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A Long Term Test of Differently Designed Evacuated Tubular Collectors

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Abstract

During three years seven differently designed evacuated tubular collectors (ETCs) utilizing solar radiation from all directions have been investigated experimentally. The evacuated tubular solar collectors investigated include one SLL all-glass ETC from Tshinghua Solar Co. Ltd, four heat pipe ETCs and one direct flow ETC from Sunda Technolgoy Co. Ltd and one all-glass ETC with heat pipe from Exoheat AB. The collectors have been investigated side-by-side in an outdoor test facility for a long period. During the measurements, the operating conditions – such as weather conditions and temperature of the inlet fluid to the collectors have been the same for all collectors. The volume flow rate through each of the collectors is adjusted so that the mean solar collector fluid temperature has been the same for all collectors. Thus a direct performance comparison is possible. The side-by-side tests were carried out with different mean solar collector fluid temperatures and in different seasons of the year. The results of the measurements are presented in this paper. The influence of the mean solar collector fluid temperature on the thermal performance of the different collector designs will be discussed. Further, the collector performances are compared for different times of the year and it is illustrated how the performance of the different collector types depends on weather conditions.

Keywords: Evacuated tubular solar collector, collector design, thermal performance, test.

1. Introduction

In recent years the evacuated tubular collectors have gained an increasing share of the market. On the world’s largest solar thermal market, China, evacuated tubular collectors have increased the market share from 30% in 1998 up to 94% in 2007 [1]. In Europe, evacuated tubular collectors of up to 240,000 m^2 were installed in 2007 [2].

On the market there is a large number of collector manufactures providing evacuated tubular collectors with a variety of types such as all-glass, heat pipe, all-glass with heat pipe, direct flow, with and without reflectors. As far as the heat pipe evacuated tubular collector is concerned, there are designs with different tube diameters and different shapes of the absorber. It is therefore important to know how the different designed evacuated tubular collectors perform. He et al. [3] made a comparison of optical performance of evacuated collector tubes with flat and semi-cylindrical absorbers. The collector tubes are utilizing solar energy from the front side. The absorbed energy of the absorber is used in the comparison. They found that the semi-cylindrical absorber outperforms the flat absorber by 15.9% annually if it is located at latitude 40° N. Fan et al. [4] carried out side-by-side outdoor tests of four heat pipe evacuated tubular collectors with a flat fin or a semi-cylindrical fin. The collectors utilize solar radiation from all directions. The measurements show that at latitude 57° the ETC with a flat fin performs better than the ETC with a semi-cylindrical fin for a tube diameter of 70 mm and a collector tilt of 67°. The ETC with flat fin tends to perform better than the ETC with the curved fin in winter and at high collector fluid temperatures.

Evacuated tubular collectors have a substantially lower heat loss coefficient than standard flat plate solar collectors. This makes ETCs very suitable for high latitude regions like the Arctic. The advantages of evacuated tubular collectors at high latitudes are not only their low heat loss and high efficiency, but also the ability to utilize solar radiation from all directions due to the large variation of the solar azimuth. The aim of this paper is to present the result of a long term outdoor test of differently designed evacuated tubular collectors utilizing solar radiation from all directions. Side-by-side tests of seven differently designed evacuated solar collectors were carried out in a period from February 2006 to August 2008. The thermal performances of the differently designed evacuated tubular collectors are compared. Based on the observations from the measurement, it will be elucidated how the collector performance is influenced by the solar collector designs, the weather and operation conditions.

2. Experiments

Seven differently designed ETCs utilizing solar radiation from all directions have been investigated experimentally. Detailed data sheet of the investigated ETCs is given in Table 1.

Side-by-side tests were carried out in an outdoor test facility at the Technical University of Denmark, latitude 56°N, see Figure 1. On the test platform, five collectors can be tested under the same conditions at a time. The collectors are directly facing south and have a tilt angle of 67° which is suitable for typical operation conditions in the Arctic. The collectors can utilize solar radiation from all directions. A glycol/water mixture of 41% by weight is used as the solar collector fluid. The fluid flow rate through each of the collectors is measured by a flow meter type Brunata HGQ1-R0. The inlet and outlet temperatures of the collector are measured by copper/constantan thermal couples, type TT. The difference between the outlet and inlet temperature is measured by a thermopile. The five collectors are parallel connected to a temperature control unit so that the inlet temperatures to the collectors are the same. A pump is used to circulate the solar collector fluid during all hours so that the inlet temperature of the fluid to the collectors is kept constant. The flow rates through the collectors are adjusted in such a way that the average temperatures of the collector fluids in all the collectors are approximately the same during the test. The accuracy of the absolute temperature measurement and temperature difference measurement is 0.5 K and 0.1K, respectively. The accuracy of the flow rate measurement is estimated to be 1.5%. The measurement data are monitored and logged every two minutes by LabView.

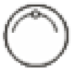
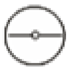
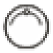
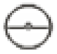
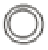
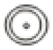
The weather data are measured in a climate station located on the roof of a building close to the test platform. The total and diffuse solar irradiance on horizontal surface and the ambient air temperature are measured.

The thermal performance of the ETCs were measured in the period from February 2006 to August 2008. The experiment is divided into three phases:
Phase 1: February 2006 – June 2006, collectors tested: ETC 1, ETC 2, ETC 3, ETC 4 and ETC 5.
Phase 2: July 2006 – May 2007, collectors tested: ETC 2, ETC 4, ETC 5 and ETC 6.
Phase 3: May 2007 – August 2008, collectors tested: ETC 2, ETC 4, ETC 5, ETC 6 and ETC 7.

During the test period, four mean collector fluid temperature levels are used: 26°C, 43-47°C, 63-68°C and 75-78°C.

Fig. 1. The side–by-side test facility.

Table 1. Data of the tested evacuated tubular collectors.

ETC no.	1	2	3	4	5	6	7
Collector type	Seido 5-8	Seido 1-8	Seido 10-20 with curved fin	Seido 10-20 with flat fin	SLL 1500	VA1858	Seido 2-16
Note	Vertical tubes, heat pipe	Vertical tubes, heat pipe	Vertical tubes, heat pipe	Vertical tubes, heat pipe	Horizontal tubes	Vertical tubes, heat pipe	Vertical tubes, direct flow
Manufacturers	Sunda Technology Co. Ltd	Sunda Technology Co. Ltd	Sunda Technology Co. Ltd	Sunda Technology Co. Ltd	Tsinghua Solar Co. Ltd	ExoHeat AB	Sunda Technology Co. Ltd
Number of tubes	8	8	20	20	50	24	16
Tube diameter	100 mm	100 mm	70 mm	70 mm	47 mm	58 mm	70 mm
Tube length	2000 mm	2000 mm	1750 mm	1750 mm	1500 mm	1800 mm	1700 mm
Tube centre distance	111-120 mm	111-120 mm	86-93 mm	86-93 mm	72-75 mm	79-84 mm	89-91 mm
Tube diameter / tube centre distance	0.83-0.90	0.83-0.90	0.75-0.81	0.75-0.81	0.63-0.65	0.69-0.73	0.77-0.79
Transparent area	1.54 m^2	1.54 m^2	2.36 m^2	2.36 m^2	3.30 m^2	2.45 m^2	1.87 m^2
Collector height	2.16 m	2.16 m	1.90 m	1.90 m	2.00 m	1.97 m	1.90 m
Collector width	0.96 m	0.96 m	1.86 m	1.86 m	3.20 m	1.99 m	1.82 m
Gross area	2.07 m^2	2.07 m^2	3.53 m^2	3.53 m^2	6.40 m^2	3.92 m^2	3.46 m^2
Absorber area	3.66 m^2	2.80 m^2	6.60 m^2	4.00 m^2	8.71 m^2	6.17 m^2	3.20 m^2
Absorber material	Aluminum	Aluminum	Aluminum	Aluminum	Glass	Glass	Copper-Aluminum
Absorber thickness	0.47 mm	0.47 mm	0.6 mm	0.6 mm	-	-	0.6
Selective coating	Aluminum Ni	Aluminum Ni	Aluminum Ni	Aluminum Ni	Aluminum Ni	Aluminum Ni	Aluminum Ni
Absorptance	0.92	0.92	0.92	0.92	0.90	0.92	0.92
Emittance	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Glass thickness	2.5 mm	2.5 mm	1.7 mm	1.7 mm	1.6 mm	1.6 mm	1.7 mm
Transmittance at incidence angle 0°	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Manifold diameter	28 mm	28 mm	38 mm	38 mm	45 mm	38 mm	38 mm
Symbol							

3. Results and Discussion

3.1. Thermal performance during the day

The power of the collectors during the day is studied to investigate the transient thermal performance of the ETCs. Figure 2 shows the collector power in an autumn day. In the morning, the direct flow ETC 7 starts up first, followed by the heat pipe ETC 4, ETC 2 and the double glass ETC with heat pipe. There is a sharp increase of the power of the heat pipe ETCs which is most likely caused by the late start-up of evaporation in the heat pipe causing “overheated” absorber temperatures. A possible explanation is that the upper part of the collector is heated up first, but the heat pipe will not be able to work until the bottom part of the heat pipe is heated up to the evaporation temperature. After 10:00 and before 15:00, the power of the ETC 6 levels out while the power of the other collectors increases in the morning and decreases in the afternoon. That can be explained by the cylindrical shape of the absorber of ETC 6. When there is almost no shadow on the tubes between 10:00 and 15:00, the irradiated surface area of the cylindrical absorber does not change significantly, therefore there is insignificant change of the collector power. The heat pipe ETC 2 and 4 and the direct flow ETC have a flat absorber, so the collector power will increase in the morning due to a decrease of incidence angle and an increase of irradiated surface area. In the afternoon the power will decrease due to increased incidence angle and reduced irradiated surface area.

The direct flow ETC 7 performs almost the same as ETC 4 but in the early morning and the late afternoon ETC 7 performs a bit better than ETC 4. The all-glass ETC 5 on the other hand starts up slowly and stops almost 1 hour later than the other collectors. This is due to its large thermal capacity since a large quantity of collector fluid is stored in the glass tubes.

Figure 3 shows power of the collectors in a summer day. In the morning ETC 4, 6 and 7 almost start up at the same time. The power of the collectors increases gradually and smoothly. The power of ETC 6 is higher than ETC 4 and 7 in the morning and in the afternoon. That is because the cylindrical absorber of ETC 6 has a larger irradiated surface than a flat absorber in the morning and in the afternoon.

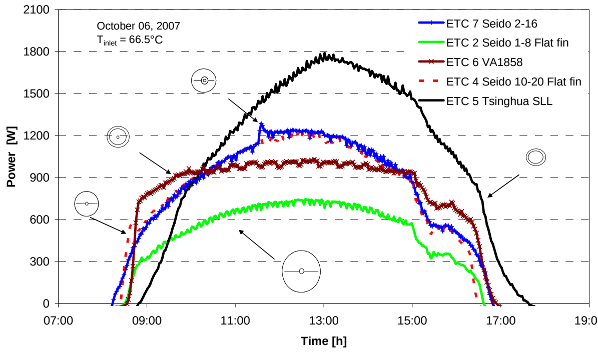


Fig. 2: Collector power in an autumn day in phase 3.

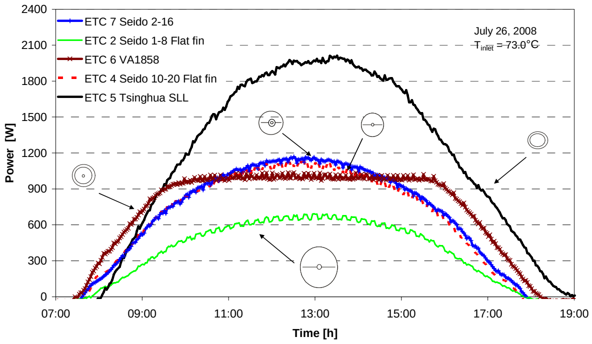


Fig. 3: Collector power in a summer day in phase 3.

3.2. Long term thermal performance

The thermal performances of the seven ETCs are compared. Figure 4 shows relative thermal performances of the differently designed ETCs. The performance ratio is defined as the ratio between the weekly thermal performance of the collector in question and the weekly thermal performance of the reference collector shown in the figure. The mean solar collector fluid temperature during operation is given at the bottom of the figure.

3.2.1 Heat pipe ETCs

The thermal performances of four heat pipe ETCs are measured. They are ETC 1, 2, 3 and 4. ETC 1 and 2 have 8 tubes of tube diameter 100 mm. ETC 3 and 4 have 20 tubes of tube diameter 70 mm. The difference between ETC 1, 3 and ETC 2, 4 is that ETC 1 and 3 have a curved/semi-cylindrical fin while ETC 2 and 4 have a flat fin. As shown in Fig.4, the performance ratio of ETC 3/ETC 4 is in the range of 0.73-0.94 meaning that the ETC with a flat fin performs better than the ETC with a curved fin. For a mean collector fluid temperature of 63°C, the ETC with a flat fin has a thermal performance 12% higher than the ETC with a curved fin. With an increase of the mean collector fluid temperature to 75°C, the thermal performance of the ETC with a flat fin is increased to be 15% higher than the thermal performance of the ETC with the curved fin. The comparison of a collector with a curved fin and a flat fin with a tube diameter of 100 mm is given by the ratio of ETC 1/ETC 2. The advantage of the ETC with a flat fin tends to weaken with an increase of the tube diameter. However, the ETC with a flat fin is better than the ETC with a curved fin for most of the test period.

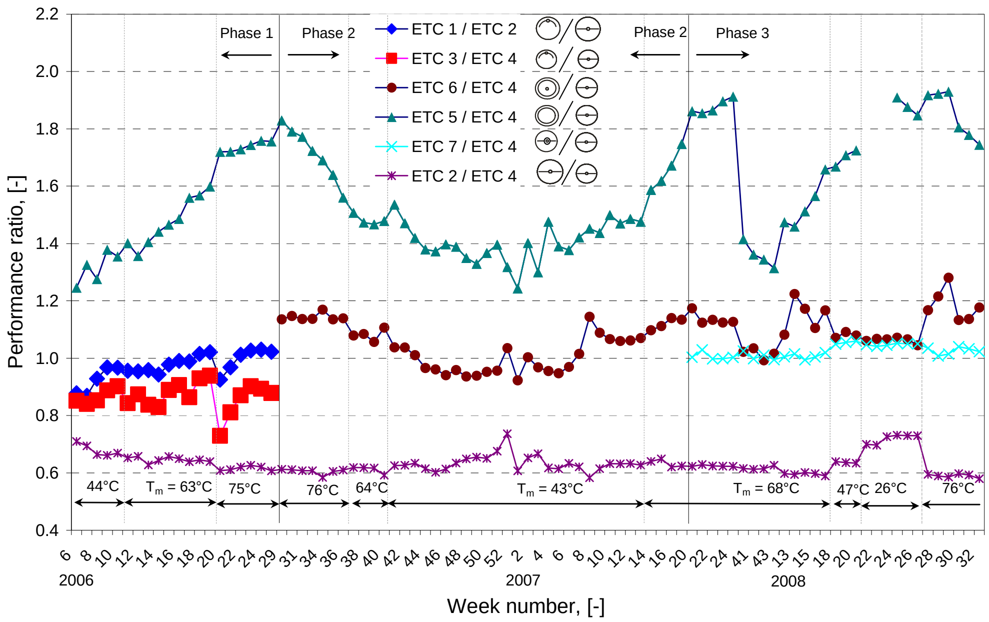


Fig. 4. Performance ratio of the differently designed ETCs.

Thermal performance of the ETCs in phase 1 is summarized in Fig. 5. The measurements were carried out half a year from winter to summer with the aim to get a better estimation of the yearly collector performance. The result shows that the collectors with flat fins perform relatively better than the collectors with curved fins. For a collector with a tube diameter of 70 mm, types 3 and 4, there is an increase of 13% of collector performance if a flat fin is used instead of a curved fin, while for a collector with a tube diameter of 100 mm, the extra thermal performance of the collector with a flat fin compared to the collector with a curved fin is quite small, only approximately 1%.

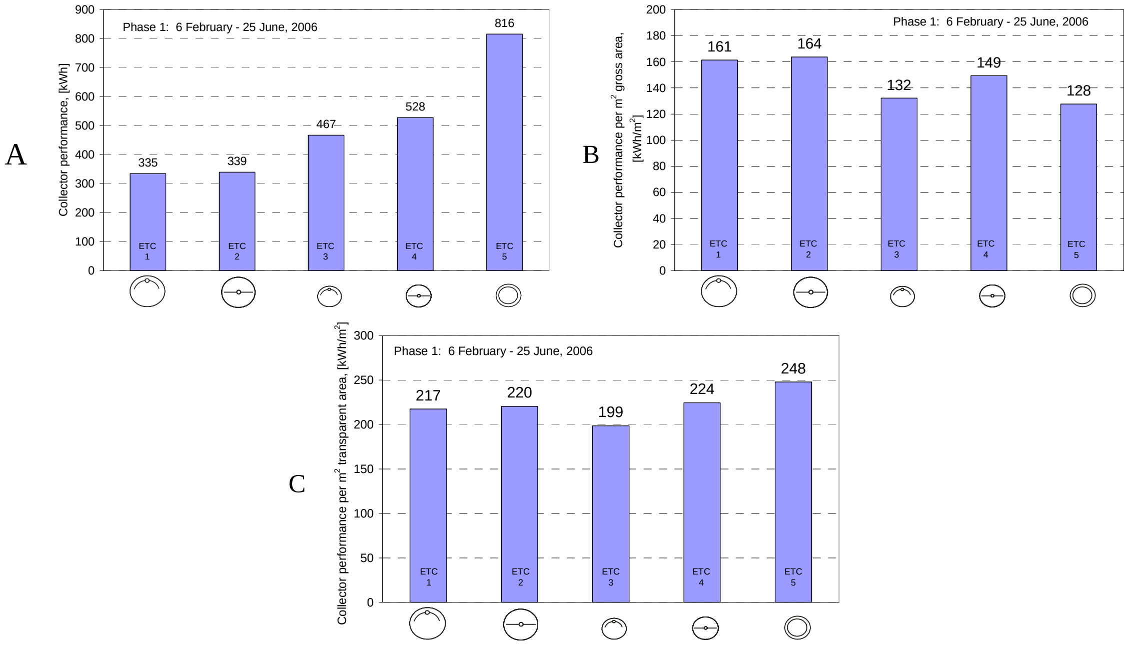


Fig. 5: Collector performance in Phase 1.

This finding seems to be contradictory to the finding of He et al. [3] who found that for a glass tube of 100 mm the curved fin absorbs 15.9% more solar energy annually than the flat fin. The explanation is the larger heat loss from the curved fin compared to that of the flat fin. The surface area of the curved fin is approx. 40% larger than the surface area of the flat fin, resulting in a higher heat loss from the curved fin and a lower thermal performance. It shall be noted that the location of the collector and the fact that He's investigations only considered solar radiation from the front side might influence the conclusion as well. The measurement presented in this paper was carried out for a latitude of 56°, while in He's investigations [3], a latitude of 40° was used.

The performance ratio between the ETC 2 and ETC 4 is less varying throughout the measuring period. This can be explained by the similarity of the fin design. The mean solar collector fluid temperature has a slight influence on the ratio of the thermal performance. There is an increase of the performance ratio with a decrease of mean solar collector fluid temperature, indicating that ETC 2 has a higher heat loss coefficient than that of ETC 4.

3.2.2 All glass ETCs

It can be seen from Figure 4 that the thermal performance of the all glass ETC 5 is always larger than that of the reference collector, ETC 4, simply due to the fact that ETC 5 has a larger transparent area. Despite of small fluctuations, it is clearly shown that the performance ratio increases from winter to summer and decreases from summer to winter meaning that the all-glass ETC 5 performs relatively better in summer compared to the winter. The reason could be the difference of the two collectors in tube orientation and the distance between the tubes. The all glass ETC 5 has east-west oriented horizontal tubes while ETC 4 has south-north oriented tubes with a tilt of 67°. Since the solar azimuth variation is much larger than the solar altitude variation, especially in the summer, the shadowed tube area, caused by shadows from neighbouring tubes, is much larger for ETC 4 than for ETC 5 in large parts of the day. Furthermore the ratio of tube diameter to tube centre distance is 63-65% for ETC 5 and 75-81% for ETC 4. Therefore there is a relatively larger tube distance and thus less shadow from neighbouring tubes of the ETC 5 compared to ETC 4. The performance ratio of ETC 5 to ETC 4 is insignificantly influenced by the mean collector fluid temperature.

The energy output of ETC 5 in the three phases is summarized and presented in Figures 5, 6 and 7. It can be concluded that ETC 5 has the smallest thermal performance per m^2 gross area while it has the second largest thermal performance m^2 transparent area because ETC 5 has the smallest ratio of tube diameter to tube centre distance and thus has the largest distance between the tubes.

3.2.3 Double glass ETC with heat pipe

In phases 2 and 3, the thermal performance of the ETC 6 was measured. It is can be seen from Fig. 4 that the performance ratio of ETC 6/ETC 4 decreases from summer to winter and increases from winter to summer. In summer the ETC 6 has a thermal performance maximum 28% higher than ETC 4 while in winter ETC 4 performs up to 8% better than ETC 6. This is due to the larger tube distance of ETC 6 and thus less shadow from neighbouring tubes. ETC 6 has a tube diameter to tube centre distance ratio of 0.69-0.73 which is a bit smaller than that of ETC 4, 0.75-0.81. It is reasonable that ETC 6 performs better than ETC 4 based on the thermal performance per m^2 transparent area, while ETC 4 performs better than ETC 6 based on the thermal performance per m^2 gross area, see Fig, 6, 7.

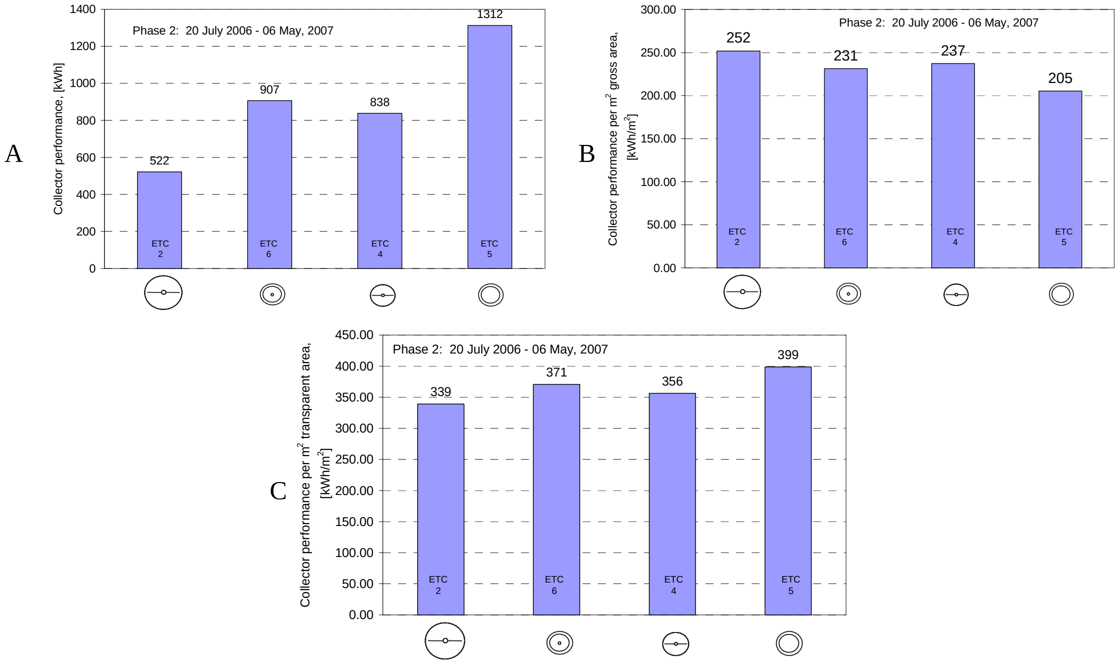


Fig. 6: Collector performance in Phase 2.

3.2.4 Direct flow ETC

The performance ratio between the ETC 7 and ETC 4 is quite constant. The influence of the seasons is marginal. The mean solar collector fluid temperature has a slight influence on the ratio of the thermal performance. There is a slight increase of the performance ratio with a decrease of mean solar collector fluid temperature. That indicates a higher heat loss coefficient of the direct flow ETC.

In Fig. 7 it is shown that ETC 7 has the largest thermal performance per m^2 transparent area and the second largest thermal performance m^2 gross area.

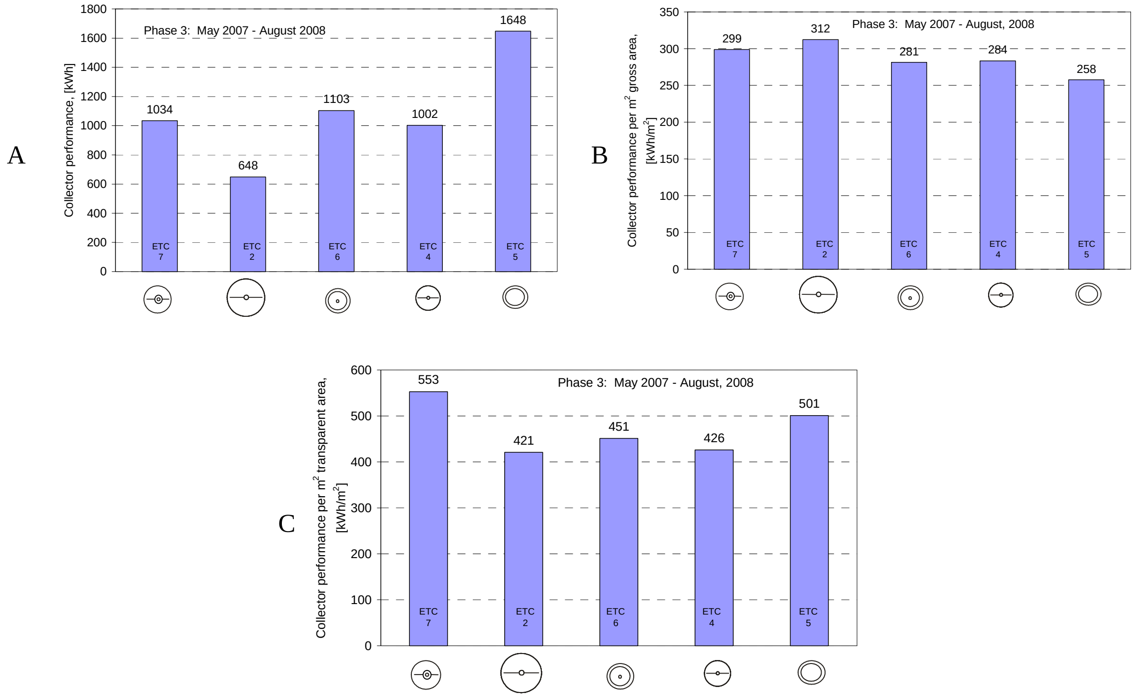


Fig. 7: Collector performance in Phase 3.

4. Conclusion

Side-by-side tests of seven differently designed evacuated tubular collectors were carried out in an outdoor test facility. The observations from the measurements show that the direct flow ETC and the all-glass ETC have relatively high thermal performance m^2 transparent area. The all-glass ETC with solar collector fluid in the tubes and the double-glass ETC with heat pipe perform relatively better in summer than in the rest of the year. This behaviour is insignificantly influenced by the mean collector fluid temperature. The heat pipe ETC with flat fin performs better than the ETC with curved fin in most of the test period and the superiority will increase in winter periods and in periods with high mean solar collector fluid temperature.

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