Standardization of Solar Process Heat Applications to Increase Market Penetration

Bastian Schmitt, Dominik Ritter, Felix Pag, Mateo Jesper, Lukas Wimmer, and Klaus Vajen

University of Kassel, Institute of Thermal Engineering, Kassel (Germany)

Abstract

Based on the necessity to decarbonize future energy systems, the market uptake of solar process heat has to be accelerated. Currently, the market development is underwhelming, not only in Germany. However, numerous solar process heat plants have been realized, focusing on a few specific applications outside the traditional industry sector. These applications, namely rearing of animals, cleaning of vehicles and drying of biomass cover approx. two third of the German solar process heat market. Since Industry is often characterised by slow hierarchal decision structures, near-term planning horizons, and short payback times it seems promising to standardize the named popular applications outside the traditional industry sector and therefore, accelerate the market development and increase the visibility of solar process heat. Based on the evaluation of planning documents from 174 solar process heat plants, standardized systems concepts for the three applications were developed including hydraulic, key facts for dimensioning of collector area and storage as well as typical turn-key costs. These concepts will enable the market entry of new solar project developers and installers and therefore help to develop the large potential of low hanging fruits in the short term and for solar process heat in general.

Keywords: Solar process heat, low hanging fruits, standardization, planning guidelines

1. Introduction

While the German Energiewende is stalling at the moment in case of renewable electricity, the transition to a wide spread renewable heat supply has not really started yet at all. Like residential buildings, the heat consumption in Industry and Commerce allocates the major share of the overall energy demand (Fig. 1). Despite the significant lower CO2-factor for heat generation in contrast to electricity generation, more than half of the energy caused CO2-emissions in Industry and Commerce is based on fossil fuels for heat supply. With respect to the necessary decarbonisation it has to be underlined that the electricity caused CO2-load of companies is reduced by itself without any activities by the companies itself through the (slow) expansion of wind and PV capacities. This is completely different for the heat supply, since every company independent of its size has its own infrastructure being itself responsible for modernization and decarbonisation. If a fossil boiler has to be changed, it is usually replaced by a new gas boiler without even considering possibilities for decarbonisation. Following, there are no significant changes in the heat supply infrastructure for the next 20 years.

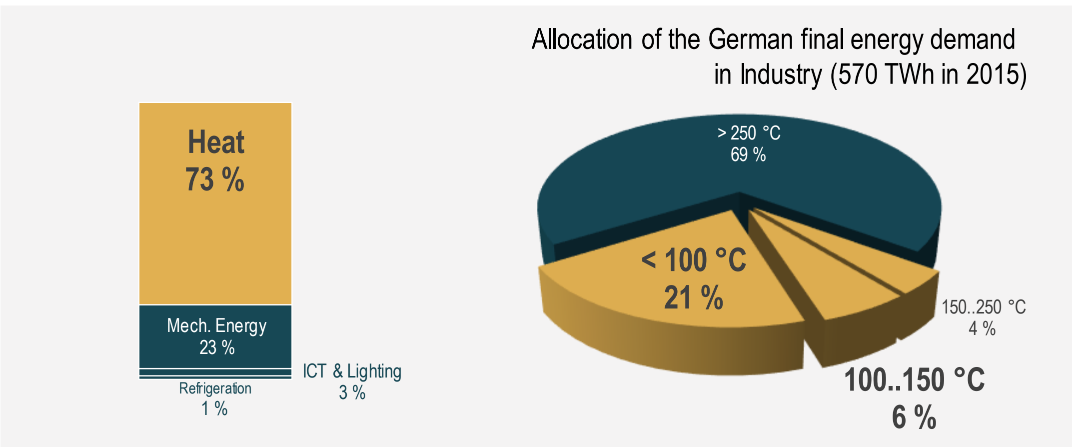

Fig. 1: Distribution of German final energy demand in Industry with respect to use and temperature level, based on BMWi (2018)

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Different potential studies state a huge market potential for solar collectors in Industry and Commerce. About one quarter of the industrial heat demand in Germany needs temperatures below 100 °C and thus can be provided by solar thermal systems. In consequence, there is a market potential of up to 150 Million m² collector area, that has to be developed in the upcoming years (VDI 3988, 2018). The market exploitation should focus on new stakeholders to speed up the dissemination of the potential for solar process heat. Therefore, simple concepts for the use of solar process heat are needed, which can also be applied by inexperienced planners and (energy) consultants. So far, in the German market there are several applications which dominate the emerging solar process heat market. Within this paper, standardized concepts for the integration of solar process heat into the conventional infrastructure are described for these applications with high potential for multiplication.

2. Solar process heat market in Germany

In the first two years after the introduction of the Market Incentive Program (MAP) for solar process heat systems with funding of 50 % of the overall investment costs, the market developed well. Whereas the market startet with nearly 2,000 m² in 2013, the approved collector area more than doubled in 2014. In 2015 and 2016, the market declined significantly, as oil prices dropped over 50 % (Ritter at al., 2017). Since 2017, a positive market development with a noteworthy growth reaching the level of 2014 can be registered again. Likewise, the first months of 2018 are promising. This growth cannot only be traced back to a growing number of applied systems but especially to an increased collector area of these systems. Currently, the largest solar process heat plant is used for drying of woodchips and hay with 1,313 m² of air-collectors. The largest water-based solar process heat plant with nearly 1,000 m² of vacuum tubes is currently installed at the Rothaus Brewery close to Freiburg while an even larger system with almost 1,300 m² of vacuum tubes for the cleaning of road trains is granted and in the detailed planning phase.

Overall, about 15,000 m² of collector area in more than 230 solar process heat systems were installed since 2012 and in addition more than 5,000 m² are planned or installed right now. Including the known systems installed before August 2012, about 25,000 m² of solar thermal collectors will efficiently produce CO_2-free process heat for industry, commerce, agriculture and forestry in Germany at the end of 2018. Although it is a very small share compared to the large market potential, these systems will increase the visibility and can be the basis for a further growth of the German market for solar process heat.

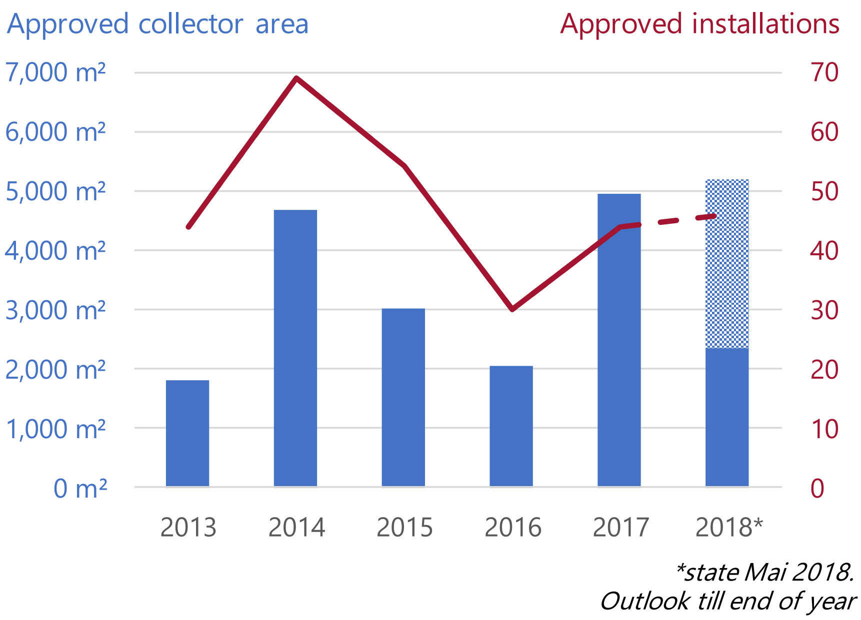

Fig. 2: Market development in Germany. Yearly approved collector area in m² (blue) and number of systems (red)

Till now, mainly flat plate collectors are used and account for 55 % of the installed collector area, vacuum tube collectors and air collectors are both a bit over 22 %. However, the share of air collectors and vacuum tube collectors increased continuously in the last years to the disadvantage of flat plate collectors, whose share dropped below 20 % in 2017.

Economic aspects

Similar to other efficient or renewable technologies, the main barrier for the implementation of solar process heat in Germany is the amortization period. Although funded systems reach high single-digit returns on invest over their life time of at least 20 years the market development is rather slow. Despite the fact that short amortization periods are not suitable for installations with a life time of 20 years or even longer, many companies simply do not accept amortization periods longer than two or three years.

Another barrier is that the turnkey cost can vary significantly, depending on the conventional process technology, collector type, selected hydraulics or even on the chosen supplier. Instead of a generalized amount for the turnkey costs of solar process heat systems comparable with photovoltaic systems it is only possible to communicate a possible range such as 350 to 900 €/m² with a large variance especially for small systems below 100 m². This leads to a reduced transparency and hinders economic feasibility assessments of potential customers.

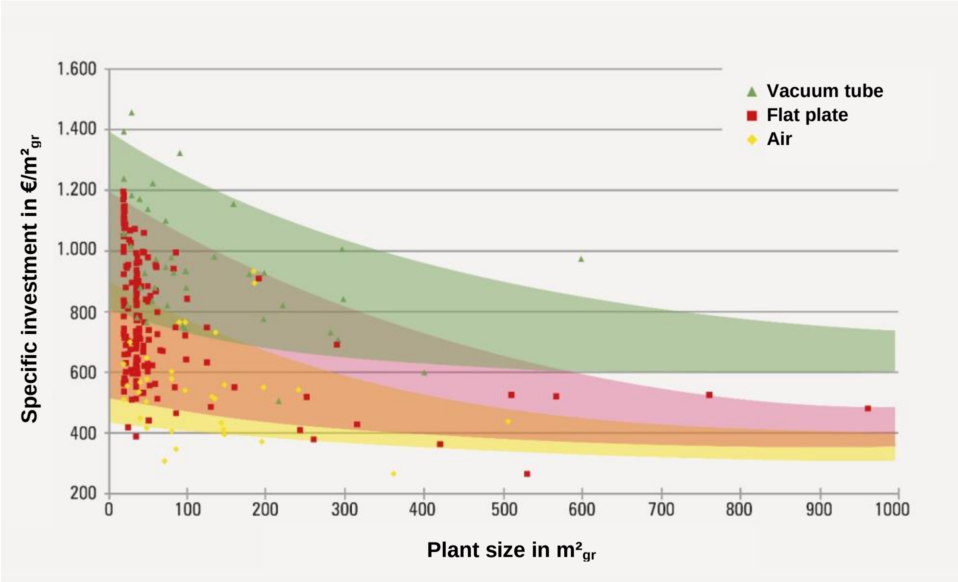

Fig. 3: Specific net investment costs (before funding) of realized solar process heat systems different sizes in Germany using different collector types (www.solar4industry.com)

3. Relevance of solar process heat outside the traditional industry sector

Having a look at the different applications, the German solar process heat market shows the importance of other sectors outside Industry such as commerce and services, agriculture, and forestry. About 80 % of the overall collector area is installed within these sectors (Ritter et al., 2017). Compared to Industry, a successful realization within these sectors is fostered by four important facts: 1. Typically, higher energy costs, 2. Less complex company structures and therefore smoother decision routines, 3. Higher payback times are accepted, and 4. Less complex energetic situation by means of number of heat sinks and potential integration points for solar heat.

With respect to the most popular applications, the market analysis showed some dominating fields. About 80 % of the systems realized since August 2012 are producing renewable heat for the rearing of animals (mainly piglets), the cleaning of vehicles, the drying of biomass with a focus on wood chips and hay, and for cleaning processes in industry and commerce. With more than 100 m² per system, the drying applications with air collectors are in average the largest systems, whereas the average collector field size in the other named application fields are in the range of 50 m². These low hanging fruits show, that even with the given low fossil energy prices there are some branches where systems can be realized successfully. Some companies are even installing solar process heat systems at each of their facilities step by step. These easy to access applications are the foundation for the solar process heat market in Germany increasing the visibility, helping to decrease costs and therefore are the basis to realize systems in larger industrial applications in the near future. Despite these main applications, there is a large variety like galvanization, brewing processes, gas pressure regulation, paint shops, meat and milk processing, and others like tanning and breeding of insects for biological pest control.

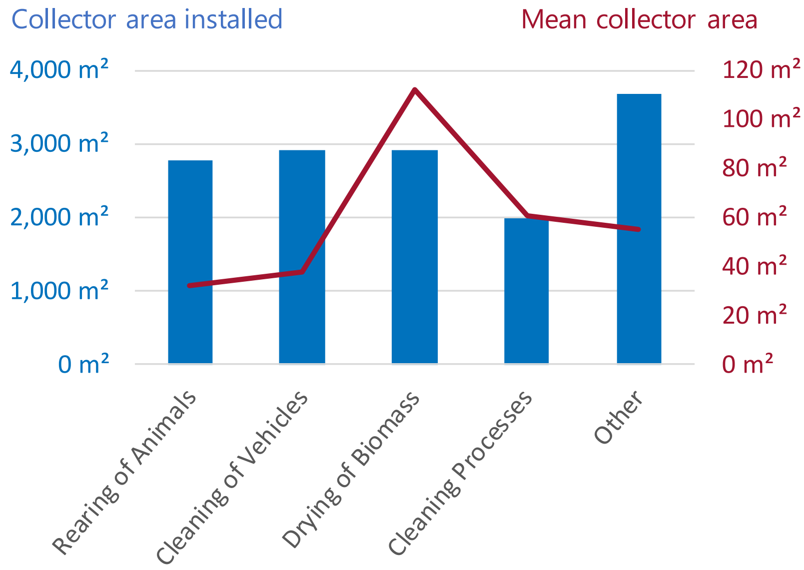

Fig. 4: Installed collector area and average collector field size for the different main applications in Germany

Whereas cleaning and washing processes may differ significantly in terms of temperature level, conventional heating equipment and suitable integration points, the three other dominating applications of solar process heat seem very promising with respect to standardization. So far, there are only a few installations, but the following analysis demonstrates that there still is a huge potential for further installations where standardized system concepts can enhance the market penetration.

In 2017 one fourth of the worldwide pig meat was produced in Europe (USDA, 2017). Within the European Union, Germany and Spain are the biggest producers of pig meat with a share of 24 % and 17 % (Eurostat, 2018). Just the livestock in Germany accounted for 28 Mio. pigs. They were kept in about 23.500 companies and used to produce about 6 Mio. tons of pig meat (Destatis, 2018a). Because more and more companies specialise either on rearing or fattening, the number of rearing companies is assumed to be lower. Furthermore, in addition to the hot water heating of piglet rearing nests, various other heating methods like electric floor heating, electric infrared heating or gas-fired infrared heating are used (Beckert et al., 2012). However, in comparison to the piglet rearing companies that are using solar process heat so far, the total number of companies that are suitable for solar process heat is adequate high to point out the assumed potential for solar process heat in this branch. The same applies to car cleaning and biomass drying systems. The total number of car cleaning companies in Germany accounted for 2.700 companies in 2016 (Destatis, 2018b). In 2014, 0,5 million m^3_{solid} of wood chips were used just in private households in Germany that have to potential to be dried with solar energy (Döring et al., 2016). Of course, not every car cleaning company or technical wood drying system will be suitable for solar process heat supply, but in comparison to the realised systems the potential seems to be more than sufficient.

4. Analysis of most popular solar process heat applications

Due to the relevance of the three applications rearing of animals, cleaning of vehicles and drying of biomass in the German solar process heat market, the paper focuses on the development of standardized concepts for these applications, which could further enhance the market uptake. As it has been demonstrated before, the potential for further implementations is significant and should be addressed. Therefore, the different hydraulic concepts and integration points for solar heat are evaluated and transferred into standardized concepts (up to three, based on the specific application - cf. 4.1). In addition, these systems have been analyzed in terms of specific costs, solar yield, specific collector area (with respect to annual heat demand) and specific storage size[1] (with respect to collector area). In total, planning documents of 174 solar process heat plants were used for the analysis

[1] The solar process heat plants for drying biomass predominantly use air collectors. Thus, apart from singular innovative exceptions no storage is installed.

4.1 Standardized solar process heat concepts

The detailed analysis of hydraulics and integration concepts showed a wide range of different concepts. The largest variety can be found for systems for the rearing of animals. Here, 12 different concepts could be identified. The application of cleaning vehicles still shows eight. Only the drying of biomass shows two different concepts in practise. Nevertheless, all concepts show a lot of similarities and only differ in detail. Within this paper, two or three standard concepts have been derived for each application combining the advantages of the different analysed concepts.

Rearing of animals

Farm animals need constant temperatures to reach a satisfying growth. Therefore, so-called "nests" are typically kept at temperature around 30 °C by floor heating systems. Similar to domestic applications, supply temperatures of 60 °C are used for this application. In order to avoid too high flow temperatures and a low return temperature, the return flow is fed partially into the flow as shown in Fig. 5. The solar heat is fed into buffer storage. The return of the heating circuit feeds into the bottom of the storage. The storage is heated by the collector field via an external heat exchanger whereby the height of the feed-in is controlled by a three-way valve. Thereby, the solar heat can be integrated at middle height (preheating) or in the top area (set temperature). As auxiliary heater the conventional boiler saves the set temperatures in the upper area of the storage.

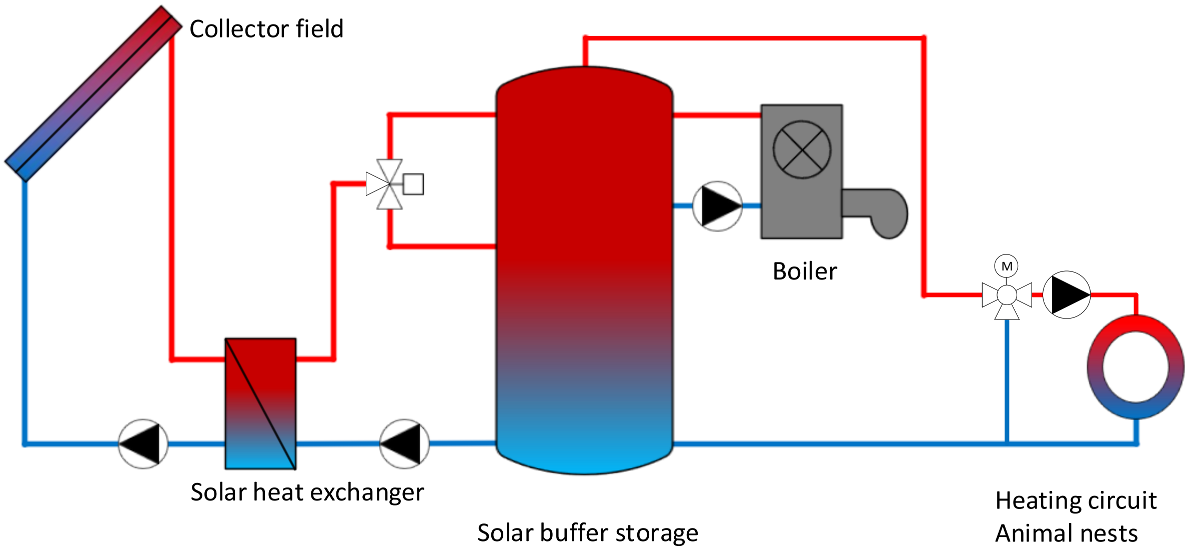

Fig. 5: Standardized solar concept for animal rearing stations with the heating circuit as heat sink

Very often, not only space heating for the animal nests but also hot water for food preparation or cleaning processes is needed. Therefore, a second integration concept is needed (Fig. 6). The hot water generation should be arranged in parallel to the heating circuit. The hot water is heated by a fresh water station which must be sized with respect to peak loads during cleaning. This concept has the advantage that all heat sinks can be provided with solar heat. Still, the set temperature for the upper area of the storage must be chosen with respect to the hot water temperature. Furthermore, it its important to have a good control of the system in a way that low return temperatures in the bottom part of the storage can be reached. That is also why the return flows are fed separately into the storage. The return of the fresh water station can reach lower temperatures than the return of the floor heating system. Latter is plugged above the storage connection of the return of the fresh water station.

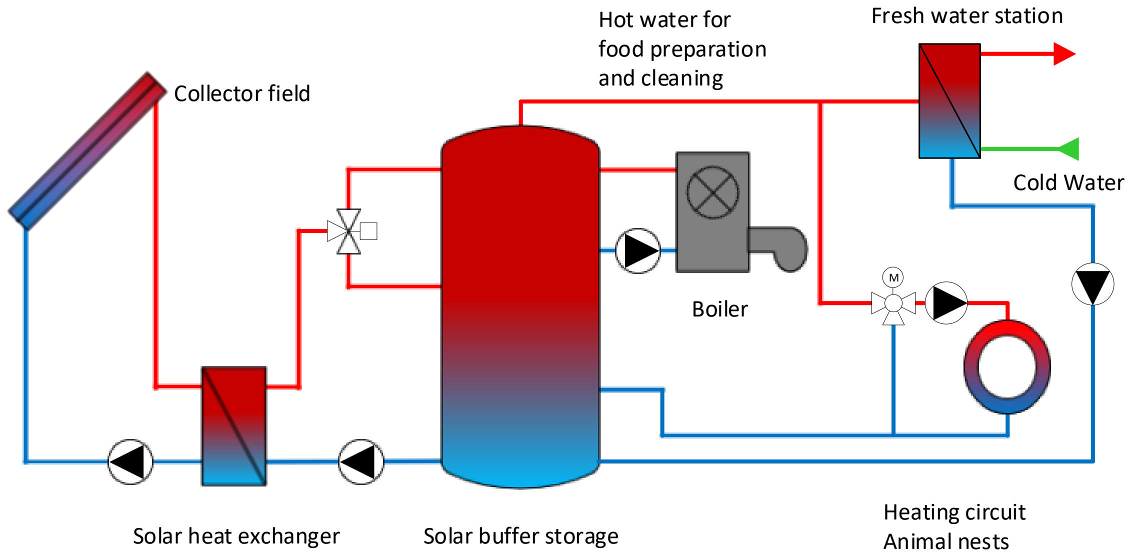

Fig. 6: Standardized solar concept for animal rearing stations with heating circuit and hot water generation as heat sinks

Cleaning of vehicles

The cleaning of vehicles consumes a lot of hot water and can be generally divided into self-service washing stations and car-wash plants, with the latter typically using cold water for cleaning. To reach a good cleaning result the hot water can be heated up to 60 °C (typically 50 °C), based on the way of cleaning and amount of cleaning agents. Besides the hot water generation for self-service washing stations, the washing area has to be kept free of ice in in winter time, which is another potential heat sink for a solar process heat plant. Therefore, floor heating systems below the cleaning areas are installed. In those cases, heating circuit and hot water preparation are connected in parallel (Fig. 7). The flow temperatures of the floor heating systems can be set very low because only icing should be prevented. Consequently, very low return temperatures are reached. So, it is suitable to mix it with the return of the fresh water station providing the hot water for cleaning and to refeed the mixed flow into the bottom area of the storage. This is the only difference to concept 2 for animal rearing stations where the return flows are kept separately. This concept is mainly used if the heat supply is going to be redesigned or if a car cleaning station is going to be built newly by itself.

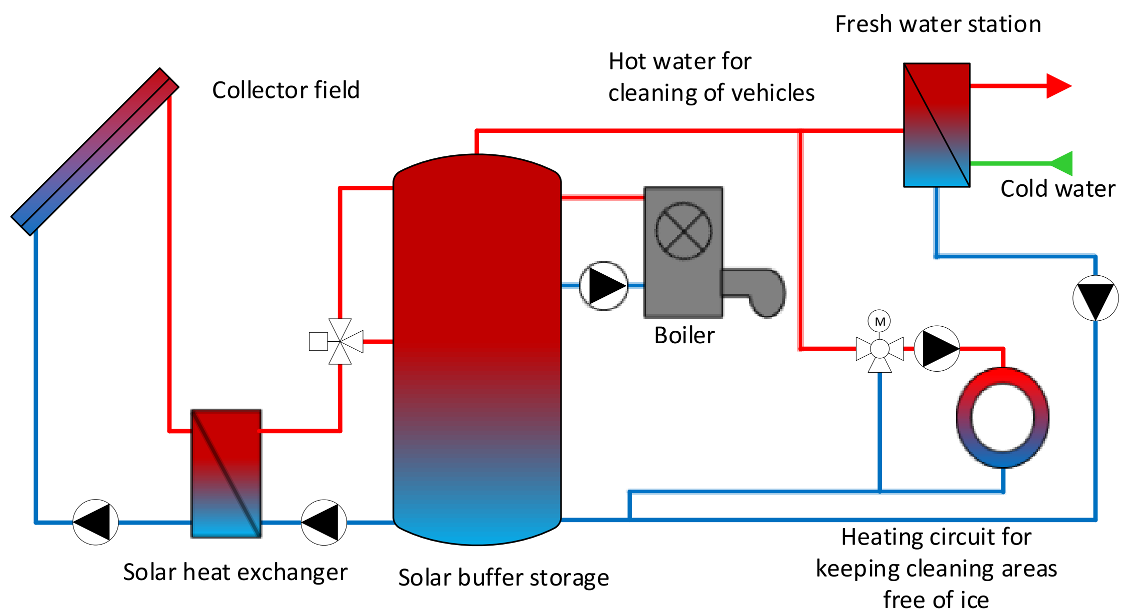

Fig. 7: Standardized solar concept for the cleaning of vehicles with one storage (new building)

If the solar heating plant is going to be integrated in the existing heat supply, another concept should be preferred which is presented in Fig. 8. The conventional system has a hot water storage to cover the typical peak loads. The heating circuit is connected to the bottom of the storage using low temperatures. The storage is heated by a fossil burner via an external heat exchanger. The hot water for cleaning is taken directly from the top of the storage. The solar thermal system is installed in serial as a preheating system. The auxiliary heating storage is fed by preheated water which is taken from the solar hot water storage. This differs to all other concepts presented where the solar storage always acts as a buffer storage. Hence, this system concept has the disadvantage that the solar heating plant can only provide heat to the overall system if there is a hot water demand. In case of no hot water is desired but the floor heating system is working, the bottom area of the auxiliary storage has to be reheated by the fossil boiler. Due to the fact that the heat demand for hot water generation is dominating and the floor heating system is only active if the cleaning places are opened this seems to be feasible.

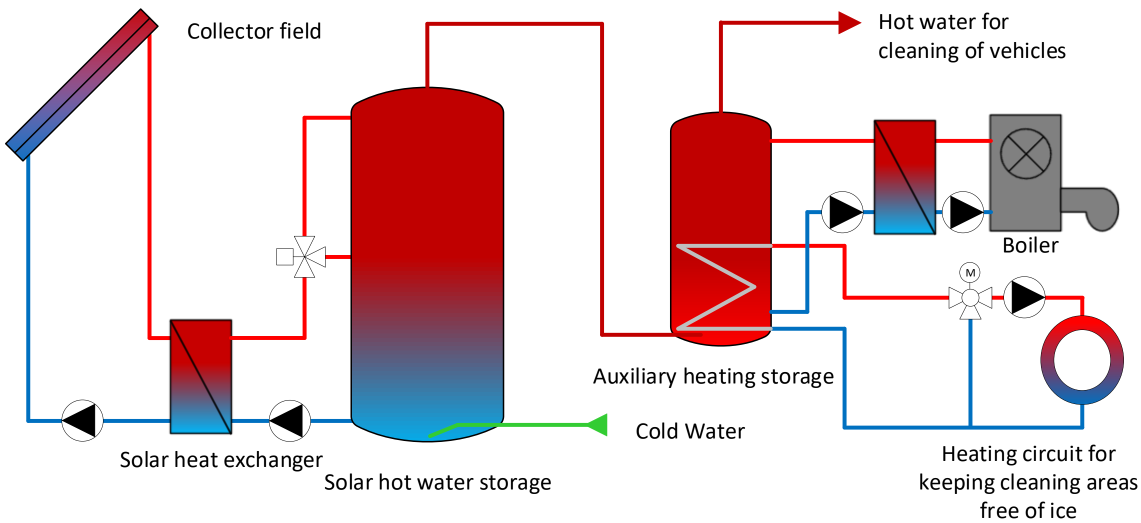

Fig. 8: Standardized solar concept for the cleaning of vehicles with one storage (old building)

Drying of biomass

Drying of agricultural products to increase or guarantee quality or for preservation reasons is an important market for solar process heat. Due to fact that air is the dominating process medium, solar air collectors play a major role for this application. Air collector fields are easier in terms of integration and control. In general, the air collectors preheat ambient air while the conventional system ensures the set temperature. Often, there is even no need for a conventional system because of the congruence of heat demand and solar radiation. Then, the products are only dried if there is sufficient solar radiation. Fig. 9 shows a typical solar drying system. Ambient air is sucked through the collector field by a ventilation system and thereby heated up. Since the collector output temperature cannot be controlled exactly the heat air can be mixed with ambient air by a mixing valve and the air temperature reduced by this means. How much additional ambient air is sucked in to reduce the drying temperature is controlled by the second fan just before entering the drying area. The drying products are placed on a grate which can be inclined in some cases. The hot air is blown in from the bottom and pushed through the raised biomass material (e.g. wood chips). In general, not heat recovery system is installed because the exhaust air is very humid and relatively cool.

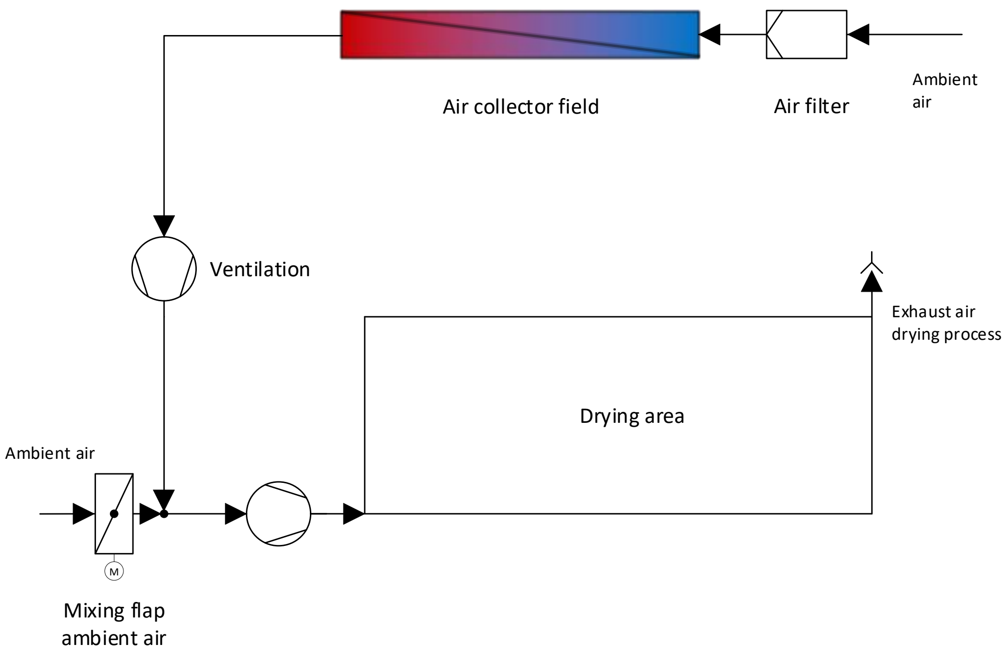

Fig. 9: Standardized concept for drying of bulk materials in (inclined) grates

In many cases, different products have to be dried with different maximum temperatures that can be accepted due to product protection. Fig. 10 demonstrates this concept for two different set temperatures. The output air stream of the collector field is cooled down by ambient air with a first mixing flap (upper left) to the set temperature which is needed in the drying containers (e.g. for wood chips). A share of the mixed stream is sucked by a second fan which is feeding the drying area (centre of Fig. 10). A second mixing flap before the fan enables to further reduce the air temperature for this drying area (e.g.in case of hay drying). Throttle flaps control the input flow of heated air into the different containers.

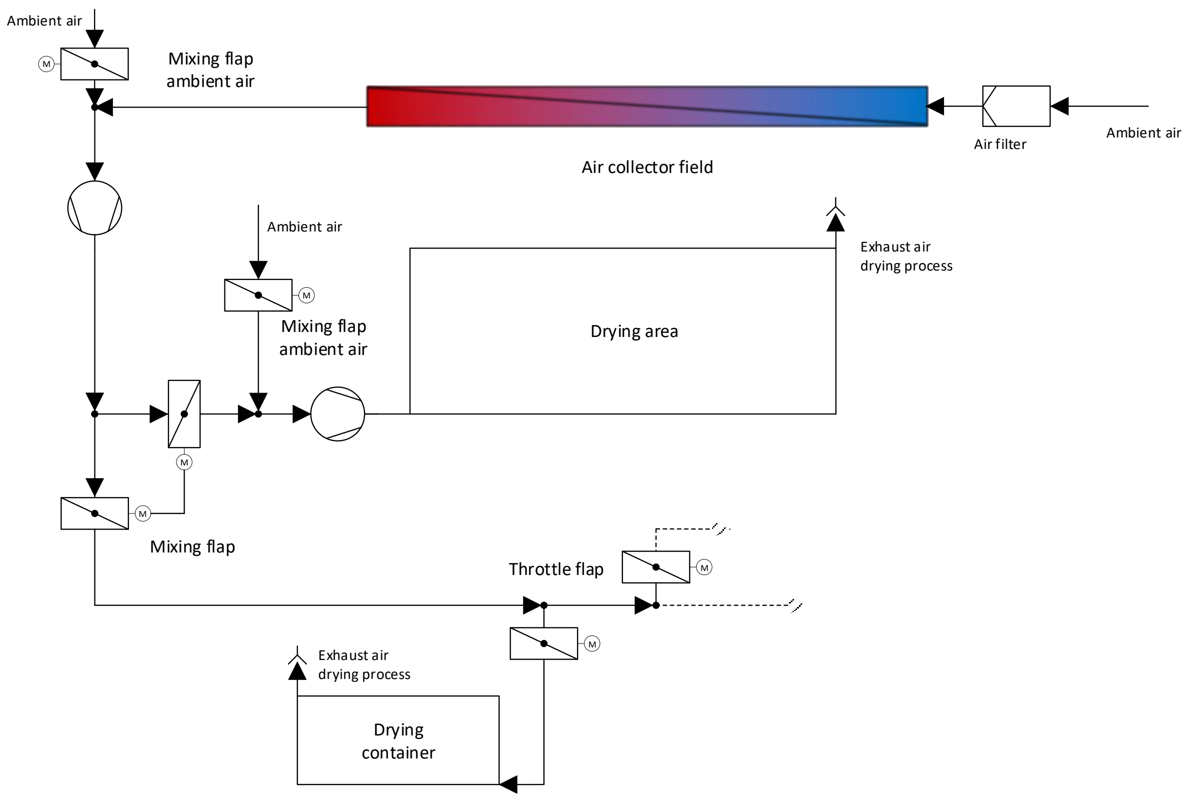

Fig. 10: Standardized concept for drying of biomass for several products with different maximum temperatures

4.2 Dimensioning, solar yield and system costs

Fig. 11 shows the results of the analysis of the dimensioning strategies for the three applications. Looking at the average collector area for “rearing of animals” shows that the specific collector area in relation to the annual heat demand is smaller compared to the other applications. As shown above, the rearing of animals predominantly needs heat for space heating. In consequence, the load profile shows a strong decrease of heat demand in summer which leads to smaller collector areas. In contrast, the heat demand for cleaning of vehicles is more constant over the year and in most cases correlated to the solar irradiation. Thus, larger collector areas in relation to the annual heat demand are possible, leading to higher solar fractions. With 60 l/m² the storage size for this application is lower than for rearing of animals, which is also based on the fact that heat demand and solar irradiation is correlating. The range of storage sizes in animal rearing stations is clearly higher which traces back on the different concepts for the use of solar heat. If heat is provided only for space heating but not for cleaning water the storage can be sized much smaller.

The application of biomass drying shows significant higher specific collector area. Similar to car washing, this application benefits from the simultaneity of heat demand (e.g. for hay drying) and solar radiation which enables larger collector areas. Additionally, these kinds of solar heating plants can be operated already with a few Kelvins of temperature difference, which increases the effect. Even so, the standard deviation is in the same range as in the other two applications the systems can be designed very differently.

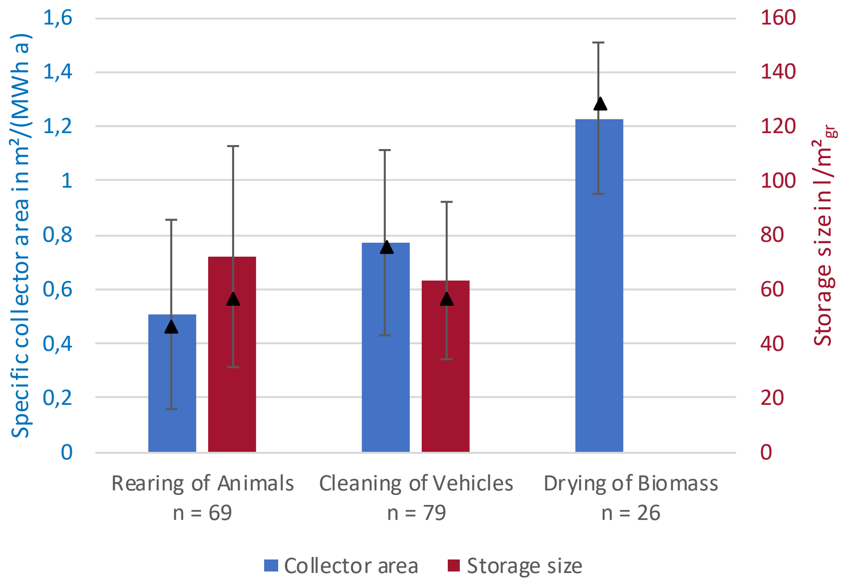

Fig. 11: Mean specific collector area and storage size for the installed systems within the three applications, error bars represent standard deviation, drying systems using air collectors without storage

As it can be seen in Fig. 12 the specific costs do not only vary between the applications but also between the installations within the same application. This leads back to differences in the conventional heating equipment and the consequent different efforts needed for the integration of solar heat. Additionally, there can be differences by the used collector technology or also by the commissioned company. Air collector systems prove to be most cost effective. These systems are less complex and easy to install by the use of air as heat medium. The systems do not need any stagnation protection or heat exchanger because air is the heat carrier and process medium rolled into one. The cheapest system reached costs below 400 €/m². In addition, the air collector systems generate high solar yields because generally all the produced heat can be used (heat demand is available every day) and the temperature level of the heat demand is very low with max. 60 °C. Due to the lack of any heat exchangers, the solar collectors do not need to work above process temperature. Depending on the material to be dried and the actual humidity even lower temperature than 60 °C are sufficient. Taking the funding into account, levelized costs of heat in the order of 10 €/MWh_{th} or even below can be reached.

The cleaning of vehicles shows higher specific costs with approximately 1,000 €/m² on average. As shown before, two heat sinks, hot water for cleaning and floor heating to keep the cleaning area free of ice, typically have to be provided with heat. The demand of hot water is not continuous showing high peaks in the demand. This affects the design of the whole system. All components have to be sized in order to be able to cover peak loads which results in higher costs. The costs for a solar process heat installation for animal rearing is in the range of 730 €/m² on average. With more than 400 kWh/m²a, the specific solar yield is in a suitable range with respect to the temperature level that has to be provided. Systems for the cleaning of vehicles reach even higher yields (450 kWh/m²a) because the preheating of water on a low temperature level and the simultaneity of heat demand and solar irradiation results in a more efficient operation of the solar process heat installation.

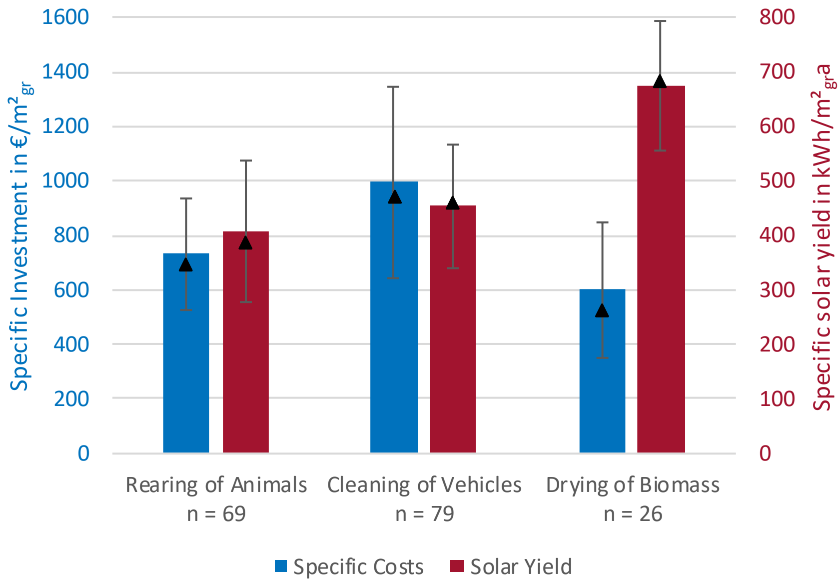

Fig. 12: Mean specific costs and solar yield for the installed systems within the three sectors, error bars represent standard deviation

5. Summary and Outlook

The solar process heat market in Germany shows a promising development after critical years in 2014 and 2015. Based on the strong funding within the Market Incentive Program, solar process heat systems can be competitive to heat generated by fossil fuels. So far, there are a few applications (Rearing of animals, cleaning of vehicles and drying of biomass) that dominate the market so far. Within this paper, standardized concepts for the use of solar heating plants for these applications have been derived by a detailed analysis of implemented systems. These standardized concepts are transferred into fact sheet that are used to facilitate the market entry of new stakeholders by providing all relevant information such as dimensioning, energetic key facts and economics. Those concepts will be available free of charge at www.solar.4industry.com and will help to tap the potential of low hanging fruits in the field of solar process heat. In future, the market is going to be monitored continuously to derive further standardized concepts for other applications e.g. for heated baths or handling units. Next to these standardized systems concepts and general information that are provided by the website, the new VDI standard 3988 “Solar thermal process heat” is a very important step to support the market by standardizing the planning and installation of solar process heat systems. Currently this standard is available in green print, the final version is expected to be published early 2019.

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