AN NBRI REPRINT

KEYWORDS: SOLAR HEATING, WATER, SYSTEMS
SLEUTELWOORDE: SONVERHITTING, WATER, STELSELS

REPRINTED FROM: PROCEEDINGS OF SOLAR PRESS CONFERENCE, PRETORIA, 10th SEPTEMBER, 1980

S 240/1
1980

NATIONAL BUILDING RESEARCH INSTITUTE OF THE CSIR

The basic principles of solar water heating

by

R.J. Page-Shipp*

Paper presented at the *Solar Press Conference,* Pretoria, 10th September, 1980

NATIONAL BUILDING RESEARCH INSTITUTE

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
PRETORIA

SUMMARY

Solar energy, although extremely abundant, is very thinly distributed over the Earth's surface. There is no doubt that it is technically a viable energy source for water heating, but good engineering design and intelligent use of solar water heaters are necessary if they are to be economically viable.

Factors of importance are:

1. position of collectors - with particular respect to orientation and inclination to the horizontal;
2. insulation - in the panel, the circulating system and the storage tank, to retain the energy collected;
3. glazing - to protect the absorber surface and reduce re-radiation;
4. plumbing - there are various appropriate ways of coupling the components of systems and many inappropriate ones;
5. auxiliary heating - which will be required in very many cases but it must be planned judiciously;
6. possible problems - corrosion and damage due to freezing remain the most intractable, but good progress is being made in combating them.

* Head: Environmental Engineering Division

Introduction

"Solar water heating - does it really work?" is a question often put to researchers, salesmen and perhaps, even technical reporters.

Everyone has picked up a hose which has been lying on the grass in the sun and found that the first few litres of water which emerge when the tap is opened, are hot - perhaps even hot enough to bath in! We all know that this is because the water in the hose has absorbed solar radiation, so we all know that solar energy can heat water. In this sense, it is indisputable that solar water heating works!

The really interesting question, however, is whether solar water heaters can supply hot water in adequate quantities, with satisfactory reliability and at acceptable cost, for one to accept a solar water heater as an alternative to or a preheater for, say, an electric geyser.

The rest of this paper and the others presented today, are devoted to those engineering design factors which must be taken into account in harnessing solar energy for heating domestic water, and to the prospects of thereby obtaining an affirmative answer to the above question.

Characteristics of solar energy

The abundance of solar energy is not always appreciated - the energy reaching the Earth's surface **each day** would supply all the world's energy needs for more than 30 years at the estimated 1981 rate of consumption (see Table 1). Alternatively one day's solar energy would keep things going into the 1990's - at projected rates of consumption. However, there are drawbacks:

- the supply is intermittent - effectively available for about 8 hours per day and at full strength only in clear weather; and
- variable - since the apparent position of the sun in the sky varies with the seasons, a fixed surface does not have the same energy collection potential throughout the year; and
- solar radiation is very thinly distributed over the Earth's surface. The maximum ground level energy density is about 1 kW m^{-2} at noon, whereas the total amount of energy received per 24 hours averages out at about 230 W m^{-2}.

For purposes of comparison, a kilogram of coal has an energy content (20 - 30 megajoules) roughly equivalent to the amount of solar radiation intercepted by a horizontal surface one square metre in area during an entire sunny summer's day in South Africa. Large areas of collectors are therefore required to collect useful amounts of energy.

By world standards South Africa is blessed with mean solar radiation intensities that are among the highest in the world (see Figure 1). The annual amount of solar radiation intercepted by a horizontal surface only 13 × 13 km in extent in the Pretoria area is equivalent to our entire annual energy consumption. What is equally important is that, over the interior, the clearest skies occur at the coldest time of year.

When considering the seasonal variability in the supply rate, one shold note that it can be evened out considerably by inclining the irradiated surface of the collector at an appropriate angle, as shown in Figure 2. The optimum angle for uniform, year round absorption is approximately equal to the latitude of the site plus 10°. More data in this connection are given in an NBRI Information Sheet.[1]

Orientation of the collector also has an effect, and true north is normally recommended, although deviations of up to 45° to either side make relatively little difference to performance (see Figure 3).

Design of solar water heaters

The basic technology of solar water heating has been available for many years; one unit at the NBRI has been operating effectively since the early 1960's. There are essentially two types of solar water heater, namely:

a. **the two-component system**, which consists of one or more collectors, coupled to an insulated storage cylinder; and

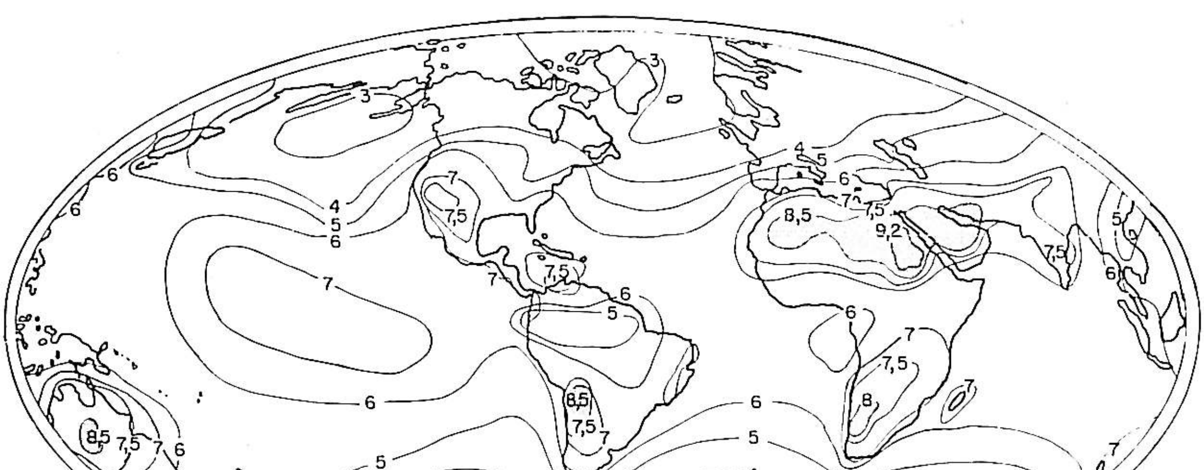

FIGURE 1

Generalized isolines of global radiation (G J m^{-2})

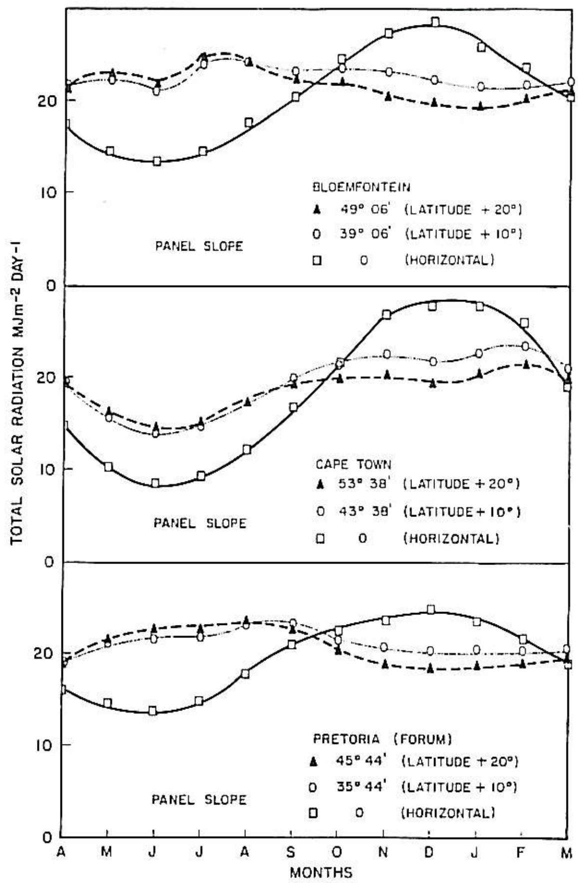

FIGURE 2

Annual variation of total daily solar radiation on horizontal and tilted surfaces for Bloemfontein, Cape Town and Pretoria

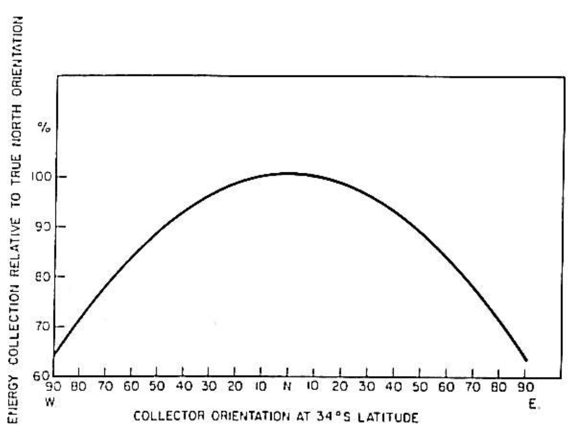

FIGURE 3

Effect of orientation of collector on energy collection

b. **the integrated system**, where collectors and storage cylinder are combined into one unit.

Its relatively low installation cost makes the latter particularly attractive for domestic applications. For larger commercial and industrial applications the two-component system is generally more suitable, because a number of collectors can be connected in a suitable arrangement to provide any required quantity of hot water.

a. Two-component system

The two major components of the solar water heating system are the collector, which absorbs solar radiation and transfers the heat to the circulating medium in contact with it, and the insulated storage cylinder for storing the water that has been heated, either directly or indirectly.

In the **direct system**, the circulating liquid is water which is stored in the tank for consumption. With **indirect systems**, the object is to avoid circulating the water for consumption through the solar collectors -usually because of corrosion or scaling problems. In this case a separate circuit is set up between the solar collectors and a heat exchanger built into the storage tank. A circulating fluid which has been treated, usually to make it non-corrosive and give it a lower freezing point, then transfers energy from the solar panels via the heat exchanger in the storage tank, into the water which is to be heated. The additional costs of the heat exchanger and circulating fluid are usually offset by avoiding the use of the expensive materials of construction which are sometimes required to resist more aggressive types of water.

The solar collector has a number of components, the most important being the absorber which is usually a flat panel made up either of an array of tubes in thermal contact with a metal plate or of two metal sheets so shaped that water channels are formed between them. This is placed on top of a 25 mm layer of polyurethane foam or other suitable insulating material to minimize heat losses to the back, and housed within a rainproof tray, which is covered with a suitable transparent material. The transparent cover allows the solar radiation to reach and heat the absorber panel while restricting the loss of heat by longer wavelength radiation from the panel ("the greenhouse effect"). At the same time, it restricts heat losses from the absorber by air movement. The panel itself is usually painted matt black, or otherwise treated to increase the absorption of radiation while at the same time restricting re-radiation of heat.

Figure 4 illustrates the piping arrangement for a conventional thermosiphon circulation system. Water heated in the panels expands and, having a reduced density, rises in the system to accumulate at or near the top of the storage tank. It is replaced by cold water from the bottom of the storage tank in a circulation cycle known as thermosiphoning. It is usually recommended that the base of the storage cylinder should be about 600 mm above the top of the collectors so as to avoid reverse circulation at night when the water in the absorber panel cools down.

In cases where it is not practicable to locate the storage cylinder above the collectors, a low capacity pump is required to circulate the water. The pump needs to be actuated by means of a differential thermostat which switches the pump on as soon as the temperature in the collectors is higher than the temperature of the water at the base of the storage cylinder.

b. Integrated system

Integrated systems consist of a shallow tank or other water vessel housed within an insu-

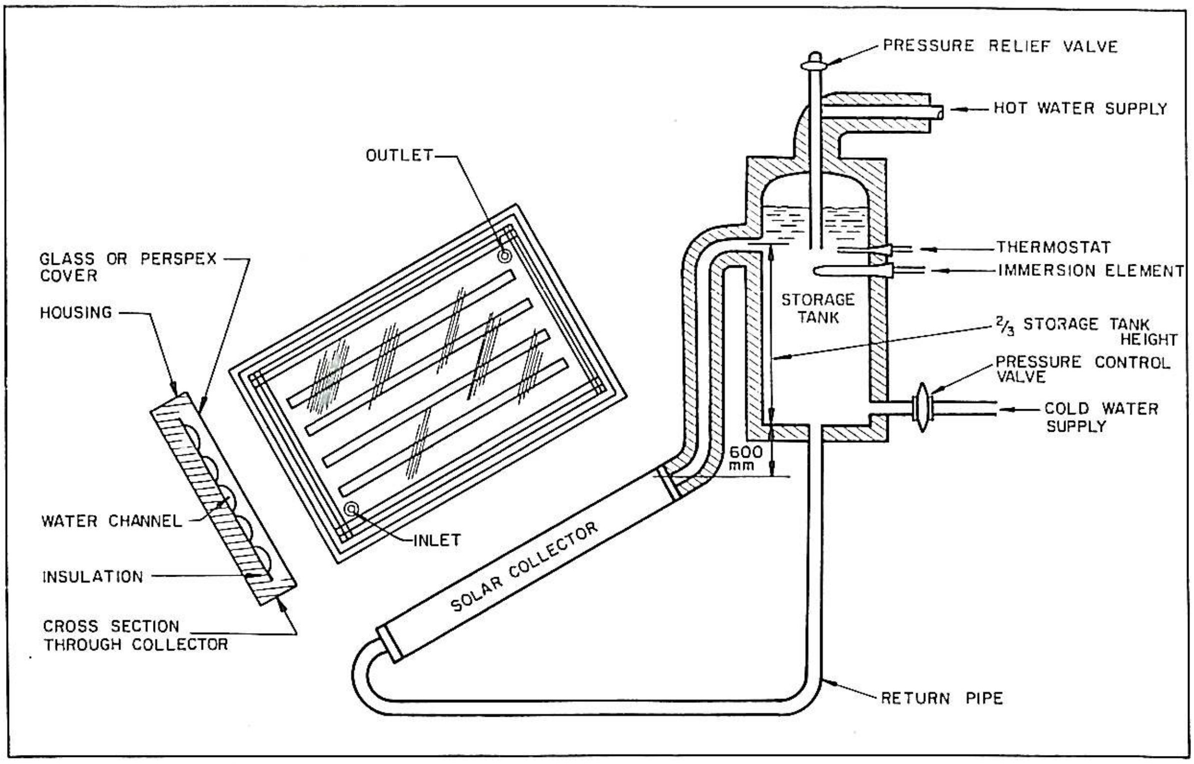

FIGURE 4

Section through typical solar water heater with auxiliary heating by means of an electric immersion element

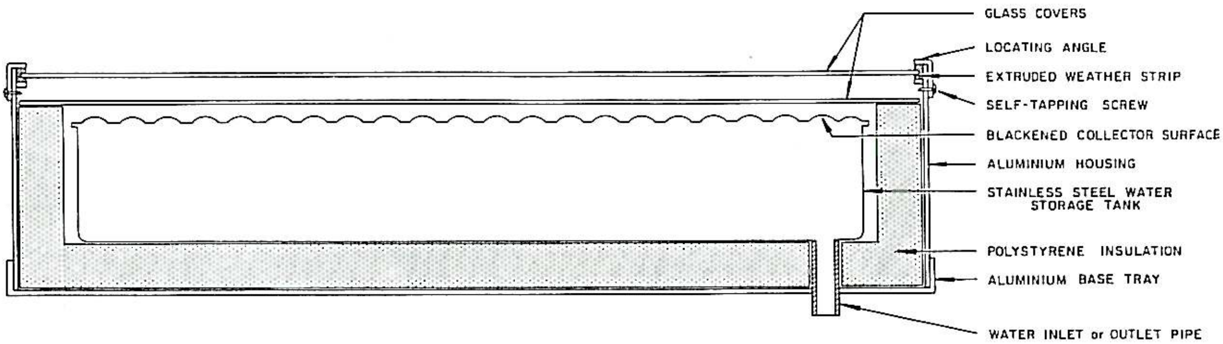

FIGURE 5

Section through solar water heater (scale 1:85)

lated tray and covered by glass or some other suitable transparent material. The irradiated surface of the absorber tank is painted matt black and also serves as the heat exchanger surface. Since there is no provision for thermosiphon circulation, the water is both heated and stored in the unit. A typical design is illustrated diagrammatically in Figure 5.

The system efficiency of an integrated unit is generally significantly better than that of a two-component system while the sun is shining. However, integrated units tend to lose most of the stored heat at night. Low income users may be able to cope with this by ensuring that most of the water is used before late evening - a minor price to pay for an economic source of hot water.

If a supply of hot water is to be assured throughout the day and night, the unit may be connected in series with an electrical or other type of insulated hot water storage cylinder. Where an electrical hot water storage cylinder is already installed, the integrated type of unit can be a very cost-effective means of preheating the water, particularly where a good deal of hot water is used in the evening, as in this case the heated water from the unit will be drawn into the geyser and protected from overnight heat loss. The plumbing is straightforward, which enables costs to be kept to a minimum.

Figure 6 shows how an integrated unit could be installed. The one illustrated is a low cost unit developed by the NBRI and the installation is suitable for low-income housing. Further details of the design are given in an NBRI Information Sheet.[2]

A further development of the integrated unit is the close coupled system; this comprises a solar panel and a storage tank, installed on a common frame and connected together. Water circulates from the collector to the storage tank and back, in a thermosiphon loop, as illustrated in Figure 7. The problem of night cooling is eliminated to a large extent. Because the unit is assembled in a factory, its installation is simple.

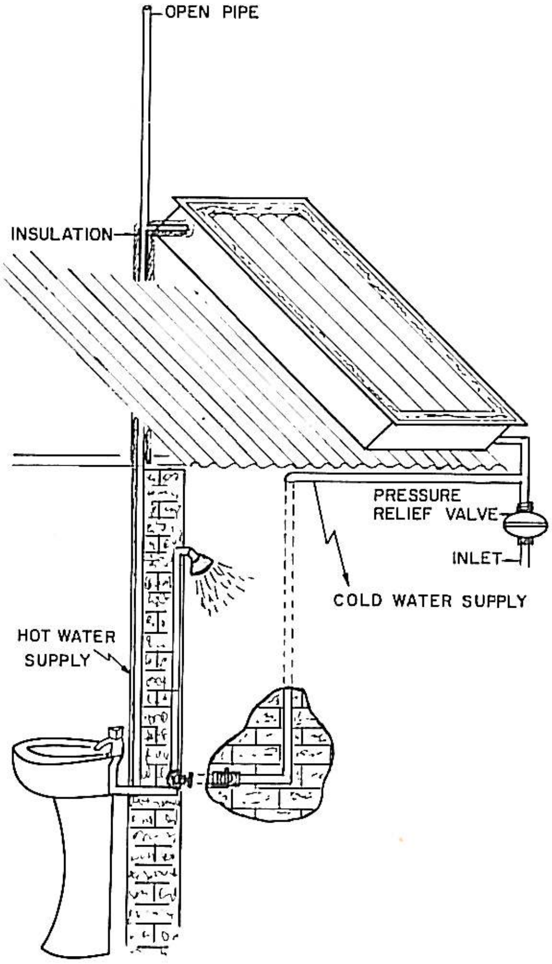

FIGURE 6

Typical installation of integral unit

Hot water storage tank

Heated water is stored until needed in the tank, which must be big enough to provide about 75 per cent of the daily needs if an auxiliary heater is installed. If no auxiliary heater is used, the tank must be large enough to supply all needs.

The pipe connections required in a solar storage tank are positioned differently from those in a conventional hot water tank (see Figure 4). The cold water pipe to the solar panel is connected to the bottom of the tank, and the hot water pipe from the solar panel enters the tank at a height of one third from the top. To minimize mixing of the incoming cold water from the supply pipe with any hot water remaining in the tank, a baffling arrangement is usually fitted to the inlet to reduce the disturbance from the jet of incoming water. The process of keeping the cold bottom and warm upper layers of water fairly distinct is called 'stratification' and is more readily achieved in vertical rather than in horizontal tanks. In houses fitted with geysers, it is often convenient to leave the existing hot water cylinder unchanged and connect the solar water tank to it in series, as shown in Figure 8.

The hot water tank, the pipe from the solar panel to the tank and the cold water return pipe must all be insulated. Insulation exposed to the elements must be protected with a suitable clip-on cover of sheet metal or plastics.

Provision must be made for adequate support of the pipes and for thermal expansion of the pipes and of the water in them.

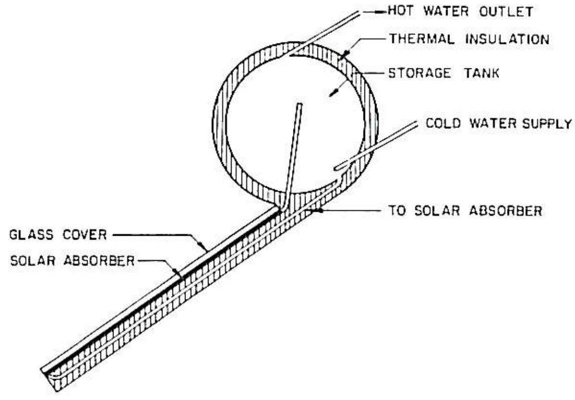

FIGURE 7

Section through direct coupled unit

Insulation of the storage tank

This topic is sufficiently important to merit a section of its own because of its relevance not only to solar water heaters, but to hot water storage generally.

The SABS specification for electrical hot water cylinders is currently undergoing revision, but the previous specification (SABS 151-1976) permitted a heat loss from a 300 litre type 3 geyser of 180 W, i.e. about 4,3 kWh per day for a water temperature of about 75 °C. At 3 cents per kWh this would cost about R47 per annum. Reducing the water temperature to 55 °C cuts this heat loss down to about half the above figure.

Geysers built to the revised specification are likely to be better insulated but it is clear that additional insulation of existing geysers is worth considering. A roll of mineral wool insulation of the type used for ceilings costs in the region of R12 - R15 and, if it were wrapped around the geyser, it would probably pay for itself more quickly than most other energy conservation efforts.

Hot water storage tanks and circulating pipes for solar systems must, therefore, be not only insulated, but adequately insulated. About 50 mm of high density mineral wool would suffice for tanks and about 25 mm for pipes.

Auxiliary heating

In overcast weather conditions the availability of solar radiation is reduced by about 70 per cent. Under such circumstances, there may be problems in obtaining an adequate supply of hot water if no auxiliary heating is provided.

For domestic purposes, the installation of electrical auxiliary heating is the most convenient method if electricity is already available in the house. New installations employing a combined solar/electric water tank must have the electrical element and control thermostat installed high up in the tank, as shown in Figure 4. For existing installations the existing hot water cylinder should be left as it is and the solar heated water must then be stored in an insulated tank which feeds the existing unit (see Figure 8). The thermostat must be set at the lowest acceptable temperature, usually approximately 50 °C.

If solar water heaters are used widely in the future, it may occur that many auxiliary water heaters will be turned on simultaneously in over-cast weather. If the resulting demand for electricity were to coincide with

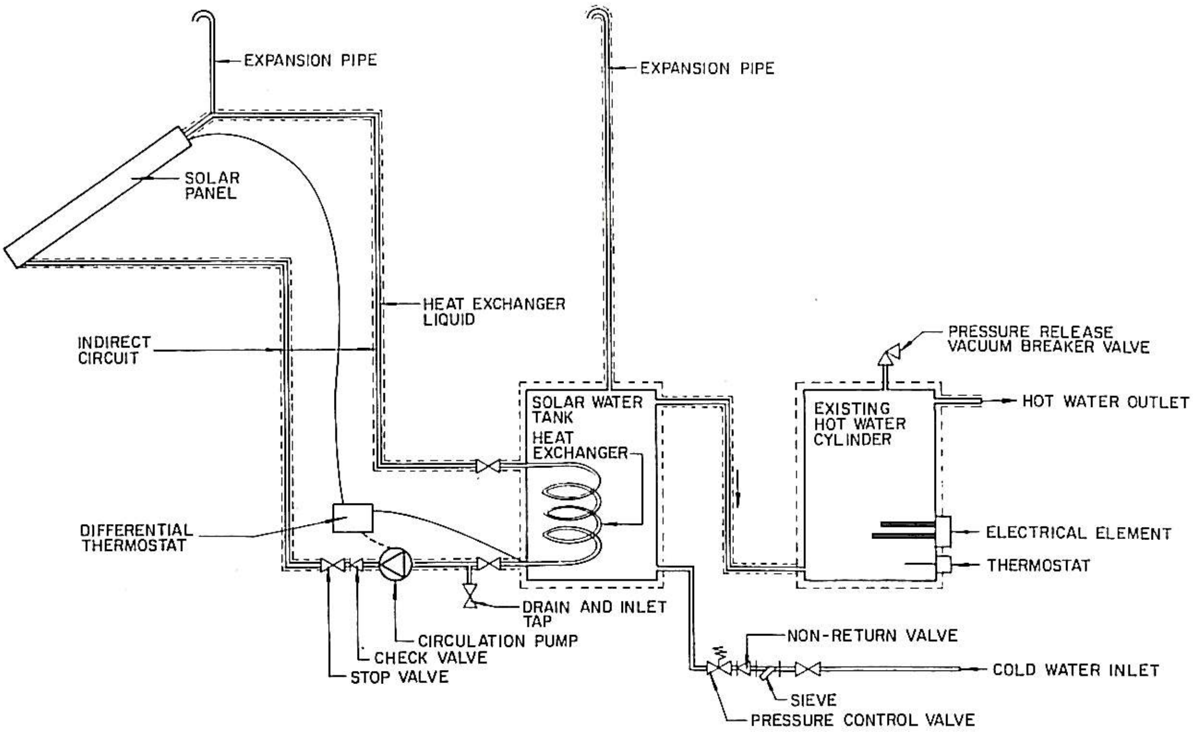

FIGURE 8

Indirect system with pump circulation in series with (existing) hot water cylinder

the winter evening demand for cooking and space heating, the authorities responsible for the supply of electricity would have to provide generation and distribution systems to meet this excessive maximum demand. On the other hand, the use of solar water heating leads to a reduced income for the electricity supply authority from the regular sale of electrical energy. Both these factors tend to prejudice local authorities against solar water heating. It is therefore good practice to install a relay that prevents the heating element from switching on when the stove is in use. Alternatively, a time switch can be fitted in the heating circuit to switch the heater off from approximately 06h00 to 08h00, and from 17h00 to 19h00. Either of these procedures would help to reduce the peak demand in any area, not only those where solar water heating is practised.

Fortunately the maximum peak load for the country as a whole occurs at approximately 09h00 on cold days in the winter, when the demand for domestic hot water is relatively low and solar energy is freely available over the greater part of the country. It is therefore difficult to accept the argument that large scale application of solar water heaters can exacerbate the problem of providing for the peak load.

Another important aspect of auxiliary heating is the usage pattern for hot water. If all the stored hot water is used overnight, a thermostatically controlled electrical heater will heat the full contents of any tank in which it is installed and keep the water hot until morning. Any solar energy input thereafter will be superfluous and the overall efficiency of the system will suffer. Consideration should be given to installing a time switch so that the auxiliary heater will come on only after solar radiation has had an opportunity to make its contribution. The switch can always be manually overridden on occasions when hot water is called for at short notice.

Problem areas

Durability

Solar water heaters must have a useful life which will enable their initial cost to be recouped in the form of energy savings, and hence, cost savings. This means that a satisfactory compromise must be sought between cost and durability. In principle a very cheap short-lived unit, which is easy to replace, could be as cost-effective as a durable but more expensive one. Most manufacturers, however, tend to aim at reasonable durability. This matter will be discussed in detail in later presentations.

Freezing conditions

As water cools down, it attains its maximum density and hence, minimum volume at approximately 4 °C, and thereafter expands gradually until it freezes at 0 °C, at which point the most dramatic expansion takes place. When this happens, the water channels in a panel, especially where the cross sectional area reduces, can be blocked with ice, and separate water compartments can form. If the water imprisoned in these compartments does not have space to expand, the unit can be damaged. In the colder climatic regions of the country, damage through freezing can largely be avoided by:

(i) the use of indirect systems, in which an anti-freeze agent is added to the fluid in the closed circuit;

(ii) the use of systems in which expansion can be accommodated, as for example in the envelope-type solar panel, which has considerable elasticity. Solar panels employing small diameter tubes are especially susceptible to damage through freezing;

(iii) draining the system when freezing conditions are expected;

(iv) activating the circulation pump in forced systems by means of a thermostat when a low temperature occurs in the solar panel or a low outside air temperature is experienced;

(v) switching on a small heating element in the solar panel when the water temperature or outside temperature reaches a certain minimum.

Solar rights

The effectiveness of a solar water heating system is considerably reduced if the collectors are shaded for substantial parts of the day by nearby trees, tall buildings, etc., and it is clear that users will seek to protect their right to, literally, a place in the sun. Existing legislation in most countries does not provide for this, but the matter is receiving attention fairly generally.

Conclusion

Solar energy, although plentiful, is very thinly distributed over the Earth's surface. Solar water heaters must therefore be designed, installed and operated in such a way that the energy is collected with optimum efficiency and thereafter carefully conserved for use when required.

References

1. NBRI Information Sheet X/BOU 2-40. *Availability of Solar Radiation in South Africa*, Pretoria, 1978.
2. NBRI Information Sheet X/Bou 2-46. *Integral low cost solar water heater*, Pretoria, 1980.

TABLE 1 : Estimated energy sources and consumption on a world wide basis

Consumption	$\times 10^{18}$ J
Total consumption before 1980	8
Consumption in 1980/81	0,25
Estimated consumption 1981 - 2000	11
Remaining sources	
Hydro-electric* (per annum)	0,2
Gas*	6
Oil*	10
Oil shale	4 000
Coal*	200
Uranium* (at less than $45/kg)	1
Uranium (at less than $75/kg + fast breeding)	500
Geothermal	600
Solar (per annum)	3 000
Solar (per day)	8,2

* Only these are currently in use in significant quantities.