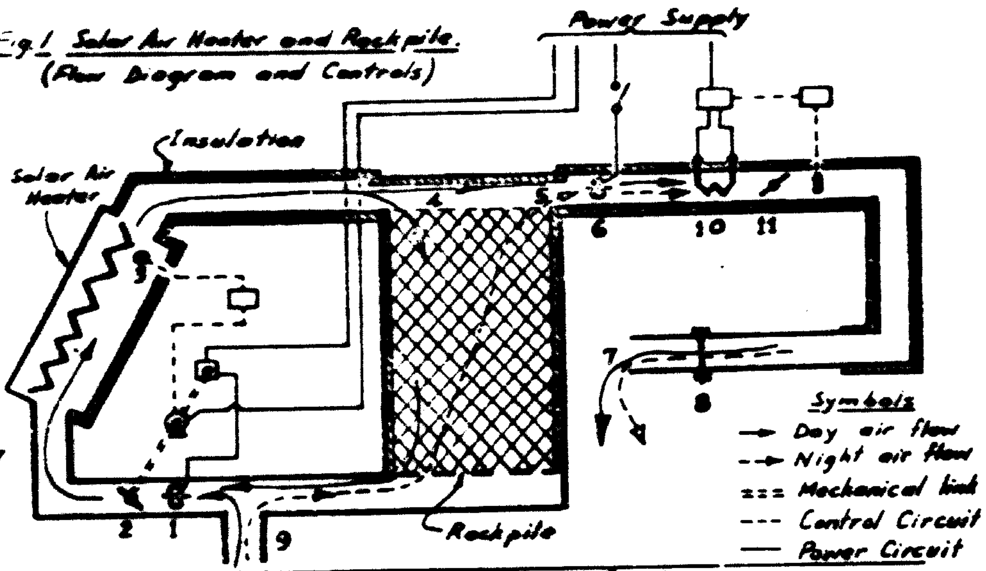
METEOROLOGY AND RADIATION MEASUREMENT

Fig.1 Solar Air Heater and Rockpile. (Flow Diagram and Controls)



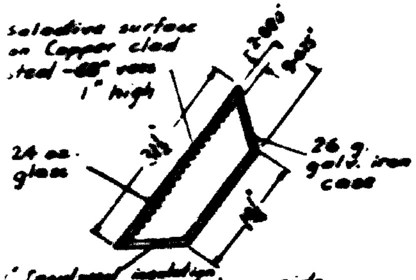




Fig. 2 Cross-Section of Solar Air Heater.

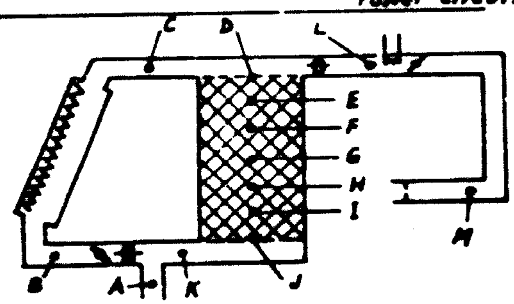



Fig. 3 Location of Thermocouples.

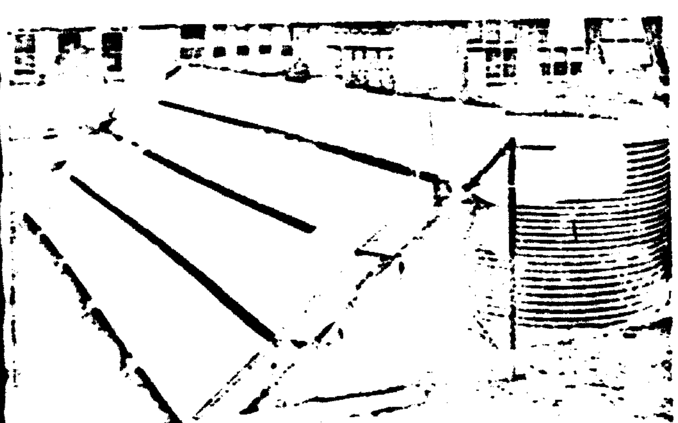


Fig.4 Solar Air Heater and Rock Pile Thermal Storage Installation. (View from the North-West)

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# THE PERFORMANCE OF A SOLAR AIR HEATER AND ROCKPILE THERMAL STORAGE SYSTEM

by

A. CHODA & W.R.W. READ

Preprint of paper to be presented at the

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**THE PERFORMANCE OF A SOLAR AIR HEATER AND ROCKPILE THERMAL STORAGE SYSTEM**

by

A. CHODA and W. R. W. READ*

## SUMMARY

This is an interim report containing initial test results of experiments performed a 300 $ft^2$ air heater and 340 $ft^3$ rock storage system.

The installation is automatically controlled to deliver a constant flow of heated which can be controlled at a fixed temperature. An electric boost is provided to pplement the solar input, if required.

The efficiency of solar collection and storage at various absorber outlet temratures will be determined and this report gives a value for 130°F, which is about 20%.

Methods of improving this are under consideration.

## NOMENCLATURE

Solar radiation incident on air heater cover, Btu/$ft^2$ day

Change in energy stored in the rock pile (+ve for increase and -ve for decrease in stored energy), Btu/day

Energy added by auxiliary heaters, Btu/day

Total energy discharged, Btu/day

Heat loss from air heaters, Btu/day

Heat loss from rockpile storage, Btu/day

Heat loss from air ducts, Btu/day

Air heater area, $ft^2$

| | |
|---|---|
| $V_r$ | Rock volume, $ft^3$ |
| $\rho_r$ | Density of rock - including voids, lb/$ft^3$ |
| $C_r$ | Specific heat of rocks, Btu/lb °F |
| $\Delta T_r$ | Temperature rise in rocks, °F |
| $\eta_D$ | Efficiency of duct system |
| $\eta_H$ | Efficiency of solar air heaters |
| $\eta_R$ | Efficiency of rockpile (Storages and heat transfer) |
| $\eta_s$ | Solar efficiency of installation |
| $\alpha$ | Absorptance of absorber panels |
| $\alpha_g$ | Absorptance of glass cover |
| $\tau_s$ | Transmittance of glass cover |

## 1. INTRODUCTION

The essential aim of this project is to obtain design data for development of an grated solar air heater and rockpile storage system suitable for providing a cheap continuous low grade source of heat using solar energy as the prime energy input.

Radiation intensity varies considerably from one location to another and also with me of the year. Therefore, in a system providing a continuous supply of heated air, icient and cheap heat store is a vital component of the installation, enabling excess collected during the sunshine hour period to be stored and used when required.

A number of forms of heat storage media and their relative merits have been dised by Close (1) and this has shown the advantages of rock as a simultaneous heat ng and heat exchange material.

The basic system consists of a bank of solar heater units connected in series and d at the extreme ends by air ducts to a rock pile thermal storage unit. (The r units are of a design used previously - see Close, Dunkle and Robeson (2)).

e authors are, respectively, Experimental Officer and Sectional Engineer at ivision of Mechanical Engineering, Commonwealth Scientific and Industrial Organization, Graham Road, Highett, Victoria, Australia.



As the temperature of the air in the heater rises to a pre-set level, fans force the air through the heater bank either directly to the load or, if in excess of process requirements, to the rockpile storage for use in periods of low insolation. Thermostatically operated auxiliary heaters are installed in the discharge duct to supplement solar energy as required to maintain the discharge air at constant temperature.

The main objects of the comprehensive test programme consist of the following:-

(1) To study the effects of different air flow rates and insolation levels on the collection efficiency of the air heater.

(2) To assess various control systems, initially using modulating control with fixed settings to control temperature at the air heater outlet.

(3) To investigate the overall efficiency of the rockpile storage, and to assess the effect of heat inputs at variable temperatures.

## 2. DESCRIPTION OF INSTALLATION

The solar air heater and rockpile system together with associated equipment and controls is shown schematically in Figure 1. The heater bank consists of 20 absorbers, each with a glazed area of 6'0" x 2'6" arranged in 4 rows and connected in series to form a serpentine circuit for the air path. (Fig. 4) The absorbers are mounted on a steel structure, inclined at an angle of 38° from the horizontal (approximate latitude of Melbourne) and for convenience face 9° East of North.

### Solar Air Heater

The solar air heater, shown in cross-section in Fig. 2, consists of a galvanised casing lined internally with rockwool insulation plus a reflective aluminium foil inter lining. The casing also supports a "V" corrugated absorber plate. A 24 oz. glass cover is attached to the edges of the casing and sealed with silicone sealant. Angle iron flanges are attached to each end of the absorbers and are pre-drilled to permit coupling of the absorbers at installation. Turning vanes are provided in absorbers at each change in direction.

### Rockpile thermal storage

The thermal storage consists of 340 $ft^3$ of 3/4" clean basalt rock screenings, contained in a 9'8" I. Dia. by 6'0" high corrugated galvanised iron tank, located on a 4" concrete slab. The tank is lined internally on the sides and top with 1" polystyrene foam insulation. The rocks are supported by 3/8" x 14 gauge galvanised wire mesh located on a number of brick supports, forming a six inch high plenum chamber beneath the wire mesh.

### Control system

The essential elements of the control system are shown in Fig. 1.

Air flow through the solar air heater is controlled by the combined effect of the heater fan (1) and modulating damper (2). When the damper is closed the fan is off. As the temperature of the air at the sensing element (3) reaches the control setting a signal from a proportional temperature controller actuates the modulating damper and simultaneously switches on the fan. The air flow is then regulated so that the air leaving the air heater is kept at the required temperature. As the air temperatures at the sensing element drop, the damper ultimately closes, and the fan is switched off.

Heated air from the absorbers enters the rockpile plenum at (4). At average and high insolation levels the magnitude of the air flow is such that part of it is discharged directly at 5, under the action of the discharge fan (6) to the load at 7. A reasonably constant air flow is maintained by means of an orifice (8) designed to suit the flow characteristics of the load fan. (Air flow variations range from 56 cfm when the solar air heater damper is open to 50½ cfm when closed.) The remaining air passes down through the rock pile causing the temperature of the rock to rise. The top layers are readily heated to temperatures approaching that of the incoming air, and the extent to which the temperature wave passes down into the storage will depend on the mass flow

When there is little or no insolation, the air flow to the load is maintained by bient air being drawn up through the rock pile. The air is heated as it passes through rocks, and if necessary, is further heated by an electrical heater (10).

The discharge duct is equipped with a manual damper (11). When this damper losed, and the load fan is off, the heater-pile system runs in closed circuit and all rmal output of the solar air heater is available for sto...

## 3. INSTRUMENTATION

The initial instrumentation consists of the following:-

Thirteen thermocouples are located in the duct and rockpile system as shown in .3 Although the thermocouples are sensing temperatures at particular points, mpts have been made to locate the thermocouples such that they are recording the rage temperatures in the particular zones of the system. Temperatures are orded by a multi-channel potentiometer recorder.

Two kWh meters record (1) power supplied to the auxiliary heater and (2) power uired for fans and controls.

The discharge orifice together with its adjacent ducting has been calibrated for ering the flow. An inclined manometer is permanently connected to pressure ings across the orifice.

Total solar radiation measured on a plane parallel to the air heater glass covers ecorded on the site.

## 4. THERMAL CHARACTERISTICS

The installation may be divided thermally into four sections, viz. the solar air ers, the heat store, the auxiliary heaters, and the associated ducting system. The ormance of each section must be analysed separately in order to obtain the most omical arrangement.

The energy input into the air heater consists of radiation absorbed by the "V" rugated panels, $\alpha\tau_g E_s$, together with that absorbed by the glass cover, $\alpha_g E_s$. heat then passes by radiation, conduction and convection to the air stream nd the corrugated panels, with a small proportion being retained in the mass of materials as stored energy. Heat is lost by re-radiation and convection to the s cover and also through the walls of the casings.

Obviously, heat lost from the thermal storage and the transfer ducts will reduce energy available, and allowance for this is made in the energy equation. As in all r devices the heat input into the absorbers is changing continuously, hence the essity to consider performance on a long term basis.

The overall heat balance relating to a given day can be expressed as follows:-

$$AE_s + E_A = E_L + E_p + L_H + L_p + L_D \quad \ldots(1)$$

solar efficiency of the installation is

$$\eta_s = \frac{\text{Solar Content of Energy Discharged + Change in Stored Energy}}{\text{Insolation}}$$

$$= \frac{(E_L - E_A) + E_p}{AE_s} \quad \ldots(2)$$

collection efficiency of the air heaters only is obtained from

$$\eta_H = \frac{AE_s - L_H}{AE_s} \quad \ldots(3)$$

rockpile efficiency has been defined as

$$\eta_R = \frac{\text{Energy discharged from top of rockpile}}{\text{Energy supplied to top of rockpile}}$$

While the efficiency of the duct system is

$$\eta_D = \frac{\text{Energy delivered by duct system}}{\text{Energy entering duct system}}$$

Thus the predicted efficiency of the solar system is

$$\eta_s = \eta_H \times \eta_R \times \eta_D$$

## 5. PREDICTED PERFORMANCE

The performance of a solar air heater installation inclined at an angle of 60° and coupled to a rockpile thermal storage system has been described by Close, Dunkle and Robeson (2). This system was used for office and laboratory heating during normal working hours. Information is now required regarding the characteristics of a system operating continuously.

For the purpose of the initial investigations predictions of performance have been based essentially on previous experience and for the experimental installation are as follows -

| | | | |
|---|---|---|---|
| Solar Air Heater efficiency $\eta_H$ | 40% | Duct efficiency $\eta_D$ | 90% |
| Rockpile efficiency (storage and Heat transfer) $\eta_R$ | 70% | Overall efficiency of solar system $\eta_s$ | 25% |

With respect to the heat storage capacity of the rockpile, it was initially intended that it should be capable of storing three days of average solar energy collection, i.e.

| | |
|---|---|
| Nominal face area of heaters | 300 ft$^2$ |
| Annual average incident radiation at Highett on 38° plane | 1385 BTU/ft$^2$day |
| Estimated average daily solar input (neglecting duct loss) (300 x 1385 x 0.40) | 166,000 BTU |

This requirement was almost exactly met by a tank size giving a rock volume of 340 ft$^3$ based on the following :-

Rock density ($\rho_r$) 86 lb/ft$^3$ Specific heat ($C_r$) 0.21 BTU/lb°F

Predicted temperature rise above ambient $\Delta T_r^{\circ}$ = 80°F

The air flow rate to the load selected for initial tests, was based on delivering the predicted solar contribution to the load at a temperature rise of 80°F relative to ambient.

## 6. TEST PROCEDURE

The prototype installation commenced operation early in October 1969. Smoke tests indicated excessive air leaks at the air heater flange connections, and in some of the joints in the duct system. Separate tests on the rockpile with the discharge fan operating but the top inlet duct and the lower return duct sealed off indicated air leakage into the top of the pile. Approximate measurements of leakage were made by isolating different sections of the system, operating the discharge fan and measuring the discharge at the orifice.

The extent of the leakage depends on the actual pressure difference between the inside and the outside of the system under operating conditions. Thus, when there is no flow in the heater, and air is being drawn in through the bottom of the pile, pressure in the top plenum chamber of the pile and the air heaters fluctuates about the zero value. (Calculated value is approximately -0.0003 inches water gauge.) Therefore the corresponding leakage is negligible. In contrast, when there is full flow in the air heaters, that is 550 cfm, the measured pressures at the heater inlet and in the top plenum chamber of the pile are +0.30 inches and +0.10 inches water gauge, respectively. Hence the mean pressure in the system is about +0.20 inches water gauge and the leakage of air to atmosphere is of the order of 30 cfm. It is very difficult to measure the actual temperature of this air. Assuming that this is at the control temperature this flow would represent a loss of approximately 5 to 6% of the collected energy at the maximum flow rate.

The location of the sensing element of the solar heater modulating damper is very

... on the centreline of the heater, with the element parallel to and two inches behind ... mid depth plane of the corrugated absorber.

The initial setting of the solar heater outlet temperature was 120°F. However, ... this setting degradation of the rockpile took place on the afternoons of days of high ...olation when the rock temperature at the base of the rockpile exceeded 120°F. The ...mperature level was then set at 130°F in order to reduce degradation of the pile ...thout unduly curtailing the period of operation of the air heaters.

For the test runs, the control for the auxiliary heater was set at 145°F.

## 6. TEST RESULTS

The following tables list either recorded or computed data taken over periods of ...ntinuous operation, with the solar heater outlet temperature controller set at 130°F.

| ...ate | Insolation $AE_s$ | Total Energy Discharged $E_L$ | Aux. Heating $E_A$ | Solar Content of Energy Discharged $E_L - E_A$ | Change in Stored Energy $E_P$ | Average Ambient Temperature |
|---|---|---|---|---|---|---|
| | Btu/day | Btu/day | Btu/day | Btu/day | Btu/day | °F |
| ...t Run No. 1 | | | | | | |
| ...v. 6 | 340,000 | 108,000 | 49,100 | 58,900 | + 600 | 61.1 |
| 7 | 227,000 | 109,500 | 53,300 | 56,200 | - 52,000 | 58.3 |
| 8 | 409,000 | 113,000 | 46,400 * | 66,400 * | + 136,000 | 57.4 |
| 9 | 296,000 | 112,000 | 46,400 * | 66,400 * | - 59,100 | 58.5 |
| 10 | 415,000 | 113,400 | 46,400 * | 66,400 * | + 31,700 | 58.1 |
| 11 | 370,000 | 111,000 | 46,800 | 64,200 | + 3,050 | 58.6 |
| 12 | 458,000 | 109,000 | 42,000 | 67,000 | + 47,000 | 61.4 |
| 13 | 430,000 | 110,500 | 35,500 | 75,000 | + 29,300 | 61.5 |
| ...tal | 2,945,000 | 886,400 | 365,900 | 520,500 | + 136,550 | |
| ...t Run No. 2 | | | | | | |
| ...v. 18 | 201,500 | 110,500 | 57,000 | 53,500 | - 51,300 | 57.4 |
| 19 | 166,500 | 110,000 | 61,000 | 49,000 | - 77,000 | 56.4 |
| 20 | 179,000 | 112,000 | 64,000 | 48,000 | - 63,000 | 54.2 |
| 21 | 445,000 | 112,000 | 55,500 | 57,000 | + 108,000 | 57.5 |
| 22 | 383,000 * | 112,300 | 40,400 * | 63,800 * | + 81,100 | 58.5 |
| 23 | 383,000 * | 101,800 | 40,400 * | 63,800 * | + 55,500 | 69.5 |
| 24 | 383,000 * | 98,500 | 40,400 * | 63,800 * | - 44,000 | 70.9 |
| 25 | 442,000 | 111,000 | 44,000 | 67,000 | + 37,200 | 60.0 |
| 26 | 340,000 | 113,000 | 41,800 | 71,200 | - 8,500 | 58.4 |
| 27 | 298,500 | 114,000 | 44,000 | 70,000 | - 34,200 | 55.8 |
| ...tal | 3,211,500 | 1,095,100 | 488,500 | 607,100 | + 3,800 | |

* Averages from three day totals.

Accordingly the solar efficiencies for the two test runs are as follows:-

...st Run No. 1 $\eta_s$ 21.3 Test Run No. 2 $\eta_s$ 19.0

It is evident that the overall solar efficiency, varies considerably from day to ... For example, for the period of increase in stored energy (No. 11th to 13th) it ...2.7%. However on some days when there is a decrease in stored energy a posi... value is not obtained. This is due to the fact that on days of low insolation heat ... from the absorber is very small, and the reduction in stored energy, which ...udes losses from the rockpile, over the 24 hour period is greater than the solar ...tent of the energy discharged from the system.

These are short term effects and solar efficiency evaluations are most meaning... periods of operation when the overall change in stored energy becomes [illegible] discharged from [illegible]

In the analysis of the energy balance carried out for one day an attempt was made to obtain a measure of relative efficiencies and losses in the major components of the installation. The losses have been calculated in order to reconcile input and output figures. A summary of the results is as follows.

Test period: 24 hours following 0730 hours (mean solar time) 27th October, 1969.
Solar heater temperature controller setting: 120°F.

| | | | |
|---|---|---|---|
| Insolation $(AE_s)$ | 572,000 Btu | Total Energy discharged $(E_L)$ | 110,500 Btu |
| Aux. heating $(E_A)$ | 44,000 Btu | Energy added to pile $(E_P)$ | 35,500 Btu |
| | | Losses from pile and ducts $(L_P + L_D)$ | 91,500 Btu |
| | | Loss from solar air heater $(L_H)$ | 378,000 Btu |
| | 616,000 Btu | | 616,000 Btu |

Efficiency of solar air heaters $\eta_H = 33.8\%$, Solar efficiency of installation $\eta_s = 17.8\%$.

The collection efficiency obtained in this analysis compares reasonably with experimental results shown in Ref. (2). These show efficiencies of 37% for mean daily insolation values ranging from 1500 to 1700 Btu/ft/day, and also for a flow rate of approximately 550 cfm.

However the overall efficiency is much lower than predicted, and this is possibly due to the losses from the rockpile and duct system which are unacceptably high.

## 7. CONCLUSIONS

Although the tests are still in their early stages, a number of initial observations can be made.

The collection efficiency of the air heaters as shown in the analysis is slightly lower than that obtained in previous experiments (2) and this may be due to air leaks from the absorbers. However tests to ascertain the collection efficiency must be performed over long periods and for a range of radiation values. The tests must be extended to also include other modes of control.

The overall solar efficiency is lower than predicted and this is believed to be due to excessive heat losses from rockpile and duct system. The airflow rates to the load and to the rockpile storage at maximum flow are believed to be the major factors contributing to these losses. Adjustments will be made to determine the optimal flow rate to the load and rockpile storage.

Modifications to the system will be required to reduce heat losses from the rockpile and duct system. Attempts will be made to continuously meter air flow through the absorbers.

Although further information is required regarding the overall performance before an accurate assessment of the cost of heat supplied can be made, preliminary investigations indicate that further work should be done on the project.

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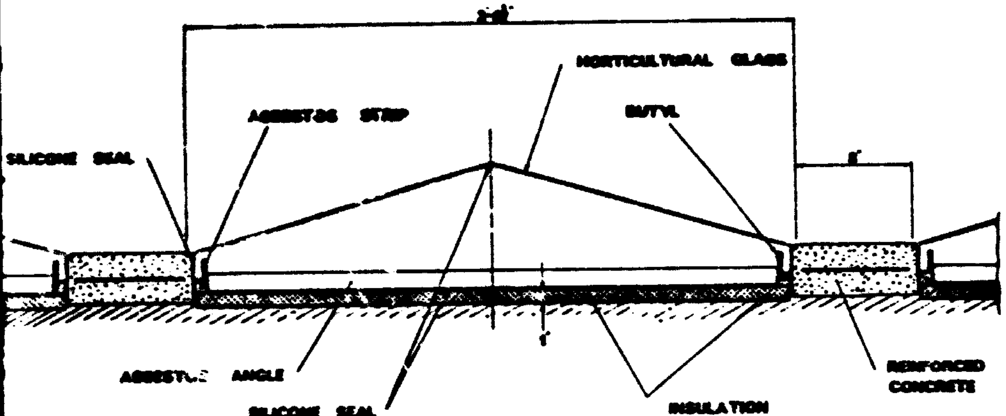



Fig. 3 - Cross-section of the MK VI design.

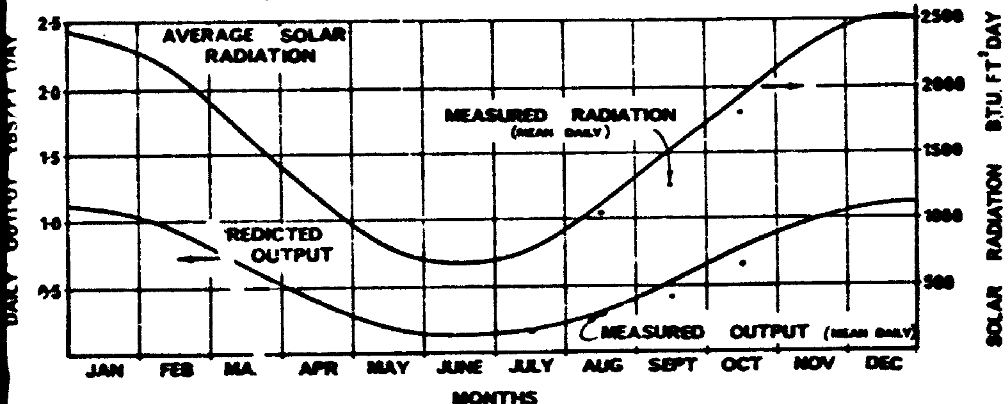
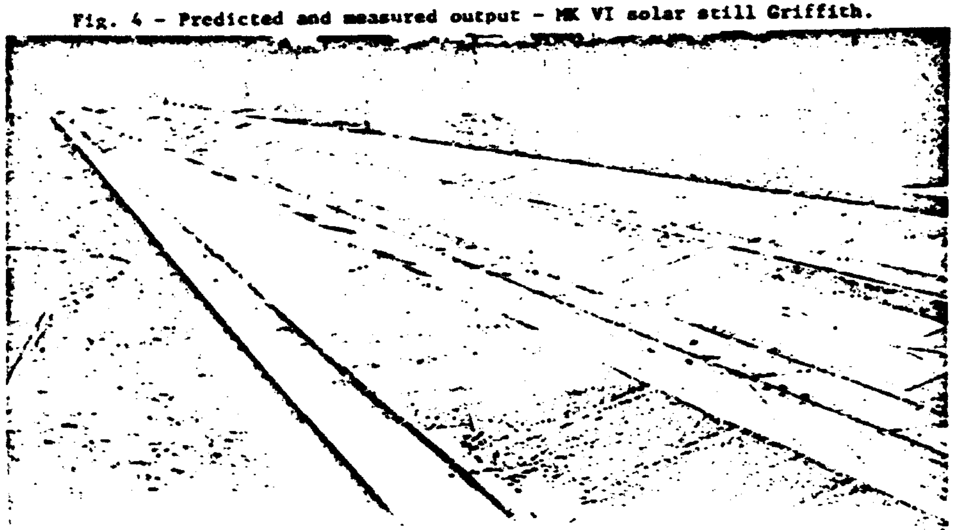



Fig. 4 - Predicted and measured output - MK VI solar still Griffith.



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# RECENT DEVELOPMENTS AND FUTURE TRENDS IN SOLAR DISTILLATION

by

W.R.W. READ

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# RECENT DEVELOPMENTS AND FUTURE TRENDS IN SOLAR DISTILLATION

by

W.R.W. READ*

SUMMARY

The latest version of the Australian solar still is discussed, together with factors leading up to this design. Its operation, performance and costs are given, together with anticipated trends in solar still development.

## 1. INTRODUCTION

The development of solar stills in Australia has been proceeding over a period of ut seven years, and during this time a succession of designs has been produced and ted. Each design has incorporated improvements based on a combination of factors, these include (a) a better understanding of the thermal characteristics of the ll, (b) operating experience gained in field experiments, and (c) the availability improved and more durable materials.

The stills are normally in areas of 500 $ft^2$, being 144 ft long by 3 ft 6 in. wide, tructed on ground at a gradient of 1:100. They consist essentially of an enclosure a transparent gable roof mounted over shallow pans, in which saline water flows at trolled rate down the length of the still. As the water is heated, part of it orates and condenses on the underside of the roof. The condensate runs down into collecting troughs located at the sides, and eventually discharges at the low end the storage system.

The economics of solar distillation have always been foremost in the design sophy, hence low cost designs with simple installation procedures and acceptable ut were the essential features of the specification. Prefabrication of components educe on-site work and transport costs was also considered a desirable character- ic required in the still, and so the design has generated from the original MK I ept (Fig. 2) through a series of stages, each aimed at overcoming weaknesses rved in field operations.

## 2. THERMAL CHARACTERISTICS

Figure 1 shows the basic heat fluxes for a solar still, and from this it may be that the energy input into the still consists of radiation absorbed by the glass r $\alpha_g H_s$ plus that absorbed by the saline water and through systems $\alpha_w \tau H_s$.

Heat is lost to the surroundings through the glass cover $q_{ga}$, and also via the s and ground $q_b$. The term $c_{wg}$ allows for the storage effect of the saline water, ground under the still and the structural members of the still.

The steady state heat and mass transfer relationships have been stated by Dunkle . and their application has been extended to both graphical [2] and computed solu- s [3], enabling the performance of stills to be predicted for known values of solar ation, ambient temperature and wind velocity, together with the values of the ze term $c_{wg}$ (Btu °F $ft^2$) and the loss coefficient $k_b$ Btu/hr $ft^2$ °F, which apply to ticular design of still.

author is an Experimental Officer at the Division of Mechanical Engineering, monwealth Scientific and Industrial Research Organization, Graham Road, Highett, toria, Australia.

ers in square brackets refer to references listed at the end of the paper.

While $k_b$ is regarded primarily as an edge coefficient, it also allows for such defects as water loss and vapour leakage from the still. All previous work has shown the substantial influence of these two parameters on still performance, and these, more than any others, are aspects under the direct influence of the designer. In the original analysis carried out on the MK I arrangement, the $k_b$ and $c_{wg}$ values proved to be 1 and 16 respectively. It has also been shown [2] that a 36% improvement in performance could be predicted with a reduction of 1 to .25 in $k_b$, and this could be further improved by reducing $c_{wg}$ to a practical minimum.

The still has developed as shown in Figure 2, the modifications including thermal, structural and material improvements, without increasing the cost of the fresh water. The approximate relative values of $k_b$ and $c_{wg}$ with the respective designs operating under identical conditions are shown in the Figure.

## 3. PRINCIPAL CHANGES IN DESIGN

| | |
|---|---|
| MK I to MK II. | Change from separate units to units interconnected with sheet metal troughs. Silicone sealant introduced at top glass joint. |
| MK II to MK III. | Metal distillate troughs replace polythene lined troughs. Silicone sealant used for all joints. |
| MK III to MK IV. | Sheet metal access troughs replaced by concrete. |
| MK IV to MK V. | Sheet metal distillate troughs replaced by insulated trough with butyl film lining. |
| MK V to MK VI. | Insulation added to the base. Asbestos cement strip and angles used to form distillate troughs and weirs. |

While thermal characteristics of a still are of considerable importance, other aspects such as reliability in operation, acceptable life of components and minimal maintenance can be even more significant. In equipment of this type in which there are no moving parts, reliability in operation primarily refers to consistency of annual output over long periods, durability of materials and structural integrity.

It has been clearly demonstrated in stills operating in remote areas of Australia that in order to meet these requirements they must be capable of operating for extended periods under the most adverse conditions, ranging from extremes in climatic conditions to neglect and, in fact, gross abuse on the part of the operator. It is vital, therefore, that these factors receive the utmost attention in any installation.

## 4. SPECIFICATION DETAILS

While the complete specification for a solar still will vary considerably from one location to another, essential elements which must be included will refer to the following:-

Operating range of ambient temperatures 40°F to 130°F.
Solar radiation over 3000 Btu $ft^2$ day.
Ability to withstand these conditions when the saline water supply has failed.
Resistance to wind velocities of up to 100 mph.
Resistance to willy-willies (whirlwinds with suction effects of approximately 1.2" wg [4]).
Resistance to corrosion of metal components.
Simplicity of operation and minimal maintenance.
Positive rain-water run-off and drainage systems. (It is essential to prevent water from permeating under the still; while having the effect of increasing heat losses from the base of the still, in the extreme it may also cause the ground to swell and so negate the effect of the gradient.)
Erosion at the end of the stills must also be prevented.

the present time it has not been necessary to take extraordinary steps to cope with these problems. The above requirements are intended to meet the needs of stills operating in Australia. They are also believed to form the basis of specifications for stills operating in other countries.

## 5. DESIGN AND OPERATION OF MK VI STILL

Following on from the progression shown in Figure 2, the most recent development is shown in Figure 3.

The main structural members consist of reinforced concrete side members, poured in situ to form continuous members running the full length of the still. They are placed directly on prepared ground which has a longitudinal gradient, preferably about 1:100. The ground under the saline pans is roughly screeded to the requisite depth, and 1" polystyrene foam insulation is then placed on the ground and sides as shown. The distillate trough is formed by locating an asbestos strip on the inboard side of the polystyrene, and covering the insulation, asbestos and inner concrete face with a .030" butyl rubber film, to form a continuous lining in the distillate troughs and saline area. Asbestos angles are used to provide additional support for the sides of the distillate trough and simultaneously form the weirs at 4'0" centres of the successive saline pans which make up the base of the still. Silicone sealant is used to fix and seal the asbestos to the butyl rubber film.

A small recess at the top inner edge of the concrete locates the outer edge of the butyl and the bottom edge of the glass roof. Silicone sealant is applied to the concrete to form a sealing bed for the edge of the butyl film. The roof consists of pairs of 12" by 18" horticultural glass panes with a ridge joint of silicone sealant. Pairs of panes are located on the butyl film in the recess, and silicone sealant is used exclusively to make all glass to glass and glass to butyl and concrete connections. Saline water is fed at a constant rate of 0.1 lbs per hour $ft^2$ continuously into the top end of the still and gravitates from one pan to the next. Excess water discharges to waste at the low end, while distillate which collects in the troughs also flows to the low end, and finally into the storage system. (Fig. 5 shows a MK VI solar still installed at Griffith.)

Performance:

The output from the first still of this design is shown on Figure 4, together with a plot of predicted performance. Obviously the test period must be extended considerably before all aspects of the performance may be assessed. While the effect of the insulation has been to reduce the values of $k_b$ and $c_{wg}$ to approximately 0.20 and 6.0, improving the thermal efficiency, it also reduces to a large extent the effect of the ground condition beneath the still.

Observations in the past have shown long term deterioration of performance, and this is believed to be primarily due to increasing moisture content in the soil caused by leakage and breakdown in the polythene and other water and vapour leakage paths. While the average initial output of the MK I still was approximately 16 gallons/$ft^2$year, the output for the MK VI is expected to be in excess of 25 imp. gallons/$ft^2$ year, where average radiation exceeds 1800 Btu/$ft^2$ day.

Maintenance:

The development of the MK VI still has followed a sequence of changes, each aimed at improving performance, durability and reliability of operation and reducing maintenance to a minimum. For stills correctly installed, with the best selection of materials, the maintenance required falls primarily into five categories:-

(a) Continuous Supply of Saline Water. - The quality of the water supply, the nature and quantity of the dissolved solids, and experience will dictate the frequency at which this should be checked. This involves observing the water flow at each inlet and occasionally adjusting the flow to free an imminent blockage. The time required for 50 stills is usually no more than 20 minutes.

(b) Preventation of Blockages in Outlet Pipe Connections. - This refers to blockages in distillate outlets, and depends largely on the initial sealing of the still during construction. Blockages are virtually unknown in stills sealed exclusively with silicone, but it is considered prudent to check the outlets every 3 months.

(c) Removal of Salt and Algal Deposits. - These deposits vary in magnitude and type from one location to another. A still which operated at Highett for about six years using sea water never required cleaning. However, inland brackish waters readily deposit calcium carbonate, and with time algal deposits also form.

While tests so far have shown no appreciable change in performance due to the presence of the impurities, a research programme is envisaged to investigate the effects and optimal frequency of cleaning.

(d) Prevention of Leakage from the Still. - Leakage may occur as distillate or water vapour from the glass roof, or as distillate or saline water from the body of the still. It may be due to deterioration of the still lining, leakage at the distillate and saline outlet connections, and imperfect drainage systems. Time is required to assess the corrective measures which have been taken by the use of silicone for sealing purposes and the replacement of polythene with butyl.

(e) General. - Other items such as glass breakages and dust removal have proven quite insignificant, and add very little to the maintenance schedule.

Under normal circumstances the design and operation is such that the total annual maintenance time should not exceed 5 to 10 man hours per 500 $ft^2$ unit.

Costs:

Factors controlling costs vary significantly with each installation. While capital costs and maintenance are essential components of any assessment, their influence can be offset by such considerations as the manner of financing the project, whether interest on capital or tax rebates may apply, and finally the purpose of the installation and how the water is to be used. Therefore it is not possible to standardize costs and every installation must be analysed separately.

However, in every case certain fundamental elements of the cost structure do apply [5], and for the MK VI still the particular values are as follows:-

| | |
|---|---|
| Installed cost in remote area | \$Aust. 1.30/$ft^2$ |
| Life (estimated) | 20 years |
| Output - | |
| Annual (@ mean annual insolation of 1,900 Btu/$ft^2$ day, and mean ambient temperature of 75°F) | 25 imp. gal/$ft^2$ year |
| Best month, average | 0.14 imp. gal/$ft^2$ day |
| Worst month, average | 0.035 imp. gal/$ft^2$ day |
| Year, average | 0.069 imp. gal/$ft^2$ day |
| Installed cost per daily gal (best month) | \$Aust. 9.30 |

## 6. FUTURE DEVELOPMENTS

From results of field installations and tests the essential requirements of solar stills are now more fully understood, and it is most important that development should continue aimed at improving the long term performance at reduced costs.

As new types and more sophisticated materials become available they should be investigated. For example, tests are in progress on samples of poly-isobutylene sheeting as a replacement for butyl as the still lining. This material appears to have better UV resistance than butyl; it is reputed to be made to closer tolerances and in thinner films with a pro-rata reduction in cost.

Water flow control and flushing out of the stills is another aspect requiring further development. [illegible]

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...ould also be investigated. A simple metering device giving a visual indication of ...stillate flow at each outlet is also envisaged. This will allow observations to be ...ce without having to disconnect piping.

In some remote communities, the possibility of distillation units operating in ...se proximity to small power generating plants cannot be ignored. Efforts should be ...e to include the utilisation of waste heat as a means of boosting output and hence ... overall efficiency of the plant. Preliminary experiments have begun at Highett on ...s work and will be reported separately.

In developing countries tests will continue using indigenous materials and tech...cal know-how. However, considerable time can be saved by building on acquired ...wledge and experience, to ensure time and money are not wasted on inferior materials ... designs.

## 7. CONCLUSIONS

Field testing has shown that low cost designs using prefabricated components and ...vthene have proven unsatisfactory in severe environments. However the availability ...more durable materials has enabled the development to continue, aimed at improving ...liability in operation, increasing the output and extending the life of the still. ...le the MK VI design is expected to fulfil these requirements, further testing is ...uired before conclusive results may be obtained. The installed cost of this design ...estimated at $1.30 ft$^2$.

The development of solar stills will not remain static, and work will continue ...e at further improvements in long-term economics. Finally, experience has shown ...alue of conducting proving tests in severe conditions, and new designs must be ...roughly tested before embarking on large-scale installations.


## ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of Mr. R.N. Morse, Chief of the ...sion of Mechanical Engineering, CSIRO, and also the efforts of many colleagues who ... assisted in this project, in particular Messrs. R.S. Trayford, R.H. Read and ... Holbery.


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## NOMENCLATURE

| | |
|---|---|
| Thermal capacity of water, still and ground | Btu/°F ft$^2$ |
| Solar radiation on horizontal surface | Btu/hr ft$^2$ |
| Thermal loss coefficient, base of still to surroundings | Btu/hr ft$^2$ °F |
| Heat loss from base of still | Btu/hr ft$^2$ |
| Heat transfer, glass cover to surroundings | Btu/hr ft$^2$ |
| Solar absorptance and transmittance of glass cover | |
| ... absorptance of brine and trough system | |

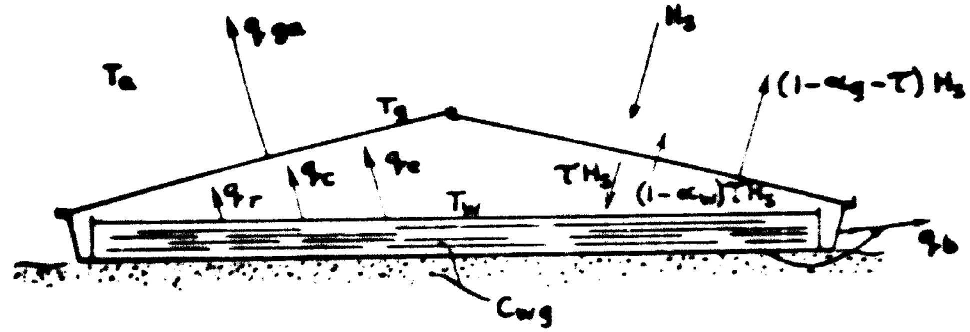


Fig. 1 - Heat fluxes for a solar still.

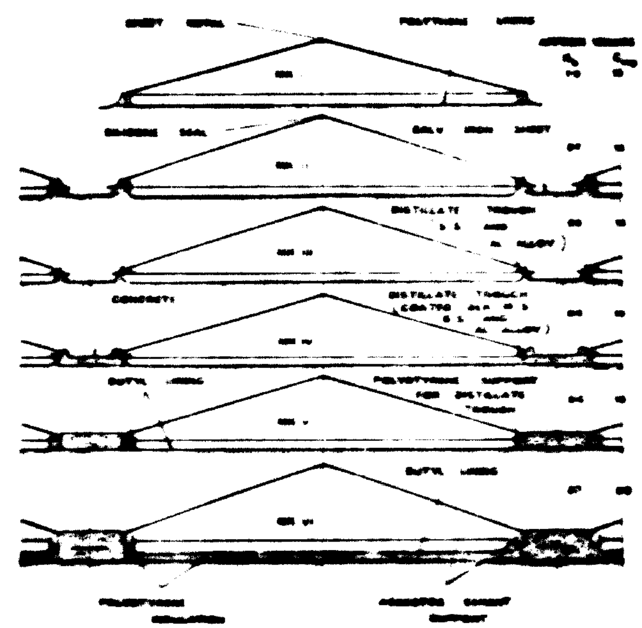

Fig. 2 - Stages of development.

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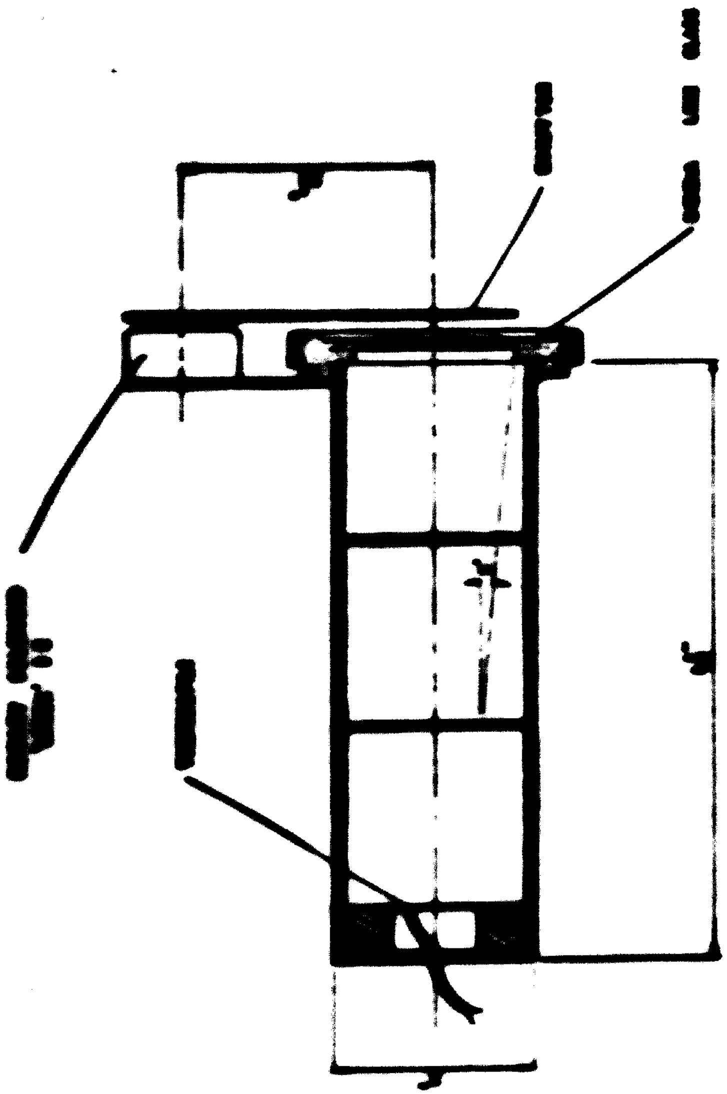

[illegible]

# DIFFUSE SKY RADIATION

by

R.J. [illegible]*

## SUMMARY

The importance of diffuse solar radiation is demonstrated by the behaviour of various solar utilization devices. The various methods of measuring diffuse solar radiation are discussed and an experimental programme to elucidate some of the problems encountered in these measurements is outlined.

## 1 INTRODUCTION

When the energy from the sun enters the earth's atmosphere some is absorbed by water vapour, ozone and carbon dioxide, some is absorbed or scattered by aerosols, dust and other particles in the atmosphere, and the remainder transmitted to the surface of the earth.

The scattered solar energy gives rise to the "diffuse solar radiation" which is the solar energy coming from all parts of the sky outside of a narrow cone about the sun. Whereas the direct solar radiation has spectral characteristics determined by the solar spectrum and the absorption of the atmosphere, the diffuse solar radiation has a spectral distribution determined by the scattering characteristics of the atmosphere and is normally shifted towards the shorter wave-lengths. In [illegible] practice it is considered that the whole of the diffuse solar radiation falls in that part of the spectrum less than 1 micron. Due to the spectral distribution of solar energy in space, the selective scattering of the short waves and selective absorption of the long waves, a negligible amount of scattered energy lies beyond 1 micron wave-length.

## 2 THE IMPORTANCE OF DIFFUSE RADIATION

The importance of diffuse solar radiation has often been overlooked in consideration of solar utilization devices such as water and air heaters and of heat loads in buildings. Increasingly architects are beginning to realise that it is generally diffuse radiation that provides illumination through windows either from the sky or reflecting bodies in view of the window.

In Melbourne the mean percentage ratio of diffuse radiation to total radiation varies from thirty per cent in January to fifty per cent in July and the mean annual ratio is approximately forty per cent. On [illegible] October [illegible] a series of readings were taken inside a north facing window fully shaded by overhanging eaves. The maximum reading occurred about noon when it reached [illegible] milliwatts per square centimetre.

In a design study for the distillation of water by solar energy, P.I. Cooper [1]† has come to the conclusion that the diffuse component of solar energy which plays an

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†Numbers in square brackets refer to references listed at the end of the paper.

[illegible] important [illegible] whereas when a solar air heater was being tested [illegible] the output, obtained when the diffuse component was the main input energy, [illegible] high. On the [illegible] December 196[illegible] when the percentage of total radiation [illegible] diffuse was ninety-two the output was [illegible] kilowatt-hours compared with [illegible] kilowatt-hours for a clear day and [illegible] kilowatt-hour for a completely overcast day [illegible] day ([illegible]) there occurred only [illegible] hours of sunshine and [illegible] of cloud [illegible] and sunshine were reported at each synoptic meteorological observation.

For the purpose of assessing solar heat loads on buildings [illegible] the solar data [illegible] is used. An analysis of the meteorological records for Melbourne [illegible] that the days of highest recorded temperature were overcast with hot air being [illegible] over the city from the northern inland areas. Whereas the highest recorded temperatures are in excess of 1[illegible]°F, the maximum temperatures recorded on clear days [illegible] exceeds [illegible]°F and is more usually in the [illegible]. On one such day [illegible] maximum temperature of [illegible]°F the ratio of diffuse sky radiation to total [illegible] on a horizontal surface was [illegible] per cent. Furthermore the distribution of [illegible] radiation over the building is quite different from that of the direct beam [illegible] is usually assumed.

## [illegible] THE MEASUREMENT OF DIFFUSE RADIATION

There are two main ways in which sky radiation may be measured.

[illegible] shading the sensitive element of a pyranometer so that it may see the greater part of the sky but not the sun. This is usually done by means of an equatorially mounted band or by a disc which tracks the sun.

[illegible] measuring the direct solar beam by means of a pyrheliometer, converting the result to represent the radiation falling on a horizontal surface due to the sun [illegible] and subtracting this from the total radiation recorded by a pyranometer.

[illegible] and solar tracking devices are generally expensive and therefore [illegible] frequently used method is to place a shade band around the pyranometer. [illegible] band excludes part of the sky a correction is usually made. Several methods, [illegible] [illegible] [2], Drummond [3], [illegible] [4] and more recently [illegible] and [illegible] [5], [illegible] proposed. All calculations are based on the assumption that the sky is [illegible] radiating or that the radiation received by the pyranometer is [illegible] [illegible]. It is usual to refer to this condition as an "isotropic sky".

[illegible] this assumption is obviously seldom valid, Drummond has proposed a further [illegible] based on measurements made at Pretoria in South Africa. Considerable [illegible] has arisen on the frequency of occurrence of isotropic sky conditions and [illegible] been carried out in Melbourne to investigate this.

[illegible] a fully analytical solution to the shade band correction factor was [illegible]. This was done by projection of the edge of the shade band onto a unit sphere [illegible] at the centre of the pyranometer element and passing through the rim of the band. The sphere was then projected onto the equatorial plane containing the [illegible]. The great circle defined by the projection of the rim of the band is [illegible] by a semi-ellipse on the equatorial plane. The area of this semi-ellipse may be [illegible] precisely. When this calculation is made for each rim of the shade band [illegible] the areas obtained give directly the shade band correction factor. This [illegible] solution has been programmed for a computer and the equations extended and [illegible] for pyranometers at any inclination to the horizontal.

[illegible] obtained from this analysis agree within one per cent of those published [illegible] for horizontal surfaces.

[illegible] was then made of thirty-eight days over a three year period on which the [illegible] records indicated that completely overcast conditions prevailed. It was [illegible] that on these days the total radiation measured would be entirely diffuse sky [illegible]. Thus the ratio of total to diffuse measurements would give a measure of [illegible] [illegible] and [illegible] that an [illegible]

[illegible] per cent [illegible] the [illegible] [illegible] than [illegible] [illegible] were [illegible] [illegible] three per cent.

[illegible] would appear that [illegible] requires an investigation of the [illegible] made. In particular on the basis of [illegible] of Pretoria, a city blessed with a [illegible]

[illegible] further [illegible] has [illegible] made using [illegible] shade [illegible] [illegible] in Table [illegible] [illegible] maximum of thirty per [illegible] and a mean [illegible] seven [illegible]

By comparing the results [illegible] with those [illegible] pyrheliometer results [illegible] good [illegible] of cirrus cloud [illegible] this causes the pyrheliometer [illegible] increased circumsolar [illegible] angle of the pyrheliometer [illegible] seven degrees.

It does appear [illegible] radiation [illegible] and [illegible] will therefore be necessary [illegible] stations recording [illegible] radiation [illegible]

Drummond has [illegible] measurements [illegible] distribution of sky [illegible] from different [illegible] of the sky [illegible] been proposed to extend [illegible] work [illegible] of radiation in different parts of the sky [illegible] measurements [illegible] so called short wave [illegible] than [illegible] those to [illegible] [illegible] important [illegible] radiation [illegible]. The region covered by [illegible] shown [illegible]

Since it is desirable to [illegible] the sky [illegible] conditions [illegible] posed that three sensors [illegible] the [illegible] around the hemisphere of the sky [illegible] meteorological observations. The [illegible] tor in such a way that [illegible] altitude [illegible] the sensors will be covered [illegible] signals amplified [illegible] on a polar diagram. The drive mechanism and [illegible] are shown in Figure [illegible] construction, and details of the short wave sensor are shown in Figure [illegible].

It is also proposed to obtain photographs of the whole sky with a [illegible] degree camera simultaneously with the readings from the three sensors.

As with all such projects the aim [illegible] the desirability of [illegible] the distribution of sky radiation [illegible] the suggestion [illegible] such work should be carried out in a variety of [illegible] before any general [illegible] can be drawn from the results.

## [illegible]

The author would like to thank Mr. [illegible] for the continued assistance and encouragement in this work.

[illegible]

Cooper, P.I. [illegible] (19[illegible])

[illegible], [illegible] [illegible] (19[illegible]).

[illegible], [illegible] [illegible], [illegible] [illegible] (19[illegible]).

[illegible], [illegible] [illegible] [illegible] (19[illegible])

[illegible], [illegible] and [illegible], [illegible] [illegible], [illegible] [illegible] (19[illegible]).

[illegible], [illegible] [illegible], [illegible] [illegible] (19[illegible]).


TABLE I

[illegible]

| [illegible] | F | [illegible] | F | [illegible] | F | [illegible] | F |
|---|---|---|---|---|---|---|---|
| 12.1.66 | 1.1[illegible] | 13. 9.66 | 0.9[illegible] | 6.12.66 | 1.0[illegible] | 13.6.67 | 1.0[illegible] |
| 11.4.66 | 1.0[illegible] | 15. 9.66 | 1.0[illegible] | 13. [illegible].67 | 1.0[illegible] | 17.6.67 | 1.0[illegible] |
| 12.5.66 | 1.1[illegible] | 2.10.66 | 1.0[illegible] | 20. [illegible].67 | 1.151 | 9.7.67 | 1.1[illegible] |
| 26.5.66 | 1.1[illegible] | 10.10.66 | 1.2[illegible] | 6. 5.67 | 1.1[illegible] | 26.7.67 | 0.9[illegible] |
| 30.5.66 | 1.1[illegible] | 18.10.66 | 1.0[illegible] | 16. 5.67 | 1.1[illegible] | 6.9.67 | 1.1[illegible] |
| 10.6.66 | 1.0[illegible] | 9.11.66 | 1.0[illegible] | 19. 5.67 | 1.0[illegible] | 20.3.68 | 1.1[illegible] |
| 9.7.66 | 1.1[illegible] | 1.12.66 | 1.043 | 5. 6.67 | 0.9[illegible] | 22.3.68 | 1.1[illegible] |
| 12.7.66 | 1.0[illegible] | 2.12.66 | 1.017 | 10. 6.67 | 1.0[illegible] | 23.3.68 | 1.1[illegible] |
| [illegible].8.66 | 1.[illegible] | 3.12.66 | 1.047 | 12. 6.67 | 0.9[illegible] | 26.3.68 | 1.1[illegible] |

F - [illegible]

$F_{max}$ - 1.2[illegible]

$\bar{F}$ - 1.0[illegible]

TABLE II

[illegible] $D_b/D_s$

| | | | |
|---|---|---|---|
| 1.0 to 1.02 | [illegible] | [illegible] | 1.[illegible] |
| > 1.02 and < 1.05 | [illegible] | [illegible] | 1.[illegible] |
| > 1.05 and < 1.10 | [illegible] | No. of days | [illegible] |
| > 1.10 and < 1.20 | [illegible] | | |
| > 1.20 | [illegible] | | |

$D_b$ - Diffuse radiation measured with a [illegible].

$D_s$ - Diffuse radiation measured with a shade band.

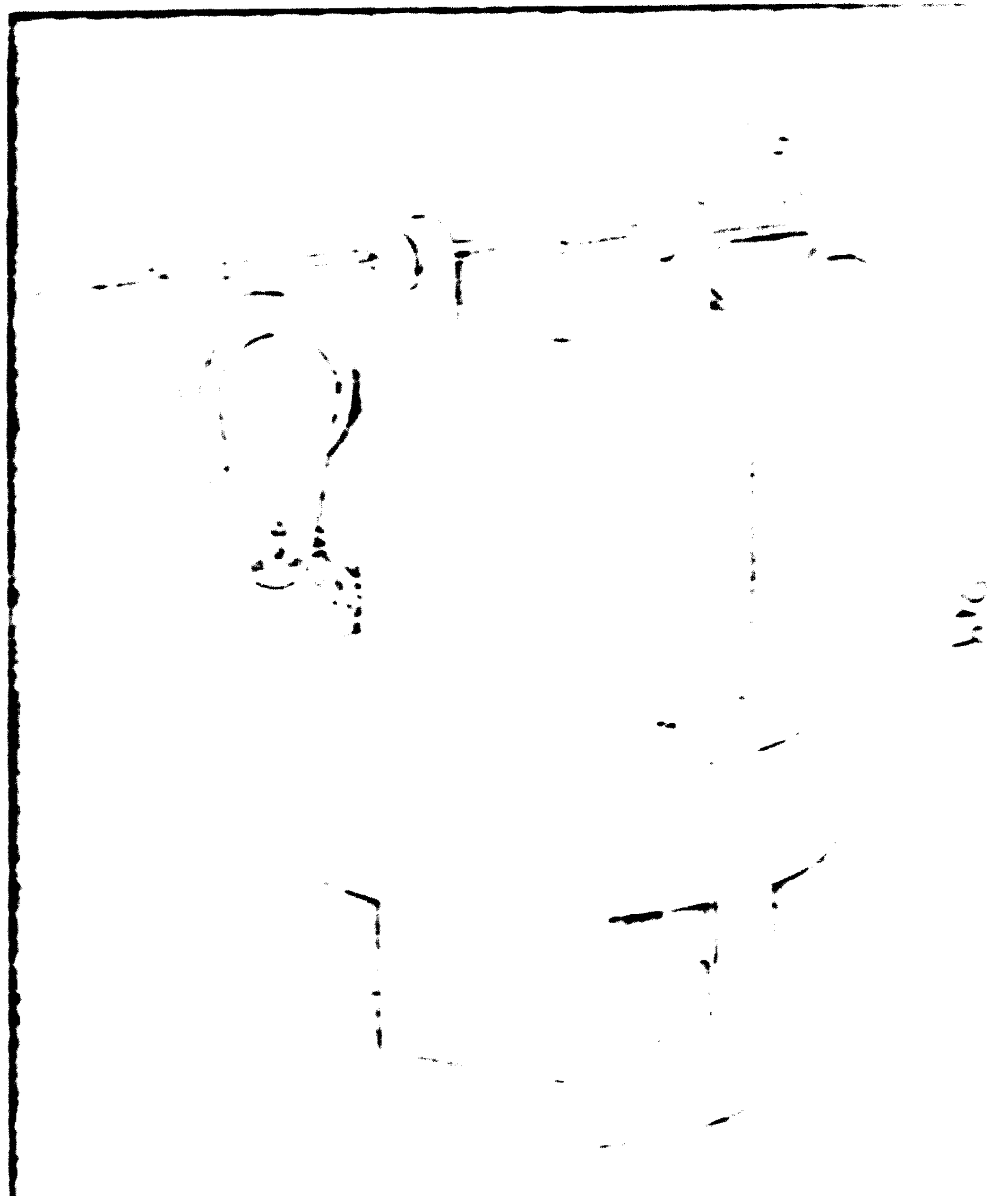

Fig. [illegible] Sky scanner and two [illegible] during [illegible]

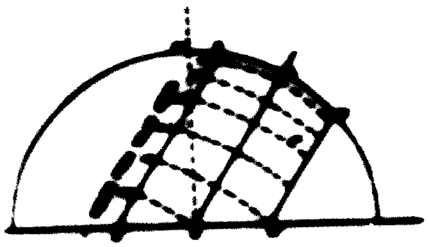

Fig. 5 - Projection of the sun's ecliptics on the N-S vertical plane.

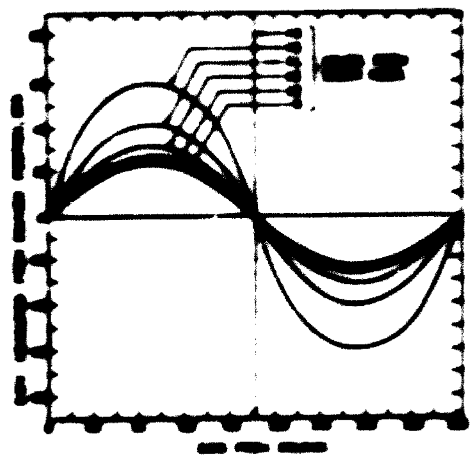

Fig. 6 - Plot showing how the [illegible] varies over the day and over the year.

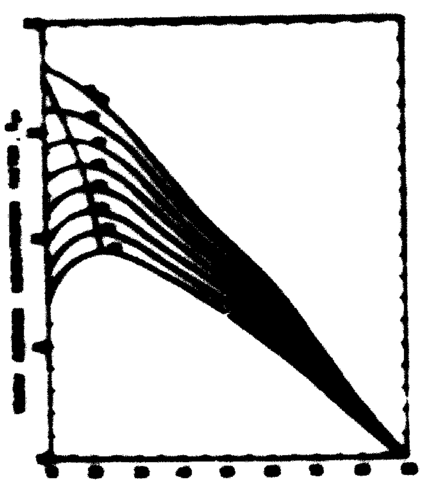

Fig. 7 - Plot of the yearly average concentration factor of a V-trough concentrator.

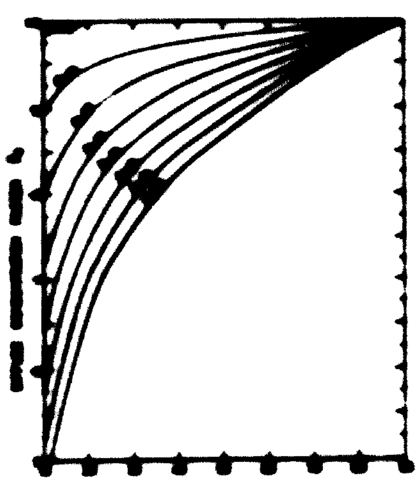

Fig. 8 - Plot of concentration factor for the diffuse component of solar radiation.

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# A CONCENTRATOR FOR THIN-FILM SOLAR CELLS

by

K.G.T. HOLLANDS & R.V. DUNKLE

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# A CONCENTRATOR FOR THIN-FILM SOLAR CELLS

by

K.G.T. HOLLANDS and R.V. DUNKLE*

## SUMMARY

This paper presents a theoretical study of a concentrating reflector suited to thin-film solar cells. The concentrator consists of a V-trough with specularly reflecting sidewalls and the thin-film cells attached to the base. It is designed to track the seasonal, but not the diurnal motion of the sun, by altering its tilt four times per year.

A method of determining the direct beam concentration factor as a function of the incidence angle, the opening angle and the sidewall angles of incidence associated with the diurnal and seasonal motion of the sun, and over an isotropic sky, has yielded the yearly average concentration factors for both the direct and diffuse components of solar radiation. Total yearly average concentration factors of two or higher appear to be possible with this concentrator design.



## 1. INTRODUCTION

It appears to be only a matter of time before solar photovoltaic cells, now well proven for space applications, will reach a price at which they can gain widescale acceptance for terrestrial use. At the present time, the thin-film, polycrystalline cadmium sulphide cell [1]* shows the greatest potential for receiving the needed price reduction.

This paper presents a study of the design of a concentrating reflector suited to thin-film solar cells. The concentrator, illustrated in Figure 1, consists of a V-trough, with specularly reflecting sidewalls and with the thin-film cells attached to the base. The trough is considered to be very long in the axial direction (normal to the plane of the drawing), and is mounted with its axis in the east-west direction, facing the equator. The concentrator is of the quasi-stationary type. By this it is meant that it tracks the seasonal, but not the diurnal motion of the sun. This is effected by manually altering its tilt four times per year.

In this paper a method of determining the direct beam concentration factor as a function of the incidence angle, the opening angle (angle ψ in Figure 1) and the sidewall reflectance is described. Integration of this concentration factor over angles of incidence associated with the diurnal and seasonal motion of the sun, and over an isotropic sky, has yielded the yearly average concentration factors for both the direct and diffuse components of solar radiation. These are presented for arbitrary opening angle and sidewall reflectance.

The treatment described here is limited to the case of perfectly specular sidewall reflectors and to the case where the dimensions of the trough are such that normal radiation suffers at most one reflection and is spread uniformly across the cells at the base after reflection. This latter condition generates a relation between the opening angle ψ and the length of the sidewalls, L (Figure 1) and is ensured if a normal ray striking the tip of the right-hand sidewall is reflected directly to the left-hand edge of the base, as does the ray of Figure 1.

## 2. DIRECT BEAM CONCENTRATION FACTOR

The fraction of direct beam solar radiation entering the trough which arrives at the base, either directly or via one or more reflections, can best be determined by an image technique applying to radiation in enclosures with specular walls [3,4]. Using this technique, a beam of solar radiation, which arrives at the base by reflection from a side reflector, is considered to have arrived at the image of the base formed when the side reflector is considered to be a mirror. Moreover, rays which arrive at the base via several reflections can be considered to arrive at successive images of the base formed by considering both side reflectors as mirrors. The case of two reflections is illustrated in Figure 2. A ray which arrives at an image of the base can be considered to have arrived at the base itself, except that its amplitude will have been decreased by an amount $\rho^n$, where n is the number of reflections it suffers.

Since the trough is considered to be infinite in the axial direction, only the projected angle of incidence of the ray to the plane of the cell need be considered

*The authors are, respectively, Senior Research Scientist and Chief Research Scientist at the Division of Mechanical Engineering, Commonwealth Scientific and Industrial Research Organization, Graham Road, Highett, Victoria, Australia.

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...e projected angle of incidence, denoted by $\phi$, is that angle which the projection of ...e incident ray on to the plane normal to the axis of the trough (i.e. the plane of ...e drawing of Figure 2), makes with the normal to the plane of the base. For conven...nce, in what follows all rays will be assumed to lie in this plane.

That each image makes an angle of $\theta$ with the preceding one, as shown in Figure 2, ... easily derived from elementary geometry. As stated in the introduction, the trough ... designed so that a normal ray ($\phi = 0$) striking the left-hand tip is reflected ...rectly to the right-hand edge of the base. In terms of the method of images, this ...plies that a normal ray striking the left-hand tip passes to the left-hand edge of ...e first image, as shown in Figure 2. Since the projection of the first image on to ...e baseline has width cos $\theta$ (the true width of the base being taken as unity), it ...llows that the width of the beam entering the trough is $1 + 2\cos\theta$, and that the ...ngth of the sidewall L, is $\cos\theta/\sin(\theta/2)$. If the irradiation on a surface normal ... the direction of the beam is $G_n$, then the irradiation incident on the cell is ... $+ 2G_n\,\rho\cos\theta$ and hence the concentration factor for normal radiation is $1 + 2\rho\cos\theta$. ...is has a maximum value of 3 when $\rho = 1$ and $\theta = 0$, in which event the length of the ...dewalls, L, must be infinite.

Now consider the case of off-normal incidence. Figure 3 shows the set of multiple ...ages produced in a typical reflector design, and the width of the parallel beam of ...diation entering the trough. The images are numbered according to the number of ...flections which a beam suffers to arrive at the image. The base itself is given the ...ber zero, images to the left are given a negative sign and those to the right a ...itive sign. The $k^{th}$ image makes an angle of $k\theta$ with the baseline, and since the ...ident beam makes an angle of $\phi$ to the normal to the baseline, the angle between the ...ident beam and the normal to the $k^{th}$ image is $\phi + k\theta$. It follows from this that, ...vided the $k^{th}$ image falls within the width of the beam, the energy incident on the ... image is $G_n\cos(\phi+k\theta)\rho^{|k|}$. In general, the energy incident on the $k^{th}$ image can be ...itten as $F_k\, G_n \cos(\phi + k\theta)\rho^{|k|}$ where $F_k$ is the fraction of the image which lies ...ide the incident beam. $F_k$ can be zero, unity or lie between zero and unity, depend... on whether the image lies completely outside, completely inside, or partly inside ... width of the incident beam. The total energy incident on the base is therefore:

$$Q_B = G_n \sum_{\substack{\text{all}\\ \text{images}}} F_k \cos(\phi + k\theta)\rho^{|k|} \qquad (1)$$

...e there no reflectors, the energy incident on the base would be $G_n \cos\phi$. Hence ... concentration factor is given by

$$K(\phi, \theta, \rho) = \sum_{\substack{\text{all}\\ \text{images}}} F_k \frac{\cos(\phi + k\theta)}{\cos\phi} \cdot \rho^{|k|} \qquad (2)$$

Using the technique outlined above, a computer program has been written which ...lculates the direct concentration factor K, for arbitrary $\theta$, $\phi$ and $\rho$. Figure 4 shows ...lot of the results of this program for some typical cases.

## 3. YEARLY AVERAGE CONCENTRATION FACTOR FOR DIRECT RADIATION

In order to determine the yearly average concentration factor for direct solar ...iation, it is necessary to integrate the direct beam concentration factor over the ...jected angles of incidence associated with the diurnal and seasonal motion of the ... in the sky. This requires a knowledge of the geometry of the sun's motion, and a ...cription of the tilting routine to be applied to the concentrator.

### ...AR GEOMETRY

Figure 5, taken from a paper of Tabor [2], is a projection on the north-south ...ical plane of the sun's ecliptics on equinox and solstice days. SS' represents the ... [illegible] ... winter solstice, and OL at the equinoxes. Angle POL is the geometric latitude, where OP is the zenith. When the ... is in a position whose projection on the north-south plane is X, angle XOL is the EWV altitude (measured from the equinox position), as defined by Tabor [2]. The EWV altitude can be calculated from the following relation, derived from solar geometry:

$$\tan(EWV(n,t)) = \frac{\tan(\delta(n))}{\cos(\frac{\pi t}{12})} \qquad (3)$$

where n is the number of days from the equinox, t is the time in hours from solar noon, and $\delta(n)$ is the solar declination. Equation 3 is plotted in Figure 6.

### TILTING ROUTINE

If a V-trough concentrator is orientated so that its axis is in the east-west direction, and tilted from facing the zenith by an angle equal to the geographical latitude, the projected angle of incidence of the solar rays on the cells is the EWV altitude. If the concentrator is then tilted from this position by an angle $\eta$, then the projected angle of incidence of the solar ray is:

$$\phi = EWV - \eta \qquad (4)$$

Since the concentration factor of a V-trough is maximum for $\phi = 0$, it is desirable to maintain $\phi$ as small as possible. This can be done by changing $\eta$ two, four or more times per year; that is by making $\eta$ a function of n, the number of days from the equinox. From Figure 6, it is evident that if $\eta$ is changed twice a year, so that $\eta = +20$ over one half of the year ($0<n<182$), and $\eta = -20$ for the other half ($182<n<365$), the maximum value of $\phi$ which the concentrator must accept in order to concentrate all radiation within ± 4 hours of solar noon, is 20°. If four changes per year are allowed, the maximum incidence angle which the concentrator must accept is correspondingly less. In this case the angle $\eta$ would be set at zero around the time of the equinoxes, and set at ± 23½° around the solstices. Thus $\eta(n)$ can be described by the following relations:

$$\left.\begin{array}{lll} \eta(n) = 0 & \text{for} & 0 < n < N_c \\ \eta(n) = \eta_c & \text{for} & N_c < n < 91 \\ \eta(n + 182) = -\eta(n); & \eta(182 - n) = \eta(n) & \end{array}\right\} \qquad (5)$$

The choice of values for $\eta_c$ and $N_c$ will be discussed at a later point.

### EXPRESSION FOR YEARLY AVERAGE CONCENTRATION FACTOR

Consider a concentrator which is tilted $\eta$ degrees from the latitude inclination. Let $G(t, n, \eta, \lambda)$ be the solar irradiation on a surface coplanar with the base of the concentrator, at time of day t, on the $n^{th}$ day from the equinox, at a site whose latitude is $\lambda$. Then the irradiation on the cells is $G(t, n, \eta, \lambda) \cdot K(\phi, \theta, \rho)$, where, from equation (4):

$$\phi = EWV(n, t) - \eta(n).$$

The daily radiation incident on the cells is:

$$\Phi_D = \int_{T_r(\lambda,n)}^{T_s(\lambda,n)} G(t, n, \eta, \lambda) \quad K(\phi, \theta, \rho)dt \qquad (6)$$

where $T_r$ and $T_s$ are the sunrise and sunset times respectively. The mean concentration factor for the day is then:

$$\bar{K}_d(n, \eta, \lambda, \theta, \rho) = \frac{\int_{T_r}^{T_s} G(t, n, \eta, \lambda)\, K(\phi, \theta, \rho)dt}{\int_{T_r}^{T_s} G(t, n, \eta, \lambda)dt} \qquad (7)$$

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The yearly average concentration factor is taken as the arithmetic mean of the daily means, that is

$$\bar{K}_Y(n_c, N_c, \lambda, \theta, \rho) = \frac{1}{365}\sum_{n=1}^{365} \bar{K}_d(n, n, \lambda, \theta, \rho) \quad (8)$$

The development above leads to a rather unwieldy expression for $\bar{K}_Y$, for not only is $\bar{K}_Y$ a function of 5 variables, it is also dependent on the shape of the solar radiation curve $G(t,n,n,\lambda)$. We therefore make some simplifying assumptions. The first of these is to represent the t dependence of $G(t,n,n,\lambda)$ by a sinusoid. That is, we put

$$G(t,n,n,\lambda) = G_m(n,n,\lambda)\cos\left\{\frac{t}{2T_r(\lambda,n)}\right\} \quad (9)$$

The second assumption is to ignore the effect of $\lambda$ on the value of $\bar{K}_Y$. The total swing of the EWV during a winter day is less than that for the corresponding summer day, for latitudes other than the equator. The daily mean concentration factor will therefore be slightly greater on a winter day than a summer day. Broadly speaking, however, what is lost in the summer will be made up for in the winter so that the effect of latitude on the yearly average concentration factor can be expected to be quite small. We can therefore, with little error, take $\lambda = 0$ and put $T_s = -T_r = 6$ hours. (On the equator, each day is exactly 12 hours long.) With these two assumptions, the expression for $\bar{K}_Y$ becomes:

$$\bar{K}_Y(n_c, N_c, \theta, \rho) = \frac{1}{365}\cdot\frac{\pi}{24}\sum_{n=1}^{365}\int_{-6}^{6}\cos\frac{\pi t}{12}\cdot K(\phi, \theta, \rho)dt \quad (10)$$

OPTIMUM VALUES FOR $n_c$ AND $N_c$

A value for $n_c$ of 23½° and for $N_c$ of 22 days has been found to represent a "near optimum" tilting routine for the concentrator, since it maximizes the yearly mean concentration factor for most concentrator designs. The details of determining this tilting routine are not presented here, but will be presented in the published form of this paper.

YEARLY AVERAGE CONCENTRATION FACTOR

The yearly average concentration factor corresponding to the near optimum tilting routine, $\bar{K}_{Y0}(\theta,\rho)$, has been calculated from equation (10) using $n_c = 23½°$ and $N_c = 22$ days. The results are plotted in Figure 7, for values of $\rho$ from .65 to 1.0 and values of $\theta$ from 10° to 90°.

## 4. THE DIFFUSE CONCENTRATION FACTOR

The diffuse concentration factor is that ratio which the irradiation on the solar cell associated with the diffuse solar radiation makes with the diffuse solar irradiation. Since diffuse radiation cannot be concentrated, the diffuse concentration factor is always less than or equal to unity. It can be shown that the diffuse concentration factor for an isotropic sky can be obtained by integrating the direct concentration factor according to the following relation:

$$\bar{K}_D(\theta,\rho) = \frac{1}{2}\int_{-\pi/2}^{\pi/2} K(\phi,\theta,\rho)\cos\phi \, d\phi \quad (11)$$

where $\phi$ is the projected angle of incidence. This integration has been performed numerically for values of $\theta$ from 10° to 90°, and for values of $\rho$ from .65 to 1.0. The results are plotted in Figure 8.

## 5. CONCLUDING REMARKS

From the preceding analysis one may conclude that total yearly mean concentration factors of the order of 2 are capable of being achieved with V-trough concentrators. Whether overall solar cell power costs can be significantly cut by use of the concentrating reflectors is a more complicated problem which it is hoped will be treated in a future paper. The answer of course depends on the relative costs of the cells and the reflectors, and must also take into account the temperature rise of the cells, as it [illegible]

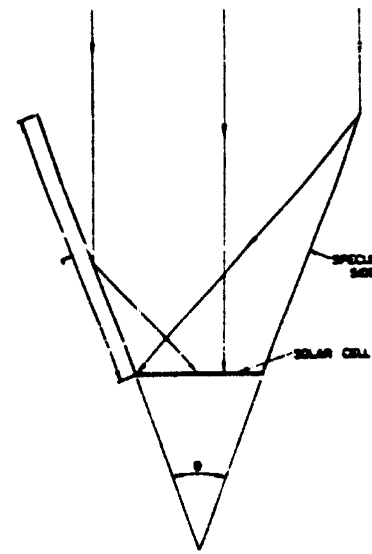


Fig. 1 - A V-trough concentrator.

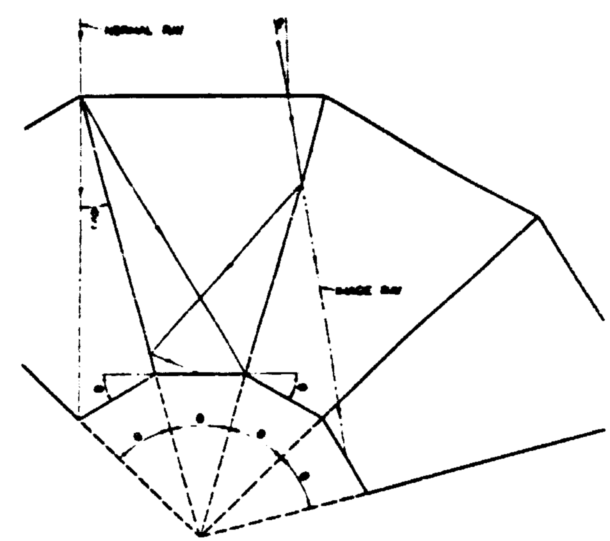


Fig. 2 - Method of images applied to a V-trough.

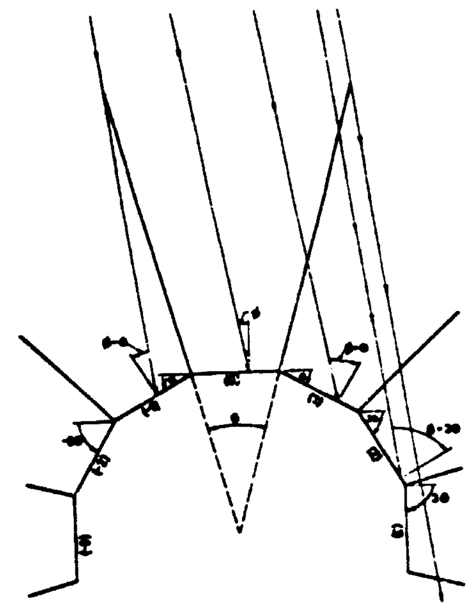

Fig. 3 - Complete set of multiple images, and a solar beam at off-normal incidence.

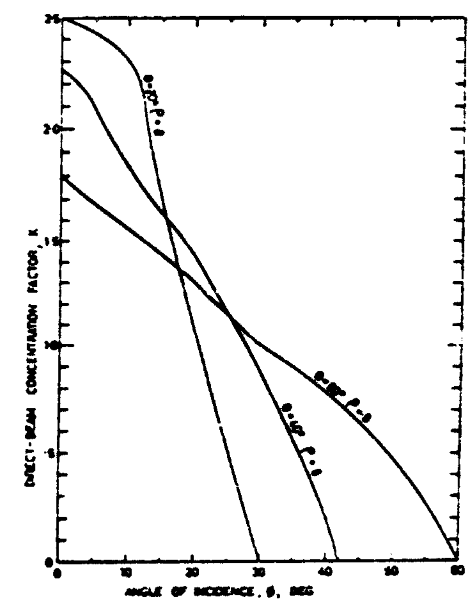


Fig. 4 - Direct-beam concentration factor as a function of the projected angle of incidence for several V-trough designs.

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# A COMPARISON OF THE MEASURED AND CALCULATED PERFORMANCE OF A SOLAR STILL

by

R.S. TRAYFORD & L.W. WELCH

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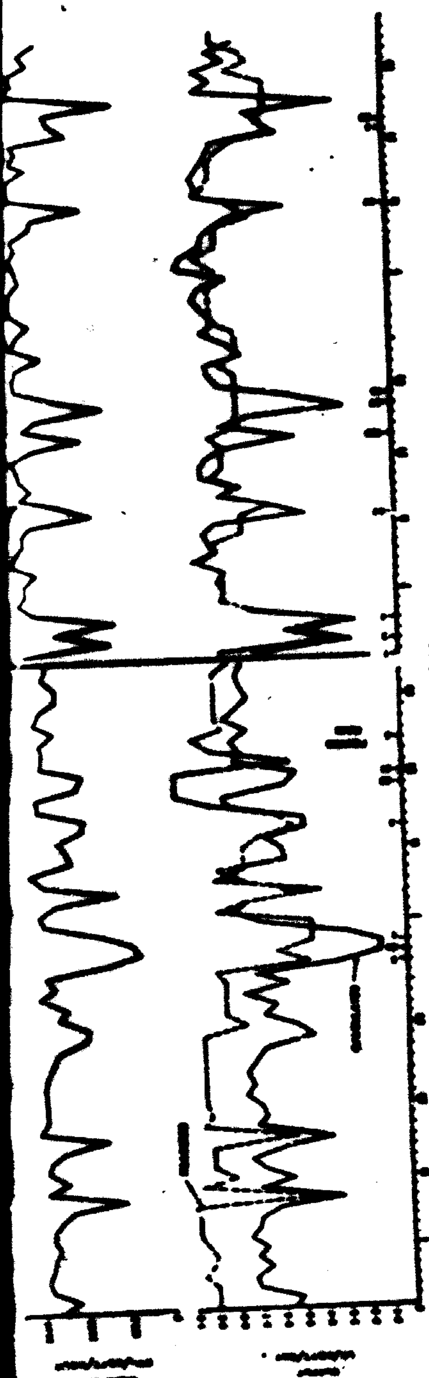

Fig. 4 - Two summers.

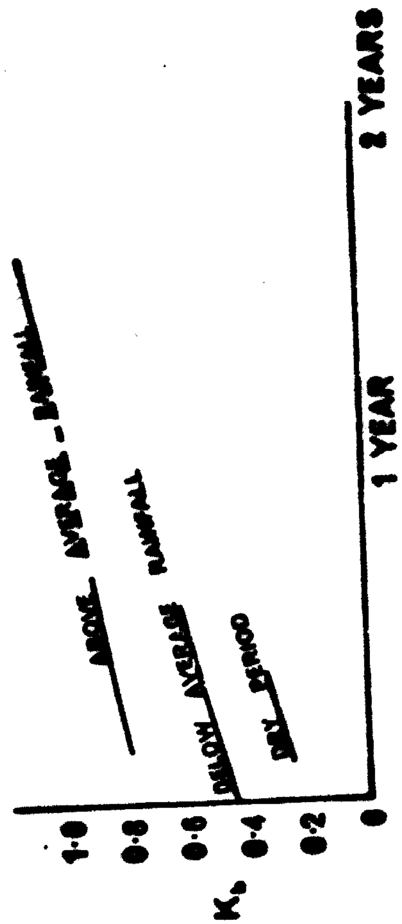


Fig. 5 - Long term changes in loss coefficient.

# A COMPARISON OF THE MEASURED AND CALCULATED PERFORMANCE OF A SOLAR STILL

by

R.S. TRAYFORD and L.W. WELCH*

## SUMMARY

A heat transfer model containing two parameters derived from experimental data has been used to compare the calculated performance with the measured output of a solar still over periods from 24 hours to 21 months. Using solar radiation and ambient temperatures as input data, hourly calculations are made for extended periods. These provide useful indications within a reasonable error band, of trends suggesting longterm changes and the influence of rain.

## INTRODUCTION

In the case of the solar still the need for a model to calculate the output is necessary in order to (a) further understand the physical process, (b) optimise the still design, (c) test the feasibility of proposed installations and (d) check the performance of existing stills.

This simplified model, following Dunkle [1]+, Morse [2] and Cooper [3], is biased towards aims (c) and (d) as it simplifies the approach to heat losses and does not consider geometric effects.

The most important simplification of this model is the treatment of the side and base heat losses. This approach leads to the consideration of two parameters, $C_{wg}$ and $K_b$, which represent the water equivalent of the base mass and the side heat loss coefficient respectively.

## THE MODEL

Figure 1 illustrates the main components of the heat balance considered in this model. A heat balance on the saline water can be written as follows:

$$\alpha_w \tau_g H_s = Q_e + Q_c + Q_r + Q_b + Q_s + M_w C_w \frac{d(T_w)}{dt} \qquad (1)$$

Considering a depth of soil such that $T_b$ remains constant then

$$Q_b = M_b C_b \frac{d(T_w + T_b)/2}{dt} \qquad (2)$$

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+Numbers in square brackets refer to references listed at the end of the paper.

Since $T_b$ is a constant

$$Q_b = \frac{1}{2} M_b C_b \frac{d T_w}{dt} \qquad (3)$$

Also

$$Q_s = K_b \quad (T_w - T_s) \qquad (4)$$

Substituting (3) and (4) in (1)

$$\alpha_w \tau_g H_s = Q_e + Q_c + Q_r + K_b(T_w - T_s) + (\frac{1}{2} M_b \quad C_b + M_w C_w) \frac{d T_w}{dt}$$

$$= \text{(Heat Transfer Water to Glass)} + K_b \ (T_w - T_s) + C_{wg} \quad \frac{d T_w}{dt} \qquad (5)$$

The still output is dependent upon the temperatures $T_w$, $T_g$. Thus if predicted output is to balance with measured output, "heat transfer water to glass" is determined; the heat balance (equation (5)) is obtained by selecting suitable values for $C_{wg}$ and $K_b$, for simplicity $T_s$ was considered equal to $T_a$.

The coefficient $C_{wg}$ can be estimated from the theoretical expression. For the particular still being considered $C_{wg}$ varies over the range 4 to 20. 4 is obtained if $T_b$ is considered to coincide with the still liner, and 20 if $T_b$ is approximately 2 feet below the liner. The coefficient $C_{wg}$ is a capacitance term and as such introduces a lag into the system. A suitable value can be assessed by comparing measured and calculated values of temperature and output at hourly intervals over a 24 hour period.

Of loss terms not considered that due to vapour leakage through air entering and leaving the still by means of an established convection path is the most important. Present knowledge does not allow a magnitude to be determined for this term. Therefore such losses are at present incorporated in the term $K_b$. Vapour loss due to the difference between internal and external pressure is negligible as can be shown by calculation. A computer program has been developed which accepts hourly data of solar radiation, ambient temperature and wind velocity (when available). It calculates the saline water temperature and the cover temperature by an iterative computation until a heat balance is obtained.

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## A THREE DAY CALCULATION

Using a MK III CSIRO design still [4] at Griffith, New South Wales, the results of an hour by hour computation over a three day period is shown in Figure 2. Solar radiation was measured on a Trickett-Norris pyranometer and recorded on a CSIRO electronic integrating recorder. The still output was measured using a tipping bucket meter and transferred by means of a reed relay circuit to form a square wave on a chart recorder. Ambient, glass and water temperatures were measured by thermocouples and recorded on a chart recorder. The results (Fig. 2) show that the computed values follow the observed values with an amplitude and phase error. The amplitude error can be made negligible by a change in the value of $K_b$. The residual phase lag indicates that a further refinement of the model is necessary. This work is continuing.

## EXTENDED PERIODS

For runs of extended periods it is advantageous to use the same values of $K_b$ and $C_{wg}$ for a suitable period. It would be unrealistic to consider abrupt changes in these values. It is considered that if calculated and measured daily outputs lie within a ± 10% error band over this period then it is justifiable to make use of the results. A period of one month has been found satisfactory. Rain days must necessarily be excluded because of the ingress of rain into the still.

The data collected from the unit considered over an extended period of two years consisted of solar radiation measured hourly as above, maximum and minimum temperature, and daily output.

... output was measured at 9 a.m. on five days per week. The accumulated output of weekend and holiday periods is a problem which has to be recognised when scoring the computed and measured results.

The hourly ambient temperatures were interpolated in the program by using a cosine relationship between the maximum and minimum values. The still was installed in August 1967 and consistent data has been obtained from the 1st September, 1967, until the present.

## THE FIRST FIVE MONTHS

The weather pattern in this period from spring until mid-summer was of decreasing rainfall with no rain at all in December then above average rainfall in January 1968. The plot of calculated and measured output is shown in Figure 3 for a $K_b$ of 0.48. It can be seen from the Figure that there is good agreement between calculated and measured outputs with solar radiation being the predominant influence. The calculated outputs are, in general, too low at the beginning of the period and too high at the end of the period, keeping in mind that rain days are excluded. The significant change in January is attributed to rain, or its effects. It has been observed that after rain, water does enter joints in the sheet metal runoff channels despite sealing and wets the ground underneath the edge of the still. The difference between the calculated output on a rain day and the measured output indicates the degree to which rainwater enters the still and is collected by the distillate channel. The weekend and holiday periods are represented as an average value on the graph. The efficiency is based on the calculated value of output and as such does not indicate changes in the side loss coefficient ($K_b$) over the period, but merely the increased radiation.

## TWO SUMMERS

To examine the possible changes over one year a calculation was carried out for the monthly pair December-January 1967/68 and 1968/69 using a $K_b$ of 0.8. The results seen in Figure 4 show that using a $K_b$ of 0.8 results in a good fit for the latter two months compared to January 1968. These three months had significant rain compared with December 1967 which had no rain. Taking this into account and considering the use of a constant $K_b$ value, it can be seen that there is a decrease in performance for the second summer compared with what could have been expected from the results of the first summer. It is probable, but not conclusive, that a long term deterioration has taken place over the period of one year and it is possible this is due to increased side losses due to greater rain water entry under the edge of the still, saline water leaking through the liner and increased vapour losses due to deterioration in sealing.

## A 21 MONTH PERIOD

A study of computed results from the available data suggests that the two predominent influences on long term changes of this particular still were rain and deterioration, in that order. This trend is shown in Figure 5 which classifies the rain pattern into three classes. The average rainfall at Griffith is 121 points per month so that above average was considered as around 200 and above, below average under 100 and the drier period as having negligible rain. The deterioration found from this latter study agrees with the two summer periods considered above.

## CONCLUSIONS

The experience with this still demonstrates the need to protect the still against the influence of rain by insulation or other means. The long term deterioration shows the need to ensure that the detailed design and general integrity of the still is unquestioned and that the materials will withstand the environment.

The collection of good data at consistent daily intervals over the complete period beginning with the installation of the still and including hourly solar radiation data for large stills. For conventional stills regular tests of the soil moisture content would help with this interpretation. Further work on insulated stills along similar lines should lead to a better experimental verification of the relative losses encountered.

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## NOMENCLATURE

| | | |
|---|---|---|
| $C_b$ | Specific heat of the ground | Btu/lb,°F |
| $C_w$ | Specific heat of the water | Btu/lb,°F |
| $C_{wg}$ | Water equivalent of saline water and ground | Btu/°F,ft$^2$ |
| $H_s$ | Solar radiation on horizontal surface | Btu/hr,ft$^2$ |
| $K_b$ | Side heat loss coefficient | Btu/hr,ft$^2$,°F |
| $M_b$ | Mass of ground - to depth x | lb |
| $M_w$ | Mass of saline | lb |
| $Q_b$ | Rate of heat transfer by conduction - saline to ground | Btu/hr,ft$^2$ |
| $Q_c$ | Rate of heat transfer by convection - saline to glass | Btu/hr,ft$^2$ |
| $Q_{ca}$ | Rate of heat transfer by convection - glass to ambient | Btu/hr,ft$^2$ |
| $Q_e$ | Rate of heat transfer by evaporation - saline to glass | Btu/hr,ft$^2$ |
| $Q_r$ | Rate of heat transfer by radiation - saline to glass | Btu/hr,ft$^2$ |
| $Q_{ra}$ | Rate of heat transfer by radiation - glass to ambient | Btu/hr,ft$^2$ |
| $Q_s$ | Rate of heat transfer by conduction - saline to still wall | Btu/hr,ft$^2$ |
| t | Time | hr |
| $T_b$ | Temperature of ground - at depth x | °F |
| $T_g$ | Temperature of glass | °F |
| $T_s$ | Temperature of still wall | °F |
| $T_w$ | Temperature of saline | °F |
| x | Depth of ground at which $T_b$ can be considered constant | ft |
| $a_w$ | Absorptance of still base for solar energy | |
| $\tau_g$ | Transmittance of glass cover plus water film for solar energy | |

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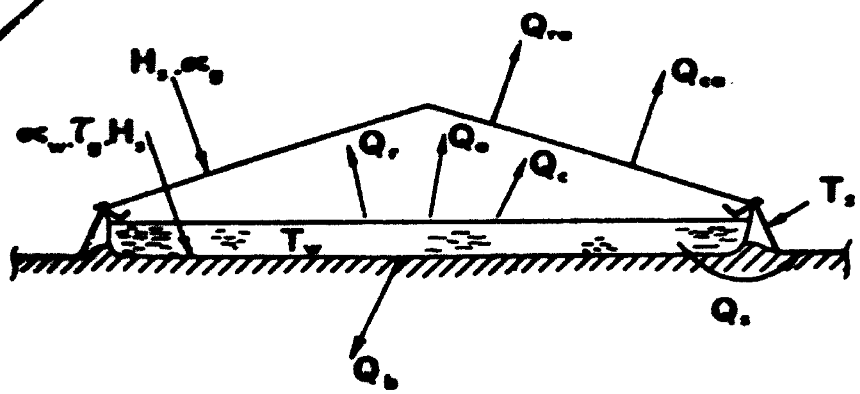


Fig. 1 - Solar still heat balance.

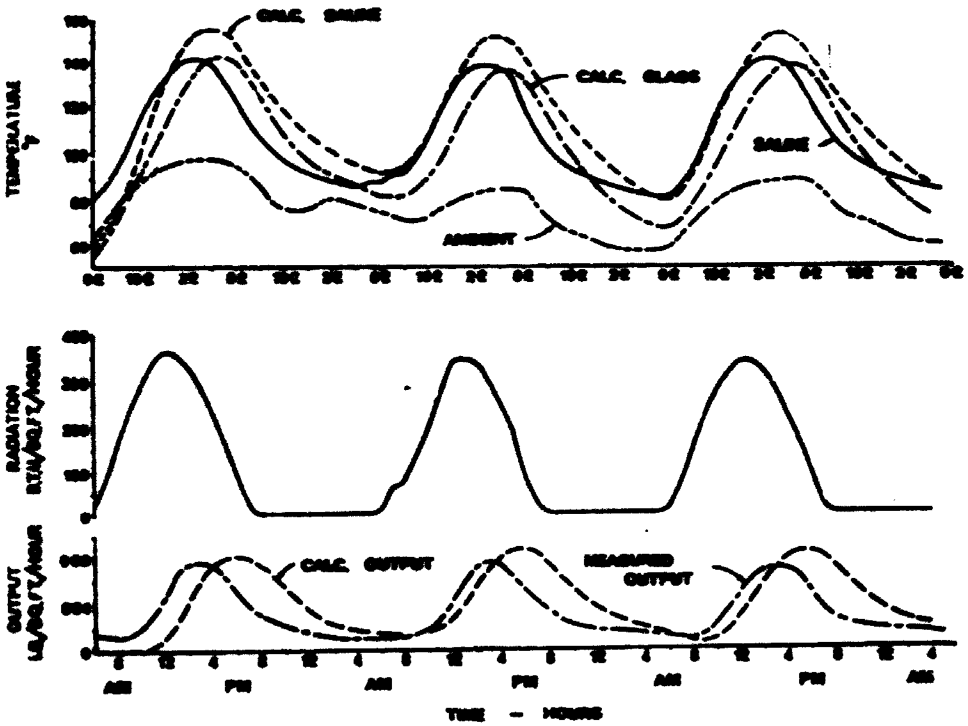


Fig. 2 - Three day performance.

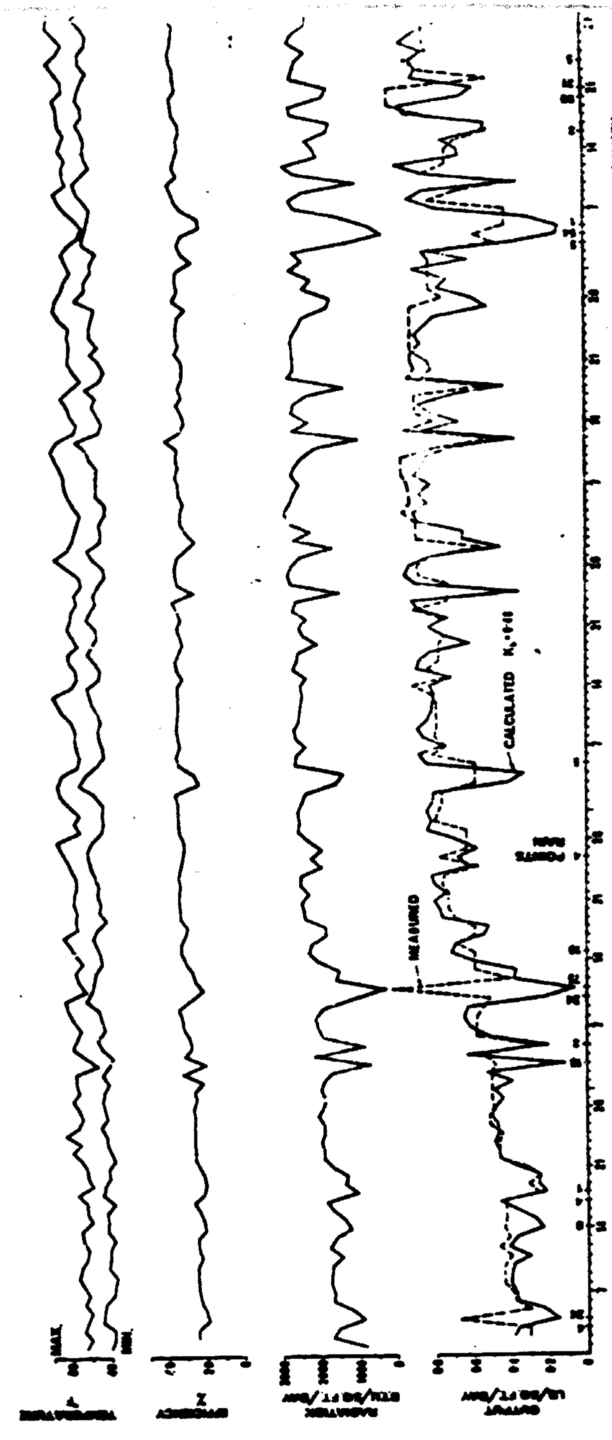


Fig. 3 - Five month performance.

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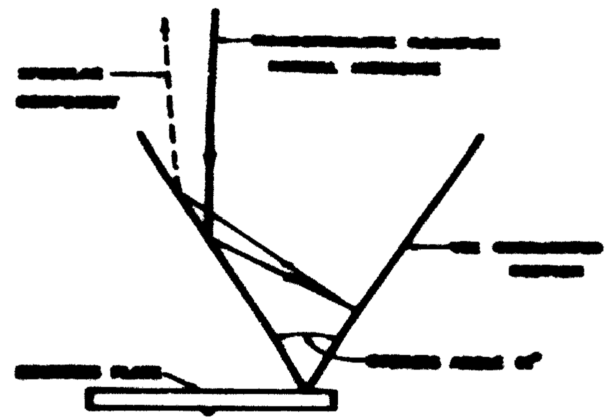

Fig. 5 - Diagram of measuring technique for a vee-corrugated section.

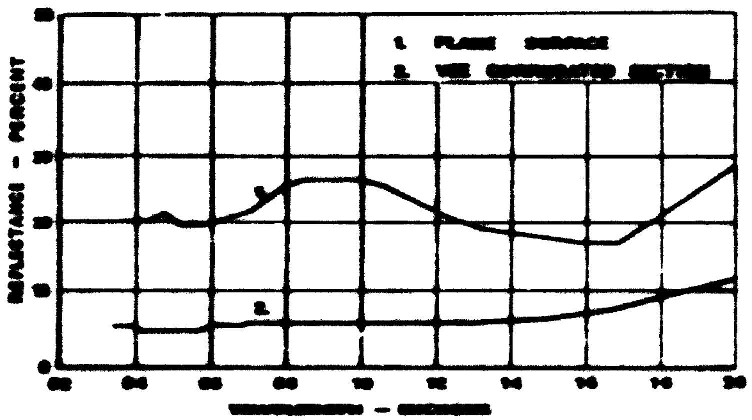


Fig. 6 - Spectral reflectance of vee-corrugated copper-clad steel with selective black.

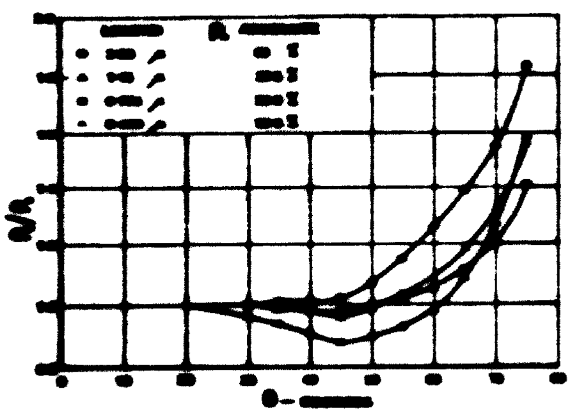

Fig. 7 - Normalized directional reflectance of selective black on copper-clad steel.

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**SPECTRALLY SELECTIVE BLACKS FOR SOLAR ENERGY COLLECTION**

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## SPECTRALLY SELECTIVE BLACKS FOR SOLAR ENERGY COLLECTION

by

E. A. CHRISTIE*

### SUMMARY

One method of reducing heat losses from a hot target for solar energy collection is to treat the absorber so that it strongly absorbs solar irradiation, and at the same time becomes a poor emitter of thermal radiation. Such a surface is known as a spectrally selective black.

The mechanism of spectral selectivity is briefly considered and methods for preparing selective blacks on steel and copper by chemical oxidation processes are described. Spectral reflectance curves for these surfaces are presented, and the method of determining the solar absorptance and thermal emittance values from the spectral data is described.

Directional selectivity is also considered and measured absorptance of a vee-corrugated surface is compared with the theoretical value for a vee-corrugated specular surface.

### 1. INTRODUCTION

In general, to make most efficient use of solar energy, it must be absorbed at the highest possible temperature. The equilibrium temperature of a surface when it is heated by solar irradiation is largely dependent on two factors:-

1. the amount of incident solar radiation absorbed. This is proportional to the solar absorptance, $\alpha_s$.
2. the quantity of radiant energy emitted by the surface. This depends on its emittance, $\epsilon_T$.

Emitted radiation at common solar collector temperatures is in a wavelength range longer than that of sunlight. The possibility therefore arises of having a surface which is selective in character, so that it will strongly absorb solar irradiation, and at the same time be a poor emitter of thermal radiations.

The advantages to be gained in using a spectrally selective black for solar energy collection were first demonstrated in separate papers presented by Tabor [1,2] and Gier and Dunkle [3] at a conference in 1955 on the uses of solar energy. Up to that time black paint had been used as the absorbing surface on solar energy collectors. Properties of black paint are very close to those of an ideal black body in that it is a very good absorber of solar irradiation, $\alpha_s$ = 95%, and generally a very good emitter of far infrared radiation with a typical emittance value being $\epsilon_{100°F}$ = 90%. Comparative values for a typical selective surface on copper are $\alpha_s$ = 90% and $\epsilon_{100°F}$ = 20%.

### 2. MECHANISM OF SPECTRAL SELECTIVITY

The basic requirement of a surface to be spectrally selective to radiation is that it must be a thin film of a black semiconductor, on a polished metal substrate which

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Numbers in square brackets refer to references listed at the end of the paper.

is highly reflecting to radiation with wavelengths longer than solar.

The behaviour of semiconductor is illustrated in the semiconductor transmission curve [4] shown in Fig. 1. High absorption occurs in region A where the energy level of the radiation is sufficient to excite the valence band electrons that they will promote to the conduction band.

An energy level in which electrons can exist in a solid is called an allowed energy band. Each solid usually has several allowed energy bands which are separated by energy levels where electrons cannot exist; these levels are called forbidden zones. In a given energy level an electron has a fixed quantity of energy and, in order to promote to a higher energy level, the electron must gain sufficient energy to cross the forbidden zone. This critical quantity of energy is known as the gap energy, Eg. Therefore, photons containing less energy than Eg will not be absorbed. This accounts for the abrupt change in the absorption constant of a semiconductor in the near infrared wavelength region. The semiconductor film becomes transparent to radiation with a photon energy level less than Eg.

Change in the magnitude of the absorption constant is usually very abrupt for a pure semiconductor, but as the concentration of impurities in the semiconductor increases the degree of selectivity to radiation decreases. The greatest variation from the abrupt change in the absorption constant is determined by the physical structure of the semiconductor. Film thickness also has an important effect on the spectral characteristics exhibited by the film. The greatest degree of selectivity is exhibited by a pure, homogeneous, continuous thin film, and the least degree of selectivity is brought about by a thick, impure, amorphous coating of the semiconductor.

To obtain maximum advantage of the transparency of the semiconductor in the infrared wavelengths, the substrate, on which the thin film is formed or deposited, must be a poor emitter of thermal radiation. Due to their very high extinction coefficients at infrared wavelengths, metals with high electrical conductivity are highly reflecting to longwave radiation. This is because of the high concentration of conduction electrons within the metal.

The reflectivity of pure highly-polished metals decreases as the wavelength of the incident radiation decreases. Spectral reflectance curves for some pure polished metal surfaces are given in Fig. 2. It can be seen that these metals are highly reflecting to far infrared radiations of wavelengths greater than 5 microns. From Kirchhoff's law, these metals are, therefore, poor emitters.

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### 3. METHODS OF PREPARING SELECTIVE BLACKS ON METALS

There are two basic methods by which spectrally selective blacks may be formed on metal surfaces, either the semiconductor is deposited on the polished metal surface or the surface of the metal is converted into a black semiconductor by some process. The first method probably allows a greater range of metals to be treated and includes painting, vacuum coating and electrodeposition processes. The second method, a direct chemical reaction, is a relatively simple process, particularly in the case of oxidation.

If a surface is to be used for collecting solar irradiation, then it must be stable against corrosion and photochemical reactions. The preparation of a spectrally selective black on steel, therefore, has very little practical significance because the surface film does not offer any protective properties to prevent the substrate from being attacked by corrosion. However, a black on steel with very good spectral selectivity has been prepared using a commercial blackening preparation known as Ebonol S-30. The film produced is a black adherent layer of ferroso-ferric oxide $Fe_3O_4$.

The aqueous bath solution contains [illegible] salts per gallon. Oxidation of the steel is carried out with the solution boiling at about 300°F. Immersion time depends on the properties required of the plate being treated. Figure 3 shows the effect of treatment time on the spectral reflectance characteristics of the sample, with a [illegible] minute immersion producing a surface with good selectivity so that $\alpha_s$ = 90% and $\epsilon$ = [illegible]%.

[illegible] treatment is expensive when [illegible] other metals, copper has many [illegible] that are desirable for fabrication of absorbers for water heating. It is [illegible] to corrosion, [illegible] can be treated by a simple [illegible] dip process to convert the surface of the metal to a selective black. Most of the solar absorbers for water heating produced commercially in Australia are [illegible] from copper sheet and tube, and a large fraction of these are treated to give [illegible] selective black by a method developed by C [illegible].

[illegible] treatment tanks are required for commercial production of a selective black [illegible] solar water heater absorber plates. The tanks, with provision for heating [illegible] solutions, are made from mild steel, and have dimensions so that the absorber plate [illegible] completely immersed in the solution contained in the tank. One tank contains an [illegible] degreasing solution, and the other contains the alkaline oxidizing solution. [illegible] container, fabricated from an acid resistant material and filled with 5% by [illegible] solution of sulphuric acid or other proprietary acid salt solution, is used to [illegible]-etch the copper.

When the plate is thoroughly clean it is immersed for [illegible] minutes in the alkaline [illegible] bath at 140°F, which contains [illegible] lb of sodium hydroxide and [illegible] lb of commercial [illegible] chlorite per gallon of solution. Immediately after removal from this solution, [illegible] plate is rinsed with water, until all traces of alkali are removed, and allowed to dry. A surface which has been correctly treated has a deep blue to black colour [illegible] slight gloss appearance.

The chemical composition of the surface is not known but it is believed to be [illegible] cupric oxide with cuprous oxide and traces of other compounds formed by [illegible] reactions. Reactions that do most likely occur during the oxidation process [illegible]:

$$2Cu + 2NaClO_2 \rightarrow Cu_2O + NaClO_3 + NaCl$$

$$Cu_2O + 2NaClO_2 \rightarrow 2CuO + NaClO_3 + NaCl$$

[illegible] spectral properties of the selective black formed on copper are shown in Fig. [illegible] [illegible] in the alkaline oxidation bath for 3 minutes gives $\alpha_s$ = 70% and $\epsilon_{[illegible]}$ = [illegible]. [illegible] immersion for 10 minutes increases $\alpha_s$ to 90% and $\epsilon$ [illegible] to [illegible].

[illegible] commercial production, regular analyses of the constituent concentrations [illegible] oxidising bath are desirable, so that the solution can be maintained at a uniform [illegible]. Sodium hydroxide content of the solution is determined by direct titration [illegible] standard acid and phenolphthalein indicator. Concentration of sodium chlorite [illegible] determined by iodimetry. The bleaching solution is treated with sulphuric acid [illegible] presence of potassium iodide, and iodine liberated is titrated with standard [illegible] thiosulphate, adding starch indicator solution near the endpoint of the titration. [illegible] reactions that occur are as follows:-

$$ClO_2^- + 4I^- + 4H^+ \rightarrow 2I_2 + Cl^- + 2H_2O$$

$$2I_2 + 4S_2O_3^{--} \rightarrow 4I^- + 2S_4O_6^{--}$$

## [illegible]. MEASUREMENT OF SURFACE PROPERTIES

[illegible] spectral reflectance characteristics of the surfaces have been measured with a [illegible] spectrophotometer. This instrument consists of a Perkin-Elmer model [illegible] monochromator [illegible] associated electronics, attached to Gier-Dunkle Thermal Instruments Integrating [illegible] and Heated Cavity Reflectometer attachments. With this instrumentation [illegible] reflectance measurements as a function of angle of incidence can be conducted over a [illegible] wavelength range from 0.3 to 25 microns. Results reported are near normal reflectance [illegible] with an incidence angle i = 20°.

[illegible] absorptance properties of a surface are measured with the sample mounted in [illegible] integrating sphere. The spectral reflectance is determined at fifty different [illegible] given in Table I. Each point in [illegible] band containing [illegible]

provides a simple method of integrating the results to give the solar reflectance [illegible] hence solar absorptance for an [illegible] sample.

Table I

| | | | | |
|---|---|---|---|---|
| 0.360 | [illegible] | [illegible] | 0.796 | [illegible] |
| 0.383 | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.425 | 0.548 | [illegible] | [illegible] | 2.05 |
| 0.440 | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.453 | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.465 | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.478 | 0.598 | [illegible] | [illegible] | [illegible] |
| 0.488 | [illegible] | [illegible] | [illegible] | [illegible] |
| 0.499 | 0.624 | [illegible] | [illegible] | [illegible] |

Emittance of the sample is determined from the spectral reflectance curve resulting from measurements at fixed wavelengths with the sample mounted in the heated cavity. Points are chosen from the graph so that each point represents a [illegible]% energy fraction of the total emissive power of a blackbody at the temperature for which emittance is to be evaluated.

For a blackbody at [illegible]°F about [illegible]% of the total emissive power has wavelengths greater than 25 microns. In calculating the emittance value for a sample it is assumed that the spectral reflectance remains constant in this region at a value similar to that between 20 and 25 microns.

Solar absorptance properties of [illegible] corrugated copper [illegible] treated [illegible] spectrally selective black, have been measured in the integrating sphere. [illegible] of the plate with an opening angle [illegible] 32° was mounted [illegible] partly irradiated with monochromatic radiation at an incidence angle normal to the plane of the plate. This means that the fin was irradiated at an incidence angle [illegible] from normal where the first reflection occurred. A schematic diagram of the measuring technique is shown in Fig. [illegible].

Solar absorptance for the plane surface for near normal incidence was measured to be $\alpha_s$ = 70% and for the [illegible] corrugated plate solar absorptance was increased to [illegible]. For a specular surface with a plane solar absorptance of [illegible]% the [illegible] [illegible] corrugation with an opening angle of 32° increases the solar absorptance to about 90%.

Spectral reflectance characteristics of the plane surface and [illegible] corrugated [illegible] are shown in Fig. [illegible] and the normalized directional reflectance for the plane surface is given in Fig. [illegible]. The degree of specularity of the surface reflectance was measured and results are given in Table II.

TABLE II

| | | | | |
|---|---|---|---|---|
| Wavelength (microns) | [illegible] | [illegible] | [illegible] | 2.[illegible] |
| Specularity % | [illegible] | [illegible] | [illegible] | [illegible] |

Specularity as measured here is the ratio of reflected monochromatic radiation scattered over an angle less than [illegible]° from the normal incident beam to the total radiation reflected from the surface for an incidence angle of 20° at the same wavelength.

## [illegible]. CONCLUSIONS

The methods of treating metal surfaces to produce spectrally selective [illegible] by simple chemical oxidation processes have [illegible] [illegible] absorbers [illegible]

... a method of measuring solar absorptance properties of vee-corrugated surface has been described.

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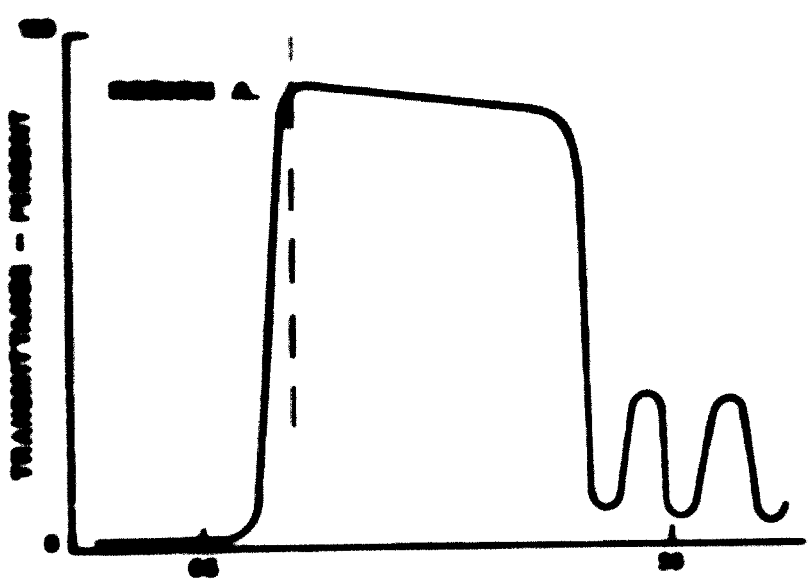


Fig. 1 - Generalized spectral transmittance for semiconductors


Fig. 2 - Near-normal spectra ...

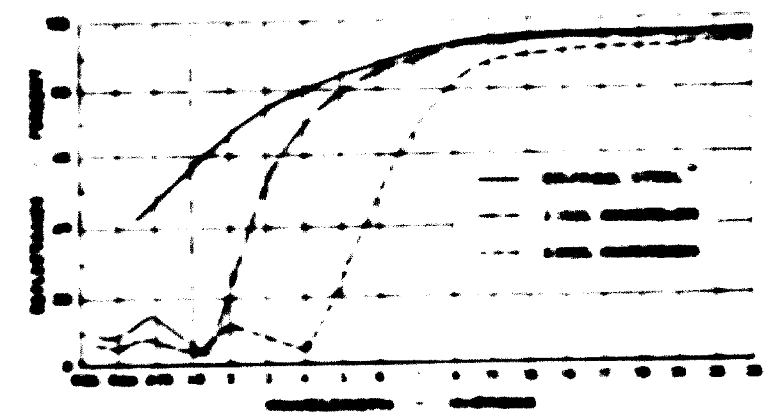


Fig. 3 - Near-normal spectral reflectance ...


Fig. 4 - Near-normal spectra ...

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[illegible]

# SIXTH WORLD POWER CONFERENCE

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SUB-DIVISION / SOUS-SECTION III.7 — PAPER / RAPPORT 119 III.7/2 — AUSTRALIA / AUSTRALIE

## SOLAR ENERGY AS AN AID TO THE DEVELOPMENT OF THE TROPICS

## L'ÉNERGIE SOLAIRE ÉTUDIÉE COMME AIDE DU DÉVELOPPEMENT DANS LES RÉGIONS TROPICALES

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### 1. Introduction

The tropical regions of the earth present a difficult challenge to the ingenuity of man in devising means to live and work comfortably and productively under adverse climatic conditions. It appears that man can only work effectively under fairly narrow environmental conditions, and where these conditions are not satisfied, productivity and the standards of living are low. Tropical areas are further hampered by fuel and power shortages, poor soils, water shortages, and under-development of natural resources. A common factor in nearly all tropical areas is a uniform and high insolation throughout the year. The purpose of this paper is to point out some of the ways in which this plentiful supply of solar energy can be utilised in the development of the tropics.

It is not generally recognised that about 40 per cent. of the land areas of the earth are subject to tropical climates, Trewartha[1], and if the frozen wastes of the Arctic and Antarctic are discounted, the figure is even more impressive. A large portion of the world's population live in tropical or sub-tropical conditions. According to Kapur[2], with a few exceptions, almost

1 G. T. TREWARTHA. "An Introduction to Weather and Climate." McGraw-Hill Book Co. Inc., New York, [illegible].
2 J. C. KAPUR. "Socio-economic Considerations in the Utilisation of Solar Energy in Under-developed Areas." U.N. Conf. on New Sources of Energy, [illegible].

the entire population of about two billion people of the under-developed areas reside within 30 degrees of the equator with the greater concentration in the north. At this point it may be worthwhile to briefly review the types of tropical climates.

According to Koeppen[1], tropical climates can be divided into two major groups: tropical rainy climates and tropical dry climates.

(a) *Tropical Rainy Climates*

The tropical rainy climate covers the portion of the earth with adequate rainfall, that is precipitation exceeds evaporation, and the mean temperature of the coldest month exceeds 18 C (64.4 F). The humid tropics comprise a somewhat interrupted and irregular belt 20 to 40 degrees wide around the earth and straddling the equator. This region is distinguished from all other humid regions of the earth by its continuous warmth; it lacks a winter. The chief interruptions of the belt of humid tropical climates are due to the mountains and plateaus of the continents where elevation affects the climate.

Approximately 36 per cent of the total area of the earth lies within the humid tropical area; this represents about 20 per cent of the total land area and 42 per cent of the ocean surface. The humid tropics have three principal subdivisions or types of climate. These are the tropical rainforest climate, in which there is no dry season and all months have more than 6 cm. of precipitation, the monsoon rainforest climate, in which unusually heavy rainfall compensates for a short dry season, and the savanna climate in which the dry period is longer and more severe, or the rainfall of the wet period is insufficient to compensate for the drought.

The solar irradiation is high in the humid tropics, but due to the high humidity and numerous clouds the diffuse component is large and may amount to as much as 50 per cent of the incident radiation. In these regions flat plate absorbers are normally more suitable than concentrating devices for solar energy installations. Heat losses from equipment are reduced as a result of the high ambient temperatures. Heat storage systems may be worthwhile due to the intermittent nature of the insolation.

The remarkable uniformity is one of the principle features of the humid tropical climate. The daily variation in temperature is small, in the order of 5°C., and is generally greater than the seasonal variation in the mean monthly temperature. As an illustrative example, the daily wet and dry bulb temperatures at 6 a.m. and 3 p.m. (approximately the maximum and minimum) for the month of January, 1960 in Darwin are plotted in Fig. 1. It will be noted that the wet bulb temperature is continually high and that the variation in dry bulb temperature from day to night and throughout the month is small. The peak temperatures are not extremely high, but the continued high humidity and lack of relief at night make this climate extremely trying.

(b) *Dry Tropical Climates*

The essential feature of a dry climate is that evaporation exceeds precipitation, that is, during the year more water can be evaporated than

[1] W. KOEPPEN, "Das Geographische System der Klimate" Vol. 1, Part C, 1936.

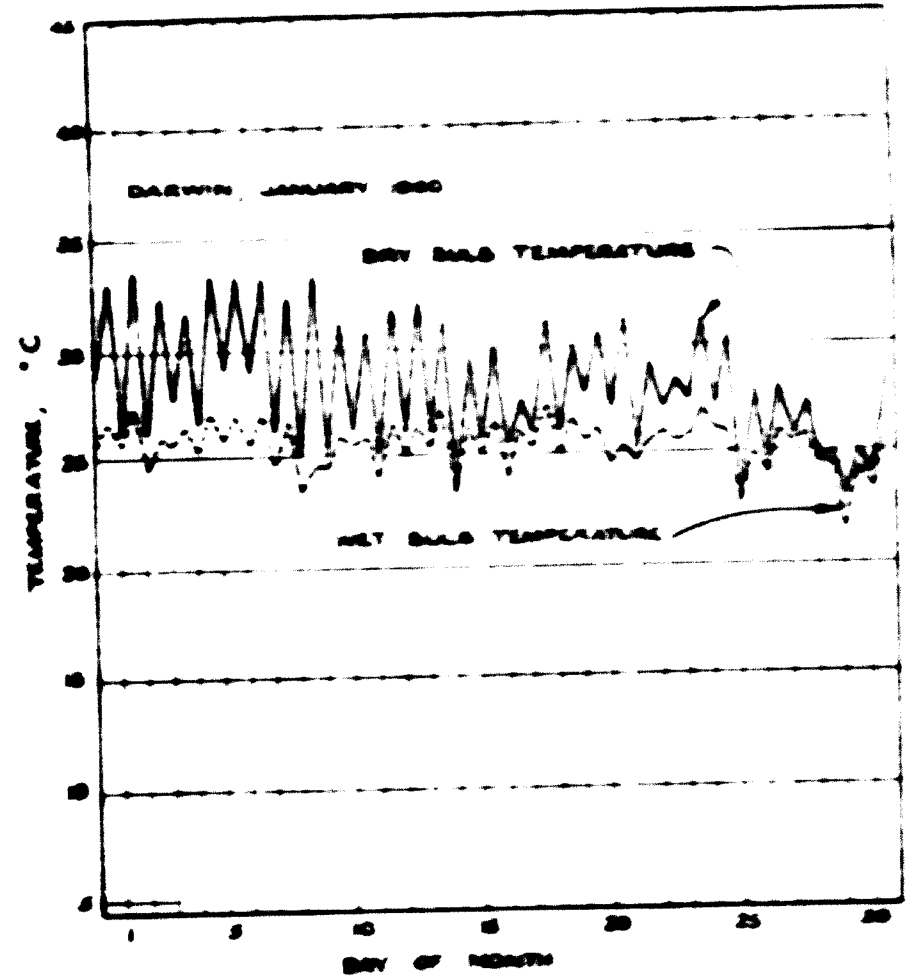


Fig. 1.
Wet and Dry Bulb Temperatures in Darwin at 6 a.m. and 3 p.m. for January 1960. Temperatures [illegible] Darwin [illegible]
[illegible]

actually falls as precipitation. Due to the greater evaporation rate at high temperatures, an amount of precipitation which will produce a humid climate in regions of low or moderate temperature may be classed as semi-arid in a hot region. The dry tropical climates can be broken into two types: the tropical and sub-tropical steppe or semi-arid climate, and the tropical and sub-tropical desert or arid climate.

In general, the steppe is a transitional belt surrounding the true desert and separating it from the humid climates beyond. The boundary between arid and semi-arid climates is relatively arbitrary, but Koppen[3] (loc. cit.) defines it as the point where the precipitation is one-half that at the boundary between the steppe and the humid climate. Dry climates occupy roughly 26 per cent. of the continental area of which 14 per cent. is steppe and 12 per cent. desert. The arid areas tend to divide the humid tropics from the temperate climates.

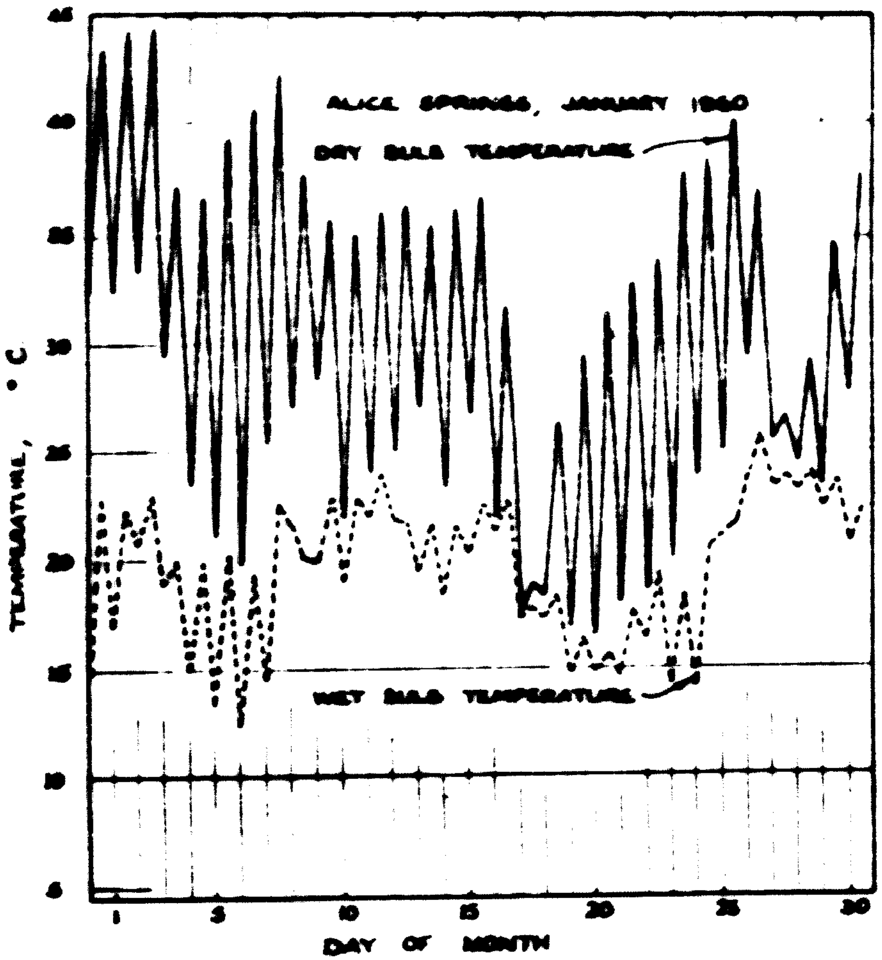


FIGURE 2

Wet and Dry Bulb Temperatures in Alice Springs at 6 a.m. and 3 p.m. for January, 1960.

Températures humides et sèches à Alice Springs à 6 heures et à 15 heures au mois de janvier, 1960.

3 loc cit.

Due to clear air, low humidity and lack of cloud cover, the arid regions receive more solar radiation than the humid tropics and the direct beam represents a higher fraction of the total insolation. As a result, concentrating systems may have wider application in these regions.

The maximum temperatures in the arid regions are higher than in the humid tropics and the variation between day and night is greater due to the low humidity and the high radiation loss at night. The temperature range throughout the year is also much larger than in the humid tropics.

The wet and dry bulb temperatures for January 1960 at Alice Springs have been plotted in Fig. 2 to illustrate the daily variation for this type of climate. It will be noted that the wet bulb temperature is much lower than at Darwin, the maximum dry bulb temperature tends to be higher, while the night temperature drops lower. There is also much more variation in the weather throughout the month.

This brief review of tropical climates was thought necessary as the climate represents one of the most severe problems in the development of the tropics. Problems common to many tropical regions will be listed, following which ways of utilizing solar energy to solve these problems will be discussed. The wet and dry tropics have some common problems, but each region has unique problems, so these will be listed separately.

## 2. The Problems of the Tropics

Problems frequently encountered in the tropics:

| Wet Tropics | Dry Tropics |
|---|---|
| High temperatures | Very high temperatures |
| High humidities | Low humidities |
| Fuel shortages | Fuel shortages |
| Power shortages | Power shortages |
| Preservation of food | Preservation of food |
| Drying of products | Drying of products |
| Shortage of fertilizers | Shortage of fertilizers |
| | Shortage of water |

### (a) *High temperatures and high humidities*

The requirement for comfort in the wet tropics involves both cooling and dehumidification, although by radiant cooling[4] it may be possible to remove sufficient heat to keep people reasonably comfortable. However dehumidification may be necessary to prevent damage due to mildew and mould. Both cooling and dehumidification can be accomplished by the use of solar energy, and several possibilities exist. One approach consists of a conventional absorption refrigeration system with solar energy used for regeneration of the solution. Sufficiently high temperatures for this purpose can be reached in a flat plate absorber with a selective surface.

An alternative approach is to dehumidify the air by adsorption or absorption and then cool the air by evaporation of water. Solar energy can be used to drive off the water from the solid or liquid material used to remove the water vapour from the air. Silica gel and activated alumina are

4 R. N. MORSE and E. KALETZKY, "A New Approach to Radiant Cooling for Human Comfort" J. Inst. of Engineers Aust. Vol. 33, No. 6, 1961.

5 H. R. SHERIDAN, "Solar Air Conditioning" J. Inst. of Engineers Aust. Vol. 33, No. 1-2, 1961.

examples of solid adsorbents, while solutions of propylene glycol, lithium chloride, lithium bromide, calcium chloride, and magnesium chloride can be used to absorb water vapour from moist air. The combination of de-humidification with evaporative cooling forms, in effect, an open absorption refrigeration system.

*(b) Very high temperatures and low humidities*

In the dry tropics the temperatures are higher and the need for cooling is greater, but dehumidification is not necessary. As in the humid tropics, solar energy can be used with an absorption refrigeration system to achieve cooling. Solar energy need not be used for cooling under these conditions, as evaporative cooling is usually quite effective.

*(c) Fuel Shortages*

Solar energy is the logical system to use in the tropics whenever relatively low temperature heat is required, such as in heating water for domestic or industrial use. Heat losses from equipment are reduced by reason of the high ambient temperatures, insolation is high, and the overall efficiency of the system is good. Furthermore, due to the uniformity of the climate the system will maintain a high level of performance throughout the year, and under these conditions the solar absorber will pay for itself in a short time[6]. A photograph of a solar water heater installation is shown in Fig. 3.

Solar energy can also be used for cooking, but for various reasons the types of solar cookers thus far produced have not been acceptable to the

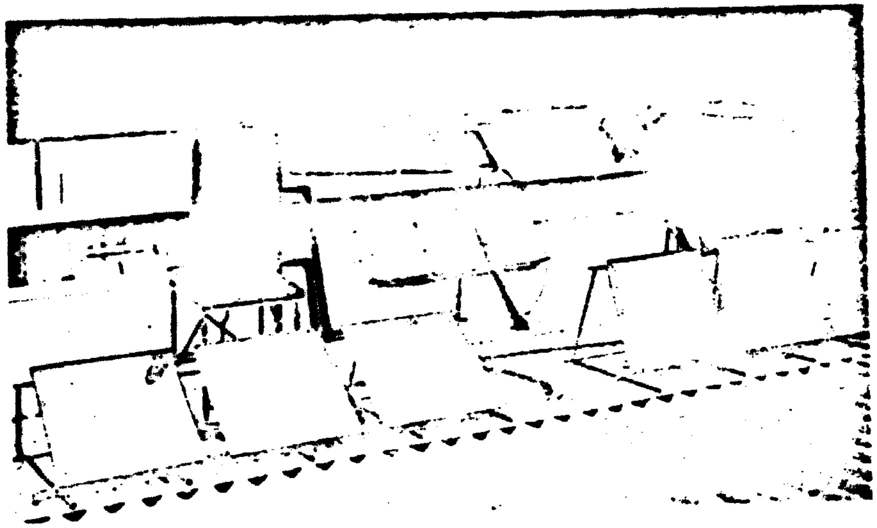

FIGURE 3

Solar Water Heater Installation. Engineering Section. C.S.I.R.O.

Une installation de chauffe-eau solaire. Section Technique. C.S.I.R.O

6 R. N. MORSE, "Water Heating by Solar Energy" U.N. Conf. on New Sources of Energy, 1961.



housewives in the underdeveloped areas. To find wide use it appears that a solar stove must be simple and reliable with heat storage so that cooking may be done indoors after sunset or during cloudy spells.

*(d) Power Shortages*

There are many ways in which electrical power can be generated from solar energy. Direct conversion by photovoltaic cells is one of the most promising methods. Recent developments in semi conductors resulting from advances in solid state physics hold promise that conversion efficiencies of over 20 per cent can be obtained, although the efficiency of the silicon solar cell is at present only about 10 per cent. However, to be really useful, the cost must be reduced by a couple of orders of magnitude. A cheap solar cell which would operate with a high efficiency at temperature of 100°C. would make possible the combination of an electric generator with a heat absorber for other purposes.

Electrical power can also be generated by thermoelectric or thermionic devices. For either one of these generators, high temperatures are necessary for high efficiencies, and it is necessary to concentrate the solar energy by suitable mirrors or lenses. Again, it is possible to combine power generation with heat absorption.

Power can also be generated by conventional vapour cycles using steam or other working fluids. One of the principal advantages of solar power generation is that it is best suited for small installations such as individual homes or small villages. Pumping water for irrigation would represent the type of application where the intermittent nature of the power supply would not be detrimental. For other applications, such as lighting or refrigeration, some type of energy storage may be necessary.

*(e) Preservation of Food*

Refrigeration and drying are both used for food preservation. As mentioned under air-conditioning solar energy can be used as the heat source for an absorption refrigeration cycle. Duffy and Daniels at the University of Wisconsin, Tabor at the National Physical Laboratory in Israel, and Farber at the University of Florida are all actively working on solar refrigeration processes.

The usual method where low temperatures are required is to employ the ammonia-water cycle. For air conditioning application there are advantages in the water vapour-lithium bromide cycle which has somewhat higher coefficient of performance and lower operating pressures.

*(f) Drying of Products*

Drying of food and vegetable products is often necessary for storage and to remove excess water. Examples of materials which are frequently dried for storage or shipment are grains, timber, fruits, and copra.

Salt production from sea water represents a very important application of solar energy. Solar energy can also be utilized for the concentration of other materials in aqueous solution. For example Khanna[7] in India has done a considerable amount of research on the concentration of palm juice.

7 M. L. KHANNA, A. L. GARDNER, T. N. DAVEY, and S. P. SURI, "Plane-glass Mirror Solar Energy Concentrators for Concentrating Sugarcane and Palm Juices", J. of Sci. and Ind. Res., 1959, Vol. 18A.

### (g) *Shortage of Fertilizers*

Many tropical soils are very deficient in nutrients, in humid areas soluble compounds are very quickly leached out of the soil. Solar energy can be used in chemical processing. It has also been suggested that solar energy can be used for nitrogen fixation with the aid of large concentrating systems so that very high temperatures can be attained.

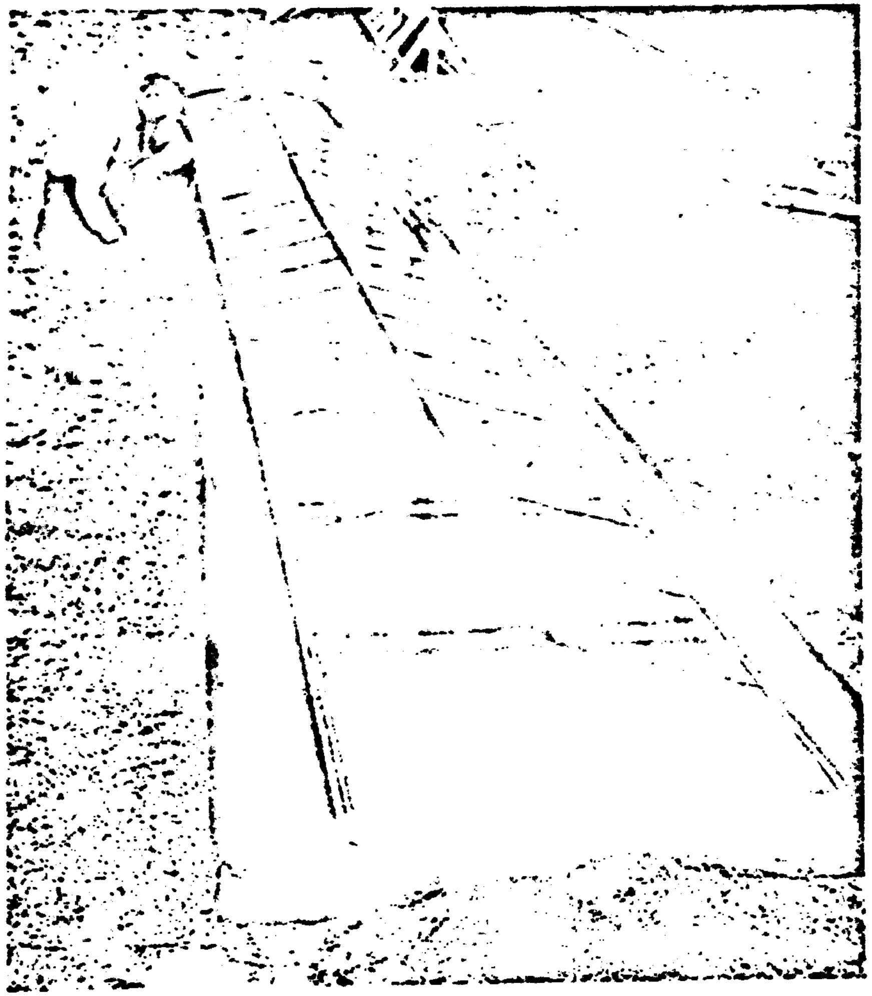

FIGURE 4

**Experimental Roof Type Solar Stills, Engineering Section, C.S.I.R.O.**

**Appareil distillatoire solaire expérimentale du modèle montée sur toit, Section Technique, C.S.I.R.O.**



### (h) *Shortage of Water*

Lack of water is primarily a problem of the arid regions. Frequently there is saline water available in these regions, sea water at the coast and bore water inland. Solar energy can be used to distill saline water[8, 9, 10]. For small amounts of fresh water, the roof type still is probably best (Fig. 4). As the energy supply is free, the cost of the water becomes dependent to a large extent on the capital cost and life of the equipment.

For greater water production, the multiple effect diffusion still appears promising[13]. For a given absorber area, the multiple effect still will yield several times as much water as the roof type still. Furthermore, with the aid of heat storage, the still can operate 24 hours a day or during cloudy periods.

For very large installations it may be worthwhile to utilize conventional multiple effect distillation systems. Another possibility is the use of flash evaporation with a low pressure steam turbine for power generation as well as fresh water production.

## 3. Prospects for the Immediate Future

Many of the applications which have been outlined need considerable technological development before they could be used on a wide scale. There are, however, in many parts of the world applications for which solar energy can be justified at the present time as the cheapest and best source of low grade heat. On the other hand, there are processes which need more development but are promising, while there are others for which the prospects for economic exploitation do not seem bright. In order to clarify this, specific instances must be examined in the light of established techniques.

### (a) *Solar Distillation for Water Desalination*

In order to provide fresh water from the salt water which is often available in arid areas, solar stills have been under development for a number of years, and while they have nearly reached the stage where construction on a large scale is practicable, the problem of cost has not yet been solved.

Water from a reticulated system in a city costs about 5d. (Australian Pence) per kilolitre (2/- (Australian Shillings) per thousand gallons), which might be compared with the 50d. per kilolitre (20/- per thousand gallons) it is believed it will cost to convert salt water into fresh using a solar still of the type illustrated in Fig. 4 in an area where the average insolation on

8 E. D. HOWE, "Solar Distillation Research at the University of California", U.N. Conf. on New Sources of Energy, 1961.

9 R. W. WILSON, "Solar Distillation in Australia" 1958. Transactions of the Conference on the Use of Solar Energy. Univ. of Arizona, Tucson, Arizona.

10 M. TELKES, "Solar Still Construction", U.S. Dept. of the Interior, Office of Saline Water Research and Development, Progress Report No. 33, 1959.

11 G. O. G. LOF, "Application of Theoretical Principles in Improving the Performance of Basin-type Solar Distillers", U.N. Conf. on New Sources of Energy, 1961.

12 C. GOMELLA, "Possibilities of Increasing the Dimensions of Solar Stills", U.N. Conf. on New Sources of Energy, 1961.

13 R. V. DUNKLE, "Solar Water Distillation, The Roof Type Still and a Multiple Effect Diffusion Still", International Developments in Heat Transfer, American Society Mechanical Engineers, New York, 1961.

a horizontal surface is 5400 kcal per m² per day (2000 BTU per ft.² per day). While this would be uneconomical in many areas there are applications where it could be justified and if the figure could be reduced to 25d. per kilolitre (10/- per thousand gallons) it is believed it would be widely used. At this figure, for instance, it would be feasible for stock watering since it amounts to only about 8 per cent. of the annual cost of raising a sheep.

It is sometimes claimed that solar energy could be used to irrigate deserts, using sea water, and while this is a challenging goal, it is not within sight at the present time, since for this purpose the cost would have to be reduced by at least an order of magnitude below our present most optimistic forecast.

The prospects, however, for solar distillation as the most attractive means of desalination of water for human and stock consumption in arid tropical areas are quite bright. More research and development is still necessary and work is proceeding in many countries[8, 9, 10, 11, 12] [loc cit].

### (b) *Refrigeration and Air Conditioning*

It seems clear that engineers can make a major contribution to the improvement of living and working conditions in the tropics by devising special refrigeration and air conditioning techniques to cope with their particular problems. The use of solar energy as a power source is a most attractive possibility, although it is essential that the basic limitations should be appreciated. In the first instance if a solar operated refrigerator using an absorption cycle with a coefficient performance of 0.5 is compared with a typical vapour compression electric powered refrigerator with a coefficient performance of 3, it will be seen that the solar unit starts off with a 6 to 1 disadvantage. It is therefore necessary to examine every possibility which can reduce its capital cost. One way is to make the absorbers an integral part of the roof of the house as proposed by Sheridan[5] [loc cit], although this is not enough in itself as the following analysis will show.

He proposed a flat plate absorber with an area of 55.7 m² (600 ft.²) and an absorption refrigeration unit with a cooling capacity of 10 580 kcal per hour (3½ tons of refrigeration) operating on the water-lithium bromide cycle with low temperature storage.

There are sound reasons for suggesting a larger absorber and a smaller refrigeration unit together with high temperature storage.

Assuming 30 per cent. mean absorber efficiency, mean daily insolation of 4600 kcal per m² (1700 BTU per ft.²), coefficient of performance of 0.5, and continuous operation of the refrigeration unit; it will be found that a unit with a cooling effect of 10 580 kcal per hour (3½ tons or $10^6$ BTU per day) would require 368 m² a day plus high temperature storage. However, this is too large for the average dwelling and could be reduced to an absorber area of 118 m² (1275 ft.²) with a refrigeration system of 4500 kcal per hour (1½ tons) cooling capacity. At £22 (Pounds Australian) per m² of absorber (£2 per ft.²), and £84 per 1000 kcal per hour of cooling capacity (£250 per ton) for the absorption refrigeration unit, and 11 per cent. per annum for annual charges; the cost of operating this unit would be £320

8, 9, 10, 11, 12 loc cit.
5 loc cit.



per annum. This is about twice the annual operating cost of an efficient vapour compression refrigerator with a coefficient of performance of 3 and electric power at 2½d. per kWh.

It is clear then that the biggest single contribution to making solar refrigeration economic would be a reduction in the cost of the absorber to about one-half its present cost.

A simple refrigeration system known as the "icy ball" which was developed many years ago is now being suggested for use in isolated areas without power. A black vessel containing dilute ammonia solution is placed at the focal point of a solar reflector, the ammonia is driven off and condensed in a receiver which is cooled by water or air. After sufficient ammonia is collected, the ammonia container is placed in the refrigerator; the ammonia now evaporates, cooling the refrigerator and is absorbed in the water in the first vessel which is now cooled by air or water.

In view of the high cost of solar refrigeration using the absorption cycle, work is in progress in this laboratory on alternatives for tropical air conditioning involving various arrangements of three system components. The components are:

(i) A solar dehumidifier employing a hygroscopic salt solution such as lithium bromide which is used to dehumidify the room air and is reconcentrated in a solar still.

(ii) A solar dehumidifier in which a solar air heater is used to provide the energy for extracting water picked up from room air by a hygroscopic material.

(iii) A novel regenerative heat/water vapour exchanger for use with (i) and (ii). This it is believed could have wider application and will be described in due course.

While it is hoped that one or other of the systems being examined will be able to compete with vapour compression refrigeration in tropical areas, no such claim can be made at the present time as considerable research and development remains to be done.

### (c) *Mechanical and Electrical Power*

Applications such as water heating, distillation and refrigeration involve the utilization of energy as heat and it has been shown how a continuous supply can be made available from an intermittent supply of solar energy by employing suitable storage techniques. However, major problems arise in regard to the storage of mechanical or electrical energy for which economic solutions are not at present available. In view of this, estimates are being made of the cost of direct conversion of solar to electric power and also of solar powered vapour turbines which have little or no provision for storage. It is not reasonable to compare costs derived on this basis with prime movers which will operate 24 hours a day.

Even on this basis it seems that the best solar powered vapour turbine is an order of magnitude higher in cost of operation than a diesel engine, whilst thermoelectric devices are perhaps 100 times more expensive. There is of course a considerable abount of research being carried out chiefly in U.S.A., U.S.S.R. and Israel to find ways of reducing these costs.

An ingenious proposal by Tabor[14] to use inflated plastic cylinders with a reflective coating on the inside as energy collectors is an important contribution and may point the way to a competitive solar powered vapour turbine.

It does appear nevertheless that the internal combustion engine for small units and the steam turbine for large installations is not yet seriously challenged.

### (d) Drying of Agricultural Products

At the present time many materials are dried by direct exposure to the sun in fields or in racks. While direct drying of this nature will probably always be used with some crops and products, superior results can be obtained with enclosed driers which protect the material from dust, rain, insects, nocturnal radiative cooling and dew formation, and photochemical degradation. Much better control of the drying process and more rapid drying can also be obtained with a properly designed solar drying system.

It is necessary to consider the climatic factors when considering new proposals. Wilson[15] has shown that in the dry areas in Australia where vine fruits are grown that solar drying cannot compete economically with open rack drying. This does not necessarily apply in humid areas.

In Fiji, for example, Tarte[16] has constructed a solar heated system for drying copra which he states saves him about £1/14/0 per ton of copra produced as compared to oil fired hot air driers. Furthermore hot air dried copra has a premium of £2/10/0 a ton over the price of copra produced on drying racks in the sun.

### (e) Water Heaters

In Australia, solar water heaters have been developed to the point where design and manufacturing costs are sufficiently established to be able to predict accurately performance and operating cost in different areas. It is therefore possible to compare the total annual costs of three types of water heater in three different localities. The water heaters to be considered are:

(i) A solar water heater without any supplementary heating having an absorber area large enough to give its rated output under the worst conditions;

(ii) A solar water heater with electric booster and controls having an absorber which is designed to give its rated output under best operating conditions, but relies on supplementary heating at all other times. This gives maximum utilization of absorbers.

(iii) An electric heater comprising a storage tank, heating elements and controls similar to (ii) but having no solar heat input. This type of unit is widely used in Australia employing power at off-peak rates.

14 H. TABOR and H. ZEIMER, "Low Cost Focussing Collector for Solar Power Units", U.N. Conf. on New Sources of Energy, 1961

15 F. W. WILSON, "The Role of Solar Energy in the Drying of Vine Fruit", U.N. Conf. on New Sources of Energy, 1961

16 J. V. TARTE, Personal communication, 1961



TABLE I

**Operating costs for water heating for humid and arid tropics and temperate zones.**

Consumption

**200 litres per day of water at 57°C.**

**(45 gallons per day at 135°F)**

**Coût du chauffage de l'eau dans les régions tropicales humides et arides et dans les zones tempérées.**

| ZONE | | | HUMID TROPICS | ARID TROPICS | TEMPERATE |
|---|---|---|---|---|---|
| LOCATION | | | DARWIN | ALICE SPRINGS | MELBOURNE |
| LATITUDE | | | 12°S | 24°S | 38°S |
| Daily insolation on inclined surface kcal/m² (BTU/ft²) | Best month | | 6070 (2240) | 6500 (2400) | 5860 (2165) |
| | Worst month | | 4420 (1630) | 4150 (1530) | 2710 (1000) |
| | Yearly average | | 5150 (1900) | 5550 (2050) | 4360 (1610) |
| *Unit Costs* | | | | | |
| 1. Cost of 318 litre (70 gal) storage tank | | £Aust. | 60 | 60 | 45 |
| 2. Solar absorbers cost per m² (ft²) | | £Aust. | 24.8 (2.3) | 24.8 (2.3) | 21.5 (2) |
| *Absorber Area Required* | | | | | |
| 3. Best month m² (ft²) | | | 3.34 (36) | 3.16 (34) | 4.46 (48) |
| 4. Worst month m² (ft²) | | | 4.64 (50) | 7.52 (81) | 11.8 (127) |
| *Solar Absorber Cost* | | | | | |
| 5. Best month basis | | £Aust. | 83 | 78 | 96 |
| 6. Worst month basis | | £Aust. | 115 | 186 | 254 |
| 7. Installation cost | | £Aust. | 25 | 25 | 25 |
| *Solar Heater only* | | | | | |
| 8. Cost on worst month basis Items 1 + 6 + 7 | | £Aust. | 200 | 271 | 324 |
| 9. Total annual cost 8 per cent of Item 8 | | £Aust. | 16 | 21.7 | 25.9 |
| *Solar Heater with Electric Booster* | | | | | |
| 10. Cost of electric booster and controls | | £Aust. | 25 | 25 | 25 |
| 11. Cost of solar + electric booster with absorber sized for best month Items 1 + 5 + 7 + 10 | | £Aust. | 193 | 188 | 201 |
| 12. Annual fixed charges 8 per cent of Item 11 | | £Aust. | 15.4 | 15.0 | 16.1 |
| 13. Annual supplementary heating required kWh (BTU) | | | 495 (1.69 x 10⁶) | 1145 (3.9 x 10⁶) | 1210 (4.12 x 10⁶) |
| 14. Cost of elec. power, pence per kWh | | | 3 | 4 | 1.45 |
| 15. Cost of supplementary electric power | | £A. | 6.2 | 19.0 | 7.3 |
| 16. Total annual cost Items 12 + 15 | | £Au. | 21.6 | 34.0 | 21.4 |
| *Straight Electric Heater* | | | | | |
| 17. Cost, Items 1 + 10 | | £Aust. | 85 | 85 | 70 |
| 18. Annual fixed charges 8 per cent of Item 17 | | £Aust. | 6.8 | 6.8 | 5.6 |
| 19. Annual power required kWh (BTU) | | | 3040 (10.4 x 10⁶) | 3750 (12.8 x 10⁶) | 4100 (14.0 x 10⁶) |
| 20. Power cost | | £Aust. | 38.0 | 62.5 | 24.8 |
| 21. Total Annual cost Items 18 + 20 | | £Aust. | 44.8 | 69.3 | 30.4 |

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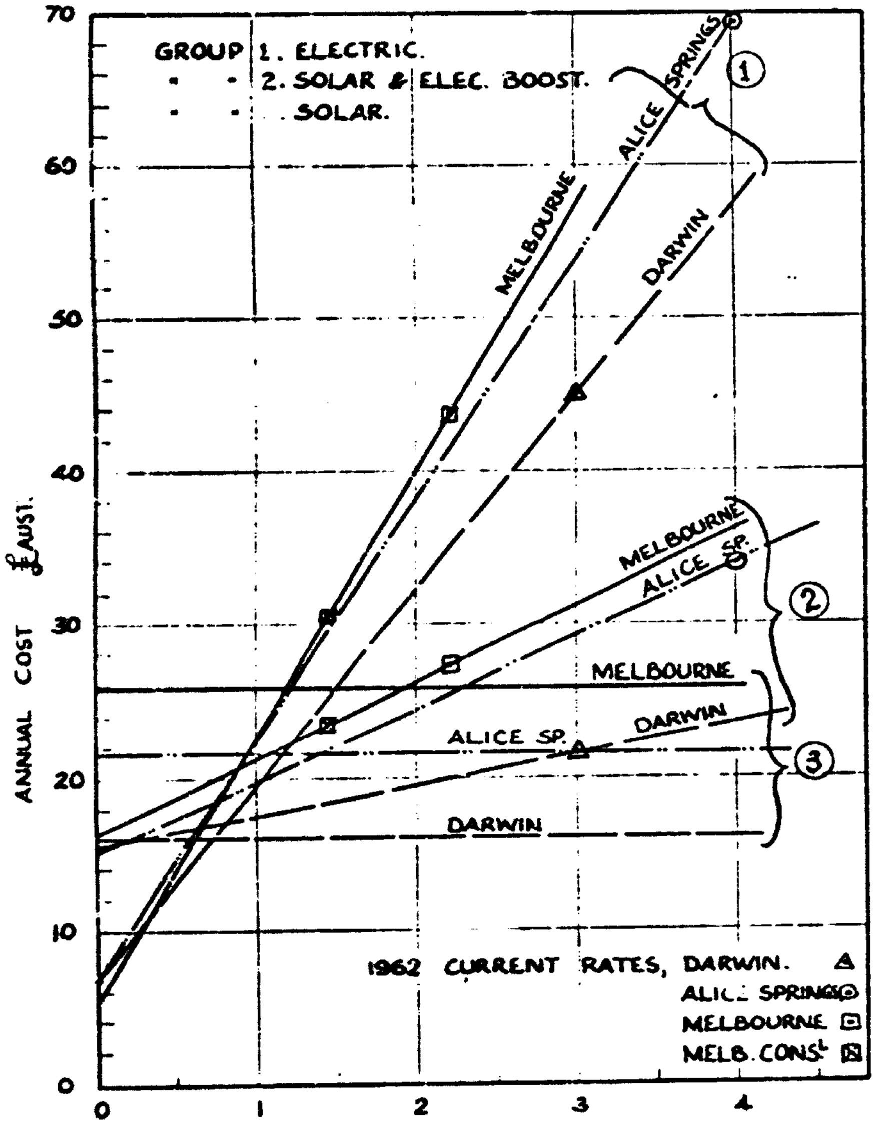


FIGURE 5

**Comparison of Costs for Solar and Electric Water Heating for Three Locations in Australia, 200 litres per day of water heated to 57°C.**

**Comparaison des coûts de chauffage de l'eau par l'électricité et par chauffage solaire pour trois sites en Australie, 200 litres d'eau par jour chauffée à 57°C.**



The localities which may be compared are:

A. The humid tropics, typified by Darwin, latitude 12°S.
B. The arid tropics, typified by Alice Springs, latitude 24°S.
C. The tempe...te zone, using Melbourne, latitude 38°S, as typical of an area where cheap electric power is available from a large and efficient grid system and solar radiation is by no means exceptional.

Table I shows how the annual cost of the various combinations is derived and is based on measurements of performance which are now well established and which have been described elsewhere[6] [loc cit]. The annual fixed charges allow for interest at 5 per cent. per annum, a 20 year life involving an average charge of 2½ per cent. per annum, and maintenance at ½ per cent. per annum, making a total of 8 per cent. per annum on the capital cost.

A unit having an output of 200 litres (45 gallons) per day is chosen because it is suitable for an average household and has been in production for some years. From the ...s given in Table I, Fig. 5 has been prepared to show the influence of the cost of electric power on the annual cost.

Three interesting points emerge from the comparison:

(i) The installation in the humid tropics (Darwin) gives the lowest annual costs of the three localities for the straight solar unit, the relative values being Darwin £16 per annum, Alice Springs £21.7 per annum and Melbourne £25.9 per annum.

(ii) There is no advantage in providing supplementary electric boosting for either the humid tropics (Darwin) or the arid tropics (Alice Springs). It is, in fact, more economical to provide the extra absorber area required for the straight solar unit in these zones.

(iii) Very considerable savings are possible in both tropical zones for solar as compared with electric units. Even in Melbourne the straight solar installation is now more economical than the straight electric unit operating on the concessional water heating tariff of 1.45 pence per kWh. A slight saving on this could be made by installing a booster provided the concessional tariff can be applied. However, this saving would disappear if the absorber cost were reduced by 10 per cent.

These points lead to conclusions which could have the most far-reaching significance. Firstly for heating water to a temperature of 57°C. (135°F.) solar energy is a very much better proposition than electric heating in the tropics, the cost being appreciably lower in the humid areas than in the arid zones. Capital can therefore be invested more economically in solar installations than electricity generating and distribution systems for this purpose.

Secondly, similar arguments can be developed for other processes requiring low grade heat which must, however, be examined on their merits, particularly in the light of the state of development reached by the appropriate solar devices. It is nevertheless highly probable that the same conclusion would be reached wherever electric power is used for low grade heat.

6 loc cit

Thirdly, where electric power is used for low grade heat in the temperate zones, perhaps extending as far as latitude 40° most of the present concessional off-peak tariffs are not sufficiently attractive to compete with solar installations and power authorities might well consider whether they wish to compete in this field by reducing tariffs or whether it would be uneconomical to do so.

Since it is believed that solar water heaters are now ready for large scale use it is worth examining two widely differing situations, firstly a highly industrialised area in Australia and secondly a developing rural area in India. For the first the State of Victoria is chosen because up to date information is available for an area of 180 000 km² (70 000 sq. miles) with a population of 2.2 million and for the second the data published by Kapur[2] [loc cit] provides a basis for a typical Indian rural community.

In the State of Victoria the total electric power consumption on a per capita basis for the area supplied in 1958/59 was 2720 kWh per annum[17] which corresponds to about 25 per cent. of the average Australian total per capita energy consumption of 4.06 metric tons coal equivalent[18].

Electric water heaters account for 12½ per cent. of all electric energy consumption including industrial and commercial power. In the home the percentage is very much higher. Some 173 500 electric water heaters consumed $700 \times 10^6$ kWh per annum out of a total domestic consumption of $1375 \times 10^6$ kWh. This is over 50 per cent. of the total domestic consumption and if every home had an electric water heater it might be as high as 75 per cent.

In areas where house heating is not necessary, it is clear that water heating is the largest domestic energy consumer and it is considered that this load can be met more economically by solar than from electric power.

Consider now Kapur's typical rural community in India. He lists the annual power requirements and individual maximum demands for the various functions. He also suggests lines along which research might be directed towards the greater use of solar energy such as the development of a high pressure steam boiler and thermoelectric generators with suitable storage. However, if we examine how solar energy could be immediately applied using proven equipment it will be seen that it can meet the quite large demand for hot water.

A modified list of power requirement is given in Table II in which it is suggested that all mechanical power and energy for cooking, lighting and refrigerating should be electric and all hot water provided by solar energy.

The hot water requirements amount to 18 - 23 litres (4 - 5 gallons) per day per person heated 45°C. (80°F.) which seems high. However, the community average of 0.155 tons per annum coal equivalent is not excessive in relation to the average for India of 0.39 metric tons per annum[18] [loc cit].

At all events, the hot water load is considerably more than 50 per cent. of the total and as this community is typical of towns and villages in India

2 loc cit

17 State Electricity Commission of Victoria. 42nd Annual Report, 1960-61, and personal communication on "Water Heating Statistics".

18 H. HARTLEY, "Energy as a Factor in the Progress of Under-developed Countries", U.N. Conf. on New Sources of Energy, 1961.



TABLE II

Energy requirements for a rural community in India. Population 1000. Based on estimate by Kapur[2].

Besoins énergétiques d'une commune rurale aux Indes.

| APPLICATION | MAXIMUM DEMAND kW | ANNUAL ENERGY REQUIREMENTS kWh | ENERGY SOURCE |
|---|---|---|---|
| Cooking | 120 | 65,700 | Electric |
| Lighting | 15 | 21,900 | Electric |
| Domestic water supply | 3 | 6,000 | Electric |
| Food processing and refrigeration | 11 | 74,000 | Electric |
| Irrigation | 30 | 40,000 | Electric |
| Agricultural machines | 30 | 22,500 | Electric |
| Textiles | 8 | 10,000 | Electric |
| Manufacture | 20 | 20,000 | Electric |
| Total electric | 237 Overall maximum demand, say 100 | 260,100 Equivalent coal 87 metric tons per annum at 33 per cent efficiency | |
| Hot water for dairy and other uses | — | 460,000 Equivalent coal 68 metric tons per annum at 75 per cent efficiency | Solar |
| Total coal equivalent | | 155 metric tons per annum | |
| coal equivalent per person | | 0.155 metric tons per annum | |

with a combined population exceeding 250 million it is clear that solar energy can play a major part in providing the power necessary to raise their living standards. It seems also that in the absence of local fossil fuels, it can provide this in many tropical areas more cheaply than any other source of energy.

As Thacker[19] has pointed out "large central power stations are well suited to the urban and industrial centres which are characteristic of the developed countries but will not be adequate to meet the special needs of dispersed rural communities in under-developed areas. It is in dealing with the latter that solar energy and wind power come to the forefront as significant sources of energy".

## 4. Conclusions

It is clear that the extent to which solar energy may be used in tropical areas is very dependent on the particular applications. In some cases large

19 M. S. THACKER, "New Sources of Energy and Energy Development", U.N. Conf. on New Sources of Energy, 1961.

scale utilization is at present justified while in others considerable research and development is necessary. Nevertheless a number of conclusions may be drawn.

1. Solar devices should not be proposed for widespread use merely because they save fuel. They should be justified on economic grounds taking all the operating costs into consideration. Since conservation of fossil fuels is important in the long run it is reasonable to give some preference to a solar unit with a long life over a fuel heated unit when the cost comparison is marginal.

2. It is not reasonable to expect people to accept inconvenient methods in order to suit the limitations of solar devices. For this reason solar cookers in their present form are not an attractive proposition.

3. Devices such as solar powered engines and thermoelectric generators, for which economical methods of storage are not yet available, should be compared with the cheapest alternative for the task they have to perform, in assessing their economic suitability.

It is difficult to see large scale applications at the present time.

4. Devices which employ heat without conversion offer the best prospects for solar energy utilization in the immediate future. Tropical areas particularly the humid zones where insolation throughout the year is remarkably uniform are very suitable for both large and small installations requiring low grade heat.

5. The drying of agricultural products is a promising possibility which needs more investigation of specific applications.

6. Solar refrigeration and air conditioning, although not yet economically practicable may well play a major part in the development of tropical areas.

7. Solar distillation as a method of water desalination is ready for pilot installation to supply water for stock and human consumption. It is very likely that costs can be reduced to the point where it will be competitive. It is not an economic possibility yet for irrigation.

8. The most promising application of solar energy on a large scale is for water heating. There is a large demand for hot water for industrial and domestic use, both in the developing communities and highly industrialized areas. In the tropical belt which has a population of $2 \times 10^9$, the savings in fuel and operating costs resulting from the use of solar energy for water heating would be enormous.

9. In the rapidly developing countries in this area, it is estimated that in the next 15 years the population will increase from $1.5 \times 10^9$ to $2.5 \times 10^9$ and the per capita energy consumption from 0.36 to 0.47 equivalent metric tons coal per annum. More than half the increase is likely to be used as low grade heat and if solar energy were to supply half of this, the fuel saving would amount to the equivalent of 100 million metric tons coal per annum by 1977.

10. This is so significant in relation to the development of these countries that it justifies an all out effort to adopt solar water heaters on a large scale.




## 5. Summary

A brief review of tropical climates is followed by a list of problems peculiar to tropical regions. Methods by which solar energy can be utilized to solve these problems are described. Prospects for use of solar energy in the immediate future are discussed. Some points in regard to the economics of solar water heating are presented and the conclusion is reached that solar water heating at present rates is more economical than electric water heating in all sections of Australia.

## Résumé

Une courte énumération des climats tropicaux est suivie d'une liste des problèmes qui se rencontrent plus particulièrement dans les régions tropicales. Des méthodes d'utilisation de l'énergie solaire afin de surmonter ces problèmes sont décrites. Les possibilités d'application de l'énergie solaire dans le proche avenir sont exposées. Quelques aspects de l'économie du chauffage solaire de l'eau sont présentés et mènent à la conclusion qu'aux prix de revient actuels le chauffage solaire de l'eau est moins coûteux que le chauffage par l'électricité dans toutes les parties de l'Australie.

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Director P C Spensley MA BSc DPhil FRIC

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Industrial Inquiry Service
Industrial Information Section
UNIDO
Felderhaus, Rathausplatz 2
A 1010 Vienna, Austria

Your reference Q 6554 Chad
Our reference
Date 28 February 1974

Dear Mr Grigore

Thank you for your letter of 13 November together with the enquiry from Mr Tomson, Fort Lamy, Chad on solar cookers.

I regret that I have no knowledge of any UK manufacturers of Solar cookers. Most of the information available on these appliances is in the form of do-it-yourself manuals and instructions and a selection of these was sent to Mr Tomson.

I am sending you a list of references which include the names and addresses of possible manufacturers of solar energy equipment. I would suggest that Mr Tomson writes to the Solar Energy Society Headquarters, Campus, Arizona State University, Tempe, Arizona 8528a, USA, who would I am sure know of recent developments in the field. Alternatively, the National Physical Laboratory of India, Hillside Road, New Delhi 12 have done some development work in this field and they may be able to help.

I enclose a duplicate copy of this letter in case you wish to pass it to Mr Tomson and if you think we can be of further help, please do not hesitate to write.

Yours sincerely

A R Paddon

South Africa contd.

Economic Solar Heater
236 Anderson Street,
Johannesburg.

... Eastern Countries

Miromit - Olympic Sun Heaters Ltd.,
233 ...street,
Tel Aviv.

Solnar Tarcici,
Amar Ben Khattab Street,
P.O.Box 3061,
Beirut. (Solar Cookers)

American

C.T.C. Manufacturing Corporation, ('Solaire' heat exchangers)
11936 Valerio Street,
North Hollywood,
California.

Solar Powered Applicances Company, (Solar hot-water space heatin.
39 St. George Street,
St. Augustine,
Florida.

Sunmaster Solar Systems,
666 West Central Avenue,
Orlando,
Florida.

Umbroiler Company,
510 Farmers Union Building, (Solar Cookers)
Denver 3,
Colorado.

Jet-Heet Inc.,
152 Van Brunt Street,
Englewood, New Jersey.
(Solar Ovens, stills and water heaters)

Clevlab,
34 Harwood Road,
Natick, Massachusetts, U.S.A.
(Solar cooker)

The Eppley Pyrheliometer,
The Eppley Laboratory, Inc.,
Scientific Instruments,
Newport, Rhode Island,
U.S.A.

[illegible] ...shire.
[illegible] ...ter Heaters.

[illegible]
[illegible] ...Heaters.

Solar [illegible] Ltd., [illegible], Staffordshire.
'S[illegible]' Solar [illegible] Heaters.
The 'Kipps' Solarimeter. British Agents, Shandon Scientific Company Limited,
6 Cromwell Place, London, S.W.7.

Australian

Braemar Engineering Co. Pty. Ltd.,
Princes Highway,
Noble Park, Victoria.

Braemar Engineering Co. (N.S.W.) Pty. Ltd.,
Bonds Road,
Punchbowl, N.S.W.

K. G. Coles, Pty. Ltd.,
14-16 Hercules Street,
Dulwich Hill,
N.S.W.

John Lysaght (Australia) Pty. Ltd.,
Newcastle Works,
N.S.W.

Braemar Eng., Coy. (Qld.) Pty. Ltd.,
Lamington Street,
New Farm,
Queensland.

Braemar Eng. Coy. (S.A.) Pty. Ltd.,
65 Flinders Street,
Adelaide,
South Australia.

Braemar Eng. Coy. (W.A.) Pty. Ltd.,
76 King Street,
Perth, W.A.

F. C. Korwill,
68 Hobbs Avenue,
Nedlands, W.A.

Arthur Neve, 'Sun E Can' Solar Hot Water Systems,
26 First Avenue,
Loftus, N.S.W.

South African

Ellson Equipment (Pty) Ltd.,
P.O. Box 8100,
Johannesburg.

Switchcraft (Pty) Ltd., (Manufacturing 'Miremit' unit under licence.)
P.O. Box 6444,
Johannesburg.

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[illegible] [illegible]twood. Ye Olde [illegible]ridge Hotel, East [illegible]

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Section 12—PHYSICAL A[illegible]

★ 3101 ★
McGill University
BRACE RESEARCH INSTITUTE
Montreal 2, Quebec, Canada
Dr. Gerald T. Ward, Director Founded: 1961

Integral unit of Faculty of Engineering at McGill University. Supported by income from endowment. Staff: 2 research professionals, 3 supporting professionals, 3 technicians, 5 others. Annual volume of research: $85,000.

Principal field of research: Development of methods for utilizing natural energy sources for provision of water and power in arid areas, including development of sun-operated water pump of one- or two-bullock power, of one-bullock power wind-driven water pump of simple design, of 10-horsepower airscrew windmill and 10 horsepower solar powered steam turbine and their application in irrigation water pumping and desalination, of a 2,000-gallon per day vapor compression distillation unit for use in arid land development and of other solar equipment for use in arid areas, applications of wind power in arid areas of the world and provision of fresh water from saline water. Maintains a field experiment station in Barbados, West Indies, where sun and wind are plentiful, provides specialist advice on solar and wind energy use and trains engineers in arid land development.

Research results published in scientific journals, technical reports and leaflets. Publication: ANNUAL REPORT. Maintains a library on arid zone development, saline water conversion, solar energy utilization and wind energy utilization.

XIV—44 (H-45)

NATIONAL PHYSICAL LABORATORY OF ISRAEL, Jerusalem, University Campus, Dan Danciger Bldg., Tel. 30211, ext. 475

FOUNDED 1950. Carries out research in applied physical sciences, especially energy conversion — mainly solar energy utilization, applied thermodynamics, and medical engineering. Maintains a basic physical standards laboratory for precision measurement and calibration.

DIRECTOR: H. Z. Tabor, Ph. D.

GOVERNING BODY: Prime Minister's Office, National Council for Research and Development.

LIBRARY: 300 books, 17 current periodicals.

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Concerning solar pumps:

Informations sur les fabricant de pumpes solaires et sur les sources d'information existant à ce sujet:

Fabricant: Etablissements Pierre Mengèn
B.P. 40
45 Montargis, France

Rechercheurs: Dr. A. Moumouni
Republique de Niger
Ministère des Travaux Publiques
Des Transports et de l'Urbanisme
Office de l'Energie Solaire, B.P. 621
Niamey, Niger

Professor H. Masson
Directeur du Centre d'Etudes Supérieure
B.P. 69, Brazzaville, Republique du Congo

M. J.P. Girandier
45 Pancourt, France

There is also a Solar Energy Society whose address is:

Solar Energy Society,
Campus,
Arizona State University,
Tempe, Arizona 85281,
U.S.A.

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telex : 27 602 Paris

Q-9453

30 MAY 1974

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24 MAY 1974

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... Therefore, we are happy to enclose herewith a copy of the list of persons who have presented a paper to this Congress. This will enable you to get directly in touch with the author of the paper the subject of which may be of interest to you.

Yours sincerely,

B. Boiko
Division of Technological Research
and Higher Education

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McGill University
MONTREAL - Canada

Co-authors : T.A. LAWAND, P. HOPLEY

DESCRIPTION OF A LARGE SCALE SOLAR STEAM COOKER IN HAITI (E 46)

C. APFELDORFER
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of Israel
JERUSALEM - Israel

Co-authors :
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W.H. KLEIN, Director, Radiation Biology Laboratory, Smithsonian Institution, 12441 Parklawn Drive, ROCKVILLE, Md 20852, USA

S. SURAQUI, National Physical Laboratory of Israel, Hebrew University, JERUSALEM, Israel

STUDY OF SPECTRAL CORRELATIONS AT JERUSALEM AND WASHINGTON (E 9)

E.W. ASHFORD
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NOORDWIJK - Netherlands

SATELLITE SYSTEM CONSIDERATIONS IN THE SELECTION OF SOLAR ARRAY GENERATORS

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Université des Sciences et Techniques
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PHOTOPERIODISME ET RYTHME CIRCADIEN CORTICO-SURRENALIEN

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EFFETS DE LA PHOTOPERIODE SUR LA FONCTION THYROIDIENNE (B 25)

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| A. ACHESON<br>School of Architecture,<br>Faculty of Engineering<br>McGill University,<br>MONTREAL - Canada<br><br>Co-authors : A. ALWARD, T. LAWAND | THE INTEGRATION OF SOLAR STILLS INTO MINIMUM COST DWELLINGS FOR ARID AREAS (E 16) |
| L. AIACHE<br>Département d'Héliophysique<br>Université de Provence<br>St. Jérôme<br>13013 MARSEILLE - France | RECENTS TRAVAUX EN MATIERE DE CONVERSION HELIO-ELECTROCHIMIQUE (E 23) |
| I.T. ALADIEV<br>Institut Energétique Krjijanovsky<br>MOSCOU - U.R.S.S.<br><br>Co-authors : V.A. BAUM, B. GARF,<br>I.N. MALEVSKY | STATIONS ENERGETIQUES SOLAIRES : PROBLEMES ET PERSPECTIVES (E 32) |
| G. ALEXANDROFF<br>ENSBA<br>74 Boulevard Beaumarchais<br>75003 PARIS - France<br><br>Co-authors : J.M. ALEXANDROFF<br>J.P. GIRARDIER | TOITURES SOLAIRES (EH 100) |
| A.E.A. AL-HADITHI<br>Building Research Centre<br>14 Ramadan Street<br>WASHASH, BAGHDAD - Iraq<br><br>Co-author : A.E. AL-MAINI(for EH 66) | COST AND PERFORMANCE OF SOLAR WATER HEATERS IN IRAQ (EH 66)<br>SOLAR AIR HEATER FOR SPACE HEATING (EH 71) |

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|---|---|
| M. AUDIBERT<br>CNES<br>18 Avenue Edouard Belin<br>31055 TOULOUSE-LEDEY - France | THE SOLAR ARRAY OF THE SATELLITE "TOURNESOL" |
| R. BADRE<br>CERTSM<br>TOULON-NAVAL - France | ETUDE BIOCLIMATOLOGIQUE DANS LES ESPACES CLOS |
| R. BAIRAMOV<br>Institut Physico-Technique<br>ACHKABAD - U.R.S.S. | RESULTATS DE L'EXPLOITATION D'UN DISTILLATEUR SOLAIRE EN TURKMENIE (E 40) |
| E.R. BALLANTYNE<br>Senior Principal Research Scientist<br>Division of Building Research,<br>CSIRO<br>P.O.Box 56<br>HIGHETT, Victoria, Australia 3190 | THE EFFECTS OF ORIENTATION AND LATITUDE ON THE SOLAR RADIATION RECEIVED BY TEST PANELS AND FENCES DURING WEATHERING STUDIES (E 124) |
| V. BALZANI<br>Istituto Chimico "Ciamician"<br>Via Selmi 2<br>BOLOGNA - Italy<br><br>Co-authors : F. BOLLETA, M. GLERIA, L. MOGGI | PHOTOCHEMICAL CONVERSION OF SOLAR ENERGY : CRITERIA FOR THE DESIGN OF SUITABLE SYSTEMS (E 117) |
| R.K. BARANOVA<br>Institut Energétique Krjijanovsky<br>MOSCOU - U.R.S.S.<br><br>Co-authors : I.I. KOKHOVA, I.N. MALEVSKY, A.I. TSVETKOV | THERMOELECTROGENERATEURS SOLAIRES (TEGS) A SEMI-CONDUCTEURS MATERIAUX ET TRANSFORMATEURS (E 19) |
| G. BARKATS<br>Aerospatiale<br>B.P. 52<br>06322 CANNES LA BOCCA - France | DEPLOYABLE SOLAR ARRAY |
| Y. BARRE<br>1 rue du Maréchal Harispe<br>75007 PARIS - France | LES RYTHMES CIRCADIENS HUMAINS |

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INTERVENTION DU SOLEIL SUR LE BILAN THERMIQUE DES ABRIS (V 20)

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Academy of Sciences of the U.S.S.R.
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ASHKHABAD - U.R.S.S.

Co-authors : A.P. LANDSMAN, B.A. BAZAROV, A.S. STREBKOV.

(E 41) B. GARF, M. KUDRIACHOVA, Y. MALEVSKY

(EH 96) A. KAKABAEV, A. KHANDURDIEV, O. KLYCHIAEVA, A. RAKHMANOV

STUDY OF SOLAR ENERGY FACILITIES EQUIPED WITH A PHOTOELECTRIC CONVERTER "PHOTOVOLT" OF HIGH VOLTAGE.

EFFET DE LA SELECTIVITE DANS LES INSTALLATIONS ENERGETIQUES SOLAIRE (E 41)

UTILISATION DE L'ENERGIE SOLAIRE DANS LES CONDITIONS PARTICULIERES DES REGIONS A CLIMAT TORRIDE ET ARIDE POUR LA CLIMATISATION EN ETE (EH 96)

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MOBILE STATION FOR AUTOMATIC MEASUREMENTS OF SPECTRAL SOLAR AND SKY RADIANCE AND THE FLUXES OF GLOBAL AND SKY RADIATION ON DIFFERENTLY ORIENTED PLANES (E 31)

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DISPOSITIF D'ANALYSE PAR SPECTROMETRIE DE MASSE ASSOCIE A UN FOUR SOLAIRE

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ROLE D'UNE VOIE RETINO-HYPOTHALAMO-HYPOPHYSAIRE DANS LA GONADOSTIMULATION LUMINEUSE CHEZ LES OISEAUX ET LES MAMMIFERES. ACTION DE LA LUMIERE BLANCHE ET DES RADIATIONS DE DIFFERENTES LONGUEURS D'ONDE (B 20)

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DESCRIPTION AND INTERPRETATION OF THE RESULTS OBTAINED ON THE TECHNOLOGICAL SATELLITE "SOLAR CELLS". (Co-authors : S. MOTTET, M. LE METAYER).

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ANALYSIS AND IMPROVEMENT OF SILICON SOLAR CELLS. (Co-authors : NGUYEN DUY, C. MOTTE, D. AMINGUAL, S. MOTTET, W. PALZ)

NEW TECHNOLOGY FOR CdS-$Cu_2S$ SOLAR CELLS OF HIGH RELIABILITY.(Co-authors : NGUYEN DUY, G. PICHARD, J. FREMY, W. PALZ).

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INVESTIGATION ON THREE CLOSED CHAMBER SOLAR WATER.

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DESIGN AND FEASIBILITY OF FLAT PLATE SOLAR COLLECTORS TO OPERATE AT 100-150 C (E 18)

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L'UTILISATION DE L'ENERGIE SOLAIRE POUR LA PRODUCTION AGRICOLE.

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SOLAR BATTERIES FOR SPECIAL TERRESTRIAL APPLICATIONS

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SUR LE CHOIX DES MATERIAUX POUR LA CONDUCTION ET LE STOCKAGE DE LA CHALEUR EN HELIOTECHNIQUE (EH 76)

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COMPARISON OF VERTICAL MULTI-JUNCTION AND CONVENTIONAL SOLAR CELL PERFORMANCE.

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ROLE DE L'ENSOLEILLEMENT DANS LA DEFINITION DU CLIMAT DES SERRES. (with co-authors)

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TECHNICAL AND ECONOMIC FACTORS IN THE IMPLEMENTATION OF SOLAR WATER HEATERS.

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CLASSIFICATION DES DIFFERENTS TYPES DE CLIMATS RADIATIFS ET LUMINEUX EN FONCTION DES CONDITIONS MOYENNES DU TROUBLE ATMOSPHERIQUE.

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DIRECT ENERGY CONVERSION BY MEANS OF SOLAR CELLS.

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THE SOLAR ELECTRIC CAR URBAN VEHICLE PERFORMANCE

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PHOTOSTIMULATION OF GONADS IN BIRDS : THE BUNNING HYPOTHESIS AND RESPONSES TO VERY SHORT DAILY PHOTOPERIODS. (B 13)

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REFRIGERATION SOLAIRE. COMPARAISON ENTRE UN INSOLATEUR PLAN ET UN CONCENTRATEUR CYLINDROPARABOLIQUE. (EH 99)

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COMPARAISON ENTRE LES FOURS SOLAIRES ET FOURS A IMAGE (E 132)

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APPROCHE THERMODYNAMIQUE POUR EVALUER L'UTILISATION DE L'ENERGIE SOLAIRE PAR LES PLANTES. (V 14).

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SOLAR ENERGY UTILISATION POTENTIAL IN INDIA (E 12)

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SPACE SOLAR POWER (E 11).

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THE PERFORMANCE OF SOLAR ARRAYS IN DEEP SPACE.

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SOME ASPECTS OF INVESTIGATION ON SOLAR STILLS. (E 101).

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A CALCULATION MODEL AND DESCRIPTIVE FORMULAS FOR THE EXTINCTION AND REFLECTION OF RADIATION IN LEAF CANOPIES. (V 6)

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AN OPEN GAS-TURBINE CYCLE FOR SOLAR ENERGY CONVERSION.

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POSSIBILITES D'UTILISATION DE L'ENERGIE SOLAIRE POUR LA PHOTOCHIMIE INDUSTRIELLE (E 115).

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STUDY ON TRANSPORT PHENOMENA IN THE $Cu_{2x}S$ IN FUNCTION OF ITS STOECHIOMETRY.

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ON THE REDUCTION OF SOLAR HEAT IN INDUSTRIAL BUILDINGS.

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SIMPLE SHEET-METAL CONCENTRATING REFLECTORS.(E 34)

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A NATURAL CONVECTION SOLAR CROP DRIER (V 26)

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LES ENQUETES EN BIOCLIMATOLOGIE PHYSIOLOGIQUE.

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ROLE OF THE PINEAL GLAND AND CERVICAL GLANGLIA SUPERIOR IN THE PHOTOSTIMULATION OF THE GONADS OF THE VERTEBRATES.

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METHODOLOGIE D'ETUDE DE L'UTILISATION DES FACTEURS CLIMATIQUES A TITRE PREVENTIF, PROBLEME GENERAL DU SPORT ET DES VACANCES.

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ON INHOMOGENEITIES OF THIN FILM SOLAR CELLS.

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THE VISUAL SYSTEM OF MAN.

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STATISTICS OF SUNFLECKS AND ITS APPLICATION TO LIGHT FLICKERING PROBLEMS IN PLANT COMMUNITIES.

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HABITATION ECONOMIQUE UTILISANT LE FLUX DE CHALEUR RESULTANT DE L'ABSORPTION DU RAYONNEMENT SOLAIRE. (EH 30)

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INTERACTION ENTRE LA PHOTOSYNTHESE ET L'ACTION DU PHYTOCHROME : CONSEQUENCES POUR LA MORPHOGENESE DES PLANTES. (V 4)

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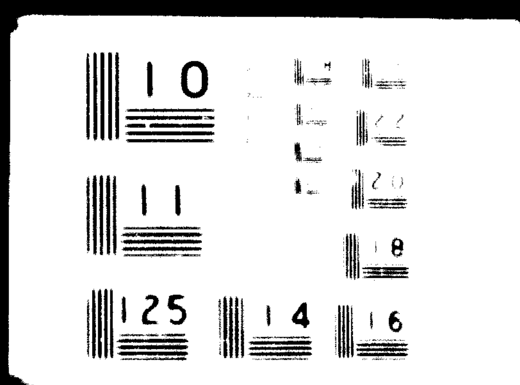

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SOLAR RADIATION DISTRIBUTION AND ITS EFFECTS ON PHOTOSYNTHESIS IN A SPRUCE FOREST CANOPY.

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ROLL-OUT SOLAR ARRAYS FOR HIGH POWER APPLICATION.

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POSSIBILITIES OF THIN SOLAR BATTERY, APPLICATIONS FOR THE TERRESTRIAL USE UNITS.

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THE SOLAR GENERATOR OF THE TELECOMMUNICATION SATELLITE "SYMPHONIE".

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RADIATION BALANCE AND SHORTWAVE RADIATIVE FLUX DIVERGENCE IN THE ATMOSPHERE FOR VARIOUS CLIMATOLOGICAL ZONES.

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ELABORATION DES MODELES D'INTERACTION ENTRE L'ORGANISME ET SON ENVIRONNEMENT (IDENTIFICATION DES SYSTEMES ADAPTIFS)

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PROBLEMES RELATIFS A LA CONSTITUTION D'UN RESEAU RADIOMETRIQUE.

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LOW-POWERED PHOTOELECTRIC GENERATORS FOR THE TERRESTRIAL APPLICATION.

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PROBLEMS OF DEVELOPMENT AND TEST OF LARGE LIGHTWEIGHT SOLAR PANELS.

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PHOTOELECTRIC POWER ENGINEERING. (Co-author : A.P. LANDSMAN).

POSSIBILITIES OF SOLAR ENERGY CONVERSION TO ELECTRICAL ONE. (Co-author : B.V. TARNIZHEVSKI).

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DNA REPAIR IN SKIN AND OTHER TISSUES DAMAGED WITH ULTRAVIOLET RADIATION AND CHEMICAL CARCINOGENS. A GENERALIZED PROTECTIVE RESPONSE. (B [illegible])

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THE VIOLET CELL AND ITS IMPLICATIONS FOR THE FUTURE.

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SOLAR CELL DEVELOPMENT IN THE FEDERAL REPUBLIC OF GERMANY.

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VARIATIONS CYCLIQUES DU CLIMAT DE VALDIVIA.

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SOLAR STILLS FOR RESIDENTIAL USE. (E 6).

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ENSOLEILLEMENT ET REGLES D'URBANISME (EH 90).

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HEAT TRANSFER CHARACTERISTICS OF A SOLAR DRIER (V 25).

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TEST FACILITY WITH LIQUID HELIUM FOR THERMAL CYCLING OF SOLAR CELL MODULES.

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MONITORING ULTRAVIOLET RADIATION WITH POLYVINYLCHLORIDE. (E 116)

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THE CdS-$Cu_2S$ HETEROJUNCTION AND ITS APPLICATION FOR SOLAR ENERGY.

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PHOTOTHERMAL CONVERSION OF SOLAR ENERGY FOR LARGE-SCALE ELECTRICAL POWER PRODUCTION . (E 13)

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ETUDE STATISTIQUE DU RAYONNEMENT SOLAIRE. (E 26)

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A SIMPLE METHOD FOR DESORPTION OF WATER BY SOLAR HEATING OF THE ABSORBENT SOLUTION USED FOR DEHUMIDIFICATION OF ROOM AIR. (EH 100)

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COEFFICIENT OF UTILIZATION OF SOLAR RADIATION ENERGY BY NATURAL AND CULTIVATED PHYTOCENOSES.

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MODIFICATIONS QUALITATIVE ET QUANTITATIVE DU RAYONNEMENT SOLAIRE DANS LES SERRES EN FONCTION DES FORMES ET DES MATERIAUX DE COUVERTURE (V 21)

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HIGH TEMPERATURE SCANNING SPECTROMETER WITH A SOLAR FURNACE. (E 15)

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THE ANATOMICAL BASIS OF RETINO-HYPOTHALAMIC AND EXTRA-RETINO-PHOTO CONNECTIONS (B21).

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FEASIBILITY OF SOLAR POWER FOR SEATTLE, WASHINGTON (E 3)

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STUDY OF THE RELATIONSHIPS BETWEEN SOLAR RADIATION, NET RADIATION AND HOURS OF SUNSHINE. (E 21)

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A PLASTIC FRESNEL LENS AS A SOLAR COLLECTORS. (E 110)

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INFLUENCE DES RADIATIONS SOLAIRES THERMIQUES ET LUMINEUSES SUR L'ACTIVITE SEXUELLE DES MAMMIFERES DOMESTIQUES (B 18).

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SOLAR ENERGY POTENTIAL AND SOLAR TECHNOLOGY OF TURKEY UP TO 2000 YEAR (E 131).

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THE CONCEPT OF "TOWN-COUNTRY", AN INTEGRATED HUMAN-BOTANICAL ENERGY PROCESS FOR HABITAT. (EH 86)

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STATUS AND OUTLOOK OF THE PHOTOVOLTAIC ENERGY DEVELOPMENT IN FRANCE.

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INFLUENCE DE LA REGULATION STOMATIQUE SUR LA TRANSFORMATION DE L'ENERGIE D'ORIGINE SOLAIRE PAR LES FEUILLES. (V 15).

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L'INFLUENCE DE L'URBANISATION ET DE L'INDUSTRIALISATION SUR LE BILAN DU RAYONNEMENT SOLAIRE. (EH 88)

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THE EFFECT OF CONTINUOUS LIGHT OR BLINDING ON DRUG SUSCEPTIBILITY RHYTHMS IN PENTOBARBITAL SODIUM AND AMPHETAMINE. (B 36)

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MODIFICATION DES TRANSFERTS RADIATIFS AU NIVEAU DES MURS EXTERIEURS DE CONSTRUCTIONS PAR L'EMPLOI DE STRUCTURES EN REVETEMENT. (EH 28)

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EXAMINATION OF SOME HEAT STORAGE SYSTEMS FOR SOLAR COLLECTORS IN BUILDING HEATING APPLICATIONS. (EH 93)

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THE ENERGY PLANTATION.

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LE SOLEIL, FACTEUR DE VIE URBAINE. (EH 85)

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THE RAE LIGHTWEIGHT SOLAR ARRAY.

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SOLAR-TO-THERMAL ENERGY CONCEPTS APPLIED TO LARGE SCALE ELECTRICAL POWER GENERATING SYSTEMS.

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INNOVATION AND CONTINUITY. PLANNING FOR SUNLIGHT IN HOUSING BRITISH EXPERIENCE. (EM 56)

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NEW DEVELOPMENTS IN ARCHITECTURAL GLASS. (EH 78).

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# How To Build
# A SOLAR WATER HEATER

Do-it-Yourself Leaflet No. L-4

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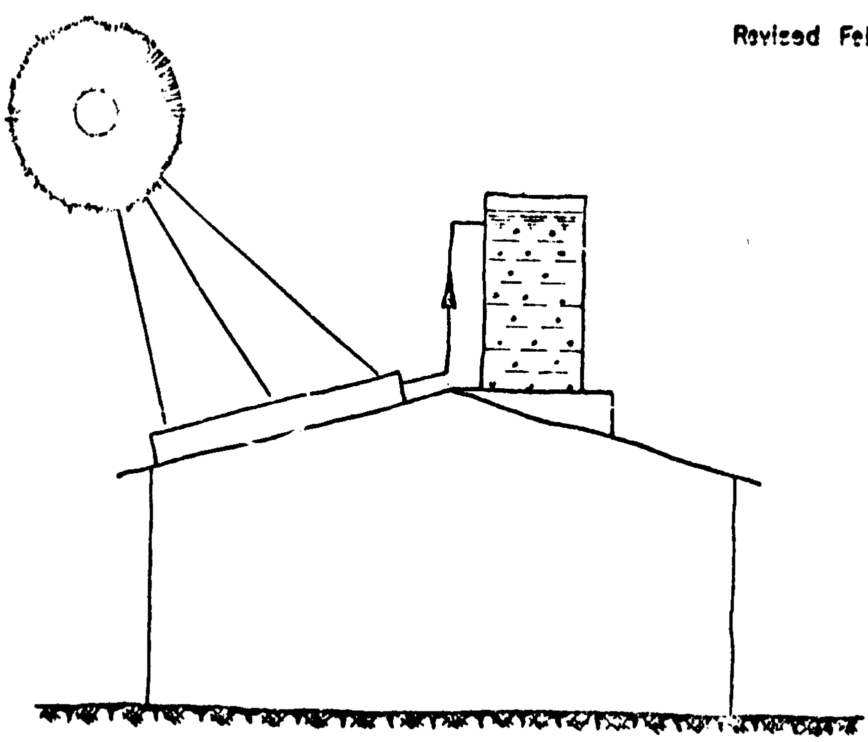

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# How to Build
# A SOLAR WATER HEATER

THIS leaflet describes how to make an inexpensive, yet efficient, solar water heater suitable for domestic or agricultural use in areas enjoying a sunny climate. Although a number of commercial firms manufacture solar water heaters in several countries, these are in the main sophisticated and expensive to buy. The unit described herein has been specially designed to incorporate low-cost materials generally available, even in relatively remote parts of the world.

This solar water heater can provide from 30 to 40 gallons of hot water per day at a temperature of 130° F to 140° F in tropical areas, depending upon the weather. The estimated cost of the materials required for the collector, hot water storage tank and cold water feed tank is the equivalent in local currency of about US $45.00. The cost of labour necessary for the complete assembly is estimated as the equivalent of about US $40.00. Therefore, for the handy man who builds his own unit, this installation can be obtained for as little as US $45.00. The life of the equipment is of the order of five years with negligible maintenance, after which time it will probably be necessary to spend about $10.00 to replace the oil-drum hot water tank and overhaul the installation. This solar water heater should be particularly useful in isolated areas where the cost of alternative methods of heating, such as electricity and fuel, are high.

### *Description of the Solar Water Heater.*

Fig. 1 shows a general view of the assembled equipment, comprising four main parts:

A — The Absorber which receives the sun's rays and heats the water,

B — The Absorber Casing which houses the absorber and the insulating material,

C — The Hot Water Storage Drum which is suitably insulated to conserve the heat in the water,

D — The Cold Water Feed Tank, made from half of an oil drum.

The Absorber, which is constructed from a corrugated galvanized steel sheet of standard roofing material and a sheet of 22 gauge flat galvanized steel rivetted and soldered together, should slope towards the equator at an angle of about 10 degrees in excess of the geographical latitude. The Absorber should be mounted in an exposed place where it will "see" the sun during the greater proportion of the day. It may be laid directly on a sloping roof, mounted on a frame on a flat roof or cantilevered out from a wall so that it serves as an awning over a door or window. The Hot Water Storage Drum must be mounted so that the lower (cold) water connection to it is at least one foot higher than the top of the absorber. Both the Hot and Cold Water Storage Drums should be installed inside the building if possible to reduce corrosion.

### *How To Build The Collector.*

A materials list and explanatory sketches are located at the back of this leaflet.

### *A — The Absorber.*

The following detailed instructions are based upon the use of a standard sheet of corrugated galvanized steel, 22 gauge, 8 ft. long by 26 in. broad, with corrugated 3 in. apart and ¾ in. deep. Should it be necessary to use another size of sheet with different corrugations, then the builder will have to modify the dimensions set out in the sketches accordingly.

**Step 1** — Part (1). Cut the galvanized steel corrugated sheet to 26 in. by 88¾in. with a pair of metal shears and place to one side.

**Step 2** — Part (2). Cut the sheet of "special" flat to 26½in. by 90⅝in. Place a piece of stiff cardboard against the end of the corrugated sheet, Part (1), and trace the shape of the corrugations on the cardboard with a soft pencil. Cut along the pencil line on the cardboard so that it can be used as a pattern. Lay the cardboard pattern on each end of the flat sheet, Part (2), in turn and mark the corrugations on Part (2) as shown in the sketch. With a pair of metal shears cut the ends of the "special" flat sheet, Part (2), as marked out by the cardboard pattern. The ends of Part (2) should then look as shown in the sketch No. Z.

Cut out two holes, 0.84 in. in diameter, as shown on Part (2) in the sketch, to allow a ½ in. galvanized steel pipe to pass through each with a tight fit.

**Step 3** — Next take the corrugated galvanized sheet, Part (1), and attach one 9 in. length of ½ in. galvanized pipe to each end, as shown in sketch No. X. First screw the 3/16 in. diameter, ¾ in. long machine screw (Part No. 5) into the ½ in. galvanized pipe, then solder the pipe to the corrugated sheet.

**Step 4** — Bend the ends of the sheet of special flat (2), at right angles, as shown in sketch No. W. The bent end sections should each be one inch long, i.e. ¼ in. longer than the depth of the corrugations to allow for overlap when soldering. Place the corrugated sheet (1) on top of the sheet of special flat (2), slipping the ½ in. pipes into the holes. It will be necessary to cut the special flat at one end to allow the pipe to enter the hole, as shown in sketch No. Y.

**Step 5** — Bend the edges of the sheet of special flat (2) over the edge of the corrugated galvanized sheet (1), as shown in sketch No. V, and solder (6) as shown. To bend the edges of the flat galvanized sheet ¼ in. from the edge, clamp the sheet between two pieces of angle iron along the edge where it is to be bent and use a hammer to obtain the right-angled bend.

**Step 6** — Drill ⅛ in. holes for the rivets in the valleys of the corrugations, spaced as shown in sketch No. U. Place the ⅛ in. galvanized rivets (3) in the holes with the heads resting on the flat galvanized sheet as shown, and peen the heads of the rivets. Next solder over the peened heads of the rivets. The collector absorber is now complete and it will be necessary to test for leaks. To do this, place the absorber in a sloping position, by putting it up against the side of a building or by placing a box underneath one end, fill the absorber with water — **do not put mains pressure on the absorber** — and allow to stand. Mark all leaks with white chalk and repair. Very slow leaks are sometimes difficult to stop — leave these as they will most probably seal themselves with time. After all leaks have been repaired, leave the absorber to stand in the sun filled with water. Paint the corrugated side of the absorber with two coats of flat black paint.

### *B — The Absorber Casing.*

**Step 7** — Cut Part (7), a 3 ft. by 8 ft. sheet of flat 24 gauge galvanized steel along one side to reduce it to a 33¾ in. by 96 in. sheet. Next cut the corners off, as shown by the solid lines in sketch No. S, and bend the sheet at right angles along all the lines shown dotted in the sketch. Having bent the casing into shape as shown in sketch No. T, rivet the four corners with 8 — ¼ in. galvanized rivets (8). Place the casing aside after drilling 2 — ¼ in. drain holes in one end of the casing, as shown in sketch No. T. When the unit is finally assembled in a tilted position, these holes must be located at the lower end of the casing so that any condensed moisture may drain off.

Step 8 — Cut out Part (10), consisting of 6 "L" brackets and drill ¼ in. holes for the rivets in the brackets.

Step 9 — Bond the ¼ in. thick felt strips 1 in. by 1 in. (11) on to the "L" clamps.

Step 10 — Locate the 6 — ¼ in. holes in the casing, one in each end and two along each side as shown in sketch No. T, and drill. Rivet the "L" supports (10) onto the casing, placing the flat rivet heads (12) on the outside.

Step 11 — Draw out the coconut fibre (9) into light straw and place a 2 in. layer of fibre at the bottom of the casing. (See sketches Nos. T and V.) Place the absorber in the casing, with the black painted corrugated surface upwards, resting the absorber on the "L" supports, Part (10).

Step 12 — Make Part (13), consisting of 4 — ¼ in. by ¾ in. by 1 in. — 22 gauge galvanized steel hold-down "L" clamps. Using Part (14), screw the hold-down clamps (13) into place to secure the collector absorber to the casing.

Step 13 — Make Part (15), consisting of a galvanized steel "T" rib to support the 2 glass sheets at the centre of the collector. The rib can be bent from a sheet of 22 gauge galvanized steel. Alternatively a pre-formed T-rib may be available commercially, e.g. the rib for the "Grecon" suspended ceiling.

Step 14 — Rivet the rib (15) to the casing as shown in sketch No. T, with 2 galvanized rivets (16) at each end.

Step 15 — Stick the ¼ in. Dor-Tite or alternative sponge rubber stripping (17) onto the ¾ in. edging on the glass supporting rib (15), as shown in sketch No. U.

Step 16 — Stick ¼ in. wide sponge rubber stripping (18) all around the ¼ in. edge of the casing.

Step 17 — Place the two sheets of glass (19) on the casing to cover the absorber, making sure that the glass rests evenly on the ¾ in. stripping (18) all round.

Step 18 — Apply the silicone sealant between the glass sheets and the centre and edge supporting ribs. Be sure to allow 1/8" on each side for expansion of the glass. The silicone sealant is very strong and should have a long life. Otherwise use ordinary putty and seal the glass to the container with black electrical insulating tape.

Step 19 — Make Part (22), 16 — ¼ in. by ¾ in. by 1 in. hold-down "L" clamps, and drill an ¼ in. diameter hole in each clamp to allow the self-threading screws to enter. Stick the ¾ in. sponge rubber strips (23) onto the glass, over the black electrical tape, where the hold-down clamps are to go — see sketches Nos. T and V. Press the hold-down clamps onto the ¾ in. stripping and drill an ¼ in. hole in the casing to correspond with the ¼ in. hole in the clamp. Use the 16 — ¼ in. self-threading galvanized screws (24) to screw the hold-down clamps onto the casing. The collector is now complete. Place to one side, then proceed to make the tanks.

### *C — The Hot Water Storage Drum.*

**Step 20 —** Thoroughly rinse out the oil drum (25) with a half pint of diesel oil (30), then rinse again with a half pint of gasoline The diesel oil dissolves any oil etc that may be in the drum, and the gasoline dissolves the remaining diesel oil and leaves the inside of the oil drum dry and free from grease, ready for painting

**Step 21 —** Next pour the pint tin of heat resistant paint (29) into the oil drum and shake thoroughly so that the whole inside of the oil drum is coated with paint. Place the oil drum aside to allow the paint to dry

**Step 22 —** Build the wooden frame-work to contain the oil drum as shown in Fig 3, using the deal boards (28) to make the supporting ribs Place the oil drum into the frame-work and cover over with the 24 gauge sheets of galvanized steel (26), making sure that the top is left open so that the coconut fibre insulation (27) can be tucked into the spaces around the drum Connect the necessary reducers to the two holes in the end of the oil drum and leave 6 in of ½ in. galvanized pipe protruding from each opening in the oil drum. Tuck the coconut fibre insulation around the tank and place the cover on The hot water tank is now complete Place to one side.

### *D — The Cold Water Feed Tank.*

**Step 23 —** Cut an oil drum in half and utilize the best half (32) Install the ½ in float valve (33) as shown in Fig 1 Paint with two coats of Rust-Oleum (35) paint of colour of your choice and let dry.

**Step 24 —** Obtain the necessary [illegible] so that the system can be connected up as shown in Fig 1 The maximum head of water acting on the absorber must not exceed 7 ft and the minimum head must not be less than 1 ft.

### *E — Assembly Of Equipment.*

**Step 25 —** Connect up the equipment as shown in Fig 1, making sure to use piping joint-sealer when tightening the pipe threads Bleed the system of all air Ensure that the collector is tilted at an angle equal to the latitude of the area plus 10 degrees and is facing the equator For economy a lay-out should be chosen which keeps the length of water piping, connecting the absorber to the hot water storage drum, to a minimum If it is not possible to place the drum adjacent to the absorber, then 1 in water piping must be used in place of the ½ in piping specified in the materials list If this is not done, the hydraulic resistance of the piping may be so high that the natural convectional circulation of water between the absorber and tank may be severely restricted and the performance of the heater suffer accordingly

Before attempting to draw hot water from the unit it should be left for one complete day to allow the system to heat up The installation should be kept permanently filled with water to prevent damage due to overheating. Should it be necessary to empty the system at any time, either for repair or to avoid winter freeze-ups, a cover should be left over the absorber glass.

**NOTE:** A simple vent pipe should be installed at the high point of the hot water return line leading from the absorber to the storage drum. (as illustrated)

## HOT WATER SUPPLIES FOR LARGER INSTALLATIONS

In many cases such as hospitals, institutions, hotels, public buildings, laundries and public baths there is a demand for hot water far in excess of the 30 to 40 gallons per day output obtainable from the domestic unit described above. To provide large quantities of hot water several absorbers can be connected in parallel with each other and to a common hot water storage tank. Provided that provision is made in the initial design of the building a very inexpensive installation can be achieved by placing the absorbers immediately under the roof and covering them with corrugated "perspex", "lucite" or other suitable transparent plastic sheets which form part of the roof, as indicated in Fig 2. It is then not essential to insulate the absorbers, although insulation will improve the performance.

***Enquiries***

Enquiries and requests for additional copies of this leaflet should be addressed:

Brace Research Institute,
Macdonald College of
McGill University,
Ste. Anne de Bellevue 800,
Québec, Canada.

***Note for Prospective Users of Solar Water Heaters in Barbados, W.I.***

January, 1965.

Two solar water heaters, similar to the one described in "Do-It-Yourself" Leaflet No 4 have already been installed on the Island and have been operating satisfactorily without maintenance for the past one year, one is at the Cottage, Mallows, St. James, and the other is at Mrs Stoute's Nursing Home, 5th Avenue, Belleville.

In Barbados the solar heat absorber should be tilted about 25 degrees below the horizontal and face south. However, if this is not possible owing to the structure of the building, it may be tilted in any direction south of east or west, the only result being a slight fall off in performance.

***Locally Available Materials***

1. Part No 15, the support rib for the glass sheets attached at the centre of the absorber casing, is available commercially as the rib for the "Grecon" suspended ceiling, the local agents are DaCosta and Co., Ltd.

2. Parts Nos 17, 18 and 23, Dor-Tite rubber strip, are obtainable from Durkle-Atwood Co., Minneapolis 13, U.S.A., the local agents are Chas McEnearney and Co Ltd.

3. Part No. 29, heat resistant paint, is obtained from Barbados Co-op Cotton Factory Ltd.

May 1972

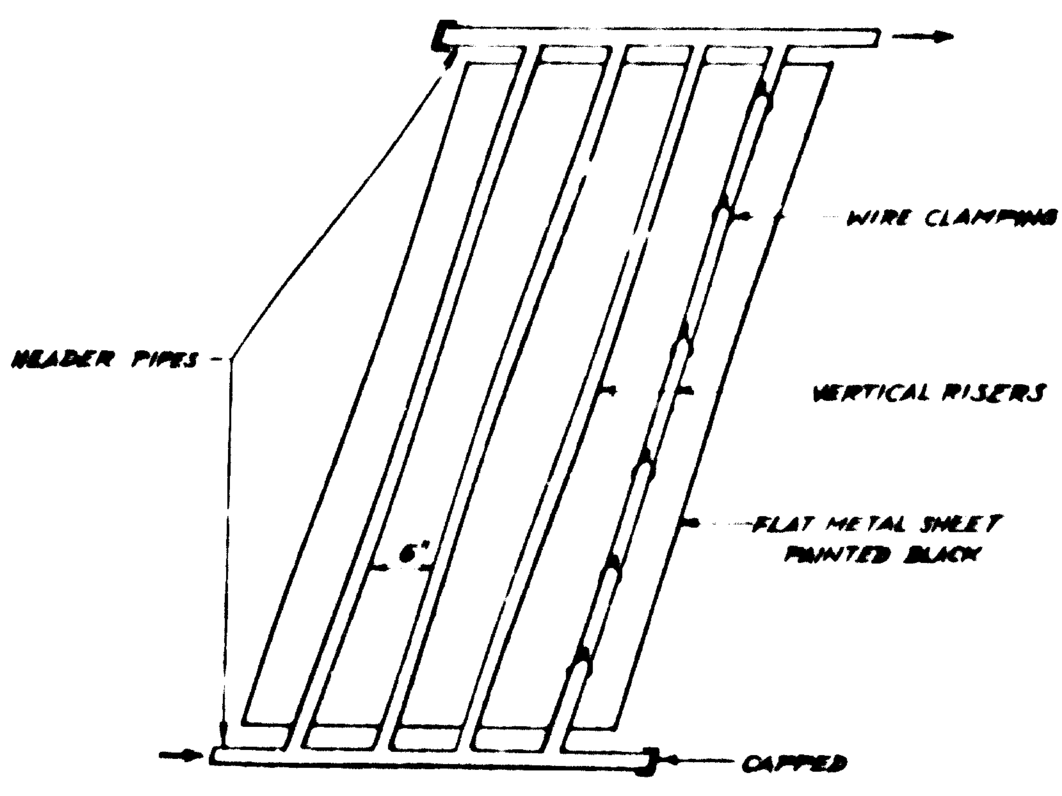
Since issuing this report a significant number of solar water heaters have been installed in Barbados. The four units at Mallows, St. James, have been performing satisfactorily for over seven years. The main problem is the occasional sticking of the ball float valve.

# Materials List

| Part No. | No. Off | Material | Size |
|---|---|---|---|
| A - The Absorber | | | |
| 1 | 1 | corrugated galv. steel sheet | 22 gauge, 8ft.x26in. |
| 2 | 1 | "special" flat galv. steel sheet | 22 gauge, 8ft.x36in. |
| 3 | 28 | galv. steel rivets | ¼in. dia., approx. 5/16in. long |
| 4 | 2 | galv. steel water pipe | ½in. I.D., 9in. long |
| 5 | 2 | m.s. machine screw | 3/16in. dia., ¾in. long |
| 6 | 2 | sticks of solder | |
| B - The Absorber Casing | | | |
| 7 | 1 | "special" flat galv. steel sheet | 24 gauge, 8ft.x3ft. |
| 8 | 8 | galv. rivets for ends of casing | ¼in. dia., approx. 5/16in. long |
| 9 | - | coco-nut fibre or equivalent insulation | 20 lbs |
| 10 | 6 | 22 gauge galv. steel sheet | 1in.x1in.x¼in. supporting "L" brackets |
| 11 | 6 | felt strips or suitable insulation | 1in.x1in.x1/8in. thick |
| 12 | 6 | galv. rivets for part (10) | ¼in. dia. |
| 13 | 4 | 22 gauge galv. steel sheet | 1in.x¾in.x½in., hold-down "L" clamps |
| 14 | 4 | galv. steel self threading screws for part (13) | 1/8in. dia.x½in. long |
| 15 | 1 | 22 gauge galv. steel sheet | 27 1/8in.x2½in., to make glass-support rib |
| 16 | 4 | galv. rivets for part (15) | ¼in. dia., approx. 5/16in. long |
| 17 | 2 | sponge rubber strip, e.g. "Dor-Tite" | ¼in.x1/8in x 17¼in. long |
| 18 | 1 | sponge rubber strip, e.g. "Dor-Tite" | ¼in.x1/8in.x22ft. long |
| 19 | 2 | window glass | 27¼in.x44¼in.x1/8in. thick |
| 20 | 1 | silicone type sealant (or equivalent) | 12 oz. cartridge |
| 21 | 1 | black plastic electrical insulating tape | one roll, 1in. wide (or nearest) |
| 22 | 16 | 22 gauge galv. steel sheet | 1in.x¾in.x¾in., hold-down "L" clamps |
| 23 | 12 | sponge rubber strip, e.g. "Dor-Tite" | ¼in.x1/8in.x¾in. long |
| 24 | 16 | galv. steel self-threading screws | 1/8in. dia. x ½in. long |
| C - Hot Water Storage Drum | | | |
| 25 | 1 | used steel oil drum | standard size 45 gallons |
| 26 | 2 | "special" flat galv. steel sheet | 24 gauge, 8ft.x4ft. |
| 27 | - | coco-nut fibre or equivalent insulation | 30 lbs |
| 28 | 2 | deal wood boards | 1in.x12in.x9ft. long |
| 29 | 1 | heat resistant paint | 1 pint tin |
| 30 | - | diesel oil | 1 pint |
| 31 | - | gasoline (petrol) | 1 pint |
| D - Cold Water Feed Tank & Piping | | | |
| 32 | 1 | used steel oil drum | standard size 45 gal., ½ only required |
| 33 | 1 | plumbing float control valve | ½ in. |
| 34 | - | ½in. galv. steel pipe and fittings | to suit particular installation |
| 35 | 1 | Rust-Oleum or similar paint | 1 pint tin |

ALTERNATIVE COLLECTOR ABSORBER

In many cases it will be possible to utilize flat aluminum, copper or galvanized steel sheet for the absorber collector, as illustrated below. In this case, a matrix of galvanized, or aluminum or copper pipe or tubing can be set out on a standard flat sheet collector, normally 3 ft x 6 ft or 4 ft x 8 ft etc. In this case the tube spacing should be approximately 6 inches, the diameter of tubing for the vertical risers should be ½ inch to 3/4 inch, and the inlet and outlet header pipes should be at least 1 inch nominal piping. In the case of steel piping the vertical risers can be cut to size and holes drilled into the headers to receive them. The ends should be welded together and the whole assembly pressure tested before attaching the matrix to the sheet. The same can be done with aluminum and copper. Under no circumstances should any dissimilar metals be used together as this will cause galvanic corrosion. However it is possible to use aluminum sheet and galvanized steel piping as there is no contact between the water and the sheet. In this case reasonable thermal contact between the tubing and the sheet can be obtained by tieing the piping to the sheet every few inches with galvanized wire. Obviously the closer the contact between the pipe and the sheet, the better the heat transfer, and the better the performance of the collector.



NOTE

This Institute distributes these leaflets with the objective of dissemenating information on these subjects. There are many methods of building a solar water heater, a windmill or agricultural dryer. What is described in this leaflet is one possibility. We suggest that you use this as a technical guide in applying this technology.

## Background Information on the Brace Research Institute

Brace Research Institute of McGill University was founded in 1959 to develop equipment and techniques for making dry lands available and economically useful for agricultural purposes. The Institute has concentrated on the problems affecting individuals or small communities in rural areas and is one of the few organizations with this basic objective.

In general, equipment developed by this Institute utilizes as many local resources as possible, whether human, energy or material, so that the technology can be easily adapted to the local environment. As a result, the Institute has concentrated on utilizing solar and wind energy as well as simple desalination systems, specifically concentrating on the problems that face isolated rural populations in developing arid areas.

Instructional manuals are available describing the use of solar energy for the

(1) heating of water for domestic and commercial use
(2) cooking of food
(3) drying of agricultural produce
(4) desalination of water for human, animal and agricultural use.

The adaptation of simple greenhouses combined with solar desalination systems for the production of food and water in arid areas is also being developed. The Institute is also adapting greenhouses to make better use of solar energy to reduce heating costs in colder regions.

In addition, simple windmills for the production of electricity and the pumping of water have been developed

Further inquiries should be directed to the

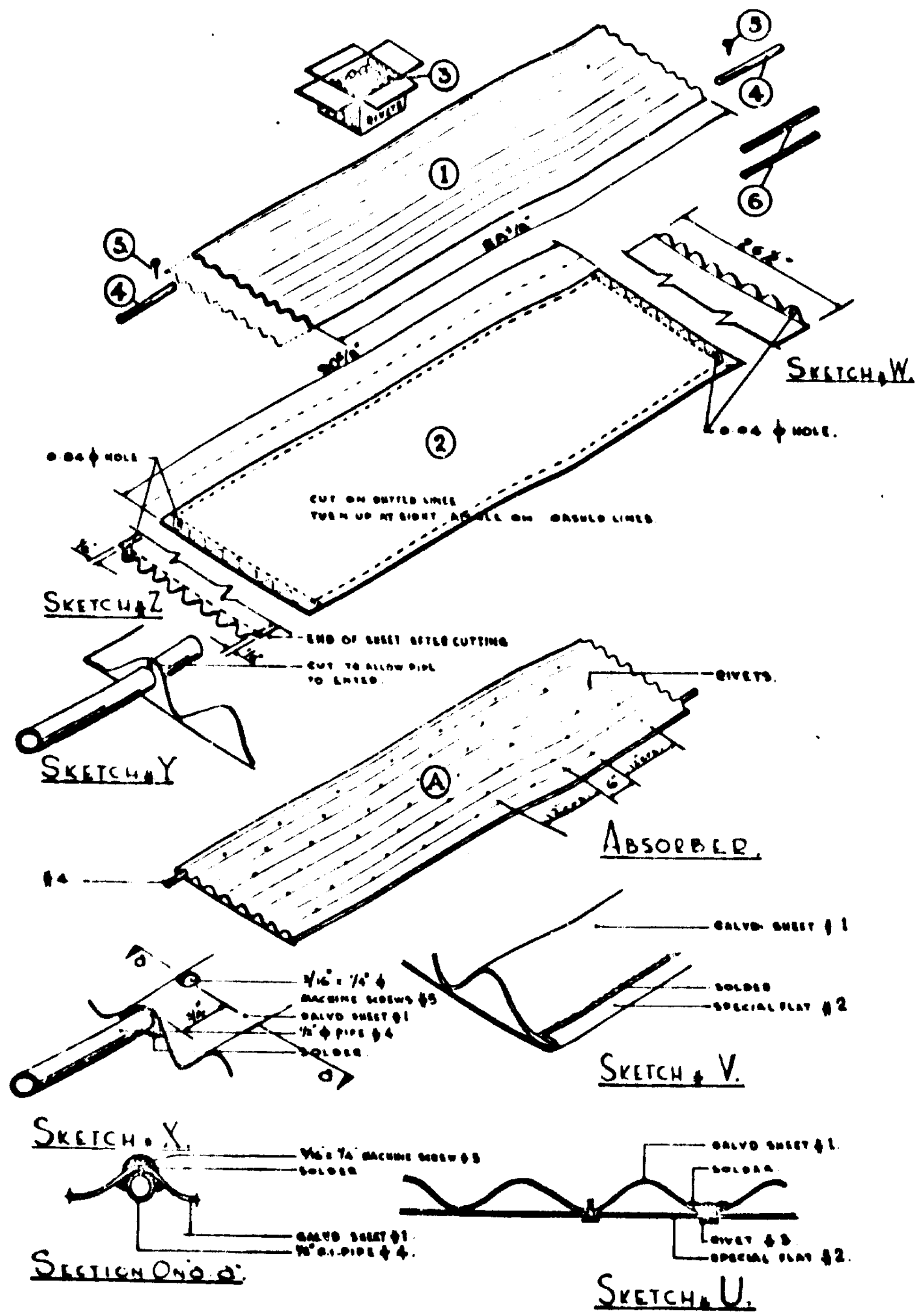
Brace Research Institute,
Macdonald College of McGill University,
Ste. Anne de Bellevue,
Québec, H9X 3M1,
Canada.

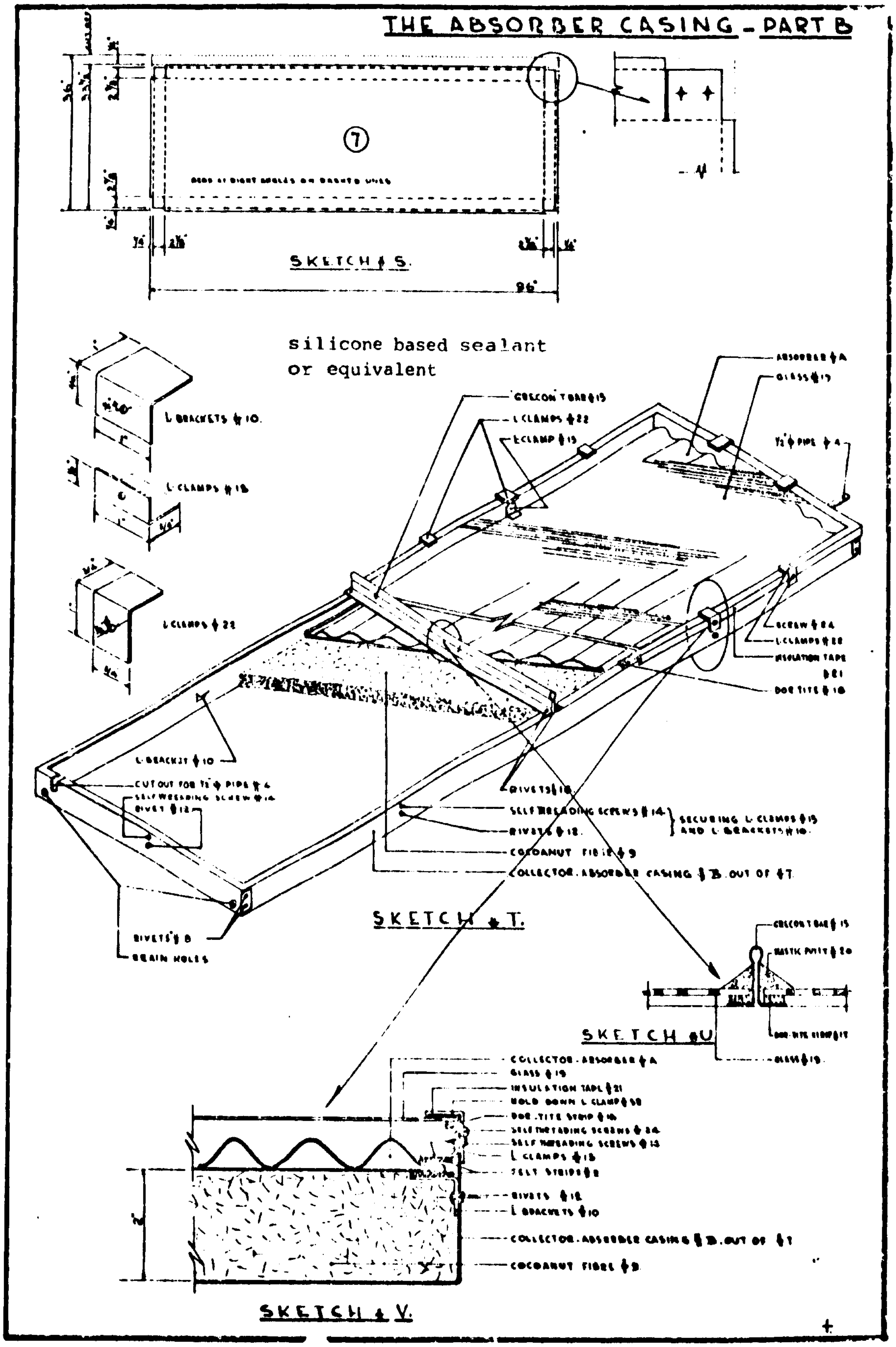
| Other leaflets available: | Price |
|---|---|
| L1 - How to Make a Solar Still (plastic covered) | $1.00 |
| L2 - How to Make a Solar Steam Cooker | $1.00 |
| L3 - How to Heat your Swimming Pool using Solar Energy | $0.50 |
| L4 - How to Build a Solar Water Heater | $1.00 |
| L5 - How to Construct a Cheap Wind Machine for Pumping Water | $1.00 |
| L6 - How to Make a Solar Cabinet Dryer for Agricultural Produce | $1.00 |
| L7 - Arabic Translation of L-6 | $1.00 |
| L8 - Spanish Translation of L-6 | $1.00 |
| L9 - French Translation of L-2 | $1.00 |
| T17 - Simple Solar Still for the Production of Distilled Water* | $1.00 |

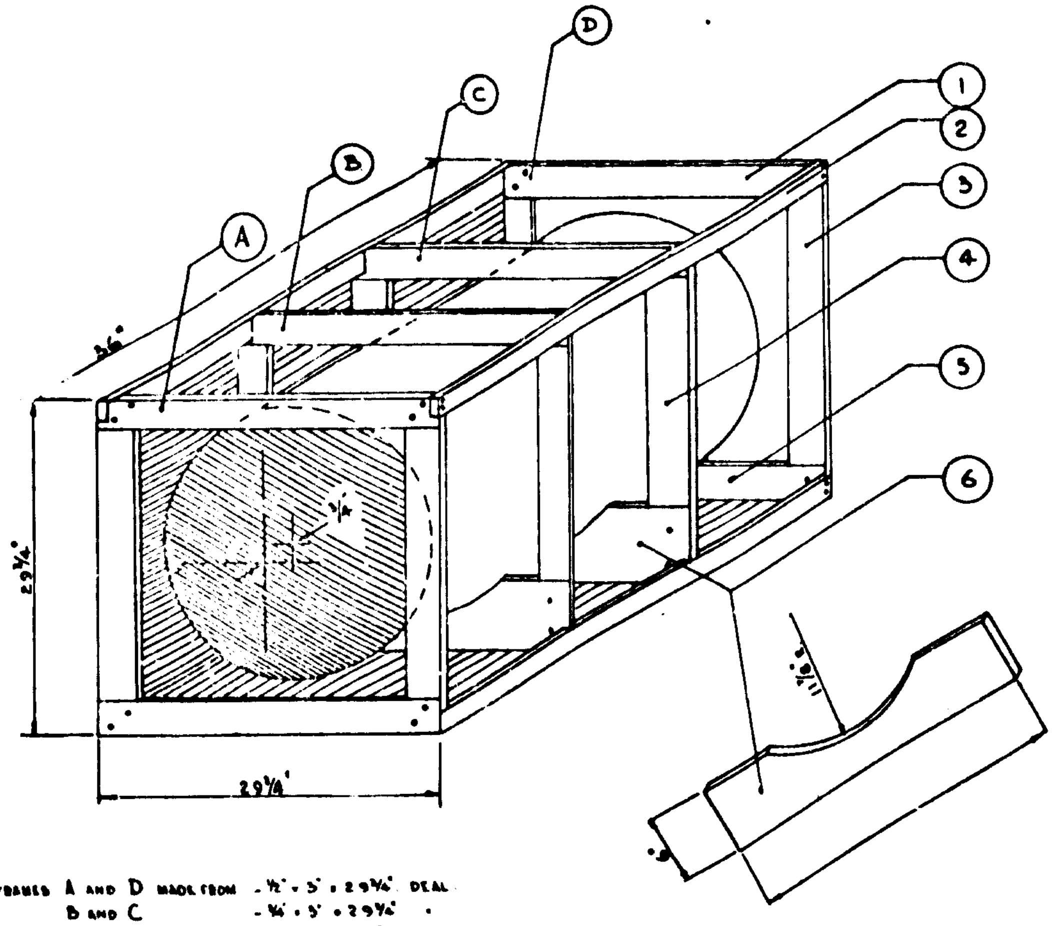
Please remit payment with money order or add $.25 to your cheque for bank handling charges.

* Also available in French, Arabic and Spanish.

# THE COLLECTOR ABSORBER - PART A.




THE ABSORBER CASING - PART B
SKETCH # S.
96"
silicone based sealant
or equivalent
L BRACKETS # 10.
L CLAMPS # 15
L CLAMPS # 22
SKETCH # T.
SKETCH # U
SKETCH # V.




| | | | |
|---|---|---|---|
| FRAMES | A AND D MADE FROM | - ½" x 3" x 29¾" | DEAL |
| | B AND C | - ¾" x 3" x 29¾" | " |
| | 1, 3 AND 5 . 8 PIECES | - ½" x 3" x 29¾" | " |
| | 2 | - ¾" x 2" x 36" | " |
| OIL DRUM 23½ [illegible] | | | |

**FIG: 3.**

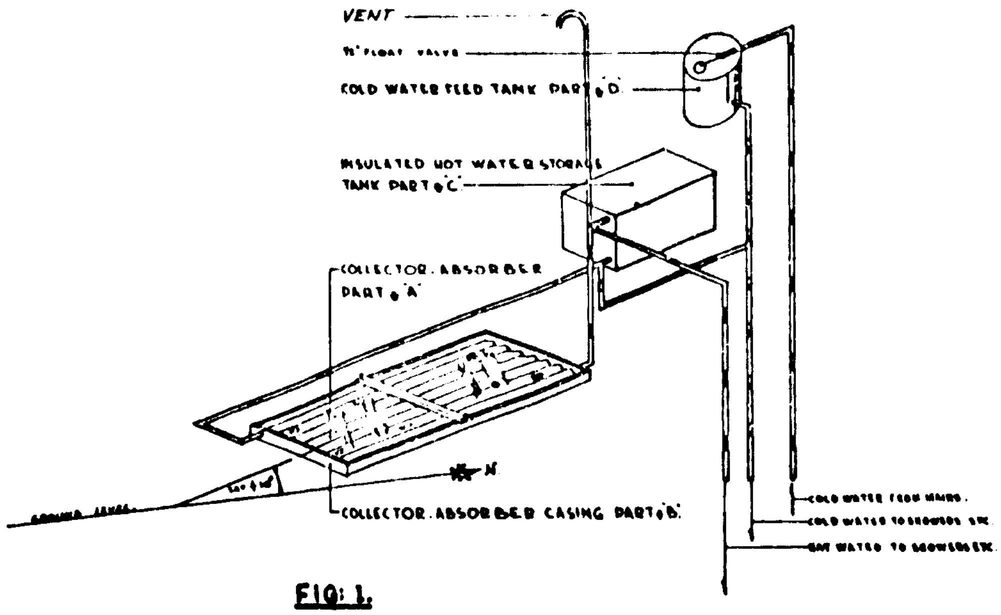

VENT
COLD WATER FEED TANK PART D
INSULATED HOT WATER STORAGE
TANK PART C
COLLECTOR ABSORBER
PART A
N
COLLECTOR ABSORBER CASING PART B

FIG: 1.

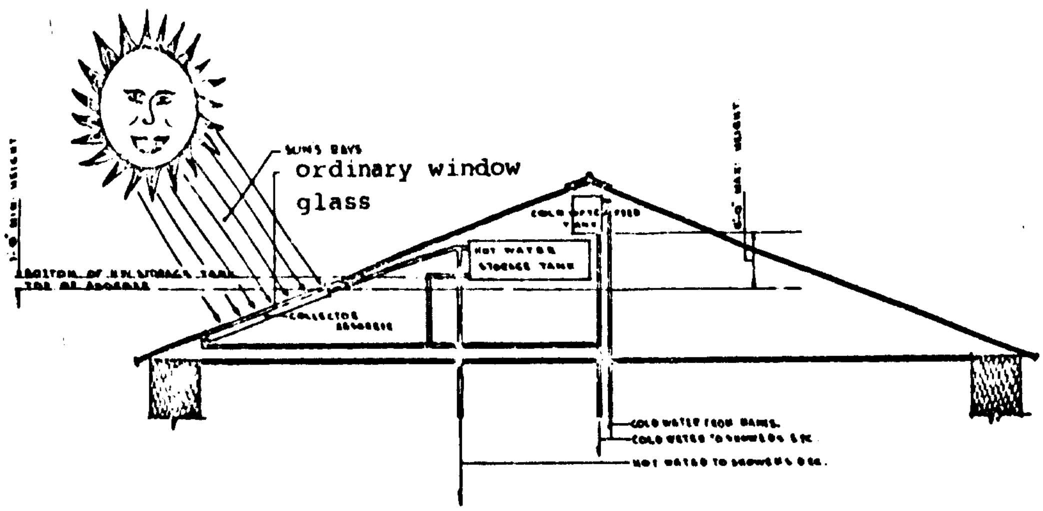

SUNS RAYS
ordinary window
glass
HOT WATER
STORAGE TANK
COLLECTOR
ABSORBER

FIG: 2.

| | | | |
|---|---|---|---|
| 1. BIBLIOGRAPHIC DATA SHEET | 1. Report No. NSF/RA/N-73-004 | 2. | 3. Recipient's Accession No. PB-223 5?? |
| 4. Title and Subtitle: Proceedings of the Solar Heating and Cooling for Buildings Workshop, Washington, D.C. March 21-23, 1973. Part I: Technical Sessions, March 21 and 22 | | | 5. Report Date: July 1973 |
| | | | 6. |
| 7. Author(s): Redfield Allen, Editor | | | 8. Performing Organization Rept. No. |
| 9. Performing Organization Name and Address: Department of Mechanical Engineering, University of Maryland, College Park, Maryland | | | 10. Project/Task/Work Unit No. |
| | | | 11. Contract/Grant No. NSF GI-32488 |
| 12. Sponsoring Organization Name and Address: Research Applied to National Needs (RANN), National Science Foundation, Washington, D. C. 20550 | | | 13. Type of Report & Period Covered |
| | | | 14. |

15. Supplementary Notes

16. Abstracts

The Proceedings contain thirty-six technical papers on solar energy for U.S. building applications areas; namely, solar collectors, energy storage, domestic hot water heating, energy conservation and insolation, solar air-conditioning, and systems for solar heating and cooling. Some foreign activities are also reviewed. Each technical paper is a report on: Proposed research, on-going research, proposed systems, or operating systems. Questions and answers from the discussion periods are included, as is an agenda and list of attendees.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms



17c. COSATI Field/Group

| | | |
|---|---|---|
| 18. Availability Statement: Unlimited | 19. Security Class (This Report) UNCLASSIFIED | 21. No. of Pages |
| | 20. Security Class (This Page) UNCLASSIFIED | 22. Price |

*Proceedings of the*

# SOLAR HEATING AND COOLING FOR BUILDINGS WORKSHOP

Washington, D.C.
March 21-23, 1973

## PART I: TECHNICAL SESSIONS, MARCH 21-22

*Prepared for the*

National Science Foundation-Research Applied to National Needs (NSF-RANN)

*by the*

Department of Mechanical Engineering
University of Maryland
under
NSF-RANN Grant GI-32488

Proceedings Edited by
REDFIELD ALLEN
UNIVERSITY OF MARYLAND WORKSHOP COORDINATOR

## ACKNOWLEDGMENTS

The University of Maryland acknowledges the very substantial guidance and assistance provided by Dr. Lloyd Herwig, Dr. Frederick Morse, and Mr. Harold Horowitz, each of whom is a Program Manager with the National Science Foundation. They joined the University in formulating the workshop agenda, and aided greatly in contacting potential attendees. They provided helpful counsel throughout the planning stages and, subsequently, served ably as workshop session chairmen.

## OTHER WORKSHOPS HELD UNDER THIS GRANT

Solar Thermal Conversion Workshop
Arlington, Virginia
January 11-12, 1973
(Proceedings in preparation)

*Any opinions, findings, conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation.*

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CONTENTS (Continued)

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## SESSION II – ENERGY STORAGE



## SESSION III – HOT WATER HEATING



## SESSION IV – ENERGY CONSERVATION, INSTRUMENTATION, INSOLATION, HEATING AND COOLING LOADS

CONTENTS (Continued)



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## CONTENTS (Continued)

*Page*

### SESSION VII – SOLAR HEATING/COOLING SYSTEMS (Continued)

## INTRODUCTION

Under the sponsorship of the National Science Foundation Research Applied to National Needs (NSF RANN) ... Solar Heating and Cooling for Buildings Workshop was held ... D.C. ... March ... 1973 ... meeting was called in recognition of the ... need for the ... among ... in the ... expanding field. It was also ... an expression of the RANN ... essential to promote ... researchers on the one hand and representatives of architectural, manufacturing, marketing, professional society ... and user sectors on the other.

At the time of the meeting ... under a grant to the University of Maryland. The Solar Energy ... charged with assessing the potential of solar ... held frequent and intensive meetings in 1972 and presented its findings in the December 1972 publication "Solar ... as a National Resource." That report has since been distributed to ... individuals in the United States and abroad.

Findings of the Solar Energy Panel affirmed that the solar energy received in the United States is received in su... to make major contributions to the nation's future heat and power requirements. Noting that there are no techn... barriers to wide application of solar energy to meet U.S. needs, the panel observed that the technology of terr... solar energy has been brought to its present limited state through very modest governmental ... and priv... Looking ahead, the panel pointed out that, whereas the cost of converting solar energy to useful forms is now ... conventional sources, solar conversion will become competitive in the future due to increasing prices of fuels and ... constraints on their use.

The Solar Energy Panel recommended that the Federal government take the lead in establishing a research and development program for the practical application of solar energy to the heat and power needs of the nation. Among the foremost applications recommended for accelerated study and development were the building heating and cooling applications. These, it was asserted, "... could reach public use within 5 years ... and 6 to 10 years ... respectively, given vigorous ... and development programs fostered by the Federal government." A main objective was seen as the development of ec... systems. Later, those systems showing both good technical and economic promise should be continued into pilot plant and demonstration phases by the Federal government and by industry, according to the Solar Energy Panel.

By the time the Solar Energy Panel report was released at the end of 1972, solar heating and cooling of buildings ... were already being undertaken at an accelerating rate, and the National Science Foundation recognized the urgent need for the exchange of information. This exchange was provided by the March 1973 workshop technical sessions and follow-on panel discussions of the broader aspects of solar heating and cooling. The technical sessions, which extended over the first two days of the workshop, are covered by the present "Part I" of the "Proceedings of the Solar Heating and Cooling for Buildings Workshop." Panel sessions on the third day, which provided for programmed interaction among researchers and architectural, manufacturing, marketing, professional society, governmental, and user sectors, will be covered by a forth... "Part II" of the proceedings. The agenda for the entire three day workshop can be found near the end of this document.

Individuals who made presentations in the technical sessions were invited to do so on the basis of their known activ... the area of solar heating and cooling for buildings, or related activities dealing with energy conservation in buildin... insolation data, and foreign developments. Considerable effort was devoted to obtaining a broad representation of ... heating and cooling activities. Other participants representing the aforementioned architectural, manufacturing, ... professional society, governmental and user interests were invited on a selective basis with the understanding that these individuals would also actively engage in the discussions. In all, about 100 participants attended the workshop. A ... participants and their mailing addresses ... included at the end of these proceedings.

[illegible] after [illegible] which are [illegible] held [illegible] and [illegible]

[illegible] certification [illegible] The term [illegible] denotes [illegible] stage [illegible] being [illegible] an agency [illegible] than NSF.

A [illegible] Summary [illegible] based [illegible] following the [illegible] Session [illegible] All [illegible] Discussion [illegible] General Discussion [illegible] are edited [illegible] Notations [illegible] represent Question, Answer, and Comment, respectively. [illegible] of those [illegible] asking [illegible] and [illegible] comments were omitted because extensive editing was employed.



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# SEAWATER DESALINATION BY SOLAR REFRIGERATION

A process devised for the development of arid zones of the Red Sea coasts and the Arabian Peninsula.

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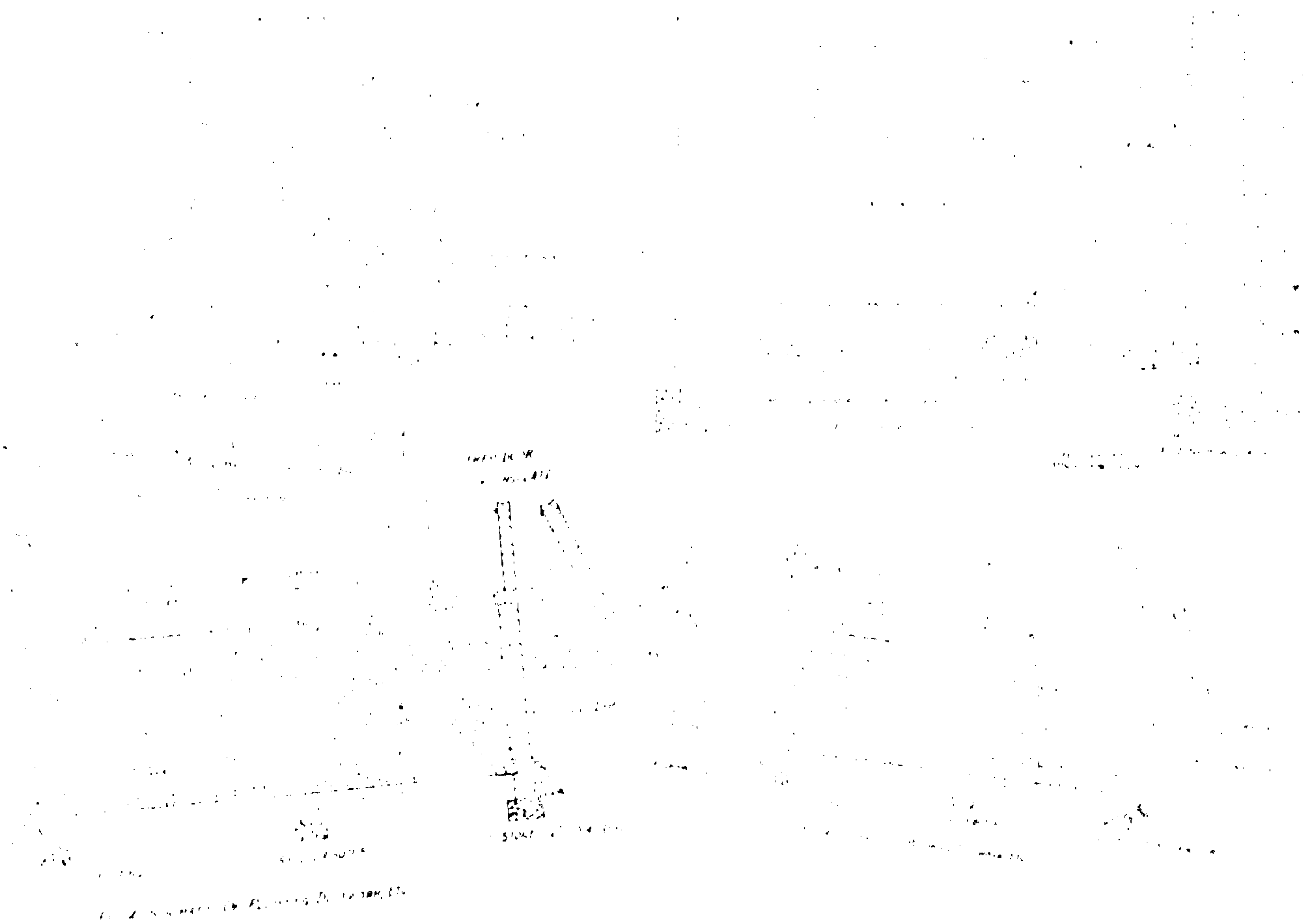

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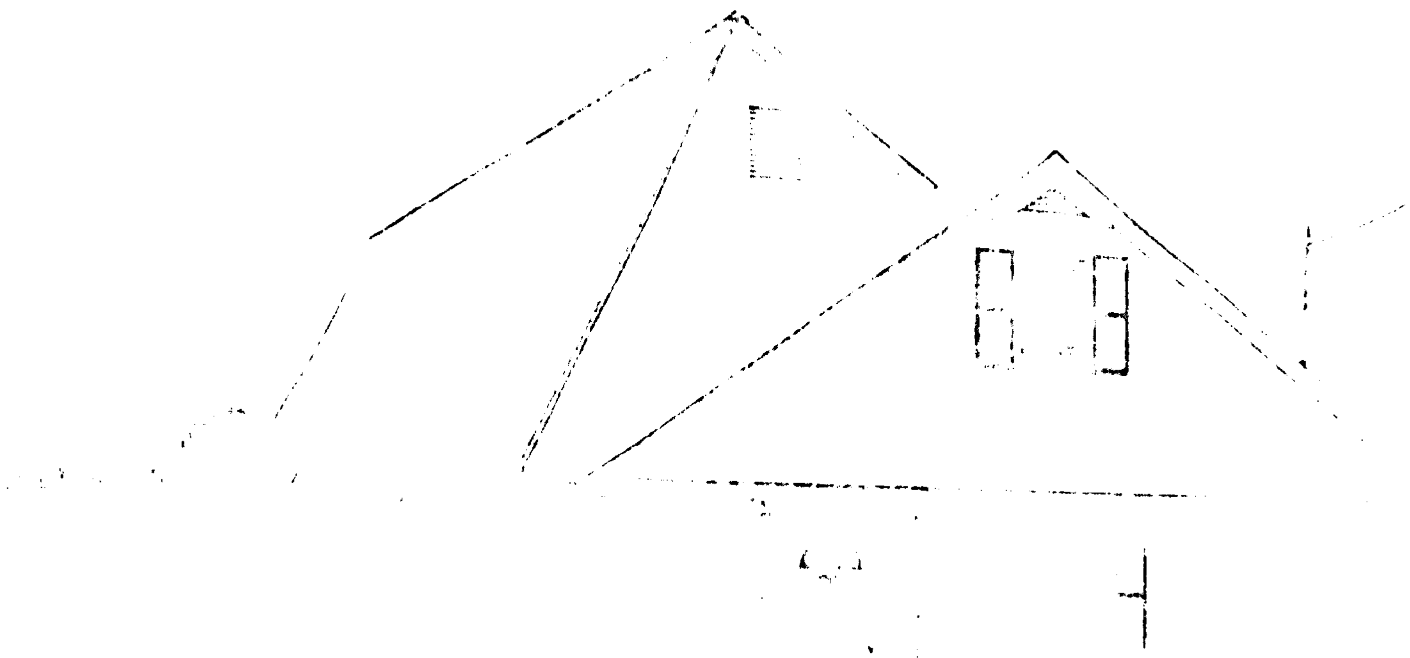

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