ENERGY CONSERVATION AND ELECTRIC ENERGY PEAK REDUCTION POTENTIAL DURING PEAK HOURS FOR A GROUP OF LOW-INCOME RESIDENTIAL CONSUMERS OF A BRAZILIAN UTILITY

Juan Pablo de Lima Costa Salazar
Samuel Luna de Abreu
Sergio Colle
Universidade Federal de Santa Catarina
Florianópolis, SC 88040-900
Brazil
js522@cornell.edu
samuel@emc.ufsc.br
colle@emc.ufsc.br

Wilson Reguse
Centrais Elétricas de Santa Catarina, S.A
Av. Itamarati 160
Florianópolis, SC 88034-900
Brazil
WilsonR@celesc.com.br

ABSTRACT

The main objective of the present work is to assess, through the use of a compact thermosyphon solar hot water heating system with a backup electric showerhead heater, the energy conservation and the electric energy peak reduction potential during the peak hours for a group of low-income residential consumers in Florianópolis, Brazil (-27.6°S). In order to quantify these potentials, a total of 90 low-income consumers were chosen to have their electric energy consumption monitored. Analysis of the collected data rendered relevant information for energy conservation policies, such as the hourly distribution of hot water consumption, the fraction of the electric energy consumption used for water heating, the average contribution of electric showerheads to the peak demand, and the estimated solar fraction for the group of consumers.

1. INTRODUCTION

Electric energy demand is marked by a pronounced peak around 18h, as can be seen in Fig. 1, a typical demand curve for the Brazilian utility CELESC from the year 2003 (CELESC, 2004). Adoption of time-of-use rates for the industrial sector inhibits electric energy consumption at peak hours. Therefore, the peak in the demand curve is attributed chiefly to the residential sector. According to a study conducted in 1987 (Jannuzzi & Schipper, 1991), water heating is responsible for 23% of the residential electric energy consumption in Brazil, only behind the contribution due to refrigeration (33%). Also, as said by the same study, 70% of electrified dwellings have electric showerheads, constituting the main water heating equipment used in Brazil. This is largely due to low price of electric showerheads and the low associated installation costs. Additional hot water piping and a hot water storage tank are not necessary. Also, investments in hydraulic power plants in Brazil over the last decades have reduced energy costs for the final consumer (Prado & Gonçalves, 1998), therefore indulging the use of electric energy for water heating.

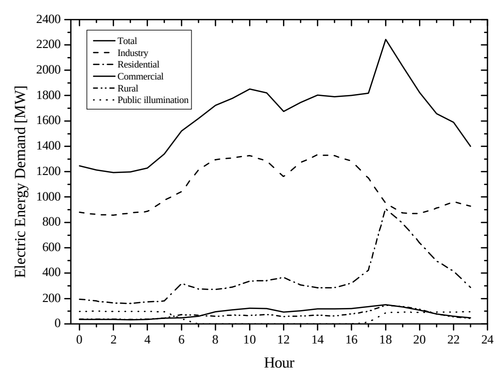

Fig. 1: Electric energy demand curve for a typical day of 2003 in the CELESC concession region.

Electric showerheads are targets of conservation policies because of their use predominantly during the peak demand hours, as well as their increasing nominal power rates and short time operation, resulting in low load factors (Prado & Gonçalves, 1998; Geller *et al.*, 1998; Oliva & Borges, 1996). Geller *et al.* (1998) estimate the associated investment by the utility per electric showerhead in US$800-1000 (generation costs only).

In the residential sector, electric energy consumption is constituted primarily of refrigeration, followed by water heating and illumination (Geller *et al.*; 1998; Almeida *et al.*, 2001). Efficient use of solar energy for water heating is an alternative towards reducing total energy consumption and the peak demand, given that the consumption occurs during peak hours.

Salazar *et al.* (2003) presented a methodology to optimize the main design parameters of the solar water heating system used in the same housing unit. Colle *et al.* (2003) deal with the insulation optimization and found it an important parameter for economic analysis. Abreu *et al.* (2004) published the first results obtained from this housing unit and in the present work it was completed with data from 11 months of measurements.

2. METHODOLOGY

The only measured physical quantity was the average power of the electric showerheads over five minute intervals. An energy meter was installed in each apartment and connected in series with the electric showerhead. All electric showerheads are from the same manufacturer and model, with a manually adjustable power rate up to a maximum value of 6.8 kW. This procedure is accomplished by turning a knob. The total group of 90 consumers was divided in two subgroups, one of 60 consumers with installed compact solar water heating systems (Group A); and a second group, of 30 consumers, which had their hot water supply fully provided by the electric showerhead (Group B). The latter group was used as a reference group. A partial view of the public housing unit with installed compact solar water heaters is shown in Figure 2. All solar water heating systems are of the thermosyphon type, with a single-glazed, collector aperture area of $1.4 m^2$, and have a storage tank of 90 liters (Fig. 3). The auxiliary heater in the thermal storage unit was deactivated. The estimated cost of each unit lies around US$300.

The consumers were chosen based on a questionnaire for identification of hot water load profiles (Vine *et al.*, 1986). Data was collected during the first 10 days of each month, from February thru December 2004. Approximately 75% of the total available data was collected. This was due to the fact that the meters were located inside the residential apartments; therefore the presence of consumers was required during data collection.

Consumption data was summed up over one-hour intervals to facilitate data interpretation and classified in three groups: business days, weekends and holidays, and all days. This classification is intended to verify different hot water usage habits between business days and weekends. The following quantities were compared between groups A and B: monthly average of hourly electric energy consumption of each showerhead; total percentage of electric energy consumption attributable to the electric showerhead and instantaneous[1] power rate at each month's day of highest demand. Also, an estimate of the solar fraction f^* was calculated based on the monthly average electric energy consumption per showerhead of both groups, according to,

$$f^* = \frac{Q_B - Q_A}{Q_B}, \qquad (1)$$

where the subscript denotes each group. This is an estimate, based on the assumption that consumers in both groups have comparable hot water load profiles.

Fig. 2: Low-income family housing unit with installed compact solar water heating systems.

[1] Instantaneous here means averaged over five minute intervals.

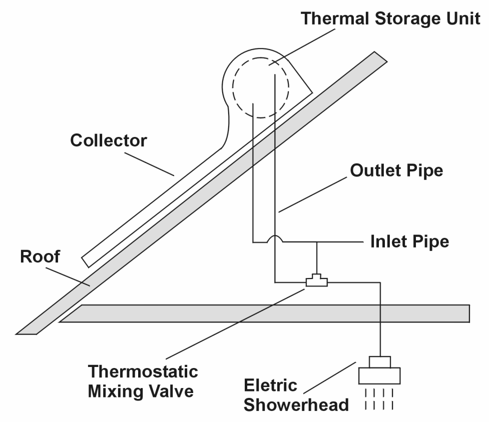

Fig. 3: Compact solar water heating system scheme.

3. RESULTS AND DISCUSSION

The most relevant quantity for economical analysis of solar water heating systems is the solar fraction. Tab. 1 show results of the estimated solar fraction over the 11 month period under consideration, along with values of the monthly average daily global radiation on a horizontal surface $\overline{H}$.

TABLE 1: ESTIMATED SOLAR FRACTION

Month	f^*	$\overline{H}$ [MJ/m^2]
February	0.56	21.52
March	0.56	17.31
April	0.59	13.74
May	0.32	9.89
June	0.40	10.44
July	0.39	8.91
August	0.14	13.33
September	0.38	13.21
October	0.45	17.64
November	0.57	18.21
December	0.63	20.71
Average	0.45	15.33

The highest solar fraction occurred during the summer month of December, whereas the lowest occurred in August. The dimensions of the system were considered low for the total hot water load of each family (on average three members, two adults and one child). Also relevant is the fact that most consumers were not acquainted with solar water heating systems, particularly this configuration. A continuing effort has been made in educating consumers about the system and solar energy. Excessively long hot water piping could not be avoided, which led to large waiting periods for hot water. Many consumers would "give-up" on the solar system, complaining about water waste. The average solar fraction for the entire period is 0.45, considered low for the level of global incident irradiation for this region, but compatible with the size of the system.

An alternative approach to the solar fraction is to estimate it over each hour of the day. These results are presented in Fig. 4. Over night hours (0-6h) consumption is very low and comparisons between both groups are less accurate. Over day hours, it is seen that the solar fraction attains a peak in the hour before noon and also at the late afternoon and early night, coinciding with peak demand hours for the utility.

The general picture shown in Fig. 4 is also depicted in Fig. 5, where the monthly average of hourly electric energy consumption for both groups is shown. Although the highest solar fraction is reached at 16h, it is during the period from 17h to 22h that electric energy consumption is highest. At the peak hour of 18h, an estimated 0.044kWh per electric showerhead is saved by the solar hot water heating system. Although this number is small when looked upon individually, the great potential lies in the large scale use of solar technology. No relevant discrepancies between business days and weekends were found. The results presented here are averaged over all days.

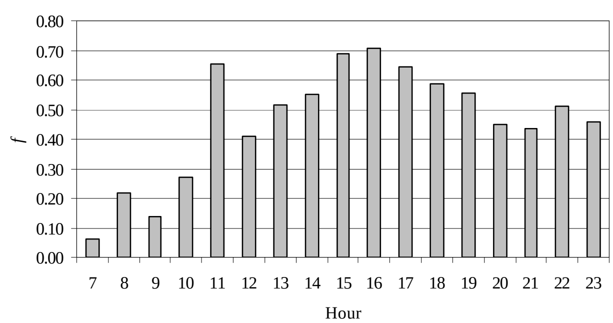

Fig. 4: Average hourly solar fraction.

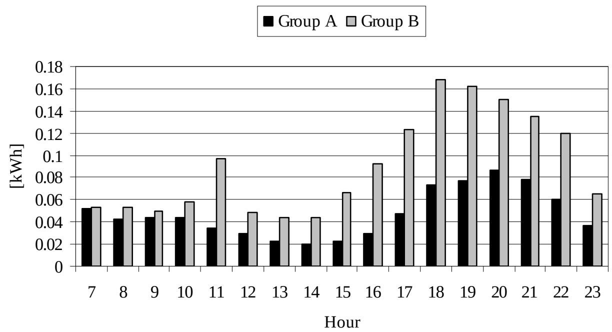

Fig. 5: Monthly average of hourly electric energy consumption.

The comparison of the peak demand in each month for both groups is shown in Fig. 6. Total peak data for September was corrupted and could not be recovered. Reduction of peak demand was observed only during summer and spring. The largest peak reduction (34%) was measured in October. This behavior is expected since there is no auxiliary heater input in the thermal storage tank. Therefore, it is rather obvious that the peak reduction potential, although existent, has to be assured by auxiliary heating of the storage tank. Future implementation of weather forecast information in an off-peak auxiliary heating scheme is under investigation. In doing so, one can assure peak demand reduction without compromising solar collector efficiency.

The fraction of each household's monthly electric energy consumption attributed to water heating purposes is shown in Tab. 2. Data is only available from February thru May 2004. The numbers shown for Group B agree fairly well with the result obtained by Jannuzzi & Schipper (1991), of 23%. The solar water heating system, although undersized, is capable of reducing the fraction of the electric energy bill spent on water heating. In May both groups present practically the same fraction, as this month is one with a very low estimated solar fraction.

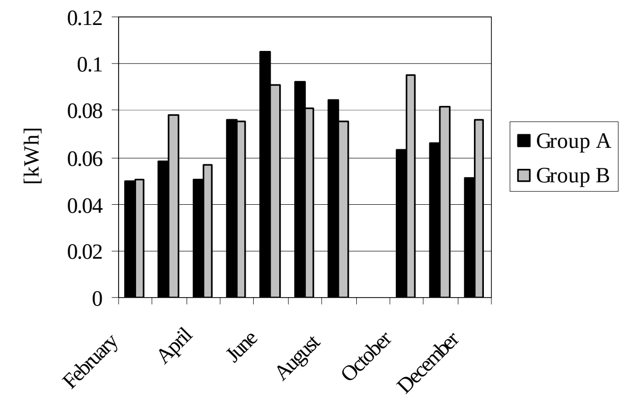

Fig. 6: Electric showerhead peak demand for each month

TABLE 2: FRACTION OF MONTHLY ELECTRIC ENERGY CONSUMPTION ATTRIBUTED TO WATER HEATING PURPOSES

Month	Group A	Group B
February	0.15	0.21
March	0.13	0.22
April	0.14	0.25
May	0.26	0.25

Analysis on hot water load trends was done using data from Group B only. The reason of this lies in the fact that no water flow measurements were made. This means that data from Group B represents the actual total hot water load, whereas data from Group A indicates the amount of energy that is not supplied by the solar water heating system. Three major profiles were identifiable: a morning profile; an afternoon profile and an evening profile. These profiles are shown in Figs. 7 thru 9. It was found that 10% of the sample had a morning profile, 18% an afternoon profile and 72% an evening profile. The predominance of an evening profile is also a factor contributing to the attractiveness of solar water heating systems for peak demand reduction. The remaining 1% had a load characterized by consumption mainly between 0-6h. Analysis of data from Group A identifies the same trend as shown for Group B, but in this case a larger fraction of electric energy consumption is found in the morning hours. It is precisely throughout this period that the probability of the solar hot water heating system failing to provide hot water is higher. Under the assumption that the hot water load profiles of Group A and Group B are similar, in months of low solar irradiation, consumption during evening hours increases, overwhelming that verified in morning hours. In contrast, during months of high solar irradiation, the ratio of evening to morning hour consumption decreases. Noteworthy is that there is very scarce information on hot water load profiles for Brazilian households, let alone for low-income families. Although no information is presented here on the amount or temperature of hot water consumed, hourly trends are clearly shown. Occasional measurements with family members indicated an approximate shower temperature of 37^{o}C.

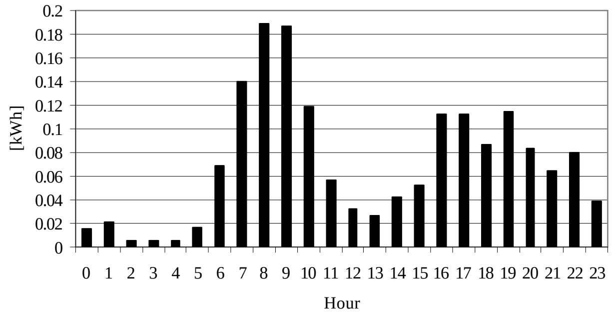

Fig. 7: Hot water load for morning profile

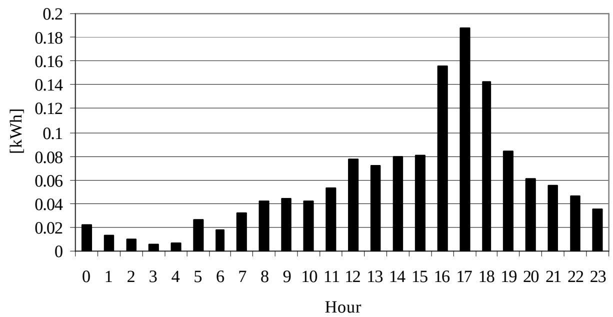

Fig. 8: Hot water load for afternoon profile

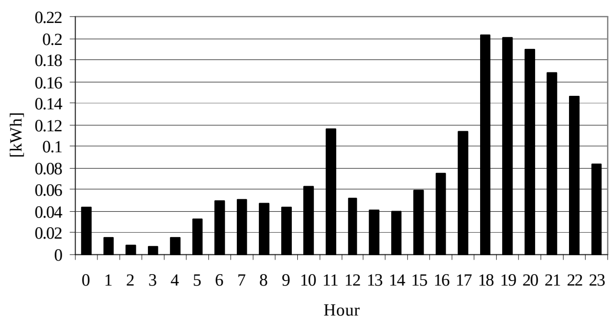

Fig. 9: Hot water load for evening profile

3. CONCLUSION

It is important to note that the results herein presented are those from a group of low-income families of a housing unit located in Florianópolis, Brazil. There was no rigorous statistical analysis of data and the extrapolation to other circumstances or regions is not recommended. The period of analysis is also limited. Another limitation of the present study is the lack of information on actual hot water load volume/mass flow rates. Nonetheless, the authors believe that the data presented is relevant for conservation policies and clearly shows potential for large scale use of solar energy for water heating purposes, as a means for energy conservation and peak load reduction (subject to auxiliary heat input in the storage tank). Finally, it is not to let without notice that this work is part of a greater effort in assessing the potential of energy conservation policies, which includes thermal system simulation with TRNSYS and multi-objective economic optimization. More information can be found in Salazar (2004). An off-peak hours storage tank preheating algorithm is being developed to guarantee peak load reduction. This algorithm will be fed by 24h window meteorological forecast information.

4. ACKNOWLEDGMENTS

The authors are deeply indebted to Caixa Econômica Federal, the Public Housing Authority responsible for the housing unit where the study was conducted, as well as to Centrais Elétricas de Santa Catarina SA, for funding the project and believing in its potential. Above all, we would like to thank the families that contributed with their patience and good will, both elements that were essential towards the important results achieved by this study.

5. REFERENCES

1. Abreu, S.L., Salazar, J.P.L.C., Colle, S., "Impact of compact solar domestic hot-water systems on the peak demand of a utility grid in Brazil", Proceedings of the EUROSUN 2004, Freiburg, Germany, 2004
2. Almeida, M.A., Schaeffer, R., Rovere, E.L., "The potential for electricity conservation and peak load reduction in the residential sector of Brazil", Energy (26) p.413-429, 2001
3. CELESC – "Load characterization", *Internal Report*, 2004
4. Colle, S., Glitz, K. L. Z., Salazar, J. P., and Abreu, S. L., "Cost optimization of low-cost solar domestic hot water systems assisted by electric energy", Proceedings of the ISES – International Solar Energy Society 2003 Solar World Congress, Göteborg, Sweden, 2003
5. Geller, H., Jannuzzi, G.M., Schaeffer, R., Tolmasquin, M.T., "The efficient use of electricity in Brazil: progress and opportunities", Energy Policy (26), p.287-306, 2002
6. Jannuzzi, G.M., Schipper, L., "The structure of electricity demand in the Brazilian household sector", Solar Energy (19) p.879-891, 1991
7. Oliva, G.A., Borges, T.P.F., "Teste de campo piloto com pré-aquecedor solar de água para chuveiros elétricos de

potência reduzida”, Proceeedings of the VII Brazilian Energy Congress, Rio de Janeiro, 1996

8. Prado R.T.A., Gonçalves, O.M., “Water heating through electric shower and energy demand”, Energy and Buildings (29), p.77-82, 1998
9. Salazar, J.P.L.C., Abreu S.L., Borges, T.P.F., Colle, S. and Reguse W., “Optimization of a compact solar domestic hot water system for low-income families with peak demand and total cost constraints,” Proceedings of the ISES – International Solar Energy Society 2003 Solar World Congress, Göteborg, Sweden, 2003
10. Salazar, J.P.L.C., “Economia de energia e redução do pico da curva de demanda para consumidores de baixa renda por agregação de energia solar térmica”, *Master Thesis* (in portuguese), Florianópolis, Brazil, 2004
11. Vine, E., Diamond, R., Szydlowski, R., “Domestic hot water consumption in four low-income apartment buildings”, Energy, (12), p.459-467, 1986