EXPERIMENTAL HYBRID SOLAR CONCENTRATOR UNIT SYSTEM FOR SANITARY WATER

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Abstract

The availability of solar energy and its use for heating sanitary water is a resource that has been used since ancient times. However, current technologies allow optimization and its widespread use. In the project carried out by the National University of General Sarmiento (UNGS), it has designed an experimental system hybrid solar concentrator unit for heating water for sanitary use. This project was intended as a complement to traditional water heating for domestic use , based on a parabolic concentrator .

The system was designed so that it can be used in existing conventional facilities or be installed as the primary system for heating water.All components are within the structure of the base parabolic concentrator, which allows transport and fixation.

The proposed project conserves the energy consumption of a traditional water heater, develop applications and combine existing technologies in a solar tracking parabolic concentrator, so to optimize its operation. Not used the traditional flat panel, but experimented with a heat exchanger mounted in the focal zone of the concentrator.

One of the main objectives of this project was to arrive at a design of an integrated product that contains all the necessary elements for operation in a single platform. This adjusted the designs and location of components achieving optimal layout of the facility, giving greater freedom in the design development and implementation of design concepts.

This system will allow conventional energy saving which is normally used for purposes of domestic water heating, but plans to integrate these conventional systems. That is why we speak of a hybrid system, which uses solar energy and conventional energy (electricity or gas).

Considering the average consumption that occur in a house with four people, this system can replace between 45% and 91% of the energy used for water heating use , depending on time of year and considering its application in the Argentina northwestern area. The components were sized according to the proposed operating conditions.

In the case of solar energy utilization, the analysis was extended to different geographic locations of the country, analyzing performance and selecting different areas favorable for the implementation of the system.

This project will lay the foundation for the future development of associated projects conducted by researchers and students of the university, such as the study of the control loops, the solar tracker system development and the possible construction of a prototype, for academic use.

Keywords: Thermo tank, solar concentrator, heat exchanger, accumulator

1. Introduction

Mass consumption of hydrocarbons is producing changes in global atmosphere. The levels of carbon dioxide (C02) which are currently detected are significantly higher than those existing in 1950. This, together with the accumulation of other gases produces the well-known greenhouse effect, which partially causes the increase in global average temperatures. Another known effect from the use of fossil fuels, is the effect known as acid rain, which causes great damage to the environment and human health. Thus both economic and ecological reasons, it is imperative to develop new energy alternatives that are less aggressive to the environment. In this regard, a large percentage of power is commonly used for heating water for domestic use. Hot water is significant energy consumption at homes, having various uses such as personal hygiene and cleanliness. Worldwide has become the second most important domestic energy use after heating and cooling. For this reason, the water heating by solar energy, beyond being an environmentally friendly alternative, it has become an economically attractive and competitive technology in many countries. In recent years there has been a significant increase in solar thermal installations in the world, technological advances allowed the manufacture of better quality systems at lower cost and society understands the need to replace fossil fuels. The use of complementary systems for the partial replacement of conventional energy sources is a valid way to improve the quality of life. This project explores the possibility of replacing some conventional energy used to heat water for sanitary use in private homes, by an alternative source that uses renewable energy. Given these guidelines an autonomous system has been designed, that will complement and replace the energy that today is used for this purpose. We will start from developments already made in the University [3] and similar works [1].

2. Solar energy and its use.

The use of the energy provided by the sun is dependent on the intensity of solar radiation received at ground level, daily and annual cycles, and weather conditions of the place.

We define solar energy as one by conversion to heat or electricity takes advantage of the radiation from the sun. From the energy point of view, the solar mass per second is radiated into space in the form of high-energy particles and electromagnetic radiation is approximately 5.6×10^{35} GeV, and from that radiation the earth receives in its outside atmosphere a total of $1{,}73 \times 10^{14}$ kW , or 1,353 kW/m^2, which is known as the solar constant whose value fluctuates ± 3% due to the periodic variation of the distance between Earth and Sun [4] . The atmosphere and land surface are at different average temperatures and therefore also radiate energy . Thus the wavelength of the solar radiation lies between 0.05 microns and 4 microns , and it means, it is long-wave emission .

From an analysis of this radiation , it follows that only 47 % of the incident solar energy reaching Earth's surface , 31 % do so directly and another 16% after being scattered by dust, water vapor and air molecules , the rest of the solar energy , 53% , does not reach the surface of the Earth. The 15 % is absorbed by the troposphere (water , ozone and clouds) , 23% is reflected by clouds , 7% is reflected from the floor , 2% is absorbed by the stratosphere , mainly by ozone and 6 % is the energy released by the atmosphere [4] .

Radiation is usable in direct and diffuse components . Direct radiation is the one that comes directly from the sun focus, without intermediate reflections or refractions . The diffuse is issued by the daytime sky due to multiple reflection and refraction phenomena in the solar atmosphere, clouds and other atmospheric and terrestrial elements . Direct radiation can be reflected and concentrated for use while it is not possible to concentrate the diffused light coming from all directions .

As we mentioned above, the radiation varies by time of day , atmosphere conditions that absorbs it, and latitude . It can be assumed that in good irradiation conditions the value is about 1000 W / m² at the earth's surface . This power is known as irradiance . Another term to remember is called heliophany, representing the duration of sunshine or daylight hours.

3. Development

In order to contribute positively to the decline in consumption of traditional energy sources , we propose to replace gas or electricity as heat source, normally used to heat water for domestic use , by a system to supplement or replace these energy sources , using a solar heating system .

On this purpose various configurations of systems were analyzed, that allow the use of these alternative sources , for then propose a system that meets technical and economic objectives .

Thus, after analyzing existing possibilities, it was decided to develop a typology that combines various technical solutions . To this aim we have proposed , to design and dimension an energy recovery system that can work independently and as a single building block , using solar thermal power and also can complement and integrate the traditional system for sanitary water heating (SWS) . This system can function not only as a replacement of the traditional system , but as an electricity or GAS economizer consumed by an ordinary water heater , thus achieving a "hybrid " system.

The use of solar panels dates back to 120 years , and during this period there were several different forms of solar thermal collectors ranging from flat to parabolic collectors and heliostats . It is estimated at worldwide installed area of 58 x 10^6 m^2

For our project collectors were used , but with a particular geometry , by combining different effects. This development can contribute to the use of an untapped resource in our country. In Argentina the use of solar collectors [5] for this purpose is very low in contrast to other countries such as Europe and China. In central and northern Argentina the weather is relatively good, but in the winter months and a few days of fall and spring it is necessary to provide heat providing order to have minimum comfort conditions in homes.

According to the analysis , taking into account climatic variations that can cause sequences of several cloudy days and / or cold , it becomes clear that it is not possible to cover 100% of the energy needed to heat water using solar energy only, and therefore required to provide a percentage of the claim with another type of energy.

This, together with the difficulties to provide heat energy in regions far from major population centers, where there is no natural gas network or the availability of electric power, justifies the implementation of a hybrid system that is developed in this paper .

3.1 Conventional solar collector

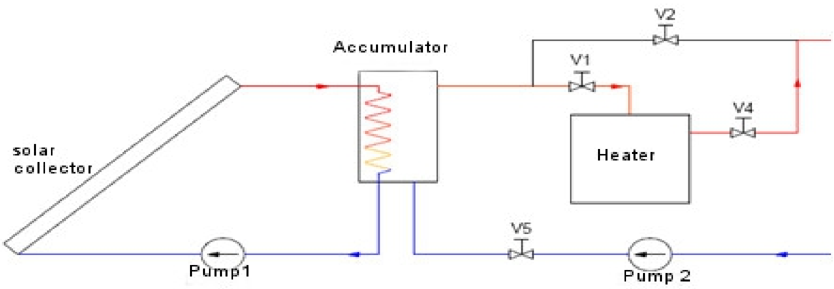

Figure 1. "Conventional" System with interchanger-Accumulator

In existing systems for heating water by solar energy we can analyze conventional collector systems [6]. In this system (Figure 1), a conventional solar collector integrated is used in the existing heating system incorporating an intermediate heat exchanger. This configuration allows the use of solar panel systems in closed water circuit and uses a heat exchanger to transfer heat energy to the water that will be used for sanitary purposes. It also allows connection to existing heating system, either a simple water heater or boiler. Generally these systems have a circulation pump.

In this application (Figure 1), water is preheated from a boiler using an accumulator that functions as a heat exchanger. Pump 1 recirculates fluid that transports energy received from the sun. This fluid through the heater which is located in the solar concentrator receives energy from the sun by conduction and convection. The heat once transferred to the accumulator warms the clean drinking water that enters through the valve V5 by Pump 2 and enters the boiler through the valve V1 preheated. This fluid, that arrives reaching a certain temperature Te, makes boiler system working in a regime lower than normal decreasing gas consumption from 10% to 15%.

In conventional solar heaters, because they are fixed related to the earth, it can be shown that absorber plates efficiency decreases for not having a mechanism to accompany the sun path during the day and thus receive sunlight directly (direct radiation). The direct impact also varies by time of year. Then Figure 2 shows the change in trajectory of a fixed point on the Earth's crust in different months of the year.

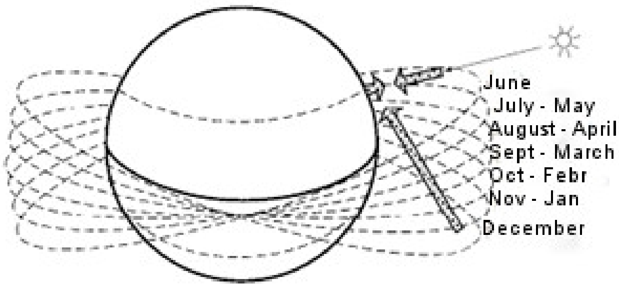

Figure 2. Trajectories of a fixed point on the Earth's crust in different months of the year

Because of these variations, and considering that the power available varies with the angle of incidence, it is observed that the system could be improved by developing a solar collector that has a tracking system accompanying the sun path during the day and thus captures more efficiently direct radiation. This device may increase system performance over conventional solar panels between 30% and 40%. To resolve issues of installation autonomy and heat loss reduction, it will be designed a compact equipment that not only allows maintaining the sun perpendicularity on the surface of incidence, but also accompany the sun on its azimuthal and zenithal journey. This equipment will be integrated into a single unit, the conventional heating system, allowing hot water availability even in cold weather, without sun or at night. The solar tracking system, is not included in this development. Within the group of university researchers, there is a parallel project developing this device [7].

3.2 System design with concentrator.

Taking into account the needs expressed and developments already made in the University [3] some objectives to be met by the design had been established.

First the system must heat sanitary clean drinking water, estimated by existing statistical data, that a temperature of 40 ° C is satisfactory for this use. The system should use solar power and have the ability to store the energy, allowing continuous use. Since it will be used autonomously must have the necessary safety devices and respond to demands of hot water during day or night.

The system has the ability to use conventional energy (electricity or gas) when solar power is not sufficient to meet demand, then responding to the concept of "hybrid" design.

These guidelines led us to design a system to concentrate sunlight on a small area, but that maintains its relative position to the sun constantly, thus taking advantage of better radiation.

To achieve these objectives, it was developed a system that incorporates a parabolic "receiver" (Figure 3) that concentrates solar thermal energy in a focal area, where a heat exchanger plate/tube type is mounted, through which circulates water for domestic use. This fluid (water) is sent to a tank through isolated pipes, which we call "Thermo Tank" and then is taken and pushed again through a recirculation pump to restart the heating cycle, constituting a closed system until effective use. The system allows water to pass also through a "conventional" heater. The latter can be gas or electricity, depending on which source is available and cheaper.

Figure 3. Parabolic concentrator design with in focus heater

This configuration allows controlled and rational use of conventional energy as a part or the whole heat is provided by the solar concentrator-exchanger, then achieving greater efficiency than other methods of heating water. It is essential then, to develop an appropriate control strategy that allows conventional systems activate only when the application is started and turned off when this ends, preventing water mass keep warm without any need.

Between the water heater and the type of "conventional" heater there is a direct connection via an isolated pipe in which a flow sensor is placed, that is used in the control strategy to maintain the water at a constant temperature. The water tank has a level control with a two-way solenoid valve located at the sanitary water supply, allowing maintaining the volume of the Thermo Tank fluid within a certain range. The electric heater will have an electrical resistor, which provides heat only when solar power is not accumulated enough to meet the needs of water to the preset temperature. The gas heater is activated at the same criteria (Figure 4).

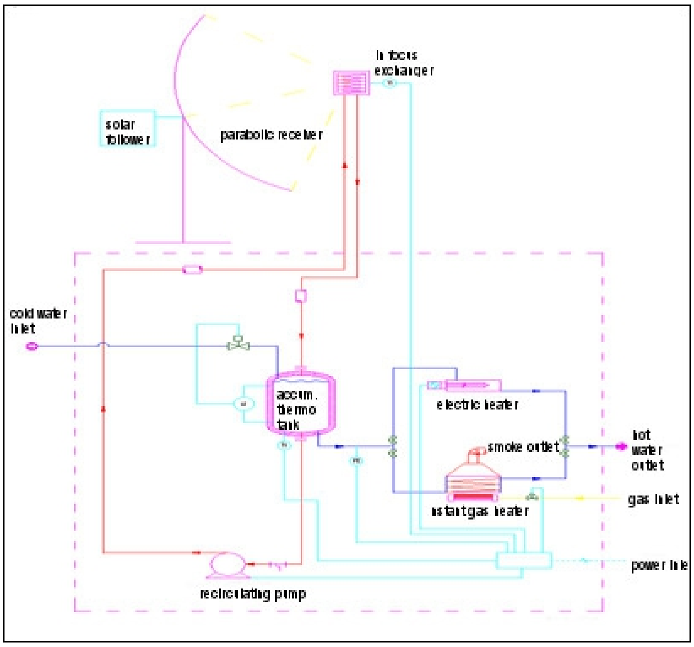

Figure 4. System functional Lay-out.

The loop that regulates the power delivered to the electrical resistor is a function of two variables: water inlet temperature , which is taken into the hot water tank and the flow detector mentioned above. This loop optimizes power consumption since resistor is activated only during hot water demand . Moreover, the power delivered to the resistor is modulated depending on the inlet water temperature and the fluid flow rate, may be in some cases zero power thanks to the use of solar thermal energy .

The gas heater will be a conventional water heater integrated into the system . The amount of burned fuel, and consequently the supplied energy will depend on the demand for hot water and the temperature at which it is accumulated in the tank. Gas regulation is realized through a control valve modulated by a controller , who receives the input signals of flow detection and accumulated water temperature, thereby modulating the amount of fuel .

The other loops are related to the partial deactivation of the process. Remembering that has an active solar tracking system throughout the day, it is proposed to disable it in set schedules for different times of the year . Moreover, when the temperature sensor located in the primary focus records a value less than the minimum profitable energy to maintain operating the recirculation pump , the controller will indicate to stop its operation. This temperature value is obtained through an energy balance which takes into account the solar energy captured and the sanitary water consumption of the recirculation pump into focus. It is proposed to obtain the temperature values for this balance empirically, once the prototype is built, since a difference in estimation of the same capacity would impact in energy use. Finally, through another balance it will be studied if the volume of water contained in the thermo tank after prolonged absence of demand, reach temperatures above 70 ° C in the interior. In this situation it will be necessary to remove the heat source. The latter will take place , again , ordering the recirculation pump to stop functioning , thus regulating the thermal energy delivered to that tank from the solar source .

Regarding the maximum providing capacity of domestic hot water (40 ° C) that this system is capable to deliver, it will be determined by the energy that can capture and absorb the available antenna (1184 series Brand Prodelin maximum diameter 1.80 m). While it has the support of some external power , this is just to ensure maximum water capacity previously proposed. In future projects the system could be scaled to meet different demands or choose the implementation of more than one of the equipment designed here. It can be concluded that the described system meets the established design objectives. (Figure 5).

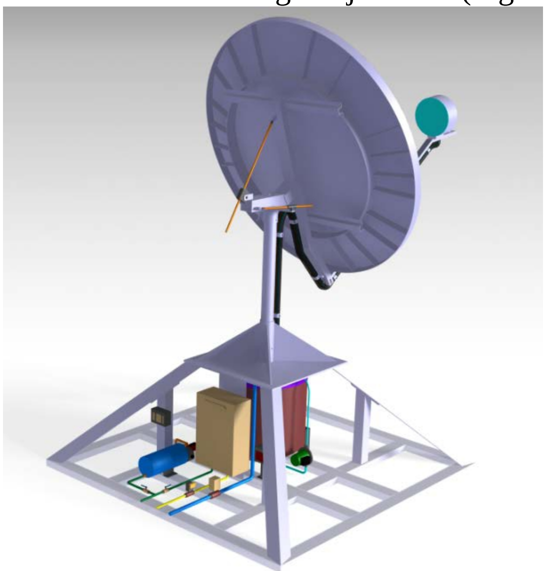

Figure 3. “Hybrid” compact System view with its components and solar concentrator

3.3. Theoretical calculation of system components

Based on the proposed concept, it is necessary to develop the theoretical calculation based on the thermodynamic conditions of each of the components to determine dimensions, capacities, operation and final geometry of the assembly. For determining the geometry of the components, it is necessary to establish their characteristics in terms of efficiency and heat exchange. This was achieved by an energy balance. Most of the processes are performed continuously, so that matters refer to the transfer of heat per time unit. The equations described below are associated with the heat balances. They can calculate the quantity of heat that must be transferred to achieve a given process condition on the flow participating in the exchange. These are equations that are associated with a purely thermodynamic pose of the problem, and are completely independent from the equipment design that will focus on the process.

We call W the mass flow (kg/s) of a stream. The subscript h indicates the hot fluid and the c the cold fluid. Also, the subscript 1 indicate the equipment input conditions, while 2 indicates output conditions. When referring to temperatures, to save subscripts, the letter T is used for the temperatures of hot fluid, whereas t designates cold fluid temperature. We will call Q to the amount of heat exchanged per unit of time (J/s). If a hot stream transfers heat to a medium which receives it, it will suffer a decrease in enthalpy that will be:

$$Q = W_h (i_{h1} - i_{h2}) \tag{1}$$

Where i is the specific enthalpy (J/kg). If such fluid experiences a cooling with no phase change, the enthalpy difference may be expressed as:

$$i_{h1} - i_{h2} = c(T_1 - T_2) \tag{2}$$

Where c denotes specific heat (J/kg K). We can say then that:

$$Q = W_h c_h (T_1 - T_2) \tag{3}$$

There are other considerations that apply when the process involves phase changes, but will not be applied in this case. To allow heat transfer between two fluids it is necessary that there is a temperature difference between them. The greater the temperature difference, the greater the rate of heat transfer. Furthermore both fluids should be separated by a surface through which heat can be transferred. The surface is called transfer area A. For example, if one of the fluids is flowing inside a tube, and the other is located outside it, the transfer area is the lateral area of the tube. The higher the transfer area between two fluids, the greater the amount of heat that can be transferred per unit time between them. Therefore the following expression is valid:

$$Q = U.A.\Delta T \tag{4}$$

Where the constant of proportionality U is called overall coefficient of heat transfer, and ΔT is the temperature difference between the two fluids. The above is a kinetics heat transfer equation. It allows calculating the area of equipment necessary to achieve Q heat transfer between two streams whose temperature difference is ΔT. This area depends on the mass transfer coefficient U, which can be varied by changing the design characteristics of the device. The basic objective of the design, will be to achieve the greatest possible value of the coefficient U that is compatible with the constraints imposed by the process. In any design problem of heat exchange equipment, the exposed two types of equations (3) and (4) are involved, i.e. there will always be to combine a balance equation with a kinetic equation, which will ultimately decide which allows if the equipment area is sufficient to meet the desired objective. It should be considered the equations to calculate the value of heat transfer coefficient U. This is calculated on the basis of peculiar ratios. In this paper we adopt a value extracted from table, from studies and trials of CENSOLAR CONICET, which serve to make first estimations of the process. Then, once built the prototype, we could get this ratio empirically through an analysis of system performance.

The energy balance of a parabolic solar collector, as we have for this work, can be represented by the following equation:

$$Q_{abs} = Q_u + Q_L + dU/dt \tag{5}$$

Where:

Q_{abs}: is the total incident heat absorbed per time unit in the collector/exchanger(W).

Q_u : is the useful heat that is finally transferred to the working fluid (W)

Q_L: is the heat loss to the surroundings by radiation, convection and conduction (W)

dU/dt: the rate of change in internal energy stored in the collector (W), this value is generally very small and is therefore be neglected in the calculation.

Making a more detailed breakdown of the terms of the above equation, we find that each of them can be represented by another equation:

$$Q_{abs} = H_T.Ac.\alpha.\beta \tag{6}$$

$$Q_u = m.Cp.dT / dt \tag{7}$$

$$Q_L = U_{LA}.c.(T_{pm} - T_a) \tag{8}$$

Where:

H_T: incident solar energy on the exchanger (W/m^2), this value will depend on solar energy available during the day, the parabolic collector area and the focus area where concentrated solar thermal energy will be used in the process..

α: concentration factor

Ac: effective area of focus (m^2).

β: the product of the transmittance of the glass and the absorptance of the heat exchanger tube located at the focus, presents the fraction of the solar radiation that is absorbed by the heat exchanger. This value is inherent in the materials used in the heat exchanger located at the focus.

mCp: the heat capacity of the working fluid (J/ºC).

U_L: loss coefficient (W/m^{2}ºC)

Substituting equations (5), (6), (7), (8) and rearranging them

$$Qu = Ac\left[S - U_L(T_{pm} - T_a)\right] \tag{9}$$

Where S = H_T. α. β, that is, the energy available in the heat exchanger per area unit.

This equation is crucial in the analysis of the solar collector operation. The only problem is that the remaining useful heat according to the T_{pm} (average temperature of the absorber plate, or in our case the absorber tubes) which is difficult to calculate or measure, because it depends on the exchanger design and variables that change continuously over time as solar radiation and temperature of the working fluid entering the collector. To skip this difficulty we will take values that will make the calculation, again, from a conservative position.

4. Developing initial calculation. Prior determination.

For preliminary calculations we considered the above equations and values arising from tables and measurements.

It will be used H : 1000 (W/m^2) , it is considered 2,8 m^2, then the total energy being captured : 2800 W while S_f: focus surface that concentrates the energy captured the antenna is 0.07 m$^{2.}$

We will define α : focus concentration factor = 0.75 , this value contemplate the losses due to the irregularity of the reflecting surface that will result in the deviation of solar beams , leaving them to converge at the focus and losing some captured power at the antenna. This value also includes the dissemination of the same rays in the atmosphere which is interposed between the collector and the parabolic concentrator and also the possible shift between the actual and the ideal focus.

We will take Ac: effective area of the heat exchanger = 0.07 (m^2), although its geometry provides a greater area than shown, it is used to calculate the maximum area limited by the surface focus concentration where the exchanger is. If the exchanger geometry would offer a smaller area tan the one mentioned above, we would have to use that magnitude to quantify absorbed energy.

β value: 0.8 comes from the copper absorptance used in the heat exchanger and the transmittance of the glass located in the receiving surface of the bulb where the energy is concentrated. Is necessary to use materials having a thermal conductivity greater than 125 W/m °C and an absorptance greater than 0.9, and must also be made of steel , copper or aluminum , and its minimum thickness is 0.5 mm , 0.2 mm and 0.4 mm respectively, depending on the material .

For UL: Below are the Thermal Loss Factors based on the type of solar collector, which we call our concentrator focus. As will be shown later, here we propose a focus vacuum exchanger so it will take to calculate the value of 2 (W/m2 ° C)

Tabla 1. Factores de pérdidas térmicas

Collector Type	Conversion Factor (η_0)	Thermal Loss Factor U_L ($W/m^2 °C$)
Without cover	0.9	15-25
Single cover	0.8	7
Double cover	0.65	5
Selective surface	0.8	5
Vacuum pipes	0.7	2

Source: CENSOLAR (Centro de Estudios de la Energía Solar)

It is necessary to use materials having a thermal conductivity greater than125 W/mº C and an absorptance greater than 0.9 and must also be made of steel, copper or aluminum, and its minimum thickness is 0.5 mm, 0.2 mm and 0.4 mm respectively, depending on the material.

Thus we have, optical and geometric relationships ideals that:

$$H_T = \frac{2800W}{0,07m^2} = 40000\frac{W}{m^2} \tag{10}$$

Then, using the coefficients mentioned above, the energy available in the Focus exchanger per area unit is S = 40000 W/m^2 x 0.75x 0.8 = 24000 W/m^2.

Considering the loss factor mentioned in the preceding paragraph and the temperature that will meet the copper tubes of the exchanger, the useful heat transferred to the domestic water in the process is applying (9) Qu = 1680W -19.6W .

Within this result, the second term corresponds to losses in focus. It can be seen that the losses due to the type of exchanger are in the order of 1.16%, considerably low taking in account that we applied a mean temperature value in the exchanger tubes of 150 °C, this being a conservative value. Finally, we conclude that we have applied to the process fluid an amount of energy of 1660W. The energy value obtained is comparable with the one of domestic water heaters.

Although we can found thermo tanks or water heaters specifications with over 10,000 W, this is because in such cases it is much energy applied in shorter times to achieve the desired temperature difference. Latter responds to sudden changes in demand and decreases the total energy used. In this case, the power output will be applied constantly during daylight hours, or while favorable weather conditions exist. The energy obtained is then transmitted to the sanitary water to increase its temperature and then be used.

The desired temperature output at the end of the calculation was set at 40 °C, which is a standard measure of consumption. The inlet temperature is taken at 10 °C, which is a representative value and conservative as in favorable conditions it may be higher. Finally, the maximum temperature reached by the fluid inside the storage tank is 70 °C and this value will also limit the system operation.

In order to simplify the calculations and obtain representative values that demonstrate the technical feasibility of the proposed system, we considered that water heating is performed in the absence of demand from the mentioned initial temperature. Therefore, it has an inventory of water to which solar energy will be applied without the use or replacement of it until it is completed the solar utilization. This consideration would represent the case of a family who leaves home in the morning and returns in the afternoon / evening, thus providing hot water when they arrive at home. Moreover, the specific heat of water is considered constant along the temperature range expected in use.

Then it is calculated the required time needed by the total volume of water stored to go from the inlet temperature (10 °C) to the output desired temperature (40 °C).

For this, it is used the equation (4) and the ratio W and Joule, yielding a time of 3hrs 9min. It is concluded that it is possible to heat the water reserve proposal (150 liters) needed to meet the needs of a town house type , carrying water from 10 ° C to 40 ° C at least in less than a solar day . This analysis is valid in a first step for the central region, in which the solar resource map provides 4.19 hours/day of use during the summer and 3.352 hours/day in winter, both with a constant $H=1000\ W/m^2$. [8].

We calculate the maximum system operation period in the absence of demand, using the equation Q = mc At , on the final temperature Tf = 70 ° C , then we get 37,656,000 W. Taking into account the relationship again Joule/W it has to be long enough 6h 18min . In conclusion we can say that the time required to reach the maximum temperature condition in the water heater exceeds the available solar time resource in any of the latitudes of the Argentine territory. However, one must consider that this time is decreased if the initial temperature is higher than the proposed 10 °C. This may be the case where there is a remaining quantity of hot water from the previous day in the tank, so that the initial temperature will be considerably greater . Therefore, there will be a temperature control loop , according to the accumulated temperature in the thermo tank that will regulate the operating time of the circulation pump, thus controlling the amount of energy delivered to the fluid, ensuring that it does not exceed the proposed maximum temperature of 70 ° C.

4. 1 Heat exchanger. Boiler.

The design of the heat exchanger located at the focus of the receiving antenna will have exterior dimensions obtained from a geometric analysis, taking into count the incidence of solar rays, according to the data sheet from the manufacturer of the receiving antenna. Because it is a parabolic concentrator, it is possible to achieve temperatures above 150 ° C in focus, so it will be necessary to guide the design to a vacuum device, in order to reduce losses. Not all captured energy is used to heat the desired fluid and which one party irrevocably lost heat to the outside air that is in contact with the collector (conduction and convection) and some is lost by radiation because when the collector temperature rises, it issues with more energy than the environment in which it is being caused losses in that regard.

Within the exchanger, absorption tube is a component designed to absorb energy and transfer it to the water available. It will be used for the design copper, whose thermal conductivity is greater than 125 W/m°C and has a greater than 0.9 absorptance, working with

0.2 mm thickness. The finish will be given to the tube is black paint, also for better absorptance . The proposed geometry brings about 0.15 m^2 of area transfer which is generated by the helical shape of a shaped tube , with the existence of welds and accessories, only found on the input and output connections . It has a cover of transparent material (glass) mounted in front of the absorber, in the upper part of the collector, creating a space (20 to 25 mm) between the absorber tube and it. It was selected tempered glass 5 mm thick as the cover material. It has better resistance to thermal shock and has greater resistance to mechanical impact and flexural strength, besides having good conditions for reflection and transmittance. (Figure 4)

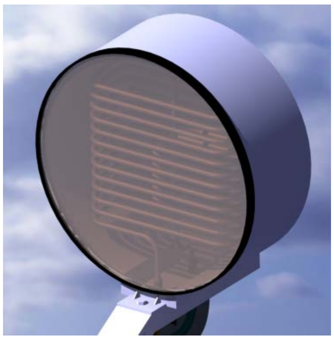

Figure 4. Heater exchanger.

Completing the design it was dimensioned the solar collector base. This structure (Figure 6) is one of the most important aspects of the proposed design. This structure will support the collector antenna, the tracking system, and the heat exchanger located at the focus. Moreover, inside this base are located all the devices that integrate the proposed solar harvesting system. These are: energy storage tank, instantaneous water heaters (1 gas unit and 1 Electric unit), the recirculation pump, a programmable controller, instrumentation, necessary valves and pipes with their insulation. (Figure 5)

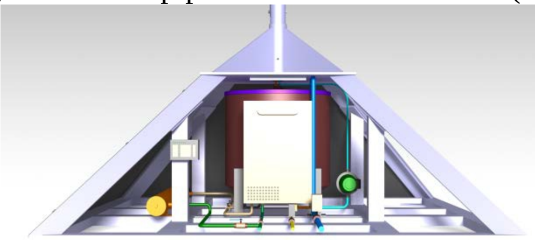

Figure 5. Base structure with components.

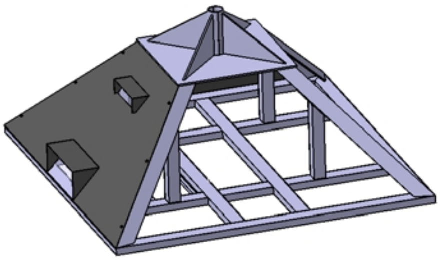

Figure 6. Tubular structure

The complete system design can be observed at Figures 7 and 8 that includes the electric heater and the Gas Thermo tank.

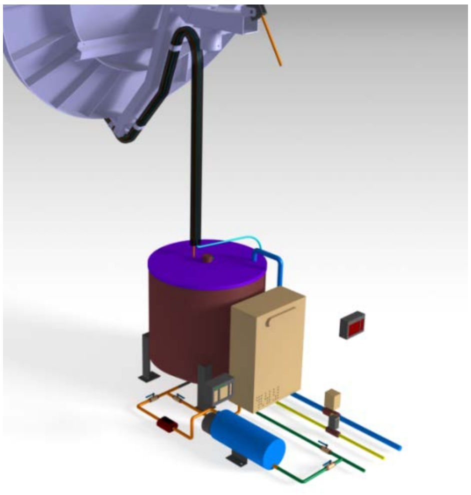

Figure 7. System components

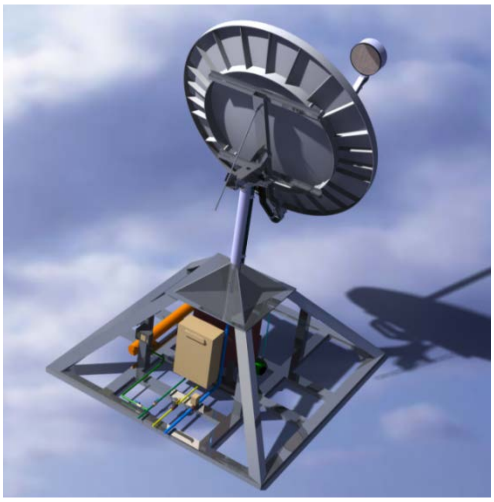

Figure 8. Structure and components.

Water storage tank is proposed with a capacity of 150 liters . While it could be selected any standard tank , the available spaces in the structure of the system are very particular, so a dedicated design is proposed . It will be constructed of stainless steel as it will be in direct contact with the sanitary hot water. It will be consisting of a main body and a lid which can be removed for cleaning the interior. At the top it will have three holes, one for the cold water inlet from the outside, another for the hot water return from the heat exchanger located at the focus and the last for the insertion of the level sensor, which will be detailed later. At the bottom it will be three more holes, one for the suction pump, one for hot water output to the consumer and one for the insertion of a temperature sensor.

One of the main features that should have this tank is the ability to store energy, this is achieved through the insulation to be placed on its outer surface. It is proposed one industrial type called Pyrogel XT, which has a high insulation capacity at low thickness of insulating material.

To complete the design, conventional heating systems should be selected to allow uninterrupted service.

The selected heaters will provide the energy needed to bring the water temperature in the accumulator tank to 40 ° C in order to satisfy proposed demand of 4 people per day, which may be estimated at 150 liters/day of CSW. Sometimes, it will be not necessary to involve them, because as it was demonstrated in the energy balance, the system has the ability to heat the entire inventory of proposed water to the desired temperature. However, we consider the extreme case where the proposed hybrid system will only work with electrical or gas energy input, such would be the case of a few consecutive rainy days.

It is noted that the proposed system, although it has two types of heaters (electric and gas), it can use only one of these sources for the extra energy needed. Namely , it is installed to operate at gas or electric mode, the former being preferred because it is the most economical among the two, mainly if natural gas is available .

For the two heaters, modulating control will be applied to optimize energy use in terms of demand. On this purpose it has a controller, actuators and necessary instrumentation to be described later.

In the case of a gas heater, the selected is one of the BOSCH brand, 660EFO model. It is adapted to the dimensions of the structure and the gas outlet is oriented conveniently for the raised design.

For the electric instantaneous water heater the selected is one of the industrial type WATLOW brand, model CBDNF29R5S , Circulations Heaters Series. It is basically an insulated steel tube containing a power resistance , which will provide the heat necessary to meet the demand . As shown in the table below, the heater type selection is mainly based on the power size of the electrical resistance contained therein. With this data we obtained after the main dimensions of the selected heater

To select the power , we used the calculation proposed by the supplier , in which we introduced the process conditions/use and it is obtained a good estimation that will serve for the selection of the suitable heater (Figure 9)

For Heating Flowing Water

Use equation:

kW = GPM* x temperature rise (°F) x 0.16

OR

kW = liters/min. x temperature rise (°C) x 0.076

Figure 9. Proposed formulas

In this case, again taking into account the most unfavorable condition , this is the inlet temperature at 10 ° C , have an increased temperature of 30 ° C. Moreover, the flow required to satisfy a standard housing is 4 liters / minute. Is then obtained 4 (liters/min) . 30 (° C) . 0.076 = 9.12 kW.

Then the heater is selected (Table 2) , whose maximum power is 10.5 kW, which will give us the worst condition a rate of 4.6 liters / min .

Table 1. Instant electric heater selection table

Description	Volts	kW	Ph	# Circ.	Code Number	Del.	Ship Wt. lbs (kg)	"A" Dim. in. (mm)	"B" Dim. in. (mm)	"C" Dim. in. (mm)
1¼ inch NPT Screw Plug (FIREBAR)										
90 W/in²	240	1.5	1	1	CBDNF7R10S	RS	26 (12)	24⅝ (625.5)	15 (381)	3⅛ (79.4)
Steel Tank	480	1.5	1	1	CBDNF7R11S	RS	26 (12)	24⅝ (625.5)	15 (381)	3⅛ (79.4)
1-Incoloy®	240	3.0	1	1	CBDNF11G10S	RS	26 (12)	24⅝ (625.5)	15 (381)	3⅛ (79.4)
Elements	480	3.0	1	1	CBDNF11G11S	RS	26 (12)	24⅝ (625.5)	15 (381)	3⅛ (79.4)
(14 W/cm²)	240	5.0	3	1	CBDNF16G3S	RS	26 (12)	24⅝ (625.5)	15 (381)	3⅛ (79.4)
	480	5.0	3	1	CBDNF16G5S	RS	26 (12)	24⅝ (625.5)	15 (381)	3⅛ (79.4)
	240	6.5	3	1	CBDNF19G3S	RS	30 (14)	32⅝ (828.7)	23 (584)	3⅛ (79.4)
	480	6.5	3	1	CBDNF19G5S	RS	30 (14)	32⅝ (828.7)	23 (584)	3⅛ (79.4)
	240	8.5	3	1	CBDNF24L3S	RS	31 (14)	32⅝ (828.7)	23 (584)	3⅛ (79.4)
	480	8.5	3	1	CBDNF24L5S	RS	31 (14)	32⅝ (828.7)	23 (584)	3⅛ (79.4)
	240	10.5	3	1	CBDNF29R3S	RS	43 (20)	42⅝ (1082.7)	32 (813)	4⅜ (111.1)
	480	10.5	3	1	CBDNF29R5S	RS	43 (20)	42⅝ (1082.7)	32 (813)	4⅜ (111.1)

4.2 Control System

To automate the use of the solar power system designed, it is proposed to use a Programmable Logic Controller (PLC) . The proposal is that the system contains a number of sensors and actuators and control logic that can perform one of these Controllers. The main idea is to centralize all control logic on a single device, both for the operation of the system described in this paper , as for the solar tracking system, that will have the receiving antenna. On this purpose, we studied the quantity and type of inputs and outputs required , as these are the most important variables when selecting the PLC . Moreover, as this is a prototype , it is interesting to have this type of controller as it offers favorable characteristics for the study of process behavior , such as historical data , possibility of raising the process information in real time, the possibility of applying preset modes as PID loops, analyzing their behavior and so on.

Below are the different inputs and outputs necessary to perform the control logic that will automate the proposed system :

1 Thermo resistance Input: accumulator tank temperature signal

1 Digital Input: Fluid Outflow hot water)

1 Analog Output: Modulating electric power applied to the instant heater resistance

1 Analog Output: Modulating Gas flow used in instant heater .

1 Thermocouple Input: temperature Signal at the exchanger focus.

1 Relay Output: pump start .

1 Relay Output : to open/close external cold water inlet solenoid valve .

1 4-20 mA Analog Input: accumulator tank level indicator signal.

It is estimated to be needed 2 digital inputs for position sensors and 2 digital outputs for actuators of both degrees of freedom.

With these estimated needs, we selected a suitable PLC for this Project.

5. Costs

To calculate the mortgage period of the set, we will compare the current thermo tank values (electric and gas) adequate for the same demand considering energy costs by type (electric or gas) with current market values .

We conducted a survey of the costs (Table 3) of each of the components of the proposed energy harvesting system .

In cases where the components are to be built by order such as the base structure , the exchanger vacuum sealed radiation and the accumulator tank , we considered the cost of the raw materials needed and the cost of skilled labor to build them.

Table 3. Current Cost of the proposed Solar System Components

DESCRIPTION	Cost (U$D)*
Receiving antenna	$ 650,00
Recirculation Pump	$ 120,00
Electric Heater	$ 300,00
Gas Heater	$ 450,00
Energy storage tank (insulated)	$ 150,00
Radiation heat exchanger vacuum sealed	$ 160,00
Base Structure (profiles + labor)	$ 700,00
PLC CPU module	$ 220,00
PLC Analog Input Expansion Unit	$ 150,00
PLC Analog Output Expansion Unit	$ 155,00
Electric Modulation Control Relay	$ 250,00
Modulating Gas Control Valve	$ 150,00
Capacitive Level Meter	$ 90,00
Flow Meter	$ 50,00
PT- 100 for Tank	$ 90,00
Thermocouple for Focus	$ 90,00
Water solenoid valve input	$ 30,00
butterfly Valve	$ 10,00
Pipe 1/2 ' isolated	$ 12,00
DC supply sources	$ 75,00
Cables	$ 10,00
AEROLINE insulated copper pipes (double run 4 meters)	$ 100,00
TOTAL COST (USD)	$ 4.012,00

Then we obtained the standard costs of both heater types ; Electric and Gas for the same water demand. (Table 4)

Table 4. Current Costs of Conventional Water Heaters

Current values for Standard Water Heating Equipment	
DESCRIPTION	**Cost (U$D)**
Electrical Thermo Tank	$ 550,00
Gas Thermo Tank	$ 450,00

6. Final Balances

As obtained in the energy balance, the proposed system achieves the heating water volume of 150 liters from an initial temperature of 10°C to 40°C , in a time of 3h 09min with the solar constant of 1000 W/m2 . This time verifies the system implementation while used in the central region , meeting the hot water consumption of 4 people in a day without the need to provide energy from other sources, such as gas or electricity . Because the proposed system is a forced circulation type , electrical and electronic components has to be energized during operating hours. Moreover conceptually it has to be considered defective insulation losses , since it is not an ideal adiabatic system .

Table 5: Energy Balance for Conventional Heaters

Component Consumption and considerable losses (W)	
Recirculation pump	75
Controller, Instrumentation and actuators	15
Defective insulation losses	< 5
Total (W)*	95

*At this stage the power needed for the solar tracking system will not be considered.

The balance is made general and oriented only to harnessed solar energy. The balance, however, do not contemplate the electrical power needed to operate the system. Although this achieves to heat the water inventory in the proposed time period, it is related to the solar constant used.

It is important to consider that to receive the total daily energy, the system must be active along the whole usable solar day. The proposed base operating time is 8 hours/day, excepting the intervals at which it is detected that the energy collected is less than the minimum to be established empirically, with actual measurements from the prototype. Then the basic operating time will be used to quantify the electrical energy required per day to let work the proposed solar harvesting system.

The proposed system requires per day 95 W x 8 hours = 760 Wh or 0.76 Kw.h of electrical energy for operation. Comparing the results, the proposed system does not totally disregard power for operation. It provides a savings of 87% of this energy, related to that required to heat the same inventory of water under the same conditions through an electric heater (5.81 Kw.h).

The percentage obtained is a good indicator of the importance of making the proposed solar harvesting system.

7. Conclusion

Based on the proposed design, it has been proved that is possible to build an autonomous compact system that allows heating the proposed water reservoir (150 liters , about 40 l/human/day) needed to meet the requirements of a town house type, bringing the water from 10 °C to 40 °C at least in less than one solar day . Therefore, this system is ideal to be used in places where there is no prior infrastructure for obtaining hot sanitary water. The system requires minimal maintenance, the same needed by a conventional system, without having a prior training. The complete installation can easily be mounted "in situ", since in the case of having no other power source than the sun, the structure can be simplified by removing unnecessary components. In this way it is only need to connect the cold water inlet and hot water outlet. In case that it will be used as a hybrid system, it would be needed in addition, a connection to the gas and/or power supply. It is under development a complementary economic feasibility study.

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