Quality Assurance in solar thermal heating and cooling technology

Keeping track with recent and upcoming developments

Synthesis
One year exposure tests performed throughout Europe on different solar thermal collectors

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Summary

The issue of the benefits of an ageing test more severe (and longer) than the exposure test in the current standard EN 12975-2, was raised. So CSTB with several European laboratories conducted a campaign of one year ageing tests.

Twenty-one solar collectors were tested before and after a one year exposure. A decrease of efficiency of 9 % in average was observed.

The exposure period of one year is a severe ageing test which cause adverse effects on several solar collectors, especially evacuated tube collectors with heat pipes.

On the evacuated tube collectors with heat pipes, a variety of degradation are observed, whose effects on performance are different from each other. Some damages affect the zero-loss efficiency, to decrease it, others affect losses, for increasing them or in some cases for decreasing them.

These results do not demonstrate the need to enlarge the standard exposure period. It is possible that the major degradation may also be detected after regular exposure time. Furthermore, it should be pointed out, that one year of dry stagnation is no common use and may result in too strong thermal stress and damages.

Contents

1 – STUDY OBJECTIVES AND PROCEDURE

As part of European work on the topic of ageing solar thermal collectors, CSTB with several European laboratories conducted a campaign of ageing tests; with the following sequence:

a) Initial thermal performances test,

b) One year exposure test,

c) Final thermal performances test and degradation observations.

The test methodology is according EN 12975-2 standard: indoor steady state, outdoor steady state and outdoor quasi-dynamic method. Some laboratories have made the entire series of tests, while others have participated as testing performance without making observations of damages. As all the test data hasn't been provided, the performance test results have been extrapolated from the 3 coefficients in the range of Tm* between 0 to 0,08 for an Irradiance of 800 W/m².

The documents used to gather information are attached (see annexes). In agreement with the observation table, it is recalled that the damages observed should be classified for each components family as follows:

0 - No problem

1 - Minor problem

2 – Major problem

Furthermore, the document requested if the laboratory could make a possible link between the degradation and the thermal performance result. If "Yes", the damage impact should be classified as "major", "moderate" or "minor". This report indicates through tables and curves, the difference between final and initial performances, completed with the laboratory observed degradations.

The laboratories which participated in the study are:

1. LES – LNEG (Portugal): test of one evacuated tube collector (ETC) with direct flow and one ETC with heat pipes.
2. TÜV Rheinland (Germany): test of two ETC with heat pipes.
3. Fraunhofer ISE (Germany): test of three ETC with one direct flow and two heat pipes.
4. ITW (Germany): test of four ETC with heat pipes and one with reflectors.
5. SPF (Switzerland): test of one ETC with heat pipes.
6. AIT (Austria) : test of one flat plate collector and one ETC with direct flow.
7. CSTB (France) : test of two ETC with heat pipes.
8. ISFH (Germany): test of four ETC with heat pipes.
9. SP (Sweden): test of one ETC with heat pipes.

21 collectors were tested.

2 – TEST RESULTS

1. LES – LNEG

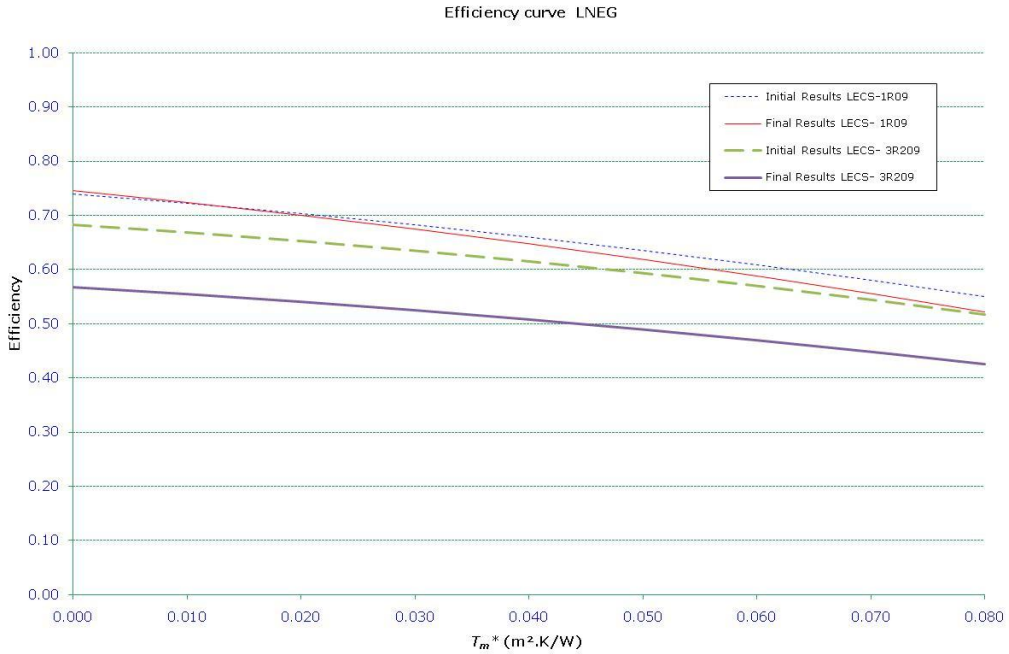
The following table summarizes the results of performance test conducted on both solar collectors:

Collector type	ETC with U-pipe direct flow			ETC heat pipe		
Test period	March 09 to feb 11			June 09 to feb 11		
	Initial Results	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**
	Outdoor Steady state method			*Outdoor Steady state method*		
η0	0.739	0.746	**1%**	0.683	0.568	**-17%**
a1 [W/(m²K)]	1.6	2.1		1.3	1.2	
a2 [W/(m²K²)]	0.012	0.011	18%	0.012	0.009	-14%

	Initial Results LECS-1R09	**Final Results LECS- 1R09**	**Variation**	**Initial Results LECS- 3R209**	**Final Results LECS- 3R209**	**Variation**
Tm*	η	η		η	η	
0	0.739	0.746	1%	0.683	0.568	-17%
0.01	0.722	0.724	0%	0.669	0.555	-17%
0.02	0.703	0.700	0%	0.653	0.541	-17%
0.03	0.682	0.675	-1%	0.635	0.526	-17%
0.04	0.660	0.648	-2%	0.616	0.508	-17%
0.05	0.635	0.619	-3%	0.594	0.490	-18%
0.06	0.608	0.588	-3%	0.570	0.470	-18%
0.07	0.580	0.556	-4%	0.545	0.449	-18%
0.08	0.550	0.522	-5%	0.518	0.426	-18%
		min	0%		min	-17%
		max	-5%		max	-18%

Note : the variation of the loss coefficients is calculated with 40 K temperature difference (variation of a1 + 40a2)

Comparison of performance curves before and after the exposure period:



Observations following the opening of solar collectors:

1st Collector (reference LECS-1R09)

- Mountings / structure :

Classification 1: Corrosion was observed in the screws supporting the collector structure.

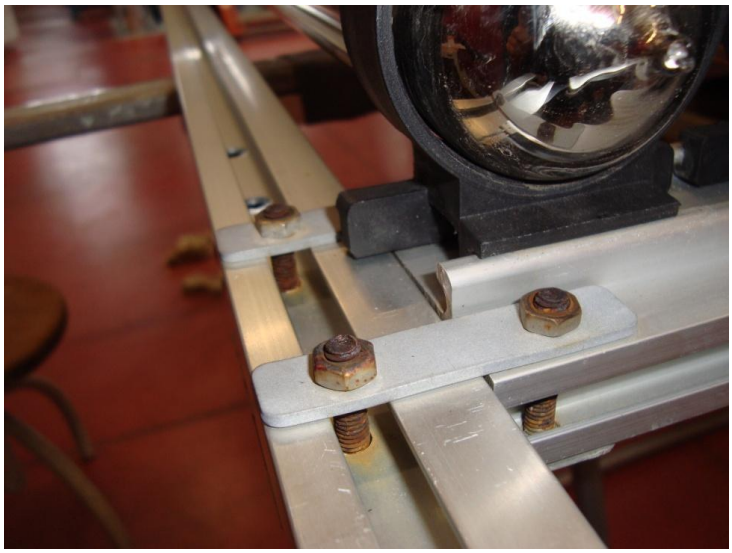


Figure 1 : corrosion in the screws supporting the collector frame

- Absorber tubes and headers :

Classification 1: 4 fins with little damage affecting contact between the U tube and the absorber tube.

Figure 2,3: Fins deformed with some points having poor contact with the absorber

Conclusion: the laboratory concluded that these damages have no impact on the thermal performance of the collector.

2nd Collector (reference LECS-3R209)

- Collector box :

Classification1:

a) Warping was observed in collector box, caused by expansion of the polyurethane.

Figure 4,5 : Problems with collector box after the long term exposure test

- Insulation :

Classification 1:

b) Colour changing and some degradation was observed in the insulation.

Figure 6 : Color changing and some degradation in the collector insulation

- Heat pipes:

Classification2:

c) From all the tubes inspected, 4 tubes contained little liquid remaining and tube n°5 contained no liquid at all, only some dirt.

d) Corrosion was observed in all copper tubes, but more evident in the beginning/end of every fin.

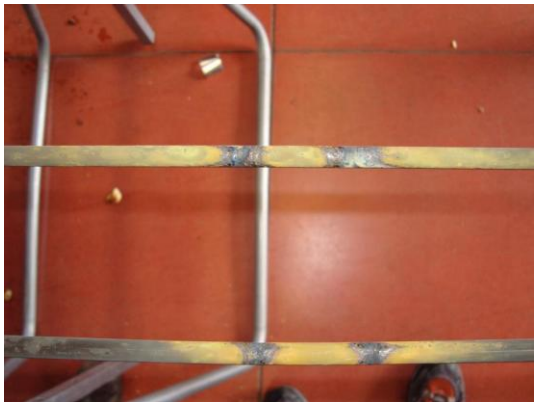


Figure 7,8 : Corrosion observed in the copper heat pipes

Classification 1:

e) Degradation in most of the fins (see figure 9). One fin showed deficient assembly on the beginning (see picture 10). In another fin, there was poor contact between the fin and copper tube (see figure 11).

Figure 9,10,11 : Problems observed with the collector fins

Conclusion: the laboratory concluded that the damage c) has a « major » impact and the damage d) has a « moderate » impact on the performance of the collector.

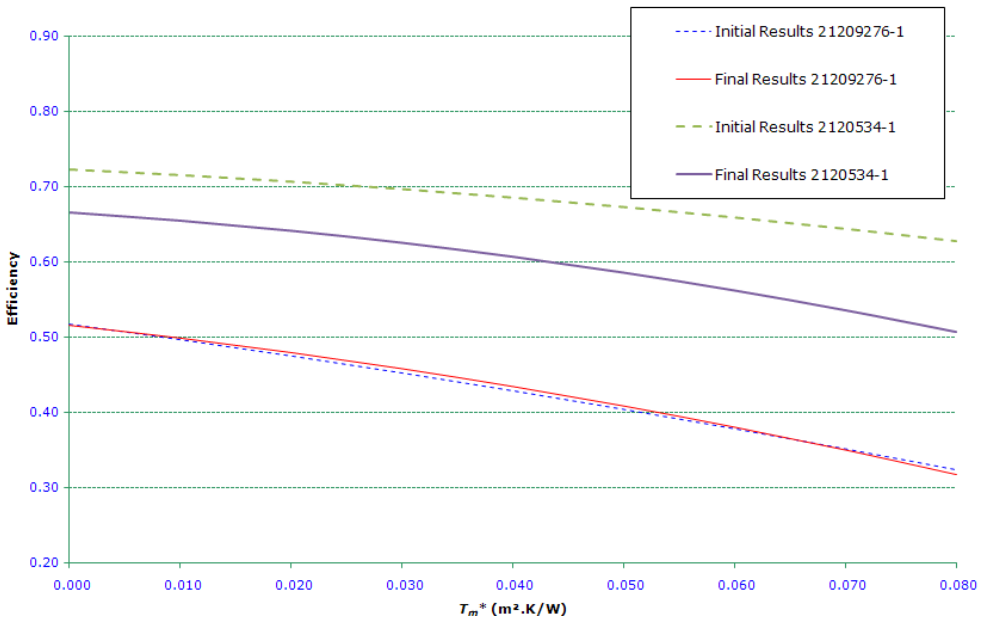
2. TÜV Rheinland

The following table summarizes the results of performance test conducted on both solar collectors:

	TÜV Rheinland					
Collector reference	21209276-1			2120534-1		
Apertur area (m²)	1.400			1.012		
Collector type	ETC Heat pipe with Sydney tube			ETC heat pipe with fins		
Test period	July 08 to sept 11			March 08 to sept 11		
	Initial Results	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**
	Outdoor Quasi-dynamic method	*Indoor Steady state method*		*Outdoor Quasi-dynamic method*	*Indoor Steady state method*	
η0	0.518	0.516	**0%**	0.723	0.666	**-8%**
a1 [W/(m²K)]	2.015	1.581		0.672	0.952	
a2 [W/(m²K²)]	0.0065	0.014	-6%	0.008	0.016	38%

	Initial Results	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**
Tm*	η	η		η	η	
0	0.518	0.516	0%	0.723	0.666	-8%
0.01	0.497	0.499	0%	0.716	0.655	-8%
0.02	0.476	0.480	1%	0.707	0.642	-9%
0.03	0.453	0.458	1%	0.697	0.626	-10%
0.04	0.429	0.435	1%	0.686	0.607	-11%
0.05	0.404	0.409	1%	0.673	0.586	-13%
0.06	0.378	0.381	1%	0.660	0.563	-15%
0.07	0.351	0.350	0%	0.645	0.537	-17%
0.08	0.324	0.318	-2%	0.628	0.508	-19%
		min	0%		min	-8%
		max	-2%		max	-19%

Comparison of performance curves before and after the exposure period:



Observations following the opening of solar collectors:

1st Collector (reference 21209276-1)

No damages observed (no final inspection because no degradation).

2nd collector (reference 2120534-1)

- Collector box / fasteners :

Classification 2 : cracking and rain penetration

Conclusion: the laboratory concluded that both damages have a « major » impact on the collector performances.

- Insulation :

Classification 1 : water retention and degradation

Conclusion: the laboratory concluded that both damages have « moderate » and « minor » impacts respectively on the collector performances.

- Heat pipe:

No liquid inspection because of toxic liquid.

3. Fraunhofer ISE

The following table summarizes the results of performance test conducted on solar collectors:

	Fraunhofer ISE								
Collector reference	U-Tube collector			Heat-Pipe-Collector 1 (with special preparation)			Heat-Pipe-Collector 2 (with special preparation)		
Apertur area (m²)	1.597			0.931			0.924		
Collector type	ETC with U-pipe direct flow			ETC heat pipe			ETC Heat pipe		
Test period	June 09 to april 11			June 09 to april 11			July 09 to april 11		
	Initial Results	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**
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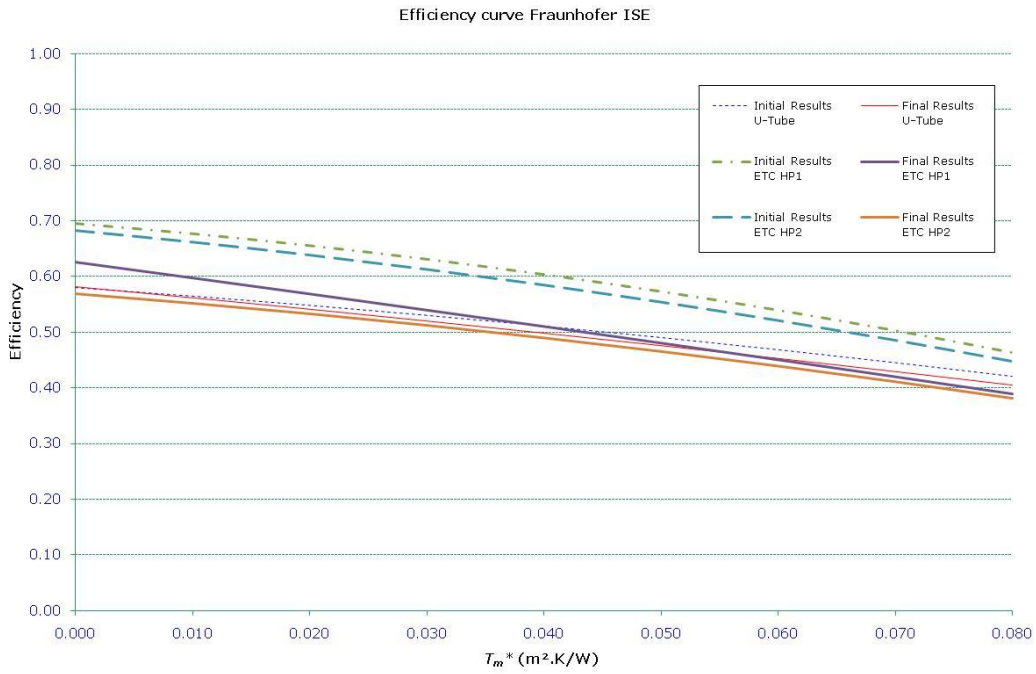
η0	0.581	0.582	**0%**	0.695	0.626	**-10%**	0.682	0.569	**-17%**
a1 [W/(m²K)]	1.464	1.953		1.674	2.81		1.95	1.611	
a2 [W/(m²K²)]	0.0084	0.0039	15%	0.019	0.0022	16%	0.0153	0.0114	-24%

	Initial Results U-Tube	**Final Results U-Tube**	**Variation**	**Initial Results ETC HP1**	**Final Results ETC HP1**	**Variation**	**Initial Results ETC HP2**	**Final Results ETC HP2**	**Variation**
Tm*	η	η		η	η		η	η	
0	0.581	0.582	0%	0.695	0.626	-10%	0.682	0.569	-17%
0.01	0.566	0.562	-1%	0.677	0.598	-12%	0.661	0.552	-17%
0.02	0.549	0.542	-1%	0.655	0.569	-13%	0.638	0.533	-16%
0.03	0.531	0.521	-2%	0.631	0.540	-14%	0.612	0.512	-16%
0.04	0.512	0.499	-3%	0.604	0.511	-15%	0.584	0.490	-16%
0.05	0.491	0.477	-3%	0.573	0.481	-16%	0.554	0.466	-16%
0.06	0.469	0.454	-3%	0.540	0.451	-16%	0.521	0.440	-16%
0.07	0.446	0.430	-3%	0.503	0.421	-16%	0.486	0.412	-15%
0.08	0.421	0.406	-4%	0.464	0.390	-16%	0.448	0.382	-15%
		min	0%		min	-10%		min	-16%
		max	-4%		max	-16%		max	-17%

Comparison of performance curves before and after the exposure period:



Observations following the opening of solar collectors:

No observation done, the exposure period has been pursued.

4. ITW

The following table summarizes the results of performance test conducted on solar collectors:

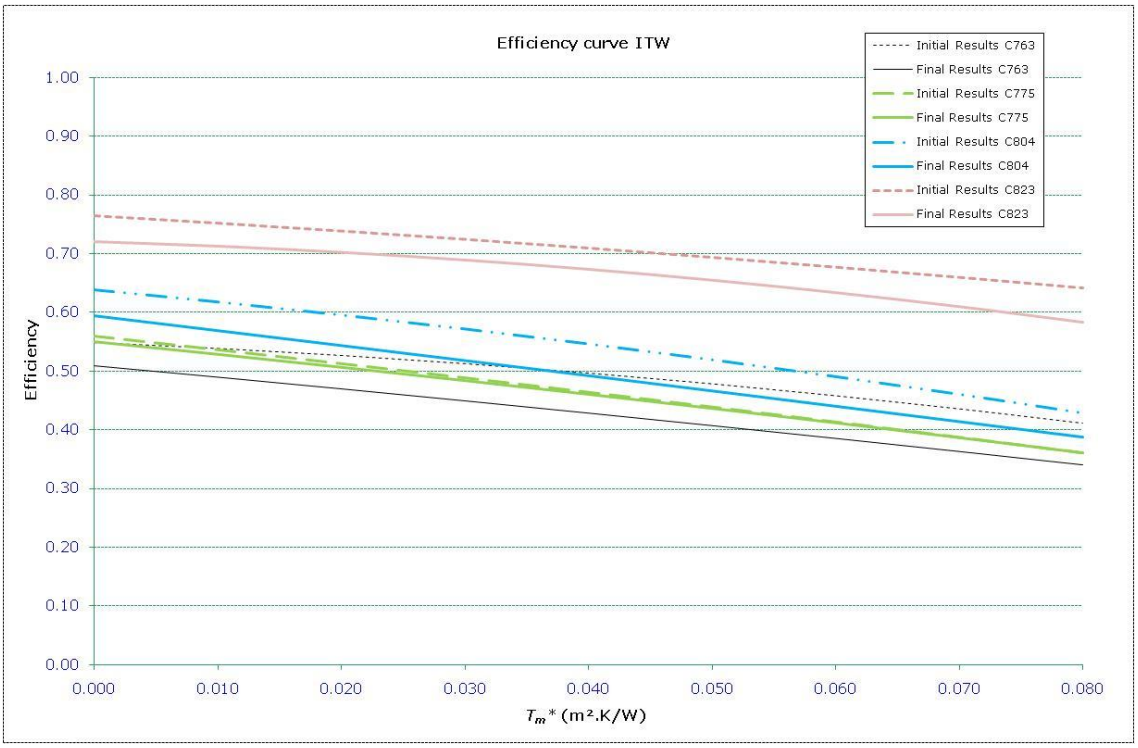
	ITW					
Collector reference	C763			C775		
Apertur area (m²)	3.710			0.950		
Collector type	ETC Heat pipe with reflector			ETC Heat pipe		
Test period	April 09 to march 11			May 09 to march 11		
	Initial Results	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**
	Outdoor Quasi-dynamic method			*Outdoor Quasi-dynamic method*		
η0	0.548	0.509	**-7%**	0.559	0.551	**-1%**
a1 [W/(m²K)]	0.869	1.923		2.275	2.125	
a2 [W/(m²K²)]	0.013	0.003	32%	0.003	0.004	-5%

	Initial Results C763	**Final Results C763**	**Variation**	**Initial Results C775**	**Final Results C775**	**Variation**
Tm*	η	η		η	η	
0	0.548	0.509	-7%	0.559	0.551	-1%
0.01	0.538	0.490	-9%	0.536	0.529	-1%
0.02	0.526	0.470	-11%	0.513	0.507	-1%
0.03	0.513	0.449	-12%	0.489	0.484	-1%
0.04	0.497	0.428	-14%	0.464	0.461	-1%
0.05	0.479	0.407	-15%	0.439	0.437	-1%
0.06	0.458	0.385	-16%	0.414	0.412	0%
0.07	0.436	0.363	-17%	0.388	0.387	0%
0.08	0.412	0.340	-18%	0.362	0.361	0%
		min	0%		min	0%
		max	-18%		max	-1%

	ITW					
Collector reference	C804			C823		
Apertur area (m²)	0.940			1.460		
Collector type	ETC Heat pipe			ETC Heat pipe		
Test period	July 09 to march 11			Sept 09 to march 11		
	Initial Results	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**
	Outdoor Quasi-dynamic method			*Outdoor Quasi-dynamic method*		
	0.638	0.594	**-7%**	0.765	0.721	**-6%**
	1.967	2.519		1.211	0.636	
	0.01	0.001	8%	0.005	0.017	-7%

	Initial Results C804	**Final Results C804**	**Variation**	**Initial Results C823**	**Final Results C823**	**Variation**
Tm*	η	η		η	η	
0	0.638	0.594	-7%	0.765	0.721	-6%
0.01	0.618	0.569	-8%	0.752	0.713	-5%
0.02	0.595	0.543	-9%	0.739	0.703	-5%
0.03	0.572	0.518	-9%	0.725	0.690	-5%
0.04	0.547	0.492	-10%	0.710	0.674	-5%
0.05	0.520	0.466	-10%	0.694	0.655	-6%
0.06	0.491	0.440	-10%	0.678	0.634	-6%
0.07	0.461	0.414	-10%	0.661	0.610	-8%
0.08	0.429	0.387	-10%	0.643	0.583	-9%
		min	-7%		min	-5%
		max	-10%		max	-9%

Comparison of performance curves before and after the exposure period:



Observations following the opening of solar collectors:

Only the collector C823 has been opened for observation, the laboratory wanted to extend the exposure period of the others.

- Collector box / fasteners :

Classification 1 : corrosion

Conclusion: the laboratory concluded that the damage has no impact on performances and the impact was considered like « minor ».

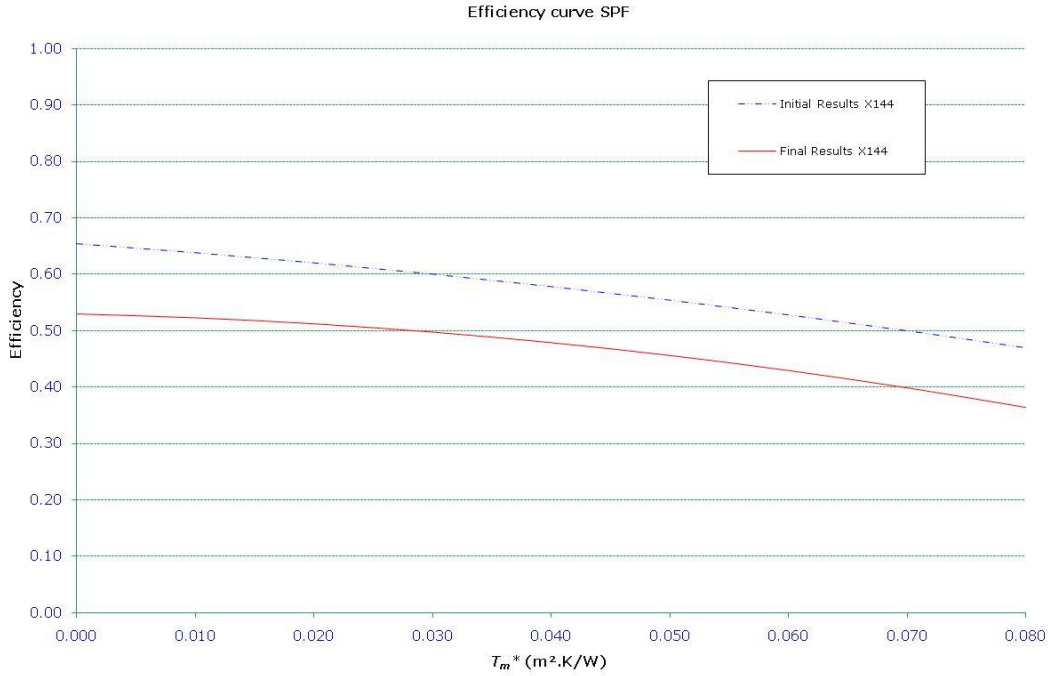
5. SPF

The following table summarizes the results of performance test conducted on the solar collector:

	SPF		
Collector reference	X144		
Apertur area (m²)	1.885		
Collector type	ETC heat pipe		
Test period	Nov 09 to aug 11		
	Initial Results	**Final Results**	**Variation**
	Indoor Steady state method		
η0	0.654	0.529	**-19%**
a1 [W/(m²K)]	1.48	0.47	
a2 [W/(m²K²)]	0.0127	0.0249	-36%

	Initial Results X144	**Final Results X144**	**Variation**
Tm*	η	η	
0	0.654	0.529	-19%
0.01	0.638	0.522	-18%
0.02	0.620	0.512	-18%
0.03	0.600	0.497	-17%
0.04	0.579	0.478	-17%
0.05	0.555	0.456	-18%
0.06	0.529	0.429	-19%
0.07	0.501	0.398	-20%
0.08	0.471	0.364	-23%
		min	-17%
		max	-23%

Comparison of performance curves before and after the exposure period:



Observations following the opening of solar collectors:

- Collector box / fasteners:

Classification 0 (but with remark): rain penetration

It was known that the side covers are not water tight. To prevent from influencing the test because of a known problem, the side caps were sealed by SPF before starting the one year test.

Figure 12: view of side cap sealed

- Absorber coating :

Classification 2: blistering

Conclusion: the laboratory concluded that the damage has a « major » impact on the collector performances.

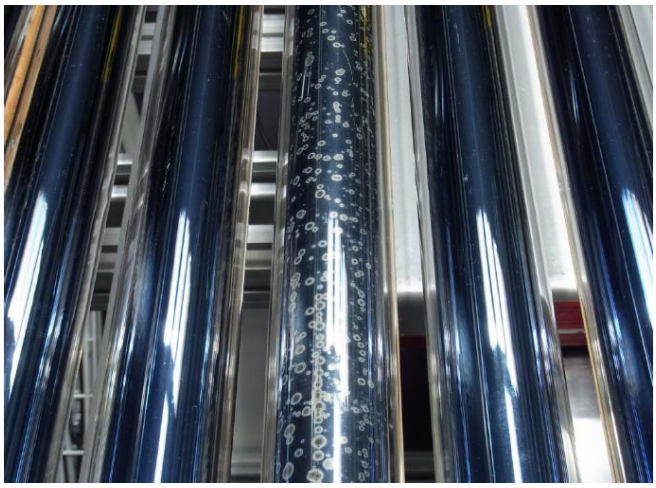


Figure 13: view of the damaged tube #4

- Insulation:

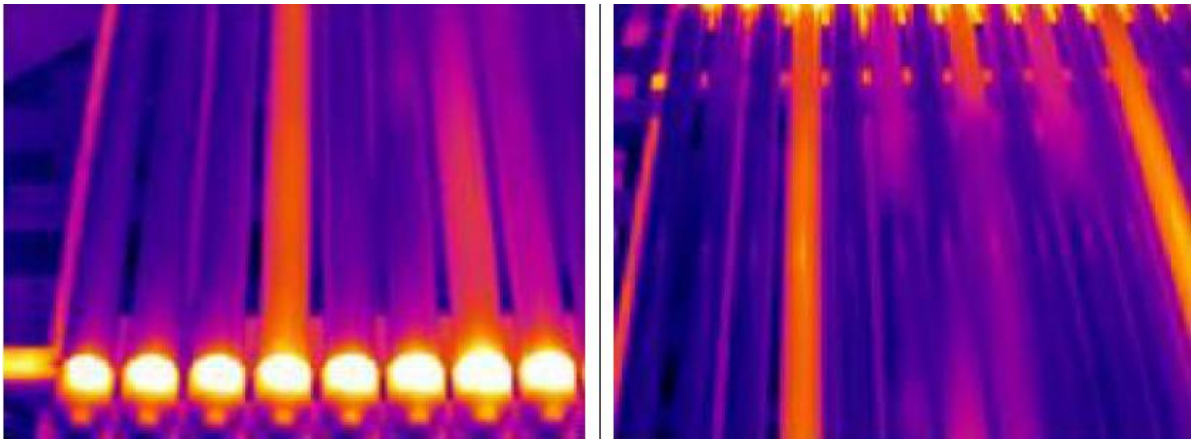
Classification 1: water retention and color changing.

Same remark as before.

- Vacuum tubes:

Classification 2: Vacuum losses and colour changing

On tube #4 the vacuum loss is obvious (getter / absorber coating). Tube #12 looks ok, but the IR photo reveals a vacuum problem (see infrared pictures).



Vacuum loss on tube #4 Hotter tube (vacuum ?) on #7	Vacuum loss on tube #4 and #12 Hotter tube (vacuum ?) on #6 #8 #10

Figure 14,15: infrared pictures

Conclusion: the laboratory concluded that both damages have « major » impacts on the collector performances.

- Heat pipes:

Classification 2: liquid losses

Classification 1: corrosion

Conclusion: the laboratory concluded that both damages have « major » and « minor » impacts respectively.

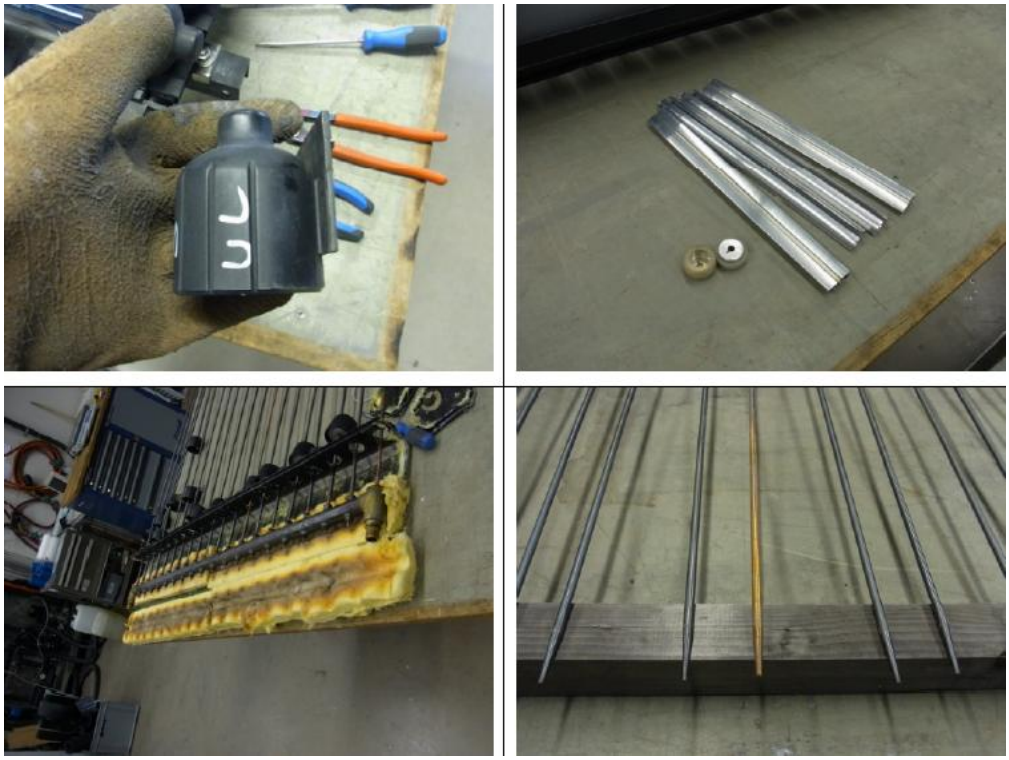


Figure 16-19: global view of components

All the components parts look surprisingly ok. No signs of severe degradation are visible. Interesting to see that all heat pipes and all the copper pipe work has been blackened. Exception: heat pipe of tube #8.

One of 20 heat pipes was empty. The others all had about the same liquid content. As we don't know the liquid content of the new heat pipes a rating of the other heat pipes would not be adequate.

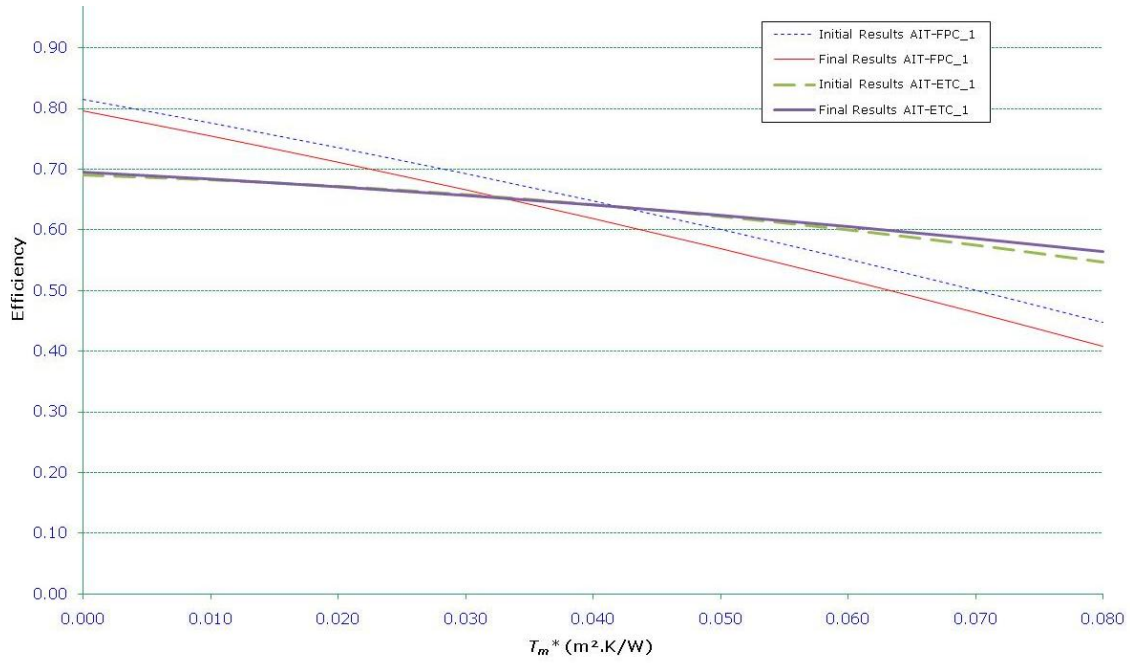
6. AIT

The following table summarizes the results of performance test conducted on both solar collectors:

	AIT					
Collector reference	AIT-FPC_1			AIT-ETC_1		
Apertur area (m²)	1.840			1.285		
Collector type	FPC			ETC directflow		
Test period	March 10 to march 11			May 10 to May 2011		
	Initial Results	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**
	Indoor Steady state method			*Outdoor Steady state method*		
η0	0.815	0.796	**-2%**	0.691	0.695	**1%**
a1 [W/(m²K)]	3.768	4.014		0.641	1.058	
a2 [W/(m²K²)]	0.013	0.013	5%	0.018	0.009	4%

	Initial Results AIT-FPC_1	**Final Results AIT-FPC_1**	**Variation**	**Initial Results AIT-ETC_1**	**Final Results AIT-ETC_1**	**Variation**
Tm*	η	η		η	η	
0	0.815	0.796	-2%	0.691	0.695	1%
0.01	0.776	0.755	-3%	0.683	0.684	0%
0.02	0.735	0.712	-3%	0.672	0.671	0%
0.03	0.693	0.666	-4%	0.659	0.657	0%
0.04	0.648	0.619	-4%	0.642	0.641	0%
0.05	0.601	0.569	-5%	0.623	0.624	0%
0.06	0.551	0.518	-6%	0.601	0.606	1%
0.07	0.500	0.464	-7%	0.576	0.586	2%
0.08	0.447	0.408	-9%	0.548	0.564	3%
		min	-2%		min	0%
		max	-9%		max	3%

Comparison of performance curves before and after the exposure period:



Observations following the opening of solar collectors:

1st collector (reference AIT-FPC_1)

There have been done only a visual inspection of the collector because it has been exposed a second year.

- Cover / reflector:

Classification 1: tearing

Some optical visible residues of water tears on the inner side of the cover caused by condensation.

Conclusion: the laboratory concluded that the damage has a « moderate » impact on the collector performances.

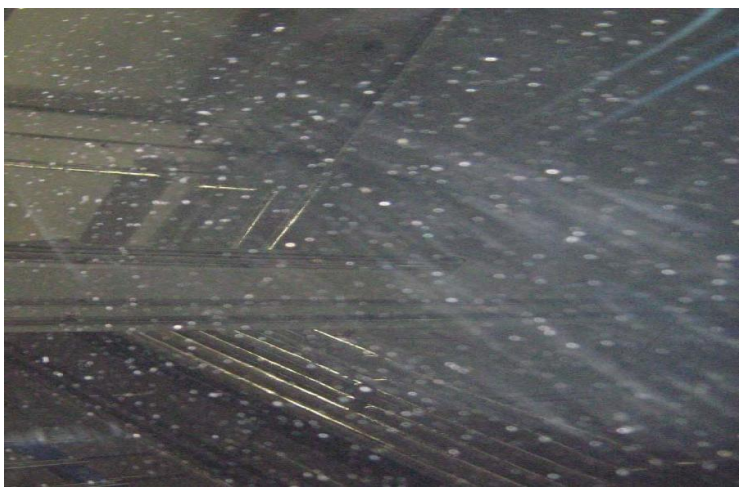


Figure 20: view of the dusting on the absorber sheet

- Absorber coating :

Classification 1: dusting

Some areas of the absorber have been dusted with the particles of the insulation.

Conclusion: the laboratory concluded that the damage has a « moderate » impact on the collector performances.

Figure 21: view of the water tear residues at the inner side of the cover

2nd collector (reference AIT-ETC_1)

There have been done only a visual inspection of the collector because the collector has been exposed a second year. No problem observed.

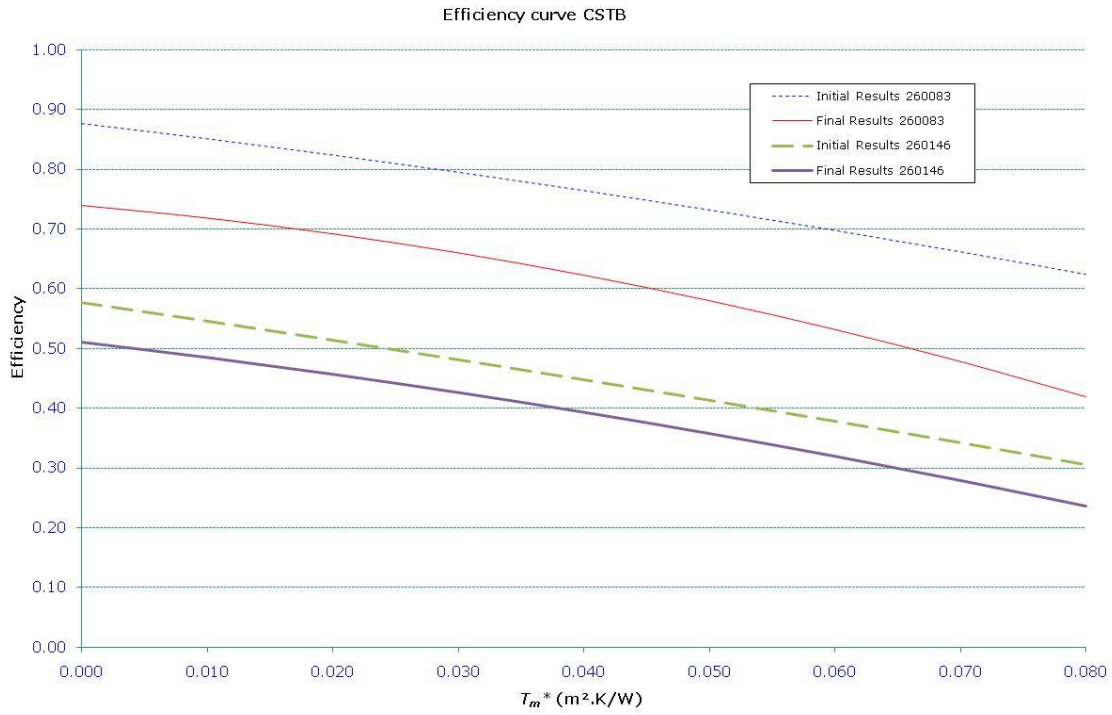
7. CSTB

The following table summarizes the results of performance test conducted on both solar collectors:

	CSTB					
Collector reference	260083			260146		
Apertur area (m²)	1.086			1.881		
Collector type	ETC Heat pipe			ETC Heat pipe		
Test period	nov 07 to aug 09			April 09 to sept 11		
	Initial Results	**Final Results**	**Variation**	**Initial Results**	**Final Results**	**Variation**
	Oudoor Steady state method			*Outdoor Steady state method*		
η0	0.877	0.74	**-16%**	0.577	0.511	**-11%**
a1 [W/(m²K)]	2.461	1.825		3.055	2.438	
a2 [W/(m²K²)]	0.011	0.034	9%	0.0051	0.0156	-6%

	Initial Results 260083	**Final Results 260083**	**Variation**	**Initial Results 260146**	**Final Results 260146**	**Variation**
Tm*	η	η		η	η	
0	0.877	0.740	-16%	0.577	0.511	-11%
0.01	0.852	0.719	-16%	0.546	0.485	-11%
0.02	0.824	0.693	-16%	0.514	0.457	-11%
0.03	0.795	0.661	-17%	0.482	0.427	-11%
0.04	0.764	0.623	-18%	0.448	0.394	-12%
0.05	0.732	0.581	-21%	0.414	0.358	-14%
0.06	0.698	0.533	-24%	0.379	0.320	-16%
0.07	0.662	0.479	-28%	0.343	0.279	-19%
0.08	0.624	0.420	-33%	0.306	0.236	-23%
		min	-16%		min	-11%
		max	-33%		max	23%

Comparison of performance curves before and after the exposure period:



Observations following the opening of solar collectors:

1st Collector (260083)

- Seals / gaskets :

Classification 2 : cracking

Five gaskets on 10, between heat pipes and collector box are stiffened and broken.

Conclusion: the laboratory concluded that the damage has a « major » impact on the collector performances.

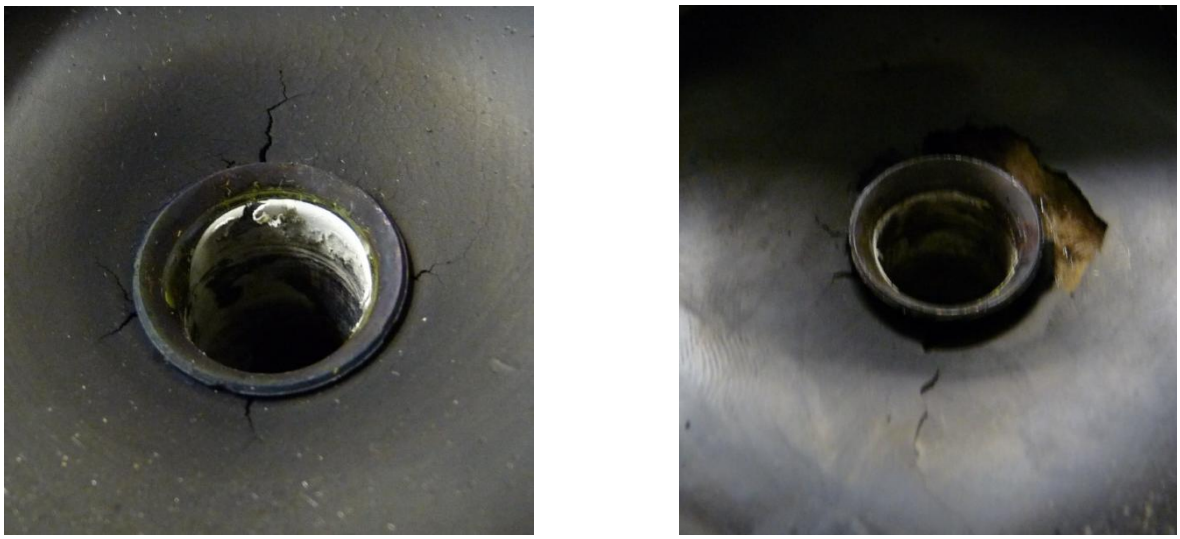


Figure 22, 23: broken gaskets view

- Absorber coating :

Classification 1: one little detachment on surface

Conclusion: the laboratory concluded that the damage has a « minor » impact on the collector performances.

Figure 24: absorber coating damage

- Heat pipes :

Classification 2: the 10 heat pipes still contained fluid after opening. However, three of them contain a tiny quantity.

Figure 25: view of heat pipe opened

Conclusion: the laboratory concluded that the damage has a « major » impact on the collector performances.

2nd Collector (260146)

- Collector box / fasteners: cracking.

Classification 2: breakage of 5 frame gaskets of 20.

Figure 26: view of cracked gasket

Conclusion: the laboratory concluded that the damage has a « major » impact on the collector performances.

- Mountings / structure:

Classification 1: discoloration of vacuum tubes gaskets

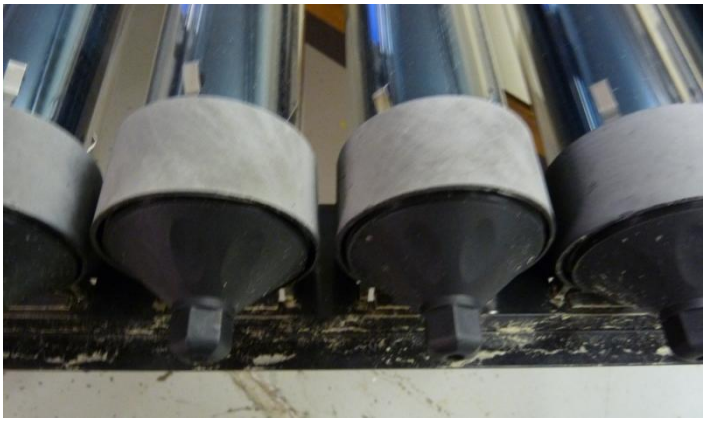


Figure 27: discoloration of vacuum tubes gaskets

- Vacuum tubes: colour changes

Classification 2: white deposit on the inner glass tube

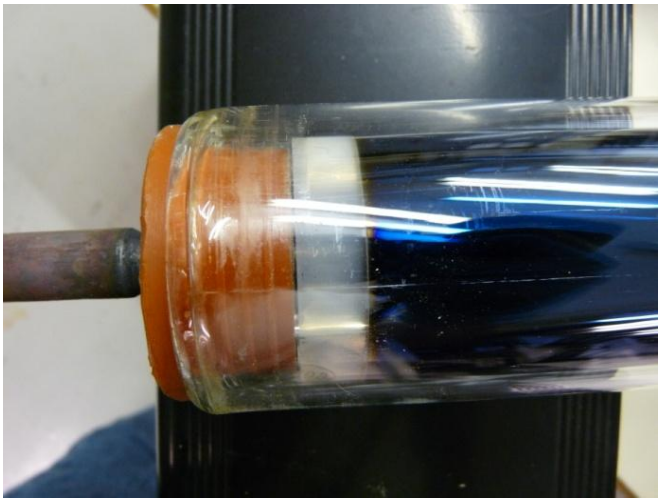


Figure 28: whitish deposit on the tube

Conclusion: the laboratory concluded that the damage has a « major » impact on the collector performances.

- Heat pipes : colour changes

Classification 1: one of the 20 tubes hasn't blackened. The 20 tubes have liquid inside but with 3 different colours:

- 9 tubes have yellowish liquid
- 6 tubes have blackish liquid
- 5 tubes have translucent liquid

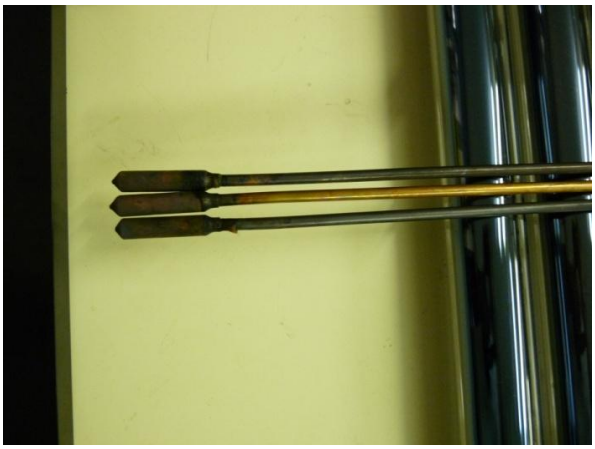


Figure 29: heat pipes view

Conclusion: the laboratory concluded that the observation has a « minor » impact on the collector performances.

8. ISFH

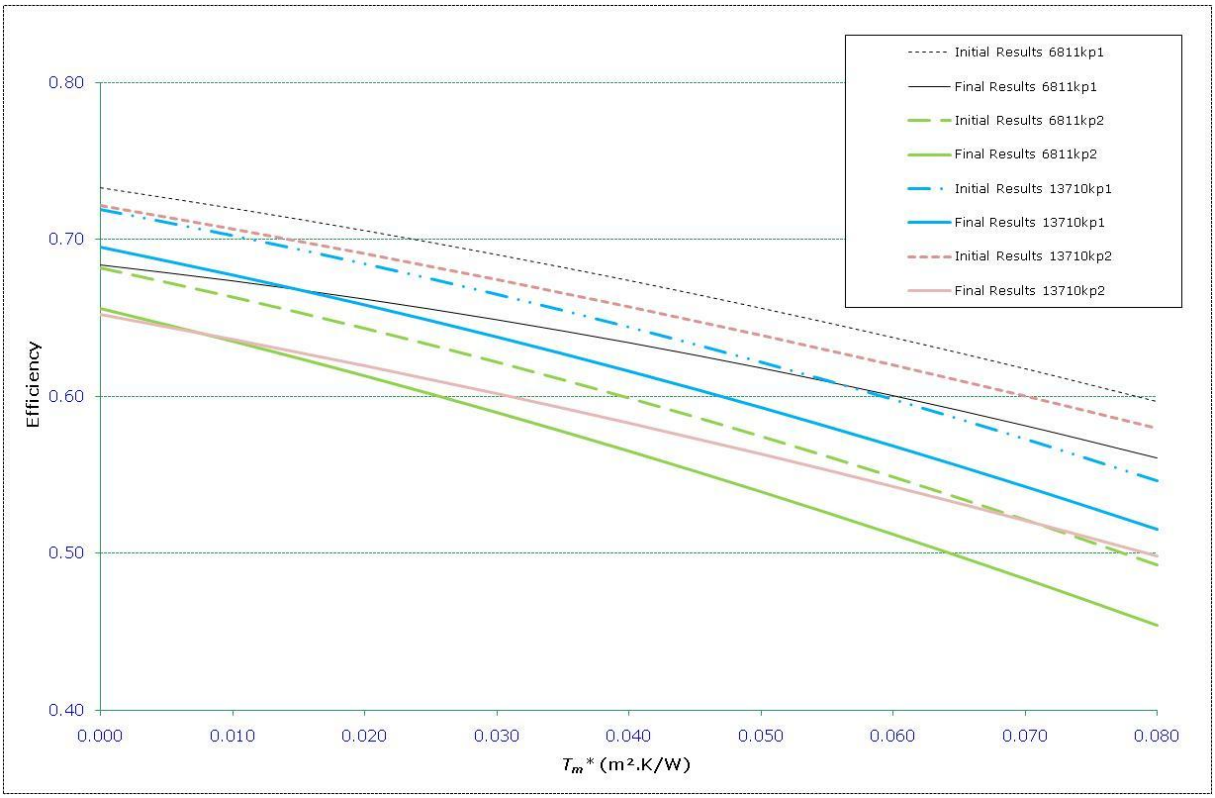
The following tables summarize the results of the performance tests conducted.

Reference	6811kp1			6811kp2		
Aperture area (m²)	2.134			1.399		
Collector type	ETC heat pipe			ETC heat pipe		
Test period	May to Nov 11			June to Nov 11		
	Initial results	**Final results**	**Variation**	**Initial results**	**Final results**	**Variation**
	Indoor steady state method			*Indoor steady state method*		
η0	0.733	0.684	-7%	0.682	0.656	-4%
a1 [W/(m²K)]	1.25	0.94		1.78	2.02	
a2 [W/(m²K²)]	0.0071	0.0094	-14%	0.0092	0.0079	+9%
	Initial results	**Final results**	**Variation**	**Initial results**	**Final results**	**Variation**
Tm*	η	η		η	η	
0	0.733	0.684	-7%	0.682	0.656	-4%
0.01	0.720	0.674	-6%	0.663	0.635	-4%
0.02	0.706	0.662	-6%	0.643	0.613	-5%
0.03	0.690	0.649	-6%	0.622	0.590	-5%
0.04	0.674	0.634	-6%	0.599	0.565	-6%
0.05	0.656	0.618	-6%	0.575	0.539	-6%
0.06	0.638	0.601	-6%	0.549	0.512	-7%
0.07	0.618	0.581	-6%	0.521	0.484	-7%
0.08	0.597	0.561	-6%	0.492	0.454	-8%
		min	-6%		min	-4%
		max	-7%		max	-8%

Note : the variation of the loss coefficients is calculated with 40 K temperature difference (variation of a1 + 40a2)

Reference	13710kp1			13710kp2		
Aperture area (m²)	2.147			1.387		
Collector type	ETC heat pipe			ETC heat pipe		
Test period	Jul 10 to Aug 11			Jul 10 to Aug 11		
	Initial results	**Final results**	**Variation**	**Initial results**	**Final results**	**Variation**
	Indoor steady state method			*Indoor steady state method*		
η0	0.719	0.695	-3%	0.722	0.652	-10%
a1 [W/(m²K)]	1.58	1.7		1.45	1.53	
a2 [W/(m²K²)]	0.009	0.0085	+5%	0.0051	0.0061	+7%
	Initial results	**Final results**	**Variation**	**Initial results**	**Final results**	**Variation**
Tm*	η	η		η	η	
0	0.719	0.695	-3%	0.722	0.652	-10%
0.01	0.702	0.677	-4%	0.707	0.636	-10%
0.02	0.685	0.658	-4%	0.691	0.619	-10%
0.03	0.665	0.638	-4%	0.675	0.602	-11%
0.04	0.644	0.616	-4%	0.657	0.583	-11%
0.05	0.622	0.593	-5%	0.639	0.563	-12%
0.06	0.598	0.569	-5%	0.620	0.543	-13%
0.07	0.573	0.543	-5%	0.601	0.521	-13%
0.08	0.547	0.515	-6%	0.580	0.498	-14%
		min	-3%		min	-10%
		max	-6%		max	-14%

Comparison of performance curves before and after the exposure period:


Initial Results 6811kp1
Final Results 6811kp1
Initial Results 6811kp2
Final Results 6811kp2
Initial Results 13710kp1
Final Results 13710kp1
Initial Results 13710kp2
Final Results 13710kp2
0.80
0.70
0.60
0.50
0.40
Efficiency
0.000
0.010
0.020
0.030
0.040
0.050
0.060
0.070
0.080
T_m* (m².K/W)

Observations following the opening of solar collectors:

1st Collector (reference 6811kp1)

No degradation was seen except the heat transfer paste on top of condenser dried out. This degradation is confirmed by the results of two additional tests performed after the final test:

	η_0	$a_1 + 40a_2$ (W/m²)
Initial test	0.733	1.534
Final test	0.684	1.316
Final test new paste	0.719	1.464
Final test no paste	0.686	1.72

Picture 30) Dried out heat transfer paste on top of condenser (after one year exposure before renewing paste)

2nd Collector (reference 6811kp2)

No degradation was seen but may be the heat transfer paste between condenser and manifold has deteriorated if one looks at the results of an additional test performed after the final test:

	η_0	$a_1 + 40a_2$ (W/m²)
Initial test	0.682	2.148
Final test	0.656	2.336
Final test new paste	0.669	2.34

3rd Collector (reference 13710kp1)

- Absorber tubes and headers:

Classification 1: Traces of corrosion on condenser heatpipe outside evacuation

- Insulation :

Classification 1: colour changing

- In addition the heat transfer paste appears dried (see pictures 33 and 34)

Picture 31) Traces of corrosion on condenser heatpipe outside evacuation

Picture 32) Insulation at the heatpipe in manifold casing

Picture 33) Fragments of heat transfer paste in manifold casing (after 30 days exposure)

Picture 34) Dried out heat transfer paste on aluminium tube at condenser (after one year exposure before renewing paste)

The degradation of the heat transfer paste is confirmed by the results of an additional test performed after the final test:

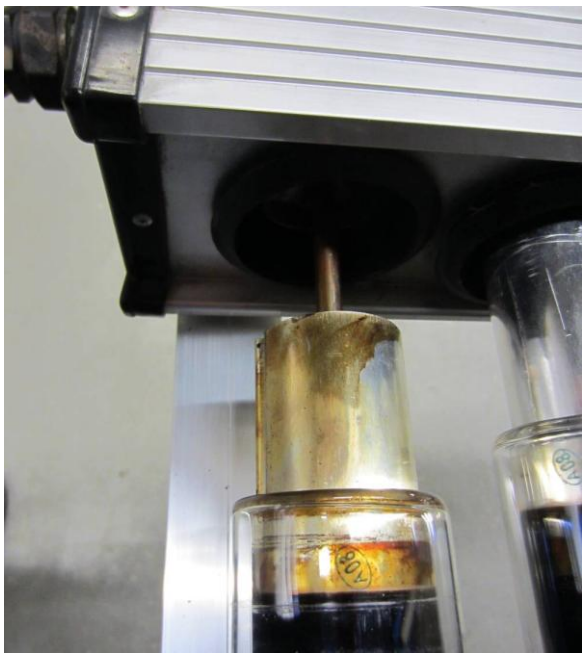
	η_0	$a_1 + 40a_2$ (W/m²)
Initial test	0.719	1.654
Final test	0.695	1.774
Final test new paste	0.706	1.798

4th Collector (reference 13710kp2)

- Gaskets: Classification 1 – loss of elasticity

Picture 35) gaskets at upper dewar tube end

- Heat pipes: Classification 1 - Traces of corrosion on condenser



Picture 36) heat conductors and glass tube after exposure

- Insulation : Classification 1 – Colour changing

Picture 37) clam-shell insulation of manifold at final inspection

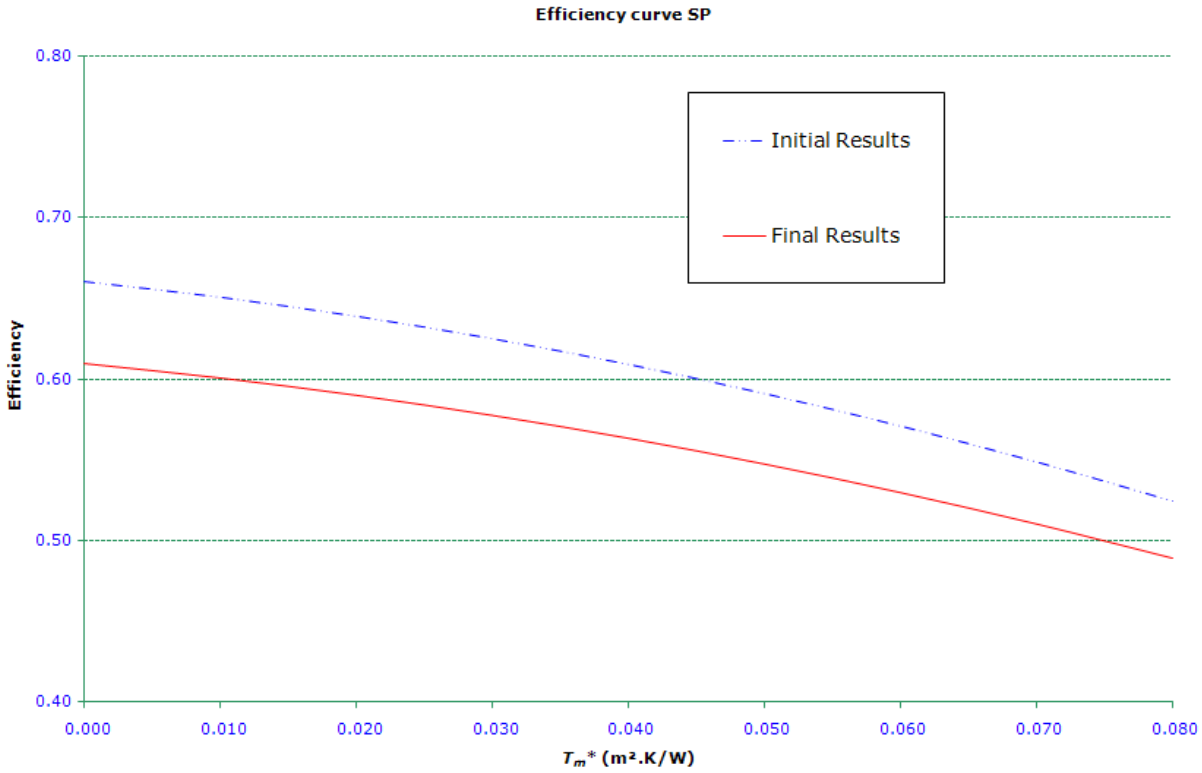
5. SP

The following table summarizes the results of performance test conducted on the solar collector:

	SP		
Collector reference	SP		
Apertur area (m²)	1.96		
Collector type	ETC heat pipe		
Test period	Oct 2010 to Feb 2012		
	Initial Results	**Final Results**	**Variation**
	Outdoor Quasi-dynamic method		
η0	0.66	0.61	**-8%**
a1 [W/(m²K)]	0.86	0.81	
a2 [W/(m²K²)]	0.013	0.011	-10%

	Initial Results	**Final Results**	**Variation**
Tm*	η	η	
0	0.660	0.610	-8%
0.01	0.650	0.601	-8%
0.02	0.639	0.590	-8%
0.03	0.625	0.578	-8%
0.04	0.609	0.564	-7%
0.05	0.591	0.548	-7%
0.06	0.571	0.530	-7%
0.07	0.549	0.510	-7%
0.08	0.525	0.489	-7%
		min	-17%
		max	-8%

Comparison of performance curves before and after the exposure period:



Observations following the opening of solar collectors:

- Collector box / fasteners: Classification 0 no problem
- Mountings/structure: Classification 0 no problem
- Seals/gaskets: Classification 0 no problem
- Cover/reflector: Classification 0 no problem
- Absorber coating: Classification 0 no problem
- Absorber tubes and headers: Classification 0 no problem
- Absorber mountings: Classification 0 no problem
- Vacuum tube: Classification 0 no problem
- Heat pipes: : Classification 0 no problem (but liquid losses were not inspected)
- The heat transfer paste was dried out when opening the collector. This has probably affected the thermal performance, but it is not possible to determine at what extent. Therefore it would be out of interest to perform further measurements on several collectors with old and aged heat transfer paste to determine its affect on the thermal performance.

3 – SYNTHESIS

The summary of results is shown below:

Reference	type[1]	variation of η_0	variation of $a_1 + 40a_2$	observed degradations
LECS-1R09	df	+1 %	+18 %	minor : fins deformed
LECS-3R209	hp	-17 %	-14 %	major : fluid loss in hp, corrosion of hp minor : fins deformed, colour changing and some degradation in the insulation
21210534(H)	hp	0 %	-6 %	major: cracking and rain penetration in collector box minor: water retention and degradation of insulation
21209267(P)	hp	-8 %	+38 %	no damages observed
U-tube coll	df	0 %	+15 %	no observation done
HP coll1	hp	-10 %	+16 %	no observation done
HP coll2	hp	-17 %	-24 %	no observation done
C763	hp	-7 %	+32 %	no observation done
C775	hp	-1 %	-15 %	no observation done
C804	hp	-7 %	+8 %	no observation done
C823	hp	-6 %	-7 %	minor: corrosion (collector box and fasteners)
X144	hp	-19 %	-36 %	major: blistering on absorber coating, vacuum losses, liquid losses minor: water retention and colour changing of insulation, corrosion of heat pipes
FPC1	fp	-2 %	+5 %	minor: residues of water tears on the inner side of the cover, dust on absorber
ETC1	df	+1 %	+4 %	no damages observed (only visual inspection)
206083	hp	-16 %	+9 %	major: gaskets between heat pipes and collector box stiffened and broken, fluid losses minor: little detachment on absorber surface
260146	hp	-11 %	-6 %	major: gaskets between heat pipes and collector box broken, white deposit on the inner glass tube minor: colour change of fluid
6811kp1	hp	-7 %	-14 %	no damage observed but probable degradation of heat transfer paste between condenser and manifold
6811kp2	hp	-4 %	+9 %	no damage observed but probable degradation of heat transfer paste between condenser and manifold
13710kp1	hp	-3 %	+5 %	minor: colour changing of insulation , traces of

[1] df : ETC with direc flow, hp : ETC with heat pipe, fp : flat plate collector

				corrosion on condenser heat pipe degradation of heat transfer paste
13710kp2	hp	-10 %	+7 %	minor: loss of elasticity of gaskets, traces of corrosion on condenser, colour changing of insulation
SP	hp	-8 %	-10%	no damage observed but probable degradation of heat transfer paste

Changes in η_0 range from +1% to -19% while change in the loss coefficient (a_1 + $40a_2$) ranging from -36% to +38%.

On the 21 tested collectors, the study showed that differences in thermal performance between the initial and final states could be between +1 % to -33 % over the range of Tm* ranging from 0 to 0.08 with an average of -9 % for Tm* = 0.04.

Among the 21 tested collectors, 17 are ETC with heat pipes. This gives an overview of how age collectors of this kind.

Effects of collector degradations

A variety of degradations are observed, whose effects on performance are different from each other. Some damages affect the zero-loss efficiency, to decrease it, others affect losses, for increasing them or in some cases for decreasing them.

The main degradations, especially those found as "major impact" are listed in the following table:

	decrease of zero-loss efficiency	**increase of losses**	**decrease of losses**
damages on collector box (corrosion, cracks…) degradation of insulation		x	
absorber degradation , corrosion, blistering	x	?	
vacuum loss		x	
heat pipe degradation (fluid degradation or fluid loss)	x		x
degradation of gaskets between heat pipes and collector box	x	?	?
degradation of heat transfer paste between condenser and manifold	x	?	?

Duration of an ageing test

The used test procedure does not include an intermediate check after current exposure test procedure with 30 valid exposure days. So we don't know whether the degradations occur during this first period or after.

One laboratory has done interim tests after the regular existing outdoor exposure. The results were intermediate between initial and final tests, suggesting that the degradations begin during this first period.

Furthermore, it should be pointed out, that one year of dry stagnation is no common use and may result in too strong thermal stress and damages.

Then we cannot conclude on the need to enlarge the exposure period. But for sure, especially for heat pipe collectors a post exposure thermal performance test will be strongly suggested.

4 – CONCLUSION

The exposure period of one year is a severe ageing test which cause adverse effects on several solar collectors, especially evacuated tube collectors with heat pipes.

On the 21 tested collectors, the study showed that differences in efficiency between the initial and final states could be between +1 % to -33 % over the range of Tm* ranging from 0 to 0.08 with an average of -9 % for Tm* = 0.04.

On the evacuated tube collectors with heat pipes, a variety of degradation are observed, whose effects on performance are different from each other. Some damages affect the zero-loss efficiency, to decrease it, others affect losses, for increasing them or in some cases for decreasing them.

These results do not demonstrate the need to enlarge the standard exposure period. It is possible that the major degradation may also be detected after regular exposure time. Furthermore, it should be pointed out, that one year of dry stagnation is no common use and may result in too strong thermal stress and damages.

However we really need to think about a post exposure performance test at least for heat pipe collectors.

ANNEXES

1. One year outdoor exposure test procedure
2. One year outdoor exposure test report sheet

1. One year outdoor exposure test procedure –V02/BK

1.11 INTRODUCTION

At the 15th meeting of CEN/TC 312/WG 1 on 2nd and 3rd of September 2009, It was agreed that different European laboratories will perform a one year exposure tests with performance measurements before and after exposure in order to gain more experience on this subject (Item 8 of 2009-11-06 Minute).

Consequently, would you please find this procedure which is a synthesis of the mains points to follow.

1.12 TEST METHOD

This test will be done in 4 successive steps:

1 - Initial thermal performance test:

Realize an initial performance test and determine the efficiency parameters of the collector (a_1, a_2, η_0 according 12975-2 requirements).

Fill in the report sheet.

2 – One year outdoor exposure period

The collector shall be mounted outdoor in a mounting system with a tilt angle equal to the latitude of the site, and shall not be filled with fluid. All of the fluid pipes except one shall be sealed to prevent cooling by natural convection.

Meteorological measurement:

For the labs which have the possibility to measure the climatic conditions, the cumulated values of monthly solar irradiance and the monthly values of average outside air temperature shall be measured and recorded during the exposure test period.

Visual following (optional?):

Each month (or other frequency), a visual control of the collector shall be done (with notes, observations and photos reported in the report sheet).

3 - Final thermal performance test:

Realize a final performance test and determine the efficiency parameters of the collector (a_1, a_2, η_0 according 12975-2 requirements).

Fill in the report sheet.

This test has to be done with the same tests conditions than the initial one (flow rate, wind speed, kind of fluid…).

4 – Opening the collector, final inspection and classification:

A global visual inspection shall be made before opening the collector.

After opening, inspection shall be conducted according to B.5.5 of 12975-2:2006.

A full description and evaluation shall be given if any observed problems or failures (minor and major failures) have occurred, as defined in 5.3.1 of EN 12975-1:2006.

For each observation, appropriate photographs have to be taken.

Fill in the report sheet.

The particularity of the table is to classify the observed failures, and to assess their impacts on the collector performance. Concerning the types of the failures observed (cracking, corrosion…), please feel free to add others if necessary.

For ETC collectors, a particular attention has to be paid to :

- the glass tubes

- the copper pipes (heat pipes : each one has to be open to verify if liquid loss has occurred and a comparison for all of them shall be done)

- the gaskets

- the insulation...

1.13 REPORTING RESULTS

The results shall be reported in the report sheet during and after the completion of the test and it will be sent to Bouzid Khebchache (bouzid.khebchache@cstb.fr) for synthesis.

Bouzid will extract the results from the report sheet and prepare a synthesis report with all results (observations, classifications, efficiency comparison curves between initial and final test…) that will be discussed by a future meeting.

2. ONE YEAR OUTDOOR EXPOSURE TEST REPORT SHEET - V02/BK

Test performed by:
Date:

1 - COLLECTOR DESCRIPTION (according EN 12975-2 Annex D)

Name of Manufacturer:
Brand Name:
Type name:
Serial N°:

1.1 Solar collector description:

Collector type:
Flate plate collector:
ETC heatpipe: with reflector (Yes/No):
ETC directflow: with reflector (Yes/No):
Year of production:
Flow range: to kg/s
Operating pressure: kPa
Stagnation temperature: °C

1.2 Collector:

Size:
Aperture area and standard uncertainty: ..... ± ..... m²
Absorber area and standard uncertainty: ..... ± ..... m²
Cover:
Number of cover:
Cover materials:
Cover thickness:
Number of tubes (ETC):
Length of tubes (ETC):
Outer diameter of cover tubes:
Absorber
Material of the absorber sheet:
Material of the absorber pipes:
Layout of the absorber pipes:
Surface treatment:
Construction type (soldering or welded):
Dimensions:
Thermal insulation and casing:
Thermal insulation thickness (back and side):
Insulation material (back and side):
Casing material:
Sealing material:

Limitations:

2 - TEST RESULTS

2.1 Test conditions:

Type of heat transfer fluid:
Fluid flowrate used for the tests:
Orientation of absorber tubes during testing (horizontal or vertical):
Precise the tilt angle of the collector during the exposure period:

(Please insert picture of the collector during initial test)

2.2 Test period:

1 - Initial thermal performance test (period):
2 - One year outdoor exposure test (period):
3 - Final thermal performance test (period):

2.3 Determination of the collector efficiency parameters by:

☐ Indoor Steady state method

☐ Outdoor Steady state method

☐ Outdoor Quasi-dynamic method

2.4 Parameter identification and standard uncertainties (reference: aperture area A_a):

	η_0 [-]	$u(\eta_0)$ [-]	a_1 [(m²K)/W]	$u(a_1)$ [(m²K)/W]	a_2 [(m²K²)/W]	$u(a_2)$ [(m²K²)/W]
Initial test		±		±		±
Final test		±		±		±

2.5 Measured values:

Initial thermal performance test

	G	$\dot{m}$	t_{in}	t_e	t_e-t_{in}	t_m	t_a	t_m-t_a	$(t_m$-$t_a)/G$	**η***
Nr	[W/m²]	[kg/h]	[°C]	[°C]	[K]	[°C]	[°C]	[K]	[(m²K)/W]	[ ]

**: Aperture area*

Final thermal performance test:

	G	$\dot{m}$	t_{in}	t_e	t_e-t_{in}	t_m	t_a	t_m-t_a	$(t_m$-$t_a)/G$	η*
Nr	[W/m²]	[kg/h]	[°C]	[°C]	[K]	[°C]	[°C]	[K]	[(m²K)/W]	[ ]

*: Aperture area

Meteorological measurements:

For the labs which have the possibility to measure the climatic conditions, the cumulated values of monthly solar irradiance and the monthly values of average outside air temperature shall be measured and recorded during the exposure test period.

Monthly values	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
H (kWh/m²)*												
ta (°C)												

*(precise if horizontal or on collector plane)

3 - FINAL VISUAL INSPECTION AND CLASSIFICATION

The table below shall be filled in.

Please indicate for each observed failure the reference number of the picture taken.

Collector component	**Potential problem Evaluation**							**See picture n°**
	Observed Failures							
1 Collector box/fasteners	cracking	warping	corrosion	rain penetration				
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								
Major Moderate Minor								
2 Mountings/structure	strength	safety						
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								
Major Moderate Minor								

3 Seals/gaskets	cracking	adhesion	elasticity					
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								
Major Moderate Minor								
4 Cover/reflector	cracking	crazing	buckling	delamination	warping	outgassing		
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								
Major Moderate Minor								
5 Absorber coating	cracking	crazing	blistering					
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								

Major Moderate Minor								
6 Absorber tubes and headers	deformation	corrosion	leakage	loss of bonding				
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								
Major Moderate Minor								
7 Absorber mountings	deformation	corrosion						
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								
Major Moderate Minor								
8 Insulation	water retention	outgassing	degradation	colors changing				
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								

How would you classify this impact?								
Major Moderate Minor								
9 Vacuum tubes	Vacuum losses	colors changing						
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								
Major Moderate Minor								
10 Heat pipes	Liquid losses	deformation	corrosion					
Gradation Scale (0,1,2) 0 - No problem 1 - Minor problem 2 - Severe problem x – Non inspected								
According to your experience, do you think the observed failure could have an impact on the thermal performance of the collector?								
Yes/No								
How would you classify this impact?								
Major Moderate Minor								

Observations, notes and pictures:

Please report your observations, notes and pictures (referenced in the table) in this paragraph.

For ETC heat pipe tubes please try to assess the liquid losses of each heat pipe tube that might occur during the test and fill in the following table:

Number of heat pipes tubes	1	2	3	4	5	6	7	8	9	10	…
Liquid content											

3: Full

2: little liquid remaining

1: empty