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A procedure for analysing energy savings in multiple small solar water heaters installed in low-income housing in Brazil

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HIGHLIGHTS

- M&V is necessary to improve solar collector-area-based subsidy programmes.
- M&V in large-scale sample should contemplate the social and economic variability.
- Samples with homogeneous subgroups contribute to a consistent energy-saving M&V.
- Solar Water Heaters in some cases may not offer energy saving in a low-income context.
- SWH performance decreases with low educational level and difficulty of operation.

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ABSTRACT

Due to government subsidies, Brazil has witnessed an increase in the installation and use of small solar water heating systems in low-income housing projects. Although the initiative has reduced the load curve during peak times due to the reduced use of electric showerheads, measurement and verification (M&V) are needed to validate the savings. M&V procedures should take into account the social and economic variability of low-income housing developments. To improve M&V in low-income housing projects, this paper presents a methodology for identifying homogeneous subgroups based on their energy-saving potential. This research strategy involved a cluster analysis designed to improve the understanding of what energy savers and other influencing factors exist. A case study in Londrina Brazil was undertaken with 200 low-income families. Five clusters, created based on savings potential, were defined. The results showed that only two clusters demonstrated good electricity savings, representing 47% of families. However, two clusters, or 37%, did not provide satisfactory savings, and the other 16% did not provide any consumption history due to previous use of illegal city electricity connection practices. Therefore, studies confirm the need for a detailed measurement of the representative subgroups to assess the influence of human behaviour on potential SWHS-induced savings.

1. Introduction

Solar water heating systems (SWHSs) have been implemented worldwide through government subsidy programmes. Although these policy programmes are relevant for the effective use of thermal solar energy (Chang et al., 2011; Kalogirou, 2003), the energy savings still need to be demonstrated. Most SWHS implementation occurs through collector-area-based subsidy programmes, which are mainly aimed at increasing the number of systems installed. This situation may not necessarily indicate that collectors' installation of these systems in a given area will cause a general decrease in energy demand, if verifications have not been established (Roulleau and Lloyd, 2008). Consequently, an investigation of the energy savings obtained requires measurements and verifications (M&Vs) (Vine and Hamrin, 2008) to assess whether the systems function efficiently and energy is saved as expected.

The Brazilian policy supporting SWHSs for low-income housing is outlined in the above discussion. The availability of solar irradiation, amounting of 2200 h of sunshine throughout the year in most regions, coupled with well-developed technology (Pereira

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et al., 2011) and successful technological experience (Fantinelli, 2006) has encouraged the inclusion of mandatory SWHSs in all low-income houses built by the collector-area-based My-House-My-Life subsidy programme. SWHSs are being subsidised for single-family homes characterised by monthly earnings of up to US$ 700[1] (Brasil, 2011b). Although it is common for over 1000 identical low-income houses to receive such benefits, scant information exists on the resultant electricity savings in new housing developments that also feature many social and economic problems.

Experiences of SWHS inclusion in low-income housing have been applied in many countries through incentive programmes. In South Africa, the system have been installed through energy efficiency subsidy programmes by electric public utility to finance project costs. In the same way, over the last years Turkey has provided residential flats for low-income families with SWHS, and México, through the Green Mortgage programme of Mexican Federal Institute for Worker's Housing, has benefited the low income population (Ropcke, 2011). Two another examples are California Solar Initiative – Thermal Low-Income program (California Public Utilities Commission (CPUC), 2013) that provides rebates to utility customers who install SWHS that displace natural gas usage, and the Solar Weatherization Assistance Program – SWAP, that through a pilot programme coordinated by Florida Solar Energy Center (Harrison and Long, 1998), provided SWHS for low-income housing and carried out a detailed M&V to prove savings.

Few studies have focused on SWHS-provided energy savings, owing to complex measurements involving all variables prior to and after their installation (Furbo et al., 2011; Thur et al., 2006). M&Vs in large scale domestic hot water systems have been discussed by Parker (2003), Parker et al. (2010) and Walker et al. (2003), whose studies were based on a statistically significant sample and on baselines structured from studies by Christensen and Burch (1994). In the context of Brazilian low-income housing, commonly the SWHS implementation happens in existing houses and M&V studies rely on historical data of consumption prior to the introduction of technology (Fantinelli, 2006), or based on a control group without solar system (Naspolini et al., 2010), both with sample defined by compatibility between family arrangement and sizing system. However, M&V studies about multiple small SWHSs implemented in new low-income housing are rare. These systems are not even mentioned in the best management practices established by the International Performance Measurement and Verification Protocol for Renewable Energy (Efficiency Valuation Organization (EVO), 2003). The inclusion of SWHS is characterised by standardised systems of identical new units aimed at different low-income family arrangements.

Better sample definitions of multiple small SWHS in new low-income housing should be taken into account in the construction of M&V methodology. Although SWHSs are standardised, the technology-receiving population is not homogeneous; instead, the public varies extensively in energy consumption and socio-economic status. Consequently, a statistically significant sample based on a large homogeneous group cannot be defined because the mean results do not characterise the total sample. Homogeneous subgroups should be identified so that the sample can provide measurements of SWHS usage with more precise results about savings.

This research presents a method for identifying homogeneous subgroups in new large-scale low-income housing within Brazil's social context. Identification will facilitate the application of a detailed M&V procedure in large-scale housing developments with multiple small solar water-heating systems to assess the influence of user behaviour and thereby determine the true electricity-savings results. This method will be the first stage in evaluating the performance of M&V in low-income housing.

1.1. Public policies of SWHS installation in low-income housing in Brazil

In Brazil, it is mandatory for electric utilities to invest 0.5% of their annual net operating revenue in energy-efficiency activities (Brasil, 2000), with 60% of the gross revenue applied to subsidising consumer electricity bills (Brasil, 2010). SWHS subsidies in low-income housing are entirely for low-income users; however, the electric utilities must prove electricity savings after technology introduction, according to the M&V protocol Efficiency Valuation Organization (EVO) (2012). Because this programme is a performance-based subsidy, M&Vs require large-scale samples due to the great number of housing units involved, and they are restricted to energy auxiliary systems operating over a short period. In contrast, current procedure (Agência Nacional de Energia Elétrica (ANEEL), 2012) recommends that M&Vs in low-income housing should consider economic and social variables, although a specific methodology has not been defined.

In tandem with the above-mentioned Brazilian electricity subsidy, the Brazilian government housing programme, My-House-My-Life, installed SWHSs in all new single-family homes. However, the total monthly income of each family had to be under US$ 700. The initiative was the product of the Brazilian Climate Change Plan (Brasil, 2008), which had a target of installing 15 million m^2 of solar thermal collectors for water heating in Brazil before 2015. The Working Group “GT-Sol” was established under the coordination of the Ministry of the Environment (Pereira et al., 2011), which was charged with introducing the systems within the framework of the My-House-My-Life programme. The “GT-Sol” prepared a Term of Reference (Brasil, 2011a) technical guidelines document detailing the specific size and installation procedures, standardised for all households receiving an SWHS through the programme.

From 2009 to 2014, 335,461 low-income families will benefit from SWHS (Associação Brasileira de Refrigeração, 2013; Agência Nacional de Energia Elétrica (ANEEL), 2013)[2], either through current government housing policies or from Brazilian electric utility programmes. The whole enterprise currently involves 671,000 m^2 of collectors installed[3], or 470 MW_{th} of total rated thermal input[4].

The relevance of the SWHS in those current Brazilian low-income housing programmes can be highlighted not only for the benefits to the families but also for the national electric system and environment as a whole. The direct benefit is the reduction of electricity bill in low-income households, allowing the transfer of the saved money to other needs. On My-House-My-Life programme, the initial investment of the technology involves U$S 875, subsidised by government. About the country benefits, the Brazilian Energy Research Company (Associação Brasileira de Refrigeração, 2014) estimates that from 2014 to 2022 the collectors only by My-House-My-Life programme, will avoid the necessity to generate 6.3 TW h, reducing also the need for expansion of distribution and transmission systems. Whereas the electric

[1] US$ 1.00 = BR$ 2.286 on 12/09/2013.

[2] A total of 263,000 SWHS-furnished housing units will be built through the My-House-My-Life programme (prior to 2014). Added to the 72,461 units (up to July 2013) installed by electric utilities, the total amounts to 335,461 units.

[3] The My-House-My-Life programme used a standardised area of 2 m^2 for each solar collector per housing unit.

[4] This figure is based on the International Energy Agency (IEA) conversion factor with a 0.7-kW_{th} rated thermal input per m^2.