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Economical and Technical Viability of a Thermosyphon Solar Water Heater in Côte D' Ivoire

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Abstract: We propose a comparative study between solar water heater energy and classical sources of domestic hot water production. This study shows that Solar Water Heater (SWH) could be more competitive if the purchase price was reduced. In order to strengthen local technical capacity, to accelerate dissemination and insure appropriation of SWH technology as well as to stimulate acceptance of other solar technologies in Côte d'Ivoire, we propose an innovated design of a thermosyphon solar water heater, using available local materials in order to reduce cost. A prototype of the study SWH has been built and tested experimentally. The results show that the system is suitable for application in Côte d'Ivoire weather conditions. All those performances, combined with manufacturing simplicity and the absence of moving parts, make the system an interesting technological solution. The results can then be used for the dissemination of the system. The economic study confirms the viability and the real potential market of the locally manufactured SWH. The purchase cost is 2.0 times lower than the imported ones.

Key words: Solar water heater dissemination, thermosyphon, useful energy, thermal performances, efficiency

INTRODUCTION

Côte d'Ivoire, where this study is performed, like most Sub-Saharan African countries, has a high annual sunning rate (Sako *et al*., 2002). The solar water heater, consequently, seems to be a viable alternative to conventional fuels or electricity for the production of domestic hot water in these countries.

The solar water heating system most used for the domestic needs is the thermosyphon solar system with natural circulation. It is one of the most interesting technological device, the simplest and the most largely widespread of solar energy exploitation. Its remarkable effectiveness coupled with the simplicity in its design, autonomy of operation, the minimization of its maintenance makes it an interesting alternative to the system using an auxiliary pump. It is made of a collector, a storage tank, connection pipes and a data acquisition chart. The collector is composed of a plate reflector, a series of riser and header tubes, a glass cover, an envelope and a heat insulation system. To avoid the use of a circulating pump, the collector must be positioned at a lower level than the storage tank in order to allow a convective thermal loop between the exchanger of the storage tank and the collector. Thus, when the sunbeams strike the collector surface, the density of the fluid in the collector becomes lower than that contained in the exchanger. The hot water of the collector goes up into the exchanger and the cold water of the exchanger goes down into the lower header tube (Andoh *et al*., 2007).

A large number of experiments were conducted around the world to predict the performance of thermosyphon SWH (Hussain, 2006; Joudi, 1999; Kalogirou *et al*., 1999; Karaghouli and Alnasser, 2001; Nahar *et al*., 1995). The studies show a difference in performance due to different designs, manufacturing materials and weather conditions. In spite of the fact that Cote d'Ivoire weather conditions are suitable for the use of SWH, it is not applied due to the following reasons. The first being the availability and low initial cost of electric water heaters (Moulot and Sako, 1999) and the second reason being the lack of knowledge among public and households about the application of solar energy.

This study aims to outline first the results of the experimental thermal performance test of the system carried out locally (in Yamoussoukro, 6.54°N of latitude)

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in order to demonstrate its applicability so as to encourage it wide use in the country. The second objective is to outline an economical comparative study between the SWH designed and the conventional energy sources water heaters (electricity and natural gas) to show its economical viability.

MATERIALS AND METHODS

Solar energy resources in Côte d' Ivoire: Côte d'Ivoire lies within a tropical region and hence experiences a tropical climate. The country has two main distinct seasons: the rainy season (from March to August) and the dry season (from November to March). The other months are the boundaries of the two seasons. The temperatures throughout the year respectively range from a minimum average of 22°C to a maximum average of 32°C. The average experiences between 5 and 8 sunshine hours per day. This gives an annual average solar insulation of about 5.0 kWh m^{-2} day^{-1}, with a peak of sunshine being received between March and April, according to regions (Tiéné, 2004) and the SODEXAM reference (Seka, 2001). The map in Fig. 1 shows the three main climate zones.

From the information provided, it is obvious that Côte d'Ivoire as a whole is well endowed in terms of Solar Energy Natural Resources and these are adequate for any type of application. The climatic conditions do not in anyway hinder the utilization of Solar Energy. In the rainy season, cloud cover may affect the effective utilization of Solar Energy while in hot seasons. The extreme heat affects the efficiency of solar collectors. But these factors do not over shadow the benefit derived from the use of Solar Energy.

Comparative study: There are less than five solar device companies in Côte d'Ivoire. It is only worth emphasizing that there is no local assembling nor manufacturing of SHW systems. All companies in the SWH business are distributors for foreign made components.

Despite the real need for hot water across economic groups and geographical boundaries, there is little use of SWHs in the country at the moment. Reliable statistics do not really exist and only a rough estimate can be made on the quantity of SWH installed in the country. Based on the Ministry of Planning and Development data, imports of SWH nearly doubled every year between 1993 and 1995. These statistic data are decreasing now because of the high purchase cost and a lack of a dissemination policy. The comparative study below shows life cycle costs between three Energy sources.

The thermal system is used to produce hot water, but the problem of cost remains. To illustrate this purpose, we made an economic analysis of imported Solar Water Heater versus electric and gas energy for a system with 200 litres storage capacity (Fig. 2).

The difference of cost between the three energy sources is well illustrated on this graph. Solar energy is more profitable than Electricity after 7 years and after 16 years in comparison with gas, whereas its life cycle is about 15 years. The high cost of solar collectors is the

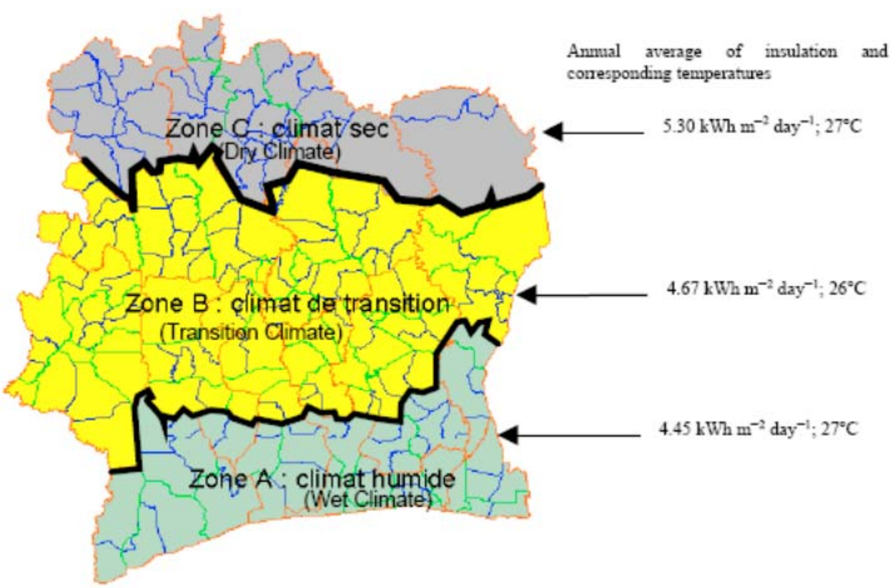

Fig. 1: The three main climate zones in Côte d'Ivoire

best explanation. The sale cost of solar systems must decrease at about 60% to be more profitable than gas used in three years (normal pay back period). The Fig. 2 also shows that the sale costs of SWH are way beyond the average income of most Ivorians. Despite the long pay back period and the high sale cost, the advantages of SWHs are as follows:

- They can facilitate energy saving.
- They are more environment friendly than firewood.
- They also require less safety measures.
- The possibility of rural development improving.

The following statements explain the higher price of Solar Systems:

- Higher duties.
- SWH not manufactured locally.
- Problem of efficiency in relation with work temperature.

A previous study of Moulot and Sako (1999) shows that locally manufactured low cost SWH company can arguably target at 25 to 30% (economical, medium standing and good standing houses) of the housing market, which represents approximately 1500 to 1800 houses a year not including hotels and hospitals; which are also potential costumers.

For these reasons, we purpose a SWH manufactured locally, using low cost local materials.

Experimental set up: The experimental system is manufactured in the Mechanical and Energetic Engineering Department, based in Institut National Polytechnique Félix Houphouët Boigny. The main parts of the system are the collector and the hot water storage tank, as shown in Fig. 3.

The system consists of a 2 m^2 flat plate collector, with a 10° angle from the horizontal, so as to receive the Maximum solar radiation, a thermally insulated horizontal storage tank of 95 L and interconnecting piping. The black painted tubing grid is spaced at 60 mm with 12 mm external diameter pipes brazed to 24 mm diameter copper tube manifolds. A 5 cm thick glass-wool (thermal conductivity: 0.04 W m^{-1} K^{-1}) is used to insulate the casing. It is placed on the back pan and around the sides. An aluminium foil is attached to the insulation to reflect the emitted heat

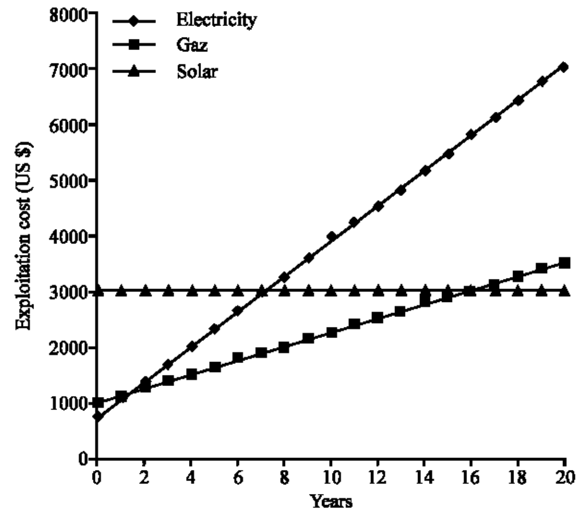

Fig. 2: Comparative life cycle costs for electric, gas and imported SWH

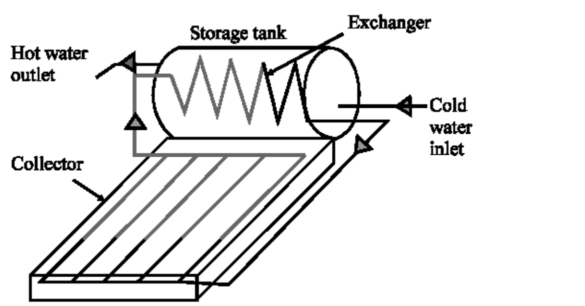

Fig. 3: The natural circulation type solar water heater

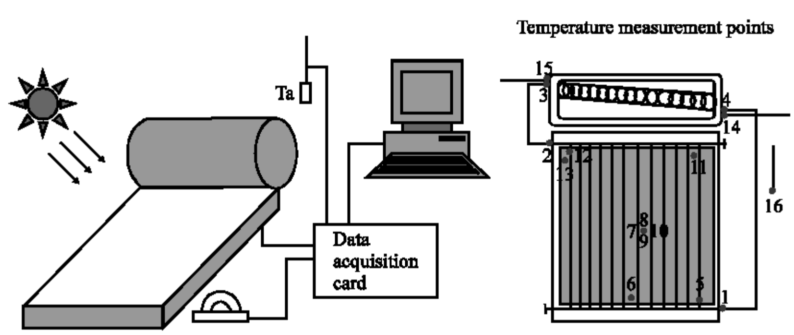

Fig. 4: System schematic diagram and measurement points position

radiation back to the absorber. The collector cover is made of 4 mm glass plate, which is attached to a galvanized steel frame. The thermosyphon system relies on the natural convection of hot water rising from the collector to carry the heat up to the storage tank. When the collector heat is transferred to the water, that water becomes less dense than the one in the storage tank. Hot water is pushed through the collector and enters the top of the hot water storage tank at higher temperature and cold water from the tank simultaneously descends to the bottom of the collector.

Test procedure: The measurements relate mainly to the global insolation and the collector temperatures in 16 points (Fig. 4) and also to the storage tank and the connecting piping temperatures. The measurements have been done from August 2004 to January 2005.

The total incident solar radiation on the collector plane is measured using a Kipp and Zonen CM 10 pyranometer. It is connected to a numerical integrator, allowing the reading of instantaneous power and energy received, by digital display, over a given period. The pyranometer is placed in an horizontal position to receive the global solar radiation. The relative error on the measures is ±2%.

To avoid perturbing fluid flow, probes of low dimensions made of diode 1N4148 with silicon of 1.6 mm diameter, of ±0.5°C precision, are used. All the probes used for measurements are calibrated. The probes are mounted as shown in Fig. 4.

Data are collected for several sunny and cloudy days. The storage tank remains filled during the day.

RESULTS AND DISCUSSION

The thermal performance of a flat plate solar collector may be expressed in the form of a linear performance characteristic, relating the rate of useful heat output per unit aperture area (E_u), the solar radiation input (I_c) and the heat losses.

$$E_u = I_c A_c(\tau\alpha) - K_c A_c(T_p - T_a) \quad (1)$$

(A_c: Absorber area in m^2; T_p: Average absorber plate temperature in °C; T_a: Ambient temperature in °C)

The instantaneous efficient ç of the collector is defined as the ratio of useful heat gain (E_u) delivered per unit area to the solar radiation intensity (I_c).

$$\eta = \frac{E_u}{A_c I_c} \quad (2)$$

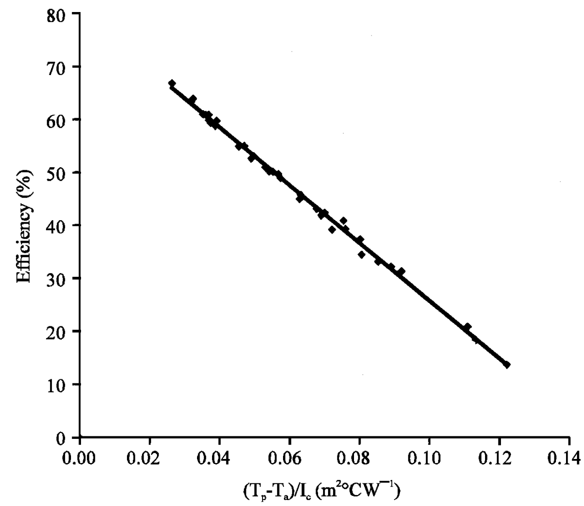

Fig. 5: The instantaneous efficiency of the solar collector

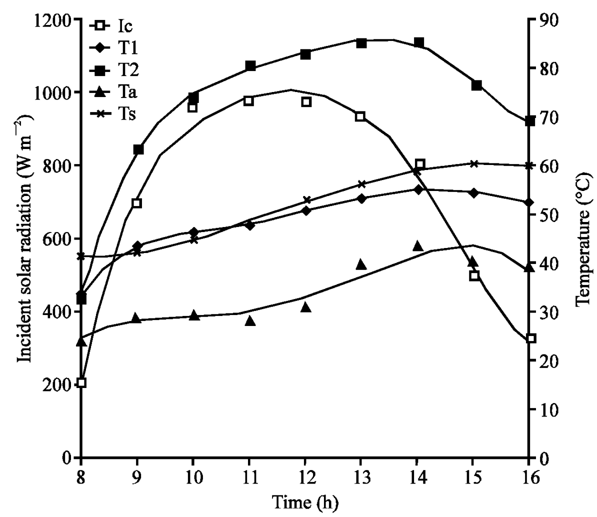

Fig. 6: Hourly variation of temperatures for a sunny day

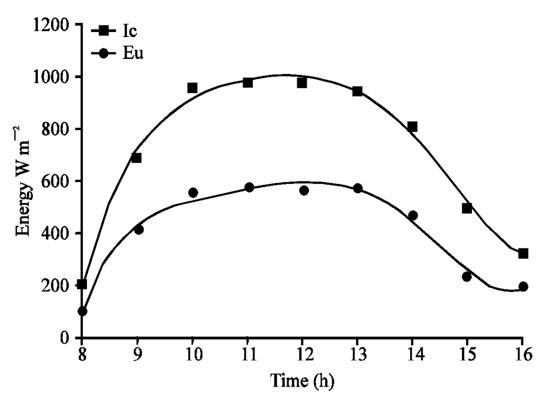

Fig. 7: Hourly variations of solar radiation and useful energy for a selected sunny day

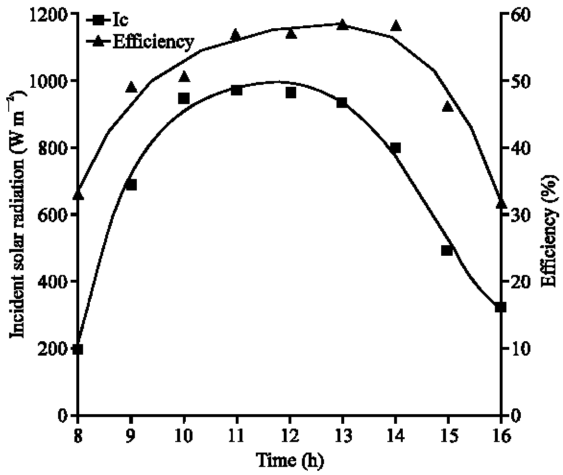

Fig. 8: Hourly variations of collector efficiency and insolation for a sunny day

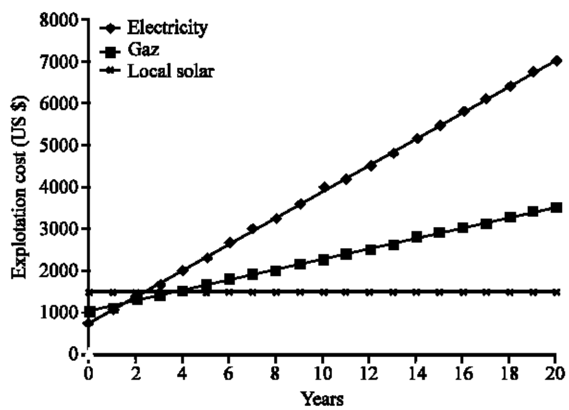

Fig. 9: Life cycle costs for electric, gas and locally manufactured SWH

The collector's instantaneous efficiency is influenced by several factors such as: the used materials, the absorber design, the glass properties, the weather and the operating conditions. According to Karaghouli and Alnasser (Karaghouli, 2001):

$$E_u = F_p[I_c A_c.\tau.\alpha - K_c A_c(T_p - T_a)] \quad (3)$$

$$\eta = F_p.\tau.\alpha - \frac{F_p K_c(T_p - T_a)}{I_c} \quad (4)$$

(F_p: Heat removal factor; τ: Transmittance of glazing; α: Collector plate absorbance)

According to Sfeir and Guarracino (1981) F_p value is function of temperature T_p used in Eq. 4. In this study, the temperature measured is the absorber's temperature. In this case, $F_p = 1$.

The efficiency curve of the experimental flat plate solar collector is shown in Fig. 5.

As expected, the instantaneous efficiency decreases as the ratio of temperature differences to insolation increase. These results are in good agreement with those of Pierson and Javelas (Pierson and Javelas, 1983), those of Karaghouli and Alnasser (2001).

The experimental data give an optical efficiency of 0.797, which is in well accordance with Sfeir and Guarracino (1981).

For a thermal system, it is important to know the quantity of energy received and its distribution in the time. The hourly global solar radiation at the 10° angle collector from the horizontal, the inlet collector temperature, the outlet collector temperature, the ambient temperature as well as the storage tank temperature, for a sunny day, are shown in Fig. 6.

As one can expect, the temperature values grow with the solar intensity to reach their maxima in the middle of the day; then they drop with the global insolation falling to reach their minima at night.

These results show also that the temperature of the water in the storage tank is higher than that of the hot fluid at the collector outlet, at the beginning and at the end of the day, allowing a circulation in opposite direction for the thermosyphon cycle. These results show the ability of the system in providing hot water suitable for household use under such weather conditions. The storage tank water temperature reached 60°C (at 4:00 pm) before sunset.

From the experimental values, the useful energy and the instantaneous efficiency are shown in Fig. 7 and 8.

The amount of useful energy and the incident solar radiation for the same sunny day are presented in Fig. 7. The insolation increases until it reaches its maximum (1000 W m^{-2}) between 11:00 am and 12:00 am, then it begins to decrease. The useful energy follows the same pattern. The difference between the incident energy and the useful energy represents the collector thermal loss.

The collector efficiency, which is the ratio of useful energy to solar radiation, should follow the same trend as the insolation and useful energy. It increases during the morning hours to reach a maximum of about 58.62% at around 1:00 pm and then decreases. That is shown in Fig. 8.

This result is a very good one compared to those of Soteris *et al.* (2000) and Karaghouli and Alnasser (2001) which are 50%.

A new economic analysis of the solar water heater designed locally versus electric and gas for a system with 100 L storage tank is made (Fig. 9). The results were obtained by using the current gas and electricity rates and a 20 years period. The approximate unit sale value of the SWH is estimated to US $1500. According to this graph, solar water heater becomes more profitable than electric one less than three years and about four years in comparison with the one using gas. These results are better than those obtained with imported solar water heater which are respectively seven years and sixteen years for electric and gas water heater. After three years the solar system gives much lower specific energy costs than electrical system. So the SWH locally manufactured using local materials allows reducing the cost.

CONCLUSIONS

Surprisingly, up to now, no local industry deals with the manufacturing of Solar Water Heaters. The main barriers to the dissemination of SWH nationally seem to be cost rather than trust in the technology, which, as shown in this study is relatively simple. Tools and man power are the same as the one found in many metal shaping shops.

The experimental results of the performance test presented above show that the system reaches an efficiency of 50%, with hot water average temperature above 55°C. These results prove that the system is suitable under the weather conditions in Côte d'Ivoire. These performances added to the relative simplicity of the system manufacturing and the absence of moving parts; make it an interesting technological solution. The approximate unit sale value of the SWH locally manufactured is US $1500. This cost is 2 times lower than the imported ones, which shows the economical viability of the SWH locally manufactured. The building market for individual housing hospitals and hotels also shows that there is a real potential for the success of a low cost of manufactured SWH in Côte d'Ivoire.

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