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Solar water heating for a hospital laundry: A case study

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Abstract

Solar energy has enormous potential in many areas of industrial activity in Brazil, since much of the country has high levels of sustained solar insolation. Unfortunately, there are few industries that use solar energy for water heating even though some industrial processes need water at temperatures that could be easily obtained from flat plate collectors. This paper uses a numerical simulation to study the technical and financial viability of a solar water heating system for a hospital laundry in the city of Recife (8.1°S and 34.9°W). After modeling the system's components, some parameters of the system were optimized, such as the tilt angle of the collector, water flow rate, area of the collectors, and the size of the water tank. The economic analysis was carried out by comparing the annualized life cycle savings for the solar powered system versus the system currently in use which burns natural gas. The results showed that the reduction in natural gas consumption brought about by using a solar heating system makes it an economically viable option.

Keywords: Solar energy; Industrial solar water heating; Flat plate collectors; Feasibility analysis; Payback time

1. Introduction

The use of renewable energies in industries reduces or replaces conventional fuels and as such reduces carbon emissions in the environment. In spite of high and sustained levels of solar insolation in most parts of Brazil, only 5000 MW_{th} of solar collectors are installed (Mauthner and Weiss, 2013). This is abysmally small compared to, for example, China (152,000 MW_{th}), taking into account that Brazil's land area is about 90% (8.5 million km^2) of that of China. It is clear that Brazil has immense potential for growth. The underutilization of its potential can also be noticed when Brazil is compared to countries with a climate which is unfavorable in terms of using solar energy such as Austria, which has a much smaller land area than Brazil, yet its installed capacity is almost equal to Brazil's (Ministry of Energy and Mines, 2010; IEA, 2011). Solar energy in Brazil is mainly used for domestic water heating, whereas many industries use water at 50–90 °C. Despite the great potential of the residential sector, the industrial application of solar energy should also be given more consideration. A substantial amount of work has been published on solar water heater with heating systems using flat plate collectors. Muneer et al. (2008) discussed the role of solar energy in the textile industry in Turkey and pointed out

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Nomenclature

Latin letters

A	surface area (m^2)
A_{tr}	transverse area (m^2)
$ALCS$	Annualized Life Cycle Savings (USD$)
$ALCC$	Annualized Life Cycle Costs (USD$)
C_{co}	solar collector cost (USD$/$m^2$)
C_{fuel}	fuel cost (USD$/J)
C_{ins}	installation cost (USD$/J)
C_{mt}	maintenance cost (USD$/J)
C_s	storage tank cost (USD$)
c_p	specific heat (J/kg °C)
d	discount rate
i	inflation rate
IRR	internal rate of return
Δx	length of storage tank node (m)
F	solar fraction
F_r	heat removal factor
I	global irradiation (W/m^2)
k	thermal conductivity (W/m °C)
K_θ	incidence angle modifier
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
n	time period (years)
N	number of nodes of the storage tank
Q	energy (J)
$\dot{Q}_{\text{aux}}$	energy rate from auxiliary system (W)
$\dot{Q}_{\text{down}}$	downward net energy rate between two adjacent nodes of the storage tank (W)
$\dot{Q}_l$	energy rate demanded by the load (W)
$\dot{Q}_{\text{loss}}$	energy rate lost by the storage tank (W)
$\dot{Q}_{\text{sol}}$	energy rate from the hot water solar system (W)
$\dot{Q}_u$	useful energy rate from the collector (W)
$\dot{Q}_{\text{up}}$	upward net energy rate between two adjacent nodes of the storage tank (W)
t	time (s)
T	temperature (°C)
U	overall heat loss coefficient (W/°C m^2)
V	volume (m^3)

Greek letters

β	collector tilt angle (°)
ϕ	latitude (°)
η	energy efficiency
$(\tau\alpha)_n$	transmittance–absorptance product

Subscripts

amb	ambient
co	collector
conv	conventional system
f	fluid
i	inlet
j	storage tank node
l	load
r	return water
o	outlet
s	storage tank
sol	hot water solar system
t	tilted surface
tub	tube
w	storage tank wall

the opportunities and barriers found in the country. Fuller (2011) reviewed the situation of the use of solar heating systems in Australia, and reported problems when designing large scale systems. In a paper, Mekhilef et al. (2011) reviewed the use of solar energy in industries and indicated the various situations where it is possible to use solar energy. Kalogirou (2003) assessed the potential of applying different types of collectors for hot water demand in an industry and used life cycle savings as a decision criterion.

Many authors have also studied solar systems and their applications for heating and cooling, Rosiek and Batlles (2012) investigated the possibility of using a shallow geothermal system integrated in a solar air conditioning in southern of Spain as an alternative to the cooling tower. The authors demonstrated that the economy in electricity consumption by using the proposed system would lead to savings of 31% compared to the other system. In terms of generating electricity, Bhandari et al. (2014) describe an approach for connecting several renewable energy sources to a small grid. Other authors have investigated new components that could help to increase the performance of solar systems such as (Deepa and Nagaraju, 2014; Zaragoza et al., 2014). Zaragoza et al. (2014), presented an analysis on the use of energy for decentralized water production by using membrane desalination systems fed with solar energy. In Rasoul et al. (2014), a solar system for four seasons for a Canadian house was developed which included heating and cooling as well as domestic hot water (DHW) in order to determine an optimal configuration in terms of the design parameters that could meet the thermal needs for the homes in Canada.

In Sawhney et al. (2014), the behavior of the Tennessee Solar Value Chain (TNSVC) in the United States was examined in order to study the factors that influence the growth of the solar industry in the state. The impact of existing incentives on the TNSVC was analyzed. The TNSVC is simulated based on inputs from on-site surveys to estimate the economic impact in terms of the number of jobs added and the tax revenue generated for the state. This model may be called a holistic one and can predict the demand for photo-voltaic installations. In addition, a sensitivity analysis on the impact of the TNSVC under