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Reduction of carbon dioxide emissions by solar water heating systems and passive technologies in social housing

Vanessa M.T. Bessa [a], Racine T.A. Prado [b,*]

[a] Escola Politecnica, University of Sao Paulo and Department of Architecture, Armando Alvarez Penteado Foundation, São Paulo, Brazil
[b] Escola Politecnica, University of Sao Paulo, tr. 2 no. 83, 05508-900 Sao Paulo, Brazil

HIGHLIGHTS

- Brazil has created public policies to increase the use of solar water heating in social housing.
- We have evaluated the potential for reduction of CO_2 emissions installing solar water heating.
- We have found that the coldest regions have the greatest potential for reducing emissions.
- Passive technologies for thermal comfort in hot climate households are more useful than solar water heating systems.

GRAPHICAL ABSTRACT

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ABSTRACT

Growing global concern regarding climate change motivates technological studies to minimize environmental impacts. In this context, solar water heating (SWH) systems are notably prominent in Brazil, primarily because of the abundance of solar energy in the country. However, SWH designs have not always been perfectly developed. In most projects, the installation option of the solar system only considers the electric power economy aspects and not the particular characteristics of each climatic zone. Thus, the primary objective of this paper is to assess the potential of carbon dioxide reduction with the use of SWH in comparison with electric showers in social housing in several Brazilian climatic zones. The Brazilian government authorities have created public policies to encourage the use of these technologies primarily among the low-income population. The results of this paper indicate that hot climactic regions demonstrate a low reduction of CO_2 emissions with SWH installations. Thus, solar radiation is not useful for water heating in those regions, but it does lead to a large fraction of household cooling loads, implying a demand for electrical energy for air conditioning or requiring the adoption of passive techniques to maintain indoor temperatures below threshold values.

1. Introduction

Currently, it is well-accepted among researchers that buildings are responsible for over a third of the world's energy demand and will eventually contribute nearly the same amount to greenhouse gas emissions (Smith and Levermore, 2008; Pilkington et al., 2011). Nevertheless, electrical water heating and space cooling will deploy in the residential sector in developing countries in the 21st century due to rising incomes, increased global warming, and rapid climate change. However, there is a workable level of passive technologies for buildings that can replace the old carbon-intensive building services and can offer respite from environmental pressures.

* Corresponding author. Fax: +55 11 30915206.
E-mail address: racine.prado@usp.br (R.T.A. Prado).

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Nomenclature

c	water specific heat (4.19 kJ/kg °C)
ES	annual energy consumed for electric shower (kW h)
G	annual solar global radiation (kW h/m^2)
K_T	clearness index
$\dot{m}$	electric shower flow (kg/min)
N	number of dwellers
Q	heat rate required for a bath (kJ)
Q_{aux}	annual auxiliary energy for the solar heating system (kW h)
RH	relative humidity (%)
SF	solar fraction (%)
SWH	solar water heating
t	bath time (min)
T_{cw}	temperature of cold water (°C)
T_{air}	average air temperature
ΔCO_2	yearly CO_2 emission reduction (kg/year).
η	electric shower efficiency

The growing global concern with climate change has motivated technological studies to minimize the effects on the environment. Among the studied technologies, SWH systems have been highlighted in both the domestic and industrial sectors because of their facility of operation and maintenance (Jaisankar et al., 2011) and their use of renewable energy. New buildings will have to be designed to fight the effects of climate change, namely, the passive buildings according to Roberts (2008). Additionally, Martins and Pereira (2011) stated a huge unexploited potential of renewable energy sources remains, such as solar, to generate electrical and thermal energy, but the effective growth of the Brazilian renewable energy market strongly depends on the policy-makers.

In the last few decades, the prevailing water heating technology in Brazil, which is present in social housing, has been the electric shower, inexpensive equipment with instantaneous operation; however, its use during peak hours can have a harmful effect on the load curve of the national electric system. Peak hours mostly occur in the residential sector.

Moreover, the electrical energy demand for water heating will continue to rise in Brazil. According to PROCEL (2007), 80.9% of Brazilian households have water heating systems, 73.7% of these systems are electric showers, and 99.6% of electric water heating is performed by electric showers. Forecasts by MME (2014) predict that the total number of electric showers will grow from 39.7 million in 2001 to 69.7 million in 2030 and will account for 56.8 TW h/year in 2030, a rise in consumption of 192% from 2008 levels (19.4 TW h/year).

When only taking into account residential electrical energy customers, the electric shower is a domestic appliance responsible for a large fraction of their electric demand. Unquestionably, it is the first focal point for a demand-side management policy. The best environmental solution is SWH.

In Brazil, the problem with expanding solar technology is the high installation cost of the system. However, Martins et al. (2012) stated that water heating in residences presented a short payback period even for residences of low-income families when the solar technology was used to replace the electric showerhead. If government incentives were implemented, Brazil would cut back a significant amount of electrical energy generated by conventional sources such as hydro, nuclear, and chiefly fossil fuel.

Currently, SWH may be installed in most building types, and it is mandatory in some cities of the country, which have laws and specific regulations known as "solar laws". To expand the use of solar technology, technical standards and urban laws that encourage the use of SWH in buildings have been developed in Brazil. Furthermore, the public sector started requiring the adoption of SWH in social housing. In January 2008, Decree 49148 was regulated, which requires the use of SWH in the city of Sao Paulo in households with four or more bathrooms and commercial buildings with an intensive use of hot water (São Paulo, 2008). The other 25 Brazilian cities have similar laws (Solar Cities, 2014). In March of the same year, the standard ABNT NBR 15569 (2008) – Solar water heating system in Direct Circuit was enforced, which regulates the design and installation of these systems. The State of Sao Paulo Housing and Urban Development Company (CDHU)[1] began to adopt these systems in new houses and buildings. Similarly, in the second phase of the "My house, my life" Program[2] where the government intends to build 2 million homes and apartments, the Brazilian government announced that houses will have solar energy systems for water heating (Caixa, 2011).

This scenario has caused this technology to spread in all of Brazil, whose market is expanding at the national level. However, it seems that the design of SWH has not always been developed with the required accuracy. One parameter that influences the efficiency of SWH but is often overlooked is the climate. In most projects, the adoption of SWH only examines the economic aspects but not the particular characteristics of each climatic zone.

According to Barroso-Krause and Medeiros (2005), the greater proximity to the equator enables lower hot water requirements throughout the year. Conversely, the higher latitude corresponds to lower environmental temperatures and, consequently, higher consumed energy to heat the water. In addition, Taborianski and Prado (2004) noted that when SWH is adopted, the warmer and less clouded regions require less electrical resistance to maintain the water temperature; thus, these regions consume less electricity and emit less pollution because CO_2 emission is directly linked to energy consumption.

In other countries, SWH systems are modeled based on the characteristics of thermal zones. In Australia, the performance of these systems is evaluated in agreement with the levels of temperature and solar radiation zones based on the climate conditions of four cities in this country, as set by the Australian Standard AS 4234. The temperature and solar radiation levels in Zones 1, 2, 3 and 4 are derived from Rockhampton, Alice Springs, Sydney and Melbourne, respectively. Because the models are derived in conformity with AS 4234, all SWH systems in Australia are assumed to have the same performance (Mills, 2004).

In Dezhou City, by estimating the demand side of hot water for a typical three-person household, Li et al. (2011) evaluated the economic potential of a SWH system in saving electrical energy and in reducing carbon dioxide emission. In conclusion, theses authors claimed that a 1-m^2 SWH collector area would reduce carbon dioxide emission by 199.6 kg per year.

The NBR 15220-3 Standard by ABNT (2005) divided the Brazilian climatic zones and classified the climate of 330 cities to help develop appropriate architectural projects based on the climatic

[1] CDHU is a São Paulo State Government company linked to the Housing Department and is a big promoter of social housing in Brazil. It aims to run housing programs throughout the territory of the State, aimed at the exclusive service of low-income families with income in the range of 1–10 minimum wages (CDHU, 2014).

[2] "My house, my life" is a program of the Brazilian Federal Government that finances houses to families with incomes of up to R$ 5000. The bank in charge of implementing the program is "Caixa", a federal public housing agency.