Ain Shams Engineering Journal (2012) 3, 299–304

Ain Shams University

Ain Shams Engineering Journal

www.elsevier.com/locate/asej
www.sciencedirect.com

MECHANICAL ENGINEERING

Glass cover temperature and top heat loss coefficient of a single glazed flat plate collector with nearly vertical configuration

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Received 27 September 2011; revised 19 February 2012; accepted 21 March 2012
Available online 25 April 2012

KEYWORDS

Solar collector;
Vertical configuration;
Glazing temperature;
Heat losses;
Top heat loss coefficient

Abstract An empirical relation for glass cover temperature of a single glazed flat plate collector for angle of tilt 60–90° is proposed. Values of glass cover temperature obtained from empirical relation have been used for computation of top heat loss coefficient of collector. Analytical equation has been employed for estimation of top heat loss coefficient, U_t. The range of variables covered in the present analysis is 20 °C to 150 °C for absorber plate temperature, 0.1–0.95 for absorber coating emittance, 20–50 mm for air gap spacing, 60–90° for collector tilt, 5–30 W/m^2 K for wind heat transfer coefficient and −10 °C to 40 °C for ambient temperature. The maximum absolute error in values of U_t is within two percent, in comparison to values obtained by numerical solution of heat balance equations, over the entire range of variables.

1. Introduction

The integration of solar thermal systems into façades of buildings to meet energy requirements of buildings (for domestic hot water, space heating, air-conditioning and lighting) is supported by many researchers in different parts of world [1–6]. It has been quoted [1] that in most European countries, buildings account for approximately 40% of the total energy use. The concept of solar buildings (solar heated and cooled and PV powered), to meet their energy requirement, is gaining momentum. Design of solar buildings requires integration of solar thermal systems, PV panels into roof or walls [1]. Krauter et al. [2] have mentioned that the application of solar energy technology to buildings often depends on its ability to be integrated into common building structures, such as façade elements. Façade-integrated photovoltaic thermal collector

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Peer review under responsibility of Ain Shams University.
http://dx.doi.org/10.1016/j.asej.2012.03.008

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Nomenclature

c	empirical factor	Pr	Prandtl number
e	empirical factor	r	ratio of outer to total resistance
e_p	emittance of absorber plate	Ra_L	Rayleigh number $g\beta'(T_p - T_g)L^3\,\mathrm{Pr}/v^2$
f	empirical factor	$\dot{Q}''_t$	top heat loss flux density (W m^{-2})
h_{cpg}	convective heat transfer coefficient between absorber plate and glass cover (W m^{-2} K^{-1})	T_a	ambient temperature (K)
h_{rga}	radiative heat transfer coefficient between glass cover and ambient (W m^{-2} K^{-1})	T_g	average temperature of glass cover (K)
h_w	wind heat transfer coefficient (W m^{-2} K^{-1})	T_p	average temperature of absorber plate (K)
k	thermal conductivity of air (W m^{-1} K^{-1})	U_t	top heat loss coefficient (W m^{-2} K^{-1})
k_g	thermal conductivity of glass cover (W m^{-1} K^{-1})	β	collector tilt angle with respect to horizontal (°)
L	air gap spacing between absorber plate and glass cover (m)	β'	volumetric coefficient of expansion (per K)
L_g	thickness of glass cover (m)	σ	Stefan–Boltzman constant (W m^{-2} K^{-4})
Nu	Nusselt number (h_cL/k)	ε_g	emittance of glass cover
		ε_p	emittance of coating of absorber plate
		v	kinematic viscosity of air (m^2 s^{-1})

has the potential to become one of the most desirable methods for electricity generation and water heating [3]. Flat plate collectors with single glazing are mostly used in building-integrated systems.

Matuska and Sourek [4] have proposed the utilization of solar energy for domestic hot water heating by installing façade flat plate solar collectors in many flats (apartments) of Czech Republic (established between 1950s and 1970s, which were ready for major renovations). Tripanagnostopoulos et al. [5] have mentioned that the integration of flat plate solar collectors in buildings should be compatible with the architectural design, while solar collectors with colored absorbers would be aesthetically preferable. The selective colored absorbers could be more effective for improving the thermal performance of flat plate collectors in a wide range of operating temperatures than the absorbers with color paints of high emissivity [5]. Zhai and Wang [6] have quoted that the current use of energy in buildings accounts for approximately 25% of total energy consumption in China, and mainly consists of domestic hot water, heating and air-conditioning systems. The government of China has been planning big in the five year plans encouraging solar energy research for the purpose of developing key technologies involved in the integration of solar thermal systems with buildings [6]. China has been pursuing plans of putting into millions of square meter of solar water collectors and integration of solar collector modules into buildings [6].

Top heat loss coefficient is required for evaluating thermal performance of solar collectors. A correct value of U_t is also important for design, simulation of heat losses or thermal performance evaluation of flat plate collectors with vertical configuration. These are used at high latitudes and are integrated with building walls. Top heat loss coefficient, U_t, has to be computed for various values of different variables like emittance of absorber coating (e_p), absorber plate temperature (T_p), ambient temperature (T_a), wind heat transfer coefficient (h_w), air gap spacing between absorber plate and glass cover (L) and angle of inclination of collector (β). Top heat loss coefficient of a flat plate collector can be computed by numerical solution of heat balance equations or approximately by empirical equations [7–12].

The most popular approximate method for calculation of U_t, using Klein's equation quoted by Duffie and Beckman [9] is:

$$U_t = \left[\frac{N}{\frac{C}{T_p}\left[\frac{T_p - T_a}{N+f}\right]^e} + \frac{1}{h_w}\right]^{-1} + \frac{\sigma(T_p^2 + T_a^2)(T_p + T_a)}{(\varepsilon_p + 0.00591Nh_w)^{-1} + \left[\frac{2N+f-1+0.133\varepsilon_p}{\varepsilon_g}\right] - N} \tag{1}$$

where f is the $(1 + 0.089h_w - 0.1166h_w\varepsilon_p)(1 + 0.07866N)$, e the $0.43(1 - 100/T_p)$, and C is the $520(1 - 0.0051\beta^2)$ for $0° < \beta < 70°$. For $70° < \beta < 90°$, use $\beta = 70°$.

Approximate method for calculation of U_t of flat plate collector has been widely used since seventies [13]. It has been analyzed [13,14] that empirical equations [9,11] resulted into large errors in U_t because the equations were derived by regrouping and approximating the convective and radiative terms since the glass cover temperature, T_g, is unknown. An improved technique for predicting U_t of flat plate collector with single glazing was proposed [13]. Analytical equation was used for calculation of U_t with an empirical relation for T_g [13]. Mullick and Samdarshi [13] proposed the use of the following analytical equation for U_t for a flat plate collector with single glazing:

$$U_t^{-1} = [h_{c_{pg}} + h_{r_{pg}}]^{-1} + [h_w + h_{r_{ga}}]^{-1} + L_g/k_g \tag{2}$$

The Eq. (2) can be written as

$$U_t^{-1} = \left[h_{c_{pg}} + \frac{\sigma(T_p^2 + T_g^2)(T_p + T_g)}{1/\varepsilon_p + 1/\varepsilon_g - 1}\right]^{-1} + \left[h_w + \frac{\sigma\varepsilon_g(T_g^2 + T_a^2)(T_g + T_a)}{T_g - T_a}\right]^{-1} + L_g/k_g \tag{3}$$

In the above analytical equation sky temperature is taken equal to ambient temperature (as in Eq. (1)). The thermal resistance of glass cover is a small fraction of total thermal resistance to upward heat flow and can be approximated. The wind heat transfer coefficient has been considered as independent