Objective methodology for simple calculation of the energy delivery of (small) Solar Thermal systems

The present document proposes a simple calculation methodology to determine the energy yield of small solar thermal systems. Such a methodology could then be used, e.g. by public authorities to base financial incentives on the expected solar thermal energy production rather than on more generic parameters like the collector area.

For small solar thermal systems both, the actual heat metering and the individual simulation of energy production would be prohibitively expensive. Therefore, this document proposes a simple method, which is based on a few selected parameters and the assumption of a constant mean temperature in the collector.

NB: At the time of writing, it is expected, that this calculation methodology will be introduced in the next version of the European Standard for solar thermal collectors, EN 12975.

Solar collectors are described by their efficiency parameters:

- Zero-loss efficiency: n_0
- 1st order heat loss coefficient: a_1
- 2nd order heat loss coefficient: a_2

Using these parameters, the **collector efficiency** can be expressed as:

$$n = n_0 - a_1*(T_m-T_a)/G - a_2*(T_m-T_a)^2/G \quad (1)$$

and hence the **power**:

$$P = A*(n_0*G - a_1*(T_m-T_a) - a_2*(T_m-T_a)^2) \quad (2)$$

where:

G = solar irradiation W/m^2
T_a = ambient air temperature
T_m = collector mean temperature
A = collector area (corresponding to the efficiency parameters)

Known parameters
To calculate the annual output, the values of G, T_a and T_m have to be known at all times.

G and T_a are weather data defined by the location; their values are (at least in principle) known for most European places.

Assumption on T_m

T_m is normally not known. Its value depends not only on the weather, but also on the load and the design and the components of the system (collector area and efficiency parameter, storage capacity, heat losses, control, ...), i.e. on the actual system and the actual operation conditions at a given point in time.

But if T_m is assumed constant all the time the case is very simple: When the collector and the location is known/specified the power output is determined at every point in time by eq. (2) below using always the same value of T_m.

The difficult task is now reduced to estimating a typical operation temperature depending on the application: At which temperature delivers the collector typically most energy to the system. Some suggestions for such temperatures are given in table 1.

Resulting annual energy output

Assuming a constant collector temperature, the annual energy output is calculated by integrating eq. (2) over a year including all positive contributions (as it is assumed that the collector loop is never operating when the contribution is negative).

$$Q_{annual} = \int [A*(n_0*G - a_1*(T_{m,constant}-T_a) - a_2*(T_{m,constant}-T_a)^2)]^+ \, dt$$

In practise it is now easy to calculate the annual output per m^2 of a given collector operating at a typical mean temperature using e.g. hourly weather data and the collector efficiency parameters.

To use this simple model to estimate real collector/system output and system savings it is needed to:

- define typical/representative collector mean operating temperatures in typical applications (see table 1 for suggestions)
- convert collector annual output to system output
- convert system output to system savings

Due to big difference from country to country (definitions/conversions depend on national traditions for hot water and heating system, solar system type and back-up system type), this should be left to decision on national or even local level – but some recommendations/suggestions are given in table 1 below.

Application	Recommended T_m [°C] for calculating	$F_{col\text{-}sys}$ Factor for	$F_{sys\text{-}sav}$ Factor for	$F_{col\text{-}sav} = F_{col\text{-}sys}*F_{sys\text{-}sav}$

	annual collector output	converting collector output to system output	converting system output to system savings	Resulting factor for converting collector output to system savings
Swimming pools	30	0,76	1,31	1,00
Domestic hot water DHW* Boiler Back-up	50	0,86	1,38	1,19
Domestic hot water DHW* Eletricity Back-up	50	0,86	1,00	0,86
Combi systems HW/SH	60	0,77	1,31	1,01
District heating without seasonal storage	Average return temperature from district heating network + 5	0,95	1,05	1,00
Cooling / AC	90	0,90	1,11	1,00
Process heat	Process temperature + 10	0,90	1,11	1,00

Table 1. Recommendations for typical T_m's and factors for converting annual collector output to system output and to annual energy savings using the factors $F_{col\text{-}sys}$, $F_{sys\text{-}sav}$ and $F_{col\text{-}sav}$. See table 2 below for the data used to make the numbers in table 1.
**) Fig.1 in the end of this section indicates that using 50°C as constant temperature for DMW systems is valid for even very different climates.*

The factors $F_{col\text{-}sys}$, $F_{sys\text{-}sav}$ and $F_{col\text{-}sav}$ are defined by the following equations:

- {System Output} = $F_{col\text{-}sys}$ * {Collector Output}
- {System Savings} = $F_{sys\text{-}sav}$ * {System Output}
- {System Savings} = $F_{col\text{-}sav}$ * {Collector Output}
- $F_{col\text{-}sav} = F_{col\text{-}sys} * F_{sys\text{-}sav}$

$F_{col\text{-}sys}$ takes into account losses in the solar system:

- $F_{col\text{-}sys}$ = {Collector Output} – {Pipe Losses} – {Extra Tank Losses})/{Collector Output}

{Extra tank Losses} are extra heat losses due to higher temperatures in summer (and bigger volume) in a solar tank (compared with non-solar tank).

$F_{sys\text{-}sav}$ takes into account losses in the back-up system:

- $F_{sys\text{-}sav}$ = ({System Output}/η_{boiler} + {Saved Stand-by Losses}/ η_{boiler}) / {System Output}
- η_{boiler} = {Boiler Efficiency}

{Saved Stand-by Losses} can be obtained if the boiler is off during summer.
If the back-up system is electricity, η_{boiler} = 1, and {Saved Stand-by Losses} = 0, hence:

- $F_{sys\text{-}sav}$ = 1 in case of electrical back-up

The data used for calculating the values in table 1 are given in table 2.

Application	Pipe Losses in % of Collector Output	Extra Tank Losses in % of Collector Output	Boiler Efficiency in %	Boiler Stand-by Losses in % of Collector Output
Swimming pools	5%	20%**	85%	10%
Domestic hot water DHW Boiler Back-up	10%	5%	85%	15%
Domestic hot water DHW Electricity Back-up	10%	5%	100%	0%
Combi systems HW/SH	10%	15%	85%	10%
District heating without seasonal storage	5%	0%	95%	0%
Cooling / AC	5%	5%	90%	0%
Process heat	5%	5%	90%	0%

Table 2. Data used for calculating the values in table 1.
***) The pool is here acting as "tank" for the solar system – the 20% tank losses indicate that in very sunny and warm periods the pool is heated above the necessary temperature level.*

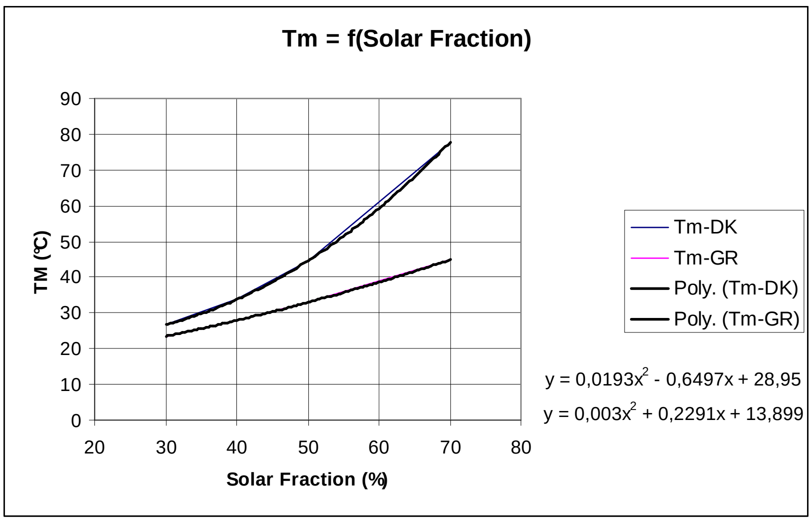

Figure 1. T_m can for each climate be correlated to the solar fraction of a typical DHW system by finding the solar fraction at which the solar input equals the collector output at T_m (°C). The figure shows this function for a typical DHW system in Greece and Denmark. The solar fraction is here defined as the fraction of solar input to the tank to the total input to the tank:

Solar fraction = Solar input / (Solar input + Supplementary input).

It is seen that T_m = 50 °C corresponds to a solar fraction in DK of 53% and in Greece of 75%, which actually correspond to typical solar fractions in the two counties.