Test method for the determination of the long-term stability of absorber welding seams in flat plate solar thermal collectors

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Abstract

Within the framework of the SpeedColl2 ("Service life estimation for solar thermal collectors and their components") project a rapid test method for the alternating thermal load of flat plate solar thermal collectors is being developed. The development of the test procedure is described based on annular solar thermal system simulations for different locations and cases of application. The test procedure consists of thermal performance tests at the beginning and end of the procedure and the appliance of alternating thermal loads on the flat plate solar thermal collector in between. The test procedure was applied using two different flat plate solar thermal collectors. The test results show very different results for both collectors, thus more collector tests have to be performed in order to gather more reliable results. The results include thermal performance tests as well as further investigation of the welding seams between the absorber and absorber pipes.

Keywords: Solar thermal collector, Test procedure, alternating thermal load, welding seams

1. Introduction

Within the framework of the research project "Service life estimation for solar thermal collectors and their components" (SpeedColl2) funded by the Federal Ministry of Economics and Energy in Germany, the development of a rapid test procedure for temperature cycling tests for solar thermal collectors which started in the predecessor project SpeedColl ("Development of accelerated ageing processes for solar thermal collectors and their components") is being continued. For the development of the test procedure that reflects the real alternating (cycling) thermal loads of the solar thermal collectors during operation in different types of systems at different locations the different operating conditions have to be taken into account.

In order to meet those real alternating thermal loads during operating conditions, data on the actual thermal loads is necessary. Solar thermal collectors always represent only a part of an entire system. Therefore, their thermal load depends not only on the collector properties and ambient conditions, but also on the operation of the entire system. Therefore, the dimensioning of the entire system, the thermal loads respectively the load profiles (i. e. domestic hot water load) as well as the control strategy of the system are important determining factors. A method for the determination of the alternating thermal loads of specific collectors at different locations for different applications is presented in Ullmann et al. (2018).

As the evaluation criterion of the test procedure the thermal performance of the solar thermal collector is considered the most important parameter. A major factor determining the thermal performance of many solar thermal collectors is the quality of the absorber welding seam between the absorber and the absorber pipes.

2. Thermal cycling load

A test procedure should cover as many use cases as possible and at the same time keep the effort for its implementation in practice to a minimum. In Ullmann et al. (2018) annual system simulations for an average flat plate solar thermal collector were performed using collector-specific performance data from Solar Keymark data. The alternating thermal loads actually occurring at the collector was determined using the simulation

doi:10.18086/swc.2019.06.05 Available at http://proceedings.ises.org

software TRNSYS. In order to determine the alternating thermal loads under different operating conditions, two different systems (domestic hot water preparation - DHW - and solar combisystems - SCS) were investigated at different locations.

It was shown that the determination of the thermal cycling load by means of system simulations is also possible with low, i. e. hourly, resolved weather data with good accuracy. The good availability of hourly resolved weather data therefore enables the determination of altitude and temperature level of alternating thermal loads from annual simulations for different locations. The 4 locations Gran Canaria (maritime climate), the desert Negev (desert), Sevilla (arid climate) and Stuttgart (moderate climate) were selected for a broad coverage of different climatic conditions.

An alternating thermal load or thermal shock herein is defined as follows:

- A thermal shock is present if at a pump start (in the collector circuit) T_{Abs} - $T_{Coll,in}$ > 0 K is given.

  with T_{Abs}: absorber temperature
  $T_{Coll,in}$: collector inlet temperature

For the evaluation, the temperature difference (T_{Abs} - $T_{Coll,in}$ at pump start) is considered as the amplitude and the associated absorber temperature is considered as the temperature level of the alternating thermal load. Table 1 shows an example of the alternating thermal loads for the locations Stuttgart and Seville.

Table 1: Number of alternating thermal loads (thermal shocks) for solar thermal system for domestic hot water preparation (DHW) and solar combisystem (SCS) for the locations Stuttgart (STG) and Seville (SVL) by amplitude (temperature difference)

	Temperature difference at pump start (load amplitude T_{Abs} - $T_{Coll,in}$) in K										
	ΔT < 10	ΔT 10 … 20	ΔT 20 … 30	ΔT 30 … 40	ΔT 40 … 50	ΔT 50 … 60	ΔT 60 … 70	ΔT 70 … 80	ΔT 80 … 90	ΔT 90 … 100	ΔT > 100
DHW STG	15	712	237	150	85	10	3	6	1	0	0
SCS STG	79	1467	130	38	38	97	0	0	0	0	0
DHW SVL	23	629	75	80	306	30	44	21	3	0	0
SCS SVL	24	1683	172	5	12	71	213	4	1	0	0
	Number of thermal shocks within given range of load amplitude (T_{Abs} - $T_{Coll,in}$)										

3. Test procedure

During the test procedure, the relevant alternating thermal loads have to be impressed on the solar thermal collector within a shortened period of time as representative as possible for all cases of application described within Section 2. Thermal shocks with a temperature difference of 50 K and more are used here as relevant thermal alternating loads. This temperature difference represents a compromise between the occurring thermal loads determined using system simulations and the desire for the shortest possible test duration. For a solar thermal combisystem in Stuttgart, this corresponds to around 2,500 thermal shocks (97 units per year) given a service life of 25 years (Table 1). In order to also reflect higher temperature differences as they occur in other application cases, it is proposed to increase the temperature difference to 75 K. The increase in temperature difference also allows a further reduction in the number of alternating loads carried out. Here 2,000 alternating thermal loads with a cooling from 90 °C to 15 °C (T = 75 K) are proposed. A maximum temperature below 100 °C was chosen in order to limit the technical effort required to carry out the alternating thermal loads (e. g. to avoid steam formation).

In addition to the thermal shocks occurring during operation of the solar thermal system, 4 thermal shocks according to ISO 9806 are carried out. Those 4 thermal shocks represent the thermal loads at the commissioning of the system and 3 maintenances during the service life of a solar thermal collector - even though this should not occur with proper filling. The test method proposed here can then be divided into the following five sections:

a. Determination of the thermal performance of the solar collector (according to ISO 9806)

b. Impression of the alternating thermal loads occurring during the entire service life (resp. operation) of the solar thermal collector in a shortened period of time (2,000 cycles with a temperature difference of 75 K)

c. Impression of the 4 alternating thermal loads during commissioning (1) and maintenance (3) according to ISO 9806

d. Determination of the thermal performance of the solar thermal collector and comparison with the original performance within a)

e. Evaluation of the result (the necessary evaluation criteria have not yet been defined at this stage).

The alternating thermal loads within section b) are impressed one after the other. An alternating thermal load consists of two phases: heating and cooling. The volume flow is impressed on the collector with a defined inlet temperature until a defined outlet temperature is reached at the collector outlet. The following boundary conditions are proposed for the two phases heating and cooling:

- Heating: Volume flow through the collector with an inlet temperature of 95 °C until a temperature of 90 °C is reached at the collector outlet.
- Cooling: Volume flow through the collector with an inlet temperature of 10 °C until a temperature of 15 °C is reached at the collector outlet.

For heating and cooling, a temperature difference between inlet and outlet of 5 K is used in order to achieve a short cycle time.

The definition of the evaluation criterion for the examination has not yet been completed. The test procedure described under b) was exemplarily performed on two flat plate collectors as described in Section 4.

4. Deployment of the test procedure

The test procedure described in Section 3 (procedure parts a, b and d) was carried out using two flat plate solar thermal collectors (A and B). The boundary conditions defined within section 3 were applied. For collector A 2,500 instead of 2,000 thermal shocks were carried out in order to gain further insights especially on the welding seams. Collector B was impressed with 2,000 alternating thermal loads according to the test procedure.

The test bench used for the impression of the alternating thermal loads is shown in Figure 1. It contains of a heating circuit with 60 kW heating power and a cooling circuit with 40 kW cooling power.

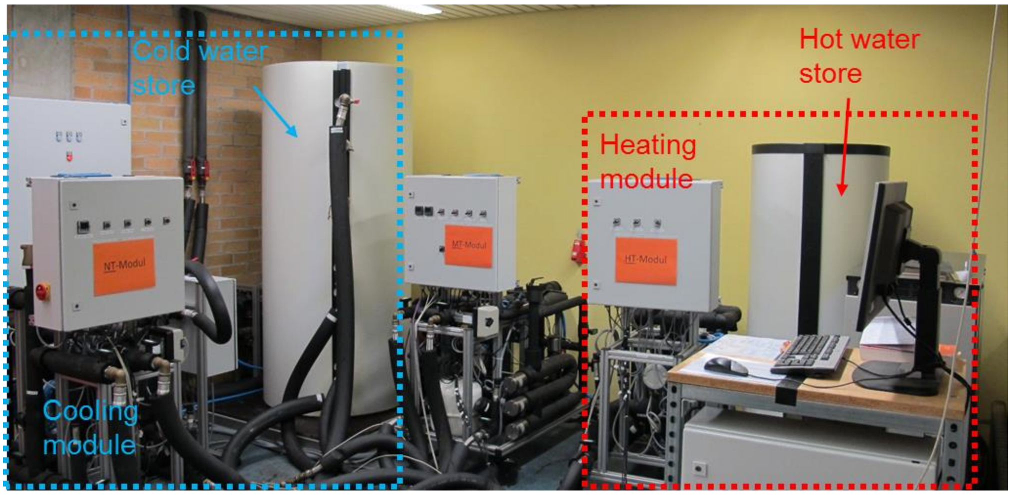

Figure 1: Test bench for imprinting the alternating thermal loads representing operation on the solar thermal collector

The test collectors both have meander-shaped absorber pipes as shown schematically in Figure 2. The collector inlet is at the bottom and the outlet is at the top of the collector (for heating and cooling). The collectors are heated via the long side of the absorber pipe manifold. The cooling or thermal shock of the collector takes place via the short side of the absorber pipe manifold in order to impress the alternating thermal load as directly as possible onto the absorber pipe. During heating and cooling, the flow exits the collector via the long side of the absorber pipe manifold in order to impress the load onto the entire welding seam.

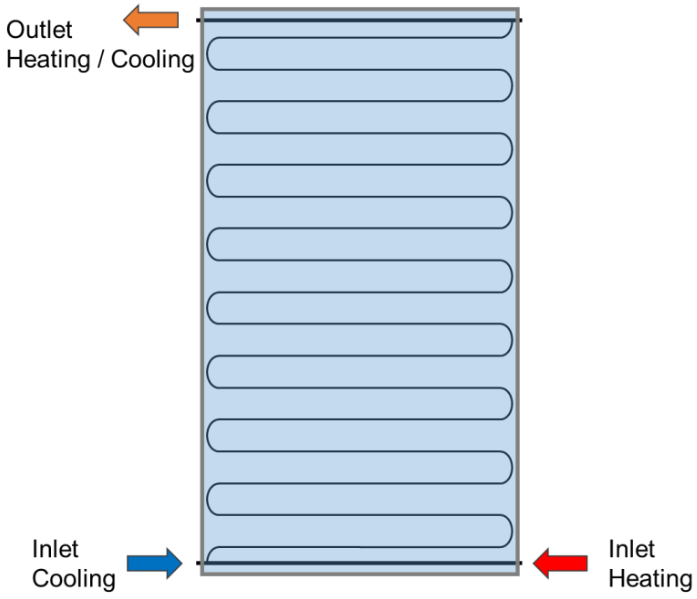

Figure 2: Schematic of the test collector with meander-shaped absorber pipe, inlet for heating and cooling and outlet (rear view)

Figure 3 shows one heating and one cooling phase (one cylce) during the test. The time required for one cycle including the heating phase is approx. 7 minutes. This results in a total test duration of almost 10 days for 2,000 alternating thermal loads. The 2,500 alternating thermal loads (cycles) for collector A were impressed onto the collector within 5 batches of 500 cycles each. The 2,000 cycles for collector B were impressed within one single batch.

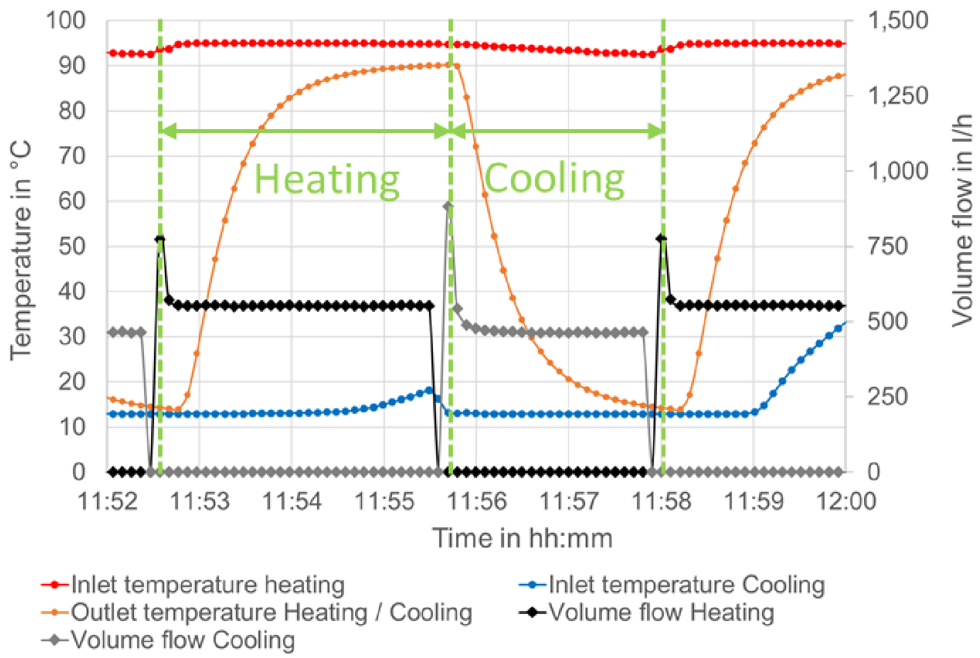

Figure 3: Course of an alternating thermal load with the two phases heating and cooling, collector A

After each batch (collector A), the thermal insulation was removed from the back of the collector and the absorber welding seams were examined. The length of the welding seam detachment between absorber and the absorber pipe was measured as shown in Figure 4. The windings of the absorber pipe are numbered from top to bottom (TL: top left). The largest welding seam detachment occurs at the inlet used for cooling - corresponding to the largest occurring temperature difference and hence largest alternating thermal load at the collector inlet at the beginning of the cooling phase.

At the corners of the collector, the length of the welding seam detachments are significantly larger than in the center of the collector. This also applies to the exit (upper) corners, even though the alternating thermal load is lowest here. The fact that the welding seam detachments here are nevertheless considerably larger than in the center of the collector can mainly be explained by the different diameters of the absorber pipe and the absorber pipe manifold. This leads to higher mechanical tension within the welding seam due to bending of the absorber sheet (from small to big pipe diameter). Furthermore the collector is clamped in the frame at the collector corners. As a result, the material has less room for thermal expansion, since the frame remains at a significantly lower temperature level and thus expands only to a small extend in comparison. The different thermal expansion (difference: 40 %) of copper (α_{Cu} = 16. 5 - 10-6 K^{-1}) and aluminium (α_{Al} = 23. 1 - 10-6 K^{-1}) is therefore more difficult to compensate. Over the total length of the welding seam (1 m), the expansion of copper at the given temperature difference (of 95 °C - 10 °C = 85 K) is 1.4 mm, that of aluminium 1.96 mm.

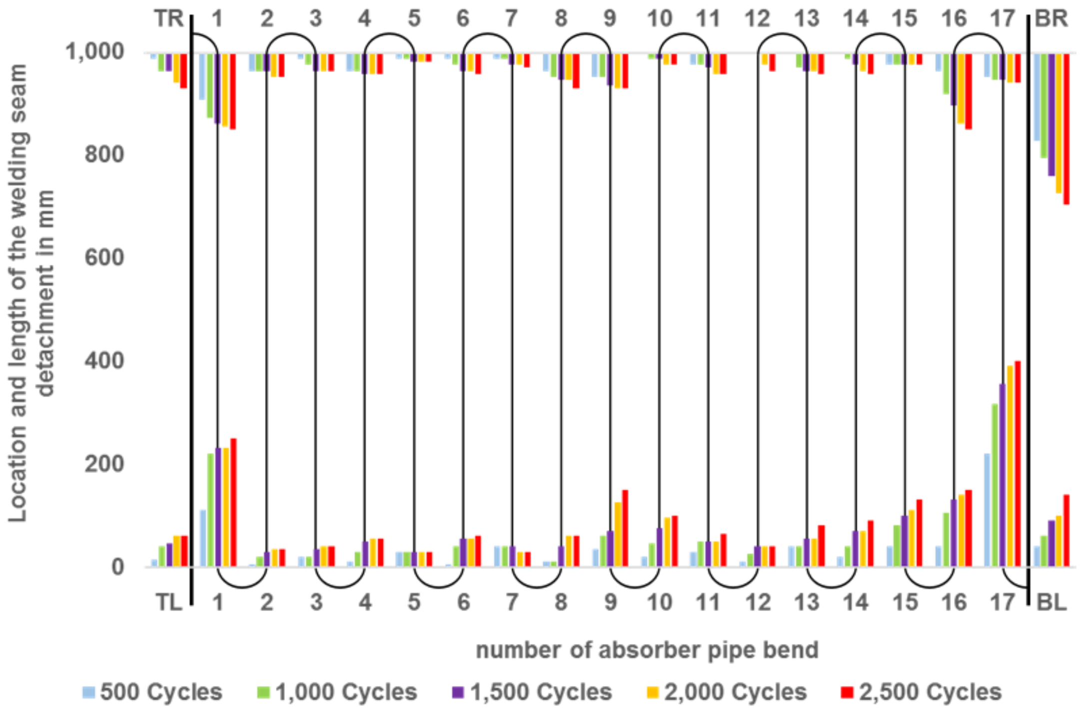

Figure 4: Welding seam Detachment between absorber and absorber pipe after 500, 1000, 1500, 2000 and 2500 cycles; numbering of the pipe bends from top to bottom (OL: top left), collector A

The proportion of the total welding seam detachment based on the total length of the welding seam is shown in Figure 5 for each of the 500 cycle batches (collector A). In this case the further detachment of the welding seam decreases significantly with increasing number of cycles.

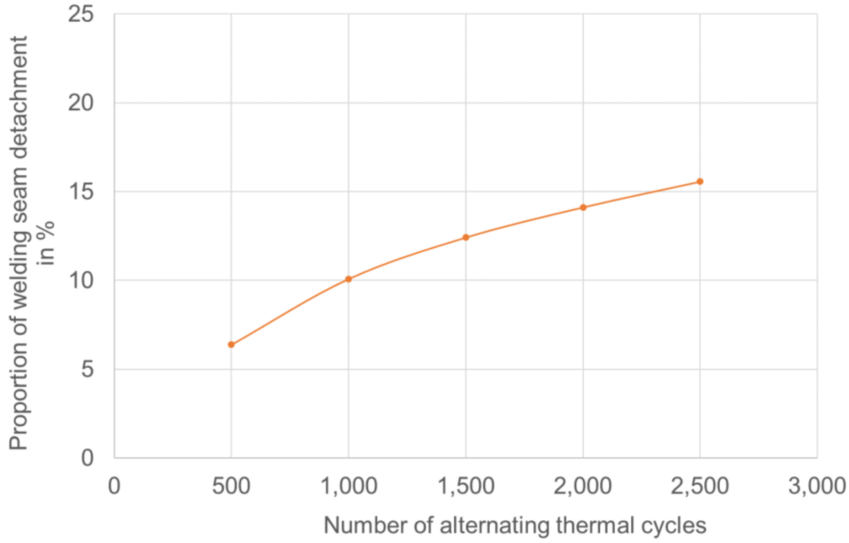

Figure 5: Proportion of the total welding seam detachment based on the total length of the welding seam between absorber and absorber pipe after 500, 1000, 1500, 2000 and 2500 cycles, collector A

The proportion of the total welding seam detachment based on the total length of the welding seam of collector B after 2,000 cycles is well below 1 %. Given these very different results, the additional implementation of this test procedure for alternating thermal loads can be considered very reasonable.

Concerning the thermal performance before and after the impression of the alternating thermal loads, collector A shows significant degradation (Figure 6), whereas collector B shows almost no degradation (Figure 7). This correlates very well with the measured welding seam detachments for both collectors and indicates the big influence of the welding seam condition on the thermal performance of solar thermal collectors.

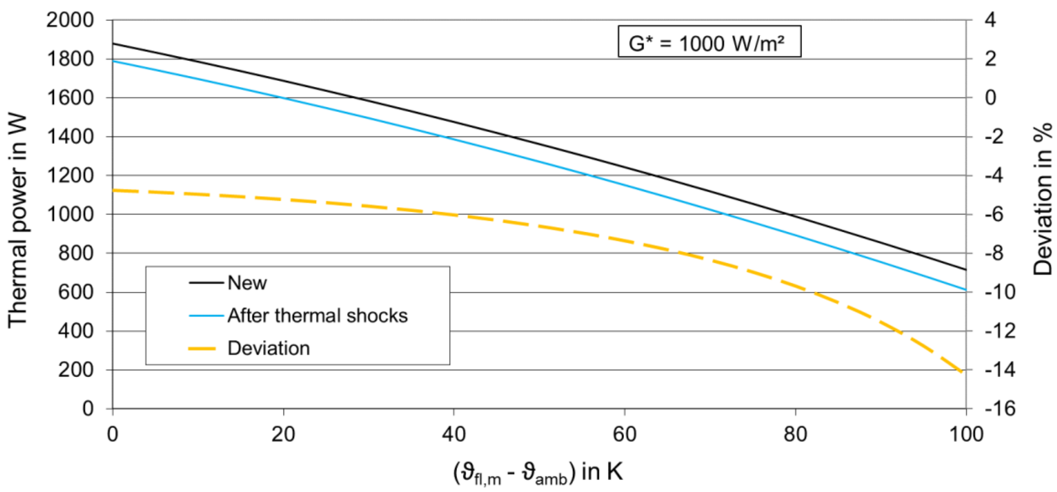

Figure 6: Thermal performance of the tested collector A before (new) and after 2,500 thermal shocks (after thermal shocks) with ΔT = 75 K

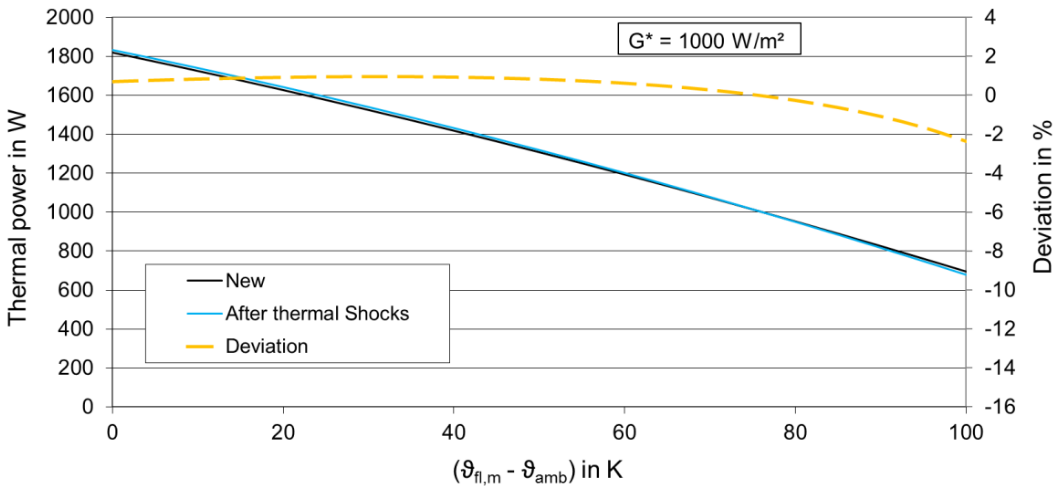

Figure 7: Thermal performance of the tested collector B before (new) and after 2,000 thermal shocks (after thermal shocks) with ΔT = 75 K

5. Summary and outlook

A rapid test procedure for the alternating thermal loads of solar thermal collectors occurring during operation, which is being developed within the framework of the SpeedColl2 project, is presented and demonstrated using two different flat plate solar thermal collectors. The test procedure includes the five sections:

a. Determination of the thermal performance of the solar collector (according to ISO 9806)

b. Impression of the alternating thermal loads occurring during the entire service life (resp. operation) of the solar thermal collector in a shortened period of time (2,000 cycles with a temperature difference of 75 K)

c. Impression of the 4 alternating thermal loads during commissioning (1) and maintenance (3) according to ISO 9806

d. Determination of the thermal performance of the solar thermal collector and comparison with the original performance within a)

e. Evaluation of the result (the necessary evaluation criteria have not yet been defined at this stage).

The alternating thermal loads to be impressed on the collector (during section b) were determined using system simulations in order to fit a wide range of applications (solar domestic hot water preparation and solar combisystem under 4 different climatic conditions), taking into account practical feasibility.

The developed test procedure was performed exemplary using two different solar thermal collectors (A and B). Collector A shows much larger welding seam detachments (approx.. 14 %) compared to collector B (well below 1 %) as well as much higher thermal performance degradation (5 - 10 % within relevant temperature range for collector A compared to almost no degradation for collector B). Given these very different results the additional implementation of this test procedure for alternating thermal loads can be considered very reasonable.

6. Acknowledgments

The research project SpeedColl2 “Service life estimation for solar thermal collectors and their components, subproject: collectors" is funded by the German Federal Ministry of Economics and Energy (BMWi) on the basis of a resolution of the German Bundestag through the project management agency Jülich (PTJ) under the funding number 0325865B. The authors are grateful for this support and accept responsibility for the content of this publication.

7. References

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