Optimization of a Mobile Remote Laboratory. From prototype to the industrial equipment

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Optimization of a Mobile Remote Laboratory. From prototype to the industrial equipment

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***Abstract*— Mobile Remote Laboratory is a prototype that, at a test scale, has shown to be able to monitor solar water heaters in diverse regions and climatic situations, in order to evaluate *in situ* their performance and efficiency. The use of this device in field requires technological upgrades and the development of a standard test protocol in behaves of use. The authors describe the upgrades already made. They also discuss the applicability of both, the UNE-EN 12975-2 normative and the Test Protocol PMI by INTI. Thereby they propose a "personal standard" (fit to user's needs) based on a performance calculation procedure beyond protocols, by using experimental data: geographical position, irradiation, temperatures, water volumes, time of day. Both, the deviation of the volume of extracted water and the difference of time of day with respect to the INTI's Test Protocol, are the parameters that illustrate "how close we are from standard conditions"**

Keywords- solar energy, remote labs, efficiency

I. Introduction

A sustainable development in the world context of growing energy demand asks for the use of renewable energy sources and the optimization of equipment and conversion processes. Although solar energy cannot substitute the energy of hydrocarbons and other non-renewable energies, it becomes a complimentary resource which is growing in its use for various applications.

The efficiency of the solar heater constitutes a parameter for the control of the mode of operation of the equipment in the use of solar energy for water domestic heating in sanitary use. The experimental determination of the efficiency of a solar heater asks for the measurement of variables of the heater itself and of the environment under working conditions.

In Argentina there exist several suppliers of solar heaters; however, there is not a system throughout the country that manages the certification and standardization of the equipment to ensure minimum quality features. Such as Garnica *et al*. (2010) highlight, after an important boost back in the '80s when the IRAM 210002 rule in force was passed for tests in flat plate collectors (IRAM, 1983) the rule for tests in whole systems has not been passed yet. In 2010 el Strategic Technological Area of Renewable Energies of the National Institute of Industrial Technology (Instituto Nacional de Tecnología Industrial (INTI)) has suggested a kind of measurement of solar systems for the supply of healthcare hot water which involves transport to test banks for measurement, test and certification (INTI, 2010).

The standard practice is that the maker supplies the efficiency value, measured in test banks, but its later placement in different environmental conditions and with particular usage patterns, cause real efficiency to show different values. The problem we need to solve now is how to measure the efficiency *in situ,* wherever the heater is, while it is working, and transmit de data recorded from the place the heater is in to a laboratory where the data are processed.

To do this, we have developed a prototype that we have called mobile remote laboratory, which has shown to accomplish that aim in a test scale (Saez de Arregui *et al*., 2013a; 2013b). The devices developed shall allow for the analysis of the behaviour of heaters in different regions and under different weather conditions in order to test their performance and efficiency. Furthermore, solar heaters manufacturing companies will be able to use this information to improve their products. In the present work the technological updates fulfilled on the prototype, in a development-oriented process to be used in the field are described.

II. The Mobile Remote Lab

As a result of a project carried out by staff belonging to two laboratories dependent on the Escuela de posgrado y Educación Continua of Facultad de Ciencias Exactas, Ingeniería y Agrimensura (FCEIA) from Universidad Nacional de Rosario: Laboratory of Renewable Energies and Remote Laboratory, a mobile device ready to interact with solar heaters and the surrounding environment and able to pass physical values by using the mobile telephone network to another device at FCEIA, which collects the field data to be processed and analysed has been designed and developed. In Figure 1 and 2 are shown the scheme of devices integrating the mobile remote station and the static station at FCEIA.

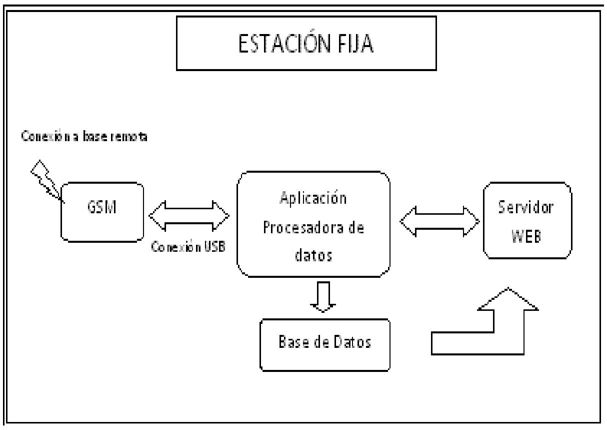


Figure 1. Fixed-based station made up of a GSM transmitter-receptor, in charge of connecting with the remote station; the processor and the data base and the web server connected to the Internet.

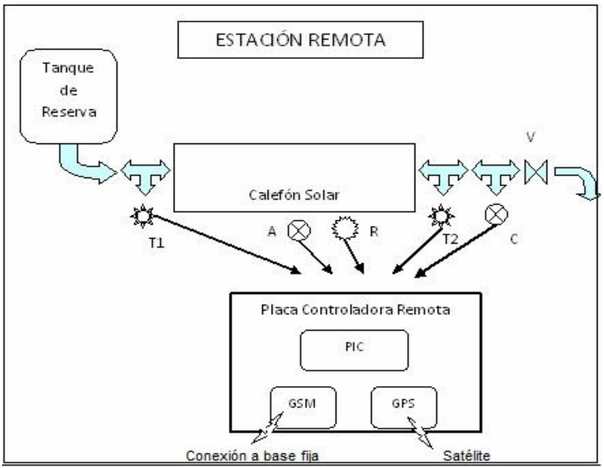


Figure 2. Mobile remote station which connects to the heater to be tested, made up of a datalogger controller board that receives and transmits analogue and digital data and a microcontroller connected to a GSM processor.

The fixed-based station is made up of three blocks: the GSM transmitter-receptor, in charge of making contact with the remote station; the processor and the data base in a PC connected to the GSM block via USB (the processor receives data from the remote station, processes them and stores them in the data base); and the web server connected to the Internet network.

The remote station is physically connected to the heater to be tested, hydraulically fed by a reserve tank. The outlet pipe of the heater is connected to an on/off valve (V) controlled by the test electronic system. On both ends there is an interposed connection that shelters a high precision semiconductor thermometer (T1 and T2) that measures in and out water temperatures. The outlet pipe is connected to a flow meter (C) that measures volumes of water expelled. On the other hand, there is a solarimeter (R) on the collector level to measure the incident solar radiation. The whole is connected to a controller board or datalloger which is in charge of obtaining and transmitting the analogue and digital data. The nucleus of this equipment contains a microcontroller; it is connected to a GSM modem (with its own line chip). The controller board also has a global position system that supplies for, as extra information, latitude, longitude and altitude over sea level, conditioning variables for the performance of the system.

The microcontroller of the system described before is programmed in C language, and it can: receive the test set up from the fixed-based station; receive the data from the sensors (temperature, radiation, flow); control the water extraction valve; carry out a beginning data processing (temperature average, volume account, etc.); arrange the information package and send it through the GSM/GPRS network to the fixed-based station in Rosario.

A. The technological update of the equipment

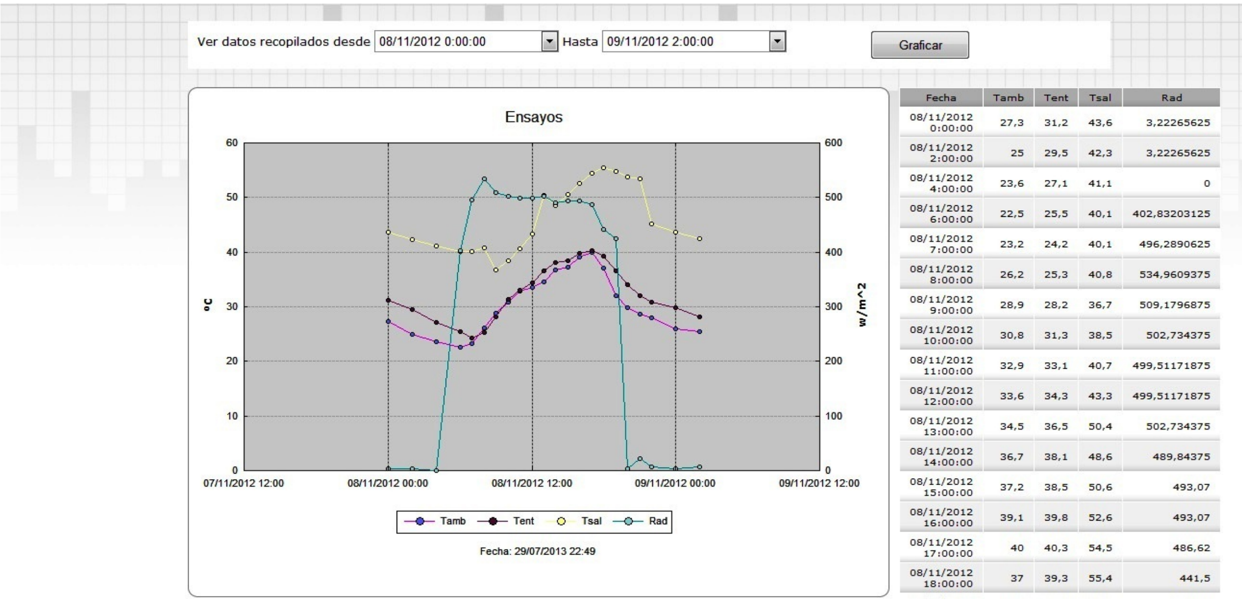
Some updates and optimizations have been carried out in the hardware and the software in order to obtain higher performance of the equipment. Such update included changing the remote station microcontroller, by another more versatile and compact one with higher memory storage capacity and processing. Besides the GSM module was substituted by another more compact one (Stick GSM). From these changes, plus some improvements in the remote firmware, the mobile station is able to receive operation commands through the GSM network to execute them and change the data collection parameters (flows and extraction intervals, etc.). Before, this process had to be done *in situ* by operating the station in the location/measurement place (see Figure 3). This clearly shows a step forward into the use of the device in field conditions.

Concurrently to the changes in the hardware, the information sending protocol has been improved through the mobile telephone network, as text messages. This procedure is known to be prone to faulty data as a result of altered characters. In order to guarantee the accuracy of data sent, a Cyclic Redundancy Code (CRC) has been included and a hand-shake type algorithm has been develop; through it, when the data sent is faulty a new sending is requested.

Figure 3. Details of the microcontroller, display and records set buttons of the remote station

When receiving an SMS message, the system checks if the message meets the features of the pre arranged message protocol. If valid, the server will communicate the remote station that data have been successfully obtained and it analyses the message. Each message might contain data from one or several tests carried out by the remote station. The whole message is checked because, in case of a mistake in the sending, the message is discarded and it is expected that the remote station shall send it again. In this regard, communication tests have been recently done from different geographical areas in our country. The ones carried out in May from Ushuaia (to 3000 km away) had just a one-minute delay against the fixed-based station in Rosario. The data from each test are processed and stored in a data base in the server; it can be later accessed through the web site in the remote laboratory.

The introduction of data into the web site will be shown as charts and graphics, in order to be able to see the temporal evolution of the 4 parameters measured (room temperature, input temperature, output temperature and radiation). In Figure 4 it is shown the graphics for an array of typical data recorded in November 2012 in Rosario; these have been taken by the equipment in one of its calibration phases.



Fecha	Tamb	Tent	Tsal	Rad
08/11/2012 0:00:00	27,3	31,2	43,6	3,22265625
08/11/2012 2:00:00	25	29,5	42,3	3,22265625
08/11/2012 4:00:00	23,6	27,1	41,1	0
08/11/2012 6:00:00	22,5	25,5	40,1	402,83203125
08/11/2012 7:00:00	23,2	24,2	40,1	496,2890625
08/11/2012 8:00:00	26,2	25,3	40,8	534,9609375
08/11/2012 9:00:00	28,9	28,2	36,7	509,1796875
08/11/2012 10:00:00	30,8	31,3	38,5	502,734375
08/11/2012 11:00:00	32,9	33,1	40,7	499,51171875
08/11/2012 12:00:00	33,6	34,3	43,3	499,51171875
08/11/2012 13:00:00	34,5	36,5	50,4	502,734375
08/11/2012 14:00:00	36,7	38,1	48,6	489,84375
08/11/2012 15:00:00	37,2	38,5	50,6	493,07
08/11/2012 16:00:00	39,1	39,8	52,6	493,07
08/11/2012 17:00:00	40	40,3	54,5	486,62
08/11/2012 18:00:00	37	39,3	55,4	441,5

Figure 4. Reading of data collected during 14 hours in Rosario, in November 2012

Solar radiation is calculated through a sample of records and the integration of values obtained during sample interval. Along with the new microcontroller, the accuracy of the estimated value of *in situ* solar radiation has been improved, because the record interval was reduced from one hour to a minute.

Another improvement introduced in the remote unit has been the inclusion of a battery providing for the current supply formerly provided directly by the electric supply network from the place. Although the remote unit is still powered by the electric network, in this new set up it only depends on the electricity supply for the battery recharge. The supply designed that way implies higher stability in case of cut-offs, voltage changes, noises in the network, etc. The charge system is intelligent and it allows for the disconnection of the battery from the equipment and for its commuting to the 220V a.c. network over a period of time when no tests are carried out. Besides, with the relationship between charge capacity (12V, 9Ah) and the equipment consumption, three-day autonomy is obtained, which also implies higher stability.

Improvements in the software also allowed for the inclusion of a verifier system in order to check that the connection to the mobile phone network is effective, thus ensuring that the system is available to send data. Finally, together with the changes in hardware, the solution was deployed in a new smaller and bulkier capsule, standardized to be hung from a DIN rail in a panel of commercial use (Figure 5).

Figure 5.Views of the new panel.

B. Water heating system use monitoring

The current water heating domestic systems contain an electric resistance whose working compensates for the shortage of solar energy at certain times and/or very cloudy days. In order to use these equipment efficiently, some use patterns must be adopted and these comprise the best time of day for use and periods of time which are unsuitable for the use of the system.

Nowadays, the tests with remote laboratory have been done by using a pre arranged protocol of use of the heating system. It takes into account periods of water extraction which simulate a rational consumption curve by an average family in the central area of the country.

It is required to monitor the real use of the water solar heating system and to report when and how much water is obtained, its temperature when it comes out, when the compensation electric source turns on etc. These data will make it possible, on one side, to know the effective use, and to measure – as a result – the efficiency of the heating equipment under real operating conditions; on the other hand, it will allow for the improvement of the equipment efficiency, the design of more efficient use protocols and the elaboration of users' manuals.

III. Applications Rules

A. UNE-EN-12975 Application Rules and INTI PMI Essay Protocol

When environmental conditions are consistent with the ones required by the rules concerned, the remote station can command the heater to carry out the standardized test, allowing for the comparison of performances operating under real conditions.

Due to its recent update the possibility to apply the European rule UNE-EN 12975-2 has been considered. In order to obtain a value for the heater performance, in comparison with the incident radiation, this rule asks for the opportunity to measure the water temperature in entry and exit of collector, as long as there is no intermediate water storage. That means that if the solar heater has a water storage this must have the chance to be clearly separated from the solar collector itself in order to carry out the appropriate measurements. This cannot be used in integrated storage heaters. However, this kind of collectors is an important part of the stock of collectors in Argentina.

The search for a suitable protocol has lead to the analysis of the protocol used by the INTI (Instituto Nacional de Tecnología Industrial of Argentina), which consists of the measurement of the heat in three volumes of water (40, 20 and 40 litres) (PMI Test Protocol appendix II, INTI, 2009). Unfortunately, the possibility to fulfill this test (which adjusts well to the national stock of solar collectors) interferes negatively in the availability of hot water for a user that has a solar heater with the remote laboratory incorporated at home, due to the huge volume of water withdrawn (100 litres).

B. Data base use and suggestion for the application of a "personal rule"

Due to the inconvenient mentioned before the performance analysis approach has been changed. A non-stop monitoring of daily consumption at home is suggested. With this consumption, by surveying the in and out temperatures and the volumes with the flow metre that the system includes, the balance of the energy gained will be done thus obtaining a performance when comparing it to the radiation. However, these performances shall be clearly out of any protocol.

The adoption of two parameters indicating "how near standardized conditions we are" is put forward. The first parameter is the volumetric difference of withdrawn water. The second is time deviation, which praises the volumes withdrawn according to their nearness to time segments stated in the protocol. That way we obtain a performance and a "rule deviation" that are 0 for the case where domestic consumption on certain day has strictly stuck to the rule and 1 for a performance that has matched neither volume nor time established beforehand.

One of the problems to cater to an interesting market is the lack of standardization, but also the lack of people's knowledge about how each kind of solar heater works. In order to obtain a proper selection of non-standardized heaters, we suggest that the data base built from the *in situ* measurements on heaters in family houses, shows who the manufacturer is and the model as well as important information such as storage volume, absorbing area, price and the coordinates of the use location. This way of analysis makes it possible to apply a "Personal Rule" to the data base built with the data from the heaters in the country; in this "Personal Rule" we shall indicate the hot water volumes and timetables featuring the lifestyle of each potential user. Once these consumptions, timetables and the geographical location of the heaters are defined, we shall work on a data base as described before, but using the personal information instead of the data in the INTI protocol. That way we shall find the consumptions of different users nearer the personal consumptions, thus obtaining useful information based on experimental data on which the kind, size and trademark of the solar heater that best fits the particular lifestyle of each possible user is. This way we hope to pave the way for the mass ownership of this technology.

Example

A potential user enters the system that gathers the data obtained along the last year, with an interface that makes it possible to ask for three pieces of information: volumes of water used, and its times, for example, 40 litres at 7 am, 20 litres at 14 pm, 40 litres at 9 pm (example in accordance with the INTI test protocol), plus the coordinates of the location where the solar heater shall be used.

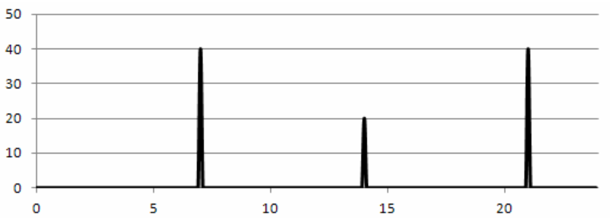


Figure 6. Detailed consumptions provided by the data base user

Firstly, the volumetric difference between input and output data on different days in different heaters in different locations in the country, is calculated according to the equation (1)

$$D_v = \frac{V_{ij}}{V_p} - 1$$

where D_v is volumetric deviation; V_{ij} is the volume of water withdrawn on day i from heater j, and V_p is the volume required for personal consumption by the person consulting the data base.

A value between -1 y + ∞ is obtained (-1 for a recorded null consumption, 0 for the same consumption, and positive values for higher consumptions). The data recorded on the days with an unacceptable volumetric deviation, below a -0,1 and over 0,1, for example, shall be discarded (limits might be changed according to the accuracy of the analysis required).

To illustrate the example, five simulated consumptions are shown in Table 1 and with random values. It can be observed that consumptions of random cases are clearly more scattered (to be expected in a family house) than the ones indicated by the potential user (Figures 7 to 11).

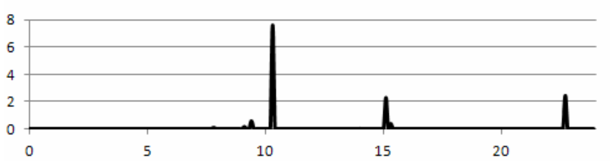


Figure 7. Simulated consumption1

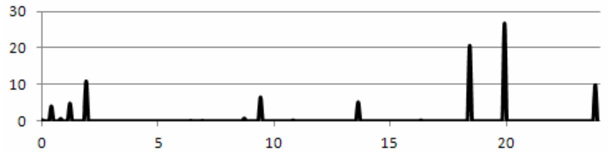


Figure 8. Simulated consumption2

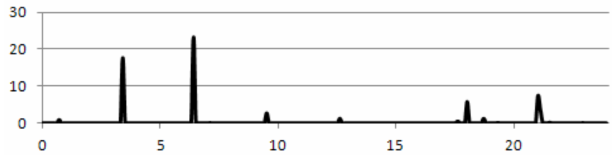


Figure 9. Simulated consumption3

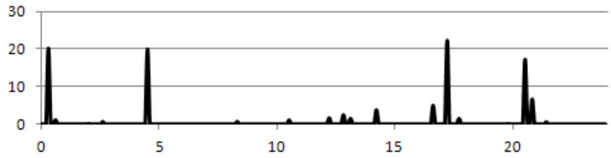


Figure 10. Simulated consumption4

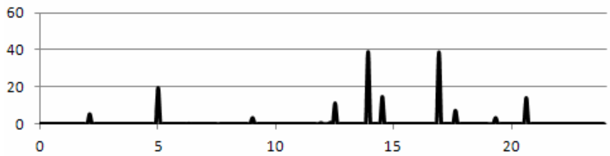


Figure 11. Simulated consumption5

Case	Consumed water	Volumetric deviation
	litres	Non-dimensional
Consumption1	13	-0.87
Consumption2	92	-0.08
Consumption3	103	0.03
Consumption4	107	0.07
Consumption5	159	0.59

Table 1. Volumetric deviation in random cases

With the judgment used before (deviations between -0.1 and 0.1), cases 1 and 5 might be discarded and only cases 2, 3 and 4 would remain standing.

In order to establish time deviation, we must determine which days each heater making part of the data base has shown the consumption at times nearer to the ones required. To do this we suggest the creation of an environment around each detailed consumption within which the consumptions measured before are considered temporarily close, as shown in figures 12 and 13. Numbers 2 or 8 in graphics show the preciseness to be applied to the analysis.

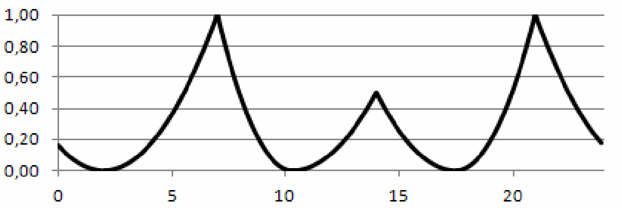


Figure 12. Temporary environment with preciseness 2

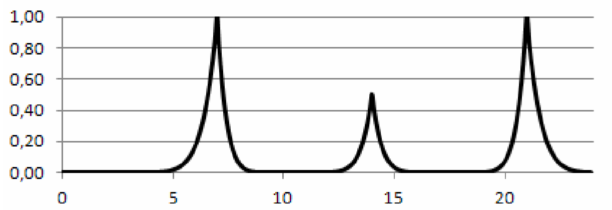


Figure 13. Temporary environment with preciseness 2

On the consumption of the heaters measured a weighing is done according to time factor (which in the graph is 0 to 1, 0 for consumptions far from the moment required by the future user, and 1 for maximum consumptions right at the moment desired). Time deviations of each case are shown in Table 2:

Case	Time deviation
	Non-dimensional
Consumption 2	0.13
Consumption 3	0.49
Consumption 4	0.28

Table 2: Time deviation in random cases

After this filter, it is concluded that we shall use the measurements on solar heaters that fulfilled the random consumption 3 and 4 carried out by the remote laboratory. It is expected that a considerable stock of heaters throughout the country and with cases for each day of the year, the cases to be used are many more (probably thousands or hundreds of thousands). It also makes it possible to filter the data from summer days, for example, in order to be certain that we will decide for a test during the coldest months of the year, which are the most critical ones, as regards health care hot water.

Efficiency is determined on consumptions 3 and 4; this is given by the relationship between the amount of energy supplied when heating the water and the irradiation measured in the collector plane (both data supplied by the remote laboratory).

The efficiency obtained based on the similarity of solar irradiation between geographical location of the user to be and the coordinates of each solar heater shall be weighed. That way, the most efficient heaters will also be the most appropriate ones as long as the measurement is done in a geographically nearby place or at least with the same irradiation.

Regarding these results, the different heaters will be filtered according to the total energy supplied during daylight in each test, translated as temperature for each volume given. That way, it is not necessary to recommend a drainage area (as usually done), since the models of very small surfaces, in spite of having a low volumetric deviation, might have, perhaps, high efficiency, but might not reach acceptable temperatures. For example, results showing temperatures below 40 degrees that would indicate very small drainage surfaces or over 85 degrees that suggest very big and misused surfaces might be rejected.

All the process described shall be invisible for the user, who will only see the conclusion: the trademark and model of the most efficient heaters according to their consumption style, together with the price (that might be provided by the seller or the manufacturer), and the average exit temperature of water with the certainty that it is recommendation based on real, new and geographically nearby data.

IV. New Improvements to be carried out on the devices

In the optimization process of devices and their benefits, several changes have been considered as necessary.

Although a solarimeter for the recording of solar radiation could be included, instead a photovoltaic panel has been chosen due to its lower costs and its possibility to be more easily reproduced in industrial scale, making it economically more viable; this asks for the panel recalibration for its effective use.

It is planned to supply the remote laboratory of energetic feeding totally by a photovoltaic solar system that shall make it independent from the need of network electric power and will make it really possible for the field measurement to be done anywhere.

As regards the conditions assuring the supply and sending of trustable data, it is previewed to incorporate an alarm system that warns about any abnormality. Depending on the level of criticality, this shall be communicated to the fixed station and/or mobile telephones.

V. Synthesis and Perspectives

Apart from the improvements detailed, some innovations in the equipment are thought forward and they shall make it possible not only to monitor but also to control the test from the fixed station through a browser.

The hardware and software updates carried out on devices have allowed, among other items, to optimize measurements, to improve the preciseness and reliability of data and to improve autonomy of the remote station. All this plus the possibility to command the remote station from the fixed station, shall lead us in the short-term to remotely located equipment that is even more reliable and accurate to be connected to a heater in use in the field. On the other hand, due to the fact that the system is designed with a DI (digital identifier) the possibility of *in situ* monitoring is not limited to only one remote station but it also reaches a big group of them simultaneously anywhere in the country.

The only use of equipment based on renewable energies does not mean efficient and rational use of these resources. It is necessary to know the real use conditions of devices in order to have the scientific foundations for the design of public awareness campaigns on the optimum and reasonable use of energetic resources.

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