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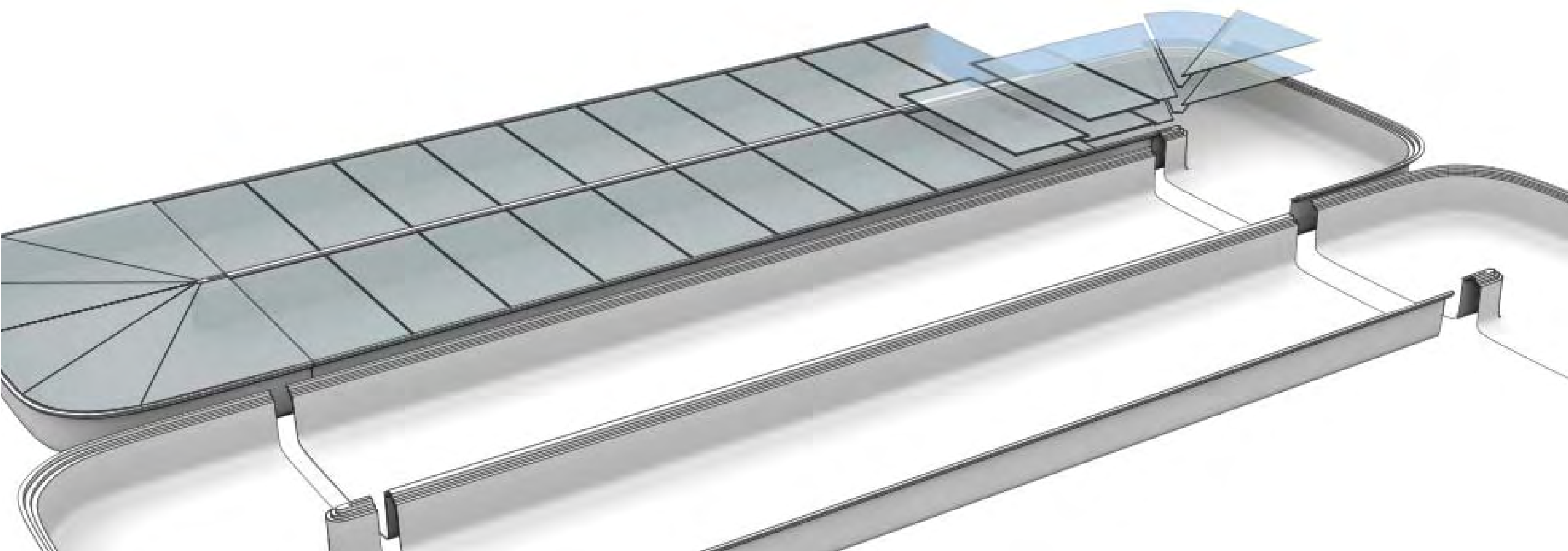
[SHELL]

Solar collector high efficiency - low enthalpy large system



SHELL
Solar collector high efficiency - low enthalpy large system

contents

Intro

Solar thermal collectors are the simplest system for capturing solar energy by converting it into heat (usually, low-enthalpy heat). With the exception of the concentration systems and those equipped with vacuum insulation (involving complex and expensive structures), normal collectors can provide water at 70-80 °C maximum, with efficiency that critically depends on the ratio between thermal jump and incoming radiation, but is usually below 50- 60%

The figure below shows the efficiency of flat and vacuum tube collectors, taken from available literature, in comparison with SHELL efficiency as got from experiments on the set-up as below. The parameter on the abscissa is the ratio between the temperature jump in °C and the radiation input in Watt/m^2.

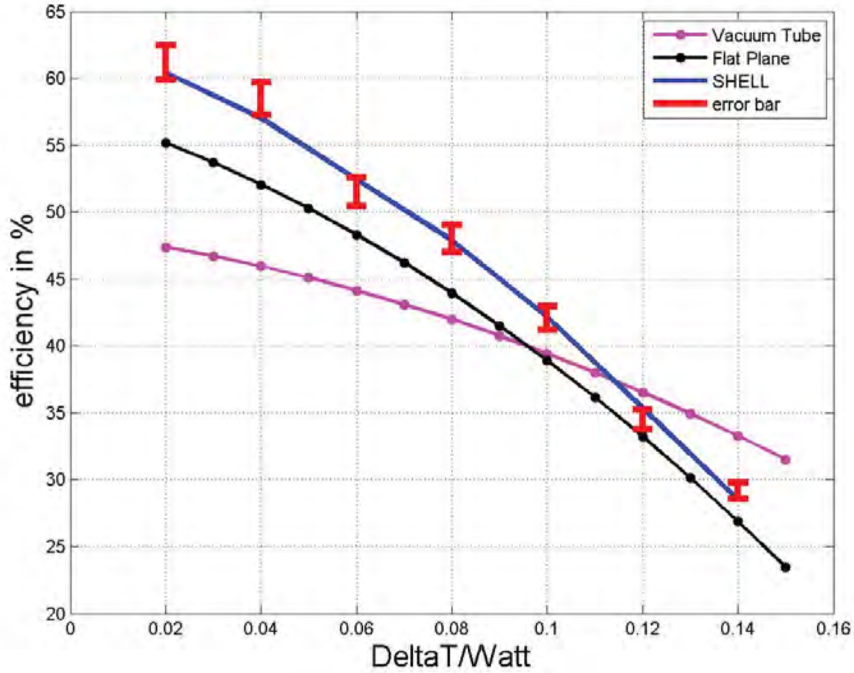


fig 1 Collector percent yield along the ratio between thermal jump and incoming radiation

Today, the available thermal collectors have, at least, two limitations:

a A rather high plant cost per m^2

b A high thermal dispersion

The latter limitation can be solved through two distinct techniques:
1 Using the most efficient thermal insulation possible
2 Accumulating the heat into a well insulated tank

The purpose of SHELL's project is twofold:

a To lower the cost by making the system simpler and stronger;

b To keep the efficiency as high as possible but with lower cost systems.

The basic ideas of the project

The longitudinal thermal gradient technique

One of the crucial problems in solar collectors is the rather high temperature that the surface collecting the radiation must attain. Since the amount of the collected energy directly depends on the surface, it becomes very important to have very large surfaces, and, at the same time, to minimize the energetic loss due to thermal radiation. These two contradictory priorities are partially fulfilled both with a concentration system (a system that transfers solar radiation onto a smaller surface) and with a very good (but unavoidably expensive) insulation system.

An alternative patented for some application in 2003 (patent N. FI2003A000008 15-01-2003), suggests a procedure that uses the thermal gradient formed along the path of the heat storage fluid.

The system is formed with a plane structure where the liquid slowly flows in small canals (from few cms. to 1m deep), heating up to the required temperature (figure 1). The time for the process depends on the dimensions of the system, and can vary from a few hours to ten days.

The cold thermovector fluid (usually water, in case salted water) is introduced into the collector where it slowly circulates until it reaches optimal temperature. The thermal gradient between the beginning and the end of the canalization is a linear one and, therefore, the losses are, roughly, halved.

This improves the system efficiency and, moreover, allows the use of “poor” materials in the collector’ surface insulation (at least, in the initial phase).

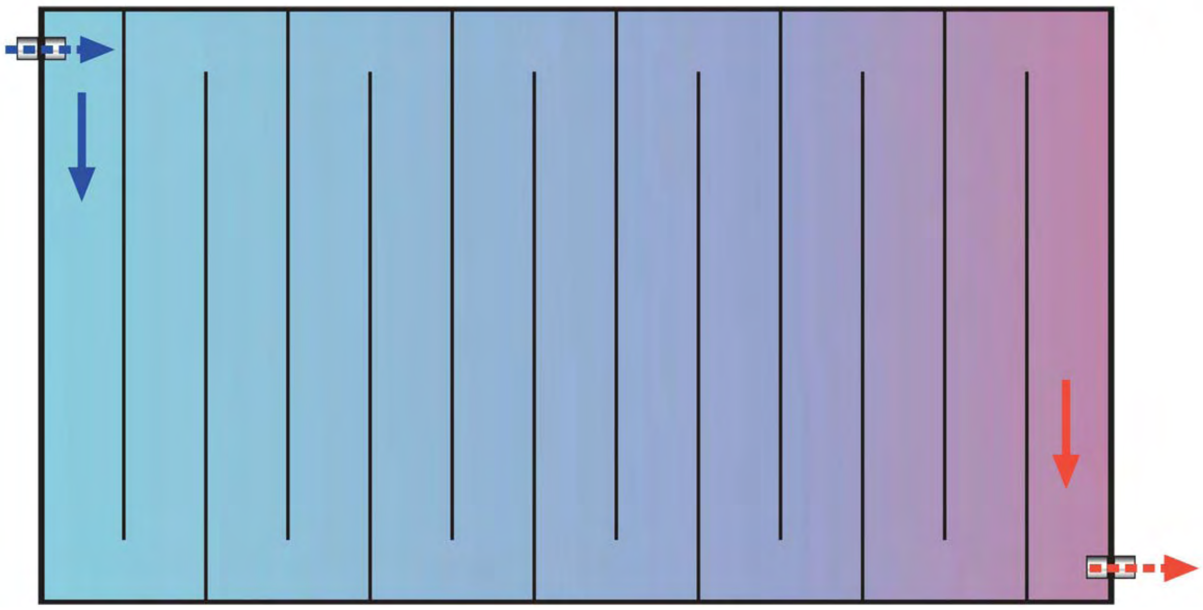


fig 2 Scheme of heat collector and storage system

A possible scheme for covering the surface consists in dividing the path into three parts.

- A first part, where the surface is free and where the temperature rises from 20 to 35 °C
- A central part covered with alveolar polycarbonate with a fairly good insulation capacity
- The final tract where the surface is shielded with a double layer anti-reflecting glass or is coupled to a concentrator to increase the water final temperature.

Recovering superficial heat: a layer model

The adoption of a forced (albeit very slow) circulation system permits us to intervene on another factor.

Solar radiation is mainly absorbed in the superficial water layers: the first 5 cm, for example, absorb 27% of the solar radiation (fig. 4), and this leads to a heat accumulation in the higher part of the canal.

It is, therefore, possible to build a double circulation by inserting a transparent and thermally insulating sheet a few centimeters under the surface, generating a fast circulation in the external part, and a re-injection of the hot fluid into the part below.

This technique is shown in the two following figures in two different variants:

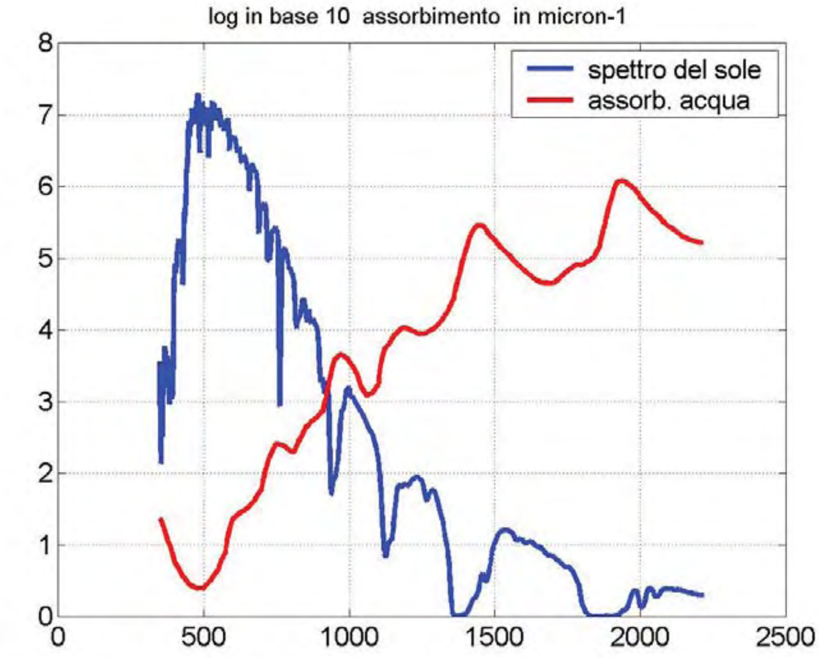


fig 3 Water absorption versus solar spectrum

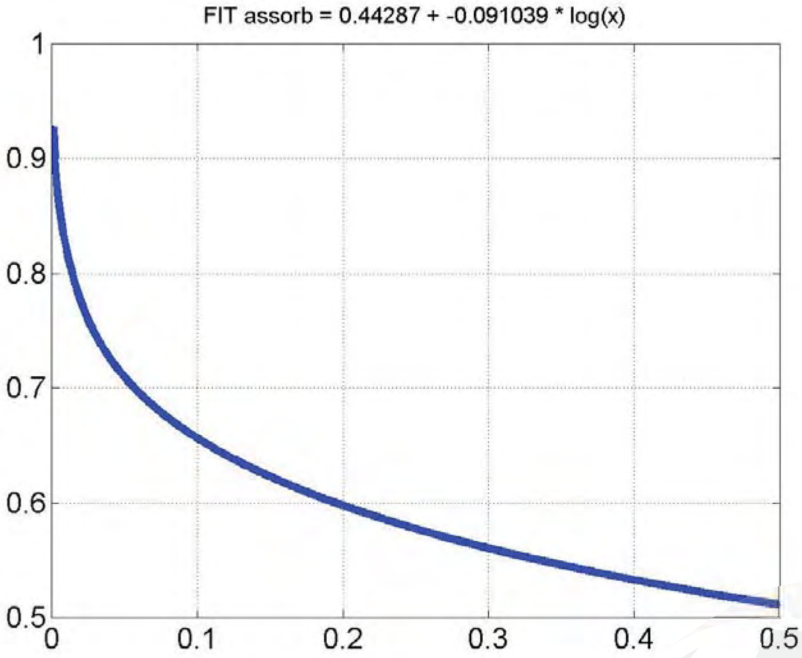


fig 4 Graph of the radiation loss in relation to the water layer thickness.

- In the first case, the water quickly circulates in an open superficial layer and, once warm, is reintroduced at the beginning of the canal in the layer below where circulation is much slower.

- In the second case, the higher layer is insulated with a suitable transparent and thermally insulating material.

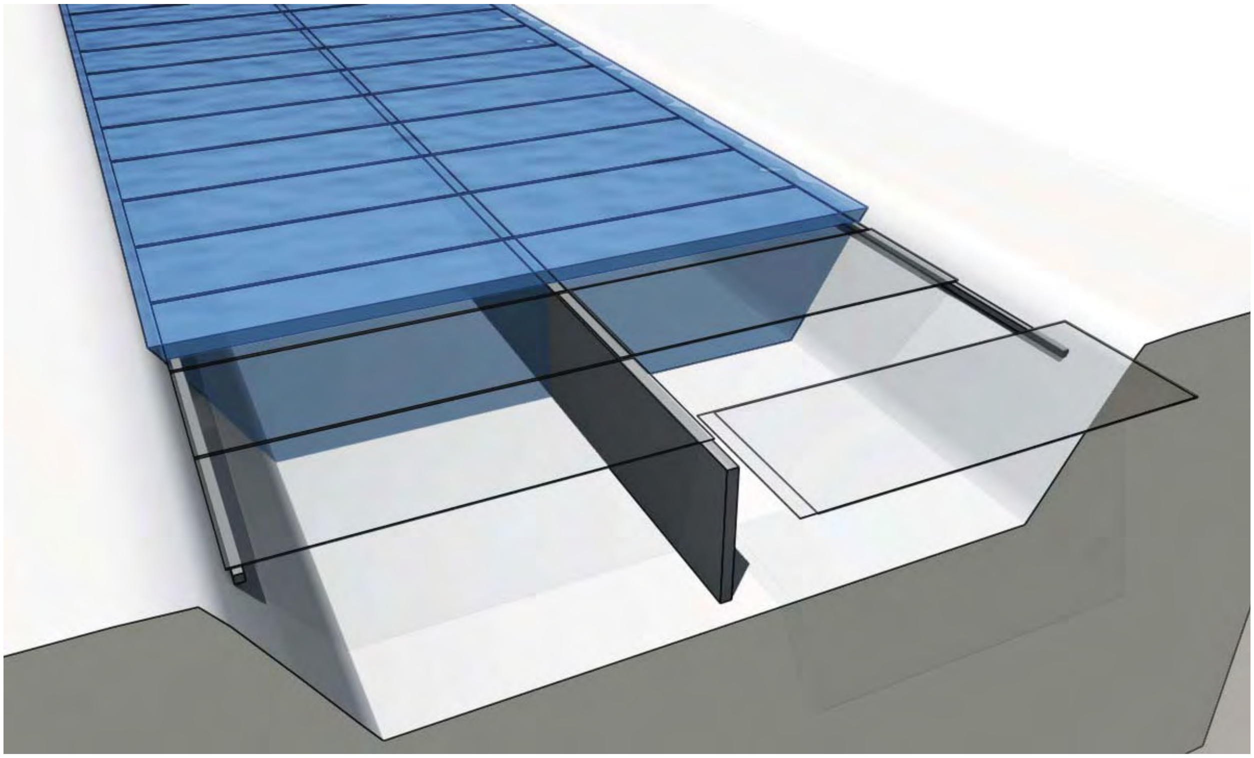


fig 5 Scheme 1 : patent SHELL

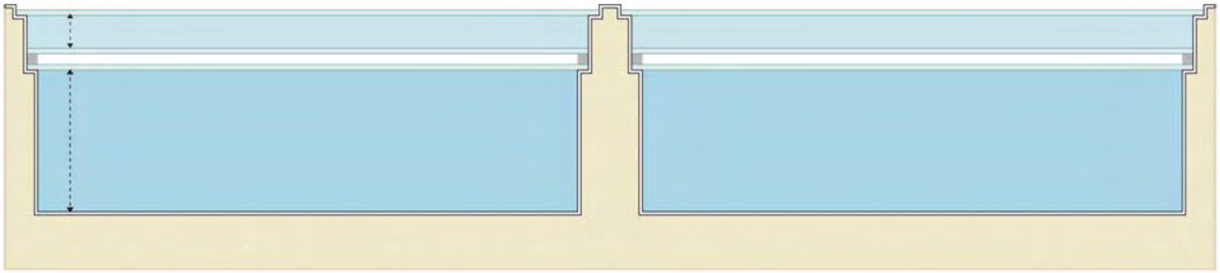


fig 6 Scheme 2 : patent SHELL

This technique further reduces thermal losses and improves the system efficiency (Patent Pending BO2007A000518).

The modular structure

An important characteristic of this system is its segmented structure. This particular structure allows the use of very large surfaces, using several recycling ponds. The need for large collecting surfaces and the modular structure suggest modular building solutions such as the one in fig. 7.

Such a structure allows the realization of scalable structures without being forced to plan ad hoc systems in advance for the various environments.

One of the most suitable materials for realizing the modules is fiberglass. Alternatively, on large flat expanses of sunken ground (preexisting salt pans or lagoons), the structure can advantageously be used by means of a polyethylene sheet resting directly on a suitably prepared ground.

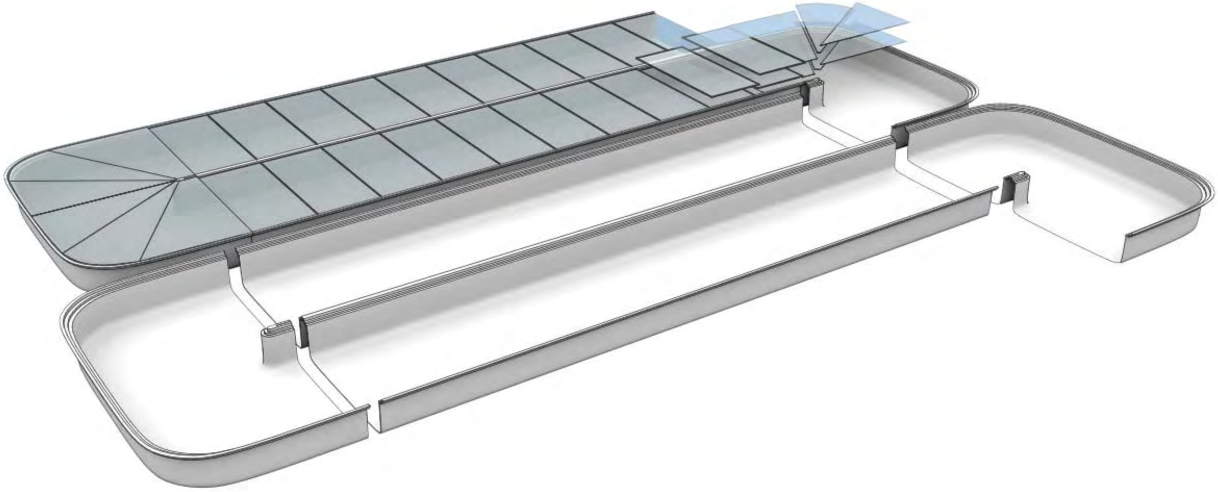


fig 7 Scheme of modulus for SHELL realisation

The concentration system

An intrinsic limit of the solar collectors is that the maximum temperature for flat collectors never exceed 70-80 °C. This limit can be overcome either by improving the insulation systems or with concentration systems. A system that couples well to the proposed modular scheme is the Fresnel mirrors concentrator already adopted in these configurations in plants for the preheating of the water at temperature higher than 80 °C.

fig 8 SHELL model with Fresnel concentrators

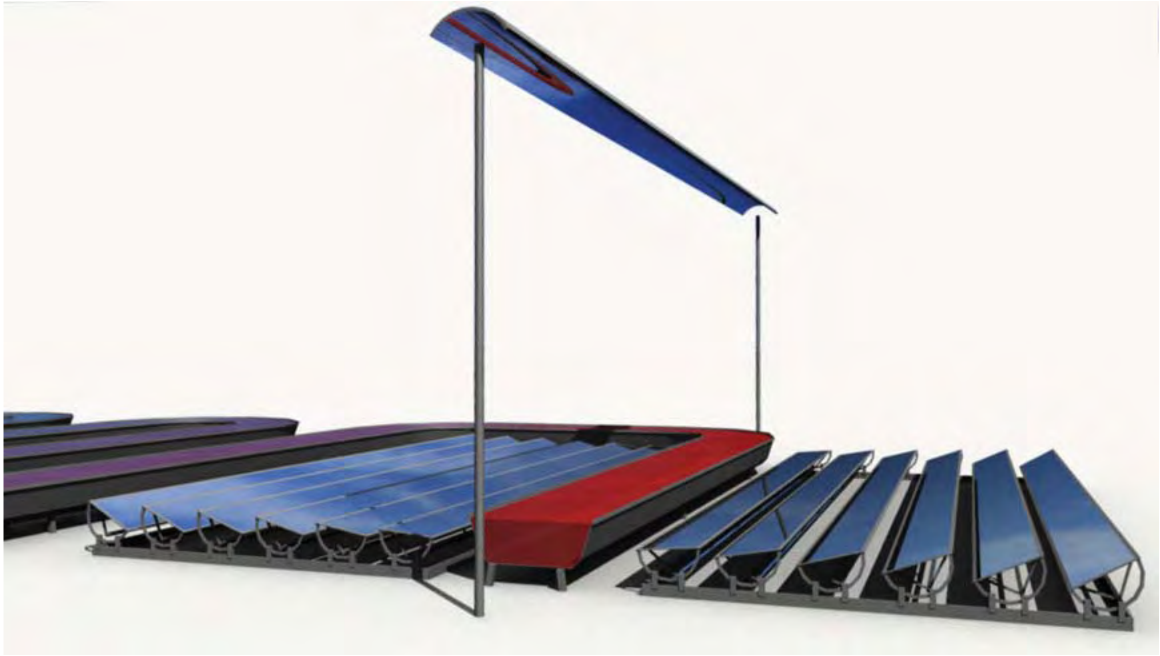


fig 9 A detail of the concentration system.

The storage reservoir

The use of a reservoir for storing the hot fluid will lead to a considerable efficiency increase (from 55-60% to 65-70%). This is particularly advantageous for systems where the heating cycle is a few hours long, so as to exploit the day-night alternation in the best way.

In this case, the heat accumulated during the day is entirely transferred into a reservoir of suitable dimensions, in order to reduce the radiant surface of the collector itself by several orders of magnitude.

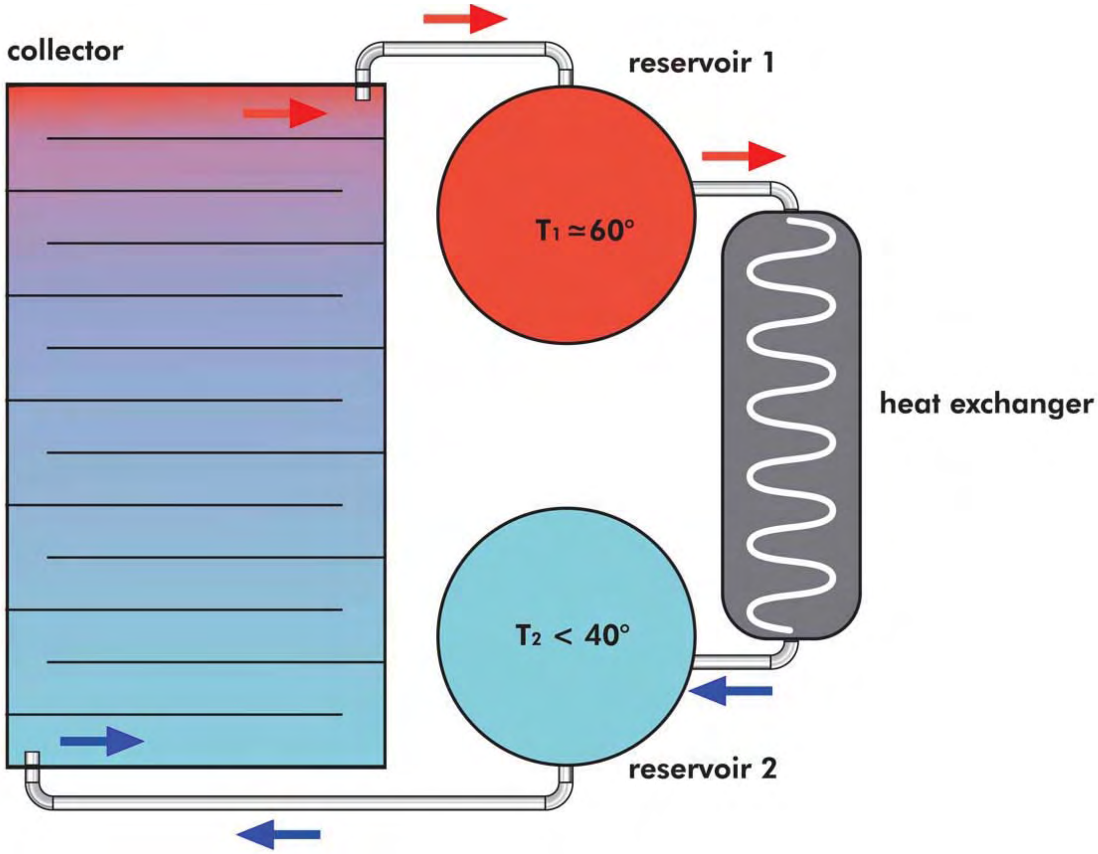


fig 10 Heat storage reservoir

Obviously, this system cannot be used if the heating cycle last for a few days, as in the case of very big plants. In such a case, the thickness of the water layer is such that the capture system coincides with the storage one.

The planarity problem

Even if in principle it is possible to think of a sloping system with canalization under pressure, SHELL is born with a horizontal configuration that guarantees the following advantages:

- Simplicity of construction
- Very low head and consumption for the water pumping and circulation system
- Use of preexisting basins and big dimension structures
- Costs reduction

The problem of lower capture efficiency compared to a surface that can be orientated is especially relevant at higher latitudes and during the winter season.

The following figures report the values (expressed in MegaJoule/m2) of the daily incident radiation in function of the system inclination for two latitudes: 40° e 20°.

The average radiation captured at latitude 40°, is 207 Watt on a plane surface, while it grows up to 248 Watt on a surface with an inclination of 30°, and 247 Watt with an inclination of 40°. However, this gain of almost 20% is reduced by the fact that the greater efficiency is shown especially from the autumnal equinox to the vernal one, when the incoming solar radiation is very low because of the worse weather conditions.

In fact, the experimental difference in these cases is slightly over 5%.

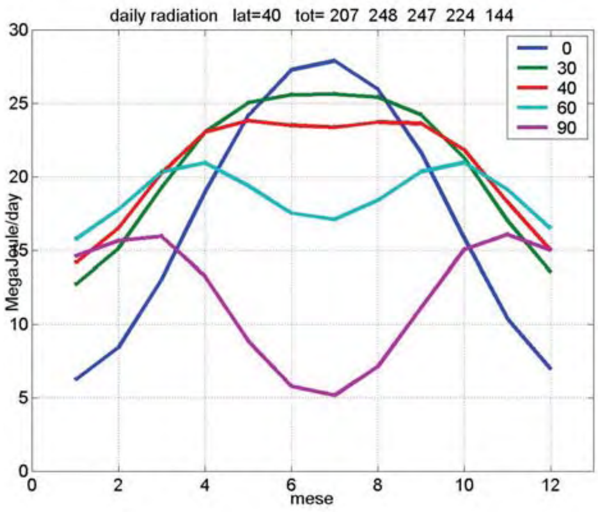


fig 11 Incoming radiation Latitude 40°

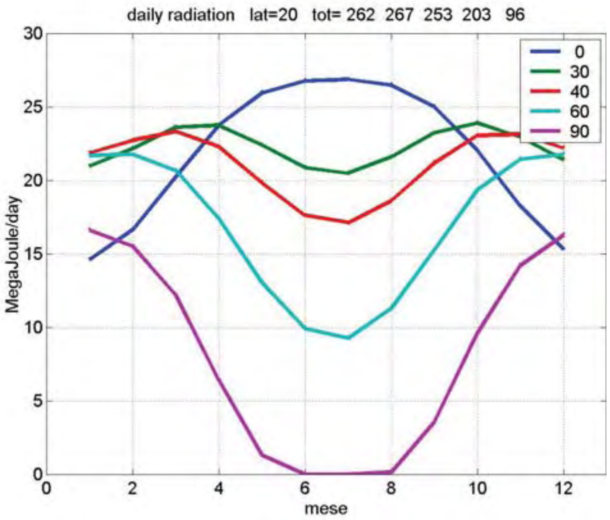


fig 12 Incoming radiation Latitude 20°

At latitude 20°, instead, there is almost no difference between a plane surface and a sloping one, and there is no real advantage in inclining the collector.

Materials

The choice of materials in this type of system is highly critical.

Concerning the surface, the important parameters are:

- Reflectivity

- Transmissibility
- The coefficient of thermal insulation
- Opacity to far infrared (3-5 micron)

Double glass and alveolar polycarbonate solutions have been both examined. Oil film systems have been studied as well: although they will cause engineering complications, it is estimated that, in the case of a free surface (fig. 3), such systems will have higher conversion efficiency and better thermal energy storage. Both for the containment canal and the bottom insulation, the fundamental parameter is the thermal conductivity. The best solution appears to be fiberglass with polyurethane. There are, however, alternative cheaper solutions.

table 1 *Characteristics of materials*

	Visible transmissibility (%)	Infrared opacity	Density Kg/m^3	Thermal insulation W/K/m
Double glass 6 mm	85%	95%	2400	2-3
Alveolar polycarbonate	80%	70%	1300	3-4
Fiberglass 5 mm	//	//	1700	5
Polyethilene 5 mm	//	//	1500	4
Polyurethane 5 cm	//	//	200	0.5

Produced calorie cost

Efficiencies have been estimated for each month of the year and at several latitudes (the values are represented in table 2

Given a typical example for a big plant (1 km^2) of an investment of 25 millions euro, amortizable in ten years, and of 2 millions/year maintenance cost, we can estimate the cost of a MegaCalorie depending on the latitude, the period of the year, and the desired average final temperature of the extracted liquid. The results are reported in Table 2.

The radiation/heat conversion efficiency has been taken into account (the efficiency can go up to 70% in some cases, but drops to 50% with high temperatures and at latitudes such as Rome).

table 2 *Cost of one MegaCalorie produced in a big SHELL plant, at different latitudes and with different output water temperatures (assuming an input temperature of 20 °C).*

	Watt/day	T=50 °C	T=60 °C	T=70 °C	T=80 °C	T=90 °C
Roma/Istanbul 42° lat	226	9,8	10,9	12,3	15,3	19.0
Il Cairo/ Ryad 31° lat	258	7,9	8,8	9,9	11.4	12.5
Rio, Hong Kong 22° lat	278	6,8	7,6	8,5	9.6	11.5

The cost must be compared with the cost of one MegaCal produced with heavy oil or methane, which are directly linked to oil prices and follow the trend described in fig. 13. At today's oil barrel price over 70 $, the cost of a MegaCal produced with heavy oil is over 30 €, while one MegaCal produced with methane is around 70 € (not including the cost of the burner and of the exchanger, weighting around

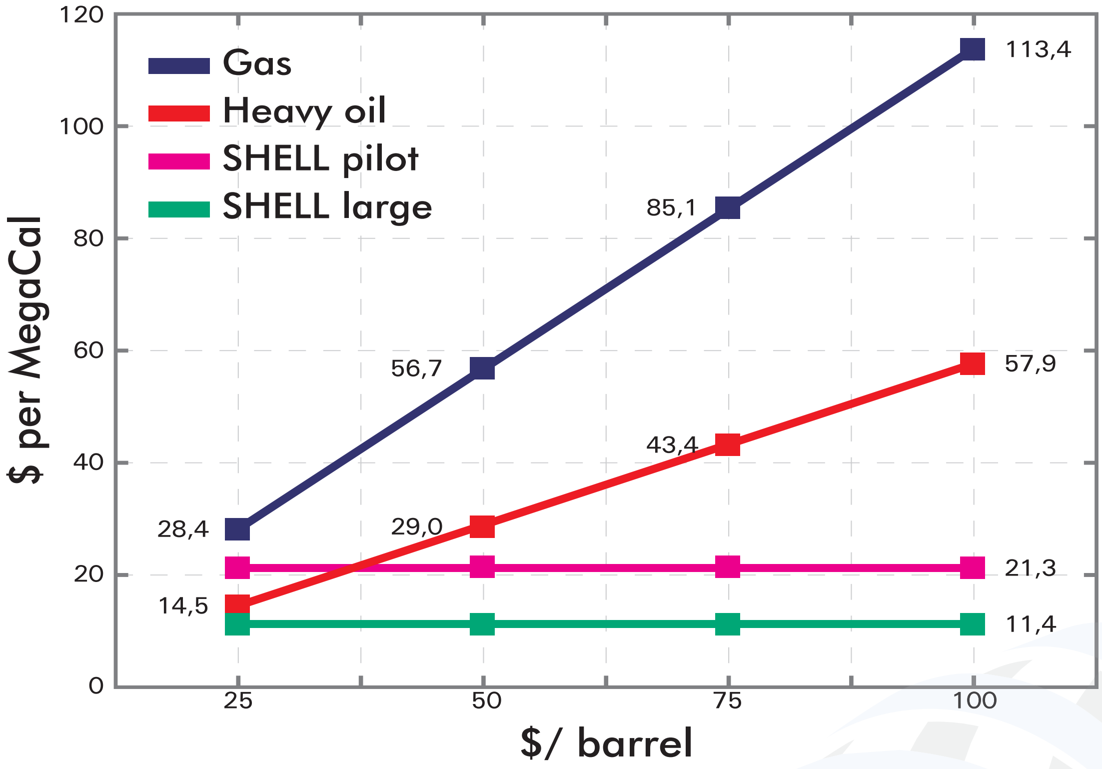


fig 13 MegaCal cost with Heavy oil or methane: final T 80°C, latitude Cairo

5% on the final costs). We can, therefore, conclude that as per today's oil price, heating with Heavy oil fuel, is 2 to 4 times more expensive than heating through a solar collector.

Of course, the enormous advantage of fossil fuels is to be able to supply the MegaCalorie at the desired temperature, and, therefore, produce high enthalpy heat whenever necessary.

However, hybrid systems integrating thermal solar and fossil chemical energy sources can, in some cases, counterbalance the limitation of collectors.

Some possible applications

There are many systems needing low enthalpy heat. Here are just a few:

- Hot water for domestic use. The limit of this application lies in the fact that the demand peaks during the winter season, when irradiation is lower. It is, however, possible:

1 To supply hot water for bath and shower all year long;

2 To provide an important contribution to heating (30% average on a yearly basis)

3 To have summer insulation plants, by means of a chiller.

- Swimming pools. SIT developed the PARS project (Piscine AutoRiscaldanti Solari = self heating solar pools) coupling a collector-reservoir to the swimming pool system, thus allowing the average water temperature in the morning to rise by 5-7 °C.

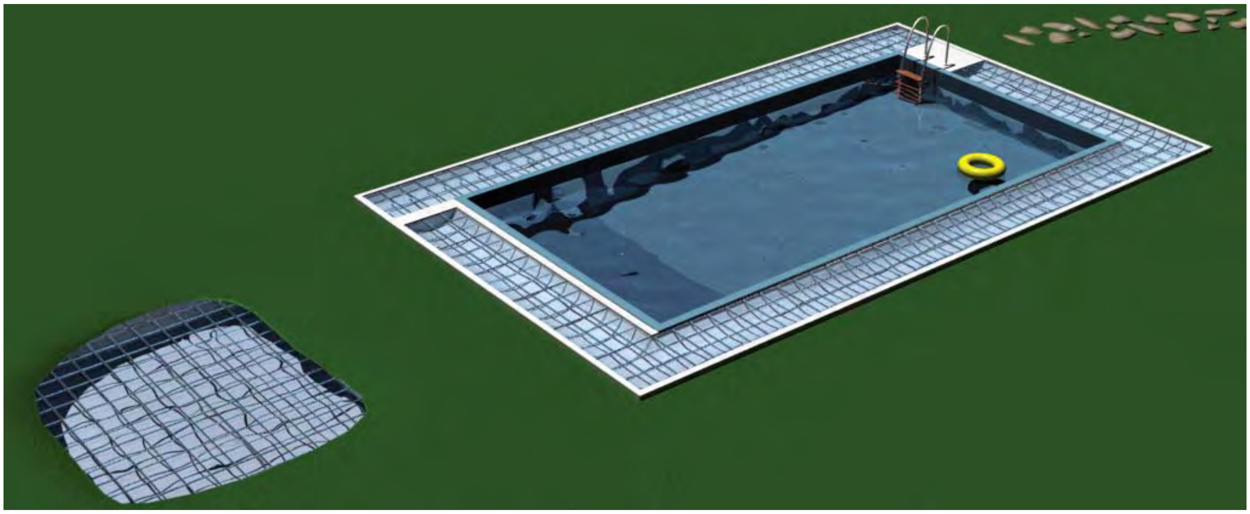


fig 14 Scheme of a solar heating pool

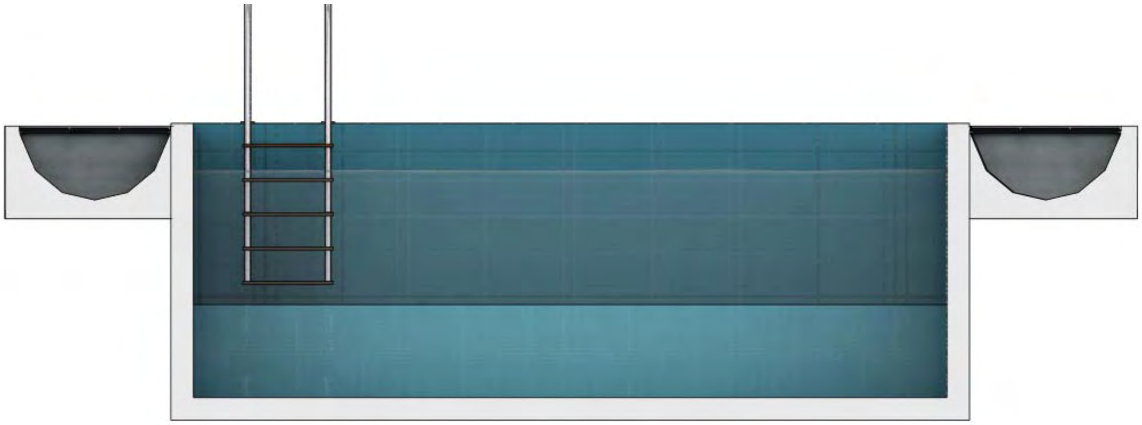


fig 15 System section

- Industrial/agricultural processes

4 Galvanic baths: required temperature 50-60 °C, usually obtained from methane burners.

5 Exsiccation and greenhouses

6 Inverted osmosis. A temperature of 50 °C increases the efficiency of reverse osmosis membranes, and allows us to work with lower pumping pressures, thus saving electric energy.

Hybrid Systems

Heat is often required at temperatures over 90 °C, where the SHELL system return falls dramatically.

In this case, using a hybrid system can be a winning solution, even if the energy provided by SHELL is only a part of the whole required amount.

Let’s briefly analyze three cases.

Electricity production with Rankine cycle: SHELL + fossil fuels

A big plant uses BTZ or powder coal to raise the water output of the condensers from around 30 °C up to overheated steam at 550 °C.

The typical parameters for a big plant are the following:

a A 1350 MW plant has a caloric requirements (electric efficiency of 40%) of 70 billion calories/day

b A 1 km^2 of plane space is available for a SHELL system with a pool protected with polycarbonate or glass and close circuit.

c SHELL can capture an energy varying between 150 and 200 MW, depending on the latitude and the season (3-4 billions calories/day) roughly equal to 5% of the plant daily caloric need.

d The 30 °C water output of the condensers is collected and injected in the collector at the same temperature, and is afterward extracted at around 70 °C.

e 5.Estimating the water flow in the boiler at 80.000 m^3/day, 3.2 billion calories/day are necessary and this is exactly the amount that can be produced using SHELL system.

Desalination through evaporation: SHELL + fossil fuels

There are many desalination systems based on evaporation, but the most widely used is the Multi-StageFlash one (MSF), a system working with temperatures between 90 and 100 °C. Operating at lower temperatures, the Multi Effect Distiller (MED) is less common, but sometimes advantageous.

The two systems are very similar. They both start from sea water at 20-25 °C, they preheat it by means of the thermal waste produced by steam condensation processes, and proceed to its evaporation in vacuum at 80-100 °C, returning the thermovector fluid around 50 °C. In such cases, SHELL efficiencies are slightly reduced, but they are still very advantageous in latitudes such as Saudi’s, where roughly half of the needed thermal energy can be supplied via solar radiation.

Electricity production with low enthalpy turbines: SHELL + concentrators

Organic cycle Rankine turbines with low enthalpy have interesting output returns starting from 100 °C: this temperature can be reached only with concentration systems. The latter, however, are rather expensive and complex, but can easily be integrated with an economic system, such as SHELL, as mentioned earlier when discussing Fresnel concentrators.

In brief, low enthalpy heat is produced by bringing the thermovector fluid from 30 to 80 °C with a SHELL system, while the rest of the heating is obtained with a concentration system. This reduces the required mirror surface by a factor of 3, and may make the production of electricity from solar energy economically interesting.

fig 16 Scheme of a collector modulus.

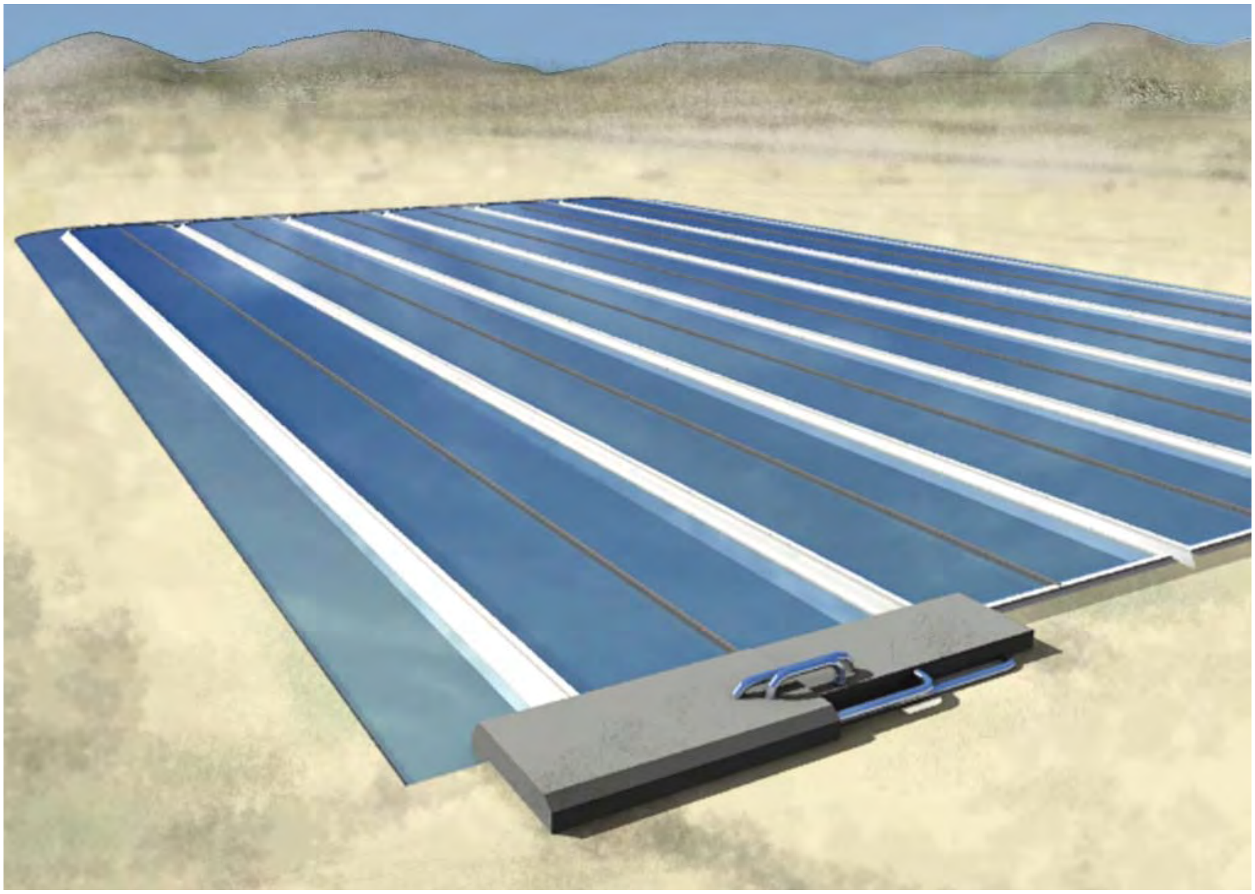


fig 17 Scheme of a group of modulus.

Advantages and problems

Advantages

- The system is modular, easily scalable, solid, and easy to maintain.

- The system is generally hybrid, and, therefore, an incidental interruption will not generate serious problems in the general performance.

- The system has a very low cost.

Problems

- When using these systems it is necessary to consider seasonal variations. Therefore it is important to devise optimization methods in function of heat availability (bigger thermal jumps in the summer). This difference strongly decreases along with the diminution of the latitude, although, seasonal climatic factors may intervene in some tropical strips (such as monsoon rain regime).

- The water flowing within the collector must be kept clean, and therefore is it necessary to solve the problem of algae formation. This can be done both with robotic systems and with chemical ones.

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