

THE UTILIZATION OF SOLAR ENERGY IN SOUTH AFRICA

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SUMMARY

Design curves based on measurements of solar irradiation in South Africa are presented for two geographic areas, the highveld and the Cape Peninsula, giving data on the amount of thermal energy that can be collected from the sun by use of flat-plate solar energy collectors. A brief description of the solar collectors and a discussion of some of the fundamental aspects of solar energy utilization are included.

An example is given to show how the design curves may be used to determine the surface area of a solar collector required for a given application. Cost figures are presented which indicate, as an example, that solar energy can be used to provide the domestic hot water supply for a private residence at a cost less than can be realized with conventional coal-burning, oil-burning, or electric systems.

INTRODUCTION

This communication is intended primarily to orient the thinking of both engineers and house designers on the possibility of making use of South Africa's abundant sunshine as a source of thermal energy. Discussion will be restricted to applications in which the energy is required at moderate temperatures, say, less than 250°F. Some applications which immediately come to mind are domestic hot water supply, winter heating of buildings, and a heat source for absorption-type refrigeration units.

DESCRIPTION OF EQUIPMENT REQUIRED FOR SOLAR ENERGY UTILIZATION

The equipment necessary for solar energy utilization is relatively simple, and consists basically of two separate units. The first and most important is the solar energy collector, which is mounted in an exposed position at the orientation best suited to intercept the radiant energy of the sun. Concentrating devices such as reflecting mirrors are not necessary when the energy

is to be collected at the moderate temperatures considered here, since the so-called 'flat-plate collector' is quite adequate. Because it may be mounted in a fixed position for year-round operation, the latter is very much simpler and hence less costly. The second component of the system is the insulated thermal storage unit in which energy collected during sunny periods is stored for use when the sun is not shining. Water is the most suitable storage medium, although other materials such as crushed rock can be used.

A flat-plate solar energy collector consists essentially of a flat metallic plate painted black on the side facing the sun to increase its absorption for the solar radiation, and insulated on the reverse side to reduce the backward heat losses. Above and parallel to the collector plate are mounted one or more air-spaced glass plates about $\frac{3}{4}$ inches apart, glass being a material which is capable of transmitting the short-wave solar radiation but is opaque to the long-wave re-radiation from the collector plate. Provision is made to transport the energy absorbed in the collector to the insulated storage unit by circulating water through tubes soldered to the collector plate. Air circulated through an air-space behind the collector plate but inside the back-insulation may also be used for energy transportation, and is preferable when a crushed solid, such as a gravel bed, is used for storage purposes.

For optimum performance the solar collector should be mounted in an exposed position facing true north, and be tilted from the horizontal towards the equator at an angle equal to, or a little greater than, the latitude. The north-facing roof of a house is ideal for this purpose. The actual angle of tilt will depend upon that time of the year when the most energy is required. For year-round performance when the winter energy requirement is somewhat greater than that during summer, a tilt

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of about 10 degrees greater than the latitude would be close to optimum.

Circulation of the water through the collector may be effected either by making use of density differences between the heated and entering water columns connecting the storage tank and collector (thermosyphon action), in which case the storage tank must be located above the level of the collector, or by means of a thermostatically controlled pump. In the latter case, the control must be such that the pump is switched on only when the collector plate is hotter than the water in the storage tank. At all other times, and provided the storage tank is located below the level of the collector, the water will drain from the collector, through the pump, back into the storage tank. This positive-control system is preferable since it results in very much improved performance over the system with thermosyphon circulation, and, in any event, it is essential when there is danger of the water in the collector freezing on cold winter nights.

PERFORMANCE OF THE SOLAR INSTALLATION

The instantaneous rate of useful energy collection, i.e. the rate at which energy is removed from the collector and transferred to the storage unit by the water stream, is the difference between the incident radiation that is absorbed by the blackened collector plate, and the heat loss from the collector resulting from the difference in temperature between the collector plate and the outside air. The temperature level of collection is determined primarily by the temperature of the entering water stream, dictated by the temperature of the storage water, and to a lesser extent by the water flow rate, and intensity of solar radiation. The net useful collection during one day is the summation of the instantaneous rates of net useful collection throughout the day. With a positive-control system this summation is made for the duration of pump operation.

Prediction of the day-to-day total useful energy collection of a given system is not possible because of the random variation of weather, and in particular, of cloudiness. However, it is possible to predict the *average* daily performance of a collection system in any one month for a given locality from

records of solar incidence such as those maintained by the Weather Bureau. It is important to keep in mind that variations in weather conditions in any month from one year to another may be large, and may cause variations of as much as 20 per cent in total solar incidence.

Before going into quantitative considerations some helpful orienting generalizations are possible concerning collector performance.² *

(1) If energy is to be withdrawn from the collector at a temperature but slightly above ambient air, the outward heat losses are negligible and a doubling of the intensity of solar irradiation of the collector doubles its useful output. If, however, the temperature of energy collection is quite high, it is apparent that a certain minimum or threshold solar intensity is necessary to maintain the collector at operating temperature only, with no net useful energy output. In a collector operating close to this critical condition it is obvious that a small percentage increase in solar intensity would produce a large percentage increase in useful output.

(2) If a collector is operating with but one glass plate, and at a collection temperature close to atmospheric, the outward loss is low. Adding a second glass plate will approximately halve the losses but they are already small, and at the same time the insolation reaching the black plate will be cut by some 10 per cent due to reflection from the additional glass. This will more than offset the reduced outward loss, and the second glass plate is unwarranted. If, however, the collector is operating at a high temperature the saving in outward losses by adding one or more glass plates will more than offset the added reflection losses. In general, then, the optimum number of glass plates is larger the higher the desired temperature of energy collection.

(3) By similar reasoning, the optimum number of glass plates is larger the weaker the insolation and the colder the outdoor temperature.

SOLAR ENERGY COLLECTION IN SOUTH AFRICA

South Africa, and for that matter most of Southern Africa south of about latitude

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

20° may be divided into two climatic zones for purposes of evaluation of solar collector performance.

Zone 1.—The highveld, characterized by summer rainfall.

Zone 2.—The Cape Peninsula and other regions south of latitude 30° that are characterized primarily by winter rainfall.

In Figs. 1 and 2, for Zones 1 and 2 respectively, curves have been plotted showing the daily average useful collection that can be realized, as a function of the temperature of collection, the number of glass cover plates, and the time of year, for collectors in which the angle of northward tilt is equal to the latitude.⁴ The temperature level of collection is defined as the difference between the temperature of the water stream entering the collector, and hence the storage temperature, and the temperature of the outdoor air. The curves have been calculated on the basis of the average daily totals of radiation on a horizontal surface that are given in Table 1.³

TABLE I

AVERAGE DAILY TOTAL SOLAR INCIDENCE ON A HORIZONTAL SURFACE
* (B.Th.U./sq. ft., day)

	Zone 1 highveld	Zone 2 Capo Peninsula
December-January ...	2,370	2,680
March-September ...	1,900	1,700
June-July ...	1,340	780

* 1 gm. cal./cm.² = 3.687 B.Th.U./sq. ft.

It has further been assumed that the solar collection system is of the positive action type in which a pump circulates water from the storage tank through the collector; that the storage tank is located below the level of the collector so that the latter is self-draining when the pump is not operating; that ordinary window glass has been used for the collector cover plates, and that the collector itself has been well designed from the point of view of assuring efficient heat removal and minimum heat losses.

It should be pointed out that the performance as indicated by the curves could

be increased by as much as 10 per cent to 15 per cent if extra care is taken in the design of the collector. The use of special low-absorptivity (low iron content) glass, and also of glass in which the surface had been optically treated to reduce reflection losses, would result in considerable improvement in performance.¹ However, such glasses are very much more expensive than ordinary window glass and the extra cost is

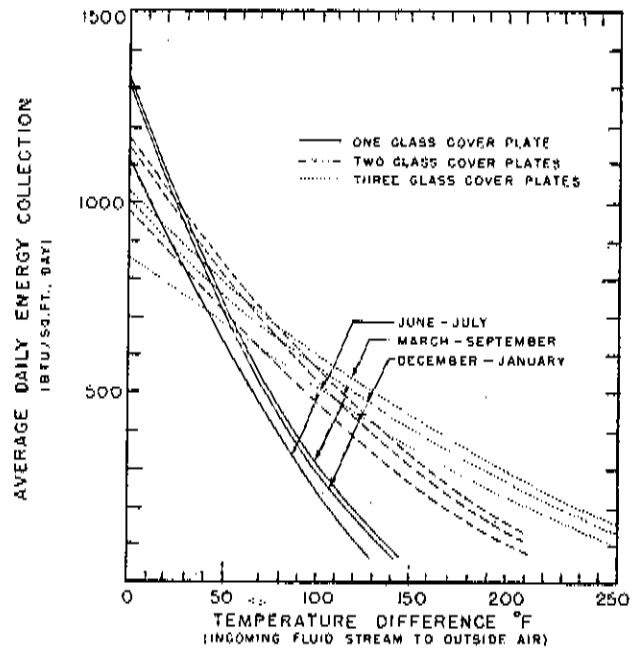


Fig. 1—Solar energy collection South Africa Zone 1—Highveld; angle of tilt — latitude

not warranted at any temperature level of operation less than about 120°F above atmospheric. On the other hand, if the circulating pump were to be dispensed with and water circulation by thermosyphon action resorted to, the performance would be considerably less than indicated in the curves, perhaps by as much as 20 per cent.

Should the daily insolation at a given locality be different from the values given in Table I for the corresponding zone, then it is necessary to adjust the curves in Figs. 1 and 2 to compensate for the difference. The exact correction is not easy to make. However, an approximate correction⁴ that is quite accurate and relatively simple to apply is the following.

Add (or subtract, as the case may be) to the curves in Figs. 1 and 2 a fraction *F* of the difference between the average daily insolation for the locality in question and the value for the corresponding zone as

given in Table I, where values of F are given in Table II.

The above corrections are only applicable south of latitude 20° for Zone 1, and south of latitude 32° for Zone 2. They are quite accurate for Zone 2, and for Zone 1 in the

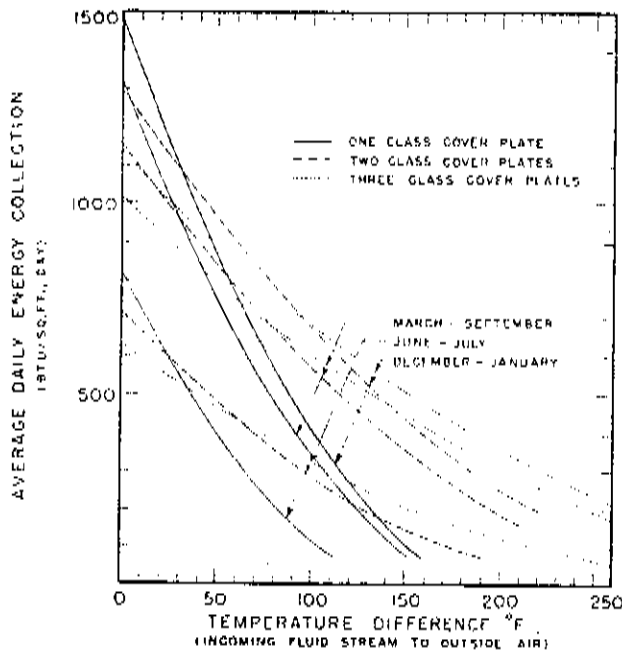


Fig. 2—Solar energy collection South Africa Zone 2—Cape Peninsula: angle of tilt — latitude

summer, but of less accuracy for Zone 1 in the winter. A correction factor greater than unity is possible because of the more favourable angle of incidence of the radiation on a tilted surface than on a horizontal surface. It should be noted that the correction factor is independent of the temperature of operation.

INTERPRETATION OF THE CURVES

Three important points regarding the characteristics of the performance curves of Figs. 1 and 2 should be noted.

Firstly, there is the strong dependence on

temperature of operation. The performance decreases almost linearly with increasing temperature. For this reason in all work connected with solar energy utilization, the temperature of operation should be kept at the lowest possible level consistent with the particular use for which the energy is desired.

Secondly, there is the effect of the number of glass cover plates. As was stated above, the optimum number of cover plates to be used increases as the temperature increases. Thus, up to a temperature difference of about 60°F, one glass plate is the economic optimum, between 60°F and 140°F two glass plates, and above about 140°F, three plates. Figs. 3 and 4 have been presented to emphasize this fact, and are the design curves recommended for general use.

Thirdly, there is the variation in performance with time of year, or, from another point of view, the effect of the angle of tilt of the collector. When the angle of tilt is equal to the latitude as in this case, the performance in summer is better than in winter, particularly in the Cape Peninsula where the winter is the rainy season. Winter performance can be improved (at the expense of summer performance) by tilting the collector even further towards the equator to favour the winter sun.

EXAMPLE OF USE OF THE DESIGN CURVES

As an example to demonstrate the use of the design curves presented above, assume that it is desired to provide the domestic hot water supply for a family of five in the Johannesburg area by use of a solar collector tilted 26° towards the north. The daily water requirement, 20 gallons per person, is to be heated from 50°F to 130°F.

1. Since performance is lowest in the winter, the June-July curve (Zone 1) will

TABLE II
VALUES OF THE CORRECTION FACTOR F

Number of glass plates	Zone 1			Zone 2		
	1	2	3	1	2	3
December—January	0.6	0.52	0.46	0.6	0.53	0.47
March—September	0.72	0.63	0.56	0.78	0.68	0.60
June July	0.87	0.77	0.66	1.04	0.91	0.80

be used for the design. Assume that the winter daytime average temperature is 55°F.

2. The mean temperature level of operation is $\frac{130 + 50}{2} = 90^\circ \text{F}$.

3. The temperature difference is thus $90 - 55 = 35^\circ \text{F}$, and a single plate collector would be used (see Fig. 3).

4. The average daily useful collection at 35°F (Fig. 3) is 800 B.Th.U./sq. ft. day.

5. Daily requirement of heat
 $= (5 \times 20) \times (10) \times (130 - 50)$
 $= 80,000 \text{ B.Th.U.}$

6. Therefore, collector area required
 $= \frac{80,000}{800} = 100 \text{ sq. ft.}$

(Note.—If the collector tilt were increased from 26° to about 35° to compensate for the tendency of winter performance to be low, a collector area of about 90 sq. ft. would suffice, and in addition the performance would be more uniform throughout the year).

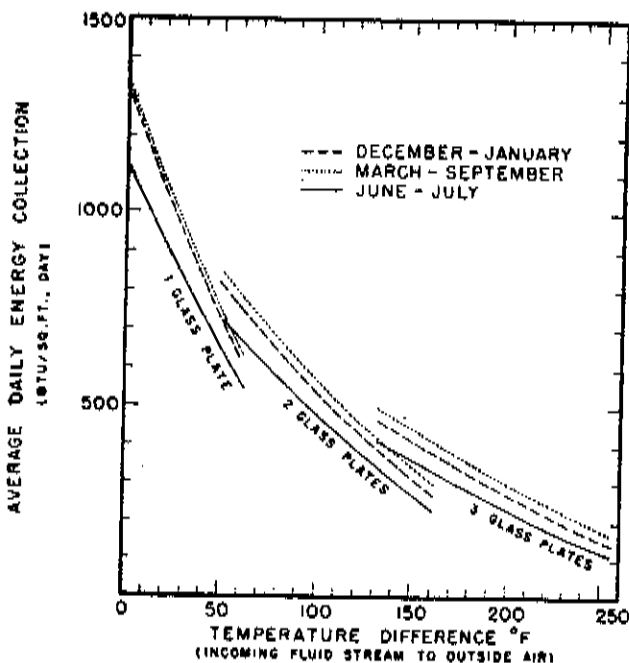


Fig. 3—South Africa Zone 1—Highveld : angle of tilt = latitude

CONCLUDING REMARKS—COST OF COLLECTOR CONSTRUCTION

A publication such as this would not be complete without a word on costs. The cost of building a solar collector is difficult to

specify because no unit conforming with the description given above has yet been built in South Africa. It is the opinion of the writer that solar collectors can be constructed at a cost somewhat less than £1 per square foot for a collector with single

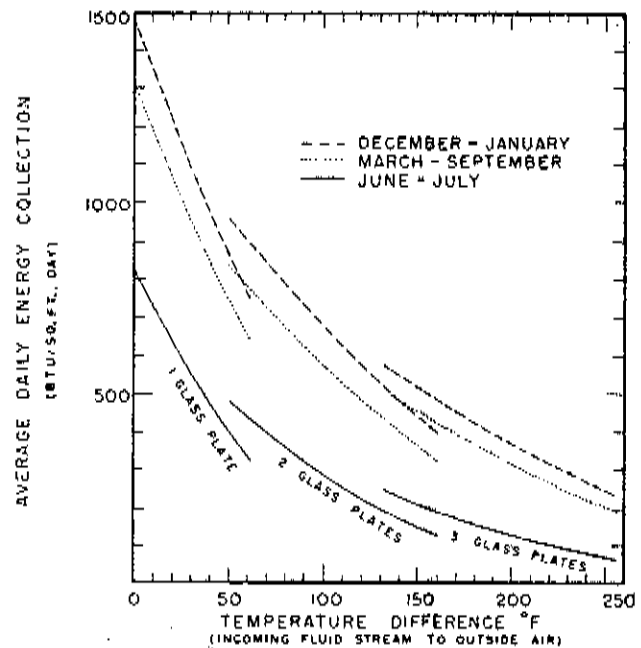


Fig. 4—South Africa Zone 2—Cape Peninsula : angle of tilt = latitude

glass cover, increasing by about 20 per cent for each additional glass plate.

In the above example the complete cost of the solar collector, insulated water storage tank, and circulating pump would amount to about £175, and assuming an annual fixed charge of 12½ per cent, the carrying cost of the installation would be £21 17s. 6d. per year. This means that the solar heater would provide hot water at a cost of only 1s. 6d. per therm (10⁶ B.Th.U.), a figure somewhat more economical than can be realized with conventional coal-burning- oil-burning, or electric systems.

Whether a solar collection system will be more economical than a conventional heating system for a given application will depend on many factors, and each particular case will have to be evaluated on its merits independently. The data presented above should prove valuable in making such an evaluation.

ACKNOWLEDGMENTS

The programme of research on which this publication is based has been under part

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sponsorship of the University of the Witwatersrand (1949 Union Post-Graduate Scholarship), and the South African Council for Scientific and Industrial Research (Senior Bursary, 1951-52 and 1952-53). The work itself has been carried out as part of the research programme of the Solar Energy-Conversion Research Project of the Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A.

DISCUSSION

THE PRESIDENT: I have consulted *Van Nostrand's Scientific Encyclopedia* and find the value of the solar constant given as 1.938 calories per sq. cm. per minute. This expresses the quantity of energy falling in unit time on a unit area placed perpendicularly to the direction of the sun at the mean distance of the earth from the sun. Converted into familiar units and neglecting the effects of atmospheric absorption this solar energy amounts to 1.5 horsepower falling on each square yard of earth per minute.

In order to appreciate the magnitude of the total solar energy falling upon the earth it is computed that its value at 0.5d. per kWh is of the order of £100,000,000 per second. This is therefore roughly the magnitude of the earth's indebtedness to the sun.

It is interesting to note that the earth's atmosphere largely absorbs the wave lengths in the end regions of the spectrum and that the solar energy reaching the earth's surface is confined mostly to the visible and near infra-red regions with a very small proportion of ultraviolet. This phenomenon is fortunate alike for human beings and many organisms because the full range of solar radiations could not otherwise be endured.

The absorption of the ultraviolet radiation is largely in the higher stratosphere whilst the longer infrared is dissipated only by dust and water vapour at lower levels, a fact which accounts for the low temperature of the air at high altitudes. Southern Africa must take a prominent place in research work devoted to the utilization of solar energy and I am sure that the future holds great possibilities in

this direction. Mr. Whillier's notes will serve to sustain our interest in this vast and yet untouched source of energy all around us.

MR S. J. RICHARDS: Mr Whillier is to be congratulated on the way he has utilized solar radiation and other climatic data pertaining to South Africa, to present information which makes the prediction of the performance of flat-plate solar heat collectors a relatively easy matter. This information should prove valuable to those contemplating the construction of such absorbers.

Although the title of the paper implies a wide field of possible applications, Mr Whillier has, in my opinion, quite rightly dealt only with flat-rate collectors, as this method of utilization appears to be the only one that holds out promise of having any wide application in this country. Many other ways of utilizing solar energy are being investigated, such as, for instance, in cooking, high temperature furnaces, low pressure steam engines, and for conversion to electrical energy. The factors of size of the units concerned and their cost and maintenance, however, limit these usages to special purpose investigations. The whole question of the feasibility of making greater use of solar energy as a factor in national economy, in view of the world's dwindling fuel stocks, was carefully investigated by a committee set up by the Department of Scientific and Industrial Research in Britain and reported in a recent issue of *Research*.* The purpose of this study was to obtain advice on what aspects of solar energy utilization should be exploited and developed

* *Research*, Vol. 5, p. 522 (1952).

by research. The committee's conclusions are somewhat disappointing in that they hold out very little hope that solar radiation could ever be used economically on any large scale in Britain or her colonies. The Committee does, however, suggest that some attention should be given to the use of solar heat for water distillation, domestic water heating, cooling and low pressure steam engines, as there is scope for these applications in some of the colonies. Further study of the question is being carried out by the Standing Committee for the Commonwealth Scientific Conference.

In South Africa, it is extremely doubtful whether solar radiation as a source of electrical energy could be made to compete with our cheap coal, of which we have, as far as can be estimated, a sufficient supply for the country's needs for a long time to come. The applications mentioned in the paper are possible exceptions to this, and may find extended use in the large rural areas of the Cape and South West Africa, where electrical power, coal and wood fuel are relatively expensive and difficult to obtain. At the National Building Research Institute we consider that domestic solar water

heating might be a worth-while proposition, and an experimental absorber unit is now under construction and will be installed in a house in Pretoria. Our prime concern is not whether the system will work satisfactorily, as we are fairly certain of this since the design is based on the experience gained in the Southern States of the U.S.A., where many thousands of solar water heating installations are in use; the main question is whether the cost of installing such a system is within the reach of the average man's pocket. The running costs are negligible but the initial outlay may be prohibitive. In this connection, I think Mr Whillier's estimated costs are far too conservative. My experience is that the simplest form of conventional-type absorber unit will cost £2 or more per square foot of effective area under present day circumstances (the materials alone will cost about £1 per square foot for the average size of unit). At this rate, a unit supplying as little as 30 gallons of hot water per day might cost about £60, and this must be compared with a slow combustion stove which can be purchased for as little as about £10.

AUTHOR'S REPLY TO DISCUSSION

I should like to thank both the President and Mr Richards for their interesting comments.

As pointed out in the discussion the paper is by no means a complete treatment of the subject; it is restricted to the *collection* of the solar energy, with a single example given to illustrate one application of the data. I am in complete agreement with Mr Richards that at the present time solar energy can compete with conventional fuel-burning systems only in low temperature heating applications such as water heating, and house heating. Regarding the cost of solar absorbers I am inclined to think that some modifications in the design of the units under study at the National Building Research Institute could greatly reduce the initial cost of the units without sacrificing thermal output and thus bring them into more favourable competition with other heating systems. However, in the absence of detailed cost data pertinent to conditions

in South Africa, I am unable to comment quantitatively on the cost figures given by Mr Richards. The cost-estimate given in the paper was derived from cost studies made by the author at the Massachusetts Institute of Technology for American conditions, with direct conversion of dollars to pounds sterling at the current rate of £1 = \$2.80. These studies indicated that the breakdown of the final cost of the absorbers is roughly one third material, one third labour and one third distribution and profit. Since no specialized fabrication techniques are involved it seems a fair assumption that the cost in South Africa should not be very different from that in the United States. In any event, no matter what the exact figure, it is clear that the initial investment for a solar collector is a relatively large sum which must be amortized over the years by the saving in fuel that is obtained.