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Savings related to solar water heating system: A case study of low-income families in Brazil

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ABSTRACT

The inclusion of solar water heaters available through subsidies of the Brazilian government has benefited more than 300,000 low-income families. Although these subsidies are important for wide implementation of this technology, the actual system performance is unclear. Moreover, it is unclear whether the performance is affected by user behavior in the context of complex socioeconomic issues. The objective of this research is to assess the influence of human behavior on the potential savings induced by solar water heaters. The research strategy integrated qualitative and quantitative measurements. We applied the cluster analysis technique to identify five homogeneous subgroups for a case study in Londrina, Brazil, in which a detailed measurement procedure was implemented to gather data on these subgroups over one year. The measurements were conducted to gain a better understanding of the factors affecting electricity consumed by showering. This study shows that the benefits of solar heaters vary according to the user and use of the technology. The annual energy savings averaged 9.51–18.6 kWh per person. A lack of technological understanding and the difficulty in effectively mixing hot and cold water were the main factors contributing to the inefficient use of the system.

1. Introduction

Since the commercialization of the first solar water heating system in 1891 [1], more than 200 million houses globally have been using solar energy collectors for heating water [2]. In fact, this use is perhaps the most popular application of solar technology [3]. In this context, some public policies include renewable energy technologies, which contribute to the wide application of solar water heating systems. These technologies have been subsidized in many countries including Austria, Germany, Switzerland, the Netherlands, Australia, Taiwan, and Cyprus [4–6].

The Brazilian government has also promoted solar heating systems in social housing. The availability of about 2000 kWh/m^2 of direct solar irradiation in most parts of Brazil [7] demonstrates the abundant potential of solar energy use within the country. The inclusion of solar heating systems in public policies has already benefited more than 300,000 low-income families [8,9]. Although this promotion is of great importance for the effective distribution of thermo-solar technology [5,6], the actual performance of the systems remains unknown, as do the effects of user behavior in the context of social housing relative to complex socioeconomic issues.

In a social housing project, it is common for hundreds of households to benefit from such a system. Although this setup is standardized with multiple small systems installed in identical units, the compositions of low-income families using this technology are not homogeneous and vary significantly in terms of energy consumption and socioeconomic aspects.

Thus, the social household context is complex and diverse, and its understanding is extremely relevant to the most effective use of the supplied solar water heaters. The solar heating system is considered to be an energy efficiency measure; as such, the resulting energy savings must be proven. However, energy consumption estimates obtained through simulations may not represent actual conditions because user behavior is variable and significantly affects the energy consumption [10–18]. Gram-Hanssen [14] reported that the heating energy consumption varied at least threefold among users even though their houses were identical.

There are many benefits to understanding the influence of the user on energy consumption in a household. From the perspective of renewable energy technology, this understanding contributes to improvements in systems that best meet the needs of the users, which ensures more efficient practices [19].

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This research considered the following factors influenced by the user, reported by Yu et al. [12] to be those that interfere with the usage of the solar water heating system:

(a) User-related characteristics (e.g., user presence);
(b) Building services systems and operation (in this case, hot water system operation);
(c) Building occupant's behavior and activities;
(d) Social and economic factors (e.g., degree of education, income, energy cost);
(e) Indoor environmental quality required (in this case, required water temperature).

Guided by the need to understand user practices, the aim of this study is to assess the influence of human behavior on the potential savings induced by solar water heaters. Real-time measurement can be employed as a strategy for examining the manner in which people use renewable energy technology, for determining whether savings and benefits are realized at the user and country levels, and for establishing a procedure for this analysis in such a diverse context.

Many researches demonstrate the potential of solar water heating systems. However, the actual performance of installed domestic systems and in use is rarely investigated [20,21]. According to Hernandez and Kenny [20] differences between measured and calculated performance can be expected in the operation of solar systems, due to different demand profiles, installation and control, maintenance factors and potential operational problems. Some experiments involving measurements related to solar heating systems [18,22–30] highlight the different approaches and demonstrate the importance of measurement in actual practice. Most of such studies include large samples and focus on energy savings. Some of them [24–26] report discrepancies between real measurements and expectations. The Florida Solar Energy Center has established a comprehensive approach for monitoring solar heating systems introduced in social housing through its Solar Weatherization Program [30]. This approach comprises both technical analyses and user perception. However, these two factors appear to be unassociated, and the measurements do not allow an understanding of the actual system usage by residents. Some surveys on consumer satisfaction [30,31] have revealed problems in the use of solar heating systems; thus, analysis is necessary to gain a better understanding of how the technology is used. Some Brazilian studies including isolated measurements of solar heating systems [28,29] have elucidated factors affecting overall energy savings. However, Parker [18] applied a more investigative line of research to examine the factors that most affect the energy demand. Although the number of users, activities performed, climatic factors, and performance of the systems were analyzed in that study, the focus was not specifically on thermosolar technology.

2. Materials and methods

On the basis of a study conducted by Giglio et al. [32], we selected five low-income families residing in a social housing project in Londrina, Brazil, composed of 1272 new single-story units with a solar water heating system.[1] The methodological procedures included a field survey containing a qualitative interview combined with non-instrumented monitoring techniques with a sample of 200 low-income houses. The relationship among data was established through cluster analysis, a multivariate data technique that classifies objects according to the similarity of one object to another based on a set of attributes. These attributes refer to socioeconomic aspects, household composition, energy consumption, and electricity cost savings. Grouping was performed by using a K-means algorithm, which is a centroid technique whereby each cluster center is represented by the mean rate of the objects in the clusters.

The reduction of variability of the samples through five homogeneous subgroups allowed for investigation of the influence of the user on energy consumption in the representative clusters.

2.1. The five monitored clusters

Families (centroids) representative of the five clusters closest to the average centers of their respective groups were selected. The new single-story units are identical. The hot water system is characterized by a thermosiphon solar water heater in which potable water is heated directly in a flat-plate collector. This technology is solely intended to heat the shower water, replacing the exclusive use of the electric showerhead predominant in Brazilian social housing. The system is supplied with cold water directly from the supply network, which initially passes through a pressure reducer (Fig. 1). The electric showerhead is used as a backup because there is no electrical resistance within the hot water tank. The backup is manually controlled by the user when the need arises to raise the temperature of the shower water delivered by the solar water heating system. The user can manually set three temperature levels including cold, warm (2.8 kW), and hot (4.5 kW).

Considering that the system, hydraulic installations, solar orientation of the solar collectors, and weather conditions are identical for all units, the five clusters differed in terms of the six influencing factors described by Giglio et al. [32]. These influencing factors and main clusters characteristics are described in Table 1.

The five monitored clusters may be explained by the attribute "electricity cost savings" described in Table 1. This attribute is based on the difference between the declared monthly average energy bill in the former residence, as declared by the family, and the measured monthly average energy bill in the new house equipped with the solar water heating system, as measured by the utility company. Declared and measured data refer to the whole building over one year. Thus, although the attribute contributed to understanding characteristics of the clusters, the isolated solar water heating system measurements are relevant for validating those results.

The centroids selected for instrumented monitoring present the following family compositions. Cluster 1, the low-savings group, is characterized by elderly people with low educational levels. This cluster is represented by an elderly woman and her granddaughter. Cluster 2, with no savings potential identified in 75% of the cases, is composed of families dissatisfied with the system and high monthly energy consumption. This cluster is represented by a couple with two toddlers and one teenager. Cluster 3, with good electricity-savings potential, is represented by a widowed single parent with two toddlers who also housed her sister and an infant during the monitoring. Cluster 4, with unknown electricity-savings potential, is represented by a couple with two toddlers occupying an irregular and highly unsanitary area in the former residence with illegal electricity connections and no water-heating system. Cluster 5, with good electricity-savings potential, is represented by a couple with a toddler and a young daughter. More than 75% of the families in clusters 3 and 5 reported positive electricity savings. These five clusters represent a heterogeneous population composed of 1272 housing units equipped with a solar heating system.

2.2. Real-time monitoring over one year

Instrumented monitoring was performed over a period of one year between April 2013 and March 2014 with data available in

[1] Through the "My House, My Life" program, the Brazilian government subsidizes new houses with solar heating systems to low-income families in large social housing projects.