BRAZILIAN SOLAR WATER HEATING SYSTEMS EVALUATION

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Abstract

The Brazilian "National Electricity Conservation Program" – PROCEL – runs regular surveys in the electric-energy-consumption market. These studies are used as valuable data to better plan the actions of this program. These data also evaluate the program's performance by identifying the level of penetration of the most efficient electric equipment within the residential sector. PROCEL's main lines of action is to promote and make available the most efficient technologies.

Based on the results from the latest survey, it is estimated that 24% of the electric-energy consumption of the residential sector is used by electric shower devices, which instantaneously heat the water that flows through them, normally using an electric resistance of 5 kW. These are an important factor in a country where electric-heating devices are present in about 73% of Brazilian households.

Keeping that in mind, the purpose of this work is to present the main results of the Brazilian Solar-Water-Heating-Systems Evaluation, finished in 2010, where 535 installations were visited and more than 50 researchers from different universities participated in the project. Moreover, seven Brazilian cities were selected to be studied. The information was collected from field research and statistically treated. The collected information focused on the adequacy of the project to the household, installation, operation and life cycle of the systems, as well as the users' satisfaction level. Technical questionnaires were developed to summarize all the required information, such as a Web site designed to organize and manage the data collected and a Matlab application that performed the dimensioning and F-chart systems evaluation. Quality indicators were created through a full system monitoring, with thermographic analysis and evaluation of shading influence at the system's efficiency, using the Ecotect software.

1. Introduction

Regarding the electric power consumption, the Brazilian residential sector spends 24% (Procel, 2007) to heat water, using an electric shower device that instantaneously heats the water as it flows through it, normally using a high electric resistance. This situation leads to a peak-hour consumption, normally between 06:00PM and 09:00PM, when the majority of the population uses these electric devices to take showers.

On the other hand, since 1997 there has been in Brazil a quality certification program for solar collectors and thermal storage tanks, coordinated by the National Metrology Standardization and Industrial Quality

Institute (Inmetro) and Eletrobras. For that program, the Pontifical Catholic University of Minas Gerais (Figure 1) and the Technology Research Institute of São Paulo are responsible for testing solar collectors and thermal storage, both helped by Eletrobras, which acquired equipment to expand the technical capacity of these laboratories. In 2011, more than 50 manufactures have joined this program, testing 290 models of solar collectors and 297 of thermal storage tanks (Inmetro, 2011). Nowadays the Brazilian market presents a total area of installed solar collectors of 6.24 million of square meters (Abrava, 2011), expressing an insertion factor of 33 m²/1000 inhabitants (less than 1% of Brazilian households currently make use of this type of energy).

Fig. 1: Solar Simulator at Pontifical Catholic University

In this context, PROCEL´s orientation is to encourage wider use of solar water heating, considering the high potential for use of this technology in Brazil, as well as to improve technological advances in solar collectors and thermal tanks. As a strategy for solar heating dissemination, PROCEL launched its awarding of the PROCEL Seal (Figure 2) for this equipment, where that seal is awarded only to solar collectors and thermal tanks with the highest indexes of quality and energy efficiency.

Fig. 2: PROCEL Seal

In order to help create government policies, Procel and seven different universities launched the Brazilian Solar Water Heating Systems Evaluation. The results of that project support a national government plan to disseminate solar thermal energy in Brazil that is aligned with the National Plan on Climate Change. Thus, the main purpose of this paper is to present the results of that evaluation project which took place between 2007 and 2010 including research *in situ* and application of questionnaires to evaluate the real situation in the residential and service sectors, including solar water heating systems in buildings, regular and middle class residences, low-income residences, hotels and swimming pools.

2. Brazilian Solar Water Heating Systems Evaluation Project

The main goal of that research, which belongs to PROCEL's actions program, was to characterize and evaluate solar water heating systems in seven Brazilian cities, thus incorporating studies in end uses in the residential and services sector, as shown in Figure 3 below.

Fig. 3: Evaluation project map

A partnership with seven universities was made for each place studied. The project was conducted by Eletrobras staff and more than 50 researchers, making it possible to study 535 solar water heating systems.

2.1. Research questionnaires

Regarding the field research, specific questionnaires were used in conjunction with manufactures and installation companies, commercial stores and end users. There were two different kinds of questionnaires: a first one for technical information and a second one for sociological and behavioral topics about the use of solar water heating.

Data like size of collector area, storage tank volume, array of collectors and insertion in the field, general conditions of operation and installation, and equipment maintenance and life cycle were generated, as well sociological and behavioral data. The inquiry blocks used is illustrated in Figure 4. With the creation of a Web site dedicated to this project, it was possible to provide secrecy and appropriate ways to transfer and store the collected information.

The maintenance of this inquiry method in all questionnaires allows the comparative evaluation of the main problems detected. Through this strategy, economic, social, cultural, climatic and technological factors associated with solar water heating become clearer and easier to understand.

Fig. 4: Inquiry blocks

2.2. Characterization of studied locations and statistical analysis

In order to characterize each city studied, a statistical evaluation was performed based on maps, utility company databases, surveys and analysis related to social, economic and physical factors, to reach the total number of systems to be visited. This research focused on the analysis of demographic density, average number of households per neighborhood and family average income.

The random stratified sample plan was used in the statistical evaluation. Basically, in this method, samples are subdivided into sub-populations or groups, leading to smaller errors. This is a consequence of a variation reduction between sample units of same group, related to variation between sample units of different ones.

Sample size was determined in two stages. In the first one, a “pilot” sample was created to collect previous information about the population, considering a maximum error of 5%. This value was also adopted to significant test level. The second stage is the sample calculation, in which pilot sample results were used. Classical statistic equations (Leite, 2004) were used for calculations of stratified sampling with the casual distribution of the piece. Since the number of factors analyzed is small and it was necessary to identify possible grouping and number of groups, the neural network technique was used. This method is very efficient for problems of multivariate analysis, grouping and prediction, besides hierarchic agglomerative techniques: centroide and Ward (Mingoti, 2005).

Euclidian distance, which is a multivariate measure, was used in selecting pieces into the groups. In agreement with data complexity, a technique was selected to get to results. Also, special software was developed in Matlab to perform the statistical data treatment. Table 1 shows the total number of solar installations visited in each city studied, as well as the use. The project took place between 2007 and 2010, where 535 installations were visited.

Tab. 1: Solar installations visited and use

City	Use	Visited installations
Rio de Janeiro (suburb)	Low-income households	82
Bauru	Low-income households	72
Campinas	High-and middle-income households	92
Belo Horizonte	Large-scale systems (buildings)	96
Porto Seguro	Hotels and Inns	77
Brasilia	Swimming pool	90
Belem	Hotels, Inns and hospitals	26

2.3. Sizing estimation and energy savings software (Long term performance)

As a part of this project, software was developed as assistant tools that help to identify the main characteristics of the systems studied. One application, developed in Matlab, estimates the necessary collector area and the storage tank volume through radiation calculations (Duffie, 1991) in tilt and arbitrary oriented planes for any location and economic level required, based on the modified model of F-Chart (Duffie, 1991). Shading incidence in solar collectors arrays is introduced in these calculations to achieve its influence value over monthly and annual energy economy generated by the solar installation. To validate data obtained, this software also simulates the value of monthly electric energy bill for studied residences through daily bath habits and other family use of electric household appliances.

Shading incidence values and consequent solar radiation reduction over the solar collectors' plane were calculated using Ecotect 5.20 (Figure 3), which is an environmental analysis tool, and a script, developed by the project's team. Thus, it was possible to estimate the reduction, due to these shading data, of annual F-chart value for each studied system.

Winter Summer

Fig. 3: Shading calculation for a studied solar installation

Moreover, studies indicate that hourly data is the most adjusted for shading analysis because similar shading values can promote different reductions in the incident radiation depending on the hour observed.

2.4. Team training and field research

Each work group consisted of one local professor and four engineering and/or physics students. The training course included solar geometry concepts, solar collectors and storage tanks, small, medium and large systems functioning characteristics, paying attention to variable factors found at each location. With practice classes, students learned how to use the field research kit, made up of GPS, tape measure, compass, turn indicator and digital cameras used to register the visited installations, as shown in Figure 4 below.

Fig. 4: Training and field research pictures

All data observed were registered by filling out technical and behavioral questionnaires and by producing two sketches: architectonic and hydraulic. These sketches included verification of collector orientation, tilt angles, array scheme and distance, main characteristics and identification – also verified for storage tanks – accessibility and safety conditions, obstacles around solar collectors and auxiliary system characteristics.

3. Main results

The main results from the solar water heating evaluation will be showed in this section. For better understanding, they were separated by end use, namely: Low-income households, High- and middle-income households, Large-scale works (buildings), Hotels and Inns, and Swimming pools.

3.1. Low-income household

From the social perspective, benefits can be perceived by the households. Reducing the electricity bill would result in good savings in the family budget, which would impact more effectively in lower social classes. In this case, the average reduction of energy consumption is about 35% (Fantinelli, 2006).

Consequently Eletrobras decided to conduct a research low-income households located in Rio de Janeiro and São Paulo states. Technical evaluations were conducted in 154 solar installations out of nearly 4,000 households identified. Samples from field can be seen in Figure 5 bellow.

Fig. 5: Samples from Rio de Janeiro's suburbs and Bauru (São Paulo)

The household's average income is USD 1,000 monthly and four inhabitants per house. The solar installation was donated by local utility companies. The installations have water storage capacity between 110 and 200 liters and solar panels between 1.4 and 1.6m^2. The average water consumption was 58 liters/person/month.

According to the results, 84% of the inhabitants approved the usage of the solar installation. In addition, around 94% of the inhabitants noticed the energy savings related to the technology. However, the researchers realized that households need to have continuous assistance so the information related to equipment maintenance and good practice in the use of hot water may not be wasted over time.

The auxiliary system for heating water in days without sunlight is always electric, represented by an electrical resistance installed in the thermal tank or, in most cases using an electric shower with a reduced power (normally 2,800 W). Example of an instantaneous electric shower heating device is shown in Figure 8.

Fig. 6: Instantaneous electric shower heating device

All inspected households showed problems in maintenance and knowledge of how to use the solar installation. For instance, about 66% of the inhabitants did not clean the solar collector glasses. Another critical aspect was that about 55% of the mixers show leaking problems. This suggests that researchers have to figure out better technological solutions.

3.2. High and middle income household

This project took place in Campinas, 90 km from the São Paulo capital, with population of 2.2 million people. The study target was families with high and middle-income household. As officially considered in Brazil, the high-income presents monthly wages higher than USD 7,000 and middle-income between USD 3,500 and USD 7,000. The education level of the inhabitants is 37% as graduate and 39% as post-graduate.

The researchers conducted their work in 92 solar installations out of nearly 2,217 households identified in the region. In this case, large systems were used, as shown in Figure 7. The collector area average presented was 8 m^2/house, the water storage volume identified 600 liters/house and 150 liters/inhabitants/month for water consumption average.

Fig. 7: Samples from Campinas

Concerning the constructed area, 53% of the buildings has more than 300 m^2 and 31% between 200 m^2 and 300 m^2. Regarding the number of bathrooms and inhabitants, we can see a direct correlation, as shown in Figure 8. Shadowing problems in the solar collectors were not detected in 86.7% households surveyed.

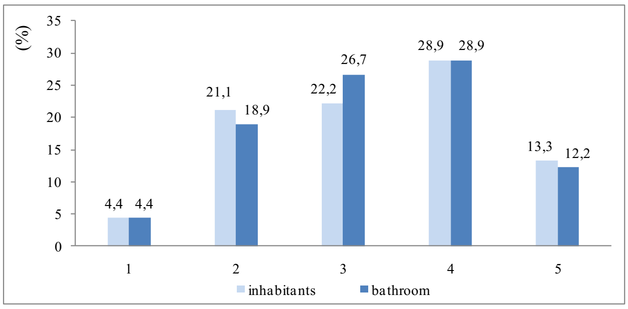

Fig. 8: Correlation between bathroom and inhabitants

Regarding the solar collectors maintenance, only 22% of inhabitants clean the collectors and 15% of collectors' glasses were broken. One point of dissatisfaction was the average waiting time for hot shower water: until 30 seconds in 23.5% of samples; between 31 and 60 seconds in 35.3% and 41.2% above 61 seconds. Although this, only 7% of the searched cases declare to be dislike with solar system. About 69% of the residents do not clean the solar collectors glasses and declare not to know this necessity. The auxiliary water heating is mostly electric, representing 72% and the gas appeared in 6% of samples.

The Brazilian electricity consumption average in households is 144 kWh/month. 70% of household studied showed electricity consumption above 300 kWh as shown in Figure 9.

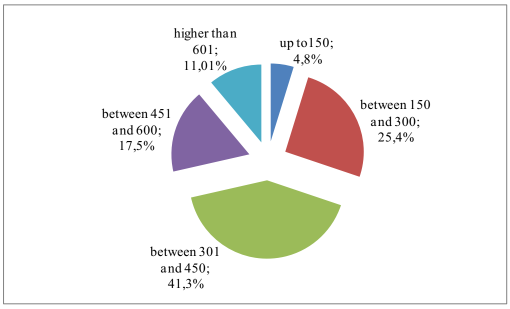

Fig. 9: Electric power consumption

3.3. Large scale systems (buildings)

For large solar water heating systems was selected of the capital state of Minas Gerais: Belo Horizonte. The city presents a population higher than 2.4 million of inhabitants. The scope of research in Belo Horizonte was middle and high-income residential buildings, characterizing the application of solar heating in large systems. The city has about 2,000 residential buildings with central solar water heating. An example studied in this project can be seen in Figure 10.

About 67% of buildings surveyed have between 12 and 24 floors and 21% from 6 to 11. 81.3% of all buildings researched present one or two units per floor. The average number of residents per apartment is 3 and 4 in 66.7% of the samples.

Fig. 10: Case studied in Belo Horizonte

The average storage volume found at Belo Horizonte's systems is 7,500 liters/building, 240 liters/household and nearly 60 liters/person. This last number is considered low if compared to high-income households consumption observed at Campinas. This fact was linked to the consumption compensation between the apartments. Moreover, there was a tiny use of hot water in Campinas' kitchens, which can also raise significantly the water consumption. Basically, LPG gas predominates at large systems in Belo Horizonte, where 72% of them use this kind of auxiliary heating as shown in Figure 11.

It was evaluated 3,610 solar panels in 96 building visited with a total area of 7,872m^2, corresponding to an average area of 82m^2 per building and 2.15m^2 per solar panels.

Fig. 11: Auxiliary heating system by gas

In this location the ideal inclination of solar panels is between 20º and 35º, observing the horizon line. This ensures the best efficiency for energy production. The field survey in Belo Horizonte showed that the installation of the collectors did not follow a default with respect to inclination, were observed 22 different angles to the slope of the solar collectors, as exemplified in Figure 12.

Fig. 12: Example of different inclination's angles

However, 88% of total solar panels evaluated were with the inclination recommended as shown in Figure 13.

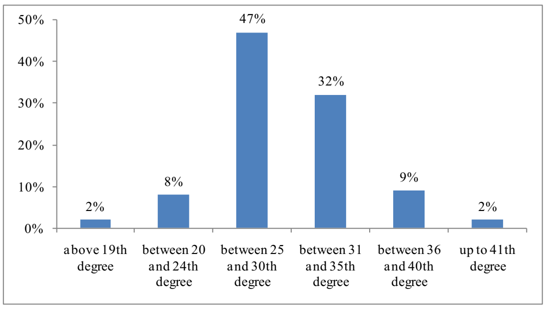

Fig. 13: Range of different inclination's angles

It was analyzed the penetration of devices with PROCEL Seal. It was identified that 61% of the equipment installed after 2000 had the Seal. As already explained, the Procel Seal ensures the quality and efficiency of equipment used. An example of this is shown in Figure 14.

Fig. 14: Procel Seal

The problems the most occurrence were leaks, deterioration of paint and rust. Leaks, as shown in Figure 15, occurred in 9.2% of assessed collectors; 63% of cases occurred in older systems, installed before 1988.

Fig. 15: Leak problem

Another important problem noted was the paint in the collector panel, which can be caused by poor paint quality or failure in the application process in the industry. It can be enhanced by moisture leak, as exemplified in Figure 16.

Fig. 16: Deterioration of paint

Figure 17 shows problems found in Belo Horizonte research.

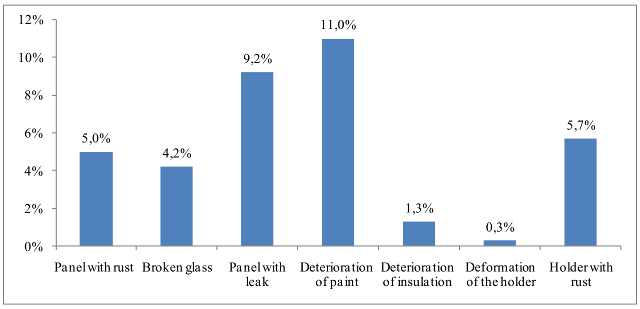

Fig. 17: Main problems founded

Problems with broken glass, deterioration of insulation and deformation of the collector were reduced in more recent installations, as expected. This indicates a need for periodic maintenance on solar heating systems, in order to ensure the equipment a 20-year lifetime.

Another problem is lack of accessibility. 30% of large systems presented elevated to high risk. Lack of monitoring and maintenance might be associated to accessibility difficulties, since these systems can't be reached. Moreover a great number of dirty solar collectors were detected: nearly 30%.

It was detected a general absence of monitoring systems and consumption control of hot water, gas or electric energy in 71% of large systems.

3.4. Hotels and Inns

The city of Porto Seguro is located on the southern coast of Bahia, in the Brazilian northeast, 714 km from the capital Salvador. It has a population of over 122,000 inhabitants. It is considered one of the most important tourism destination in Brazil.

It was identified more than 600 hotels and inns in the area, and about 25% used solar water heating. A sample universe of 150 businesses were identified by telephone survey and field visit. The sample was consolidated at 77 units. The hotel sample can be seen in Figure 18.

Fig. 18: Sample studied in Porto Seguro

The city management plan limits the construction of buildings to 2 stores. The survey found that the hotel buildings are predominantly with only one store high (93.5%). The tourist classification in number of stars is represented in the Table 3. The majority of the hotels surveyed did not have tourist classification in stars. 52% of the surveyed businesses had up to 40 guestrooms and number of guestrooms was 3,771.

Tab. 3: Hotel classification in number of stars

Number of stars	Absolute frequency	Relative frequency (%)
5	1	1,3
4	15	19,5
3	12	15,6
No star	45	58,4
Unanswered	4	5,2
Total	77	100

Regarding the cleaning of the glass collectors, 72.8% reported making monthly or annual cleanings; 14.3% reported they didn't know of this requirement. It was found on site inspection that only 58% of the samples were clean.

Electric system is used as auxiliary heating in 88.3% of buildings, gas in 5.2% and 6.5% do not use auxiliary system.

The survey found that most collectors were between 20m² and 40m² (18%), followed by surfaces of 10m² to 20m ² (17%), 40m² to 60m² (17%) and 60m² to 80m² (12%) - as shown in Figure 19.

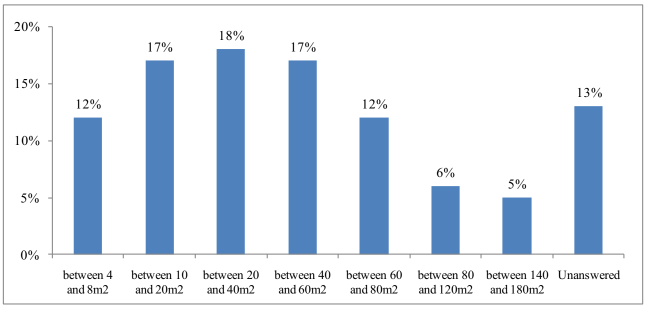

Fig. 19: Collectors' area studied in Porto Seguro

The number of collectors found varies from 2 to 90 units. In 29% of surveyed solar installations was found from 2 to 9 collectors. In 19% from 10 to 19 collectors and 17% presented from 20 to 29. There are at least 11% of solar installations that have between 50 and 90 panels.

The partial shading on the collector panels was observed, at the time, in 27% of solar installations as can be seen in Figure 20. It was also noticed some oxidation in the aluminum box of the solar panels in 18% of the samples. Problems with broken glass were found in 31% of samples studied.

Fig. 20: Shading on the collector panels

Moreover, panels with rust and leak were found in 27% of installations surveyed, deterioration of paint in 18%. Regarding the collector's holder: 11% were deformed and 6% with rust.

The average storage volume found at Porto Seguro's installations is presented in Figure 21. 27% of the storage tank samples have from 3,000 to 10,000 liters. It was found that 21.8% of the storage tank surveyed had some kind of deformation or oxidation. Difficulties to access the solar installations, absence of measuring hot water or auxiliary power system were also checked.

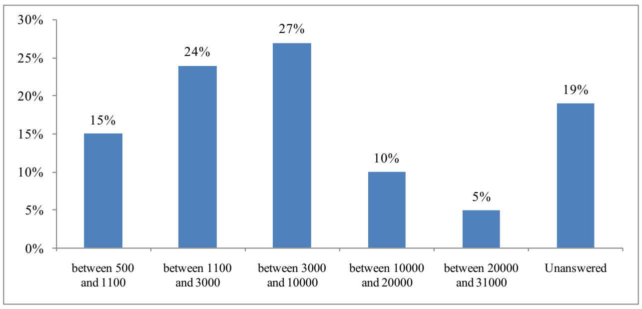

Fig. 21: Storage tank samples (in liters)

3.5. Swimming pool

Brasilia, FD, is located in the central region of Brazil and is the fourth-largest Brazilian city with a population exceeding 2.6 million. That location results in high levels of sunlight that reaches 2,600 hours annually. The average temperature throughout the year varies from 19°C to 23°C, and annual relative humidity in the Brazilian capital is 67%, varying considerably in the period from April to September, when it suffer a decrease and can reach levels below 25%.

Due to these facts, combined with the reasonable standard of living of this population and distance from the coast, Brasilia FD can be an example where a residence with a swimming pool that makes use of solar energy for heating poll water can easily be located. One example can be seen in Figure 22.

Fig. 22: Water heating in swimming pool

The values for the depth of the pools vary between 0.95m and 1.65m, with width values of 1.4m (19.5%) and 1.5m (36.4%). The average area is more usual between 41m^2 and 50m^2, as shown in Figure 23. 85.7% of the swimming pools surveyed make use of thermal covers; this is necessary to reduce the evaporative losses.

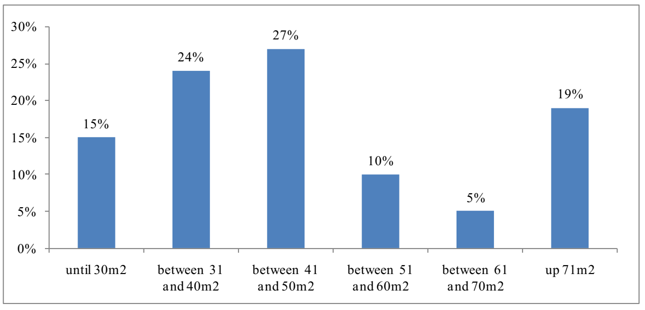

Fig. 23: Swimming pool area

The solar pool heating is a low-temperature application characterized by large volumes of water and collector area. Because of that, a transparent cover for the solar collector is not necessary in. On the other hand, the material of the equipment must be resistant to chemicals commonly added to treat pool water. The material most commonly used is polymer, as shown in Figure 24, which shows good results in terms of durability. The most common type of collector for solar pool heating is the open kind, which was identified in 94.8% of installations visited.

Fig. 24: Collector panels for solar pool heating

The collecting areas identified are distributed as follows: less than 22m² (13%), 22 m² to 40 m² (10%) and 9% higher than 40m^2. In 67% of the samples, it was not possible to have access to the installations. No leak in collectors was seen in the 90.9% of the 90 installations surveyed. That proves the quality of the materials used in these installations.

4. Conclusions

The use of electricity is predominant for water heating amongst Brazilian households due to the strong presence of instantaneous electric showers as the device most commonly used for this purpose. The immediate consequence of this fact is reflected in the inflated demand during the electric system´s peak-hour.

These studies were conducted in partnership with the following universities: IFBA, PUC-MG, UERJ, UFPA, UNB, Unesp and Unicamp. According to the project results, there is a high satisfaction level among the users, mainly due to the energy savings observed. However, there is a barrier associated with the equipment cost, especially for low-income households.

Problems of maintenance and the lack of knowledge proved to be occurring at all the inspected sites. Dirty solar panels, due to lack of access to the systems, collectors with broken glass and leaks are the most common problems.

It was not possible to analyze fully the energy benefits for users of solar water heating systems because monitoring systems were not available in most installations visited. In low-income households there is a study that installed 100 solar installations where this analysis was possible. The project was implemented in 2001 and carried out monitoring in the following four years and the energy savings result was around 35%.

Results observed in this research demonstrate the need to develop capacity building programs focused on design, installation, operation and maintenance of solar installations. Thus, it is necessary to stimulate the sustainable growth of the solar heating market in Brazil through the Procel Seal and the equipment labeling program. Finally, in cooperation with GIZ agency, a plan is being develop to provide the government policy guideline on solar water heating systems.

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