UTILISABILITY METHOD FOR THE PERFORMANCE EVALUATION OF SOLAR WATER HEATERS WITHOUT STORAGE

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ABSTRACT

It is well known fact that the solar water heaters are used in residential, domestics and industrial applications. More than hundred years ago, black painted water tanks were being used as simple solar water heaters. Solar water heating (SWH) technology is greatly improved during the past century. In SWH technology hot water is stored until it is needed at a later time in a mechanical room, or on the roof in the case of a thermo-siphon system.

In this paper effort is made to introduce 'Utilisability Method' for the performance evaluation of solar water heater without storage, in detail. This method enables the calculation of monthly amount of energy delivered by hot water system, given monthly values of incident solar radiation, ambient temperature and load.

KEYWORDS: Solar water heater, Utilisability method, solar radiation, temperature.

INTRODUCTION

SOLAR WATER HEATING BACKGROUND

Using the sun's energy to heat water is not a new idea. More than one hundred years ago, black painted water tanks were used as simple solar water heaters in a number of countries. Solar water heating (SWH) technology has greatly improved during the past century. Today there are more than 30 million m2 of solar collectors installed around the globe. Hundreds of thousands of modern solar water heaters are in use in countries such as China, India, Germany, Japan, Australia and Greece. In fact, in some countries the law actually requires that solar water heaters be installed with any new residential construction project (Israel for example).

In addition to the energy cost savings on water heating, there are several other benefits derived from using the sun's energy to heat water. Most solar water heaters come with an additional water tank, which feeds the conventional hot water tank. Users benefit from the larger hot water storage capacity and the reduced likelihood of running out of hot water. Some solar water heaters do not require electricity to operate. For these systems, hot water supply is secure from power outages, as long as there is sufficient sunlight to operate the system. Solar water heating systems can also be used to directly heat swimming pool water, with the added benefit of extending the swimming season for outdoor pool applications.

BASICS OF SOLAR ENERGY

Declination

The declination is the angular position of the sun at solar noon, with respect to the plane of the equator. Its value in degrees is given by Cooper's equation:

$$\delta = 23.45 \sin\left(2\pi \frac{284+n}{365}\right)$$

Where n is the day of year (i.e. n =1 for January 1, n =32 for February 1, etc.). Declination varies between -23.45° on December 21 and +23.45° on June 21.

Solar hour angle and sunset hour angle

The solar hour angle is the angular displacement of the sun east or west of the local meridian; morning negative, afternoon positive. The solar hour angle is equal to zero at solar noon and varies by 15 degrees per hour from solar noon. For example at 7 a.m. (solar time2) the solar hour angle is equal to –75° (7 a.m. is five hours from noon; five times 15 is equal to 75, with a negative sign because it is morning). The sunset hour angle ωs is the solar hour angle corresponding to the time when the sun sets. It is given by the following equation:

$$\cos \omega_s = -\tan \psi \tan \delta$$

where δ is the declination, calculated through equation (1), and ψ is the latitude of the site, specified by the user.

Extraterrestrial radiation and clearness index

Solar radiation outside the earth's atmosphere is called extraterrestrial radiation. Daily extraterrestrial radiation on a horizontal surface, H0, can be computed for the day of year n from the following equation:

$$H_0 = \frac{86400 G_{sc}}{\pi}\left(1+0.033\cos\left(2\pi \frac{n}{365}\right)\right)\left(\cos\psi \cos\delta \sin\omega_s + \omega_s \sin\psi \sin\delta\right)$$

Where Gsc is the solar constant equal to 1,367 W/m2, and all other variables have the same meaning as before. Before reaching the surface of the earth, radiation from the sun is attenuated by the atmosphere and the clouds. The ratio of solar radiation at the surface of the earth to extraterrestrial radiation is called the clearness index. Thus the monthly average clearness index, K T, is defined as:

$$\bar{K}_T = \frac{\bar{H}}{\bar{H}_0}$$

Where H is the monthly average daily solar radiation on a horizontal surface and H0 is the monthly average extraterrestrial daily solar radiation on a horizontal surface. K T values depend on the location and the time of year considered; they are usually between 0.3 (for very overcast climates) and 0.8 (for very sunny locations).

PRINCIPLE OF THE UTILISABILITY METHOD

Glazed or evacuated collectors are described by the following equation

$$\dot{Q}_{coll} = F_R(\tau\alpha)\,G - F_R U_L\,\Delta T \quad (1)$$

Where, Q□coll is the energy collected per unit collector area per unit time, FR is the collector's heat removal factor, τ is the transmittance of the cover, α is the shortwave absorptivity of the absorber, G is the global incident solar radiation on the collector, UL is the overall heat loss coefficient of the collector, and ΔT is the temperature differential between the working fluid entering the collectors and outside.

A solar collector is able to collect energy only if there is sufficient radiation to overcome thermal losses to the ambient. According to equation (1), for a glazed collector this translates into:

$$G \geq \frac{F_R U_L (T_i - T_a)}{F_R(\tau\alpha)} \quad (2)$$

Where, Ti is the temperature of the working fluid entering the collector and all other variables has the same meaning as in equation (1). This makes it possible to define a critical irradiance level Gc which must be exceeded in order for solar energy collection to occur. Since the model is dealing with monthly averaged values, Gc is defined using monthly average transmittance – absorptance $(\overline{\tau\alpha})$ and monthly average daytime temperature Ta (assumed to be equal to the average temperature plus 5°C) through:

$$G_c = \frac{F_R U_L (T_i - \overline{T}_a)}{F_R(\overline{\tau\alpha})} \quad (3)$$

Combining this definition with equation (1) leads to the following expression for the average daily energy Q collected during a given month:

$$Q = \frac{1}{N} \sum_{days} \sum_{hours} A_c F_R (\overline{\tau\alpha})(G - G_c)^+ \quad (4)$$

Where, N is the number of days in the month, G is the hourly irradiance in the plane of the collector, and the + superscript denotes that only positive values of the quantity between brackets are considered. The monthly average daily utilisability φ is defined as the sum for a month, over all hours and days, of the radiation incident upon the collector that is above the critical level, divided by the monthly radiation:

$$\overline{\phi} = \frac{\sum_{days} \sum_{hours} (G - G_c)^+}{\overline{H}_T N} \quad (5)$$

Where, HT is the monthly average daily irradiance in the plane of the collector. Substituting this definition into equation (4) leads to a simple formula for the monthly useful energy gain:

$$Q = A_c F_R \left(\overline{\tau\alpha}\right) \overline{H}_T \overline{\phi} \qquad (6)$$

The purpose of the utilisability method is to calculate φ from the collector orientation and the monthly radiation data entered by the user (or copied from the RET Screen Online Weather Database). The method correlates φ to the monthly average clearness index KT and two variables: a geometric factor R Rn and a dimensionless critical radiation level Xc, as described hereafter.

Geometric factor R Rn

R is the monthly ratio of radiation in the plane of the collector, HT, to that on a horizontal surface, H:

$$\overline{R} = \frac{\overline{H}_T}{\overline{H}} \qquad (7)$$

Where HT is calculated as explained in above section. Rn is the ratio for the hour centered at noon of radiation on the tilted surface to that on a horizontal surface for an average day of the month. This is expressed through the following equation:

$$R_n = \left(1 - \frac{r_{d,n} H_d}{r_{t,n} H}\right) R_{b,n} + \left(\frac{r_{d,n} H_d}{r_{t,n} H}\right)\left(\frac{1+\cos\beta}{2}\right) + \rho_g \left(\frac{1-\cos\beta}{2}\right) \qquad (8)$$

Where, rt,n is the ratio of hourly total to daily total radiation, for the hour centered around solar noon. rd ,n is the ratio of hourly diffuse to daily diffuse radiation, also for the hour centered around solar noon. This formula is computed for an "average day of month," i.e. a day with daily global radiation H equal to the monthly average daily global radiation H; Hd is the monthly average daily diffuse radiation for that "average day", β is the slope of the collector, and ρ g is the average ground albedo. rt,n is computed by the Collares – Pereira and Rabl equation, written for solar noon:

$$r_{t,n} = \frac{\pi}{24}(a+b)\frac{1 \quad \cos\omega_s}{\sin\omega_s - \omega_s \cos\omega_s} \qquad (9)$$

$$a = 0.409 + 0.5016 \sin\left(\omega_s - \frac{\pi}{3}\right) \qquad (10)$$

$$b = 0.6609 - 0.4767 \sin\left(\omega_s - \frac{\pi}{3}\right) \qquad (11)$$

With ωs the sunset hour angle, expressed in radians. rd, n is computed by the Liu and Jordan equation, written for solar noon:

$$r_{d,n} = \frac{\pi}{24} \frac{1 - \cos\omega_s}{\sin\omega_s - \omega_s \cos\omega_s} \quad (12)$$

Dimensionless critical radiation level Xc, Xc is defined as the ratio of the critical radiation level to the noon radiation level on the typical day of the month:

$$\overline{X}_c = \frac{G_c}{r_{t,n} R_n \overline{H}} \quad (13)$$

Where, rt,n is given by (9) and Rn by (8).

Monthly average daily utilisability φ

Finally, the correlation giving the monthly average daily utilisability φ as a function of the two factors R Rn and Xc calculated previously, is:

$$\overline{\phi} = \exp\left\{\left[a + b\frac{R_n}{\overline{R}}\right]\left[\overline{X}_c + c\overline{X}_c^2\right]\right\} \quad (14)$$

With,

$$a = 2.943 - 9.271\,\overline{K}_T + 4.031\,\overline{K}_T^2 \quad (15)$$

$$b = -4.345 + 8.853\,\overline{K}_T - 3.602\,\overline{K}_T^2 \quad (16)$$

$$c = -0.170 - 0.306\,\overline{K}_T + 2.936\,\overline{K}_T^2 \quad (17)$$

With this, the amount of energy collected can be computed, as shown earlier in equation no. (6).

CONCLUSION

In this paper effort is made to introduce 'Utilisability Method' for the performance evaluation of solar water heater without storage, in detail. This method enables the calculation of monthly amount of energy delivered by hot water system, given monthly values of incident solar radiation, ambient temperature and load. This is one of the innovative methods for calculation of monthly and hence yearly energy delivered.

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