Eight Feasibility Studies Demonstrating the Potential of Solar Process Heat in the European Automotive Industry

Felix Pag, Bastian Schmitt and Klaus Vajen

University of Kassel, Institute of Thermal Engineering
Kassel, Germany

Abstract

Solar process heat is an important part of future decarbonised heat supply but has not been able to meet the expectations of the market penetration. The automotive industry is a globally leading industry sector cutting edge research and technical innovation. Together, a large-scale implementation within this sector could bring the much-needed breakthrough for the widespread use of industrial solar process heat. To enable such a reality, several case studies have been carried out within the research project "SolarAutomotive" to detail all relevant industrial heat sinks suitable for solar process heat integration. Within this paper, exemplar results are presented, demonstrating the potential of this application to reduce the CO_2-emissions in industrial heat supply. The collector potential identified in the presented case studies totals to more than 11,000 m^2_{gr} (gross area), which are currently being discussed internally within the companies.

Keywords: Solar process heat, SHIP, Feasibility study, Automotive, Industry, Depreciation, Solar economics

1. Introduction

The automotive industry and their suppliers comprise the most important global industry sectors based on turn-over and employees and have a leading role regarding technical innovations. More than three million people are employed in the European automotive and associated industries representing more than 10 % of the EU manufacturing employment. The sector accounts for about 4 % of the European gross domestic product (GDP). The overall energy consumption (heat and electricity) is 39 TWh and annual CO_2-emissions of 10 million (ACEA, 2017).

Solar heat for industrial processes (SHIP) is a reliable, carbon-free technology for industrial heat supply. Despite hundreds of implementations world-wide, a significant market penetration has not yet been still achieved. If the major automotive players begin to adopt the use of SHIP at their production sites, it can be a strong signal to begin a sustainable and self-reinforcing market uptake. The automotive industry and their suppliers are comprised of 12 sectors, from the OEMs (Original Equipment Manufacturer) themselves to comparably small companies producing textiles, plastics, or electronics. These sectors cover a wide spectrum of production processes required to generalise SHIP projects and eventually transfer the results to other industrial sectors. Therefore, within the research project "SolarAutomotive" several feasibility studies are conducted in the automotive industry. Based on a detailed analysis of various production sites, including heat supply and heat-consuming processes, integration concepts for solar process heat have been technically developed and economically evaluated. Twenty-five case studies in eight European countries have been conducted with eight presented with this paper.

2. Methodology

The case studies are targeted at the complete value chain in the automotive industry and their suppliers. They cover the most relevant heat sinks such as central heating networks, bath heating, drying, and supply of hot water. Very influencing boundary conditions are represented, such as different climatic conditions (irradiation and ambient temperature) and economic parameters (available subsidies, gas prices, internal CO_2-reduction goals and accepted mitigation costs). Within the feasibility assessment all relevant collector technologies such as flat plate collectors (FPC), evacuated tube collectors (ETC), compound parabolic concentrators (CPC) and air collectors (AirC) are considered depending on the respective heat sink and temperature level. The analysed production sites and the relating industry sectors are in Fig. 1.

doi:10.18086/swc.2017.26.11 Available at http://proceedings.ises.org

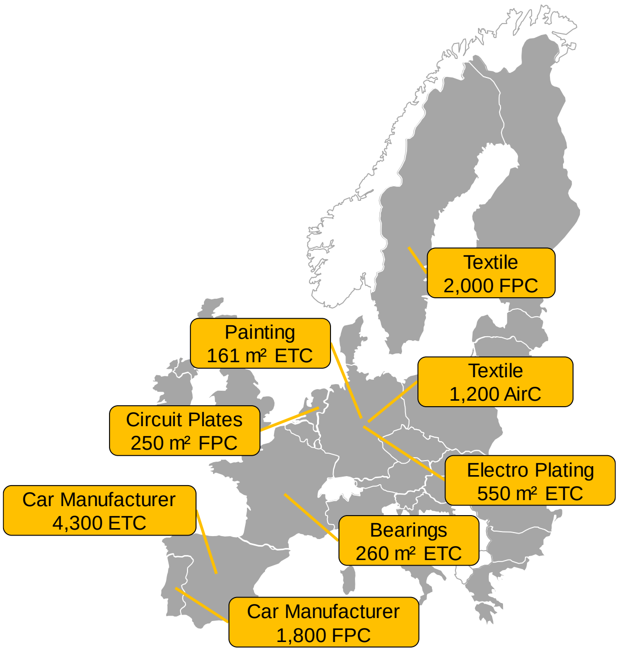

Fig. 1: Analysed production sites within Europe and related industry sectors

2.1 Technical Evaluation

Based on the daily summer heat demand and the heat sink (process) temperature, the maximum potential collector area is calculated. By this design, the solar heating plant produces no excess heat during regular operation and on sunny days the entire heat demand can be covered. This method allows both a relatively high solar specific yield and solar fraction in a highly economical way. Often, the largest solar process heat plant cannot be realised due to site limitations and zoning restrictions. Using Lauterbach (2014), the solar yield and the utilisation ratio of the solar heating plant can be determined for various daily heat demands and installed solar process heat plant size ratios. The energy analysis and solar heating plant performance is then discussed with the company's persons in charge. If there is further interest, a detailed on-site inspection is performed to refine the analysis, which includes suitable roof or ground areas identification and heat sinks as well as heat supply infrastructure. Based on the situation at the production site and the results from the inspection, the collector area of the solar heating plant is reassessed, which often leads to a reduced solar heating plant size and solar fraction. However, an undersized solar heating plant can operate at lower collector temperatures, thus increasing efficiency and utilisation factor. Finally, a detailed simulation with Polysun is performed to calculate the solar yield, utilisation ratio, and the solar fraction, inputs for the economic assessment.

This approach is distilled into a pre-design tool to calculate all relevant parameters within the feasibility assessment. It is based on hundreds of dynamic simulations with different load profiles, process temperatures, geographic locations, and collector technologies (Lauterbach, 2014). The tool uses the production site's latitude to estimate the annual irradiation and peak solar availability in summer for plant sizing purposes. Process flow and return temperatures and an estimated daily load and its profile can be selected by the user. With this information, the tool calculates the potential collector area and storage size, followed in an estimated solar yield and utilisation ratio. If the irradiation at the respective geographic location is known, the solar yield can be recalculated by the product of annual irradiation and utilisation factor for a more accurate result. The tool and its results for those feasibility assessments are validated with Polysun and prove very good compliance. The pre-design tool can be used free of charge (designtool.solar4industry.info).

2.2 Economic Evaluation

Two different economic evaluation approaches are considered. On the one hand, the levelised cost of solar heat are calculated over the life time of the system based on the recommendations of Task 54 (Louvet et al., 2017), comparing solar to conventional heat supply costs over a 25 year lifetime. The conventional heat supply costs are calculated using a gas price and an estimated utilisation factor of the boiler (typically between 75..85 %). On the other hand, the total cost of ownership method is used to determine payback time, internal rate of return and net present value. The solar heating plant investments are estimated by experience and detailed analysis of solar process heat systems in Germany based on size, collector technology, plant location, and integration effort. Other relevant parameters for the economic calculation are in Tab. 1.

Tab. 1: Technical and economic parameters for the calculation of the levelised cost of solar heat and for the total costs of ownership

Parameter	Value
Performance factor[1]	70..100
Price increase of fossil fuels	3 %/a
Inflation	0.8 %
Maintenance, repair, and insurance	0.7 %
Discount rate	4 %
Operation time	25 a

In addition to the natural gas savings, the depreciation of the solar heating plant is considered for a detailed economic assessment. Depreciation is an allocation method that enables a company to reduce the economic value of an asset over a certain time. The depreciated value of the asset reduces to company-wide profit and thus the tax load over the depreciation period. This can significantly decrease the payback time and increase the internal rate of return. Approaches not considering the depreciation of the solar heating plants cannot evaluate the investment correctly.

Assed depreciation is defined by the national tax law and varies between different countries in both number of years and its calculation method. The method of depreciation can either be straight-line or a declined-balanced method. Whereas the straight-line method continuously and equally depreciates the complete investment, the declined-balanced method has an accelerated depreciation in the first years and a decelerated in the final years. Therefore, it is not possible to depreciate the complete investment with the declined-balanced method. The actual additional benefit of a solar heating plant by reducing a company's tax burden is calculated on an annual basis by the product of the depreciation rate per year (DEP in €) and the respective business tax rate (TR in %) shown in eq. 1.

$$Tax\ Benefit = \sum_{i=1}^{\substack{Years\ of \\ Depreciation}} DEP_i \cdot TR \qquad \text{(eq. 1)}$$

In tab. 2**Fehler! Verweisquelle konnte nicht gefunden werden.** different depreciation parameters and tax rates are presented for the analysed countries showing the additional benefit of depreciating a solar heating plant. The depreciation duration plays a significant role regarding the tax benefit of the solar heating plant, most notable for the declined-balanced method within the first four years. Since nearly all companies solely base capital investment on payback time, the first years are most important in reaching a decision in industrial companies.

---

[1] Ratio of delivered solar heat to used electricity

Tab. 2: Overview of the depreciation methods and rates in the related countries of the EU

Country	Depreciation method	Depreciation factor[1]	Years of depreciation	Depreciated investment in the first 4 years	Corporate tax rates	Additional benefit[2] within the first 4 years
DE	Straight-line	-	10	40 %	29.88 %	12 %
ES	Straight-line	-	14	29 %	25 %	7 %
FR	Declined-balanced	2.25	10	64 %	34.43 %	22 %
NL	Straight-line	-	5	80 %	25 %	20 %
PT	Declined-balanced	2.5	4	98 %	25.5 %	25 %

As an example, the German depreciation method is fixed to the straight-line method with a 10 years depreciation period and the business tax of 29.83 %. In contrast, the Portuguese depreciation period is reduced to four years and applies the declined-balanced method (with an accelerating factor of 2.5). The business tax in Portugal is 25.5 %. Assuming 100,000 € investment, 40,000 € can be depreciated within the first four years in Germany, resulting in an additional economic benefit of 11,932 €. In contrast, the benefit in Portugal is more than double with 24,955 € within four years, nearly depreciating the entire solar heating plant. For a better understanding of the cash flows regarding both depreciation methods, Fig. 2 shows the annual depreciation rates (bars) and the additional benefit (dashed line) of solar heating plants. The Portuguese results for the declined-balanced method with four years depreciation period are in green and the German straight-line method over ten years is shown in red. Exemplarily, a corporate tax rate of 25 % has been assumed for both calculations for a better consistency. As quickly seen, the tax benefit of both methods is the same over ten years. In Portugal, a greater tax benefit is realised within the first years and as such the payback time is significantly reduced.

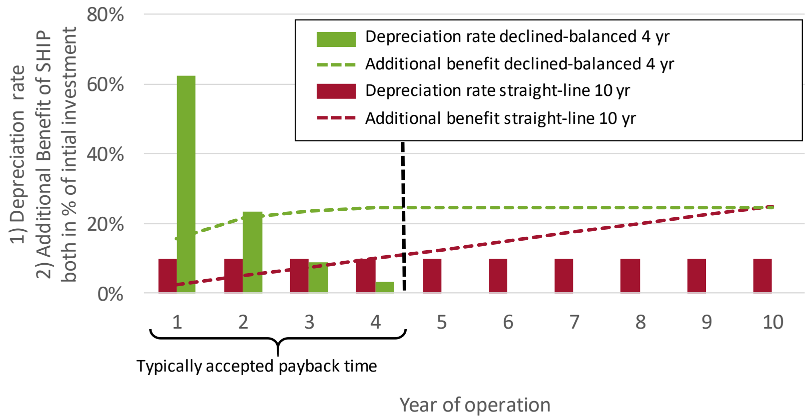

Fig. 2: Comparison between two depreciation methods and duration regarding the depreciation rate and additional tax benefit of a solar heating plant. The depreciation factor for declined-balanced method is 2.5 and the corporate tax rate is 25 %

To conclude, the payback time of solar heating plants in industry is reduced by depreciating capital investments. This boosts the market uptake, already seen in some countries, such as Portugal, France, and also in India. In addition, governmental tax revenue is not affected long term by the inclusion of depreciation and should not be a hinderance in future economic policy.

[1] Only existent for declined-balanced method
[2] In relation to the initial investment

3. Results

As already mentioned, numerous feasibility studies including solar heating plant pre-design are carried out within the project "SolarAutomotive". By several case studies in companies specialised in surface treatment, it is seen that this sector in general and electro plating in specific are very promising for the use of solar process heat. In this sector, many baths must be heated and kept at elevated temperatures, easily achievable for solar heating plants. In summer, there is a significant base heat load and any possible heat recovery barely reduces overall heat demand. Solar process heat integration for heated baths is also fairly easy through dimple plates or by external heat exchangers.

Only a few selected case studies are discussed in this work to provide a wide range of examples. For a more detailed assessment on a German electroplating company Pag et al. (2017) details a performed case study and proposes a concept to use of solar process heat in combination with a micro gas turbine.

Tab. 3 shows an overview of the selected feasibility studies, followed by a summarised explanation.

Tab. 3: Overview of the performed feasibility studies
Heating network, supply/return temperature; Heat recovery network, supply/return temperature; Hot water, start..set temperature; Bath heating, bath temperature; Drying, start..set temperature

Country	Sector	Heat sink	Pre-design[1]	Irradiation in kWh/m^2a[2]	Specific solar yield in $kWh/m^2_{gr}a$	Solar fraction[3]
ESP	Car manufacturing	Heating network, 130/110 °C	4,300 m² ETC	1,670	410	5 %
PT	Car manufacturing	Heating network, 70/40 °C	1,800 m² FPC, 75 m³	1,920	830	34 %
GER	Electro Plating of Plastics	Heating network, 80/70 °C	1,000 m² ETC + 317 kW_{th} CHP,	1,010	350	18 %
NL	Circuit boards	Hot water 15..60 °C	250 m² FPC, 15 m³	1,130	430	5 %
FR	Bearings	Heat recovery network, 80/60 °C	260 m² ETC, 25 m³	1,210	485	5 %
GER	Textile processing	Drying, 10..60 °C	1,200 m² AirC	1,040	480	10 %
SWE	Textile processing	Hot water, 10..60 °C	2,000 m² FPC, 175 m³	1,040	550	23 %
GER	Painting	Bath heating, 43 °C	161 m² ETC, 8 m³	960	390	31 %

3.1 Car manufacturing in Spain

The production site analysis in northern Spain shows that the specific yield does not allow an economic integration of solar heat at the moment, even though there is a good irradiation and significant open land for plant construction. The return and flow temperatures of the central hot water network are unnecessarily high but cannot be lowered due to one single process (wax bath) with a high temperature level. In addition, there are six weeks in summer

[1] If not specified differently, the collector area given refers to the summarised gross area of the collector field
[2] On tilted surface
[3] Solar fraction is given with respect to overall heat consumption (central heating network) or to process heat demand (Hot Water, Bath heating, Drying) if not specified differently.

(two weeks in June and four weeks in August) when the production site is closed completely and the hot water network is shut down. To handle this long period during times of high irradiation without a heat sink, parabolic trough collectors that can be defocused and evacuated tube collectors with a built-in switch-off temperature are considered within the feasibility assessment. The latter concept with 4,300 m² collector area still reaches specific annual yields of more than 400 kWh/m²$_{gr}$. The potential plant site is located more than a kilometre away from the boiler site and complicates the integration. The closest reasonable integration point is 900 m away and still challenging. Due to no subsidy program for solar process heat plants in Spain, an implementation is not realistic and further investigations have been put on hold.

3.2 Car manufacturing in Portugal

Within the production site of a Portuguese car manufacturer, a hot water network is operated with a 70 °C flow and process dependent 40..50 °C return temperature. In addition to heat recovery from the thermal oxidiser in the paint-shop, three gas boilers with an overall capacity of 13 MW provide heat for an annual heat demand of 4.4 GWh. Process heat demand is distributed more or less evenly over the day with a light peak in the morning. Heat demand will be significantly increased due to a doubling of production capacity until the end of 2017. The future designed heat load is estimated to be 7 MWh/d to be served with a flat-plate collector field of 1,800 m². Due to the high local irradiance, a low temperature level and constant load profile, a specific solar yield of 830 kWh/m²a can be achieved. The levelised cost of heat were calculated with 25 €/MWh over 25 years. Despite the four-year declined-balanced deprecation period for solar heating plants in Portugal, the payback time is 15 years due to the low gas price and no other solar process heat plant subsidies.

3.3 Electro plating of plastics in Germany

The analysed electro plating line has a heat demand of 2 GWh/a. Due to a high electrical base load, a combined heat and power plant (CHP) is taken into consideration. In Germany, subsidies for a CHP are paid over a fixed period of full load hours. This opens up the possibility to change the typical dimensioning of a CHP and its operational mode because it is no longer necessary to continually operate the best economic return. To increase the share of heat supplied by CHP in winter, the plant is designed based on the winter load. In return, the CHP is switched off between May and September to avoid inefficient part load behaviour and increased burner cycling. This enables a larger solar heating plant to be integrated, covering a relevant share of the summer heat demand. The residual heat load is covered by a conventional gas boiler. The CHP has a thermal capacity of 318 kW. The collector field is designed with 1,000 m² ETC. This technology coupling covers more than two thirds of the heat demand with low carbon heating technologies (CHP: 50 %, solar: 18 %). The investment is estimated to be 570,000 €, with an internal rate of return of nearly 10 % over 15 years. Using the conventional design rules for CHP (summer load), a CHP with a thermal capacity of only 212 kW could be implemented with no further potential for solar heat due to the reduced heat load during summer that is already covered by CHP.

3.4 Production of circuit boards in the Netherlands

Circuit boards are produced in continuous loop and plunged consecutively into various baths. The company has several production lines with over 500 baths in total (several hundred litres each), with 56 requiring heat up to 60 °C. The baths are electrically heated with an overall nominal capacity of 455 kW. Due to the large number of baths and their small volume, solar process heat integration for direct bath heating would be very complex and expensive. However, the baths are fed with fresh water to compensate evaporation and carryover losses. This is currently done by cold water, which has to be electrically heated. A new concept is developed with a second feed line for fresh water at 60 °C. This enables a simple and cost-efficient possibility to integrate solar heat. The amount of hot water is estimated to be 7 m³/d with a FPC solar process heat potential of up to 250 m². Due to the constant load profile during the week (five days, two to three shifts), a specific yield of 430 kWh/m²a can be achieved (118 MWh/a) and corresponds to a solar fraction of about 5 % with respect to the overall heat demand at the production site. The levelised cost of heat is estimated between 24.5 €/MWh and 37.2 €/MWh depending on the development of the tariffs of the feed-in subsidy scheme.

3.5 Production of bearings in France

The heat for the French production site is currently supplied by a steam boiler. Within 2018, the steam network will be completely replaced by a hot water network with a 70 °C supply and 40 °C return temperature and a condensing gas boiler. Heat recovery from compressed air generation from compression chillers will be implemented and its recovered heat is fed into the network. There is a still a residual heat demand that can partially be covered by solar heat. A solar heating plant is designed to have 260 m² ETC collectors and includes a storage of 25 m³ generating 126 MWh/a. The levelised cost of solar heat is approximately 20 €/MWh due to an existing national subsidy for solar process heat in France. Following detailed measurements after the implementation of the new heat network, the solar heating plant will be redesigned and built by the end of 2018 if the solar heating plant is still economically feasible.

3.6 Textile processing in Germany

This company with more than 140 employees covers the whole spectrum of product finishing with processes such as sizing, dyeing, and coating of textiles and relating materials. The three-shift operation over five days is very water and energy intensive, constantly needing massive amounts of hot water at different temperature levels up to 90 °C. Due to expansive use of heat recovery from a regenerative thermal oxidiser that purifies exhaust air, the hot water demand is nearly fully covered. The exhaust air originates from several stenters and a dryer that uses fresh air heated to 200 °C. By using all the heat recovery for water (pre-) heating, the fresh air for these applications must be heated internally by internal and external heat exchangers from the central steam network. Solar air collectors can be used to preheat the required air for these heat sinks. Based on the air volumetric flow rates and the set temperatures of the stenters (46,400 m³/h; 200 °C) and the dryer (8,000 m³/h; 140 °C), the heat demand has been estimated by 22.4 MWh/d in summer (ambient air temperature 20 °C), considering a simultaneity factor of 0.5 and 15 hours of operation per day. This results in a yearly heat demand of 5.2 GWh. To cover a relevant share by solar collectors, an air collector system with 1,200 m² is designed and simulated. These collectors preheat the incoming air from ambient temperature to a maximum of 60 °C. The solar heating plant obtains a collector yield of 707 kWh/m²a but only 481 kWh/m²a can be used in the processes due to the lack of storage. Still, a solar fraction of 10 % with respect to the process can be achieved. The estimated investment of 350,000 € including 50,000 € for installation, results in solar heating costs of 12 €/MWh.

3.7 Textile processing in Sweden

The production site is operated 24 hours per day and 6 days per week with a three weeks summer production break. More than 400 m³/d of 60 °C hot water is required for dyeing and washing leading to a daily heat demand of 21 MWh in the summer. The heat demand is met with a steam boiler at 190 °C. To cover the summer daily heat demand, nearly 5,000 m² FPC are theoretically required. A flat roof offers an area of about 10,000 m² but considering roof statics, skylights, and collector spacing the feasible collector area is approximately 2,000 m². Depending on the currently unknown actual hourly load profile the specific solar yield can range between 520 and 580 kWh/m²a and up to 1.2 GWh/a in total. This corresponds to an annual solar fraction of about 22.5 %. A hot water storage of 90 m³ is already installed to ensure the hot water supply during peak demand. This must be complemented with a solar heat storage with up to 175 m³, depending on the load profile and the actual peak loads. During the detailed planning, it will be investigated if the current storage can be used to store the solar heat. Given the size of the collector field, selected technology and integration type, a specific investment of 450 €/m² is estimated. This way, solar heat can be provided with levelised costs of heat of 49 €/MWh, currently below the actual cost of steam.

3.8 Painting process in Germany

This company is specialised in the painting of large scale parts, e.g. of commercial vehicles. In a pre-treatment step, these parts must be removed from rust and debris (pickling). This is done in a 15 m³ acid bath, kept at 43 °C with electrical heaters having a nominal capacity of 42 kW. Measurements show that 28 kW (67 % of the nominal capacity) are constantly required 24 hours per day. The electrical heaters are switched off midday on Saturday until early Monday morning to provide the set temperature for production. This corresponds to a daily heat demand of about 700 kWh in summer and 210 MWh per year.

Based on these data and available roof areas, four solar heating plants with different collector field sizes are designed and simulated with Polysun. Double sided evacuated tube collectors have been chosen due to their low static load when installed. The solar heating heat is integrated with an external heat exchanger into a circulation pipe, which constantly mixes the bath contents. The simulated result are in Fig. 3. The corresponding solar fractions range between 15 % (88 m², no storage) and 58 % (337 m², 32 m³). The company decided for a medium-sized collector field of 161 m² in combination with an 8 m³ storage having a solar fraction of 31 %. Due to expensive electrical energy used to currently heat the bath, a 35 % internal rate of return and a payback time of less than three years can be achieved.

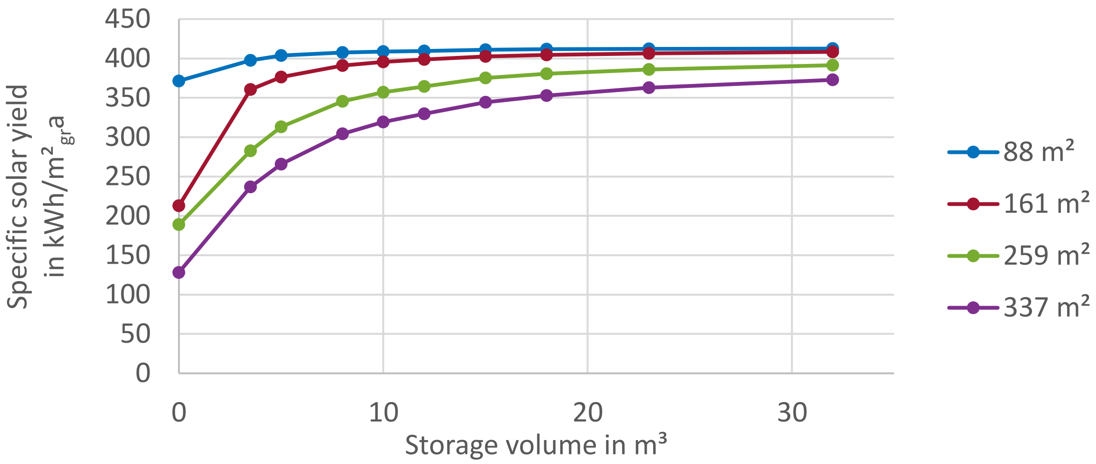

Fig. 3: Specific solar yields for the four different collector field sizes and storage volume variation

The painting hall, where the painting process itself is performed by hand, requires heat that can be covered by solar heat. During the painting process fresh air (74,000 m^3/h) must be supplied at 20 °C to guarantee acceptable working conditions. Due to a high load of paint particles, the air cannot be circulated. Afterwards, the painted parts must be dried. Therefore, the hall is heated up to 60 °C with the same air volumetric flow rate as in the painting mode, whereas 67,000 m^3/h (90 %) is recirculated and the rest is provided by fresh air. The air volumetric flow rates are provided by an air handling unit that can switch between the painting/drying operational modes and is heated by an air-to-water heat exchanger. A heat recovery system is installed for preheating the fresh air by the exhaust air. By conducting detailed air measurements, it is established that there are either one or two painting cycles per day followed by a drying period during night. Based on these measurements, the heat load profile for the air-handling unit can be calculated and in a further step extrapolated over the year taking into account the seasonal temperature profile of a near-by weather station. The yearly energy demand is estimated to be 270 MWh/a with a daily summer load of 800 kWh/d. By installing an additional heat exchanger, solar heat can be integrated. First simulations recommend a 250 m^2_{gr} ETC solar heating plant. The efficiency of the solar heating plant is increased by varying the supply temperature depending on the actual operation mode (painting vs. drying).

4. Conclusion

The automotive industry and their suppliers have many technical possibilities to integrate solar heat into various processes. In general, central heating networks are available that can be used for solar integration. Depending on the industry sector, there are also individual processes that allow an efficient decentralised use of solar process heat. Generally, companies who specialise in textile and surface treatment, operate multiple baths at a feasible temperature for solar process heat. If there are any restrictions on-site (e.g. space) and solar heat cannot be integrated easily into the baths, the pre-heating of feed-water for carry-over and evaporation loss compensation offers a possibility to cover a small fraction of the overall heat demand with solar heat. Drying for paint-shops, which is comparable to other industries plays a key role with respect to the energy demand. Since fresh air is often needed, the use of solar for air pre-heating can be a cost-effective solution.

Many economically feasible solutions were identified, which were highly dependent on national subsidy programs and on-site boundary conditions. Within the performed case studies, the levelised cost of solar heat ranged between 12 and 49 €/MWh. The most economical concept has an internal rate of return of 35 % and the least economical still has a return of 6 %. Unfortunately, the decision for or against a capital investment in efficiency and renewable energy is still primarily made based on the payback time, regardless of solar process heat's proven long term economic benefit. To help overcome this hurdle, regulations regarding depreciation and corporate tax have a major positive influence on payback time. As such the national tax legislation plays a significant role to obtain the required financial decision metrics by industry.

To date, only a few companies have committed themselves to significantly reduce CO_2-emissions in a way that may conflict with economic decision criteria. Additionally, low natural gas prices currently globally impede further market uptake of solar heating plants. The subsidy programs for solar process heat, if existent, are typically not sufficient to satisfy the economic targets in industry due to the small difference between the conventional heating costs and the solar heating costs. If some stakeholders in the automotive industry and their suppliers can be encouraged to take the first step, it will be a tipping point for a wider adoption of this reliable, CO_2-free technology. Optimising the depreciation tax legislation for low carbon heat capital investments is a promising possibility to support the necessary market uptake.

5. Acknowledgement

The authors gratefully acknowledge the financial support provided by the German Federal Ministry for Economic Affairs and Energy (contract no. 0325863A) as well as the industry partners within “SolarAutomotive” for the cooperative and trustful cooperation.

6. References

ACEA (European Automobile Manufacturers Association), 2017. The Automobile Industry Pocket Guide 2017-2018

Lauterbach, C., 2014. Potential, system analysis and preliminary design of low-temperature solar process heat systems, kassel university press, Germany

Louvet, Y., Fischer, S., Furbo, S., Giovanetti, F., Mauthner, F., Mugnier, D., Philippen, D., 2017. LCOH for Solar Thermal Applications, Task 54, INFO Sheet A.2, available at (last access: 20 September 2017):
http://task54.iea-shc.org/data/sites/1/publications/170306-IEA-SHC_Task%2054-Info_Sheet_LCOH-Final.pdf

Pag, F., Majewska, P., Schmitt, B., Vajen, K., 2017. Combination of solar process heat with a micro gas turbine in a medium-sized electro plating company, in: Proceedings OTTI Staffelstein, Germany (in German)