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The application of the Typical Day Concept in flat plate solar collector models

David James Wojcicki [1,2,3]

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ABSTRACT

Flat-plate solar collectors (FPSCs) utilize solar radiation, an alternate energy source, as fuel to heat a working fluid. However, since solar radiation and environmental conditions are different throughout the world, FPSCs cannot be considered one-size-fits-all systems. Therefore, FPSCs must be properly designed for use at a specific location. One of the methodologies to do so is to create models. Many FPSC models assume initial conditions, such as the initial absorber plate temperature and the initial heat transfer coefficient values. Assuming initial condition values is a major weakness in such models as it could cause erroneous or inaccurate output values. To overcome the necessity to assume initial condition values, the Typical Day Concept may be applied to FPSC models. By applying the Typical Day Concept in a FPSC model, all of the equations that calculate the output data for every single time step in a 24 h period are essentially combined into a single balance equation. The single balance equation eliminates the need to assume initial condition values while only allowing one single correct solution to the model's output data. This should help reduce the amount of time, money, and difficulty that may come with designing a FPSC.

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1. Introduction

With all the potential for utilizing free alternate energy sources, it seems that the average consumer is paying too much for energy. Whether he/she is using electricity created by burning coal, oil/gasoline to power vehicles, or natural gas to heat water, consumption of these traditional energy sources can cost a large sum of money. In addition, the consumption of traditional energy sources is a major factor in the Earth's pollution and consequent climate change [1]. For these reasons, alternate energy sources could be a much more attractive option.

Flat-plate solar collectors (FPSCs) utilize solar radiation, an alternate energy source, as fuel to heat a working fluid. The working fluid is typically air or water. Alternate energy systems, such as FPSCs, could potentially allow users to be less dependent on traditional energy suppliers, allow users to be less impacted by price inflation of traditional energy sources, and reduce the amount of pollution output to the environment. However, since solar radiation and environmental conditions are different throughout the world, FPSCs cannot be considered one-size-fits-all systems. Therefore, FPSCs must be properly designed for use at a specific location. Otherwise, the potential benefits that come with the use of FPSCs may not be realized.

[1] Work done as part of dissertation for Ph.D. in Energy Engineering from the University of Massachusetts Lowell.
[2] Tel.: +1 603 315 1311..
[3] Permanent Address: 3 Galloway Road, Unit 37, Merrimack, NH 03054.
E-mail address: davidwojcicki@yahoo.com

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Nomenclature

Latin symbols

A_c	area of the FPSC absorber plate
FPSC	flat-plate solar collector
g	gravitational constant
h_{ccgi}	convective heat transfer coefficient between the absorber plate and the cover
$h_{ccgi}0$	initial convective heat transfer coefficient between the absorber plate and the cover
$h_{ccgi}(24)$	convective heat transfer coefficient between the absorber plate and the cover calculated for hour 24
h_{rcgi}	radiative heat transfer coefficient between the absorber plate and the cover
$h_{rcgi}0$	initial radiative heat transfer coefficient between the absorber plate and the cover
$h_{rcgi}(24)$	radiative heat transfer coefficient between the absorber plate and the cover calculated for hour 24
h_{rgoa}	radiative heat transfer coefficient between the cover and the environment
h_w	wind loss coefficient
I_b	direct normal radiation
I_{hor}	global horizontal radiation
k	thermal conductivity of the fluid
L	plate spacing between the absorber plate and the cover
N	number of cover layers
Nu	Nusselt number
q_u	rate of useful heat transfer
R_a	Rayleigh number
R_1	thermal resistance from the cover to the surroundings
R_2	thermal resistance between the absorber plate and the cover
T_a	Ambient temperature
T_c	FPSC absorber plate mean temperature
T_c0	initial FPSC absorber plate mean temperature
$T_c(24)$	FPSC absorber plate mean temperature calculated for hour 24
T_{gi}	mean cover temperature
tol	user defined tolerance value
T_{sky}	sky temperature
$T_{w,out}$	outlet working fluid temperature
U_c	overall heat loss coefficient for the FPSC
v_{wind}	wind velocity

Greek symbols

α_{air}	air thermal diffusivity
β	slope of the FPSC
β'	volumetric coefficient of expansion
ΔT	temperature difference between the absorber plate and the cover
ε_g	emittance of the cover
ε_p	emittance of the absorber plate
$\eta_{collector}$	efficiency of the FPSC
σ	Stephen Boltzmann constant
v_{air}	air kinematic viscosity

Experimentation is one of the methodologies used to determine how FPSC designs will perform at a specific location. Experimentation can be expensive, time consuming, and the results could be inconclusive. Another methodology for FPSC design is to use models. Many FPSC models assume initial conditions, such as the initial absorber plate temperature and the initial heat transfer coefficient values [2–6]. Initial conditions refer to the state of the FPSC at hour 0, or right before the simulation of the FPSC starts. Assuming initial condition values is a major weakness in such models as it could cause erroneous or inaccurate output values. In addition, assuming initial condition values could cause uncertainty as to whether or not the model's output data are an accurate prediction of how the FPSC will perform when installed. The reason is that there could be any number of solutions to the model's output data since there is an endless number of initial condition values that may be assumed. To overcome the necessity to assume initial condition values, the Typical Day Concept may be applied to FPSC models. By applying the Typical Day Concept in a FPSC model, all of the equations that calculate the output data for every single time step in a 24 h period are essentially combined into a single balance equation. The single balance equation eliminates the need to assume initial condition values while only allowing one single correct solution to the output data. Therefore, FPSC models that incorporate the Typical Day Concept can be used to optimize or design a FPSC for use at a specific location. These models may also be used to compare the expected performance of available FPSCs. This should help to reduce the amount of time, money, and difficulty that may come with designing a FPSC. It should also allow users to be more confident that a FPSC designed using such models will perform as anticipated when installed.

This work describes how one may apply the Typical Day Concept in a FPSC model. It also describes how to define the solar radiation and ambient temperature data that are representative of a particular month of the year at a specific location. These data are referred to as the typical day data. The typical day data represents the environmental conditions the FPSC is expected to experience [7]. In addition, this work validates the application of the Typical Day Concept in a FPSC model. The validation was accomplished by comparing FPSC experimental data to the output data from a FPSC model (the Typical Day Model) that incorporates the Typical Day Concept.

2. Initializing the FPSC output calculations

In order to initialize the calculation of a FPSC's output, heat balance equations are often used in FPSC models. Below is one such heat balance equation for heat transfer through the top of a single glazed FPSC [7]

$$h_{ccgi}A_c\left(T_c-T_{gi}\right)+\sigma A_c\frac{T_c^4-T_{gi}^4}{\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_g}-1}=h_wA_c\left(T_{gi}-T_a\right)+\varepsilon_g\sigma A_c\left(T_{gi}^4-T_{sky}^4\right) \tag{1}$$

where

- h_{ccgi} = the convective heat transfer coefficient between the absorber plate and cover, $\mathrm{W/m^2K}$;
- h_w = the wind loss coefficient, $\mathrm{W/m^2K}$;
- T_c = the FPSC absorber plate temperature (mean value), K;
- T_{gi} = the cover temperature (mean value), K;
- T_a = the ambient temperature, K;
- T_{sky} = the sky temperature, K;
- ε_p = the emittance of the absorber plate;