Impact of compact solar domestic hot-water systems on the peak demand of a utility grid in Brazil

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Introduction

A particular characteristic of the electric energy consumption in Brazil is the widespread use of electric showerheads and the resulting peak demand between 18h and 21h. Over 90% of the residences in Brazil have electric showerheads. Studies have shown that electric showerheads represent approximately 23% of a household's energy consumption and this fraction increases to around 35% of the total demand during the peak hours for low-income consumers (Prado and Gonçalves, 1998). Electric showerheads are very cheap, usual prices lie under US$30 in Brazil, have a nominal power between 4kW and 8kW and are very efficient in terms of energy conversion. All these aspects contribute to the large scale use of electric showerheads for water heating among low-income consumers. Furthermore, showering is the only use of hot-water by this class of consumers in Brazil. Therefore, Compact Domestic Solar Hot-Water Systems - CDSHWS, cheaper and easy to install when compared to conventional solar hot-water systems, may be an economically attractive alternative to supply large scale hot-water usage, with the benefit of reducing the peak demand on the utility grid.

Utilities in Brazil are obliged by regulation laws to supply electric energy to low-income consumers. However, the associated costs of energy generation and distributions are heavily affected by the power of the electric showerheads, making investments in almost all cases economically unviable. Januzzi and Schipper (1991) estimate that the marginal expansion costs lie around US$ 1,500.00 per kilowatt. (falta ref para inserir). This scenario leads to the conclusion that the utility can account for the large scale installation of CSDHWS in its investment policy. In other words, the utility can share the cost of the solar heaters, which lies around US$ 300,00, with low-income electricity consumers.

In a previous work, Salazar et al. (2003) optimized seven parameters of a CSDHWS using peak demand and total cost as constraints. The optimized parameters were: collector aperture area, storage tank volume, heater power, electric showerhead power, set-point temperature of the storage tank, mixing valve temperature and collector slope. The chosen optimization procedure was successful, but the lack of information on hot-water consumption profiles is a limitation on the reliability of the predictions.

Colle et al. (2003) carried out the economical optimization of the CSDHWS storage tank insulation thickness. The optimization showed that life cycle cost savings are sensitive to insulation costs, when preheating of the storage tank during the morning early hours is required in order to avoid the expected peak demand. This optimization concern should be taken into account, in order to minimize the cost of CSDHWSs.

To study the effects of CSDHWSs on the peak demand, ninety low-income consumers from a housing unit were chosen to have their showerhead electric energy consumption monitored. Sixty consumers were equipped with CSDHWSs, while the remaining consumers served as a reference case. The electric energy

consumption of the showerheads was continuously measured, providing the profiles from which the results of this paper are derived.

Experimental Setup

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The CSDHWS works in a single phase thermosyphon mode, consisted of a single glazed flat-plate collector and a horizontal storage tank equipped with a resistor located immediately above the collector, as shown in Fig. 1. The system can be easily accommodated on the rooftop and integrated with existing piping (see Fig. 2). An additional electric showerhead, with continuously adjustable power, provides extra heat input. Therefore, auxiliary energy can be added to the system either in the storage tank or in the electric showerhead, but in the present analysis only the electric showerhead was used. The system is also equipped with a thermostatic mixing valve at the storage tank outlet pipe, which prevents scalding. The compact system is only used for showering purposes. Table 1 shows the technical characteristics of the system. The solar collector was tested according to European flat-plate collector test standards (Müller-Steinhagen, 2002).

Table 1. Technical characteristics of the compact solar hot-water system

Flate-plate Collector		
	Aperture area	1.36 m^2
	Absorber area	1.32 m^2
	Glazing	Single glass cover
	Plate	copper
	Absorber coating	Black organic paint soluble in water with total absorptance equal to 0,95.
	Risers and headers	copper
	Insulation thickness	50 mm glass wool (20kg/m^3)
	Manufacturer	Solares LTDA, Brazil
Storage tank		
	Volume	100 l
	Insulation thickness	50 mm glass wool (20kg/m^3)
	Heater Power	1.5 kW (disabled)
Electric Showerhead		
	Power	0-6.8 kW
	Manufacturer	Botega, Brazil
Thermostatic Mixing Valve		
	Mixing Range	30°C-70°C
	Manufacturer	OSTACO AG, Switzerland
Piping		
	Material	CPVC
	Insulation	10 mm polyethylene

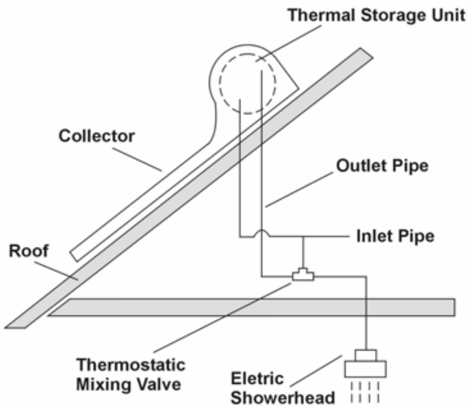

Figure 1. Compact solar hot-water system scheme

A total of two hundred consumers from a housing unit for low-income families (monthly income from US$250.00 to US$500.00) were interviewed using a questionnaire based on a model suggested by Vine et al. (1986). Ninety families were selected according to the similarity with a standard hot-water consumption profile and sixty of them received a CSDHWS. The groups are named as follows:

(i) Group A – sixty consumers with CSDHWSs.
(ii) Group B – thirty consumers without CSDHWSs.

Fig. 2 shows the systems installed on the rooftops. The buildings were financed by Caixa Econômica Federal (Federal Brazilian Savings Bank) under a leasing contract.

Figure 2. Compact solar domestic hot-water systems on the roof of the buildings

The power of the electric showerheads of all ninety consumers was averaged over five minute intervals. The consumers without the CSDWHS were used to characterize the typical energy consumption profile of a group of low-income consumers. The comparison between the two groups was used to estimate the solar fraction provided by the solar systems.

Discussion of the results

The values presently analyzed were measured during the summer month of February, 2004. Although the solar absorbed energy is high, the number of showers per inhabitant tends to increase compared to other seasons, possibly having a negative net effect on the solar fraction.

Fig. 3 shows the daily totals of solar irradiation on a horizontal surface and the daily average of ambient temperature during February 2004. The daily total of solar irradiation data and the daily average ambient temperature were measured in a site[1] located 25 km distant from the housing unit. The solar irradiation distribution as well as the ambient temperature is similar to those measured at the reference site. It can be observed in Fig 3 that the analyzed month had high solar irradiation levels, low values occurring only on two days. The daily average temperatures during the month lie between 20°C and 30°C, which are typical values for the summer season in Florianópolis.

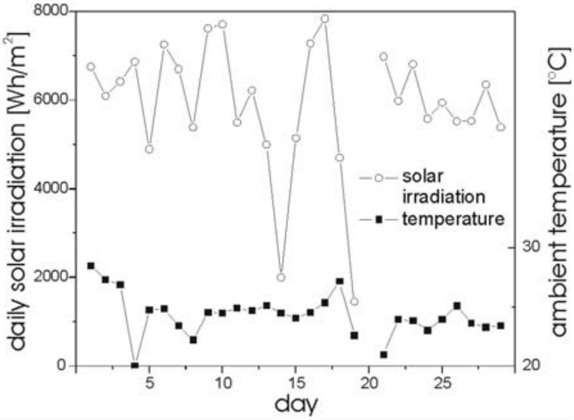

Figure 3. Daily solar irradiation and average ambient temperature during February 2004.

Suspicious data, collected from vacant apartments or resulting from incorrect use of the CSDHWS, were discarded from the analysis. Measured data from a total of 44 consumers from Group A and 24 consumers from Group B were used.

The measured power of each of the showerheads was totalized in hourly intervals and divided in three subsets according to the weekdays as follows:

(a) workdays;

(b) weekends and holidays;

(c) all days.

This division is intended to verify if differences exist in the consumption profiles between workdays, weekends and holidays.

Fig. 4 shows the mean electricity consumption profile of Group B. It can be seen that the consumption profile is characterized by a very low consumption from 2 AM to 5 AM. After this time interval, the energy consumption rises to a new level that persists until the middle of the afternoon (4 PM). During this period, a small peak was found before noon, probably caused by those who work or study only during the afternoon. At the end of the afternoon, the energy consumption increases substantially, reaching its peak around 7 PM, to then decrease. The relation between the average consumption and peak demand (load factor) was 0.37. The visual inspection of Fig. 4 leads to the conclusion that there is no considerable difference between workdays and weekends.

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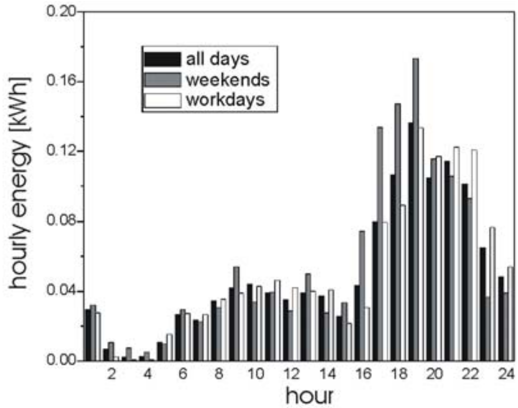

Figure 4. Monthly average of the hourly energy of the electric showerheads of Group B

The average hourly energy consumption of Group A is compared with the values for Group B in Fig. 5. The hourly peak of energy consumption still remains in Group A, however, the energy consumption is significantly reduced compared to Group B. The load factor was 0.38, which is practically the same value obtained for Group B. Comparing the peaks of the two groups, it was found that the peak demand of Group A is 60% lower than the peak demand of Group B.

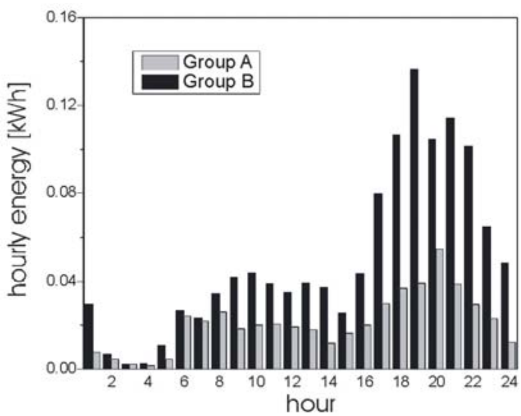

Figure 5. Monthly average of the hourly energy of the electric.

Fig. 6 shows the hourly solar fraction, considering that the hot-water consumption profile is the same for both groups. It can be observed that the solar fraction varies from 40% to 80% during most of the day, but it becomes lower in the morning periods. This is probably due to the storage tank heat losses during the night and also to those cases where stored hot-water was consumed during the previous day. From to 2 AM to 5 AM the solar fraction is not representative since hot-water consumption is low. The solar fraction obtained during the analyzed month (February 2004) was 58%.

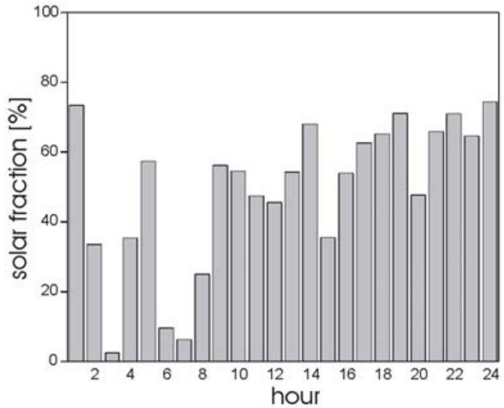

Figure 6. Hourly solar fraction.

The true peak demand can be identified from instantaneous power values. In the present analysis, power is averaged in 5 minute intervals, which can be considered a good approximation of the instantaneous values. Fig. 7 shows the average power of Group B on the day during which the highest peak occurred (01-Feb-2004). The same is shown in Fig. 8 for Group A (28-Feb-2004). It can be seen in Fig. 7 that the maximum contribution of the electric showerhead to the peak of each low income consumer was 0.57 kW. On the other hand, Fig. 8 shows that for a group of consumers with the same characteristics, but owning a CSDHWS, the contribution to the peak is around 0.30 kW. Therefore, the power necessary to supply electricity to the showerheads was reduced by 47% with solar heating.

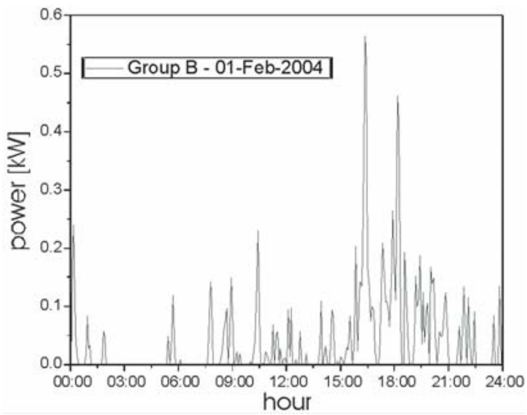

Figure 7. Average power consumption for Group B (01-Feb-2004).

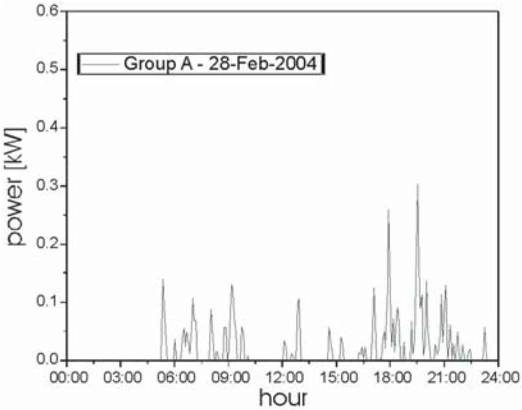

Figure 8. Average power consumption for Group A (28-Feb-2004).

Conclusions

The impact of the use of CSDWHSs on the peak demand of a utility grid was determined for a group of low-income consumers. The energy consumption profiles of the groups are an average of the individual profiles; therefore they represent a variety of electric energy consumers.

The peak demand still remains, even with solar heating, but its use can reduce the peak by 60% on a monthly average basis of the hourly values. Using the power recorded in 5 minute interval averages, a reduction of 47% was achieved for the days where the highest values occurred. However, the obtained results were derived using only one month of data of a specific housing unit, therefore, results presented here are far from being conclusive. Data measurement will continue until one year is completed.

The estimated solar fraction for this period was 58%, but there is a high variability among the results for different families.

The ongoing research will take into account the determination of typical individual consumption profiles and the relative contribution of each profile on a group of low-income families. These consumption profiles will provide the basis for simulation of CSDHWSs conjugated to showerheads. The theoretical results will be validated against experimental data collected in the same housing unit. The validated results will be used to evaluate the impact of CSDHWSs on the peak demand of urban utility grids for other locations in Brazil.

An additional measure to further reduce peak demand on days of low solar irradiation may be electric preheating in the storage tank using weather forecast information. In this case, better thermal insulation of the storage tank as well as improved tank design may be necessary in order to maintain the stored water at acceptable temperature levels over long periods. The authors are presently investigating an algorithm that uses weather forecast information as input to predict the need of storage tank preheating.

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