Performance improvement of large-scale solar water heating systems by using remote monitoring

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Abstract This work focuses on the study of real performances of a collective solar water heating system using the remote monitoring technique in Algerian climatic conditions. This is to ensure proper operation of the system at any time, determine the system performance and to check to what extent solar performance guarantee can be achieved. The measurements are performed on an active indirect heating system of 12 m² flat plate collectors surface installed in Algiers and equipped with a various sensors. The sensors transmit measurements to a local station which controls the pumps, valves, electrical auxiliaries, etc. The system provides a yearly solar yield of 6277.5 kWh for an estimated annual need of 7896 kWh; the yearly average solar cover rate amounted to 79.5%. The productivity is in the order of 523.13 kWh / m²/year. Simulation results are compared to measured results and to guaranteed solar performances. Remote monitoring shows that 90% of the expected solar results can be easy guaranteed on a long period. Furthermore, the installed remote monitoring unit was able to detect some dysfunctions. It follows that remote monitoring is an important tool in energy management of some building equipment.

Keywords: Large-scale solar water heater, real energy performance, remote monitoring, solar performance guarantee, solar thermal energy.

1. INTRODUCTION

Algeria is not only a significant hydrocarbons producer and exporter but also holds a very high solar potential. Direct solar irradiance reached an average more than 3000 hours of sunshine / year (CDER, 2014; Sahnoun et al., 2013). Moreover, there are no restrictions in space available due to wide desert areas. The large space combined with the abundant solar resources has made Algeria one of the promising areas for substitution of fossil energies by solar energy and particularly for installation of solar energy plants for producing electricity and heat. Over the past ten years, socio-economic development and increasing urbanisation generate a high demand for electricity and natural gas, about 10% growth per year (MEM, 2013; Sonelgaz, 2011). The housing sector is very energy intensive, more than 40% of electricity consumption. Due to this strong demand and declining reserves conventional energy and their impact on the environment, the country focused on renewable energies promotion. In recent years, political support for renewable energy has been growing continuously. A legislative and regulatory framework has been promulgated and the country adopted an ambitious program of renewable energy and energy efficiency development (MEM, 2011). With this program, electricity production will be 40% of solar origin to 2030. The achievement of this program will also contribute to reducing GHG emissions by about 300 MT CO₂ eq. in 2030 (Sahnoun et al., 2015). In the field of energy efficiency, the actions planned by the program focus, in particular, on the housing sector. Proposed measures include the development of individual and large-scale solar water heating systems (SWHS).

Solar thermal systems available today provide reliability, efficiency and significant environmental benefits (Houri et al., 2013; Shukla et al., 2013; Jaisankar et al., 2011). In housing, they can satisfy the hot water demand and reduce energy bills by 60% or more. Additionally, collective systems or large-scale solar thermal systems are increasingly used in different conditions for hot water applications and space heating in hotels and multi-family homes, hospitals, nursing homes and sport halls as well as in commercial and industrial building (Boehm, 2013; MSAA, 2009; IEA, 2008; Karagiorgas et al., 2001). The importance of water-based solar thermal systems is reflected in the increased development of installed capacity. By the end of 2012, the number of systems in operation worldwide is about 78 million corresponding to a total of 384.7 million square meters of collector area. In the year 2012, the newly installed capacities amounted worldwide to 75.3 million square meters. This means an increase of 9.4% compared to the year 2011 (Mauthner et al., 2014; REN 21, 2013). The distribution by kind of application (Figure 1) shows that 79% of the total installed capacity were used for domestic hot water preparation in single family houses, 9% were attached to larger domestic hot water systems for multifamily houses, hotels, etc. and 8% were used for swimming pool heating. Around 4% of the worldwide installed
capacity are solar combi-systems that supply heat for both domestic hot water and space heating. The share of large-scale domestic hot water applications tends to increase more rapidly than other kind of systems. They represent 9% of total capacity but 17% of newly installed capacity in the year 2012 (Mauthner et al., 2014).

In Algeria, currently installed surface of collective or large scale systems does not exceed 200 m². Neighbouring countries such as Tunisia and Spain have capacities of 14,063 m² and 1,422,156 m² respectively (Mauthner et al., 2014). This lack of enthusiasm for thermal solar equipments and market weakness in Algeria, is mainly due to lack of experiences for collective systems and feedback about the real performance of existing systems.

There is an abundant and well-documented literature on the individual domestic solar water heaters but much less on collective systems and the implementation of solar performance guarantee. Particularly, in-situ real performance data for collective SWHS has not been extensively outlined. We often meet cases, especially for collective systems, where measured real performance is lower than expectations (Parker, 2003; Hernandez et al., 2012). Some studies report cases of low efficiency and wide discrepancies between expectations and the real operation. The solar output for hot water can be 30% less than expected during design (Wall, 2006; Thomsen et al., 2005).

The approach focused on quality has been tested in recent years in some European countries where manufacturers have developed a solar performance guarantee (IEE, 2008). This guarantee agreement between the customer and the manufacturer must include a monitoring and control on-site of results. The control can be performed by remote monitoring (Sahnoune et al., 2012; IEE, 2008). The need for monitoring is explained by the fact that an unsupervised installation may consume more energy than it generates. Through the auxiliary, we have energy, but solar generation system may be out of service for a long time before anyone noticing. The use of remote monitoring allows to measure the actual energy supplied by the solar heating system and to ensure conformity to expected or guaranteed energy performance.

In order to support the promotion of solar water heating use, we focused in this work on monitoring over on long period of energy performance of a collective SWHS in local climatic and environmental conditions (relatively high humidity and dust pollution). For this purpose, we use for the first time in Algeria the technique of remote monitoring to show that collective systems technology can provide excellent performance in Algerian climatic conditions and manufacturers can guarantee the solar results of their systems.

2. DESCRIPTION OF THE IMPLEMENTED SOLAR WATER HEATING SYSTEM

An integrated system composed of large-scale solar water heating system and a remote monitoring unit to control solar energy performances was designed, implemented and installed in a building in Algiers (latitude 36°7′N). It is an active indirect (closed looping) heating system where the heat transfer fluid is circulated through the collector and rejects heat through a heat exchanger to the water in the storage tank. This system is no sensitive to freezing conditions and could provide hot water of higher temperature than open system. The installation requires a set of measuring instruments connected to a central data acquisition. About the web connection, we can access to all collected data.

The solar water heating system consists of 12 m² surface of flat plate collectors, two solar storage tanks each with 300 l, an immersed heat exchanger, 200 l auxiliary storage, two circulating pumps, one primary and one secondary and a pulse emitter flow meter. In order to collect and deliver heat efficiently, an active control system regulates the flow of the heat transfer fluid. The primary pump of the solar system is controlled by a photoelectric cell. The pump turns on in the morning and stops in the evening. The secondary pump, that is servo operating with the primary pump, is controlled by a differential controller which compares the difference between the collector inlet temperature at the bottom of solar storage, and the collector outlet temperature of the
water at the top of the storage tank. If the difference is positive, the pump is activated. The pump is turned off if the solar radiation level falls below the level required to maintain a positive differential. The installation is also provided with an expansion vessel as overheating protection and an electric resistance as auxiliary heating. The hydraulic scheme of the installation is illustrated in figure 2.

![Hydraulic scheme of the installation](image)

**Figure 2.** Hydraulic scheme of the installation

For the remote monitoring study, we have further equipped the installation with a control unit Rio-Phenix from Napac (Schneider Electric). This unit provides a visual representation of the SWHS with real-time information. It allows to measure the solar radiation intensity, the flow of consumed hot water, the cold water temperature at inlet of tank 2, the solar hot water temperature at outlet of tank 1, the water temperature from heat exchanger to the collectors and the return temperature from collector to the heat exchanger for controlling operation of primary and secondary pumps. From measurements, the unit processes the signals from the sensors and converts them into directly usable information. The remote controller device is equipped with automated alerts and web access to inform the user or maintenance service company if any failure or malfunction occurs in the installation. Overall, the device provides numerous data logging using graphs and an energy balance including pumps operation.

3. RESULTS AND DISCUSSION

3.1 Simulation of the installation

The sizing and the performance simulation of the designed solar system is calculated by using the Solo2000 software developed by the French Scientific and Technical Center for Building (CSTB, 2006). This software presents the advantage to be able readily evaluate the monthly averages energy performances and has been used successfully as a tool for calculating in some studies relating to the guaranteed solar results (IEE, 2008).

The numerical data used for the simulation of the solar system are summarized in Table 1. The technical characteristics of collectors are given by the gains coefficient B and thermal losses coefficient K (table 1).

The monthly average inlet water temperature varies from 14.2 °C in January to 21.2 °C in August. The ambient temperature ranges from 11.1 °C to 25.2 °C. The annual average temperatures are 17.43 °C and 17.37 °C respectively for air and inlet water.

The simulation results show that incoming solar radiation on the collector plane amounts to 2790 Wh/m².day in winter and reaches in summer 6170 Wh/m².day. The corresponding solar cover rate rises a minimum of 48% in December and reaches a maximum of 98% during the summer months July and August. The monthly variation of solar heat yield is illustrated in figure 3. The low solar energy yield in August is linked to the holiday period.
The so calculated annual mean values of solar cover rate, solar energy yield and productivity are summarized in Table 2. The performed simulation shows that the average solar cover rate amounted to 79.5%, the annual solar energy yield reached 6277.5 kWh/year for an estimated annual need of 7896 kWh.

The solar productivity is about 523 kWh/m² year. Overall, the design results are very satisfactory. We get, for Algiers climatic conditions, a very high solar coverage and very good annual productivity. It is generally agreed that a solar system is correctly sized if it gets to satisfy 50-80% of hot water demand. With such an installation the manufacturer can theoretically guarantee the solar results. It must however, ensure that over a several years period of operation, the calculated energy performances are met in the practice. It is in precisely this area where remote monitoring can make a significant contribution.

### 3.2 Performance monitoring of the remote controlled SWHS

The remote monitoring was carried out over four years. We followed up several parameters, but we will discuss here the essential operating parameters, in particular, the hot water consumption, the two pumps operations and the energy output. Generally the real energy production of the collective SWHS must be at least equal to 90% of the calculated production (Gilliaert et al. 2000). Our results will be compared to that rate. This level is also widely adopted in countries that have implemented the solar performance guarantee. We also refer to this level in our discussion of the guaranteed solar results. This security margin of 10% compared to the expected energy production is generally enough to cover weather variations from one year to another.

The monitoring shows that the real incident radiation on the collector surface is in average 13 % higher than the reference radiation (Figure 4). The measured annual incident radiation which rises to 1825 KWh/m² year is characteristic of the Mediterranean coastal areas.
The monthly and daily measured and guaranteed hot water consumptions are illustrated in figures 5 and 6 respectively. Based on those monitoring data, it can be seen that the real consumption is in good accordance with the considered reference. This result is important because any eventual drop of the consumption leads to a reduction of the performance of the solar thermal installation, as well as a decrease in the expected energy delivered to consumption.

**Figure 4.** Measured irradiation and reference (2007)

**Figure 5.** Monthly measured hot water consumption and reference consumption, 2007

As illustrated in figure 6, the daily evolution of the consumption shows, as is often the case, that the demand is not stable; a wide variation of hot water consumption in the monthly consumption pattern is observed.

**Figure 6.** Daily measured and guaranteed consumption (November 2007)
The analysis of the results related to the daily operating hours of the pumps (primary and secondary loop) shows that the latter normally work with a good agreement between the operating hours of the pumps in the primary and secondary loops. An example of the pump operating times is illustrated in figure 7 for November. During this month, it should however, be noted that over two days the primary pump worked less than the secondary. This normally occurs when the daily consumption is high or in case of problems related to flow control. However, this type of minor anomaly doesn’t influence the solar energy performance.

As illustrated in figure 8, the monitoring carried out in 2007 indicates that the produced solar energy measured from the output of the solar tank approximately ranges from 5.3 to 10.2 KWh/day depending on the month. This energy output is compatible with the consumption and is furthermore in good accordance with the theoretical one. The data from 2008 shows that, due to different weather conditions, the energy performance of the system is slightly lower than that recorded in 2006 and 2007 (on average, solar radiation was slightly weaker in 2008 than in previous years). For this year, there is also a very good agreement between the theoretically accessible and the measured energy. Overall, the deviations between the measured energy and the theoretical do not exceed 5% (Figure 9). These results clearly mean that during the first years of operation the designed SWHS is working properly and has very good energy performance.
The frequent on-site inspections showed that the system operates very well, there is at any time hot water production to the desired temperature by solar energy. Additionally, during this period, and as illustrated in figure 9, the guaranteed solar performance is respected and the solar heater system has proven its ability to deliver the annual amount of expected energy. From May 2009, the system was not working at full operational conditions. The installation was confronted with various technical problems. The commonly encountered failures are damaged or dirty sensors, pressure primary loop, leak in pipework, irregular operation of pumps, corrosion problems, frequent water cut-offs, and in absence of an adequate maintenance service, system performance began to decline. The consumption fell sharply, and as indicated in figure 9, solar energy productivity is no longer ensured. This phase of the study shows the importance of the presence and participation of a management and maintenance service, when wishing to set up a solar performance guarantee contract.

Through this study, it clearly recognizes the importance of remote monitoring use. If the number of installed sensors is sufficient, it allows to:
- Ensure conformity to expectations by comparing the real and the calculated or guaranteed energy performance
- Ensure proper operation of the system by detecting and analyzing incidents which induce a decrease of the performance and to inform the operations manager who will bring the relevant corrections.

Finally, such a solar performance guarantee certainly helps to the emergence of sustainable market by contributing to:
- Reduce, in case of malfunction, the financial risk to the client and may be the bank and to ensure both the payback period and the lifespan of the installation
- Facilitate access to public subsidies and ensure proper use of the provided subsidies
- Promote the production of quality installations and participate to dissemination of the best practices

According to surveys we have conducted, it appears that in Algeria, the main barriers for solar thermal market development are:
- A limited experience with collective systems and its real performances. The payback period and the quality of the equipments used are often not enough known
- A lack of visibility about the subsidy schemes which will have to be better disseminated
- Currently, the fossil energies are subsidized and solar thermal probably cannot be competitive with the low prices of natural gas.

Faced by these constraints, it would be advantageous that a more significant role be devoted to the implementation of remote monitoring and that regulatory measures and related procedures be promulgated to ensure high efficiency of solar thermal systems.

4. CONCLUSIONS

In Algeria, the process of enacting, and implementing of renewables, particularly solar energy, is ongoing. Like in other countries around the Mediterranean, collective solar thermal systems for hot water production have a great role to play in the future years.

Although the market potential is high, there are currently a few hesitations among customers and industry due to lack of experiences for collective systems and misunderstanding of the installations quality and their real energy performances.

In order to encourage the use of these systems and overcoming some barriers which hinder solar thermal development, we have by using the remote monitoring technique studied and followed the performance of a solar system over an extended period. The implemented collective solar water heating system which is equipped with a unit to remotely monitoring can produce up to 80% of hot water needs. The solar heat yield is about 6200
kWh/year and the productivity amounted to 523 kWh/m².year. The results show that remote monitoring allows to supervise readily the real system operation and its real energy performance. However, a successful remote monitoring of collective SWHS depends on the correct choice of measuring instruments and their location. The obtained data also show that for climatic conditions of northern Algeria, the system can work for several years with very high performance and the measured energy output is often higher than the calculated amounts. As a result, the manufacturers can guarantee the performance of their product. Remote monitoring is therefore an essential tool in effectively implementing of guaranteed solar performances. This is particularly important because any counter performance can lasting damage the image of the solar thermal application.

To achieve the targets of the Algerian program of energy efficiency and for successful implementation of collective SWHS planned in housing and tertiary sector, the public authorities should encourage this kind of application through subsidies and low-interest loans and generalize the solar performance guarantee by appropriate mechanisms. All these facilities, together with increased awareness of potential users, will certainly help to the emergence of a sustainable solar thermal market in the country. Furthermore, based on the results and experience acquired, it is now appropriate to extend the remote control application to other regions where solar irradiance is higher than Algiers and the lower humidity.

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