Summary

The purpose of the work is to analyse the relationship between daily energy collected and daily total solar insolation in the plane of the collector observed in so called input/output diagrams. As a first approximation linear regression lines are used to present this relationship.

In this paper we describe a way how to take into account the variation of the daily and seasonal distribution of the irradiation, which influence the daily energy output significantly.

A model has been developed for analytical calculation of the average input/output relation with high accuracy.

1. INTRODUCTION

Input/output regression lines are often used for comparing solar collector array performance from different systems and climates. So is done within the IEA Solar Heating and Cooling task VI for evacuated collectors.

Usually for well performing solar collector systems a very linear relationship is experienced between daily solar irradiation \( H \) and daily energy collected \( Q \) (see ref 1) and Fig 7. In general this relationship can be expressed by

\[
Q = a H - b
\]  

were \( a \) give the slope of the curve and \( b \) represent the daily threshold energy for the system.

2. THEORY

An analytical expression for the daily energy flows can be derived from a short term energy balance for the solar collector system.

The collectors are modelled with the Hottel Whillier Bliss equation including angle modifier, dynamic losses, piping losses and pumping energy dissipation.

When integrating this equation for 24 hrs we get a very simple analytical expression for the daily energies:

\[
Q = A H - B \langle\Delta T\rangle_{24\ h} - C
\]

\( A \) is the all day zero loss efficiency and \( B \) is the collector array heat loss factor. \( \langle\Delta T\rangle_{24h} \) is the 24 hrs average temperature difference between collector mean and ambient temperature. \( C \) is a correction term.
where parasitic energies as pumping energy dissipation and piping losses are taken into account. In a well designed system C is almost zero. But in a test system C can be significant.

By dividing this equation with H we get an expression for the daily efficiency. This equation has been tested with experimental data showing that A and B really can be approximated by constants. See Fig 1.

In practice H and <ΔT>24h are not independent variables as shown in Fig 2. There is a clear tendency that the <ΔT>24h increases with H due to a systematic variation of the average time distribution of H.

This means that the resulting input/output relation for constant operating ΔT is composed of daily results along individual lines for constant <ΔT>24h according to equation 2. See Fig 3.

This explains why the regression line has a slightly lower slope than the all day zero loss efficiency A. The <ΔT>24h dependence on the time distribution of the insolation during the day explains the variation of Q by season and also the scatter for individual days. For example the shorter winter days give a lower <ΔT>24h for the same H and operating ΔT. This results in a higher Q compared to summer operation.

For the purpose of system modelling the coefficients A, B and C as well as <ΔT>24h have to be derived analytically.

This can be done by establishing a system energy balance according to Fig 4. From this energy balance a substitution for B<ΔT>24h can be derived and inserted into equation 2. For simple analytical treatment however some approximations are necessary. These approximations are explained by means of Fig 5 which shows a typical daily irradiation. A x H is the thermal energy input to the system and B<ΔT>24h is the energy losses from the collector array.

The total 24 hr energy losses from the array B<ΔT>24h is substituted by analytical expressions for the four loss areas M, R, E and D. R is derived from the operating ΔT requirement and the operating time. M and E are derived from the difference between daylength and operating time and the shape of the limiting curve represented by an empirical form factor f. D is the all day capacitance energy which is leaving the system as heat losses after the operating period.

M, R and E have expressions with the operating time involved. The operating time increases with H in a systematic way and corresponds to the previously observed increase in <ΔT>24h with H. Longterm data analyses for both operating time and irradiation time-distribution show a very linear average relationship, see Fig 6. This has been used to eliminate the operating time from M, R and E.

When inserting the expression for <ΔT>24h into 2 we get a model where all the important system parameters are in explicit form and the input/output average relations according to the regression lines can be analytically predicted. C is not shown in explicit form as it normally can be neglected.

\[
Q = H(A - U \cdot ΔT(1-f)d) + U \cdot ΔT \cdot s - U \cdot ΔT \cdot f \cdot (S_{day} + S_{s}) - ΔT \cdot C \cdot s - C
\]

Q = Daily energy from collector array \( \text{MJ/m}^2 \text{ day} \)
H = Daily insolation in the plane of the collector \( \text{MJ/m}^2 \text{ day} \)
A = All day zero loss efficiency for the collector array
U = Array heat loss coefficient (= B/24/3600) \( \text{W/m}^2 \text{ K} \)
ΔT = Average temperature difference between mean collector temperature and ambient during operating time
f = form factor for energy losses outside operating time \(^{(\approx 0.30)}\)