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A modified efficiency equation of solar collectors

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Abstract

This paper describes the derivation of a modified equation for solar collector efficiency that is expressed using the heating load term instead of the inlet fluid temperature term from the currently used linear collector efficiency equation. The parameters in the modified equation are estimated using test data measured for 14 days. In evaluation of the equation's validity, the calculated daily collector efficiency agrees well with the measured daily collector efficiency, with a correlation coefficient of 0.9110. The equation is also be expressed in another form by including the term for the shape of the hot water storage tank in the solar heating system. Collector efficiencies with parametric changes are calculated with the estimated parameters and compared with different global solar irradiance on solar collectors, daily average ambient temperature and heating loads per collector area. It would be necessary to estimate the parameters for better performance of the efficiency equation with more data from long-term system simulations at various operating conditions.

Keywords: solar collector; efficiency equation; inlet temperature; heating load

1. Introduction

Solar collector efficiency is expressed in the form of either a linear or a quadratic equation [1]. The equations can be used to estimate the energy performance of a solar heating system using detailed system simulation tools such as TRNSYS [2] that can calculate inlet fluid temperature or mean temperature. However, the energy performance estimation using the detailed simulation tools is time-consuming and relies on user expertise and skill to deal with

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the software tools. Therefore, it would be more productive and convenient if an efficiency equation is available that does not require the inlet fluid temperature or mean temperature for quick assessment of solar heating systems. In this paper, a modified collector efficiency equation is proposed for solar heating systems and its validity is evaluated using experimental data.

Nomenclature

A_c	collector area
A_{st}	floor area of hot water storage tank
h_{st}	total height of hot water storage tank assuming cylindrical shape
$h_{st,low}$	height of the lower part below heat exchanger in hot water storage tank
F_r	heat removal factor
F_r'	modified heat removal factor
G_s	global solar irradiance
$M_{st,low}$	mass of lower part in hot water storage tank
Q_L	daily heating load
q_u	heat transfer rate
SR	slenderness ratio defined as the ratio of h_{st} to A_{st}
T_a	ambient air temperature
$T_{c,i}$	fluid temperature at collector inlet
$T_{st,low}$	fluid temperature at lower part in hot water storage tank
$T_{wh,in}$	inlet city water temperature to hot water storage tank for domestic hot water supply
$T_{wh,mix}$	supplied water temperature to hot water demand for domestic hot water supply
$T_{wh,o}$	outlet water temperature from hot water storage tank for domestic hot water supply
U_L	heat transmittance coefficient
$\tau\alpha$	product of transmittance and absorptance of solar collector
ρ_{st}	water density in lower part of hot water storage tank

2. Development of modified solar collector equation

2.1. Derivation of collector efficiency equation

The purpose of deriving a modified equation for solar collector efficiency is to enable quick assessment of the system, by replacing the inlet fluid temperature term in the equation with the heating load term that is usually available at the conceptual design stage. To accomplish this, the entire system including the solar thermal storage tank and heating load is considered, as seen in Fig. 1. The following assumptions are used in this study:

- The inlet mass flow rate into the solar thermal storage tank is constant.
- The auxiliary heater is controlled such that $T_{wh,o}$ is maintained at a constant temperature setpoint.
- The mixed hot water flow is maintained constant by an automatic control valve or through manual adjustment by hot water users.

The rate of useful heat gain q_u from the solar collector is expressed as in [3]:

$$q_u = F_r A_c\left[G_s\tau\alpha - U_L(T_{c,i} - T_a)\right] \tag{1}$$

Introducing a modified heat removal factor F_r' changes equation (1) to

$$q_u = F_r' A_c\left[G_s\tau\alpha - U_L(T_{st,low} - T_a)\right] \tag{2}$$