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RECOMMENDATIONS FOR THE REDUCTION OF FAILURESDURING THE PLANNING AND INSTALLATION PHASES OF SOLAR THERMAL PROCESS HEAT SYSTEMS

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Abstract

Although several studies investigated failures in large solar thermal systems (STS) in the past, some of these failures still occur in recently built systems for solar process heat applications. Besides technical issues according to the long term reliability of components, which have to be addressed by the manufacturers, many problems lead back to insufficient planning or failures during installation. Such failures in STS can reduce the performance perceptibly and will continually impair the image and acceptance for solar thermal process heat systems. To support the market development of large individualized STS the "human caused failures" should be reduced significantly. Therefore, wide spread problems, especially those with a high impact on the performance, will be collected, analyzed and disseminated to the target groups to provide applicable failure prevention recommendations.

Keywords: *failure prevention, large solar thermal systems, individualized systems, solar process heat*

1. Introduction

Even if there is a large potential of 50 TWh/a for industrial and commercial applications up to a temperature of 250°C[1] for STS in Germany, the market uptake is rather slow. In fact the growth of market for solar process heat, that could be detected between August 2012 and the beginning of 2015, is declining at the moment. Besides the major influence of the dropped oil prices in the middle of 2014, some other barriers have to be addressed for a lasting increase of the number of newly installed solar process heat systems in Germany and other countries.

At first the relation between the high installation costs and the low operating costs of STS seem to be a barrier for many entrepreneurs. To address this barrier 50 % of the overall investment costs for solar process heat systems is subsidized in Germany, enabling investors to achieve an amortization time of seven to ten years in most cases. But these amortization times are still too long for many companies, although STS have a long operating life of 20 to 25 years.

The second problem is the missing knowledge of most entrepreneurs that solar thermal can be used to provide heat for processes. In addition, some of those who are aware of this fact fear a bad influence on the operational reliability, although there should be no risk if planned and installed correctly. Also, as solar thermal process heat systems should be realized after the implementation of obvious energy efficiency measures, there is an extra effort to realize such projects. In addition the systems have to face the competition to combined heat and power (CHP) and industrial heat pumps (HP). Perhaps in future even direct PV-heating could compete with solar thermal in industry, depending on the development of prices for PV and STS.

[1] including space heating and domestic hot water

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Another important factor that is slowing down the market is that only few companies deal with solar thermal process heat systems professionally and even fewer companies are offering the full projecting of planning, installation, start-up and if necessary also the operation of STS as a package. Besides, there are installers at the market with no trust and no will to deal with solar thermal process heat systems, as conventional oil and gas boilers as well as CHP and HP are normally less complex in planning and installation.

This complexity leads to the last point, the higher efforts for a precise planning and faultless installation of solar process heat systems, which are mostly individualized systems in contrast to the standardized systems for domestic applications. Especially in such a small market where new companies are trying to sell projects, the required high precision during planning and installation unveils a large potential for human caused failures that can be done.

Although there has been intense research on the performance of and failures in large scale solar heating systems, the resulting knowledge has not been condensed into applicable guidelines or tools as it was done e.g. for process heat specific knowledge on the pre-dimensioning and the definition of integration points [Schmitt et al. 2015, Muster et al. 2015]. This was one reason for the German Federal Ministry for Economic Affairs and Energy to fund the research project “Analysis and Development of the German Market for Solar Process Heat in Germany” (Ident. No. 03MAP286). This project has three work packages: The first one is the economic and technical analysis of planning documents that have to be handed in to apply for the 50 % investment grant. The second work package is the assessment of the solar yield of STS with a collector area larger than 100 m^2_{gross} and the detailed monitoring of three selected systems newly built within the funding program. The third work package is the preparation of gained knowledge out of the project as well as existing knowledge and the dissemination into the market by organization and conduction of regional roadshows and workshops for planners and installers. A very important part of the work package is the preparation and dissemination of specific knowledge as guides for planners and installers to reduce failures in large scale STS with the focus on solar process heat. The input for these guides are mainly failures detected within the technical analysis of the planning documents done in work package one and the identified problems in the three monitored systems. These failures are extended with the documented problems in literature. At the end the guides should cover common failures especially those with a large impact on the performance. They have to be provided in a compact but comprehensive way to both target groups – planners and installers. These guides for planning and installation will probably become a standard whose abidance planers and installers have to confirm as an indication on following the state of the art. The guides will be provided as additional information material together with the application form for requesting the subsidies.

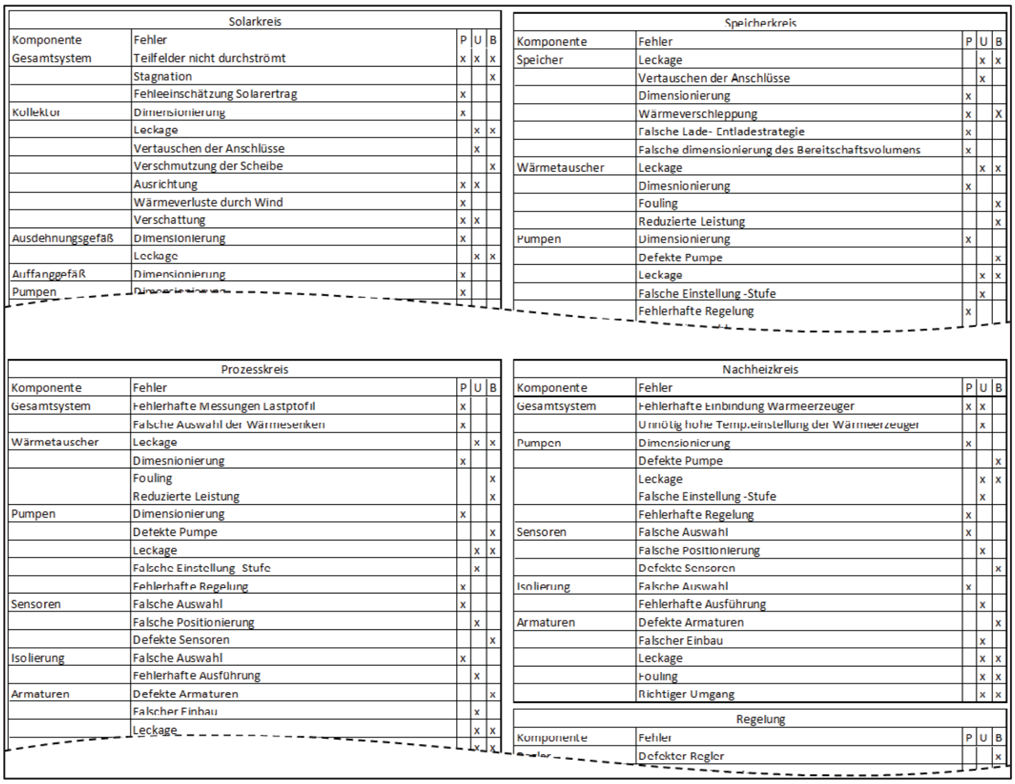
2. Failures in Large Scale Solar Thermal Systems

Although several studies investigated failures in large scale STS in the past, a lot these failures still occur in recently built systems for solar process heat applications. Besides technical issues according to the long term reliability of components, which have to be addressed by the manufacturers, many problems lead back to insufficient planning or failures during installation. Such failures in STS can reduce the performance of the particular system perceptibly and will additionally lead to a continually impair of the image and acceptance for solar thermal process heat systems. To support the market development of individualized solar process heat systems, the “human caused failures” should be reduced significantly. Therefore, wide spread problems, especially those with a potentially high impact on the solar yield, were collected and analyzed to provide applicable failure prevention recommendations.

For the preparation of these recommendations, the failures detected in the three monitoring systems within the before mentioned research project as well as within over 260 planning documents and those out of literature were collected. The main used literature sources on failures in large scale STS are Peuser et al. (2009), Croy and Wirth (2006), Fink et al. (2006), Wiese (2006), Lanz et al. (2013), Remmers et al. (2001), Peuser et al. (2001), Lauterbach et al. (2012). Finally, a list of nearly 80 different failures could be prepared.

Out of these failures those that are not relevant anymore were deleted like the discoloration of the absorber or torn inner collector covers (material problems with the used foil) as well as leak absorber pipes. Afterwards failures that are not caused by inaccurate planning or installation but by quality problems according the long term reliability of the components were identified, as they are disregarded for the recommendations for the planning and installation phases. These problems concerning material defects or production failures have to be addressed by the manufacturers. In addition, as such failures according the long term reliability can never entirely be prevented, the University of Kassel is starting a research project on the automated system evaluation and failure detection together with several partners out of solar industry. Applying the FSC method (fractional solar consumption) developed in IEA Task 32, which is used to compare the actual fractional energy savings of a system with the theoretical maximum of the actual systems configuration, manual analysis of measurement data will be redundant. Moreover, an algorithm-based fault detection method can be applied, which is able to determine in which subsystem or component a fault has probably occurred.

Having deleted the failures not relevant anymore and disregarded those occurring during several years of operation, a list of failures that can be caused by insufficient planning or poor installation remains. These failures can be referred to different parts of the solar system, as it can be seen in Figure 1 [in German language].



Solarkreis				
Komponente	Fehler	P	U	B
Gesamtsystem	Teilfelder nicht durchströmt	x	x	x
	Stagnation			x
	Fehleeinschätzung Solarertrag	x		
Kollektor	Dimensionierung	x		
	Leckage		x	x
	Vertauschen der Anschlüsse		x	
	Verschmutzung der Scheibe			x
	Ausrichtung	x	x	
	Wärmeverluste durch Wind	x		
	Verschattung	x	x	
Ausdehnungsgefäß	Dimensionierung	x		
	Leckage		x	x
Auffanggefäß	Dimensionierung	x		
Pumpen	[illegible]	x		

Speicherkreis				
Komponente	Fehler	P	U	B
Speicher	Leckage		x	x
	Vertauschen der Anschlüsse		x	
	Dimensionierung	x		
	Wärmeverschleppung	x		X
	Falsche Lade- Entladestrategie	x		
	Falsche dimensionierung des Bereitschaftsvolumens	x		
Wärmetauscher	Leckage		x	x
	Dimesnionierung	x		
	Fouling			x
	Reduzierte Leistung			x
Pumpen	Dimensionierung	x		
	Defekte Pumpe			x
	Leckage		x	x
	Falsche Einstellung -Stufe		x	
	Fehlerhafte Regelung	x		

Prozesskreis				
Komponente	Fehler	P	U	B
Gesamtsystem	Fehlerhafte Messungen Lastptofil	x		
	Falsche Auswahl der Wärmesenken	x		
Wärmetauscher	Leckage		x	x
	Dimesnionierung	x		
	Fouling			x
	Reduzierte Leistung			x
Pumpen	Dimensionierung	x		
	Defekte Pumpe			x
	Leckage		x	x
	Falsche Einstellung Stufe		x	
	Fehlerhafte Regelung	x		
Sensoren	Falsche Auswahl	x		
	Falsche Positionierung		x	
	Defekte Sensoren			x
Isolierung	Falsche Auswahl	x		
	Fehlerhafte Ausführung		x	
Armaturen	Defekte Armaturen			x
	Falscher Einbau		x	
	Leckage		x	x

Nachheizkreis				
Komponente	Fehler	P	U	B
Gesamtsystem	Fehlerhafte Einbindung Wärmeerzeuger	x	x	
	Unnötig hohe Temp.einstellung der Wärmeerzeuger		x	
Pumpen	Dimensionierung	x		
	Defekte Pumpe			x
	Leckage		x	x
	Falsche Einstellung -Stufe		x	
	Fehlerhafte Regelung	x		
Sensoren	Falsche Auswahl	x		
	Falsche Positionierung		x	
	Defekte Sensoren			x
Isolierung	Falsche Auswahl	x		
	Fehlerhafte Ausführung		x	
Armaturen	Defekte Armaturen			x
	Falscher Einbau		x	
	Leckage		x	x
	Fouling		x	x
	Richtiger Umgang		x	x

Regelung				
Komponente	Fehler	P	U	B
[illegible]	Defekter Regler			x

Figure 1: Example for the allocation of the detected failures to the different parts of the solar system

The first part of the system failures can occur in is the solar loop. Main source for potential failures are related to the collector field like an uneven flow distribution in the different collector rows. Also the dimensioning and installation of the expansion vessel and the pump seems to be a problem in some cases. The second part is the storage loop, here including the heat exchanger for charging the storage. Most problems emerge due to incorrect connections causing natural circulations. The dimensioning of the storage volume and the heat exchanger is also a common source for failures. Following, the process loop was defined, starting with the heat exchanger for the discharge of the storage. An example of failures for this loop is the underestimation of the peak load of the heat sink, leading to an undersized heat exchanger. Completing this classification failures were also allocated to the secondary heating loop (e.g. oil or gas burner) and the controller loop. Examples are fouling in the heat exchanger due to the wrong choice of the type or simply a wrong control strategy that could for example use the conventional boiler as primary heat source instead of the solar thermal process system.

In the following section some examples for failures made during planning or installation of recently built systems are named as well as a short description of the effect on the system.

3. Examples for Failures found in Solar Process Heat Systems

The analysis of planning documents and the detailed monitoring of three selected STS in industry and commerce within the project "Analysis and Development of the German Market for Solar Process Heat" (Ident. No. 03MAP286) showed that several failures were made during planning and installation. In addition, the University of Kassel had the opportunity to discuss with several planners and installers as well as with companies that invested into a solar process heat system, which could be used as an additional source of information. Following some examples of the failures that were found are given. Some of these failures appeared several times in different STS.

It was assessed that some planers do not choose the collector type according to the application with its necessary temperature levels. They typically use one specific collector type independent from the intended application (domestic hot water or process heat). Using this approach, systems were built with evacuated tube collectors heating up cold water to a desired flow temperature of only 40 °C. For this temperature level a single glazed flat plate collector would have been a more efficient choice compared to evacuated tubes additionally with lower costs at higher specific solar yields. Even unglazed collectors would reach a higher efficiency over a long period of the year. Such a poor choice of the collector type leads to unnecessarily high solar heat generation costs due to higher cost for the component and the lower solar yield.

Another failure that often occurs is the realization of the desired storage volume by connecting several small storages, often in parallel. The highest number of interconnected storages was 14, each with a volume of only 1 m³, realized as two storage batteries each with seven storages connected in parallel. Compared with a one single large storage, the interconnection of multiple storages leads to significantly increased costs for hardware and installation as well as increased heat losses due to the higher storage surface and multiple connections between the storages. In addition measurements in STS showed that storages connected in parallel always start interacting over the time, even if they were installed correctly hydraulically balanced. This leads to uncontrollable charge and discharge of the storages and therefore to a mixing of different temperature levels, reducing the useful solar yield. In general, the monitoring of several systems showed, that it is always preferable to use one single storage but never more than two in parallel or three in series (Peuser er al., 2001).

According to the realization of the storage, some systems were planned to be built with vacuum-insulated storages. As they are very expensive – prices between 3,000 and 3,500 €/m³ were found in the planning documents – it can only be reasonable to use them as mid or long term storages for systems with excess energy gains in summer or autumn. As the systems were designed to achieve a solar fraction of less than 50 % in the summer months, there is no need for such storage. The only effect is an increase of the solar heat costs. An exception for using a vacuum storage in such cases could be very little space at the installation site.

One point that came up during discussions with owners/operators and planners of solar thermal process heat systems was that the installing company used tap water instead of demineralized water for the storage. This resulted in a rapidly decrease of heat transfer from the primary to the secondary solar loop as the plates of the heat exchangers were calcified. This finally led to a lower utilization ratio as the heat produced by the collectors cannot sufficiently be transferred into the storage leading to higher temperatures in the solar loop and therefore to higher heat losses and lower collector efficiencies.

Another failure caused during the planning phase was the selection of incorrect pump combinations, leading to unbalanced capacity flows in the primary and secondary solar loop. Systems were found in which the capacity flows of the primary loop always exceeded the capacity flow of the secondary loop. In this case, the temperature of the storage was charged with heat very close to the solar flow temperature. As the solar loop fluid cannot be cooled down to the return flow temperature of the storage charging loop, the heat losses increase and the collector efficiency drops as its mean plate temperature is unnecessarily high. Once again, this failure leads to a lower system utilization ratio and higher solar heat generation costs.

It could be also found that single speed pump designed for medium irradiations on the collectors were selected for the primary solar loop. The utilization of these kinds of pumps causes inefficient operating conditions at low radiation as well as at times with high radiation. At low radiation, the volume flow is very high for heating up the solar loop fluid and only very low temperature differences between flow and return flow can be achieved. The result is a comparably long time until the storage can be charged with the desired minimum or set temperature. In contrast, at times with high solar radiation, the average temperature in the solar loop is very high as the produced heat cannot sufficiently be dissipated. Summed up, in the morning, evening and on days with a low radiation, there are unnecessarily high electricity costs for the pump and unfavorable operating conditions for the solar thermal system. On days with a high radiation the temperature in the solar loop is higher than required, causing higher heat losses, a lower collector efficiency and probably even unnecessary additional stagnation times.

An additional problem, planners have to take care of, is the determination of the daily load and the peak load of the chosen heat sink. As this data is usually not available in companies, it should be measured on a typical production day and not only be estimated. But as the measurement takes a little time and financial effort, the system dimensioning is often done using a rough estimation. The estimation of a higher daily load leads to lower solar yields compared to the simulation, as less heat is needed than expected. If the peak loads are estimated too low, it is very likely that an undersized heat exchanger will be installed, not able to heat up the process medium or fluid stream to the designed temperature, even if the storage is fully charged. This leads to a higher conventional heat demand than necessary and higher heat losses of the storage as the discharge is lower than expected. Both mistakes – overestimation of the daily load and underestimation of the peak load – were found within the project.

It also happened that the chosen gaskets in the solar loop were sufficiently temperature resistant for regular operation conditions but not for stagnation. The results were leakages at the connections of the solar loop making it necessary to drain the loop, dismount all connections close to the collector that could be affected during stagnation, and to renew the gaskets. At the end the solar yield that could have been gained between the time the leakages emerged and the resumption of operation were given away and additional costs for the reparation were caused.

Another failure that could be found is missing valves to reliably close different loops being used at different times at different temperatures providing several heat sinks. This is necessary to avoid fault forced circulation between the loops. The effect of missing valves is a mixing of flows and / or return flows with different temperatures making it nearly impossible to achieve the desired temperature in the different heating loops.

The last detected problem that will be mentioned here, is the inaccurate installation of the temperature sensors in the last collector of each collector row. In two systems the sensor was not correctly plugged in the collector causing an offset between the measured and real temperature. In addition the offset increased with higher temperatures. If this measured temperature is used as the solar flow temperature for the controller to control the pump, the result is again an unnecessary high temperature in the solar loop, causing additional heat losses and a lower collector efficiencies.

4. Concept for Failure Prevention Recommendations

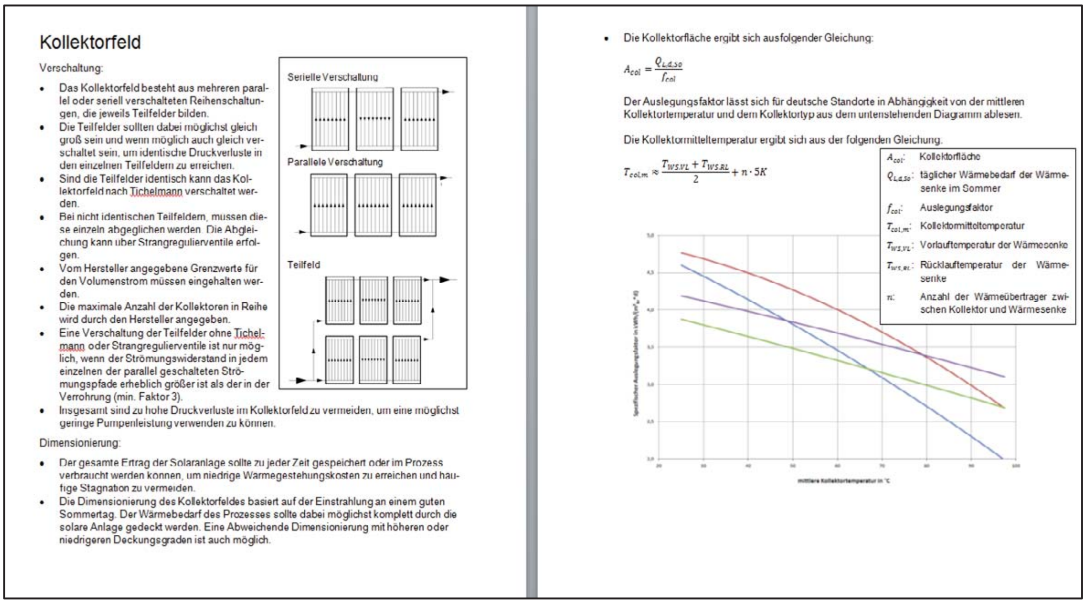
To prospectively prevent the failures found within the analyzed systems as well as those found in literature, they have to be prepared in such way planners and installers are willing to consider within their daily routine. Therefore it had to be evaluated, which information at which extend is suitable for these two target groups. As these groups have different needs and duties, two varied designs of the failure prevention recommendations with diverging information are the result of this evaluation.

For both groups it has to be as short as possible without being inaccurate and the recommendations should only cover the most important points to reduce the paperwork that should be used by the target groups. As it cannot cover the whole planning and installation steps of a solar thermal system, it can only be used as an addition to the existing knowledge and tools to prevent the most common failures.

First draft of the recommendations for planners

The main steps the planner is responsible for, is collecting the necessary data to make a feasibility study and to submit an offer to the particular company. Afterwards a detailed system design and hydraulic scheme has to be prepared including all dimensions and specifications for the required components. In addition, a suitable control strategy has to be designed. After the realization of the solar process heat system an appropriate documentation of the system should be handed over to the operator.

As the planner should be used to deal with paperwork and formulas to design a whole system, it seems reasonable to provide recommendations of two to three pages for the components failures often occur including descriptions in continuous text or bullets together with schemes and formulas for the correct dimensioning. Figure 2 gives an example on the recommendations, in this case for the collector field [in German language].


Kollektorfeld

Verschaltung:

- Das Kollektorfeld besteht aus mehreren parallel oder seriell verschalteten Reihenschaltungen, die jeweils Teilfelder bilden.
- Die Teilfelder sollten dabei möglichst gleich groß sein und wenn möglich auch gleich verschaltet sein, um identische Druckverluste in den einzelnen Teilfeldern zu erreichen.
- Sind die Teilfelder identisch kann das Kollektorfeld nach Tichelmann verschaltet werden.
- Bei nicht identischen Teilfeldern, müssen diese einzeln abgeglichen werden. Die Abgleichung kann über Strangregulierventile erfolgen.
- Vom Hersteller angegebene Grenzwerte für den Volumenstrom müssen eingehalten werden.
- Die maximale Anzahl der Kollektoren in Reihe wird durch den Hersteller angegeben.
- Eine Verschaltung der Teilfelder ohne Tichelmann oder Strangregulierventile ist nur möglich, wenn der Strömungswiderstand in jedem einzelnen der parallel geschalteten Strömungspfade erheblich größer ist als der in der Verrohrung (min. Faktor 3).
- Insgesamt sind zu hohe Druckverluste im Kollektorfeld zu vermeiden, um eine möglichst geringe Pumpenleistung verwenden zu können.

Dimensionierung:

- Der gesamte Ertrag der Solaranlage sollte zu jeder Zeit gespeichert oder im Prozess verbraucht werden können, um niedrige Wärmegestehungskosten zu erreichen und häufige Stagnation zu vermeiden.
- Die Dimensionierung des Kollektorfeldes basiert auf der Einstrahlung an einem guten Sommertag. Der Wärmebedarf des Prozesses sollte dabei möglichst komplett durch die solare Anlage gedeckt werden. Eine Abweichende Dimensionierung mit höheren oder niedrigeren Deckungsgraden ist auch möglich.
- Die Kollektorfläche ergibt sich aus folgender Gleichung:

$$A_{col} = \frac{Q_{L,d,so}}{f_{col}}$$

Der Auslegungsfaktor lässt sich für deutsche Standorte in Abhängigkeit von der mittleren Kollektortemperatur und dem Kollektortyp aus dem untenstehenden Diagramm ablesen.

Die Kollektormitteltemperatur ergibt sich aus der folgenden Gleichung.

$$T_{col,m} \approx \frac{T_{WS,VL} + T_{WS,RL}}{2} + n \cdot 5K$$

A_{col}:	Kollektorfläche
$Q_{L,d,so}$:	täglicher Wärmebedarf der Wärmesenke im Sommer
f_{col}:	Auslegungsfaktor
$T_{col,m}$:	Kollektormitteltemperatur
$T_{WS,VL}$:	Vorlauftemperatur der Wärmesenke
$T_{WS,RL}$:	Rücklauftemperatur der Wärmesenke
n:	Anzahl der Wärmeübertrager zwischen Kollektor und Wärmesenke

Figure 2: Example for the failure prevention recommendations for planners

The recommendations for the planners are not as standardized as the hints for installers, as the aspects are varying. They include short descriptions of the general requirements, advices on which aspects have to be considered for a suitable selection of the particular part of the system as well as formulas and graphs to support the correct dimensioning. If the failures found in literature and within the project indicated the necessity, there are also hints on how to integrate the particular part correctly into the whole system.

First draft of the recommendations for installers

The installers' job is to install the system according to the planners' specification and with respect to the state of the art. In addition he is responsible (sometimes together with the planner) for the start-up of the system, giving the owner of the system an introduction.

As installers are always dealing with one component or connection after another, they need specific hints regarding single components, not the whole system. In addition, during installation there is normally no time to deal with extensive paperwork. Therefore, very short but precise hints on how to prevent common failures are necessary, always dealing with one single installation step. To support a quick grasp of the information included in the recommendations, schemes are given. Figure 3 is an example of the first draft of the hints that should be considered to reduce failures made during installation [in German language]. The format of each hint is a half DIN A4 page.

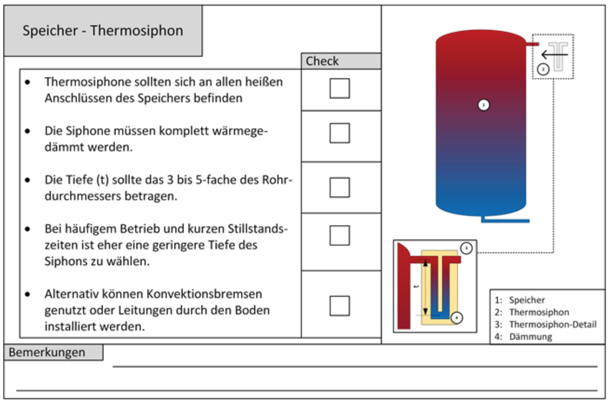


Figure 3: Example for the failure prevention recommendations for installers

The figure shows a few bullet points – here for the installation of thermos syphons at the hot connections of storages - with the information needed to prevent natural convection losses. Beside these bullet points are check boxes that can be used to confirm the observance of the given information. On the right hand side of the recommendations is a scheme with a short legend naming the parts visualized in the scheme. If necessary or helpful selected parts of the scheme are zoomed to capture more details. At the bottom of the hints an empty space is left where special circumstances, problems occurred or alternate solutions can be written down.

5. Outlook

As failures during the planning and installation phases were done in the past and will occur in the future there is a need to reduce them by giving guides like it is described in the previous sections.

The developed concept was discussed with a company mainly offering the planning, installation and if requested also the operation of solar process heat systems or other large scale STS, to confirm if the key aspects are covered in the recommendations and if they are short but still precise enough to be used by the target groups. As the feedback was positive and some additional input could be added, the recommendations seem to be suitable for the failure prevention.

Although the gathered recommendations can never cover every possible failure, a solid basis of identified failures occurring during planning and installation as well as hints to their prevention could be developed. In addition, the list of recommendations can easily be extended or revised if it is necessary.

The next steps are the final editing and dissemination of the hints and a definition on how to ensure, that planners and installers are aware of the content. To ensure that, one way of publishing the recommendations will be the download together with the application forms for the 50 % investment grant.

After publishing, the recommendations will become a defined document for the state of the art for realizing solar process heat systems. It is even possible that these recommendations will become a standard that have to be used if the planners and installers want to apply for the investment grant. This could be ensured by the need of signature that the system will be realized with respect to these failure prevention recommendations. With this approach a lot of failures could be prevented, supporting a market development on basis of systems delivering good performances.

A further module for supporting solar process heat systems to achieve constantly high yields even after several years of operation is the project on the automated evaluation of the fractional energy savings mentioned before.

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References:

Croy, R., Wirth, H. P., 2006: Analysis and evaluation of large combisystems for domestic hot water and space heating (in German language). Final Report, Ident. No. 0329268B.

Fink, C. Riva, R., Pertl, M., Wagner, W., 2006: OPTISOL Monitoring of demonstration projects for optimized and standardized solar systems for multi-family-housing (in German language). Reports “Energie- und Umweltforschung 50/2006”. Ministry for Transport, Innovation and Technology.

Muster, B., Hassine, I. B., Helmke, A., Heß, S., Krummenacher, P., Schmitt, B., Schnitzer, H., 2015: Integration Guideline. Guideline for solar planners, energy consultants and process engineers giving a general procedure to integrate solar heat into industrial processes by identifying and ranking suitable integration points and solar thermal system concepts. IEA SHC Task 49. Deliverable B 2.

Lanz, M., Schramm, S., Wirth, H.-P., Adam, M., Anthrakidis, A., Faber, C., 2013: Solar-Process Heat-Standards. Short title: Sol-Pro-St, (in German language). Final report, Ident. No. 0329609G & 0329609F.

Lauterbach, C., Schmitt, B., Vajen, K., 2012: Pilot plant for solar thermal process heat at the Hütt brewery (in German language). Proc. Gleisdorf Solar 2012, Gleisdorf, Austria, 12.-14.09.2012.

Peuser, F. A., Remmers, K., Schnauss, M., 2001: Long-term experience with solar thermal. Guide for the successful planning and installation of solar thermal systems (in German language), Berlin: Solarpraxis

Peuser, F. A., Croy, R., Mies, M., Rehrmann, U., Wirth, H. P., 2009: Solarthermie-2000, program part 2 and Solarthermie2000plus. Scientific and technical supervision and monitoring (phase 3) (in German language). Final report, Ident. No. 0329601L.

Remmers, K., Antony, F., Fischbach, M., Luchterhand, J., 2001: Large scale solar thermal systems. Getting started in planning and practice (in German language), 2nd revised edition, Berlin: Solarpraxis

Schmitt, B., Lauterbach, C., Vajen, K., 2015: Guideline for the pre-dimensioning of solar process heat. Feasibility assessment and pre-dimensioning of solar thermal process heat systems (in German language). http://www.solfood.de/uploads/1/9/8/3/19830089/solfood_leitfaden_vorplanung.pdf

Wiese, F., 2006: Long term monitoring of large solar integrated heat supply systems (in German language). Dissertation (Dr. Ing). Department for Mechanical Engineering. Kassel University. kassel university press.