DEVELOPING QUALITY INDICATORS FOR LARGE SOLAR HEATING SYSTEMS AND DISTRICT HEATING

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Abstract

The Brazilian energetic matrix is composed by 50% of renewable energy as well as an electrical matrix that reaches levels greater than 80%. However, with national economic growth, it is necessary to expand the site of generation and distribution, promote the rational use of energy and especially to encourage and introduce a greater share of renewable sources in national energy matrix, for example the intensive program for replacement of electric showers by solar thermal systems that has been adopted by the government. This work was developed over the premise of the need to enhance quality and proper functioning of the solar heating systems. By laboratory tests, computer simulations and data analysis on the quality evaluation of the solar thermal installations in residential buildings in the city of Belo Horizonte (ECV Eletrobras Project 184/2006) was possible to establish the indicators of quality for large solar heating systems and elaborate a methodology for certification of such systems. This work was developed under the project ANEEL/CEMIG – R&D 183 – District Heating, which intends to apply the indicators and methodologies developed on the district solar heating system, which will be installed to attend about 50 low-income families, in an unprecedented action in the country.

Keywords: Solar Heating, District Heating, Quality Indicators, Systems Certification, TRNSYS

1. Solar water heating in Brazil

The use of solar water heating in Brazil, as in many countries, begun in the early 70's as a result of the worldwide oil crisis. However, the use of solar systems until the mid 90's was exclusive to higher income families and was often seen as a luxury. With sector regulation, rise of the electricity fares, reduction of the solar heating devices prices, better organization of the productive sector and the creation of Brazilian Rating Program/INMETRO **t**he solar water heating market in Brazil started to grow on annual rates as high as 20% in the last four years. [1]

According to the Brazilian Energetic Balance (BEN - 2008) [2], Brazil's residential sector was responsible for 22.2% of the electricity consumption, of which 24% is used to heat water for shower use (PROCEL, 2007). Therefore, over 5% of all the electric energy produced in Brazil is used for heating bath water. This fact, made even more staggering by the showering habits of the Brazilian population, concentrated in between 6 pm and 8 pm, and by the massive use of electric showers heads, with average power of 5.4 kW, in 78% of the Brazilian households, shapes a very critical scenario to the national electrical sector.

It's important to point out that under the Laws of Thermodynamics point of view and the concept of energetic availability, the thermal efficiency of the electric shower, calculated using the 1^{st} Law, it's of the order of 95%. However, when analyzed under the 2^{nd} Law, the efficiency is drastically reduced to 3.5%. This value means 96.5% of its potential is degraded into low quality thermal energy (water heating from 20ºC to 40ºC).

With the improvement of the quality life in Brazil, the reduction of the country's housing deficit, and the sustaining of the same water heating practices, the country would need an additional 8.6 GW of power to keep up with the demand. Based in these premises, the Federal Government created, in 2010, financial incentives for the massive adoption of solar water heating, mainly focused in low-income population. Extension of the subsidies for four more years are under study.

Brazil's solar heating industry, according to data collected from PUC Minas GREEN Laboratory's database, consists today of 120 manufactures. Often these companies act from production all the way to the commercialization and installation of the systems. As the market grows, it's expected that these companies will focus on manufacturing, allowing room for specialized companies, such as re-sellers and installation and maintenance.

2. Objectives

This study intends to establish a quality indicator for primary circuit of solar heating installations of medium and large sizes, based on field evaluations, experiments and mathematical simulations, using the TRNSYS software. The quality indicators and the suggestion of installation certification will be tested and evaluated in a later study for the primary circuit of a district heating system for low income families.

3. Background Fundamentals

Initially, an extensive bibliographical research was conducted on the subject of the study: solar collectors, monitoring techniques and solar heating system projects. The reports of Peuser, Remmers e Schnauss [3], of the Solarthermie 2000 project conclusions on the evaluation of solar heating installations in Germany, and the procedure proposed by Bonsanac e Nielsen [4] to verify in the field the performance of batteries of collectors, from monitoring the results and simulations in the TRNSYS, are of note.

The monitoring techniques of Christensen e Burch [5], in which the main objective was to validate the model proposed by the OG300 - Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems [6], stand out, for compiling different solar heating system monitoring approaches: from simple analysis of utility bills to the more complex approaches, through measurement and verification of a working system. Meir et al.[7] proposed the use of the calorimetric method to determine the efficiency of the installation, comparing the measured data to the TRNSYS simulations.

Some experiments were carried out in the laboratory : the evaluation of shading impact on the aboserber area, based on the studies by Appelbaum e Bany [8] and the drop in transmittance caused by dust over the glass, as described by Duffie and Beckman [9] citing the works of Dietz and Garg.

4. Methodology

Step 1 – Field research of several Solar Heating Installations in medium and high income multi-family buildings, developed in Project Eletrobrás (ECV 184/2006)[1] in the city of Belo Horizonte, with volumetric

[1] Project supported by Eletrobrás and executed by seven research groups to evaluate the quality of Brazilian solar water heating installations in different applications.

capacity superior to 3000 liters. Samples were chosen through research with the manufactures, maintenance firms and building administrations. A total of 547 installations were identified, of possible two thousand installations according to BHSolar, an association of manufacturers from Belo Horizonte. A sample size of 98 installations was determined according do a stratified random sample.

Step 2 – Consolidation of the field research results, data collected in the field surveys were divided in four groups: components of the heating system, sizing of each component, system design and operation conditions. Each group provided data to be used in simulations, laboratory tests and qualitative analysis of the installation.

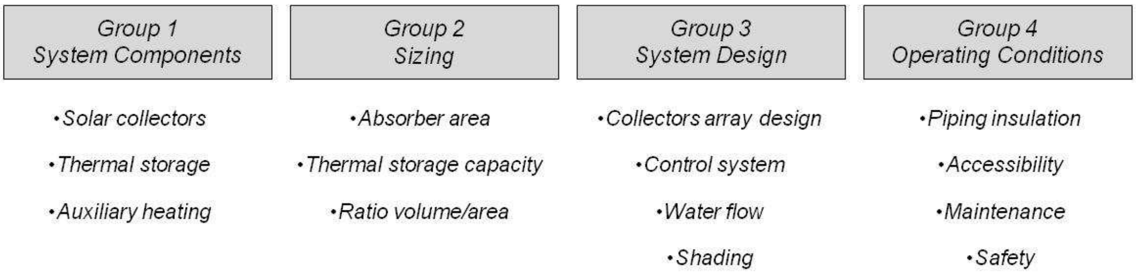


Fig. 1. – Groups of analysis for determining the installation quality indicators.

Step 3 – Planning of the Computerized Simulations – a “reference” installation was modeled and simulated using TRNSYS, as show in Figure 2, with the following properties:

<u>Installation conditions</u>: Belo Horizonte – MG (latitude 20º South) with surface azimuth angle 180º and collector slope 30º.
<u>Heat load typology</u>**:** daily consumption of 6000 liters at 40°C, 40% of the total volume between 6 am and 8 am and rest between 6 pm and 8 pm.
<u>Solar collector</u>: 30 solar collectors, each with 2 m² of absorber area, in two groups in series, each group containing three modules in parallel, each module consists of five collectors in parallel.
<u>Thermal storage tanks</u>: two storage units with 3000 liters each, with 5 nodes and global heat loss coefficient of 3.0 W/m².K
<u>Auxiliary energy supply</u>: gas-based heating system with thermal efficiency of 83% and set temperature of 45°C.
<u>Control System</u>**:** on-off control schemes with a differential temperature controller: ΔT_{on}=2°C e ΔT_{off} = 5°C . The flow rate through the system was of 1440 liters per hour.

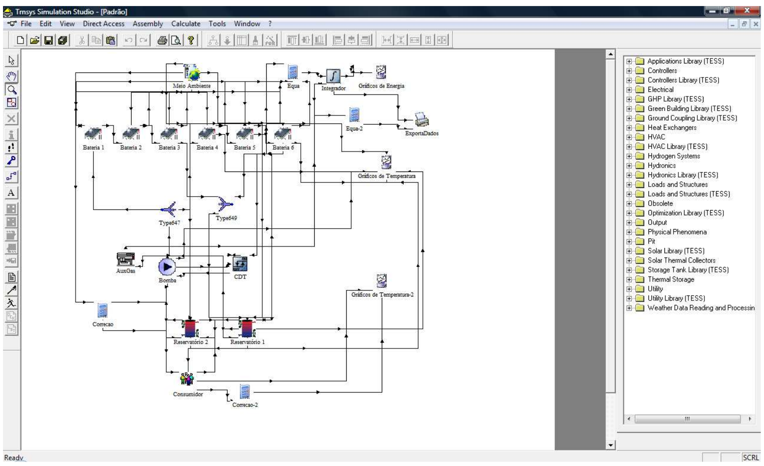


Fig. 2. Example of the screen TRNSYS Simulation

Step 4 – Laboratory Tests were conducted using GREEN Solar's solar simulator to estimate the drop in efficiency of a single collectors, caused by shading and lack of maintenance of the absorber area.

Evaluation of the reduction of the efficiency of a solar collector without cleaning: a flat solar collector was exposed to solar radiation for a period of 6 months without any maintenance or water flow. After the exposure period its thermal efficiency was evaluated, dirty, at first, and after cleaned, according to the EN 12975 standard [10], indoor tests were performed with a solar simulator.

Efficiency evaluation under various degrees of shading: usually caused by other collectors or the building itself, tests were run using an opaque polymeric material covering from 0% to 50% of the absorber area, with steps of 10%. The tests were run shading the collector from bottom to top and from top to bottom.

Fig. 3. Detail of the solar collector shadowed by a battery ahead.
Source: GREEN Archives

Step 5 –Definition of qualitative and quantitative indicators of central solar heating installations as to create a certification. Through data analysis, several criteria for evaluating the installation were defined and were given weight, based on how heavily the criteria influence the overall quality of the installation.

5. Results

It was evaluated 3610 solar collectors, with a total area of 7622 m², and a total hot water storage capacity of 518,287, 63.5% of the installations have 10 years or less, 12.9% are between 10 and 15 years old, 3.5% of the samples are over 15 years and for 20.1% the age of the installation was not identified. In 70% of the installations had auxiliary heating devices fueled using LPG, while the 30% had electric-based backup.

As an example on how the quality of certified collectors can vary widely, collectors from a manufacturer exhibited 257 issues, either infiltration, oxidation or paint degradation while, collectors of another manufacturer showed only 72 problems, even though the field research found that the latter had three times as many collectors. This example illustrates the urgent need for the rapid adoption of the new standard ABNT NBR 15.569 [11], heavily based on EN 12975, which includes more rigorous quality tests.

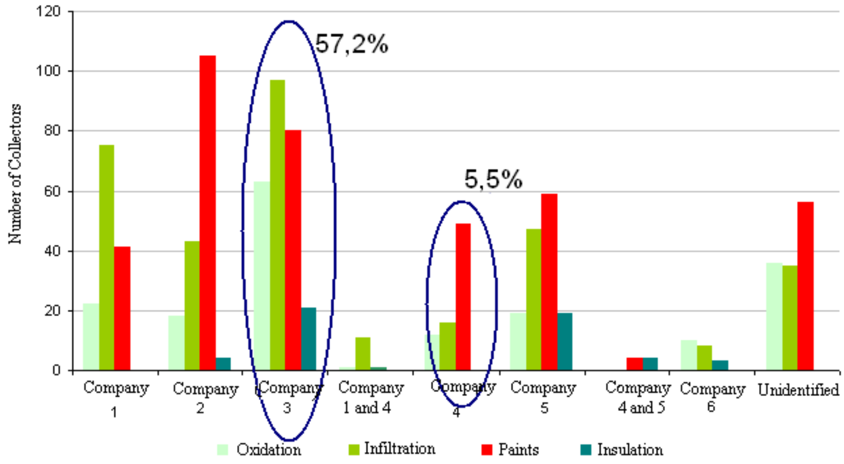
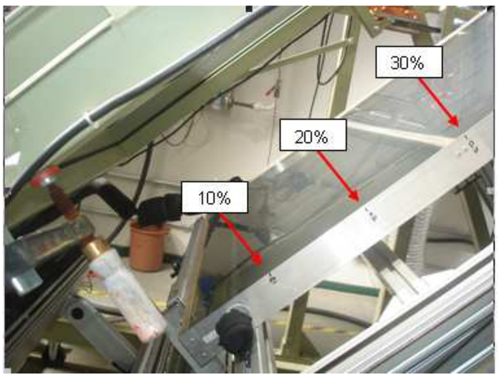


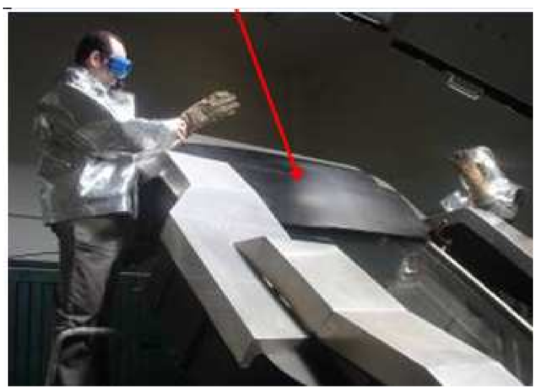
Fig. 4. Incidence of oxidation, infiltration, paint deterioration and isolation problems by researched manufacturer.

System design errors were also frequent, 59% of the installations consisted of only collectors in series, in one instance the system was a single series of 28 collectors, in 26% of the samples all collectors were in parallel with each other and only 14% had mixed design. Installers justified the serial design because such installations are easier to perform and smaller quantities of pipelining, accessories and insulation reduce the initial cost of the system, by doing so installers disregard the recommended upper limit of five collectors in a single series. Only 9% of the samples respected this upper limit, showing a lack of knowledge of the best practices of large solar heating system design.

On Group 4, it was evaluated the pipes thermal isolation, the accessibility to the solar heating installation, the maintenance and the safety aspects. A recurring fail in the systems maintenance was evidenced, with rating of 30% to dirty collectors most likely associated to access difficulty. In 29.2% of the works, the access to the collectors was evaluated as medium and extreme risk.

In the shadowing, laboratory tests, Figure 5, it was demonstrated that the shadowing in the lower-half of the collector is more critical than at the top. This behavior was expected, since the heat losses are greater in the top-half of the collector, when this part receives only diffused radiation, the global loses of the collector are minimized.





(a) Markings used to indicate the simulator percentage of shadowing in the solar collector

(b) Mounting of rampart in the solar

Fig. 5. Test of evaluation of the shadowing effect over the efficiency of the solar collector.

The test of thermal efficiency with the dirty solar collector demonstrated a reduction in the order of 2 percent points in the efficiency of the collector when compared to it clean which contributed to the quantification of this aspect in the quality indicators, Figure 6.

(a) Clean collectors in the beginning of the exposition test (12/10/2008)

(b) Dirty collectors in the end of the exposition test (05/15/2009)

Fig. 6. Collectors exposition test to the evaluation of the incrusting

Based on the results of over 160 simulations, it became possible to identify the weights to be considered in the installation quality indicators, specially to collectors and hot water storage. This initial proposition, showed on Table 1, was validate for three different installation, being that the final result was considered adequate since the final values found reflect a consensus of the team as of the quality of the system.

Table 1 – Quality indicators weights – part 1.

A. COMPONENTS			
1 - Solar Collectors	**Options**	**Points**	**Maximum Points**
Cleanliness	Clean	2	**21**
	Dirty	0	
Oxidation Level	Absent	4	
	Low (up to 15% of collectors)	2	
	High (above 30% of collectors)	0	
Coverage	Good	3	
	Cracked	1	
	Broked	0	
Leak	Good	4	
	Condensation	2	
	Infiltration	0	
Paint	Good	5	
	Middle level (up to 15% of collectors)	3	
	Critical (above 30% of collectors)	0	
Insulation Deterioration	Good	3	
	Bad	0	
2 - Thermal Storage	**Options**	**Points**	**Maximum Points**
External deformations	No	2	**13**
	Yes	0	
Bracket oxidation	Absent	3	
	Low (up to 15% of collectors)	1	
	High (above 30% of collectors)	0	
Leak	Absent	5	
	Critical	0	
General state of insulation	Good	3	
	Median (perceived fails in the insulation)	1	
	Poor (high number of failures)	0	

Table 1 – Quality indicators weights – part 2.

3 - Auxiliary Heating	Options	Points	Maximum Points
Eletric			
Eletrical parts identification	Yes	3	7
	No	0	
Cable protections	Yes	4	
	No	1	
LPG Heaters			
Smut sinals in the heaters	Absent	3	7
	Low	1	
	High	0	
Shelter for the gas heaters	Appropriate	3	
	Inadequate	1	
LPG tubes identification	Existent	1	
	Absent	0	
4 - Pumps	**Options**	**Points**	**Maximum Points**
Oxidation Level	Absent	2	4
	Low	1	
	High	0	
Leak	Absent	2	
	Critical	0	
B. PRIMARY CIRCUIT (Solar collectors and Storage connection)			
1 - Thermal Insulaion	**Options**	**Points**	**Maximum Points**
General quality	Good	4	4
	Poor	2	
	Absent	0	
2 - Electrical components	**Options**	**Points**	**Maximum Points**
Security	Good	4	4
	Median	2	
	Poor	0	
3 - Maintanence	**Options**	**Points**	**Maximum Points**
Accessibility	Good	3	3
	Median	2	
	Critical	0	
4 - Collectors Brackets	**Options**	**Points**	**Maximum Points**
Oxidation	Good	3	5
	Median	2	
	Critical	0	
Deformation	No	2	
	Yes	0	
5 - Shading	**Options**	**Points**	**Maximum Points**
Annual solar fraction (SF) reduction	SF < 3%	4	4
	3% <= SF < 6%	3	
	SF >6%	0	
C. SOLAR FRACTION			
1 - Solar Fraction	**Options**	**Points**	**Maximum Points**
Solar Fraction (SF)	90% <= SF < 80%	35	35
	80% <= SF < 70%	28	
	70% <= SF < 60%	21	
	60% <= SF < 50%	17	
	50% <= SF < 40%	7	
	SF < 40%	0	

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