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Comparison of Thermal Performance of Different Solar Collector Technologies for Solar District Heating Systems Based on Solar Keymark Certificates and SCEnOCalc

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Abstract

An easy and standardized method for the determination of the thermal performance of solar collectors is introduced. The method is based on the results published in Solar Keymark certificates and uses the publically available software tool to ensure a high transparency and reliability of the calculation and results. Using this method eight different types of solar collectors, ranging from a standard flat plate solar collector a high performing evacuated tubular solar collector with CPC reflector, are compared with respect to their thermal performance under different temperature levels (50 °C, 75 °C and 100 °C), different collector orientations (tilt and azimuth) and different locations (Stockholm, Würzburg and Athens). The results give an indication which yearly energy yield can be expected from the different solar collector technology at different temperature levels, orientations and locations.

Keywords: solar collector, Solar Keymark, SCEnOCalc, yearly energy yield, standardized method

1. Introduction

During the design phase of a solar district heating system different issues have to be considered. Apart from topics like the overall system concept, demand temperature, storage technology, hydraulic schemes, costs and available space for the collector field one crucial factor is the thermal performance of the solar collector to be used.

To answer this important question up to now no standardized procedure or method was used to determine and assess potential collector types in terms of thermal performance with regard to solar district heating systems.

This contribution will introduce an easy and standardized method for the determination of the thermal performance of solar collectors. This method is based on the results published in Solar Keymark certificates and uses the publically available software tool SCEnOCalc (**S**olar **C**ollector **En**ergy **O**utput **Calc**ulator).

This method using certified solar collector performance data and the software tool SCEnOCalc gives at present the best available guarantee for a reliable assessment and comparison of the thermal performance for solar collectors.

The figures of the yearly energy yield given within this paper do not represent the actual yearly energy yields which can be achieved in a real installation because transient behavior, the collector field hydraulics, the solar system integration and the control strategy are not taken into account. Hence the presented method does not replace a detailed dynamic system simulation to determine the yearly energy yield of a solar district heating system but can be used to preselect solar appropriate solar collectors for the detailed dynamic system simulation.

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2. Solar Collector Energy Output Calculator (SCEnOCalc)

The software tool SCEnOCalc used for the study presented within this paper was developed within the European project QAiST (**Q**uality **A**ssurance **i**n **S**olar **T**hermal Heating and Cooling Technology), mainly by SP Technical Research Institute of Sweden. The tool is used within Solar Keymark scheme, the European quality labeling scheme for solar thermal products, to calculate the yearly solar collector yield per collector module for different European locations documented in the Solar Keymark Certificates which are published on the Solar Keymark homepage (www.estif.org/solarkeymarknew/) for all Solar Keymark certified solar collectors.

The user-friendly, free and publically available software calculates the yearly gross collector yield under the assumption of a constant mean fluid temperature. The tool is not designed to perform systems simulations but gives a very good estimation about the performance of different solar collectors at fixed temperatures to preselect appropriate solar collectors for different applications, e.g. domestic hot water preparation, space heating, district heating or solar process heat, for a further detailed dynamic system simulation.

The method has three major advantages:

1. A high transparency due to the fact that the collector performance test results as well as the validated software tool are publically available (www.estif.org/solarkeymarknew/)
2. Only reliable thermal performance test results which were determined by accredited test laboratories are listed in the Solar Keymark Certificates
3. The quality of the produced collectors is controlled by periodically conducted factory inspections of the production sites and physical inspections of the certified solar collector

3. Solar collector data basis

The comparison was performed for 8 different solar collector technologies and for each technology one representative was selected from the Solar Keymark database (www.estif.org/solarkeymarknew/). The 8 solar collectors are briefly described and listed together with the Solar Keymark license number in Tab. 1.

Tab. 1: Overview about the solar collectors used for the comparison

No.	Solar collector	Solar Keymark licence no.
1	High end evacuated tubular collector with CPC reflector and direct flow	011-7S2031 R
2	Evacuated flat plate collector	011-7S1890 F
3	Standard evacuated tubular collector with CPC reflector and direct flow	011-7S768 R
4	Standard evacuated tubular collector with heat pipe and without reflector	011-7S2122 R
5	Standard evacuated tubular collector with direct flow and without reflector	011-7S060 R
6	High end large scale flat plate collector with double glazing	011-7S1520 F
7	Standard flat plate collector with high selective coating	011-7S052 F
8	Standard flat plate collector with selective coating	011-7S1145

Basis for the comparison is the yearly gross collector yield per m² gross area. The gross area was chosen due to the following reasons:

- The solar collector is sold and bought per module having gross area
- Gross area is the area used by the solar collector when installed and the most appropriate area when solar thermal yield is compared with energy yield from PV systems
- Gross area can be very well correlated to the area needed for installation
- With the introduction of the EN ISO 9806:2013 (EN ISO 9806, 2013), which replaced the EN 12975-2:2006 (EN 12975-2, 2006) in November 2013, the gross area is the only reference area for the determination of the solar collector efficiency parameters

Note: Independent of the reference area used (gross, aperture, absorber) the solar collector yield per module remains the same.

4. Results

The results are presented for different mean fluid temperatures (50 °C, 75 °C and 100 °C), different solar collector tilt angles (0°, 30°, 45°, 60° and 90°), different solar collector azimuths (east (-90°), south-east (-45°), south (0°), south-west (45°) and west (90°)) and three different climates: Stockholm (Sweden) representing northern European climate, Würzburg (Germany) representing middle European climate and Athens (Greece) representing south European climate. Tab. 1 lists the yearly horizontal irradiation (global irradiation) and the mean ambient temperature for the three locations as implemented in SCEnOCalc.

Tab. 1: Yearly climate date for Stockholm, Würzburg and Athens

Location	Yearly horizontal irradiation kWh/(m^2 yr.)	Mean ambient temperature °C
Stockholm	979	7.5
Würzburg	1095	9.1
Athens	1607	18.5

All results are presented in different figures and tables and can be checked using the Solar Keymark data base and SCEnOCalc.

4.1. Standard orientation

As standard orientation for the solar collectors a tilt (angle between the solar collector plane and the horizontal ground) of 30° and an azimuth of 0° (south facing solar collectors) was used. Figures 1 to 3 show the yearly energy yield per m² gross area for the three locations at mean fluid temperatures between 50 and 100 °C.

Tables 3 to 5 show the results in terms of normalized values for the yearly energy yield $Q_{rel}(\vartheta_{fl,m})$ and the gross area $A_{rel}(\vartheta_{fl,m})$ for a mean fluid temperature $\vartheta_{fl,m}$ = 50 °C, 75 °C and 100 °C. The solar collector 6 was used as reference being a typical representative used for large scale solar district heating installations. Values showing more than 110 % of the yearly energy yield of the reference and less than 90 % of the gross area of the reference respectively are shown in green. Values showing less than 90 % of the yearly energy yield of the reference and more than 110 % of the gross area of the reference respectively are shown in red.

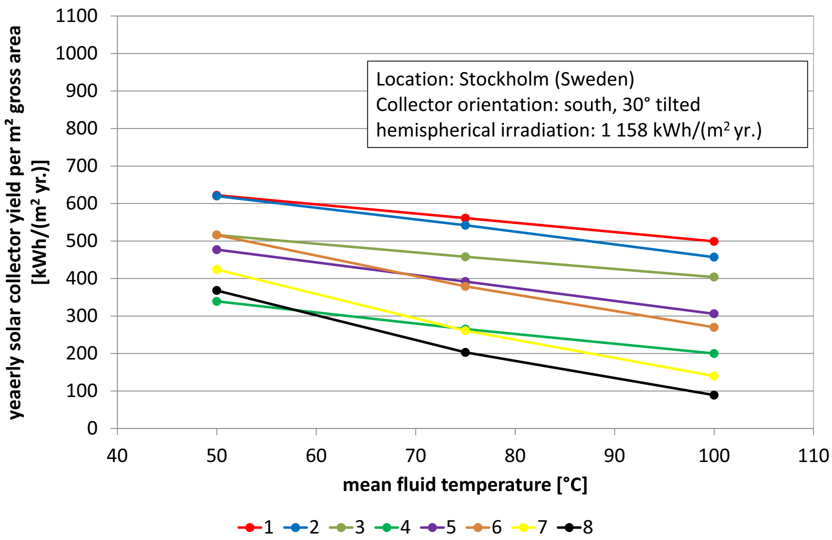

Fig. 1: Yearly solar collector at different mean fluid temperatures at the location Stockholm

Tab. 3: Normalized values for Stockholm with standard orientation

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C)	1.21	1.20	1.00	0.66	0.92	1.00	0.82	0.71
Q_{rel}(75 °C)	1.48	1.43	1.21	0.70	1.03	1.00	0.69	0.54
Q_{rel}(100 °C)	1.85	1.69	1.50	0.74	1.13	1.00	0.52	0.33
A_{rel}(50 °C)	0.83	0.83	1.00	1.52	1.08	1.00	1.22	1.40
A_{rel}(75 °C)	0.68	0.70	0.83	1.43	0.97	1.00	1.45	1.87
A_{rel}(100 °C)	0.54	0.59	0.67	1.35	0.88	1.00	1.93	3.03

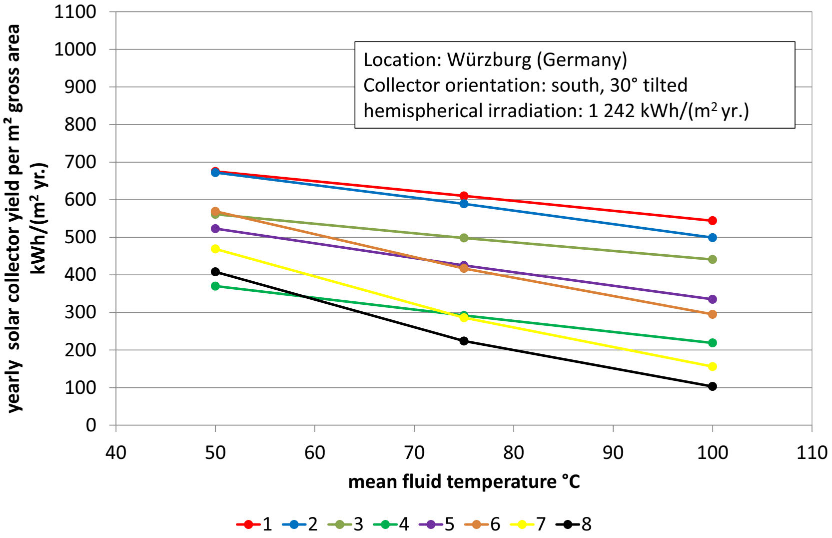

Fig. 2: Yearly solar collector at different mean fluid temperatures at the location Würzburg

Tab. 4: Normalized values for Würzburg with standard orientation

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C)	1.19	1.18	0.99	0.65	0.92	1.00	0.82	0.72
Q_{rel}(75 °C)	1.46	1.41	1.19	0.70	1.02	1.00	0.69	0.54
Q_{rel}(100 °C)	1.84	1.69	1.49	0.74	1.14	1.00	0.53	0.35
A_{rel}(50 °C)	0.84	0.85	1.01	1.54	1.09	1.00	1.21	1.39
A_{rel}(75 °C)	0.68	0.71	0.84	1.43	0.98	1.00	1.46	1.86
A_{rel}(100 °C)	0.54	0.59	0.67	1.35	0.88	1.00	1.89	2.86

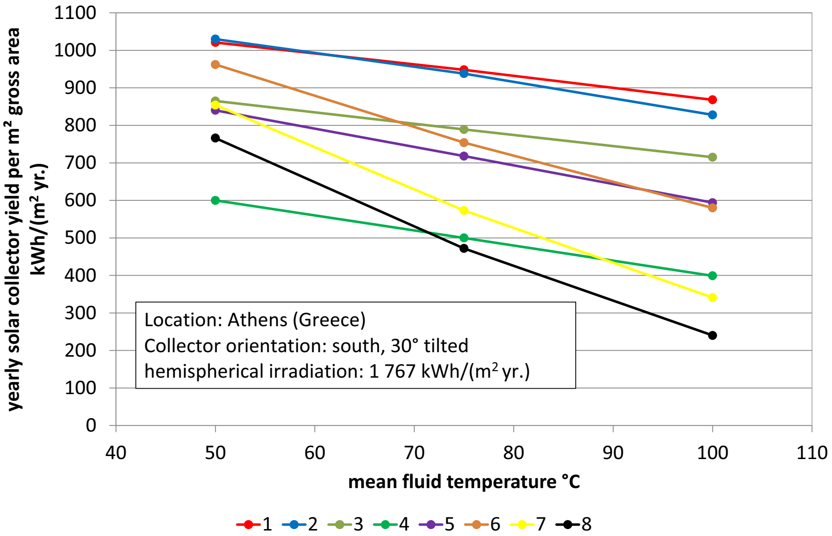

Fig. 3: Yearly solar collector at different mean fluid temperatures at the location Athens

Tab. 5: Normalized values for Athens with standard orientation

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C)	1.06	1.07	0.90	0.62	0.87	1.00	0.89	0.80
Q_{rel}(75 °C)	1.26	1.24	1.05	0.66	0.95	1.00	0.76	0.63
Q_{rel}(100 °C)	1.50	1.43	1.23	0.69	1.02	1.00	0.59	0.41
A_{rel}(50 °C)	0.94	0.93	1.11	1.60	1.15	1.00	1.13	1.26
A_{rel}(75 °C)	0.80	0.80	0.96	1.51	1.05	1.00	1.32	1.60
A_{rel}(100 °C)	0.67	0.70	0.81	1.45	0.98	1.00	1.70	2.42

The results presented in figures 1 to 3 and tables 3 to 5 show that

- High performing solar collectors (solar collector 1 and 2) show a higher yearly yield in the range of 6 to 85 % depending on the temperature range of 50 to 100 °C of the mean fluid temperature resulting in a reduced gross area of 6 to 46 % to reach the same energy yield than the reference
- With higher values of mean fluid temperature the surplus yearly yield is increasing and the required gross area is decreasing (solar collector 1, 2 and 3) compared to the reference
- The benefit of collector 1, 2 and 3 decreases with rising ambient temperature and rising yearly irradiation
- Evacuated tubular collectors without reflector do not have higher collector gains than flat plate collectors due to a small ratio of aperture to gross area

4.2. Variation of the tilt angle

In a second step the tilt angle of the solar collector was varied in the range of 0° (horizontal) to 90° (vertical) to evaluate the impact of the tilt angle. For this comparison the orientation of the solar collectors remained facing south.

Figures 4 to 6 show the yearly energy yield per m² gross area for the locations Würzburg at mean fluid temperatures of 50 °C, 75 °C and 100 °C.

Tables 6 to 8 show the results in terms of normalized values for the yearly energy yield $Q_{rel}(\vartheta_{fl,m}, \beta)$ and the gross area $A_{rel}(\vartheta_{fl,m}, \beta)$ for mean fluid temperatures $\vartheta_{fl,m}$ = 50 °C, 75 °C and 100 °C. The solar collector 6 was again used as reference. Values showing more than 110 % of the yearly energy yield of the reference and less than 90 % of the gross area of the reference respectively are shown in green. Values showing less than 90 % of the yearly energy yield of the reference and more than 110 % of the gross area of the reference respectively are shown in red.

Values for a tilt angle of 30° are documented in table 3 to 5 and values for a tilt angle of 45° are not given because they do not differ significantly from the values at a tilt angle of 30°. Values at a tilt angle of 0° are not given due to low relevance.

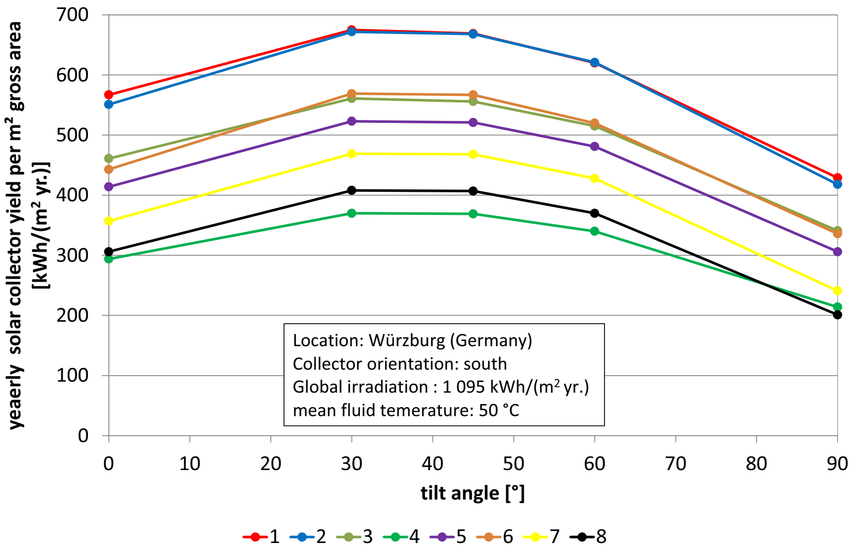

Fig. 4: Yearly solar collector at a mean fluid temperature of 50 °C at the location Würzburg

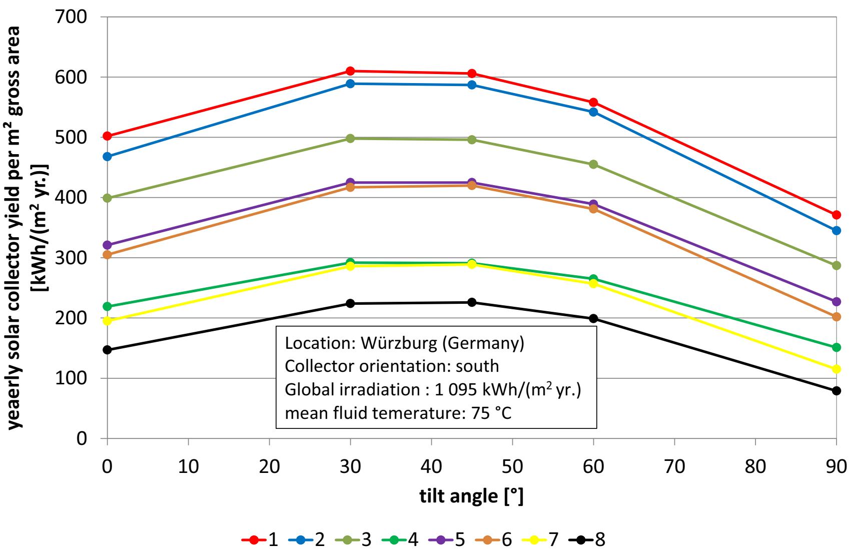

Fig. 5: Yearly solar collector at a mean fluid temperature of 75 °C at the location Würzburg

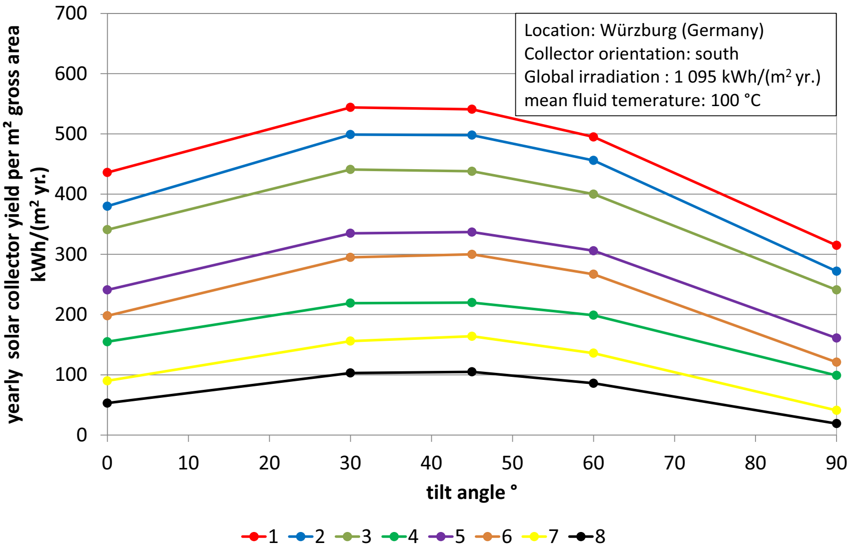

Fig. 6: Yearly solar collector at a mean fluid temperature of 100 °C at the location Würzburg

Tab. 6: Normalized values for Stockholm for different tilt angles

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C, 60°)	1.19	1.20	0.99	0.65	0.92	1.00	0.82	0.71
Q_{rel}(50 °C, 90°)	1.31	1.30	1.06	0.67	0.96	1.00	0.78	0.65
A_{rel}(50 °C, 60°)	0.84	0.84	1.01	1.53	1.08	1.00	1.21	1.40
A_{rel}(50 °C, 90°)	0.76	0.77	0.95	1.49	1.04	1.00	1.28	1.53
Q_{rel}(75 °C, 60°)	1.46	1.42	1.19	0.70	1.02	1.00	0.68	0.53
Q_{rel}(75 °C, 90°)	1.71	1.62	1.35	0.73	1.09	1.00	0.59	0.41
A_{rel}(75 °C, 60°)	0.69	0.71	0.84	1.43	0.98	1.00	1.46	1.87
A_{rel}(75 °C, 90°)	0.58	0.62	0.74	1.37	0.91	1.00	1.69	2.41
Q_{rel}(100 °C, 60°)	1.82	1.69	1.48	0.74	1.13	1.00	0.52	0.32
Q_{rel}(100 °C, 90°)	2.36	2.09	1.84	0.80	1.30	1.00	0.34	0.15
A_{rel}(100 °C, 60°)	0.55	0.59	0.68	1.36	0.89	1.00	1.94	3.13
A_{rel}(100 °C, 90°)	0.42	0.48	0.54	1.25	0.77	1.00	2.94	6.57

Tab. 7: Normalized values for Würzburg for different tilt angles

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C, 60°)	1.19	1.19	0.99	0.65	0.93	1.00	0.82	0.71
Q_{rel}(50 °C, 90°)	1.28	1.24	1.01	0.64	0.91	1.00	0.72	0.60
A_{rel}(50 °C, 60°)	0.84	0.84	1.01	1.53	1.08	1.00	1.21	1.41
A_{rel}(50 °C, 90°)	0.78	0.80	0.99	1.57	1.10	1.00	1.39	1.67
Q_{rel}(75 °C, 60°)	1.46	1.42	1.19	0.70	1.02	1.00	0.67	0.52
Q_{rel}(75 °C, 90°)	1.84	1.71	1.42	0.75	1.12	1.00	0.57	0.39
A_{rel}(75 °C, 60°)	0.68	0.71	0.84	1.43	0.98	1.00	1.46	1.86
A_{rel}(75 °C, 90°)	0.54	0.59	0.70	1.34	0.89	1.00	1.76	2.56
Q_{rel}(100 °C, 60°)	1.85	1.71	1.50	0.75	1.15	1.00	0.51	0.32
Q_{rel}(100 °C, 90°)	2.60	2.25	1.99	0.82	1.33	1.00	0.34	0.16
A_{rel}(100 °C, 60°)	0.54	0.59	0.67	1.34	0.87	1.00	1.96	3.10
A_{rel}(100 °C, 90°)	0.38	0.44	0.50	1.22	0.75	1.00	2.95	6.37

Tab. 8: Normalized values for Athens for different tilt angles

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C, 60°)	1.08	1.09	0.91	0.63	0.88	1.00	0.88	0.78
Q_{rel}(50 °C, 90°)	1.23	1.20	0.99	0.65	0.91	1.00	0.81	0.70
A_{rel}(50 °C, 60°)	0.93	0.92	1.10	1.59	1.14	1.00	1.14	1.28
A_{rel}(50 °C, 90°)	0.81	0.83	1.01	1.54	1.09	1.00	1.23	1.43
Q_{rel}(75 °C, 60°)	1.31	1.29	1.08	0.67	0.97	1.00	0.74	0.60
Q_{rel}(75 °C, 90°)	1.69	1.59	1.31	0.73	1.07	1.00	0.61	0.45
A_{rel}(75 °C, 60°)	0.77	0.78	0.93	1.49	1.03	1.00	1.35	1.68
A_{rel}(75 °C, 90°)	0.59	0.63	0.76	1.37	0.93	1.00	1.64	2.23
Q_{rel}(100 °C, 60°)	1.63	1.54	1.33	0.72	1.08	1.00	0.56	0.37
Q_{rel}(100 °C, 90°)	2.43	2.13	1.89	0.81	1.27	1.00	0.43	0.24
A_{rel}(100 °C, 60°)	0.61	0.65	0.75	1.39	0.93	1.00	1.79	2.73
A_{rel}(100 °C, 90°)	0.41	0.47	0.53	1.24	0.79	1.00	2.34	4.09

At high tilt angles of 60° and 90° the high performing solar collectors (solar collector 1 and 2) show even a higher yearly yield than at the standard tilt of 30° compared to the reference. At a mean fluid temperature of 100 °C and a tilt angle of 90° solar collector 1 reaches 260 % of the energy yield of the reference solar collector resulting in a reduction of 62 % of the required gross area to reach the same energy yield then the reference solar collector under the same conditions.

4.2. Variation of the azimuth angle

In the third step the azimuth angle of the solar collector was varied in the range of -90° (east) to +90° (west) to evaluate the impact of the azimuth angle. For this comparison the tilt angle of the solar collectors remained at 30°.

Figures 7 to 9 show the yearly energy yield per m² gross area for the locations Würzburg at mean fluid temperatures of 50 °C, 75 °C and 100 °C.

Tables 9 to 11 show the results in terms of normalized values for the yearly energy yield $Q_{rel}(\vartheta_{fl,m}, \gamma)$ and the gross area $A_{rel}(\vartheta_{fl,m}, \gamma)$ for mean fluid temperatures $\vartheta_{fl,m}$ = 50 °C, 75 °C and 100 °C. The solar collector 6 was again used as reference. Values showing more than 110 % of the yearly energy yield of the reference and less than 90 % of the gross area of the reference respectively are shown in green. Values showing less than 90 % of the yearly energy yield of the reference and more than 110 % of the gross area of the reference respectively are shown in red.

Values for an azimuth angle of 30° are documented in table 3 to 5 and values for azimuth angles of +45° and +90° are not given because they do not differ significantly from the values at azimuth angles of -45° and -90° respectively.

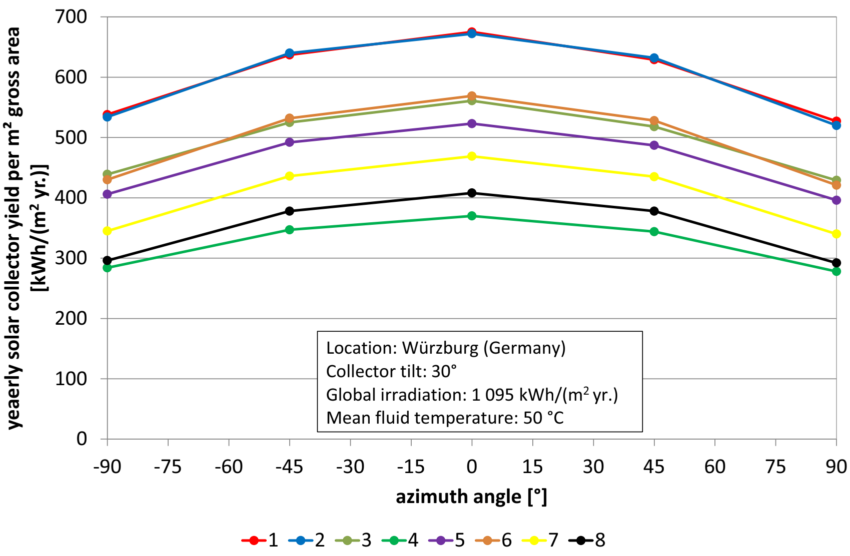

Fig. 7: Yearly solar collector at a mean fluid temperature of 50 °C at the location Würzburg

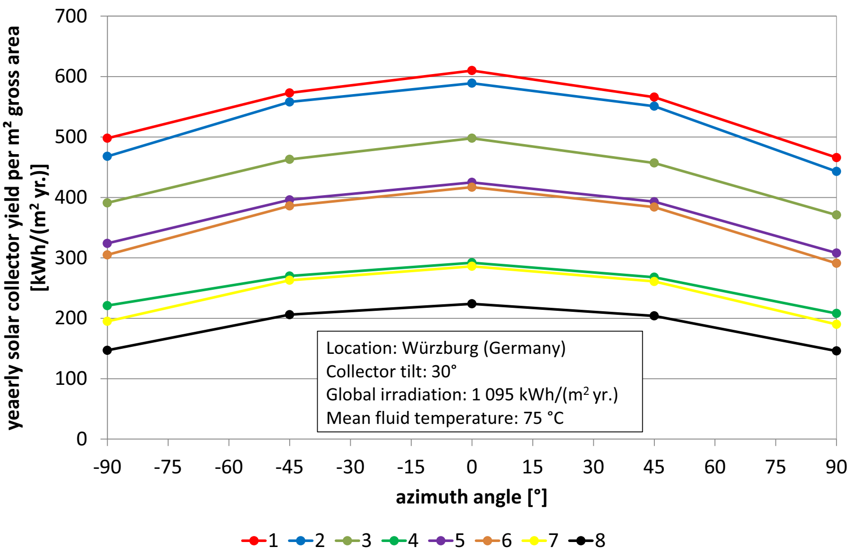

Fig. 8: Yearly solar collector at a mean fluid temperature of 75 °C at the location Würzburg

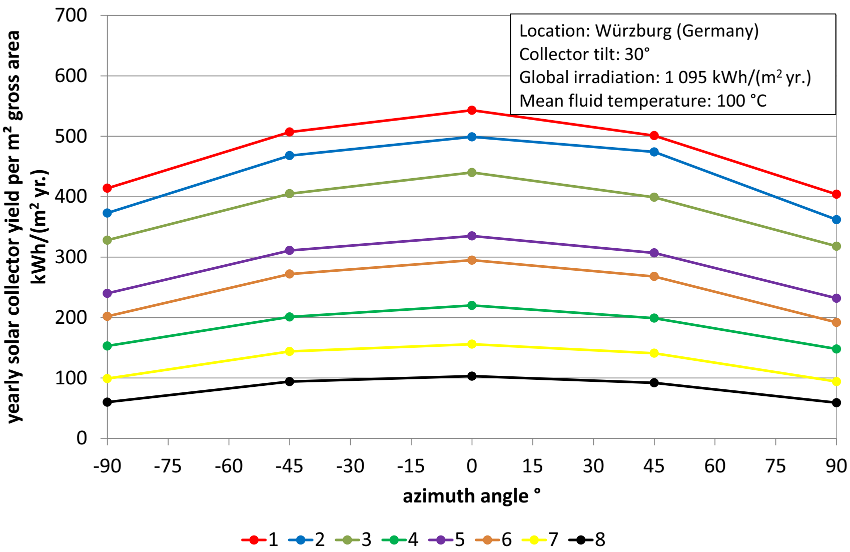

Fig. 9: Yearly solar collector at a mean fluid temperature of 100 °C at the location Würzburg

Tab. 9: Normalized values for Stockholm for different azimuth angles

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C, -90°)	1.28	1.26	1.04	0.67	0.96	1.00	0.79	0.68
Q_{rel}(50 °C, -45°)	1.22	1.22	1.00	0.66	0.93	1.00	0.82	0.71
A_{rel}(50 °C, -90°)	0.78	0.79	0.96	1.49	1.05	1.00	1.26	1.48
A_{rel}(50 °C, -45°)	0.82	0.82	1.00	1.52	1.07	1.00	1.22	1.42
Q_{rel}(75 °C, -90°)	1.64	1.55	1.31	0.73	1.08	1.00	0.50	0.47
Q_{rel}(75 °C, -45°)	1.50	1.45	1.21	0.70	1.03	1.00	0.67	0.52
A_{rel}(75 °C, -90°)	0.61	0.64	0.77	1.38	0.93	1.00	2.01	2.14
A_{rel}(75 °C, -45°)	0.67	0.69	0.83	1.43	0.97	1.00	1.48	1.92
Q_{rel}(100 °C, -90°)	2.16	1.92	1.71	0.78	1.23	1.00	0.43	0.24
Q_{rel}(100 °C, -45°)	1.89	1.74	1.51	0.74	1.15	1.00	0.50	0.31
A_{rel}(100 °C, -90°)	0.46	0.52	0.59	1.27	0.81	1.00	2.32	4.18
A_{rel}(100 °C, -45°)	0.53	0.58	0.66	1.34	0.87	1.00	1.98	3.23

Tab. 10: Normalized values for Würzburg for different azimuth angles

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C, -90°)	1.25	1.24	1.02	0.66	0.94	1.00	0.80	0.69
Q_{rel}(50 °C, -45°)	1.20	1.20	0.99	0.65	0.92	1.00	0.82	0.71
A_{rel}(50 °C, -90°)	0.80	0.81	0.98	1.51	1.06	1.00	1.25	1.45
A_{rel}(50 °C, -45°)	0.84	0.83	1.01	1.53	1.08	1.00	1.22	1.41
Q_{rel}(75 °C, -90°)	1.63	1.53	1.28	0.72	1.06	1.00	0.64	0.48
Q_{rel}(75 °C, -45°)	1.48	1.45	1.20	0.70	1.03	1.00	0.68	0.53
A_{rel}(75 °C, -90°)	0.61	0.65	0.78	1.38	0.94	1.00	1.56	2.07
A_{rel}(75 °C, -45°)	0.67	0.69	0.83	1.43	0.97	1.00	1.47	1.87
Q_{rel}(100 °C, -90°)	2.05	1.85	1.62	0.76	1.19	1.00	0.49	0.30
Q_{rel}(100 °C, -45°)	1.86	1.72	1.49	0.74	1.14	1.00	0.53	0.35
A_{rel}(100 °C, -90°)	0.49	0.54	0.62	1.32	0.84	1.00	2.04	3.37
A_{rel}(100 °C, -45°)	0.54	0.58	0.67	1.35	0.87	1.00	1.89	2.89

Tab. 11: Normalized values for Athens for different azimuth angles

Normalized values	Solar Collector Technology							
	1	2	3	4	5	6	7	8
Q_{rel}(50 °C, -90°)	1.14	1.15	0.94	0.64	0.91	1.00	0.84	0.74
Q_{rel}(50 °C, -45°)	1.09	1.11	0.91	0.63	0.89	1.00	0.87	0.77
A_{rel}(50 °C, -90°)	0.88	0.87	1.06	1.56	1.10	1.00	1.18	1.35
A_{rel}(50 °C, -45°)	0.92	0.90	1.10	1.59	1.13	1.00	1.15	1.30
Q_{rel}(75 °C, -90°)	1.44	1.42	1.16	0.69	1.01	1.00	0.70	0.55
Q_{rel}(75 °C, -45°)	1.30	1.32	1.08	0.67	0.98	1.00	0.73	0.59
A_{rel}(75 °C, -90°)	0.69	0.70	0.86	1.45	0.99	1.00	1.44	1.81
A_{rel}(75 °C, -45°)	0.77	0.76	0.92	1.48	1.03	1.00	1.36	1.68
Q_{rel}(100 °C, -90°)	1.86	1.74	1.48	0.74	1.14	1.00	0.52	0.34
Q_{rel}(100 °C, -45°)	1.64	1.57	1.32	0.72	1.08	1.00	0.56	0.38
A_{rel}(100 °C, -90°)	0.54	0.57	0.68	1.35	0.88	1.00	1.92	2.96
A_{rel}(100 °C, -45°)	0.61	0.64	0.76	1.39	0.92	1.00	1.78	2.65

The variation of the azimuth angle shows similar results to the ones achieved while varying the tilt angle. At east or west orientation the high performing evacuated solar collectors outperform the high performing flat plate collector even to a higher extent than at the reference solar collector orientation with a tilt angle of 30° due south. The largest surplus in the yearly energy yield compared to the reference solar collector for Stockholm at a mean fluid temperature of 100 °C facing east and west, respectively. With this orientation the surplus reaches 216 % resulting in a reduction of gross area of 54 % compared to the reference solar collector.

5. Summary and conclusion

An easy and standardized method for the determination of the thermal performance of solar collectors is introduced. This method is based on the results published in Solar Keymark certificates and uses the publically available software tool SCEnOCalc (Solar Collector Energy Output Calculator).

The method was applied using 8 different solar collectors ranging from a high performing evacuated tubular solar collector with CPC reflector over to a high performing flat plate solar collector to a flat plate collector with black chrome coating at different locations and orientations of the solar collector and mean fluid temperatures.

The comparison has shown that

- High performing evacuated solar collectors show a significant higher yearly yield, up to 85 % higher, than high performing flat plate solar collectors resulting in a reduction of required gross area up to 54 %. The difference in yearly energy yield increases if the orientation of the solar collector is changed from facing south with a tilt angle of 30° to an orientation receiving less irradiation, e.g. to the east at with a tilt of 60°
- The benefit of high performing evacuated solar collectors decreases with rising ambient temperature and rising yearly irradiation but remains significant
- Evacuated tubular collectors without reflector do not have higher collector gains than flat plate solar collectors due to a small ratio of aperture to gross area.

Although other criteria like costs and installation have to be considered apart from thermal performance, high performing evacuated solar collectors must be considered when planning solar district heating systems, especially at higher temperatures.

6. References

ISO 9806:2013, 2013. Solar energy — Solar thermal collectors — Test methods
EN 12975-2:2006, 2006. Thermal solar systems and components – Solar collectors - Part 2: test methods

7. Nomenclature

Quantity	Symbol	Unit
Ratio between required gross solar collector area of a solar collector and the reference solar collector	A_{ref}	
Ratio between yearly solar collector yield and yearly solar collector yield of the reference solar collector	Q_{ref}	
Tilt angle	β	°
Azimuth angle	γ	°
Mean fluid temperature	$\vartheta_{fl,m}$	°C