Annual efficiency- Easy understanding of collector performance

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Abstract

The Solar Keymark certification with the now mandatory data sheet 2 shows an annual collector output for reference locations and reference conditions. This enables the determination of a new parameter called annual efficiency η_a (ϑ_m) for collectors, which is typical for the respective climate zone and the belonging temperature level or applications with this temperature requirement. A study of the range of collectors available on the market from the simplest non-selective to the high vacuum collector at various locations worldwide shows an almost linear dependence of the annual efficiency on climatic conditions. This confirms that annual efficiency is a technical parameter that determines the performance of collectors. It can be used as a simple and single parameter for comparisons in a first selection process without the need for complex simulations. Moreover, a comparison to the efficiency of PV is possible too.

Keywords: Solar Keymark, annual collector output, annual efficiency

1. Introduction

For many years, there has been no agreed rating and performance system for solar thermal collectors. While for PV the module efficiency and peak power are undisputed parameters, which allow for a simple calculation of the energy yield, the huge and complicated set of performance parameters for solar thermal collectors, e.g. peak collector efficiency, heat loss and incident angle modifier facilitates various interpretations. Unlike PV, where the output in form of electricity is barely influenced by ambient temperature and not by the application, for solar thermal collectors the ambient and supply temperature play a significant role in combination with the irradiation and rule their performance. The assessment of the different parameters regarding the energy output for a selected temperature level is difficult for experts, for consumers such figures are useless.

2. Initial situation and task description

Solar heat suffers from the fact that, in the competition for renewable energies, it is usually not possible to make a first quick statement about how much energy collectors can supply. The experts' answer is usually: „It depends on the application, we have to simulate it". So customers prefer photovoltaics, which likes to make simple and concrete statements immediately about performance and costs. This has led to the fact that solar thermal energy is usually no longer in demand and PV is on everyone's lips. The advantage that solar collectors can harvest 3-4 times more energy per square meter than PV is little known but very important when it comes to making optimal use of limited available space for solar heat and power supply. Instead, valuable solar power is also used for direct heating of water. The task is therefore easily defined: The competitiveness of solar heat is to be represented physically and technically correct with the help of one single parameter. This is not only technically necessary but also politically required. Due to the lack of a suitable parameter, the EU Commission has determined a so-called collector efficiency η_{col}. It is defined in CDR (EU) No 811/2013[1] as collector efficiency of the solar collector at a temperature difference between the solar collector and the surrounding air of 40 K and a global solar irradiance of 1000 W/m². In the EU regulation and its labelling for heating systems η_{col} is used as the sole parameter to describe the contribution of the solar thermal system to space heating and so represents an efficiency criteria. Up to now this unrealistic and improper value is not actively questioned by solar industry and experts but has found access to European standards according to the stipulations. To protect solar thermal from further harm this situation must be changed and an appropriate parameter found to easily show the potential performance of solar collectors.

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3. Basis and methodology

The Solar Keymark database[2] provides the necessary basic information especially data sheet 2 which has been introduced 2011 and is today an obligatory part of the certification scheme. While the known collector performance parameters are listed in data sheet 1, data sheet 2 shows the annual collector output ACO_{module} of the collector modules for 3 medium collector temperatures ϑ_m (25 °C, 50 °C and 75 °C) at 4 reference locations. The latest certificates also show the specific ACO per m² of gross collector area ACO_{spec}. This annual output is generated by a free and publicly accessible Excel program called ScenoCalc[3]. Test institutes have validated this software and it is acknowledged in Europe. Thus, the specific annual collector output is a physical correct value, which is determined by simulation. It is obvious to generalize this parameter. This can be done by dividing the ACO_{spec} with the sum of the belonging hemispherical irradiation H which is also given on the datasheet 2. This leads to the new parameter annual efficiency η_a (ϑ_m).

$$\eta_a(\vartheta_m) = \frac{ACO_{spec}(\vartheta_m)}{H} \qquad \text{(eq.1)}$$

4. Worldwide evaluation and results

The examination was conducted for a whole series of typical collectors. They cover the entire range of non-concentrating available collectors. From simple non-selective flat plate, collectors to high-end vacuum flat plate collectors and various versions of vacuum tube collectors were examined (see Tab. 1).

Note: ETC were calculated with their belonging bi-axial incidence angle modifier not presented in the table.

Tab. 1: Overview of the collectors examined

Collector		Performance parameters/gross area			
Type	**Model**	η_0	a_1	a_2	$K_{hem}(50°)$
Flat plate collectors	(7) Vacuum-FPC	0,675	0,630	0,005	0,92
	(6) double glazing	0,729	2,250	0,005	0,92
	(5b)=(4)+better insulation = Premium FPC	0,729	3,150	0,014	0,92
	(5a)= (4)+ better F' or AR	0,756	3,600	0,014	0,92
	(4)= (3) + better absorber coating	0,729	3,600	0,014	0,92
	(3)= (2)+ better glazing	0,711	3,600	0,014	0,92
	(2) simple selective FPC	0,693	3,600	0,014	0,88
	(1) min. FPC for grants	0,693	4,050	0,014	0,88
	(0) non selective FPC	0,675	5,400	0,027	0,85
Evacuated tubular collectors (ETC) with single glazing (SG) or double glazing (DG)	(7) ETC-DG/direct flow + CPC reflector	0,606	0,540	0,003	0,96
	(6) ETC-SG/direct flow + reflector 6 tubes	0,528	1,338	0,002	1,18
	(5) ETC-SG/Heat pipe + reflector 6 tubes	0,486	1,360	0,000	1,25
	(4) ETC-SG/direct flow 7 tubes	0,570	1,422	0,004	1,00
	(3) ETC-SG/direct flow 6 tubes	0,488	1,219	0,004	1,00
	(2) ETC-SG/Heat pipe 7 tubes	0,510	1,614	0,004	1,03
	(1) ETC-SG/Heat pipe 6 tubes	0,437	1,383	0,003	1,03
	(0) ETC-DG/Heat pipe	0,387	1,382	0,000	1,34

In addition to the European locations implemented in the standard version of ScenoCalc, more locations in North America, Asia and Oceania were selected from the Database of Meteonorm 7[4] which are typical for their climatic zones (see Tab. 2) and are used as reference locations or interesting because they have special climatic conditions. Together they cover the world's most important climate regions. For every collector model at every location the annual collector output for 25 °C, 50 °C and 75 °C was determined at a fixed collector tilt β facing the equator according the stipulations of the Solar Keymark data sheet 2. Moreover the annual efficiency was calculated.

$$\beta = \max[(|\Phi| - 15°) \text{ rounded to the nearest } 5°\,; 25°] \qquad \text{(eq.2)}$$

Tab. 2: Overview of the locations examined

Continent	Location/ Latitude Φ	Reference for colder, average, or warmer climate of the continent	Annual irradiation on collector plane *H* [kWh/m²]	Mean annual ambient air temperature $\overline{\vartheta_a}$ [°C]	Collector orientation, tilt β	Reference
Europe	Athens/38,0°	warmer	1765	18,5	South, 25°	ScenoCalc 5.1
	Davos/46,8°	-	1630	3,2	South, 30°	
	Würzburg/49,8°	average	1244	9	South, 35°	
	Stockholm/59,3°	colder	1166	7,5	South, 45°	
	Moskva/55,8°	-	1166	6,3	South, 40°	Meteonorm 7
Asia	Xigaze/29,3°	-	2337	7,6	South, 25°	
	Abu Dhabi/24,4°	warmer	2130	28,2	South, 25°	
	Mumbai/19,1°	average	1936	27,4	South, 25°	
	Beijing/40,0°N	colder	1540	12,9	South, 25°	
	Novosibirsk/55,1°	-	1516	2,2	South, 40°	
North America	Los Angeles/33,9°	warmer	2017	16,7	South, 25°	
	Denver/39,8°	-	1918	10,3	South, 25°	
	Orlando/28,4°	-	1739	22	South, 25°	
	New York/40,7°	average	1605	12,2	South, 25°	
	Winnipeg MB/49,9°	colder	1724	3,4	South, 35°	
Australia/ New Zealand	Alice Springs/-23,8°	-	2405	21,6	North, 25°	
	Rockhampton/-23,3°	warmer	2139	22,4	North, 25°	
	Sydney/-33,9°	average	1851	18,1	North, 25°	
	Auckland/-37,0°	colder	1709	15,2	North, 25°	

Temperature specific analysis

The annual efficiency of a collector can be plotted in a diagram above the ratio of annual irradiation sum *H* and the temperature difference ΔT between the mean collector ϑ_m and mean annual ambient temperature $\overline{\vartheta_a}$.

$$\Delta T = \vartheta_m - \overline{\vartheta_a} \qquad \text{(eq.3)}$$

Thus only one digram is necessary to display the results for one temperature level. On the linear axis, the different locations worldwide are listed according to their ratio *H/DT*. From cold Swedish capital Stockholm with low irradiation to hot reference location Abu Dhabi with high irradiation. Fig. 1 shows a selection of 3 different flat plate and 3 evacuated tube collectors at 50 °C for all reference locations. It is obviously that the annual efficiency of a collector at a medium collector temperature of 50 °C is in very good approximation a linear function of the ratio of annual irradiation sum per temperature difference $H/\Delta T$ in [kWh/K]. The same fact can be extracted from Fig. 2 where the annual efficiency is presented at 75 °C.

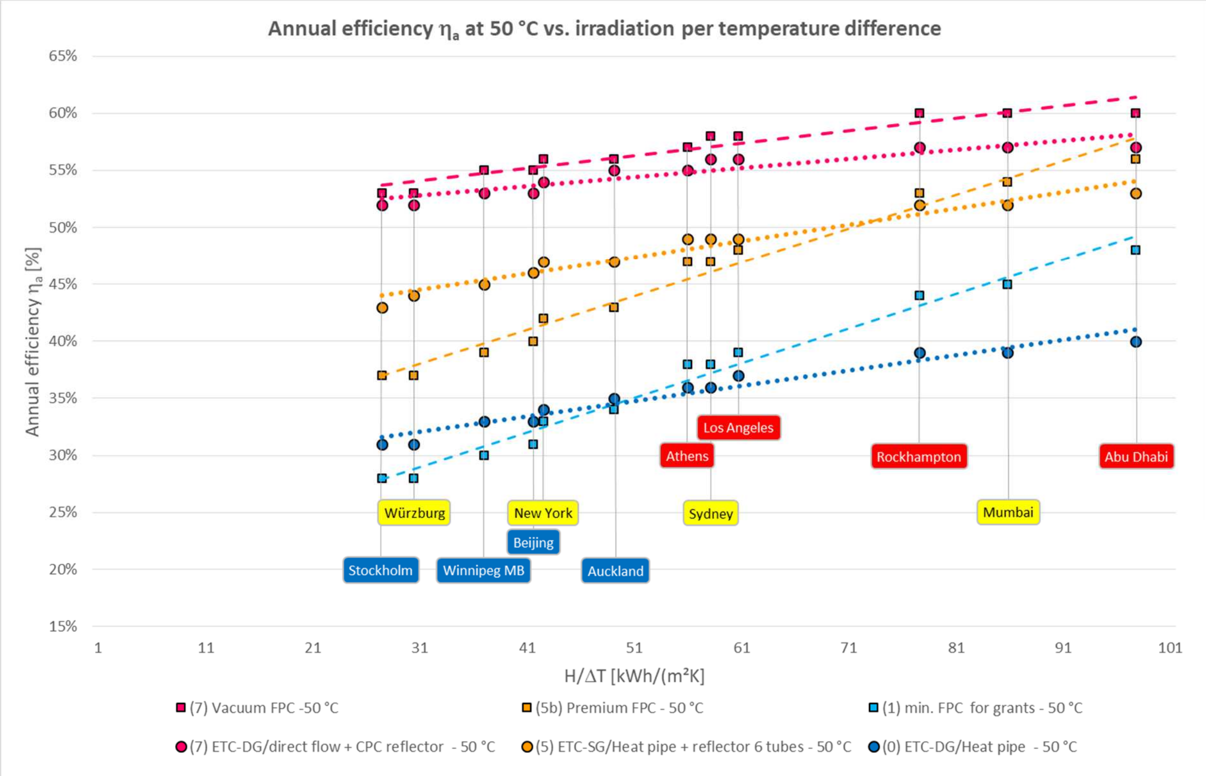

Fig. 1: Annual efficiency at 50 °C medium collector temperature

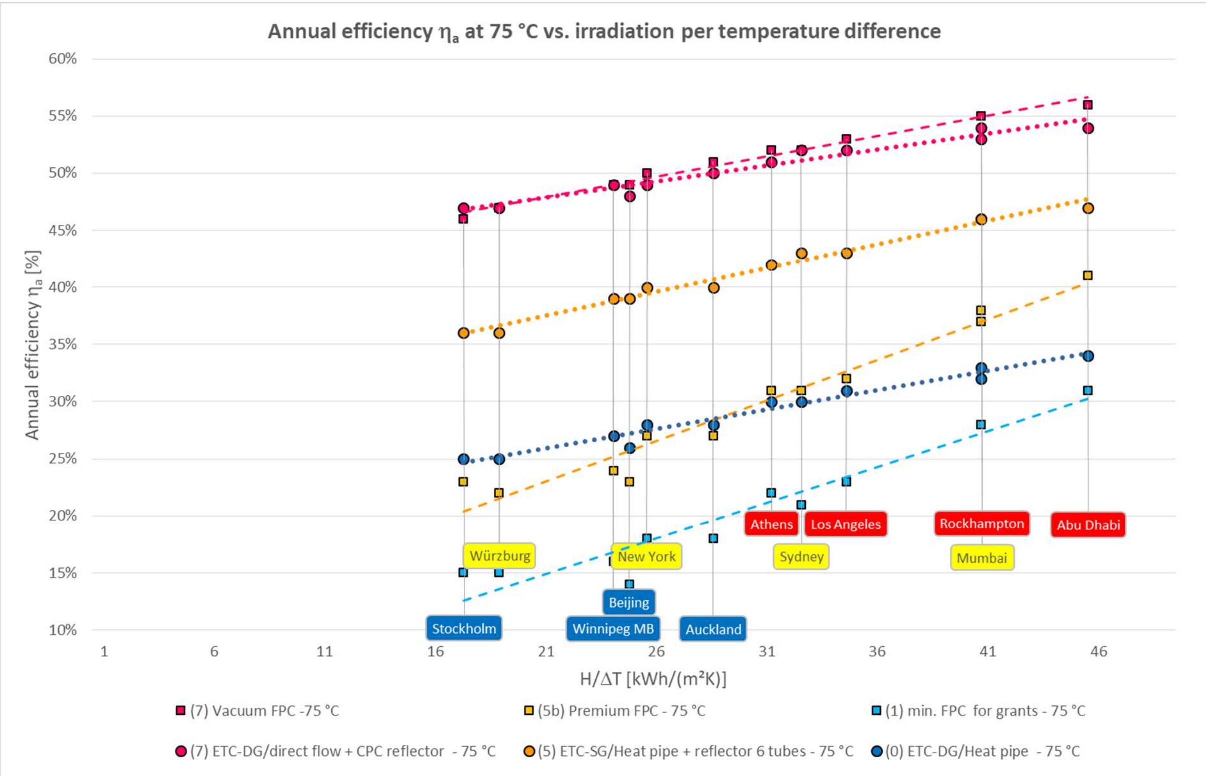

Fig. 2: Annual efficiency at 75 °C medium collector temperature

The accuracy of the linear fit curves is quite high. Even considering the extreme climates, which are not shown in the diagram, the coefficient of determination R^2 is typically > 0.9 and for most reasonable application >0.95. Another finding: The lower the heat losses of the collector models are, the more accurate the linear fit. Using the annual efficiency of Würzburg and Rockhampton for a linear curve provides already very good results so there is no need for extensive calculations.

General analysis

A further investigation was to combine the results of the annual efficiency for 25 °C, 50°C and 75 °C in one diagram. For this purpose as similar approach as for the instantaneous efficiency of collectors has been chosen. The annual efficiency was plotted over the ratio of the temperature difference per irradiation sum *ΔT/H* in [m²K/kWh].

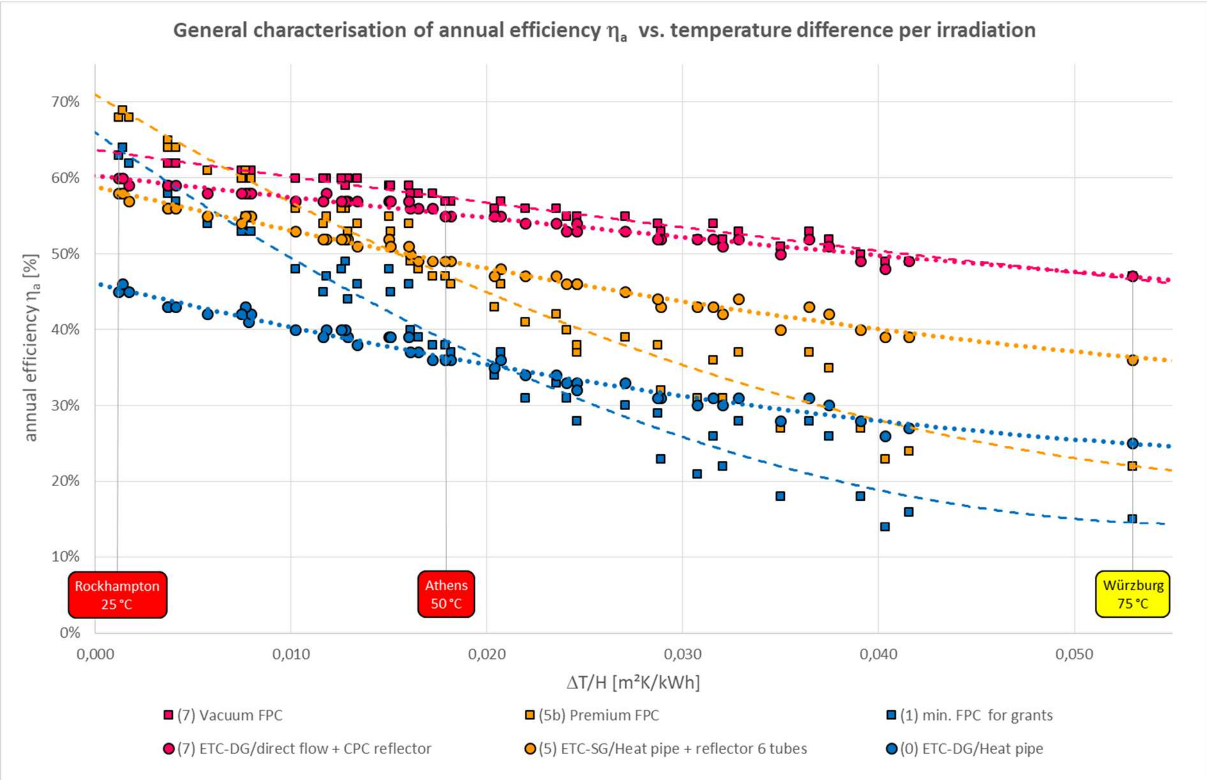

Fig. 3: General characterization of annual efficiency using all annual efficiencies of all reference locations

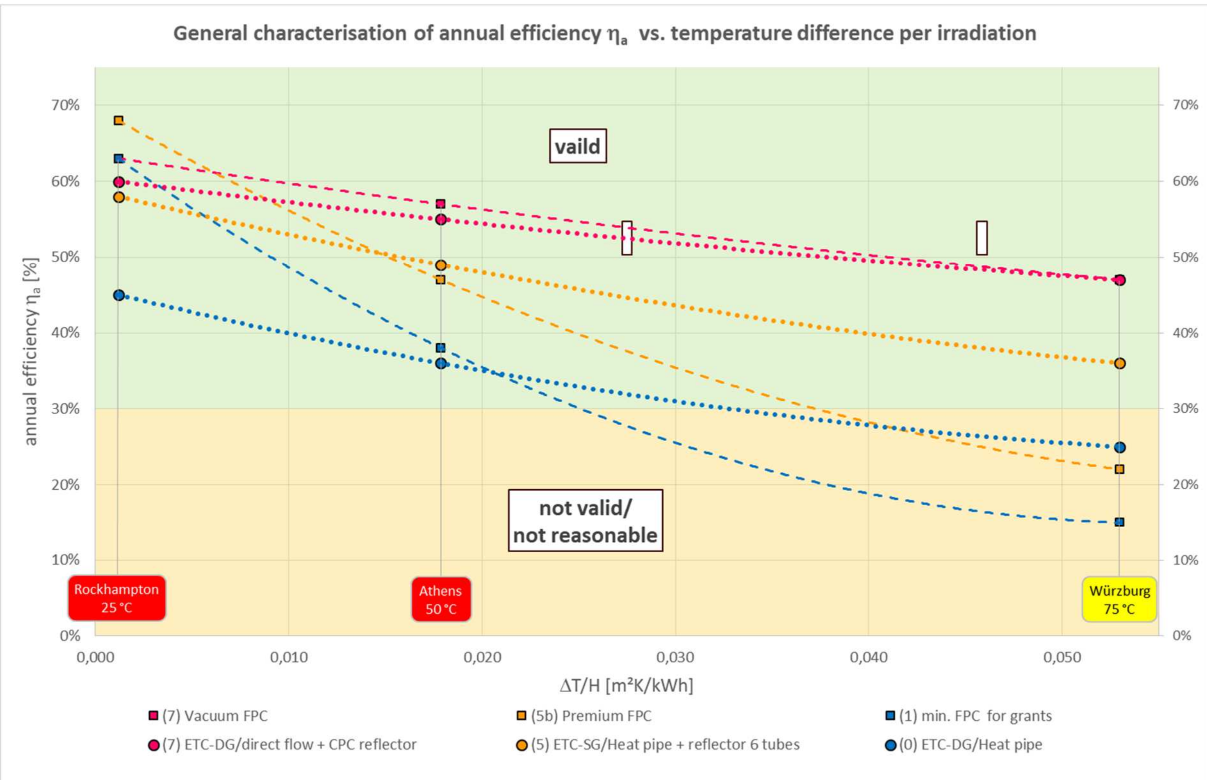

Fig. 4: General characterization of annual efficiency using only 3 annual efficiencies of 3 reference locations

In Fig. 3 this general characterization is highlighted for the same selection of collector models like for the specific analysis. The single points for each collector can be approximated by a second order polynomial curve. While the shape for vacuum collectors is almost linear, collectors with higher heat losses have a concave characteristic. This means that they lose disproportionally more efficiency with higher temperature differences and/or lower irradiation sums at low $\Delta T/H$ values while the decline is reduced for higher $\Delta T/H$ values. With 3 efficiencies of Rockhampton at 25 °C, Athens at 50 °C and Würzburg at 75 °C the polynoms can be determined with a similar accuracy as with the entire data set. Anyway the scope of validity should be limited to η_a > 30%, as the accuracy of the modelling decreases with low efficiencies and practically it does not make sense to use products for applications with such low values while PV is already approaching the 20% mark.

Conclusion:
The parameter η_a allows a simplified but nevertheless technically correct representation of the annual efficiency of solar collectors worldwide. The determination of the annual energy yield for 3 locations is sufficient. Two of them are already available in the Solar Keymark data sheet 2 (Würzburg and Athens). In addition, the calculation must only be performed for the reference site Rockhampton in Australia which is included in the registration process for the SOLERGY label Oceania. With the help of the corresponding annual efficiencies, curves and diagrams as described above can be determined. They can be used to estimate η_a (ϑ_m) worldwide either for concrete temperature levels with very good accuracy or even in general in good approximation. To determine results for any location, only the annual sum of the irradiation on the tilted collector plane H and the ambient air temperature averaged over the year $\bar{\vartheta}_a$ is required. This simplification is made possible by the fact that the annual collector yield already processes all important relevant collector parameters through the simulation with ScenoCalc. The evaluation shows that the data of the locations, such as latitude, global radiation sum, ambient air temperature, which are very different worldwide, do not have such a significant influence that a good approximation is impossible. For collectors with low heat losses, the error in determining the yield is in the order of magnitude of the fault tolerance of collector tests. The validity of the study refers to the optimal inclination and orientation of the location as specified by Solar Keymark and is limited to positive temperature differences ΔT. Although variations of inclination and azimuth were not investigated, it can be expected that smaller deviations of collector tilt and orientation are represented as well when the belonging irradiation sum is used.

5. Application

The method of annual efficiency provides a simple but technically correct understanding of different collector technologies and their potential performance on a global scale. The annual efficiency is useful to select appropriate collectors for different temperatures levels resp. applications and thus gives transparent information for costumers. It can be used to bridge the gap between solar thermal experts and nonprofessionals like consumers, users and politicians. The annual efficiency also enables fair competition with other renewable energies such as PV and biomass. The first implementation of the annual efficiency was carried out by DIN CERTCO as part of the voluntary registration scheme Collector Output Label[3]and can be found in the collector output sheet of registered companies see Fig. 5. The values have been classified in accordance with the EU efficiency label in order to give the end customer a better understanding. They are displayed graphically in labels and are available for Europe and Oceania see Fig. 6. Labels for North America and Asia are in preparation.

A further necessity is to replace the meaningless η_{col} of the EU in the regulation. The annual efficiency η_a cannot only provide a reasonable substitute but has the potential to be used in calculations for the package label as well. Proposals have already been made for the revision. Implementation in the collector standard ISO 9806 makes sense in order to strengthen the position of solar thermal as important basis for the energy transition in the heating sector.

The general characterization of a collector enables the easy assessment of deviations concerning the irradiation and temperature level and their influence on the collector yield. This tool can be used e.g. in contracts about output guarantee to determine the annual efficiency/yield in case of larger deviations from the agreed boundary conditions.

TÜVRheinland® DIN CERTCO

Kollektorertrags-Datenblatt
Collector output data sheet

Reg.-Nr. / Registration No	EL 123456789	EL 123456789
Ausstellungsdatum / Date of issue	30.10.2017	20.11.2017
Labelinhaber / Label holder	**Company name**	**Company name**
Reg.-Nr. Solar KEYMARK Zertifkat / Registration No. Solar KEYMARK certificate	123456789	123456789
Typbezeichnung / Type designation	**Premium flat plate**	**Premium flat plate**
Bruttokollektorfläche / Gross area	**1,00 m²**	**1,00 m²**

50 °C	**Stockholm**	**Würzburg**	**Athens**	**Auckland**	**Sydney**	**Rockhampton**
Ertragsklasse des Kollektors / Output class of collector	A+++	A+++	AA	A+++	AA	AAA
Bruttowärmeerträge des Kollektormoduls [kWh] / Annual collector output per module [kWh]	429	463	830	738	876	1131
Bruttowärmeerträge pro m² [kWh] / Annual collector output per m² [kWh]	429	463	830	738	876	1131
Jahreswirkungsgrad des Kollektors / Annual efficiency of collector	37%	37%	47%	43%	47%	53%
75 °C	**Stockholm**	**Würzburg**	**Athens**	**Auckland**	**Sydney**	**Rockhampton**
Ertragsklasse des Kollektors / Output class of collector	A	A-	A+++	A++	A+++	AA
Bruttowärmeerträge des Kollektormoduls [kWh] / Annual collector output per module [kWh]	263	279	549	464	576	801
Bruttowärmeerträge pro m² [kWh] / Annual collector output per m² [kWh]	263	279	549	464	576	801
Jahreswirkungsgrad des Kollektors / Annual efficiency of collector	23%	22%	31%	27%	31%	37%

Fig. 5: Collector output data sheet Europe and Oceania

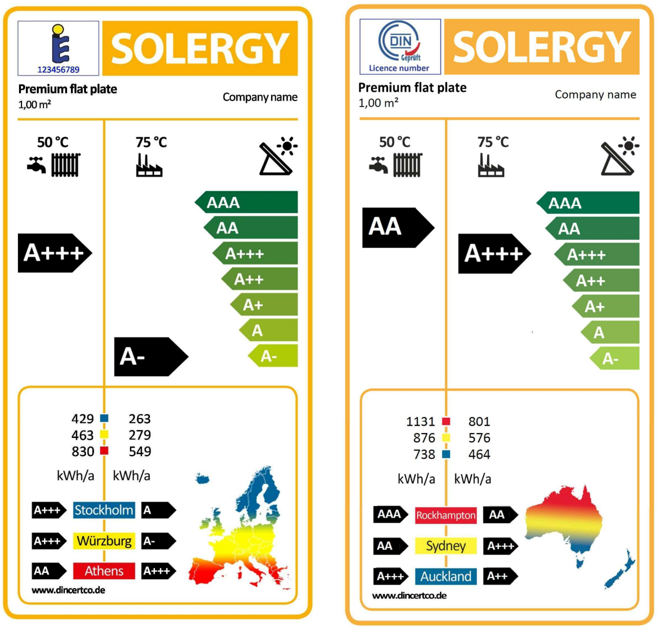

Fig. 6: Collector output Label Europe and Oceania

6. References

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0811&from=DE

[2] http://www.solarkeymark.dk/CollectorCertificates

[3] http://www.sp.se/en/index/services/solar/ScenoCalc/Sidor/default.aspx

[4] https://www.meteonorm.com/

[5] http://www.dincertco.de/en/dincertco/produkte_leistungen/zertifizierung_produkte/umwelt_1/kollektorertragslabel/kollektorertragslabel.html

7. Appendix: Units and Symbols

Quantity	Symbol	Unit
Latitude	Φ	0 to ± 90°; North is +ive
Collector tilt	β	°
Irradiation sum on tilted plane	H	kWh m^{-2}
Mean annual ambient temperature	$\bar{\vartheta}_a$	°C
Medium collector temperature	ϑ_m	°C
Peak collector efficiency collector	η_0	-
Heat loss coefficient	a_1	$Wm^{-2}K^{-1}$
Temperature dependence of the heat loss coefficient	a_2	$Wm^{-2}K^{-2}$
Incidence angle modifier for hemispherical solar radiation	K_{hem}	-
Annual Collector Output of collector module	ACO_{module}	kWh
Specific Annual Collector Output	ACO_{spec}	kWh m^{-2}
Annual efficiency depending on the mean collector temperature	$\eta_a\,(\vartheta_m)$	%
Collector efficiency (EU-Definition)	η_{col}	%