REPORT

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Description of Microsoft excel code for energy output evaluation

Introduction

This report summarise how to use the excel code to evaluate solar collector performance, as well as describe the equations used to calculate collector efficiency etcetera.
The main idea is to have a transparent tool, so that comparisons can be made on an equal basis. This report documents the equations used in the calculations in the excel tool.

System requirements

The Excel calculation tool was developed in Microsoft Excel 2003 Version 11.0, Build 8169. This version or later should be used for the evaluations. The program have not been tested under different versions, but should be compliant in later versions.

Information flow

The user of this code starts by pressing the button "Evaluate performance" (Figure 1). In the user interface that then appears, the user is asked to input data, see "User input" below. When the data has been typed, the visual basic code calculates the monthly amount of heat that could be extracted from the solar collector, depending also on the distribution system temperature. The results are presented as a table and as a figure. As an extra option, there is the possibility to add a user specified city by clicking the button "User specified city" and fill out the required data for that city (marked blue).

User input

When pressing the "Evaluate performance" button, the user is prompted to input information on the location of the Collector installation (Figure 2). Location weather data is then taken from the sheets containing location data, see Description of worksheets. Next is the input of collector data and tilt angle (Figure 3), followed by setting the distribution system temperature (Figure 4).
Finally input on IAM type is supplied and the OK button is pressed to perform the calculations (Figure 5).

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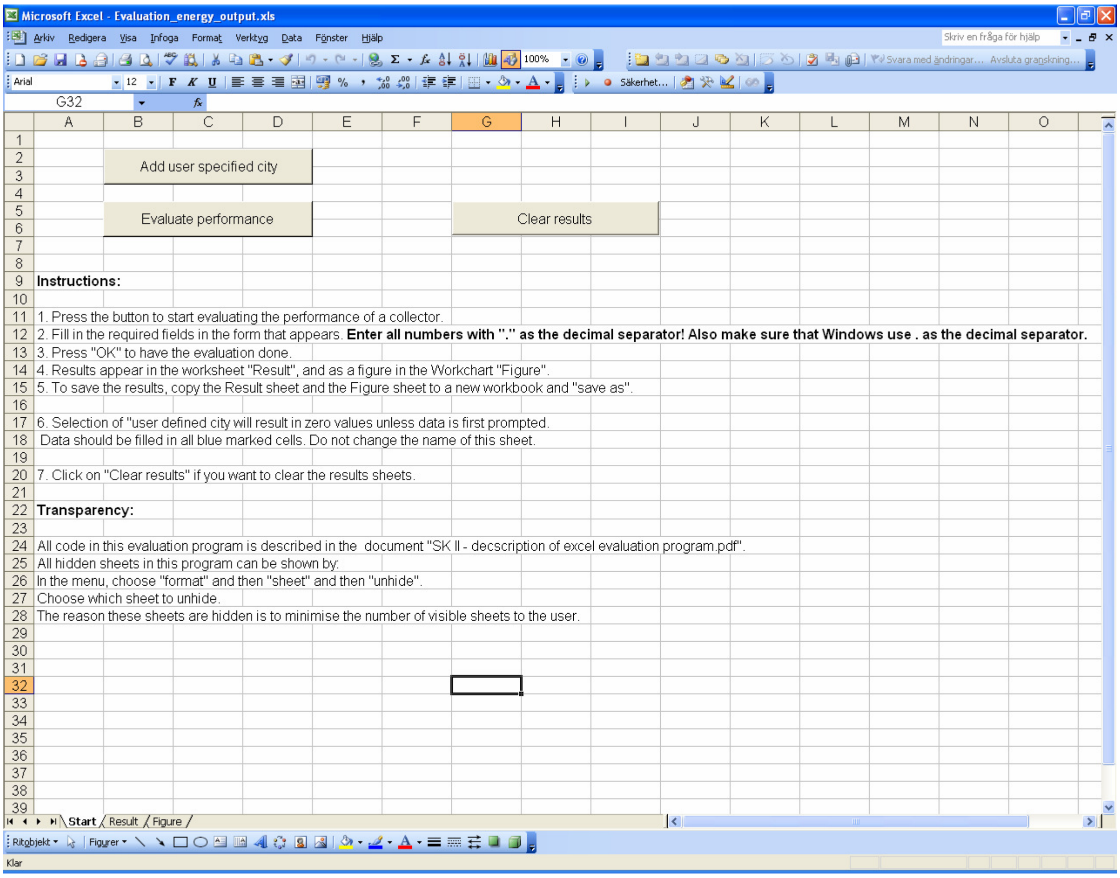

Figure 1. Main screen.

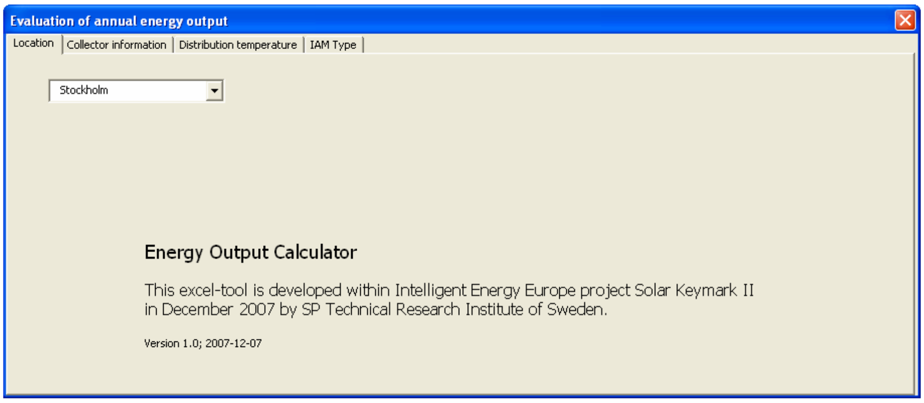

Figure 2. Location input.

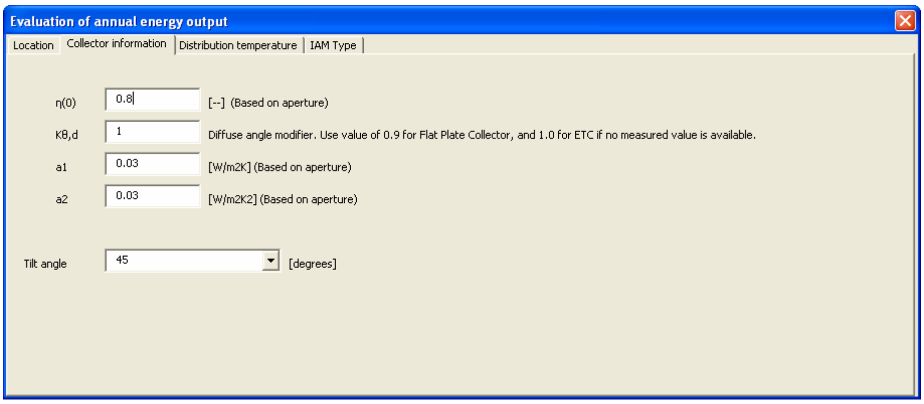

Figure 3. Input of collector constants and tilt angle.

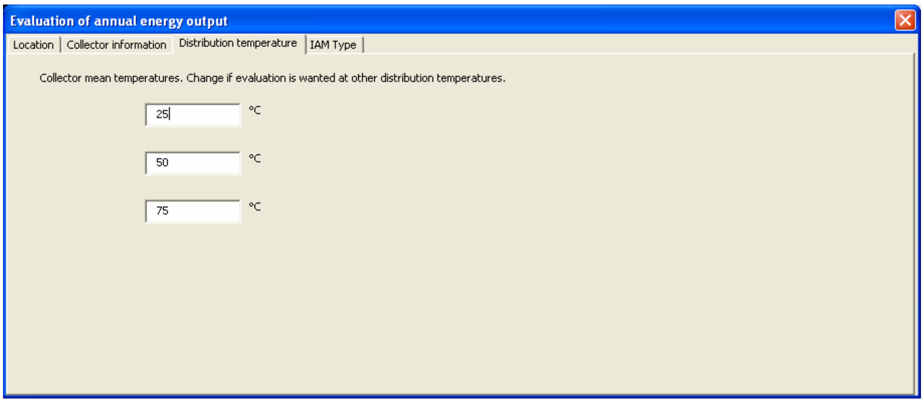

Figure 4. Input of distribution system temperature levels.

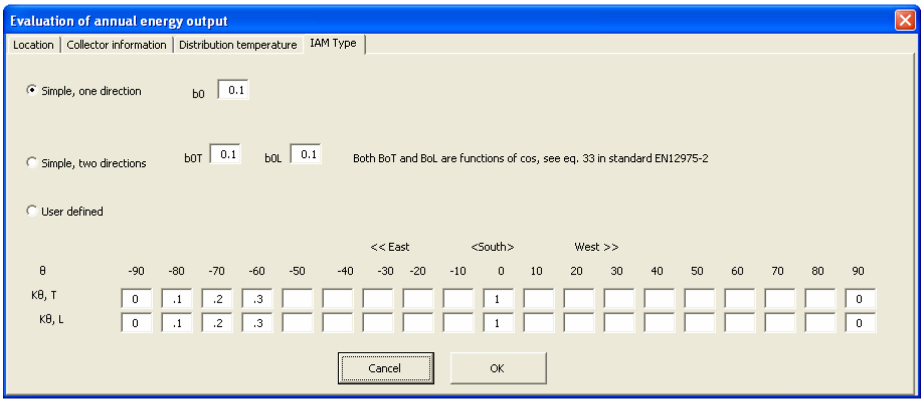

Figure 5. Information on IAM type.

Calculations

All calculations are made by the VBA code in excel. Calculations are made for hour by hour resolution of the climatic data. Detail about the calculations that are performed are described in Description of calculations.

Results

Hour by hour results are written in a hidden worksheet. These data are then summarised as monthly data in the worksheet “Result” and in the chart “Figure”. For transparency, the hidden worksheet can be accessed if further information is requested.

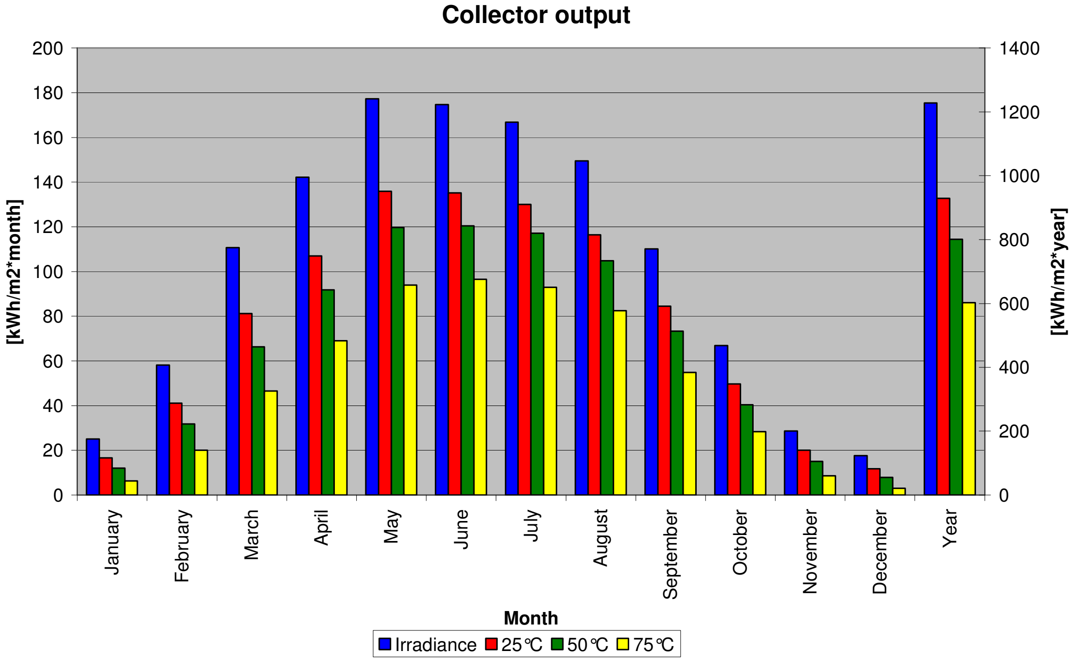

Figure 6. Example of "Figure " output.

Table 1. Example of results shown in the sheet "Result".

Monthly irradiance and yield expressed in kWh/m2

	Irradiance	Collector mean temperature (°C)		
		25°C	50°C	75°C
January	25	17	12	6
February	58	41	32	20
March	111	81	66	47
April	142	107	92	69
May	177	136	120	94
June	175	135	120	97
July	167	130	117	93
August	149	116	105	83
September	110	85	73	55
October	67	50	40	28
November	29	20	15	9
December	18	12	8	3
Year	**1228**	**929**	**800**	**603**

Loocation: Stockholm
Longitude: 18.08
Latitude: 59.35
Climate data, time period: 1996-2005

Collector information

η_0 0.8
a1 0.03

a2	0.03
Tilt angle	45
Kθd	1
IAM Type:	Simple, One-direction b0=0.1

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Description of calculations

Calculation of the heat delivered to the distribution system

The heat delivered to the distribution system (kWh/m^2)is calculated according to Equation 1 below for each time step:

$$Q/A_a = \eta_0 * K_\theta(\theta) * G_b + \eta_0 * K_{\theta d} * G_d - a_1(t_m - t_a) - a_2(t_m - t_a)^2 \quad [kWh/m^2] \qquad \text{(Eq. 1)}$$

Where $\eta_0 = F'(\tau\alpha)_{en} * K_{\theta b}(\theta = 15) * 0.85 + F'(\tau\alpha)_{en*} K_{\theta d} * 0.15$

($K_\theta(\theta)$ corresponds to $K_{\theta b}(\theta)$ under quasi-dynamic conditions)

The efficiency factor, $F'(\tau\alpha)_e$, is referred to as $\eta(0)$ in the calculation tool.
Negative values of Q/A are not meaningful, therefore if Q/A < 0 in any time step, Q/A is set to zero (0).

Calculation of $K_{\theta b}$

The angle modifier $K_{\theta b}$ is calculated differently depending on the IAM type. In this version of the excel tool the user can choose between Simple model (flat plate collector) or User defined factor in different angles (ETC and concentrating collectors).
In all three models, when $K_b<0$, K_b is set to zero (0).

Simple (flat plate collector)

$$K_{\theta b}(\theta) = 1 - b_0 * (1/\cos(\theta) - 1) \qquad \text{(Eq. 2)}$$

ETC with flat collector without reflectors and flat plate collectors with structured glazing

$$K_{\theta b}(\theta_T) = 1 - b_{0,T} * (1/\cos(\theta_T) - 1) \qquad \text{(Eq. 3)}$$

And

$$K_{\theta b}(\theta_L) = 1 - b_{0,L} * (1/\cos(\theta_L) - 1) \qquad \text{(Eq. 4)}$$

Then

$$K_{\theta b}(\theta) = K_{\theta b}(\theta_T) * K_{\theta b}(\theta_T), \text{ T = transversal, L = longitudinal} \qquad \text{(Eq. 5)}$$

User defined factor in different angles (ETC with circular collector, concentrating collectors and ETC with reflectors)

From the user input, a linear interpolation of the $K_{b,i}$ value is made between the angles closest to the given one. For example, if the angle is 73°, the K_b-value is calculated as (both Transversal and Longitudinal):

$$K_{b,i}(73°) = (70° - 73° / (70 - 80) * (K_{b,i}(80°) - K_{b,i}(70°)) + K_{b,i}(70°) \qquad \text{(Eq. 6)}$$

i = T or L

$$K_{\theta b}(\theta) = K_{\theta b}(\theta_T) * K_{\theta b}(\theta_T), \text{ T = transversal, L = longitudinal}$$

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Intermediate calculations

Beam_irradiation = G* - G_d (Eq. 7)

Solar_time= (Hour_day* 3600 + E* 60 + 4 * (STD_longitude - longitude) * 60) / 3600 (Eq. 8)

“Reference time” for the hourly data
Hourly values for hour number i are:
Mean values of the period between hour number i-1 and i.
Hour number given relates to:
The local time (no summer time shift)

ω= Asin(sin(Φ) * sin(δ) - cos (Φ) * cos(δ) * cos(Solar_time * 15)) (Eq. 9)

γ= Acos((sin(δ) * cos(Φ) + cos(δ) * sin(Φ) * cos(Solar_time * 15)) / (-cos(ω))) Eq. 10)

w = -180 + Solar_time * 180 / 12 (Eq. 11)

SZ = cos(Φ) * cos(w) * cos(δ) + sin(Φ) * sin(δ) (Eq. 12

sn = sin(β) * (sin(Φ) * cos(w) * cos(δ) - cos(Φ) * sin(δ)) + cos(β) * (cos(Φ)* cos(w) * cos(δ) + sin(Φ) * sin(δ)) (Eq. 13)

If SZ > 0 And sn > 0 Then

θ_T = (Atn(sin(w) * cos(δ) / sn)) * 180 / π (Eq. 14)

Else
θ_T = 90

If SZ > 0 And sn > 0 Then
θ_L = Atn((cos(β) * (-sin(Φ) * cos(w) * cos(δ) + cos(Φ) * sin(δ)) + sin(β) * (cos(Φ) * cos(w) * cos(δ) + sin(Φ) * sin(δ))) / sn) * 180 / π (Eq. 15)

Else
θ_L = 90

θ = (Acos(sin(Solar_degree) * cos(β) + cos(ω) * sin(β) * cos(γ))) * 180 / π (Eq. 16)

References

[1]
[2]

Kommentarer att beakta:
Solar_degree not defined
To be considered:
Include drawing showing the angles
Include capacity of collector (dynamic simulation)
Include tracking and semi-tracking collectors

Appendix 1

Please give references to equations used
Did you check/validate calculations (with e.g. METEONORM)?

Hour_day not defined (Eq. 8)
E not defined, equation of time
STD_longitude not defined

Solar altitude? (haven't seen ω used as name for that before)
δ equation not given, declination

Solar azimuth? surface azimuth always zero, I assume (it could be considered to allow for surface rotation also in azimuth direction)

w not given in nomenclature, but is the solar hour angle normally named ω or ω_s

SZ not given in nomenclature, zenith angle of sun

sn not given in nomenclature

if eq. 14 and 15 are not fulfilled you set the accordand angles to 90°, this can result in positiv collector output if the IAM is not 0 under 90°
referring to eq.1 of the documentation you use the incident angle modifier for diffuse irradiance, however I did not find the possibility to enter a value within the sheet.

Description of worksheets

The excel model contains a total of nine worksheets:

- Start
- Result
- Figure

- Result (hidden)
- Athens
- Davos
- Stockholm
- Wurzburg
- User Specified City

The first three sheets are visible, the six latter are hidden.
In the “Start” sheet the user starts the evaluation by clicking the button.
Results are printed in the “Result” sheet as a table, and in “Figure” as a figure.

“Result (hidden)” contains the calculated data that is necessary to plot the figure and make the table.
All worksheets named with locations contain specific location data such as ambient temperature, global and diffuse irradiation on a hourly basis. The irradiation data is available for the angles that are possible to do the evaluation for.

All hidden sheets in this program can be shown by:
1. In the menu, choose "format" and then "sheet" and then "unhide".
2. Choose which sheet to unhide.

The reason these sheets are hidden is to minimise the number of visible sheets to the user.

NO CHANGES SHOULD BE MADE TO ANY WORKSHEETS, SINCE THAT COULD AFFECT THE CALCULATIONS.

Nomenclature

$a1$	heat loss coefficient at (Tm - Ta)=0 $Wm^{-2}K^{-1}$
$a2$	temperature dependence of the heat loss coefficient $Wm^{-2}K^{-2}$
A_a	aperture area of collector m^2
b_o	constant for the calculation of the incident angle modifier
b_1	heat loss coefficient at (Tm - Ta)=0 $Wm^{-2}K^{-1}$
b_2	collector efficiency coefficient $Wsm^{-3}K^{-1}$
F'	collector efficiency factor
$G*$	global hemispherical solar irradiance Wm^{-2}
G''	net irradiance Wm^{-2}
G_b	direct solar irradiance (beam irradiance) Wm^{-2}
G_d	diffuse solar irradiance Wm^{-2}
LT	local time h
$K_{\theta b}$	incidence angle modifier for direct radiation
$K_{\theta d}$	incidence angle modifier for diffuse radiation
m	mass flowrate of heat transfer fluid kgs^{-1}
Q	useful power extracted from collector W
t	time s
t_a	ambient or surrounding air temperature °C
t_m	mean temperature of heat transfer fluid °C

β	tilt angle of a plane with respect to horizontal degrees
γ	azimuth angle degrees
ε	hemispherical emittance
δ	declination
ω	solar hour angle degrees
θ	angle of incidence degrees
Φ	latitude degrees
η	collector efficiency, with reference to T^*_m
η_o	zero-loss collector efficiency (at $T^*_m = 0$), reference to T^*_m
$(\tau\alpha)_e$	effective transmittance-absorptance product

1. McIntire, W.R. and K.A. Reed, *Orientational relationships for optically non-symmetric solar collectors.* Solar Energy, 1983. **31**(4): p. 405-410.
2. *SVENSK STANDARD SS-EN 12975-2:2006 Solvärmeteknik – Solfångare – Del 2: Provningsmetoder Thermal solar systems and components – Solar collectors – Part 2: Test methods*. 2006.