

**DELIVERABLE NO WP4.D2  
DRAFT PROCEDURES AND RESOURCE  
DOCUMENTS**

**Subtask 9: m<sup>2</sup> → power and energy**

***Dissemination level: Public***

August 2007

**CONTENTS**

*In total this Deliverable consists of  
35 pages.*

The task of WP4.D2 “draft procedures and resource documents” was divided into the following 9 subtasks:

1. advanced collectors
2. advanced stores
3. advanced controllers
4. combisystems
5. solar cooling
6. solar desalination
7. fluids
8. LCA (Life Cycle Assessment)
9. m<sup>2</sup> -> power and energy

The resource documents of subtask 9 “m<sup>2</sup> → power and energy” (subtask leader: ESTIF) are included in this report.

WP4-D2.9.a Conversion of m<sup>2</sup> to power - ESTIF

More details - ESTIF

WP4-D2.9.b ENEA proposal - ENEA

WP4-D2.9.c Simple model, collector output - ESTIF

WP4-D2.9.d IEA->f(G0) - ESTIF

WP4-D2.9.e Comparison of different methods - ESTIF

# Converting Installed Collector Area to Annual Energy Production based on IEA-SHC World Statistics

5<sup>nd</sup> draft, 15/6, 2007

Jan Erik Nielsen (JEN)

## Summary

The IEA-SHC *Solar Heat Worldwide 2004* statistics are used for this investigation of the collector yield and energy savings per m<sup>2</sup> collector in the main EU markets<sup>1</sup>.

On an average European level the collector yield per m<sup>2</sup> is: 411 kWh/m<sup>2</sup> - weighted for distribution between countries and all applications (including unglazed collectors for swimming pool heating) in 2004. The collector yield is the input to the storage tank.

As the piping losses are approximately 15% , the corresponding **energy output of the collector is 473 kWh/m<sup>2</sup>** - weighted for distribution between countries and **all applications**. With a conversion factor of 0,7 from m<sup>2</sup> to kW this corresponds to the **equivalent number of full load hours** of:

$$473 \text{ kWh/m}^2 / (0.7\text{kW/m}^2) = \mathbf{675 \text{ hours}}$$

It is shown that it is very easy to give an estimate of the collector production (in countries with mostly DHW systems) :

$$\begin{aligned} \mathbf{Q_{total}} &= \mathbf{EFLH * P} \\ &= \mathbf{0.6 * G_0 * P} \end{aligned}$$

with:

EFLH: Equivalent number of full load hour [hours]

P: Installed power capacity [MW]

G<sub>0</sub>: Global radiation [W/m<sup>2</sup>]

On an average European level the energy savings per m<sup>2</sup> of collector is: 624 kWh/m<sup>2</sup> - weighted for distribution between countries and all applications in 2004.

**Excluding un-glazed collectors** for swimming pool heating the energy the **energy output of the collector is 497 kWh/m<sup>2</sup>** - weighted for distribution between countries and **all applications**. With a conversion factor of 0,7 from m<sup>2</sup> to kW this corresponds to a **number of full load hours** of: 473 kWh/m<sup>2</sup> / (0.7kW/m<sup>2</sup>) = **710 hours**

It is shown that the collector yield and energy savings can be expressed as simple functions of the horizontal global radiation concerning the systems for swimming pool heating and domestic hot water. Concerning combi systems the yield and savings seem to be independent of the radiation.

---

<sup>1</sup> Including also non significant markets does not change the values very much – on a total overall basis the values are:

- Collector yield: 409 kWh/m<sup>2</sup>
- Collector production: 491 kWh/m<sup>2</sup>
- Energy savings: 623 kWh/m<sup>2</sup>

## ***Intro***

At the IEA-SHC / Solar Thermal Associations meeting in Malaga 23/5, 2006 a Task Group was formed to deal with this issue:

Werner Weiss, Gerhard Strii-Huib, Uwe Brechlin, Lex Bosselaar, Jan Erik Nielsen.

At the 1<sup>st</sup> task group meeting in Brussels 30/5, 2006 (without Lex Bosselaar) the following was agreed:

- i. Produced energy to be defined as: The energy output of the collector in a reference system. The produced energy can be calculated by national committees based on national defined reference systems.
- ii. A general approach valid in cases where national input is missing will be developed by the task group – based on a draft proposal from JEN. This draft proposal should be based on the existing statistics given in the IEA-SHC publication "Solar Heat Worldwide". As a starting point an approach valid for Europe will be made.
- iii. Werner Weiss (WW) will provide JEN with more detailed info on the methodology used in "Solar Heat Worldwide".

This paper gives a draft for the general approach mentioned in "ii" above.

## ***Applications***

The applications chosen here are the ones defined in "Solar Heat Worldwide":

- Swimming Pool Heating with unglazed collectors; SPH
- Domestic Hot Water for Single Family Houses; DHW-SFH
- Domestic Hot Water for Multi Family Houses (incl. hotels and district heating); DHW-MFH
- COMBI systems for domestic hot water and space heating – single family houses; COMBI-SFH

## ***Counties included***

The countries included are – for each application - the European countries with a significant installed capacity (>20 MW  $\approx$  30,000 m<sup>2</sup>) – see table 1.

Country	Application				Total	%
	SPH	DHW-SFH	DHW-MFH	COMBI-SFH		
Austria	411	1.176	46	305	1.938	16,6%
Belgium		34			34	0,3%
Cyprus		504			504	4,3%
Czech Republic		35			35	0,3%
Denmark		185	28		213	1,8%
France	70	460			530	4,5%
Germany	543	3.196	319	479	4.537	38,8%
Greece		2.054	42		2.096	17,9%
Italy		312			312	2,7%
Netherlands	204	183			387	3,3%
Poland		64			64	0,5%
Portugal		182			182	1,6%
Slovak Republic		40			40	0,3%
Slovenia		70			70	0,6%
Spain		459	24		483	4,1%
Sweden	27		36	93	156	1,3%
United Kingdom		118			118	1,0%
Total	1.255	9.072	495	877	11.699	100,0%
%	10,7%	77,5%	4,2%	7,5%	100,0%	

*Table 1. MW installed in 2004 (Source: Solar Heat Worldwide 2004  
+detailed tables from AAE-INTEC)*

*SPH: Swimming Pool Heating with unglazed collectors*

*DHW-SFH: Domestic Hot Water for Single Family Houses*

*DHW-MFH: Domestic Hot Water for Multi Family Houses (incl. hotels and district heating)*

*COMBI-SFH: Combined systems for domestic hot water and space heating – single family houses*

It is seen from Table 1 that systems for domestic hot water in one family houses accounts for almost 80% of all systems.

## Swimming Pool Heating, SPH

Swimming pool heating systems make up 11% of the installed capacity in the investigated countries. Values for Collector Yield and Energy Savings are given in table below:

Country	Collector Yield kWh/m <sup>2</sup>	Energy savings kWh/m <sup>2</sup>
Austria	227	370
France*	197	340
Germany	215	372
Netherlands	151	249
Sweden	133	207
Weighted average	206	346

Table 2. Values used – the average is weighted with the distribution of installed capacity

### Collector Yield versus Global Horizontal Radiation – Swimming Pools

As seen from figure 1, a simple equation with only the annual global horizontal radiation as parameter represents the annual Collector Yield rather accurate:

- $(\text{Collector Yield})_{\text{SPH}} = 0,48 * G_0 - 310 \text{ kWh/m}^2$

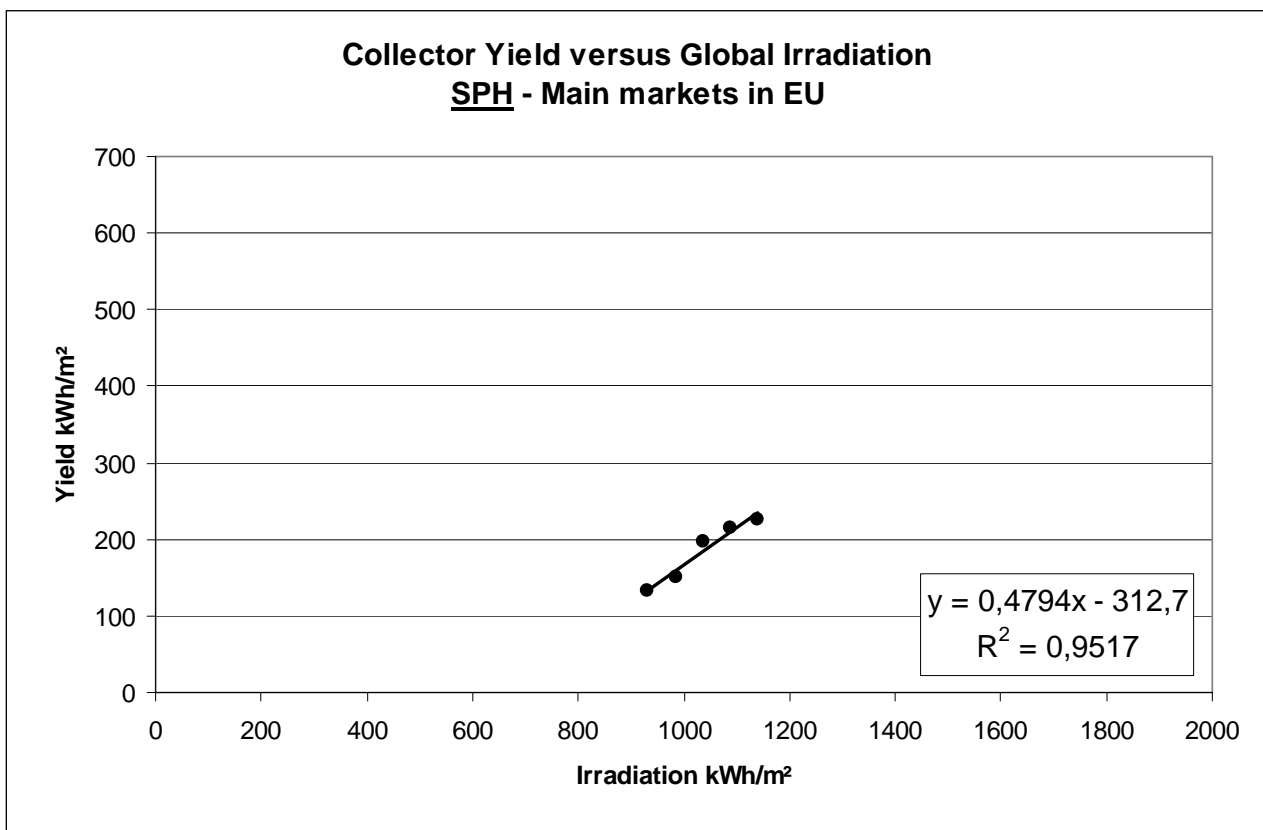


Figure 1. Swimming Pool Heating – SPH, Collector Yield as a function of the global radiation.

### Energy Savings versus Global Horizontal Radiation – Swimming Pools

As seen from figure 1, a simple equation with only the annual global horizontal radiation ( $G_0$ ) as parameter represents the annual Collector Yield reasonable well:

- $(\text{Energy Savings})_{\text{SPH}} \approx 0,86 * G_0 - 590 \text{ kWh/m}^2$

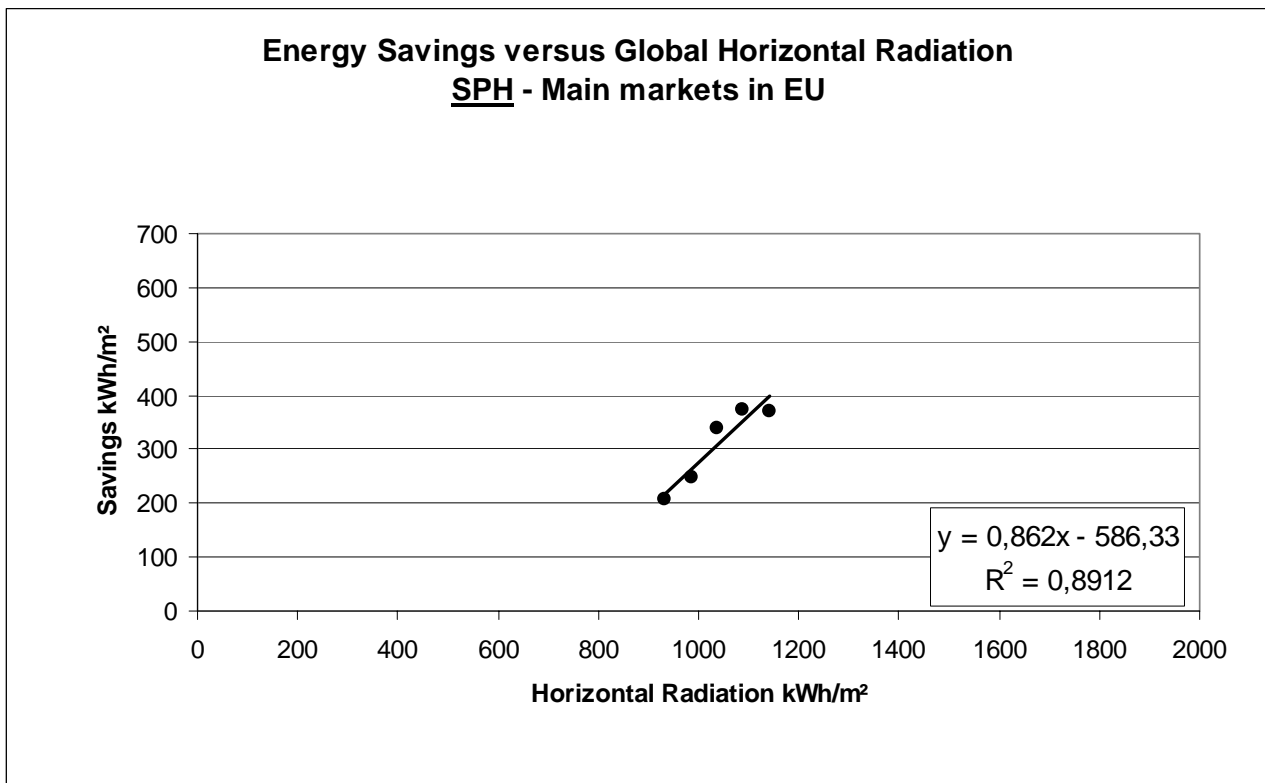


Figure 2. Swimming Pool Heating – SPH, Energy Savings as a function of the global radiation.

### **Domestic Hot Water Systems for Single Family Houses, DWH-SFH**

Solar domestic hot water systems for single family houses make up 78% of the installed capacity in the investigated countries. Values for Collector Yield and Energy Savings are given in table below:

Country	Collector Yield, kWh/m <sup>2</sup>	Energy savings, kWh/m <sup>2</sup>
Austria	385	542
Belgium	387	543
Cyprus	627	1070
Czech Republic	316	460
Denmark	345	479
France*	374	544
Germany	363	520
Greece	565	912
Italy	429	677
Netherlands	324	450
Poland	321	468
Portugal	627	1014
Slovak Republic	401	600
Slovenia	359	525
Spain	609	911
United Kingdom	333	477
Weighted average	445	675

Table 3. Values used – the average is weighted with the distribution of installed capacity

### Collector Yield versus Global Horizontal Radiation – DHW-SFH

As seen from figure 3, a simple equation with only the annual global irradiation as parameter represents the annual collector yield quite well:

- $(\text{Collector Yield})_{\text{DHW-SFH}} = 0.35 * G_0$

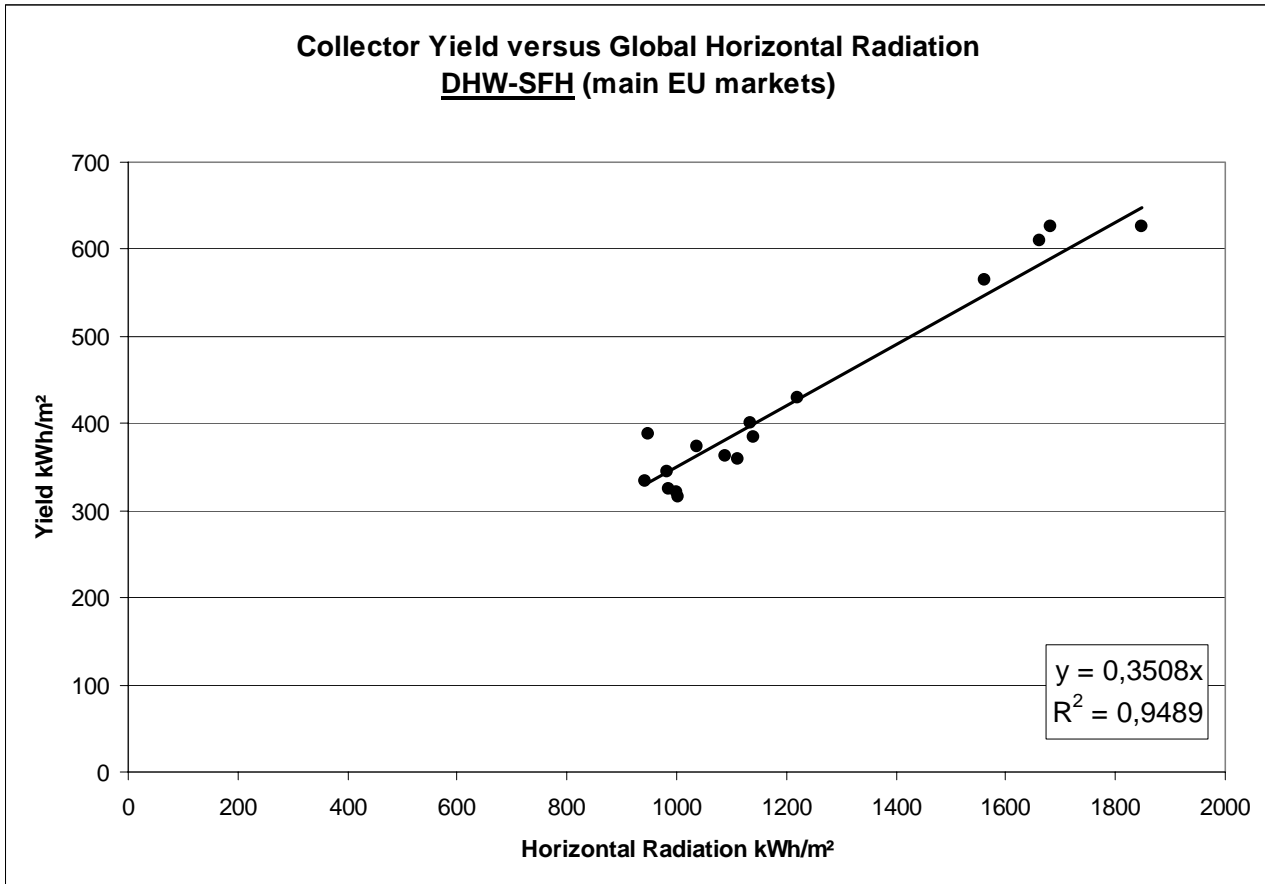


Figure 3. DHW-SFH Collector Yield as a function of the global irradiation.

### Energy Savings versus Global Horizontal Radiation – DHW-SFH

As seen from figure 4, a simple equation with only the annual global horizontal radiation ( $G_0$ ) as parameter represents the annual Collector Yield rather well:

- $(\text{Energy Savings})_{\text{SPH}} \approx 0,70 * G_0 - 210 \text{ kWh/m}^2$

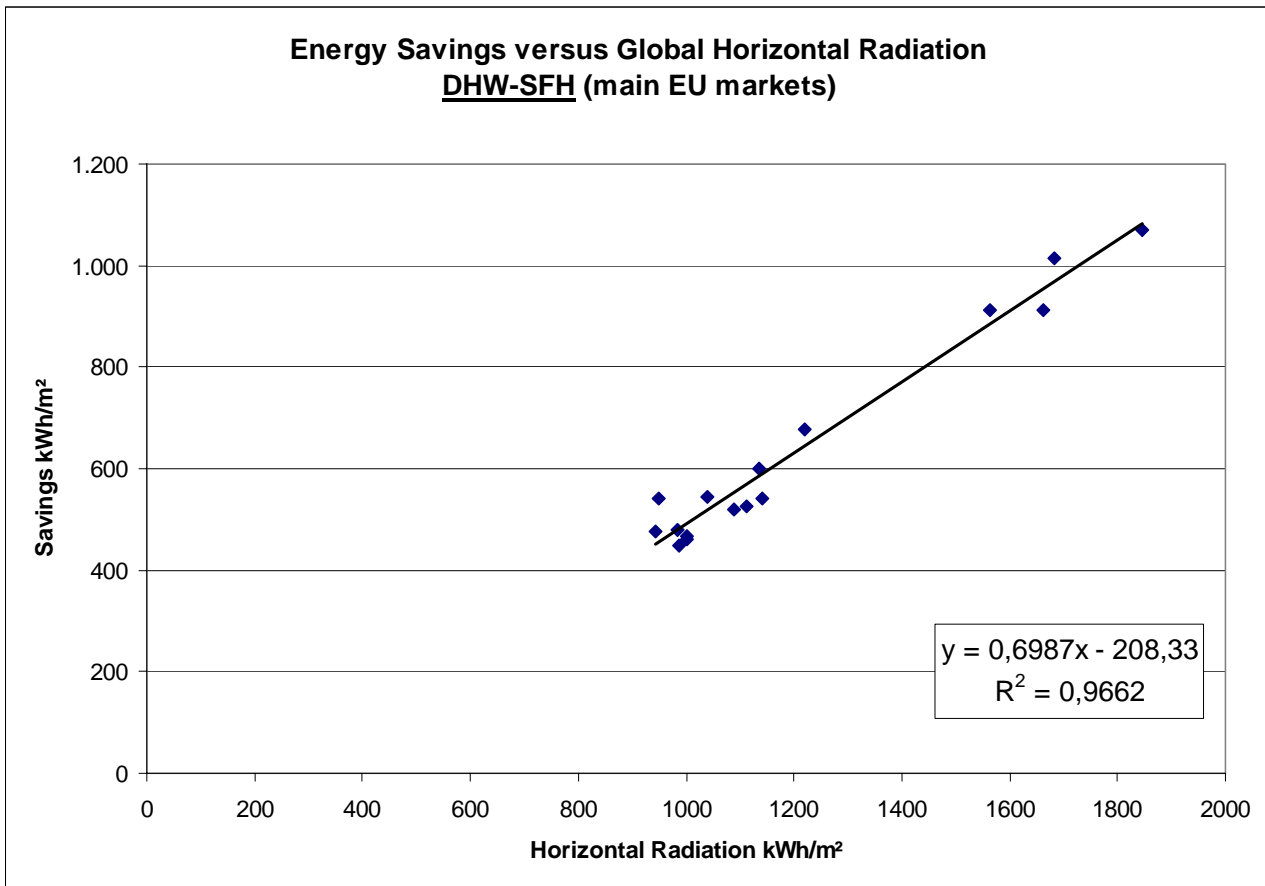


Figure 4. DHW – Single Family Houses, Energy Savings as a function of the global horizontal radiation.

### **Domestic Water Heating – Multi Family Houses, DWH-MFH**

Solar domestic hot water systems for multi family houses (incl. hotels and district heating) make up 4% of the installed capacity in the investigated countries.

Country	Collector Yield kWh/m <sup>2</sup>	Energy savings kWh/m <sup>2</sup>
Austria	410	655
Denmark	352	542
Germany	390	638
Greece	600	1131
Spain	635	1089
Sweden	329	470
Weighed average	415	685

Table 4. Values used – the average is weighted with the distribution of installed capacity

### Collector Yield versus Global Horizontal Radiation – DHW-MFH

As seen from figure 5, a simple equation with only the annual global irradiation as parameter represents the annual output rather accurate:

- $(\text{Collector Yield})_{\text{DHW-MFH}} \approx 0.37 * G_0$

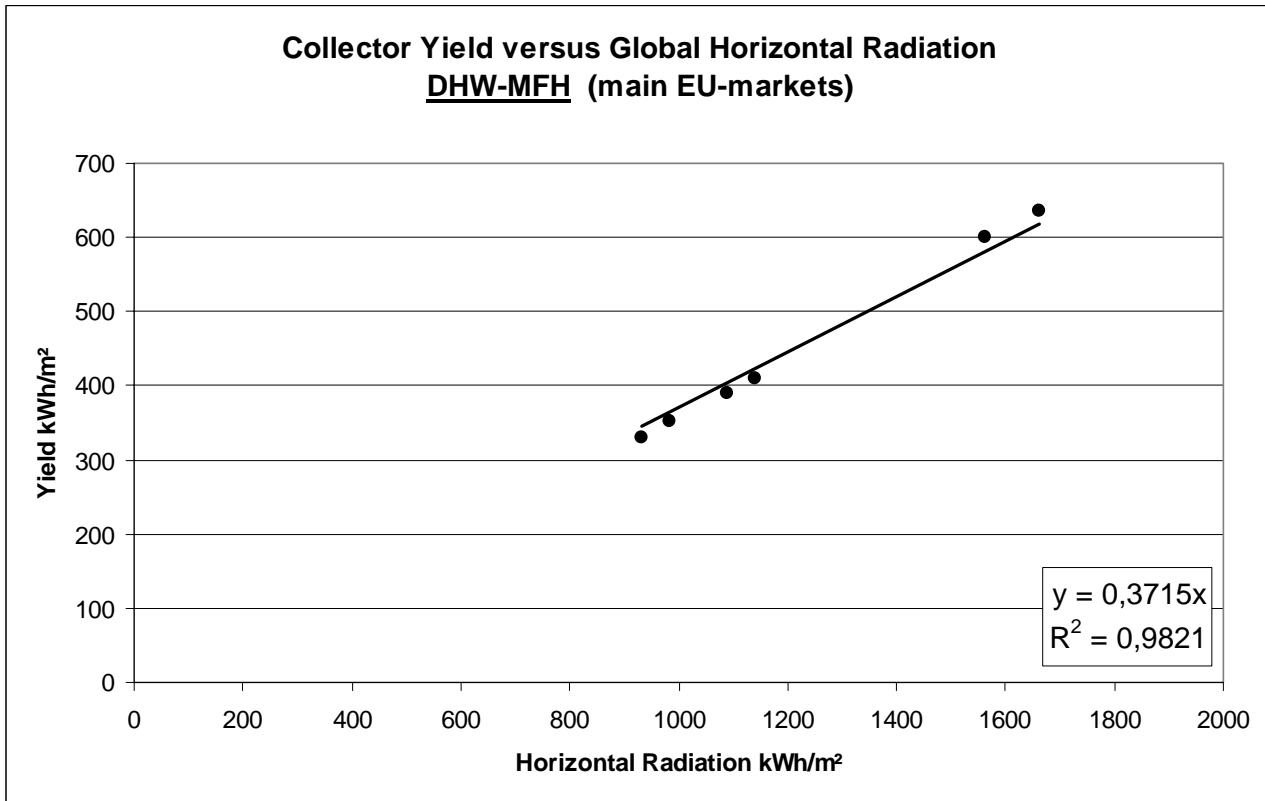


Figure 5. DHW-Multi Family Houses - Collector Yield as a function of the global horizontal radiation.

### Energy Savings versus Global Horizontal Radiation – DHW-MFH

As seen from figure 6, a simple equation with only the annual global irradiation as parameter represents the annual output rather accurate:

- $(\text{Energy Savings})_{\text{DHW-MFH}} \approx 0.91 * G_0 - 370 \text{ kWh/m}^2$

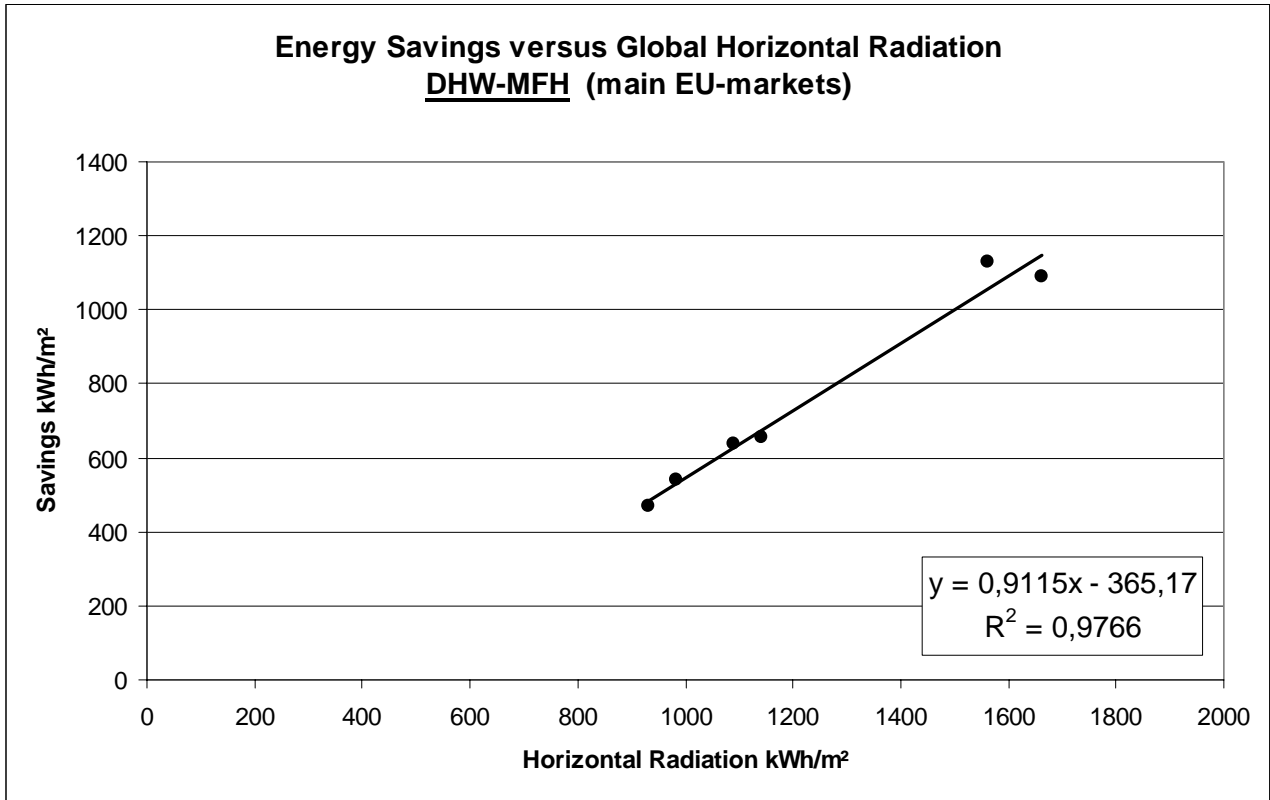


Figure 6. DHW-Multi Family Houses – Energy Savings as a function of the global horizontal radiation.

### Combined systems for domestic hot water and space heating for single family, COMBI-SFH

Combined systems for domestic hot water and space heating for single family houses make up 8% of the installed capacity in the investigated countries.

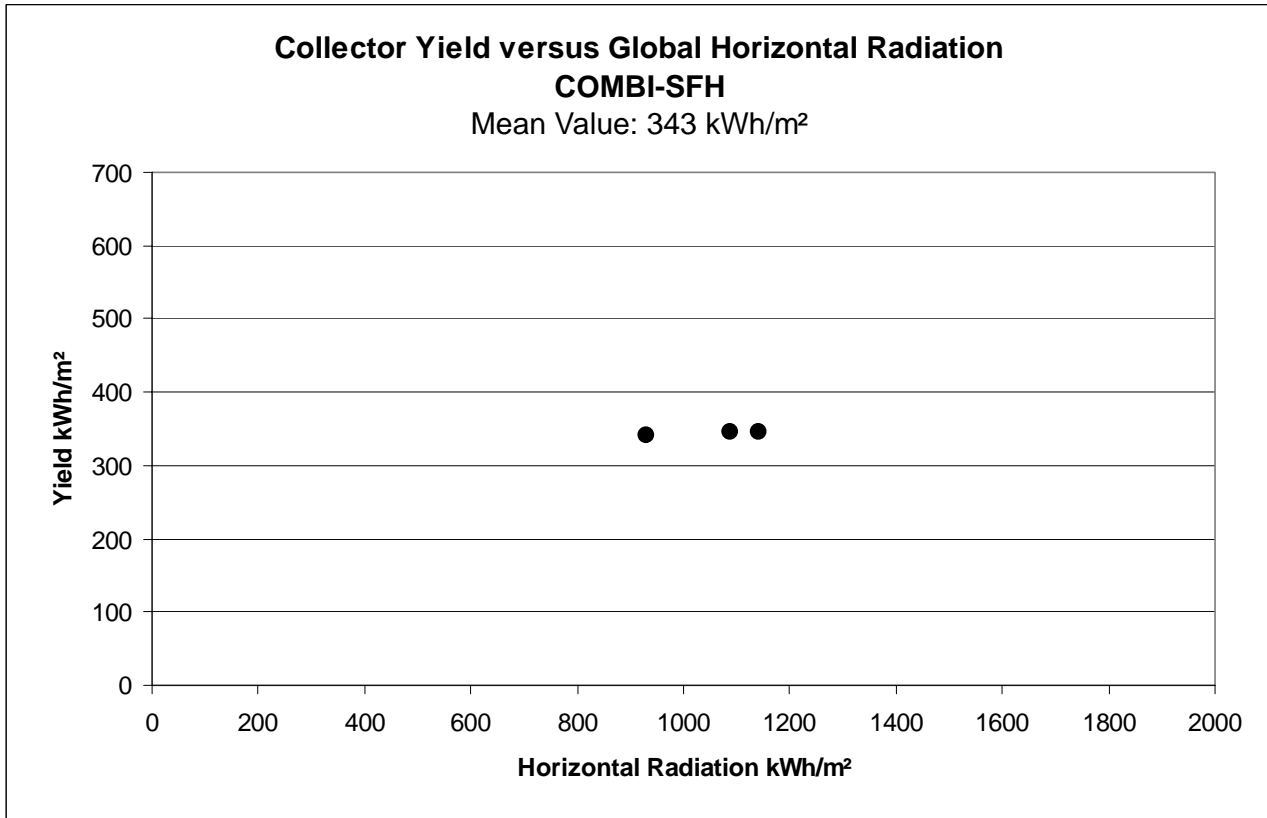
Country	Collector Yield kWh/m²	Energy savings kWh/m²
Austria	345	457
Germany	345	469
Sweden	340	444
Weighted average	344	462

Table 5. Values used – the average is weighted with the distribution of installed capacity

### Collector Yield versus Global Horizontal Radiation – COMBI-SFH

Results from the 3 larger markets (Austria, Germany and Sweden; installed capacity > 20 MW) show that the collector yield seems to be constant and independent of the annual global irradiation:

- (Collector Yield)<sub>COMBI-SFH</sub> ≈ 340 kWh/m²



*Figure 7. Combi Systems – Single Family Houses - Collector Yield as a function of the global horizontal radiation.*

**Energy Savings versus Global Horizontal Radiation – COMBI-SFH**

Results from the 3 larger markets (Austria, Germany and Sweden; installed capacity > 20 MW) show that the collector yield seems to be constant and independent of the annual global irradiation:

- $(\text{Energy Savings})_{\text{COMBI-SFH}} \approx 460 \text{ kWh/m}^2$

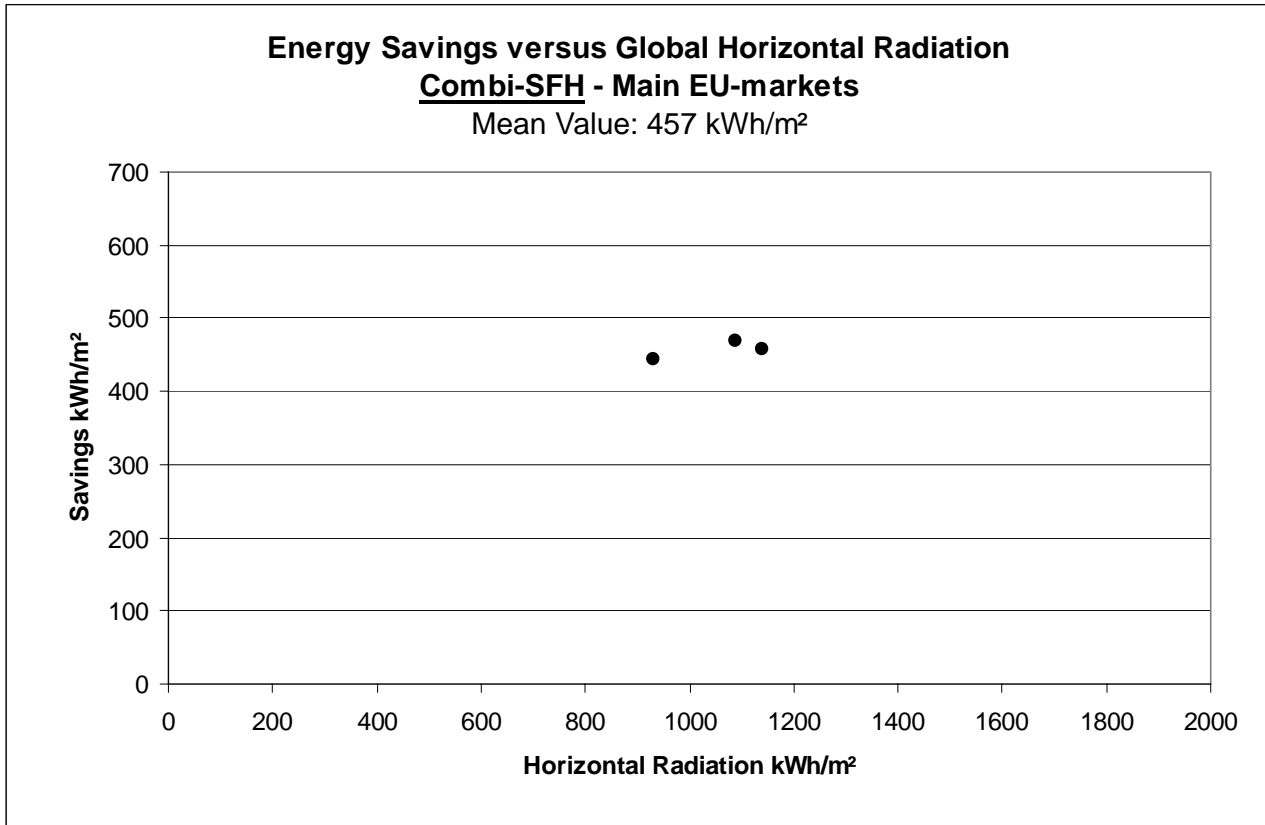


Figure 8. Combi Systems – Single Family Houses - Energy Savings as a function of the global horizontal radiation.

## Results – Overview

The results are summarised in the tables below:

System Type	Collector Yield in kWh/m <sup>2</sup>			
	Weighted average	Correlation to Horizontal Radiation		
		Offset	Factor on G <sub>0</sub>	R <sup>2</sup>
SPH	206	-310	0.48	0.95
DHW-SFH	445	0	0.35	0.95
DHW-MFH	415	0	0.37	0.98
COMBI-SFH	344	340	0	
All weighted	<b>411</b>			

Table 6. Collector Yield - summarised

On an average European level the **collector yield per m<sup>2</sup>** is: **411 kWh/m<sup>2</sup>** - weighted for distribution between countries and applications in 2004.

It is seen that the collector yield can be expressed as simple functions of the horizontal global radiation for the three first system types with good correlation; for combi systems the yield seems to be independent of the radiation.

System Type	Energy Savings in kWh/m <sup>2</sup>			
	Weighted average	Correlation to Horizontal Radiation		
		Offset	Factor on G <sub>0</sub>	R <sup>2</sup>
SPH	346	-590	0.86	0.89
DHW-SFH	675	-210	0.70	0.95
DHW-MFH	685	-370	0.91	0.98
COMBI-SFH	462	460	0	
All weighted	<b>624</b>			

Table 7. Energy savings - summarised

On an average European level the **energy savings per m<sup>2</sup>** of collector is: **624 kWh/m<sup>2</sup>** - weighted for distribution between countries and applications in 2004.

It is seen that the energy savings can be expressed as simple functions of the horizontal global radiation for the three first system types with good correlation; for combi systems the energy savings seems to be independent of the radiation.

### **Introducing “Collector production”**

The “Collector yield” is in the IEA-SHC study defined as the solar input to the storage (or swimming pool). To find the “Collector production” defined as the energy output of the collector array correction for pipe losses shall be made. For systems with glazed collectors these losses are normally in the range of 5-20% depending on application, system size and piping layout. 15% piping loss is considered to be representative – this is a typical value for the majority of small DHW systems in Europe. Multiplying the values in table 7 with 1.15 gives the values in table 7

System Type	Collector production in kWh/m <sup>2</sup>			
	Weighted average	Correlation to Horizontal Radiation		
		Offset	Factor on G <sub>0</sub>	R <sup>2</sup>
SPH	237	-357	0.55	0.95
DHW-SFH	512	0	0.40	0.95
DHW-MFH	477	0	0.43	0.98
COMBI-SFH	396	396	0	
All weighted	<b>473</b>			

Table 8. Collector production

### **Introducing “Number of Full Load Hours”**

Now a day the installed capacity is normally given in power capacity instead of m<sup>2</sup>. The general valid conversion factor is 0,7 kW per m<sup>2</sup>.

Using this conversion factor the specific collector production can be expressed in terms of kWh/kW:

System Type	Collector production in kWh/kW = Equivalent of Full Load Hours, EFLH			
	Weighted average	Correlation to Horizontal Radiation		
		Offset	Factor on $G_0$	$R^2$
SPH	339	-510	0.79	0.95
DHW-SFH	731	0	0.57	0.95
DHW-MFH	681	0	0.61	0.98
COMBI-SFH	566	566	0	
All weighted	<b>675</b>			

Table 9. Equivalent of Full Load Hours, EFLH

Now the total production of collectors for a given application can be given as:

$$Q_{\text{total}} = \text{Specific collector production [kWh/kW]} * \text{Installed capacity [kW]}$$

The specific collector production actually has the unit [hours], it corresponds to the number of hours needed to provide the annual energy production when the collector is operating at the nominal power (0.7 kW/m<sup>2</sup>). Such an entity is normally called: Equivalent of Full Load Hours, EFLH.

So it is seen that the Equivalent of Full Load Hours, EFLH depends on the solar irradiation – more sun shine hours gives longer the collectors operating time.

As a rough estimate the expression:

$$\text{EFLH} = 0.6 \text{ [hours/(kWh/m}^2\text{)]} * G_0 \text{ [kWh/m}^2\text{]}$$

is valid for most systems (DHW).

It is then very easy to give an estimate of the collector production (in countries with mostly DHW systems) naming the installed power capacity in kW with P :

$$\begin{aligned} Q_{\text{total}} &= \text{EFLH} * P \\ &= 0.6 * G_0 * P, \text{ [kWh]} \end{aligned}$$

Relating to m<sup>2</sup> this gives (A is installed collector area):

$$Q_{\text{total}} = 0.42 * G_0 * A, \text{ [kWh]}$$

## **Simple calculation of annual output of solar thermal collectors**

*Jan Erik Nielsen, 24/9, 2006, updated 31/7, 2007*

A very simple model for calculating annual output of solar collectors is described. The model is based on an assumption of constant mean temperature in the collector. The model described here is the model which will be introduced in the next version of the European Standard for solar thermal collectors, EN12975.

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:

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

and hence the power:

$$P = A \cdot (n_0 \cdot G - a_1 \cdot (T_m - T_a) - a_2 \cdot (T_m - T_a)^2) \quad [\text{W}] \quad (2)$$

$G$  = solar irradiation [ $\text{W}/\text{m}^2$ ]

$T_a$  = ambient air temperature [ $^{\circ}\text{C}$ ]

$T_m$  = collector mean temperature [ $^{\circ}\text{C}$ ]

$A$  = collector area (corresponding to the efficiency parameters) [ $\text{m}^2$ ]

To calculate the annual output the values of  $G$ ,  $T_a$  and  $T_m$  have to be known all the time.

$G$  and  $T_a$  are weather data defined by the location; they are known (at least in principle) when the location is defined.

$T_m$  is normally not known.  $T_m$  is depending 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) using always the same value of  $T_m$ .

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

$$Q_{\text{collector,annual}} = \int [A \cdot (n_0 \cdot G - a_1 \cdot (T_m, \text{constant} - T_a) - a_2 \cdot (T_m, \text{constant} - T_a)^2)]^+ dt \quad (3)$$

In practise it is now easy to calculate the annual output per  $\text{m}^2$  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
- 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 level – but some indications/recommendations are given in table 1 below.

Application	Recommended $T_m$ [°C] for calculating annual collector output	$F_{col-sys}$ Factor for converting collector output to system output	$F_{sys-sav}$ Factor for converting system output to system savings	$F_{col-sav}$ Factor for converting collector output to system savings
Swimming pools	30	0,75	1,29	0,97
Domestic hot water* DHW	50	0,85	1,35	1,15
Combi systems HW/SH	60	0,75	1,29	0,97
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  $F_{col-sys}$ ,  $F_{sys-sav}$  and  $F_{col-sav}$

\*) See fig.1 in the end of this section.

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

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

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

- $F_{col-sys} = \frac{\{Collector Output\} - \{Pipe Losses\} - \{Extra Tank Losses\}}{\{Collector Output\}}$

{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).

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

- $F_{sys-sav} = \frac{\{System Output\} / \eta_{boiler} + \{Saved Stand-by Losses\} / \eta_{boiler}}{\{System Output\}}$
- $\eta_{boiler} = \{Boiler Efficiency\}$

{Saved Stand-by Losses} can be obtained if the boiler is off during summer.

If the back-up system is electricity,  $\eta_{boiler} = 1$ , and {Saved Stand-by Losses} = 0, hence:

- $F_{\text{sys-sav}} = 1$  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	10%	5%	85%	15%
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.

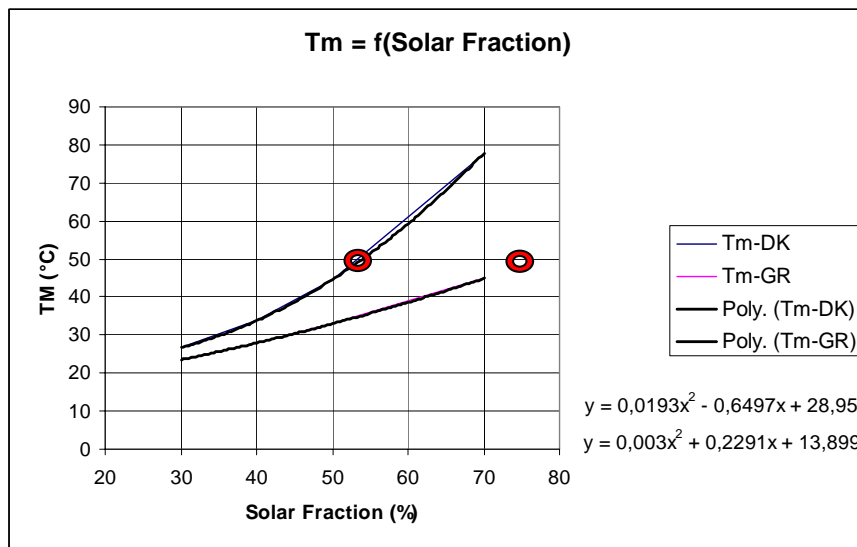


Figure 1. Tm can for each climate be correlated to the solar fraction of a typical DHW system by finding the solar fraction at which the solar input equals the collector output at Tm (°C). The figure shows this function for a typical DHW system in Greece and Denmark. The solar fraction is here defined as the fraction of solar input to the tank to the total input to the tank:  $\text{Solar fraction} = \text{Solar input} / (\text{Solar input} + \text{Auxiliary input})$ .

It is seen that Tm = 50 °C corresponds to a solar fraction in DK of 54% and in Greece of 74%, which correspond to typical solar fractions in the two counties.

## NEGST.WP4

### Conversion of m<sup>2</sup> to power and energy

#### *Discussion Paper*

#### *Rev. 1*

*Domenico Marano, Vincenzo Sabatelli, Giuseppe Fiorenza*  
 ENEA - Research Centre Trisaia

#### **1. Introduction**

In the ENEA previous paper a possible approach was proposed for conversion from collector area to annual useful energy output. Following up the positive feedback, a revision has been carried out in order to investigate more deeply some of the aspects mentioned in the final remarks: this will lead to more consistent results and, possibly, to a reduced ultimate relationship between energy output and the environmental parameters.

#### **2. Steps ahead**

In the preceding analysis, a daily hot water usage of 60 litres/m<sup>2</sup>, constant for all locations, was assumed for evaluating the global output of the solar system. This initial hypothesis was due to simplification needs, but it is obvious that, for a given load, the required area of the solar field decreases when climate conditions are more favourable.

Furthermore, it is to be noticed that increasing the load per m<sup>2</sup>, the global efficiency of the system grows too, but the solar fraction becomes very soon negligible. Therefore, the achievement of the maximum efficiency does not appear to be a viable goal, from the techno-economic point of view, while designing the solar system.

In conclusion a reasonable dimensioning criterion should be introduced in order to establish the optimal daily hot water usage per m<sup>2</sup> for each site considered. The principle followed in this paper consists in assuming a collector area able to completely cover the thermal load in the most favourable month, so as to avoid any over-sizing of the system.

In general, this criterion leads to a slight overestimation of the efficiency with respect to a real solar system. Actually, the collecting area is in most cases calculated in order to meet the need of minimizing the production cost or reaching a high solar fraction. Typically, at South Italy latitude the solar system is sized so as to completely cover the thermal load already in April or May.

In addition, according to the final remarks made in the previous paper, the considered climatic database has been expanded, in order to achieve more general results. The added locations (Zurich, Bergen, Vlissingen, etc.) are all from NEGST Project Countries. The required data have been processed starting from those contained in the archive of the RETScreen software.

Finally, a preliminary attempt to take also into consideration thermosyphon systems is performed. For this purpose some experimental data, collected by our Laboratory, have been used. However an enlargement of the information base is absolutely needed.

#### **3. Calculation method: assumptions and results**

The performance on annual basis of an effective solar system has been carried out using the *f-Chart* method. The values assigned to the main parameters are listed below:

- System type: Active DHW system
- Collector types:
  - 1<sup>st</sup> case: Glazed flat-plate collectors

- Efficiency curve parameters:  $\eta_0 = 0.78$ ,  $a_1 = 3.2$  (W/m<sup>2</sup>)/K,  $a_2 = 0.015$  (W/m<sup>2</sup>)/K<sup>2</sup>
- 2<sup>nd</sup> case: Evacuated tubular collectors
- Efficiency curve parameters:  $\eta_0 = 0.76$ ,  $a_1 = 1.2$  (W/m<sup>2</sup>)/K,  $a_2 = 0.008$  (W/m<sup>2</sup>)/K<sup>2</sup>
- Collector azimuth and slope: South, 45°
  - Water volume/collector area: 75 litres/m<sup>2</sup>
  - Water set temperature: 45°C
  - UA of auxiliary storage tank: negligible
  - Pipe heat loss: negligible
  - Collector-store heat exchanger: YES
    - Tank-side flowrate/area: 0.015 (kg/s)/m<sup>2</sup>
    - Heat exchanger effectiveness: 0.7

As it can be noticed, they are the same as the previous paper, with the exception of the effectiveness of collector/store heat exchanger, which has currently been assumed equal to the typical value of a more efficient plate heat exchanger. This hypothesis is again suggested by the target of finding out an upper limit to solar system output. Anyway it brings an increase of only a few points per cent in system global efficiency.

Moreover, the value of the daily hot water usage, assumed constant throughout the year, has been calculated by iteration for each site, imposing the condition of a solar fraction equal to 1 only in the month with the most advantageous weather conditions.

The results obtained are reported in the following table:

Location	H <sub>45</sub> [kWh/m <sup>2</sup> ]	Glazed			ETC		
		Daily load [litres/m <sup>2</sup> ]	Q <sub>s</sub> [kWh/m <sup>2</sup> ]	η [-]	Daily load [litres/m <sup>2</sup> ]	Q <sub>s</sub> [kWh/m <sup>2</sup> ]	η [-]
Almeria	1945	77	766	0.39	92	936	0.48
Athens	1676	84	686	0.41	98	835	0.50
Bergen	1017	45	375	0.37	54	494	0.49
Copenhagen	1200	55	476	0.40	64	594	0.50
Lisbon	1870	81	770	0.41	95	927	0.50
Nice	1771	74	731	0.41	86	879	0.50
Rome	1685	71	676	0.40	84	827	0.49
St. Hubert	1131	41	410	0.36	51	537	0.48
Stockholm	1274	63	530	0.42	72	647	0.51
Stuttgart	1167	45	427	0.37	53	556	0.48
Vlissingen	1186	46	437	0.37	56	566	0.48
Vienna	1201	52	450	0.37	61	584	0.49
Würzburg	1250	48	470	0.38	59	603	0.48
Zurich	1223	52	479	0.39	63	606	0.50
ENEA-Trisaia	1659	68	681	0.41	80	822	0.50

As it can be observed, the value of solar system efficiency on annual basis is practically the same for all locations, thus a simple conversion factor from total solar radiation to useful energy output can be introduced, assigning to it the average value of **0.39** and **0.49** for glazed flat plate and ETC-type collector respectively.

With regard to the results delivered in the previous paper, the value of annual output does not vary significantly for North Europe locations, while it proves to be increasingly underestimated moving towards more favourable climates, up to about 18 and 35% for glazed-collectors and ETC respectively in Almeria. As anticipated in the previous section, this difference is due to the initial

simplified assumption of a daily hot water usage equal to 60 litres/m<sup>2</sup> for all sites. Really, the table shows that this value is slightly optimistic for North Europe climates and clearly pessimistic for South Europe ones.

#### 4. Thermosyphon systems

Thermosyphon systems hold a remarkable share of SDHW systems market, especially in South Europe Countries. A survey of the Italian data shows that over the 80% of the cumulative area of solar collectors installed in 2003 was of this type. Therefore it is essential to validate the use of the previous conversion factor for estimating the annual energy output of these type of systems too.

For this purpose, the data relevant to 6 systems using selective coated collectors, amongst those tested by the ENEA Laboratory according to the CSTG method, have been considered. On average, the chosen collectors have a maximum efficiency and a linear heat loss coefficient equal to 0,79 and 5 (W/m<sup>2</sup>)/K respectively.

The introduction of a dimensioning criterion does not make sense in this case, since the system has a prefixed size. However, in order to make uniform the hypotheses, the same daily hot water usage, previously calculated for forced circulation systems, has been assumed for each location. Again this value has been considered constant throughout the year.

Once more this appears to be slightly optimistic. Actually, taking into account the typical Factory Made Systems sizes available on the market, the average number of persons per family and the estimated daily hot water requirement per person, normally the load is lower than the supposed value.

Finally, it is to be noticed that, similarly to the *f-Chart* method, the system efficiency, reported in the following table, has been calculated as the ratio between useful energy and solar irradiation.

Location	Efficiency on annual basis						Mean
	System 1	System 2	System 3	System 4	System 5	System 6	
Almeria	0.42	0.40	0.43	0.42	0.42	0.43	<b>0.42</b>
Athens	0.44	0.42	0.45	0.43	0.44	0.46	<b>0.44</b>
Bergen	0.40	0.38	0.39	0.37	0.42	0.38	<b>0.39</b>
Copenhagen	0.42	0.40	0.42	0.40	0.44	0.42	<b>0.42</b>
Lisbon	0.44	0.42	0.45	0.44	0.44	0.46	<b>0.44</b>
Nice	0.43	0.41	0.44	0.43	0.44	0.45	<b>0.43</b>
Rome	0.42	0.40	0.43	0.42	0.43	0.43	<b>0.42</b>
St. Hubert	0.37	0.36	0.37	0.35	0.39	0.36	<b>0.37</b>
Stockholm	0.43	0.41	0.43	0.41	0.45	0.44	<b>0.43</b>
Stuttgart	0.38	0.37	0.39	0.36	0.40	0.37	<b>0.38</b>
Vlissingen	0.38	0.37	0.39	0.37	0.40	0.38	<b>0.38</b>
Vienna	0.41	0.39	0.40	0.38	0.42	0.40	<b>0.40</b>
Würzburg	0.38	0.37	0.39	0.37	0.40	0.38	<b>0.38</b>
Zurich	0.41	0.39	0.41	0.39	0.43	0.41	<b>0.41</b>
ENEA-Trisaia	0.44	0.42	0.44	0.44	0.44	0.45	<b>0.44</b>
<b>Mean</b>	<b>0.41</b>	<b>0.39</b>	<b>0.42</b>	<b>0.40</b>	<b>0.42</b>	<b>0.41</b>	<b>0.41</b>

It can be observed that the values are little affected by the location and not much dispersed with respect to the different systems. Therefore a figure of 0,41 appears to be a quite reasonable average value on European basis, as far as the assumed sample can be considered reliable due to its limitation.

Moreover, it must be emphasized that this result also is quite optimistic, since the investigation has been restricted to high quality products. On the contrary, an appreciable percentage of non selective collectors, especially in Southern Europe, is still operating.

In conclusion, a preliminary hypothesis for the conversion from  $m^2$  to energy on European basis can be made, as for as glazed flat plate collectors for DWH are concerned. Actually, the results obtained in the last 2 sections show that the ratio between annual useful energy and solar irradiation of these collectors, working either as pumped or thermosyphon systems, can be assumed equal to **0.4**. Even if the average value is slightly higher, the rounding down is justified, besides simplicity reasons, numerous favourable suppositions assumed in the calculations.

### 5. Unglazed collectors and space heating

In this preliminary analysis unglazed collectors and solar systems for space heating are not considered.

Actually, unglazed collectors does not appear to have a wide diffusion. For example, in Italy they amount to about 5% of the total installed  $m^2$  in 2003. If this situation is confirmed for the remaining European Countries, the impact of this type of collector on the assessment of an overall conversion factor, from solar irradiation to useful energy output, would be negligible. In any case, a different sizing criterion should be adopted for evaluating the performance of an unglazed collectors system, due to its seasonal working. Certainly, the productivity on annual basis would prove to be substantially reduced with respect to glazed collectors.

Similarly, the use of solar collectors for space heating is not attractive for South Europe climates, but the situation appears to be very different moving towards North. Supposing that this application reaches a significant figure on European scale, an appropriate sizing criterion has to be introduced for it too. However, solar heating systems are usually markedly oversized in the hottest season, in order to contribute significantly to the covering of the thermal load in the coldest one. Therefore, the inclusion of these systems in the present evaluation would bring about a diminution of the overall conversion factor.

### 6. Further developments

Finally the additional steps, which should be taken in order to validate and, possibly, improve the previous estimation, are briefly remarked.

- The sizing criterion for forced circulation systems needs a deeper discussion, based upon the data relevant to existing systems and the experience of designers.
- The experimental data set for thermosyphon systems should be significantly enlarged, including ETC type collectors too.
- Simulation of both forced and natural circulation systems by means of the TRNSYS software could be useful.
- Assessment of the contribution of the different collector types and applications via a market survey represents a key step towards an all-inclusive conversion factor from  $m^2$  to energy output.
- Insertion into the analysis of unglazed collectors and combisystems also would be mandatory, if the percentage of installed  $m^2$  relevant to these applications proves to be appreciable.
- The potential definition of a sizing criterion for space heating systems should be carried out according to the experience made in the regions where the dissemination of these systems is wider: the common approach for Southern Europe would be too penalizing, due to the limitation of heating requirements to a brief period.
- A sensitivity analysis could help in estimating the impact of different parameters and possibly fine-tuning their values.

# Recommendation<sup>1</sup>: Converting solar thermal collector area into installed capacity (m<sup>2</sup> to kW<sub>th</sub>)

## 1. Introduction

In the past, the installed base of solar thermal systems was measured in terms of collector area (square meters or square feet) rather than in terms of installed capacity to produce heat. As a consequence, solar thermal was not easily comparable with other (renewable) energy sources and thus was often left out of relevant statistics.

On 8<sup>th</sup> September 2004, representatives of the International Energy Agency's Solar Heating and Cooling Programme (IEA SHC) and several major solar thermal trade associations met in Gleisdorf, Austria (for a list of participating associations please see the end of this document). During this meeting, they discussed and agreed on an official recommendation for how to convert solar thermal collector area into installed capacity. Work is currently being done on defining also a suitable methodology to convert collector area into energy yield.

This recommendation was published jointly by IEA SHC and the involved associations who hope that this methodology will be used worldwide by all those who are concerned with solar thermal statistics.

## 2. The recommended conversion factor

For the purpose of solar thermal statistics, the installed capacity ([kW<sub>th</sub>] – Kilowatt thermal) shall be calculated by multiplying the aperture area of the solar collector area [m<sup>2</sup>] by the conversion factor 0.7 [kW<sub>th</sub>/m<sup>2</sup>].

This factor shall be used uniformly for unglazed collectors, flat plate collectors and evacuated tubular collectors.

## 3. Explanatory Note

The following notes explain the origins of the conversion factor of 0.7 kW<sub>th</sub>/m<sup>2</sup>.

### 3.1 Area

Three definitions of collector area exist:

- Absorber area = the area of absorber
- Aperture area = the area in which the solar radiation enters the collector
- Gross area = the area based on the outer dimensions of collector

All three areas are defined for glazed liquid heating collectors in the European standard EN12975-2 annex I. In EN12975-2 test reports all three areas are given. Efficiency coefficients in these reports are given based on both absorber area and aperture area. As there is a current trend towards using aperture area on certificates (e.g. DIN CERTCO Solar Keymark, SPF Factsheets) aperture area<sup>2</sup> shall be used.

---

<sup>1</sup> This document is based on a discussion paper by ESTIF technical consultant Jan Erik Nielsen.

<sup>2</sup> For unglazed collectors the three areas are the same

This implies:

- It is assumed that the existing statistics have counted aperture area.
- Aperture area should be counted in future statistics.
- Capacity conversion is done using the efficiency based on aperture area.

### 3.2 Collector classification

Proposed collector classification:

1. Unglazed flat plate collectors: All unglazed collectors (selective and non-selective, tubes, tube/fin, all-wetted, ...).
2. Glazed flat plate collectors: All glazed collectors of every type (single/double glazed, with/without convection suppression, selective and non-selective, tubes, tube/fin, all-wetted, air/gas...).
3. Evacuated tubular collectors: All types of evacuated tubular collectors (heat-pipe, direct, tube/fin, all-glass, ...).

### 3.3 Typical collector efficiency

The capacity conversion is based on the following simplified typical collector efficiencies (based on aperture area):

1. Unglazed flat plate collectors<sup>3</sup>:  $\eta_0 = 0,90$ ,  $a_1 = 20,0 \text{ W}/(\text{K}^*\text{m}^2)$ ,  $a_2 = 0,00 \text{ W}/(\text{K}^2*\text{m}^2)$
2. Glazed flat plate collectors<sup>4</sup>:  $\eta_0 = 0,78$ ,  $a_1 = 3,2 \text{ W}/(\text{K}^*\text{m}^2)$ ,  $a_2 = 0,015 \text{ W}/(\text{K}^2*\text{m}^2)$
3. Evacuated tubular collectors<sup>5</sup>:  $\eta_0 = 0,76$ ,  $a_1 = 1,2 \text{ W}/(\text{K}^*\text{m}^2)$ ,  $a_2 = 0,008 \text{ W}/(\text{K}^2*\text{m}^2)$

### 3.4 Operation conditions

For the capacity conversion the following typical operation conditions are assumed<sup>6</sup>:

1. Unglazed flat plate collectors:  $G = 1000 \text{ W}/\text{m}^2$ ,  $T_a = 20 \text{ }^\circ\text{C}$ ,  $T_m = 30 \text{ }^\circ\text{C}$ ,  $u = 1,5 \text{ m}/\text{s}$
2. Glazed flat plate collectors:  $G = 1000 \text{ W}/\text{m}^2$ ,  $T_a = 20 \text{ }^\circ\text{C}$ ,  $T_m = 50 \text{ }^\circ\text{C}$
3. Evacuated tubular collectors:  $G = 1000 \text{ W}/\text{m}^2$ ,  $T_a = 20 \text{ }^\circ\text{C}$ ,  $T_m = 50 \text{ }^\circ\text{C}$

### 3.5 “Installed” or “nominal” capacity: Capacity per m<sup>2</sup> of collector area

Definition 1:

“Nominal Capacity” of unglazed flat plate collectors is the instantaneous thermal output of the collector with the operation conditions:

- $G = 1000 \text{ W}/\text{m}^2$
- $T_a = 20 \text{ }^\circ\text{C}$
- $T_m = 30 \text{ }^\circ\text{C}$
- $u = 1,5 \text{ m}/\text{s}$

---

<sup>3</sup> Estimate

<sup>4</sup> Average of last 10 EN tested flat plate collectors in SPF Collector Catalogue 2004

<sup>5</sup> Average of last 10 EN tested ETC collectors in SPF Collector Catalogue 2004

<sup>6</sup> These operation conditions are given in the power tables in the “conformity report” in the EN12975-2

Definition 2:

“Nominal Capacity” of glazed flat plate collectors and evacuated tubular collectors are the instantaneous thermal output of the collector with the operation conditions:

- $G = 1000 \text{ W/m}^2$
- $T_a = 20 \text{ }^\circ\text{C}$
- $T_m = 50 \text{ }^\circ\text{C}$

Definition 3:

“Specific Nominal Capacity” of a collector is the nominal capacity of a collector divided by its aperture<sup>7</sup> area.

Using the assumption above, the factor for converting – for each collector type – square meters of collector area to specific nominal capacity:

1. Unglazed flat plate collectors:  $P/A = 0.7 \text{ kW}_{\text{th}}/\text{m}^2$
2. Glazed flat plate collectors:  $P/A = 0.671 \text{ kW}_{\text{th}}/\text{m}^2$
3. Evacuated tubular collectors:  $P/A = 0.717 \text{ kW}_{\text{th}}/\text{m}^2$

Taking into consideration the uncertainty on each value it is reasonable to use only one value:  $0.7 \text{ kW}_{\text{th}}/\text{m}^2$ .

#### **4. Participating organisations**

The following organisations participated in the Gleisdorf meeting where the conversion factor of  $0.7 \text{ kWth/m}^2$  was agreed upon:

- **Austria Solar** – [www.austriasolar.at](http://www.austriasolar.at)
- **Bundesverband Solarindustrie, Germany (BSi)** – [www.bsi-solar.de](http://www.bsi-solar.de)
- **Canadian Solar Industries Association (CanSIA)** – [www.cansia.ca](http://www.cansia.ca)
- **European Solar Thermal Industry Federation (ESTIF)** – [www.estif.org](http://www.estif.org)
- **Holland Solar** – [www.hollandsolar.nl](http://www.hollandsolar.nl)
- **Solar Heating and Cooling Programme of the International Energy Agency (IEA SHC)** – [www.iea-shc.org](http://www.iea-shc.org)
- **Solar Energy Association of Sweden (SEAS)** – [www.solenergiforeningen.se](http://www.solenergiforeningen.se)
- **Solar Energy Industries Association, USA (SEIA)** – [www.seia.org](http://www.seia.org)

---

<sup>7</sup> For unglazed collectors the aperture area equals the absorber area

## Collector area -> annual energy output / savings

Overview of different methodologies to convert from installed collector area to annual energy performance.

Proposing a formula with a simple factor to convert installed capacity into annual energy savings of solar DHW systems

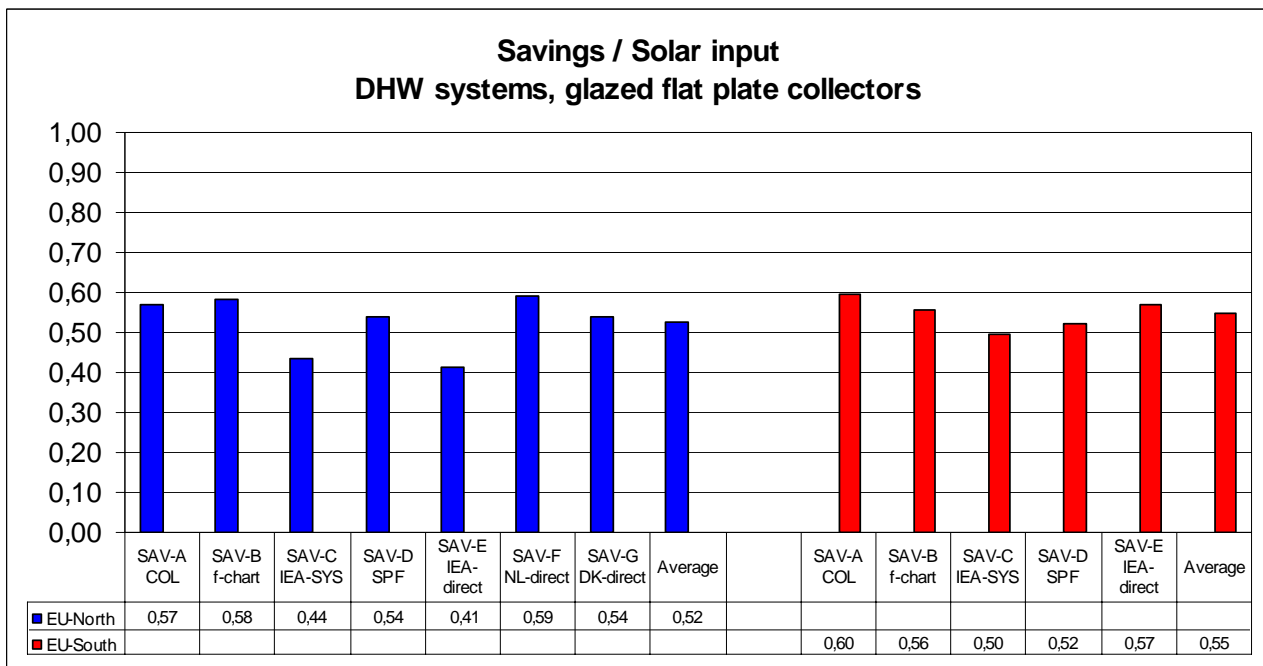
Jan Erik Nielsen, 2. draft, 9/4, 2006

### Summary

The aim of this paper is to give an overview of different methodologies to determine the annual energy savings. Further more simple formulas with one general factor each for determination of conversion from collector area as well as thermal power capacity to annual energy savings are proposed for discussion.

Different methodologies for determination of the energy savings of small DHW solar systems (operation with optimal conditions) from collector area have been investigated and the results were correlated to the solar input on the collector plane. The methodologies were applied to a typical northern/central European climate (Würzburg, D) and system type (pumped system) and to typical southern European climate (Athens, GR) and system type (thermo siphon).

An overview of the results is given below in fig.1.



*Figure 1. Overview of system savings in the northern and southern part of Europe determined with different methodologies. Savings are given related to the radiation on a 45° tilted plane, direct South*

It is seen that the deviation are within reasonable limits (compared with the uncertainty of market figures for installed area/capacity). So, it is proposed to use the very simple relation that the energy savings is proportional with the solar irradiation on the collector plane in a given region/country.

The energy savings are determined for the system operating under optimal/ideal conditions. To compensate for the fact that solar systems in real life do not operate under optimal/ideal conditions it is recommended to introduce a penalty factor.

Now using the overall average for ideal system savings, 0.534 and a penalty factor of 0.8, the relation between annual energy savings and collector area becomes:

$$\text{Energy savings} = 0.43 * A * G \text{ [kWh]}$$

where A is collector area in m<sup>2</sup>, and G the solar irradiation in kWh/m<sup>2</sup> on a south-ward plane inclined 45° to the horizontal in the given region/country.

Using now also the conversion factor of 0.7 kW/m<sup>2</sup> developed in [1] and now generally accepted, the relation between annual energy savings and installed thermal capacity (now rounded to one digit only) becomes:

$$\text{Energy savings} = 0.6 * P * G \text{ [kWh]}$$

where P is installed thermal capacity in kW and G still the solar irradiation in kWh/m<sup>2</sup> on a south-ward plane inclined 45° to the horizontal in the given region/country. The factor 0.6 is 0.614.

The above equations are valid for glazed flat collectors only. Systems with collectors of the ETC type are found to give approx. 15% more energy savings per m<sup>2</sup> or thermal power capacity in southern Europe and approx. 30% more in northern Europe.

In case the solar system replaces electricity, the savings should be multiplied by a factor 2.5 to give the primary energy savings. In case of replacing electricity the primary energy savings are then

- Primary energy savings = 1,5 \* P \* G [kWh]

## Collector Based Methodology, COL

This methodology frames the collector and determines the output of the collector only.

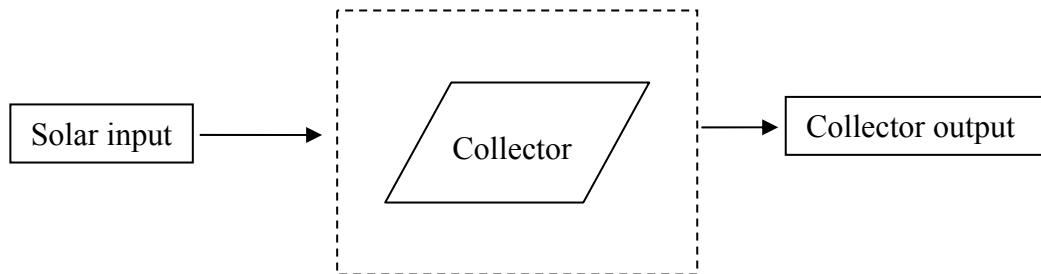


Figure 2. Energy balances – system methodology

To calculate the annual energy output of a collector the following data are (at least) needed:

- Collector parameters:  $A$ ,  $\eta_0$ ,  $a_1$  and  $a_2$  (collector area and related efficiency parameters)
- Solar irradiation (hourly, daily or monthly basis)
- Ambient air temperature (hourly, daily or monthly basis)
- Collector mean temperature (hourly, daily or monthly basis)

Assuming that collectors<sup>1</sup> are oriented towards south with an inclination of  $45^\circ$  and operates at a constant typically mean temperature of  $50^\circ\text{C}$  and simulating the collector output hour by hour in the four CEN weather data sets gives the following results [1]:

	Location	Irradiation	Temperature	Collector output kWh/m <sup>2</sup>		Output/Input	
		G (S, 45°) kWh/m <sup>2</sup>	T <sub>a</sub> °C	Glazed	ETC	Glazed	ETC
COL	North and central Europe	1270	10	583	768	0,46	0,60
	Southern Europe	1720	19	968	1142	0,56	0,66
Average				776	955	0,51	0,63

Table 1. Collector performance

This methodology (or similar) might be introduced in next version of the EN12975.

## System Based Methodologies, SYS

System output is here defined as (see figure 2):

- System output = Collector output – Losses – Parasitic energy

<sup>1</sup> The following simplified typical collector efficiencies (based on aperture area) are used [1]:

1. Glazed flat-plate collectors:  $\eta_0 = 0,78$ ,  $a_1 = 3,2 \text{ W}/(\text{K} \cdot \text{m}^2)$ ,  $a_2 = 0,015 \text{ W}/(\text{K}^2 \cdot \text{m}^2)$
2. Evacuated tubular collectors:  $\eta_0 = 0,76$ ,  $a_1 = 1,2 \text{ W}/(\text{K} \cdot \text{m}^2)$ ,  $a_2 = 0,008 \text{ W}/(\text{K}^2 \cdot \text{m}^2)$

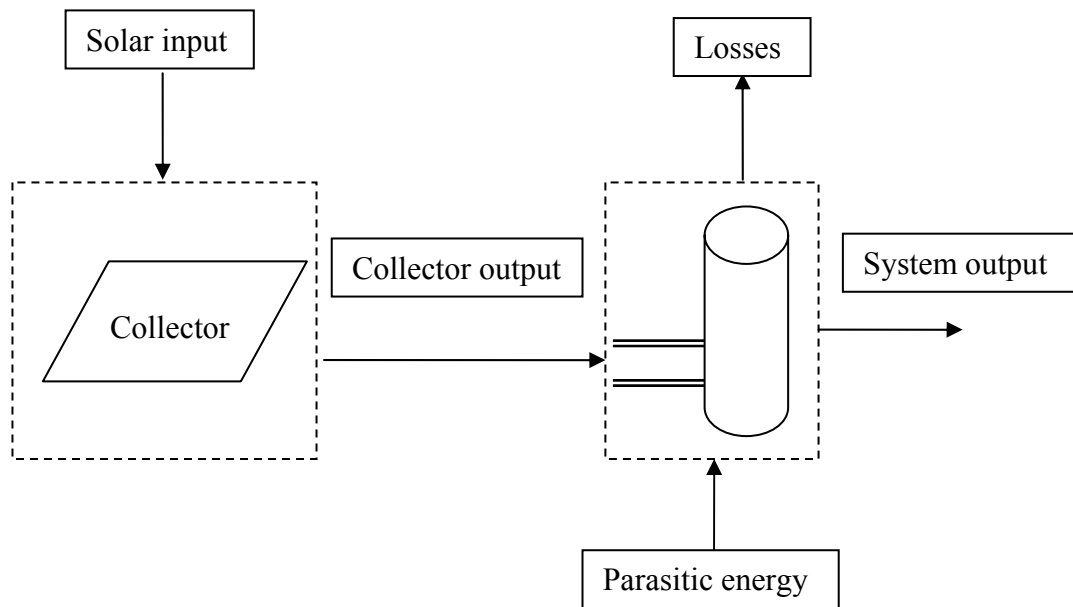


Figure 3. Energy balances – system methodology

### System output – Method SYS-A COL: Converting collector output to system output

Assuming a system efficiency of 80%, i.e. losses = 20% of the collector output, the system output for this methodology is calculated very simple (and rough). Results are seen in table 2, line SYS-A COL.

### System output – Method SYS-B: f-chart calculation of system output

In [2] f-chart calculations of a solar DHW system with glazed flat plate and an ETC collector have been carried out. The load used in these calculations has been determined in a way that at least one month a year has a solar fraction of 100%. Results separated to North and South Europe are seen in table 2, line SYS-B f-chart.

The results are confirmed by calculations of 6 different thermo siphon systems with selective flat plate collector in 15 different EU climates. All systems in all climates perform with a system efficiency (System Output / Solar Input) in the range 0,35 – 0,45, with an average of 0,41

In the study [2] it is then concluded: *As it can be observed, the value of solar system efficiency on annual basis is practically the same for all locations, thus a simple conversion factor from total solar radiation to useful energy output can be introduced, assigning to it the average value of 0.39 and 0.49 for glazed flat plate and ETC-type collector respectively.*

## System output – Method SYS-C: IEA

In [3] the contribution from solar thermal systems to the supply of energy worldwide is estimated. For the two locations chosen here to represent North and South Europe figures<sup>2</sup> are given in table 2 line SYS-C IEA.

## System output – Method SYS-D: SPF

In [4] typical solar fractions for typical systems in 10 EU countries are reported. The numbers are given by experts in the respective countries. For the two locations chosen here to represent North and South Europe figures are given in table 2 line SYS-D SPF.

	Location	Irradiation	Temperature	System output kWh/m <sup>2</sup>		Output/Input	
		G (S, 45°) kWh/m <sup>2</sup>	Ta °C	Glazed	ETC	Glazed	ETC
SYS-A COL	North and central Europe	1270	10	466	614	0,37	0,48
	Southern Europe	1720	19	774	914	0,45	0,53
SYS-B f-chart	North and central Europe	1250	10	470	603	0,38	0,48
	Southern Europe	1676	19	686	835	0,41	0,50
SYS-C IEA	North and central Europe	1250	10	342		0,27	
	Southern Europe	1676	19	584		0,35	
SYS-D SPF	North and central Europe	1250	10	432		0,35	
	Southern Europe	1676	19	625		0,37	
Average	North and central Europe			428	609	0,34	0,48
Average	Southern Europe			667	874	0,40	0,51
Average				547	742	0,37	0,50

Table 2. System output – different methodologies

## Energy Savings Methodologies, SAV

On top of the solar thermal system output, installing a solar system results in savings due to saved tank losses and in some cases conversion losses in connected oil/gas boiler.

### Saved tank losses

Heat loss coefficient for small domestic water tanks are typically in the range of 2-3 W/K. A value of 2 W/K is chosen corresponding to the recommended max. value for a 150 litre tank given in the ENV 12977-1<sup>3</sup>. Assuming a temperature difference of 35 K between the tank and the ambient environment, this gives on an annual basis a heat loss of approx. 600 kWh. Depending on the placing of the tank all or part of these tank losses are saved due an installation of a solar system.

<sup>2</sup> For the location chosen for North Europe the figure relates to all system types and not only DHW systems – that might be one reason for the low figure. I have tried to get in contact with Werner Weiss to have the clean DHW figures and to discuss the methodology with – some more work are needed to analyse the “IEA-figure(s)”.

<sup>3</sup> ”The stand-by heat loss rate (UA)<sub>s,a,sb</sub> of stores of small custom built systems should not exceed the value given by ... (UA)<sub>s,a,sb</sub> = 0,16 √V<sub>s</sub> in W/K where V<sub>s</sub> is the nominal volume of the store in litres”

- If the tank is placed in non-heated environment all tank losses are saved. The tank loss saving factor  $F_{\text{tank,loss}} = 1$ . In southern European countries the  $F_{\text{tank,loss}}$  is typically 1. The saved tank losses in southern Europe is then: Saved tank losses S: 600 kWh/y.
- If the tank is placed indoor in a way that the heat losses anyway contributes to the heating of the building in the heating season, only part of the tank losses are saved. The tank loss saving factor  $F_{\text{tank,loss}} < 1$ . In northern European countries the  $F_{\text{tank,loss}}$  is typically 0,33 (corresponding to a heating season of 2/3 of the year). The saved tank losses in northern Europe is then: Saved tank losses N: 200 kWh/y.

### Conversion losses / boiler efficiency

The conversion losses in a connected boiler depends very much on the boiler type and age. Typical non-condensing boilers 5-10 years old have an efficiency of 0.7 – 0.8 on an annual basis and as low as 0.5 – 0.6 in the summer period where they only produce hot water. The corresponding numbers for high performing modern condensing boilers are 0.8 – 1.0 annually and 0.7 – 0.9 in the summer. As a solar thermal system replaces far most energy in the summer an overall value of the boiler efficiency is chosen to be 0.7 for the further calculations below.

### Savings

#### 1. Systems **not** connected to oil/gas boilers (**southern Europe**)

These systems are typically thermo siphon systems placed in southern part of Europe having a collector area of 2,4 m<sup>2</sup> (Greece) [5, SiA]. The savings,  $S_S$  for these systems are:

$$S_S = \text{System output} + \text{Saved tank losses } S = \text{System output} + 600 \text{ kWh}$$

The system output per m<sup>2</sup> collector is then:

$$S_S/m^2 = \text{System output} / m^2 + 250 \text{ kWh/m}^2$$

As these system typically replaces electricity, one could argue to introduce a primary energy factor of 2.5. This gives:

$$S_{S,p/m^2} = 2.5 * \text{System output} / m^2 + 625 \text{ kWh/m}^2$$

#### 2. Systems connected to oil/gas boilers (**northern Europe**)

These systems are typically pumped systems placed in northern part of Europe having a collector area of 5 m<sup>2</sup> (Germany) [5, SiA]. The savings,  $S_N$  for these systems are:

$$\begin{aligned} S_N &= (\text{System output} + \text{Saved tank losses } N) / \text{Boiler efficiency} \\ &= (\text{System output} + 200 \text{ kWh}) / 0.7 \end{aligned}$$

The system output per m<sup>2</sup> collector is then:

$$\begin{aligned} S_N/m^2 &= (\text{System output} / m^2 + 40 \text{ kWh/m}^2) / 0.7 \\ &= 1.43 * \text{System output} / m^2 + 57 \text{ kWh/m}^2 \end{aligned}$$

### System savings – Method SAV-A COL, SAV-B f-chart, SAV-C IEA-SYS, SAV-D SPF: Converting system output to system savings

The above equations are used to calculate systems savings from system output in the four cases:

- SAV-A COL
- SAV-B f-chart
- SAV-C IEA-SYS
- SAV-D SPF

### **System savings – Method SAV-E IEA direct**

In [3] the method to calculate system savings is given. The principle is based on simulation of typical reference systems<sup>4</sup>.

### **System savings – Method SAV-F NL direct**

In [6] the method to calculate system savings in The Netherlands is given. The method is system based not m<sup>2</sup> based, - the typical collector area used to convert from savings per system to savings per m<sup>2</sup> is taken from [4] and [5], both agreeing on a typical collector area for DHW systems of 2,7 m<sup>2</sup>. The method is rather rough: A saving of 169 m<sup>3</sup> gas is given for a solar DHW system.

### **System savings – Method SAV-F DK direct (EPBD method prEN15316-4-3)**

In Denmark a national version of EPBD calculation method (prEN15316-4-3) [7] has been implemented in the official tool for calculating the energy performance of buildings. Based on calculations with this tool “standard values” for savings due to installation of DHW solar systems have been established. The figure given in table 3 for this methodology is the mean value of the standard value for SDHW in existing buildings (combined with a non-condensing boiler) and the standard value for SDHW in new buildings (combined with a condensing boiler). The principle is to calculate the energy performance of a typical building with and without a typical SDHW system – the savings are the difference in the energy performance of the building for these two cases.

---

<sup>4</sup> Not all details behind the method are given in [3] – the method will be analysed more in detail. This method gives lower values for savings in northern Europe.

## Overview of results of system savings

	Location		Irradiation	Temperature	System savings kWh/m <sup>2</sup>		Output/Input	
			G (S, 45°) kWh/m <sup>2</sup>	Ta °C	Glazed	ETC	Glazed	ETC
SAV-A COL	North and central Europe		1270	10	723	935	0,57	0,74
	Southern Europe		1720	19	1024	1164	0,60	0,68
SAV-B f-chart	North and central Europe		1250	10	729	919	0,58	0,73
	Southern Europe		1676	19	936	1085	0,56	0,65
SAV-C IEA-SYS	North and central Europe		1250	10	546		0,44	
	Southern Europe		1676	19	834		0,50	
SAV-D SPF	North and central Europe		1250	10	674		0,54	
	Southern Europe		1676	19	875		0,52	
SAV-E IEA-direct	North and central Europe		1250	10	514		0,41	
	Southern Europe		1676	19	953		0,57	
SAV-F NL-direct	Amsterdam	NL	1176	10	695		0,59	
SAV-G DK-direct	Copenhagen	DK	1218	8	655		0,54	
Average	North and central Europe				650	927	0,52	0,74
Average	Southern Europe				924	1124	0,55	0,66
Average overall					756	1026	0,53	0,70

Table 3. System savings – different methodologies

## Discussion

### Conversion formulas

In figure 4 the determined solar system savings related to systems with **flat plate collectors** are shown separately for systems in the northern and the southern part of Europe. The central part of Europe is included in the northern part.

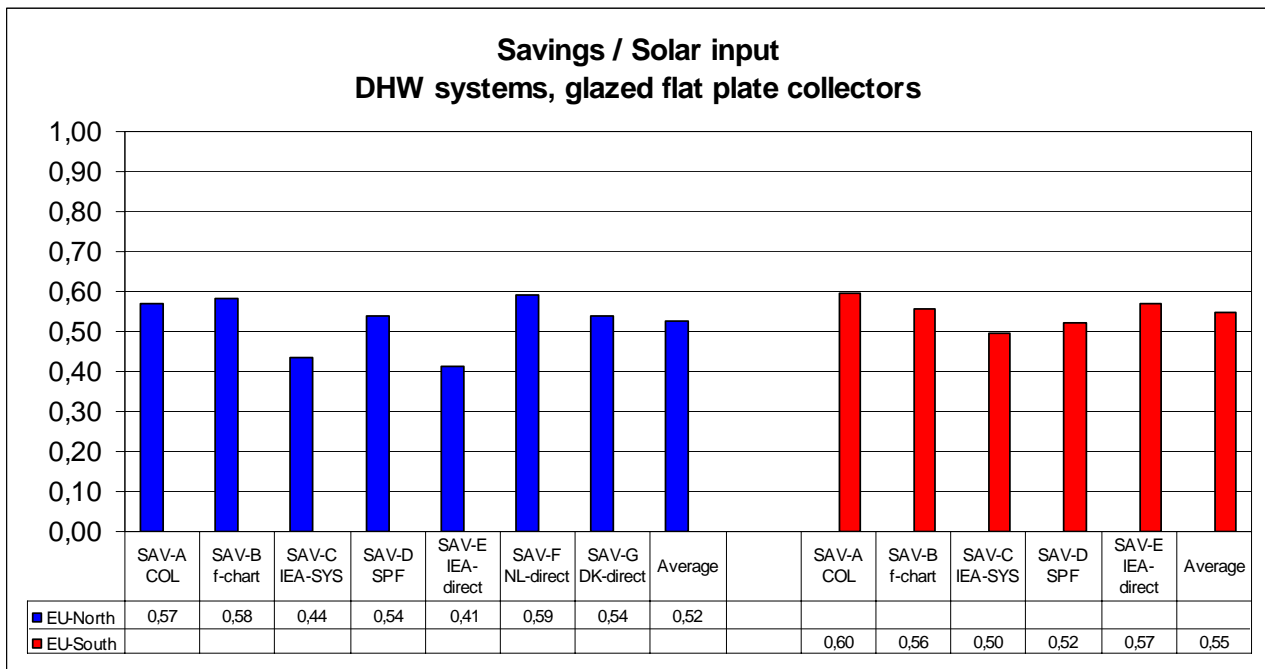


Figure 4<sup>5</sup>. Overview of system savings in the northern and southern part of Europe determined with different methodologies

It is seen that the system savings per m<sup>2</sup> collector are between 0.4 and 0.6 times the incoming solar irradiation per m<sup>2</sup>.

- The average for northern European systems is 0,52. Corresponding to annual saving per m<sup>2</sup> of collector in **Germany** of  $0.52 * 1270 \text{ kWh/m}^2 = \mathbf{640 \text{ kWh/m}^2}$ .
- The average for southern European systems is 0,55. Corresponding to annual saving per m<sup>2</sup> of collector in **Greece** of  $0.55 * 1720 \text{ kWh/m}^2 = \mathbf{950 \text{ kWh/m}^2}$ .
- The overall average for all of Europe 0,53.

The deviations between the different methodologies are not that big – the max. deviation from the overall average is approx. 20%. As the uncertainty on the installed number of systems / collector area in many countries is at this level too, it could be acceptable to choose the very simple formula given below to convert installed capacity in terms of collector area:

- Energy savings per m<sup>2</sup> =  $0.53 * G \text{ [kWh/m}^2]$

<sup>5</sup> fig.4 is copied to the summary, being here fig.1.

G being the solar irradiation on a south-facing plane inclined 45° to the horizontal.

However all methodologies<sup>6</sup> determine the savings under optimal conditions for the solar systems:

- optimal orientation
- optimal constant load through out the year
- optimal design of system related the load applied to the system
- no shadowing

Hence it could be argued that a correction factor should be introduced to compensate the ideal conditions to be closer to real conditions.

- Energy savings =  $F * 0,53 * G$  [kWh/m<sup>2</sup>]
- $= F_{E \rightarrow m^2} * G$  [kWh/m<sup>2</sup>]

The “full load hours” converting installed thermal power capacity into annual energy saving is – using the conversion factor of 0.7 kW per m<sup>2</sup> - then:

- Full load hours =  $F / 0.7 * 0,53 * G$  [h]
- $= F_{E \rightarrow P} * G$  [h]

This is the number of hours to which the installed capacity in a given region has to be multiplied in order to get the corresponding annual energy savings.

Below a table is given showing the consequences of choosing different values of the factor F compensating for real life conditions.

F	$F_{E \rightarrow m^2}$	$F_{E \rightarrow P}$	Energy savings in kWh/m <sup>2</sup> in Germany	Energy savings in kWh/m <sup>2</sup> in Greece
0,80	0,43	0,61	543	735
0,85	0,45	0,65	577	781
0,90	0,48	0,69	611	827

*Table 4. Consequences of choosing different factors F to compensate for non-ideal conditions for solar DHW systems.*

My recommendation for a realistic factor for the compensation for non-optimal conditions will be the factor  $F = 0,8$ . This gives then the final relations to be used all over Europe to convert collector m<sup>2</sup> and thermal power capacity into annual energy savings:

<b>Energy savings from m<sup>2</sup> = 0.43 * G [kWh/m<sup>2</sup>]</b>
---

<b>Full load hours = 0.61 * G [h]</b>
---------------------------------------

<sup>6</sup> except maybe the IEA ones

Taking into consideration the uncertainties, the 0,61 should be given as = 0,6 (this correspond also the number of digits given for the  $m^2$  to power conversion factor.

## Evacuated tubes

It is seen in table that concerning evacuated tubular collectors (ETC) the relations are apparently not as simple as systems with these collectors have different relation to the solar input, depending on whether they are placed in the southern part or the northern part of Europe. These collectors perform significantly relatively better in the northern part. Further analysis in the ETC field will be done.

## Discussion of parasitic energy

- In case of the thermo siphon systems most wide spread in South Europe no parasitic energy for pumps and controllers are necessary.
- In case of the pumped systems most wide spread in North and Central Europe one could argue that it is balanced by less use of electricity in the conventional heating system, pumps control, ventilators, ... Concluding that no extra parasitic energy is needed in this case too.
- **Ergo: Solar DHW systems do not require use of extra parasitic energy**

## Discussion of primary energy savings

- A big part of especial the thermo siphon systems most wide spread in South Europe is replacing electricity. Using a factor of 2.5 to convert to primary energy and the formula for the energy savings above ( $0.43 * G$ ) gives the interesting result that – **in this case – the solar system saves more energy than the amount of solar irradiation on the collector**. The primary energy savings in case of replacement of electricity is:
- **Primary energy savings (replacing electricity) =  $1.07 * G$  [kWh/m<sup>2</sup>]**

## References

- [1] Nielsen, *Conversion of  $m^2$  to power and energy*, SolarKey Int., NEGST, WP4, September 2004
- [2] Marano et al., *Conversion of  $m^2$  to power and energy*, ENEA, NEGST, WP4, December 2004
- [3] Weiss et al., *Solar Heating Worldwide, Markets and contribution to the energy supply 2003*, IEA-SHC, May 2005
- [4] Vogelsanger et al., *Summary report on today's system technology*, SPF, NEGST WP1.D1, draft 24/3, 2006
- [5] ESTIF, *Sun in Action II – A Solar Thermal Strategy for Europe*, April 2003
- [6] SenterNovem, *Dutch Renewable Energy Monitoring*, March 2006
- [7] prEN15316-4-3. *Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-3: Space heating generation systems, thermal solar systems*, CEN, October 2005