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The role and benefits of solar water heating in the energy demands of low-income dwellings in Brazil

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ABSTRACT

In Brazil the widespread use of electrical showerheads for providing hot water for domestic consumption contributes to a load curve that peaks in the early evening, imposing a considerable burden to generation, transmission, and distribution utilities. On average, over 73% of Brazilian households use these 3–8 kW electrical resistance showerheads. In some of the more temperate climate regions in the south of the country, where most of the Brazilian population is concentrated, electrical showers are present in over 90% of residential buildings. For the residential consumer, while these high-power heating devices are the least-cost investment alternative, they lead to high running energy costs. Furthermore, due to their very low load factor (typically below 2%), each of these high-power showerheads results in considerably low return on the high investment costs in terms of infrastructure for the electricity sector. Particularly in low-income dwellings, electrical showerheads represent by far the highest electrical loads, resulting in a considerable component in the monthly energy bill. On the other hand, Brazil is one of the sunniest countries in the world, and solar water heating technologies have demonstrated large financial benefits and short payback times. Due to their comparatively higher initial investment costs, however, domestic solar water heaters are used mostly in higher income residences. In this work we present the potential of a low-cost version of the typical domestic solar water heating system for low-income dwellings, where the electrical resistance, which is normally installed inside the hot water tank, is replaced by a variable power electrical showerhead. This design avoids the use of electrical power as auxiliary heating for the whole of the boiler volume, since only the water which passes through the showerhead might be heated by the electrical resistance. This system configuration is a commercially available low-cost solar water heater option. A case-study is presented for a statistically representative group of low-income dwellings with solar water heating systems in Florianópolis – Brazil. Our results show that the economies obtained are considerable, both in terms of energy consumption (kW h) and peak demand (kW) reduction. When compared with higher income typical users of solar water heating technologies, these economies represent a relatively higher benefit, both for the low-income population, as well as for the utilities involved. Our results also show that the *avoided power costs*, a benefit for the distribution utility company, might be more substantial than the *avoided energy costs*, a benefit for the end user. In the energy constrained on-peak hours period, the utility company might benefit from being able to sell this energy to other higher paying tariff consumers.

1. Introduction

The Brazilian solar radiation resource can be described as evenly distributed, with a small annual variability, and is one of the largest in the world [1], making solar water heating a natural choice of technology for residential buildings [2–4]. Fig. 1 shows the Brazilian Solar Radiation Atlas, with a sample map showing the annual average global horizontal irradiation and the corresponding annual variability. Nevertheless, electrical power showerheads are the most widespread water heating devices in use in Brazilian residences. Historically, this can be traced back to a lack of natural gas availability in the country, associated with the low costs of hydroelectricity generation and the relatively high efficiency of these devices [5]. Fig. 2 shows the fraction of Brazilian households with electrical showers, with a total national average of 73%, and with over 90% of the most populous regions in the south of the country using these high-power electrical devices to heat water. In this context, water heating is one of the largest single contributors to the total residential electricity bill, averaging

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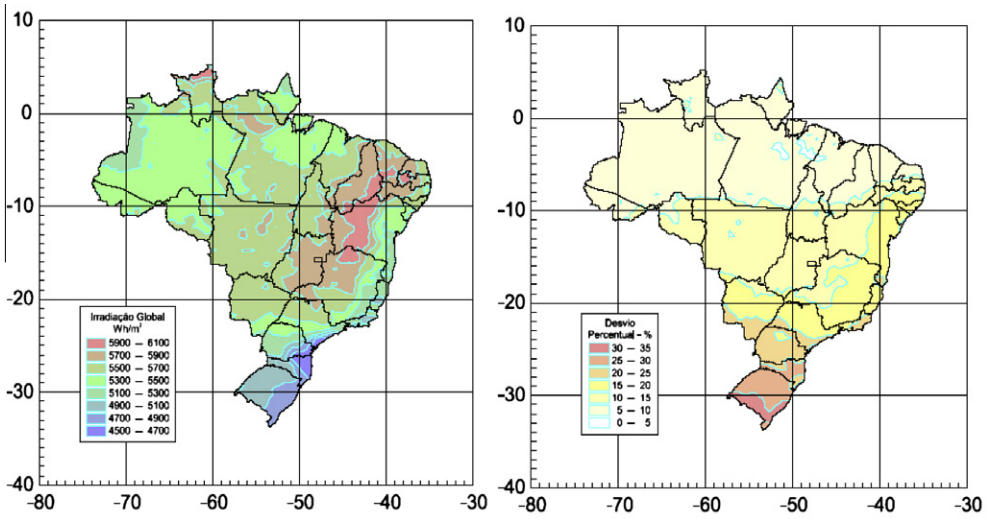

Fig. 1. Brazilian Solar Atlas, showing the global horizontal daily average irradiation (left) and the yearly variability of the solar radiation resource availability in the country [1].

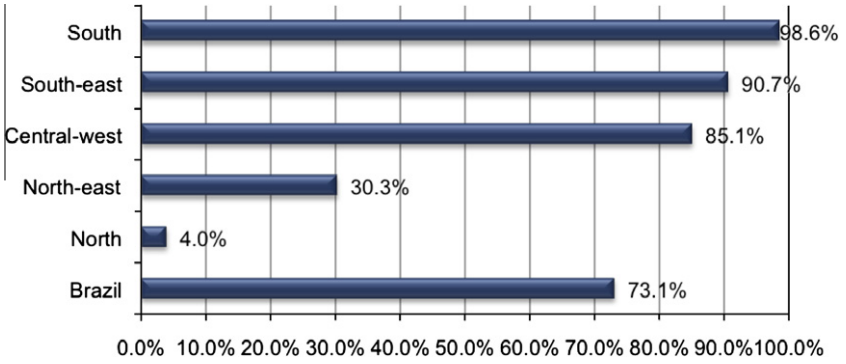

Fig. 2. Percentage of electrical showerheads in Brazilian residences by geographical region [5].

Table 1
Share of residential electricity consumption by end use and income class in Brazil [7].

End use	Up to 400	400–600	600–1000	1000–2000	More than 2000	Average
Income level (US$)						
Water heating	22.8	20.3	18.9	29.9	18.5	22.2
General services	15.8	13.5	13.6	12.2	16.9	14.8
Food conservation	37.6	36	34.9	26.2	27.1	30.2
Ambient heating and cooling	4.5	6.5	8.3	9.4	12.4	9.5
Leisure	11	10.4	9.7	7.3	6.1	8
Lighting	8.3	13.2	14.6	15.1	19	15.4
Total	100	100	100	100	100	100

over 22% of the monthly bill [6,7]. Table 1 shows the share of residential electrical energy consumption by end use and income class in Brazil.

The daily load curve of the Brazilian electricity distribution system peaks in the period between 18:00 and 21:00, with a maximum around 19:00 [8]. The residential sector is responsible for a considerable fraction of this peak, and electrical showerheads are by far the highest-power devices present in a household. According to the national utility ELETROBRÁS [9], electrical showers are responsible for some 60% of the residential load at peak load hours. For the distribution utility, the electrical shower represents a serious inconvenience, since it operates mostly at on-peak hours, with very high power demands and for a very limited period (low load factor). In recent years, the problem has intensified, since the typical nominal power of these devices has continuously increased from around 3 kW on average, to a range from 4.4 kW to 6.5 kW, and even 8 kW in some more luxurious models. Using electricity for direct water heating in Brazil is therefore one of the serious energy problems the electricity sector faces. For a distribution utility, the use of electrical showerheads by the low-income population at peak hours represents an even higher cost component, since energy for these consumers is usually under a subsidized pricing scheme. Residential consumers with a monthly energy consumption of up to 220 kW h can be classified in the low-income residential consumer class in Brazil. This includes nearly 20 million households [9] and a total of some 80–100 million consumers, meaning that electricity for direct water heating is subsidized for over half of the population in Brazil. The typical economic analysis of solar water heating systems that can be found in the literature [10–15] is usually from a users perspective. In this work we present results that are also of interest to the distribution utility company, quantifying the potential benefit of solar water heating in reducing demand peaks.

Bermann [16] has proposed a domestic "energy package" for the typical Brazilian household, comprised of five family members per four-room dwelling, which includes energy for lighting, water