Solar process heat

Supporting industrial and commercial processes with solar thermal energy
Straight to the point

Most users are familiar with solar heating plants above all for space heating or supply of domestic hot water in residential buildings. Rightly so: around 90% of all systems are installed in single- and two-family homes (as of 2015). However, there are other areas in which it can make sense to use solar thermal energy. These include, for example, the integration of solar thermal energy into local and district heating networks, solar air conditioning and solar process heat for industrial and commercial use. For companies who want to save on energy costs in the long term and improve their own CO₂ balance, integrating solar thermal energy into their processes can be an interesting option. The extent to which costs can be saved with a solar heating plant depends on many factors: the scale of the measures, the technology selected and not least the future development of energy prices. One thing is certain, however, and that is that a solar heating plant contributes towards reducing CO₂ output.

Since heat cannot be transported over long distances at low loss, only those sites are suitable for using solar process heat which offer both favourable irradiation conditions and sufficient space to set up collectors. During periods of low solar irradiation, conventional systems have to cover the full energy requirement. The integration of solar heating plants is an interesting option for companies that operate only during the day and with processes for which a comparatively low temperature is required. Here, the food industry has suitable areas of use, for example.

Unlike space heating and domestic hot water, solar process heat is used in operations for the production, further processing or finishing of products, or for the provision of a service that requires process heat. The use of renewable energy sources for the provision of heating and cooling is supported by the market incentive programme for the promotion of renewable energy sources on the heating market (MAP) funded by the German Federal Ministry for Economic Affairs and Energy. Here, there are also funding opportunities for process heat generated in solar heating plants.

The system concepts for industry and commerce vary much more widely than domestic applications. Planners must adapt the solar heating plants to the individual requirements of each company. This publication introduces special technical features and typical areas of use, and provides guidelines and funding opportunities for the use of solar process heat.

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In order to reduce CO₂ emissions in industry and commerce in the long term, heat requirements must be reduced and the use of renewable energy sources must increase. In order to achieve this, companies must first check whether measures for increasing efficiency or heat recovery make sense. For example, in production halls and workshops, exhaust heat is frequently generated which can be re-used for processes such as heating or drying. In many cases, industrial processes can be supported with renewable energy sources. Here, solar process heat offers a wide range of options for reducing the need for fossil energy sources. Solar process heat can be used particularly efficiently when temperatures below 100 °C are required, no exhaust heat can be used for the purpose, and there is a consistent need for heat, at least during the radiation-rich months of April to September.

The theoretical potential for the use of solar thermal energy can be estimated from the heat requirements of the individual sectors. The leading player here is industry, which uses 73 % of final energy for heat. It is followed by the trade, commerce and services sector (TCS) with 55 %. However, it is not enough simply to consider the process and space heating needs in order to identify potential uses for solar process heat. A key selection criterion is the temperature level needed. According to calculations made by the University of Kassel, for the maximum temperature range of 300 °C which can be technologically realised, solar process heat can cover around 3.5 % of the industrial heat demand. This corresponds to around 16 TWh p.a. With an average system yield of 400 kWh/(m² p.a.), this is the equivalent of around 40 million m² of collector area, in other words, around 5,600 football fields. Due to the low level of direct radiation in Germany, however, the focus is on the temperature range below 150 °C, however.

Processes below 100 °C are particularly well suited for integrating solar heat. This temperature level is needed for many processes in industry, commerce, trade and services. They include heating of feed water or make-up water for boilers, with which industrial processes are heated, as well as washing, cleaning or drying (Fig. 2). A significant portion of the low temperature heat demand is caused by air handling units. These are used in many fields in order to create production conditions that are defined by specified air humidity and temperature levels. The temperatures needed for a process can vary strongly, depending on the field of use and the product to be produced, processed or finished.

In the TCS sector, there are almost no processes that require the high temperature range. This means that a far larger share of the heat requirement could theoretically be covered by solar thermal heat. With a collector area of around 100 million m² (as a comparative value: in Germany, a collector area of around 20 million m² is currently installed), solar thermal energy could, according to the estimates made by the University of Kassel, provide 40 TWh p.a. of heat in this sector. Unlike in the industrial sector, the heat requirement here is affected to a far greater extent by the seasons, since the share of space heating needed is greater. During the summer, the need for space heating decreases.

Fig. 1 Industrial heat demand according to temperature level
Source: University of Kassel

- 21 % | < 100 °C
- 8 % | 100–200 °C
- 2 % | 200–300 °C
- 4 % | 300–500 °C
- 65 % | > 500 °C
In theory: the food industry is of particular interest

Compared to other industrial sectors, the chemical and food industries require a very large amount of heat. This makes them of particular interest when it comes to using solar process heat. However, in the chemical industry, over 60% of the heat needed is at a temperature of above 500 °C. As a result, significant quantities of waste heat are available which can be used for low-temperature processes, and which limit the usage options for solar thermal energy. Accordingly, the food industry is the most promising field of use for solar process heat. This is also reflected in the relatively high number of solar heating plants used worldwide to date in the production or processing of foodstuffs.

A large proportion of the processes during the production and processing of foodstuffs run at a temperature of below 100 °C (Fig. 3). Since strict hygiene rules apply in the food industry, cleaning processes play an important part here. Depending on the respective cleaning process, this results in a large heat demand to operate the automated cleaning systems or a supply of hot water. Aside from the cleaning of production plants, this also relates to the containers used, such as bottles, boxes, glasses or moulds, which hold the interim or final product.

Another relevant process stage is drying, which is frequently the final stage in the thermal process chain, and which can considerably influence a company’s energy consumption. In many cases, only low temperatures are required for drying in order to protect the products. In addition, drying can sometimes take a very long time. Both of these factors make this process particularly interesting when it comes to using solar heat.

Food is frequently pasteurised in order to make it stay fresh for longer. During this process, the product is heated to around 70 °C to 100 °C. If the food is heated at higher temperatures, the process is called “sterilisation”. This procedure can also be supported by solar energy, although it is more difficult to use.

As well as the food industry, classic mechanical engineering is also of interest with regard to using solar process heat. During the production of cars and metal products, as well as in mechanical engineering, a large share of the heat required is used for hot water, space heating and air handling units. The temperature level needed for this purpose makes the use of solar energy a feasible alternative.

The majority are commercial and agricultural plants

In the meantime, over 200 solar heating plants for supplying process heat are either in operation, under construction or being planned in Germany. Even if the greatest potential for their use lies in the industrial field, until now, most of these plants have been installed in commerce and agriculture, with generally smaller collector areas (60 m² on average). The areas of application of the existing plants indicate that a quarter of them (with regard to the collector area) are used for drying. Here, biomass drying plays a particularly important role. Another large share is taken up by vehicle cleaning and livestock breeding. While for vehicle cleaning, there are also several plants with a collector area of over 100 m² (the largest has around 600 m²), the plants built for livestock breeding are almost all smaller than 100 m² (the average size is 50 m²). By contrast, the solar heating plants in the industrial sector, such as in breweries, galvanic operations or gas pressure regulating stations, have far larger collector areas, some of which cover several hundred square metres. Despite the high potential and wide range of potential applications of solar process heat, the market has only developed slowly until now. This is often due to the fact that potential users do not know enough about the possibilities for using solar heat, and there are higher-priority efficiency measures that also have considerable potential. In addition, industrial companies are reluctant to pay the money
needed to integrate and install solar heating plants, and usually demand very short payback periods.

After the funding rate for solar heating plants for providing process heat was increased to 50% following the amendment of the market incentive programme in August 2012, the number of solar heating plants for this area of application increased significantly. Before the amendment, around 20 plants were in operation in Germany with a collector area of at least 4,000 m² in total. After the amendment alone, around 250 applications were approved, with more than 16,500 m² of collector area for the provision of solar process heat. Just over half of these plants are using flat plate collectors, around 30% evacuated tube collectors, and around 20% air collectors. Of the 250 plants approved, as of the end of 2016, around 180 plants are in operation with around 11,500 m² of collector area, while the remaining plants are still in the planning or construction phase.

International perspectives

The new insights into suitable areas of application in Germany can also be transferred to other countries. The “Renewable Energy in Industrial Applications” report from the United Nations Industrial Development Organization specifies a technical potential for solar thermal process heat of around 2,200 TWh p.a. in 2050. This corresponds to around three percent of the global industrial energy demand. As is the case in Germany, the average theoretical potential throughout Europe for the use of solar energy is 3 to 4% of the industrial heat demand. In countries with considerably higher irradiation than Germany (such as Chile, India or the MENA – Middle East & North Africa – region), the opportunities are likely to be considerably greater, since here, companies can also make use of concentrating collector technologies such as parabolic trough collectors. These collectors are capable of providing heat at a higher temperature of up to 250 °C. This increases the bandwidth of processes that can usefully be supplied.

As in Germany, the food industry has the most opportunities for using solar thermal heat worldwide. Experts see potential here for around a third of areas of use. Other important fields are mechanical engineering and vehicle construction, mining and mineral and earth excavation, and the production and processing of leather and textiles.

Around one third of the potential is available each in China, OECD member countries, and other nations. One area of application that has not yet been developed, but which is highly promising, is in the field of crude oil extraction, e.g. in so-called “enhanced oil recovery” in the Middle East. With this method, large quantities of steam are required which can be produced using concentrating collectors.
Compared to domestic applications, standard solutions for integrating solar process heat tend to be the exception. The plants must usually be individually adapted to existing systems. In general, a differentiation can be made in this regard as to whether they are integrated into the supply or the process level (Fig. 6). The supply level covers the overall heat supply system of a company. For this purpose, there is a boiler house in many industrial or commercial operations, which generates and distributes the heat. A central distribution network supplies the consumers with the heat generated. Above a temperature of 100 °C, most steam networks take on this task at temperatures of between 140 °C and 200 °C (4 to 15 bar). The steam is then used indirectly via a heat exchanger or directly for heating the various different heat sinks.

In this way, for example, the steam can be directly injected into cold water during washing processes in order to achieve the target temperature.

Heat transfer medium

The central integration of solar heating plants at the supply level differs according to the heat transfer medium used. With warm water or hot water networks, a solar heating plant can be used in serial to increase the return temperature, or in parallel to provide the supply temperature. If steam is used as a heat transfer medium, however, there are three options for integrating the solar heat (Fig. 7). In sunny locations, which enable the use of concentrating solar collectors, parallel integration is possible. During the process, solar steam is generated and fed into the conventional steam distribution system (1). In more moderate climate zones, such as northern and central Europe, serial integration can be used for the solar heating of make-up water for boilers (3), and in some cases also the boiler feed water (2). While the boiler feed water begins to be heated at 100 °C, and can exceed 150 °C depending on the desired steam pressure, boiler make-up water is heated from around 20 °C up to 95 °C or 105 °C.

Generating steam using solar energy

Solar steam generation is only possible with concentrating collectors. These bundle the solar irradiation and in this way are able to efficiently produce the required heat at the high temperature level. Steam can be generated using solar energy either directly or indirectly. With direct steam generation, the boiler feed water is guided through the collector and partially evaporates there. The water-steam mixture is then taken to a steam drum and is separated there. The remaining water is again fed to the collector circuit. When the steam in the steam drum has reached the pressure level of the conventional steam supply, it is fed into the existing network. With indirect steam generation (Fig. 11), pressurised water or thermal oil is used in the collectors as a heat transfer medium. When the heat transfer medium has been heated to the required temperature by the collectors, it is fed over heating coils into a special heat exchanger which contains the boiler feed water. Through the addition of heat the boiler feed water evaporates. The heat exchanger is operated in the same pressure range as the steam network, so that the steam generated can be fed directly into the existing network.

If steam generated by solar energy is fed into the network, the conventional steam generator behaves in the same way as with a reduced load, and produces less steam. The maximum amount of solar steam that can be fed into the system without any significant loss of boiler efficiency depends on the relationship between the installed capacity of the solar heating plant and the steam generator, as well as the typical load applied and the modulation behaviour of the steam generator.

With decentralised integration at the process level, the solar heat is used directly for one or more processes. In many cases, this offers the advantage that the process temperature lies significantly below the temperature of the supply level. This fact has a positive impact on the yield of the solar heating plant. However, there are a larger number of processes with different plant technologies and different target temperatures at the process level.
This makes it difficult to generalise the procedures when integrating the solar heat.

If solar heat is to be integrated for a specific process, the existing heating of this process plays a decisive role. Depending on whether this process is heated with an internal or external heat exchanger, an electric heating cartridge or direct steam injection, the additional integration of solar heat can be anything from simple to highly complicated. Accordingly, different concepts can emerge for integration depending on which heat sink is intended to be supplied with solar heat.

**Heat exchanger**

Solar heat can be integrated into a process which is usually heated with an external heat exchanger. Through this exchanger, a product or a process medium (such as milk, juice, water, lye or air) is preheated or heated. The solar-driven heat exchanger is serially integrated before the conventional one for this purpose. Here, either the entire product or process medium flow or only a part of it can be heated with solar energy.

Aside from the subsequent integration of an external, solar-driven heat exchanger, internal heat exchangers can also be heated with solar energy. These are integrated into baths, machines or tanks, for example. In most cases, conventional and solar-driven heat exchangers are connected in parallel.

At the process level, too, solar steam can be provided at a reduced pressure level. Here, there is the option of making steam available in the low pressure range, i.e. below 100 °C. It can therefore be used for a large number of evaporation processes in the food industry (such as for the production of fruit juice concentrate or the de-alcoholisation of beer). On the other hand, there is the option of providing steam at a temperature of 110 to
135 °C. This steam can be used for processes which are conventionally heated using direct steam injection (such as the heating of water baths for poultry slaughter or the sterilisation of milk). Unlike steam generation at the supply level, the solar heating plant must here in some cases provide considerably lower temperatures. For this reason, this concept is possible with stationary collectors (such as CPC or vacuum flat plate collectors), including for applications in Germany or comparable climate zones.

**A selection of suitable integration points**

With larger companies in particular, there are often several potential integration points for solar heat at the supply and process level (Fig. 9). In such a case, the identified possibilities should be compared and contrasted. The required temperature, the operating time and the cost of integration are the three most important criteria to be taken into account when deciding whether it makes sense to integrate solar heating plants.
In general, the efficiency of a collector decreases as the average collector temperature rises. This decreases the yield. For this reason, in Germany and in countries with similar climatic conditions, the temperature that is to be provided by a solar heating system is the most important criterion when deciding on an integration point. Applications with a low process temperature or processes with which pre-heating is possible are therefore of particular interest for solar integration. Here, it should be noted that no generalized conclusion can be derived from the temperature of a process to the temperature that a solar heating plant needs to provide. The temperature to be provided by the solar heating plant varies depending on the way in which the solar heat can be integrated into the process. For example, if a cleaning bath for metal parts operated at 60 °C is heated using solar energy with the aid of an additional external heat exchanger, a solar supply temperature can already be used which is 10 K higher than the process temperature. If, however, the solar heat were to be integrated into the process via heating jacket, the solar supply temperature would have to be considerably higher than 70 °C, since this type of heat exchanger requires a higher temperature difference in a parallel circuit between the heating medium and the medium to be heated.

With regard to the load profile, processes should be preferred which feature the longest and most constant operational times possible during the course of a week and a year. Here, the daily load profile of a heat sink is usually less important. Since most operations only produce from Monday to Friday or Saturday, the buffer storage tank of a solar heating plant should be dimensioned in such a way that at least the solar energy influx for one day can be stored. This means that the heat volume that has been irradiated over the weekend is not wasted. The buffer storage tank therefore usually has sufficient capacity to compensate for any fluctuations in the load within the course of a day. The daily load profile is only important when planning the size of the storage system for operations or integration points which require heat for seven days a week.

If the load profile is taken as a basis, the integration of solar heat at the supply level in particular offers considerable advantages over the integration of solar heat for an individual process. Due to the large number of heat consumers connected to the network, there is usually a constant load profile at the supply level during production. There is also the option here of using solar thermal energy outside production periods. The feed in solar heat can compensate the standby losses of heat supply and distribution, for example during the weekend.

Finally, the cost of integrating the solar heat into the existing system is a decisive factor when selecting a suitable integration point. The level of expense depends on the process in question. While in the best case, only one heat exchanger plus periphery (pump, valve, piping, etc.) is required for integration when providing hot water for cleaning purposes, for example, this can be far more complicated when it comes to heating of baths or machines. Costly retrofitting with special internal heat exchangers may be required here. In most cases, inte-

Using the sun to wash cars

In sunny weather, car wash facilities work at full pace. The high solar irradiation can be exploited with the aid of a solar heating plant in order to partially cover the heat needed. The Mr Wash chain is taking advantage of this opportunity in its Mannheim and Hanover operations. An additional solar heating plant will be put into operation in 2017 at a car wash facility in Bremen.

The osmosis water used to wash the cars is pre-heated using a heat exchanger. Osmosis water is tap water that has been purified of lime and hazardous substances, with a considerably reduced level of water hardness. If this filtered cleaning water were to be directly heated, the risk would be too great of it becoming contaminated. Also, a different operating pressure, which is not compatible with standard solar heating plants, would be required to directly integrate osmosis water into the plant. The air used to dry the cars is also pre-heated with solar heat. Here, the system is separated using a water/air heat exchanger.

In all three plants, the free roof surface was at most used to elevate Compound Parabolic Concentrator (CPC) evacuated tube collectors. In Mannheim, these collectors cover around 200 m², with around 600 m² covered in Hanover. None of the facilities have a hot water storage tank. Since the “produced” heat is usually directly removed, no buffer is required, and does not make any economic sense.

On Sundays, when no cars are being washed, the facility goes into temporary stagnation. If the solar radiation is not sufficient to cover the heat requirement, the facility in Mannheim is heated through the district heating. The two other operations are heated with gas in such a scenario.
First VDI Standard being drafted

A draft of the first VDI Standard on solar process heat is due to appear in 2017. Experts from science and industry have been working for about two years on the development of this standard with number VDI 3988. This standard is directed in particular at planners of solar heating plants for industrial processes. However, contractors can also refer to the standard as an orientation. It defines how processes should be assessed and when solar thermal energy is suitable for use. The entire planning process – from the pre-planning stage through to implementation – is covered and examples of evaluation bases are provided to help assess the solar heating plant. The information is designed to provide an overview and is formulated in such a way that it can be applied to all sectors. One area covered is the external factors, such as structural and static adaptations or construction approvals, which may influence the installation of the solar heating plant, as well as the individual items that make up the plant costs.

Economic efficiency and financial support

The investment costs for solar process heat plants vary widely. The amount depends on the collector type used, the plant hydraulics and the process integration. Specific investment costs for turnkey systems range from 350 euros/m² to 1,000 euros/m². In exceptional cases, e.g. due to a very costly process integration, the amount can be even higher.

As part of the market incentive programme for the promotion of renewable energy sources on the heating market (MAP) funded by the German Federal Ministry for Economic Affairs and Energy, there are funding opportunities for technologies used to generate heat from renewable energy sources. Funding of up to 50 % of the net investment costs is possible for plants providing solar process heat (as of 2017). Here, different variants are possible. Solar process heat plants of 20 m² and above are funded by the German Federal Office of Economics and Export Control as an investment cost contribution (http://bit.ly/2ohho6C). Plants of 40 m² and above can also be funded with repayment subsidies for a low-interest loan from the Kreditanstalt für Wiederaufbau (http://bit.ly/2oikoyf); however, in all cases, only one of the two funding options is available. This should be taken into account when calculating economic efficiency in just the same way as the very low costs for operation and maintenance over the entire life time of 20 to 25 years.

The plant performance factor for large-scale solar heating plants can be used as a measure for the low operating costs. This is the relationship between generated thermal energy and the electrical energy used for the purpose. This can easily be 50 to 70 kWhth/kWhel. By way of comparison: The annual performance factor of heat pumps only rarely exceeds 5 kWhth/kWhel. Within the subsidy limits according to European law, small and medium-sized enterprises (SMEs) have the option of increasing the funding rate, e.g., by combining it with regional funding programmes.

The payback period for a typical plant is usually approximately seven years. In some cases, or when combined with measures for increasing energy efficiency, the payback time can be shorter. However, due to the long life time, equity returns of over 5 % can be achieved. Those who are reluctant to make their own investment can still benefit from the advantages of solar process heat by using solar thermal contracting. Here, a contractor takes on the planning, funding, realisation and operation of the solar heating plant and delivers the heat to the company at a per kWh price that has been contractually agreed.
Before companies start integrating solar process heat, they should carefully check whether such a plant makes sense, and if so, in what form. Heat recovery and efficiency measures can sometimes be the more economic alternative. A guideline helps companies make the right decision.

For a successful heating transition, there must be a huge decrease in the use of fossil fuels in industry and commerce in the future. As well as solar thermal energy, there are other technologies available that can provide emission-free or low-emission heat. These include heat pumps, CHP plants and biomass boilers. Before these are used by companies, they should first take measures to reduce the process heat demand. This can be achieved both through efficiency measures and heat recovery. It is particularly important to check potential heat recovery measures, since these can be in direct competition to the integration of solar process heat. For this reason, having a high heat requirement below 100 °C does not automatically mean that solar heat can be beneficially integrated in a company.

Efficiency measures can have both a positive and a negative impact on the ability to implement solar process heat. New technological developments in thermal processes can lead to a reduction in target temperatures, making the integration of solar heat possible in the first place, or considerably more efficient and therefore economically more attractive. Conversely, however, thermally driven processes can also be replaced by electrically driven processes (such as ultrasonic). In this case, it is no longer possible to use solar heat. In general, however, many developments, such as the conversion from discontinuous to continuous processes or the reduction of thermal peak loads, have a positive impact on the integration of solar process heat.

There are unexploited waste heat flows in almost all companies. For this reason, a check must always be made as to whether the waste heat can be used, depending on its temperature, the time it is produced and its form (such as waste water or exhaust air). Here, the distance to a suitable heat sink also plays an important role. As well as process-specific heat recovery measures, the utilities including the provision of heat, cold and compressed air, should also be taken into account, since unused exhaust heat flows are also to be found in compressors or in the boiler house. This is of key importance when planning a solar process heat plant, since the exhaust heat produced is usually in direct competition with the solar heat as a result of the temperature level, and its utilisation is usually cheaper.

Implementation tools for practical use

In order to integrate solar process heat in companies, both a sector and a process-oriented approach can be taken. In the past, researchers focused their work in particular on producing so-called “sector concepts” for the use of solar heat. These serve mainly to provide information to solar planners about the production sequences and plant technology within the respective sector, and to facilitate cooperation with the companies. By contrast, the purpose of the process-specific approach is to assess the technical feasibility of a solar heating plant. When integrating solar heat, the sector is
of minor relevance, in contrast to the respective process with the plant technology used.

While there are design guidelines for household applications and rules of thumb for scaling collector areas and storage volumes, this has not been the case to date for applications in the industrial and commercial field. The aim is to change this by offering guidelines developed by scientists for practical implementation. One key component of these recommendations for action is the feasibility assessment. The purpose of this assessment is to clarify whether it makes sense to use solar heat in a company, where and how the heat should be integrated, which solar technology is needed, and how large the plant should be for the most economically efficient design possible. In order to be able to conduct an economic assessment on the basis of these technical specifications, the potential yield from the solar heating plant must be calculated.

As part of the project “SolFood – solar heat for the food industry” funded by the German Federal Ministry for Economic Affairs and Energy (project number 0325541A), scientists and engineers have developed tools which enable the identification of suitable integration points and the preliminary design and yield estimation of solar process heat. The “Guideline for pre-planning solar process heat” produced as a result offers the opportunity of conducting a feasibility assessment in a far more efficient way. This enables participants such as solar companies, planners, energy consultants and energy managers to initiate and implement a larger number of projects in the industrial and commercial sectors. During their investigations, the experts studied the following European cities in relation to their preliminary design and yield estimation of solar process heat: Copenhagen, Madrid, Toulouse and Würzburg.

For the preliminary design of the collector area, the VDI 6002 Standard, “Solar heating for potable water – Basic principles – System technology and application in residential buildings”, was transferred to solar process heat. Here, the solar heating plant is designed for a sunny summer’s day (global radiation > 7 kWh/(m²d)). On such a day, it is designed to just be able to cover the heat demand of the integration point. This avoids surpluses and achieves high specific yields, which is of key importance for the economic efficiency. Different design factors result for the scaling of the solar heating plant, depending on the location, the collector type used, the target temperature of the solar heating plant and the load profile of the heat sink. For example, if the aim is to provide hot water, which must be heated from 15 °C to 60 °C in Germany with a flat plate collector, a solar yield of around 4 kWh/m² can be assumed on a summer’s day for the design. With a temperature level of 50 °C to 80 °C, this would then only be 3 kWh/m²d, however. The storage volume can be determined depending on the target temperature and the load profile.

In order to be able to estimate the yield, the resulting utilisation ratio of the solar heating plant must be determined in order to set the site, load, temperature and

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**Fig. 13** Annual utilisation rate of solar process heat at the Würzburg site for different collector types and process temperatures with the resulting specific annual yield (related to the gross area)

*Source: University of Kassel*

**Fig. 14** With a feasibility assessment in six stages, interested companies can assess whether and in what form it makes sense to integrate a solar heating plant.

*Source: University of Kassel*
Points of view

Why invest in solar process heat?

Christoph Brunner

During the transition from producing operations to a systematically networked “Industry 4.0”, the intelligent use of renewable energy that occurs on a fluctuating basis is an integral part of this guiding principle. Here, the use of solar process heat plays an important role in a hybrid energy supply system at different temperature levels, depending on the technology used (concentrating and non-concentrating collectors) and the production location.

In connection with weather data, location-related energy yields are calculated during the planning stage, which guarantee a secure supply of thermal energy to the processes. Here, a solar thermal energy supply stands for consistent, calculable energy costs, since the technologies used can be operated with a low degree of maintenance and after the plant costs have depreciated, the energy is available almost free of charge. With this in mind, economically efficient solutions can be offered by solar heating plants for selected industries.

In practice

Solar thermal energy integrated in a laundry

Laundries have a high heat demand at temperatures below 100 °C. Whenever exhaust heat cannot be used, the relevant processes are of interest with regard to solar process heat use. Laundries, most of which are medium-sized family-owned companies, have fewer problems with the relatively long payback periods, since they tend to plan for the longer term.

In the SoProW research project funded by the German Federal Ministry for Economic Affairs and Energy (project number 0325999), partners from the field of solar research (Fraunhofer Institute for Solar Energy Systems), the laundry industry, the solar thermal energy industry and software development are working to develop measures to improve energy efficiency and integrate solar heat in laundry operations. To do so, they are analysing the processes in ten laundries, and are simulating and evaluating different integration concepts.

One suitable process is heating washing water, in which steam is injected into the water. Another process that is highly suited to solar support is the generation of steam with which the laundry is sprayed. In this process, the system loses steam and water. These must be treated and returned to the boiler. The heating of this boiler make-up water is another process into which solar heat can be integrated.

As part of the project, the partners involved are planning process heat plants for three laundries in Freiburg, Offenburg and Bonndorf in the Black Forest. They intend to use these laundries as flagship projects for similar operations. They are also developing a concept and guidelines for the laundry industry.

After years of testing and use in practice, solar thermal energy has proven that it fully meets our high standards with regard to supply reliability for plants in our natural gas supply network. We also contribute to avoid CO₂ emissions and thus to protect the environment, and reduce our operating costs by reducing fossil energy sources in favour of lower-cost solar process heat. This has been made possible through close cooperation with a young, regional and innovative company which has specialised in the development, construction and operation of large-scale solar heating plants.

This company provides us with the process heat we need, including from a large-scale solar thermal energy plant, as part of a renewable heat contract. We have a contractual guarantee that the solar heat price will always be slightly below the current natural gas price.

We are convinced that process heat generated by solar thermal energy will emerge as the winner in the price competition with fossil-generated heat in the near future. For this reason, we see the potential for transfer in our own gas pressure regulating stations – as well as those owned by other gas network operators – as being very high.

Fig. 15 The dirty laundry is taken to be washed on the loading belt shown. The washing water used can be pre-heated using solar energy.
Source: Fraunhofer ISE, Stefan Hess
Practical tools for preliminary planning and design

• Interested companies will find the “Guideline for pre-planning solar process heat” and the “Guideline for the use of solar process heat in the food industry” here: [http://www.solfood.de/downloads.html](http://www.solfood.de/downloads.html) (only in German available)

• As part of the “Solar Process Heat – SO-PRO” European initiative, design guidelines were developed using nomograms as a basis: [www.solar-process-heat.eu/guide](http://www.solar-process-heat.eu/guide)

• Yields from solar heating plants under different framework conditions can be simulated with freely available tools such as the Gain Buddy programme: [www.spf.ch/GainBuddy.297.0.html](http://www.spf.ch/GainBuddy.297.0.html)

Even within Germany, the utilisation ratio can vary widely. Depending on the boundary conditions, the potential utilisation ratios here lie between 10 % in the least favourable scenario (target temperature between 80 and 95 °C, use of a flat plate collector) and 60 % under optimal conditions. Due to this bandwidth, the individual framework conditions must always be taken into account when assessing the anticipated yield. Typical rough estimates that apply to standard hot drinking water or combined systems can deviate significantly from these figures.

As well as the guideline for pre-planning solar process heat, which can be used for all sectors, the “Guideline for the use of solar process heat in the food industry” was also produced as part of the “SolFood” research project. This includes all the key information on integrating solar heat in the branch of industry which currently has the greatest potential. However, the information can also be transferred to other fields of industry or commerce. As well as a description of the most important heat-intensive processes with the respective temperature level, the possibilities for integrating solar heat are also presented.

**Guideline for the food industry**

It is typical for the food industry that heating and cooling run in parallel. Solar heating plants frequently compete with the use of exhaust heat from cooling systems or the integration of large-scale heat pumps.

Thus, for example, just a few characteristic values (the cost of electricity and heat, daily hot water demand and daily electricity consumption for cooling) can be used to estimate how the heat recovery from vapour compression chillers can be optimally operated (Fig. 16). From an economic perspective, it can make sense to increase the condensation temperature of the chiller in order to provide more hot water through heat recovery. On the other hand, it can also be more economically efficient, however, to operate the chiller at the lowest possible condensation temperature and to provide hot water using solar thermal energy.

Further orientation is provided by the recommendations for action included in the European initiative, “Solar Process Heat – SO-PRO”. These recommendations include information on the four processes that are particularly suitable for solar process heat, and which a frequently used in industrial operations. These are “provision of warm or hot water for washing or cleaning processes”, “heating of boiler make-up water for (partially open) steam networks”, “heating industrial baths or tanks”, and “convective drying with hot air in open systems”. System concepts have been drafted for these applications and the energy yields have been simulated. The “So-Pro Guideline” is very helpful in order to obtain an initial insight and make an initial estimation. If there are different conditions in reality on the site, or with regard to the load profile or collector type, the design principles no longer apply.
Process heat collectors

The way in which a solar heating plant is configured and scaled for use in the industrial sector varies widely and depends on the specific requirements of the individual company. With standard application temperatures of 20 to 250 °C, very different collector technologies are available and planners must decide on an individual basis which type is most suitable for use.

One decisive factor when choosing the right collector type is primarily the cost and the performance under the planned operating temperature. Other criteria that should be taken into account are the structural conditions for the installation and any restrictions related to them (e.g. space requirements, roof stability and pitch, etc.). So-called “gross heat yields” can help assess the performance. These are idealised energy yields in kWh/m² a calculated with a constant collector temperature throughout the year and a limitless storage capacity. This information is available for any collector that has been tested and awarded a Solar Keymark certificate. Here, however, the yields are only determined for firmly defined, representative European locations and collector orientations at fluid temperatures of 25, 50 and 75 °C. Taking into account the actual load profiles and plant configurations, these results can deviate strongly from the system yields on the ground.

The most widely used collector type for process heat are flat plate collectors, which can be used covered or uncovered up to approximately 100–110 °C. They offer a simple, compact, robust assembly, can optimally use both direct and diffuse radiation, and are less expensive than other technologies. Beside fluid-operated collectors, air collectors have also gained a significant share of the market. These are used for processes which run with air as a heat transfer medium, particularly for drying woodchips and other biomasses.

Above 70–80 °C, only highly efficient products are suitable for use. The efficiency increase in flat plate collectors can be achieved by reducing the heat losses into the environment through the front panel, which constitutes a large portion of the overall losses. Some manufacturers use double covers which consist of glass panels with anti-reflective layers. The space between the panels is usually open to the atmosphere. An even more performing version consists of adapted insulating glass units with low-emissivity (low-e) layers and an inert gas filling. This option is currently being tested at the Institute for Solar Energy Research in Hamelin (ISFH) as part of a research project (funded by the German Federal Ministry for Economic Affairs and Energy, project number 0325973).

As an alternative convection brake and thermal radiation shield, the second glass panel can be replaced by a highly transparent polymer film, which is tensioned between the glass cover and the solar absorber. However, the long-term stability is lower than with glass, and the film can form folds. To counteract this, current developments in industry and research are opting to fix the film on four sides. This also reduces thermal losses, since the film remains flat at an optimised distance from the glass panel and from the absorber. At the Bavarian Center for Applied Energy Research (ZAE), for example, a new tensioning device is being tested (research project funded by the German Ministry for Economic Affairs and Energy, project number 0328957A). Here, the film is not fixed in the collector housing, but in a glass-film compound element, which

Fig. 17 In a working group (SHC Task 49) of the International Energy Agency, participants recorded the data from 200 plants installed worldwide in a database. The systems are classified according to collector technology below. Source: www.ship-plants.info, own data compilation, ISFH

- 10 % · Flat plate collectors (air)
- 49 % · Flat plate collectors (water)
- 20 % · Evacuated tube collectors
- 12 % · Parabolic troughs
- 1 % · Fresnel collectors
- 7 % · Dish collectors
- 1 % · Other
can in principle be integrated into any standard collector frame. Regardless of whether a film or a glass panel is used, the double cover reduces thermal losses by 25–30 % on average compared to a single-glazed flat plate collector (with $T_{\text{fluid}} - T_{\text{environment}} = 80 \, ^\circ\text{C}$), which enables an extension of the temperature range for the use of this collector typology of around 30 K.

The thermal insulation of the collector cover can be enhanced by using honeycomb structures made of cellulose beneath the glass panel. The optical properties of the material and the special honeycomb geometry guarantee a very high transmittance for solar radiation with simultaneous suppression of the losses by convection and thermal radiation. This type of collector has been successfully used for the solar assistance of processes for washing wine vats and containers in a winery, for example, and in a laundry at temperatures up to 85 °C.

Highly evacuated flat plate collectors, which can generate heat for process temperatures up to 180 °C, exhibit a considerably higher increase in performance levels. Due to the high cost, only a small number of demonstration plants has been realised to date, such as in the bitumen industry. Here, however, considerable cost reductions are anticipated in the coming years, as a result of which they could gain traction in the area of process heating.

Evacuated tube collectors, which are also used for process heat, are the second most common typology. Due to their evacuated structure, they have considerably lower heat losses than standard flat plate collectors, and can be efficiently operated up to temperatures of 160 °C. The so-called CPC (Compound Parabolic Concentrator) collectors, with which a low-concentration parabolic reflector is positioned behind the glass tubes, are in the upper-level performance class. In this way, the radiation that they collect can be used more effectively. These collectors differ in terms of the design and type of glass tube (simple or double-wall), the absorber (flat or cylindrical) and the heat exchanger (U- and coaxial tube). Here, the version with gravitation heat pipes can offer particular advantages also with regard to process heat applications. Compared to direct flow systems, the heat pipe offers an additional thermal resistance in the usage path, which leads to slight impairment in the performance. However, the separation between the collector circuit and the solar circuit enables simpler hydraulics and the minimisation of the temperature load in the system if stagnation occurs. Since the heat is transported from the absorber to the solar circuit through a two-phase process in the heat pipe (evaporation and condensation), the maximum process temperature can be determined by systematically selecting and dosing the heat transfer fluid. This guarantees reliable operation, particularly with plants designed for maximum solar coverage.

Concentrating collectors for high temperatures

For industrial processes which require heat at even higher temperatures up to 250 °C and above, highly concentrating collectors are used. A typical area of application is direct or indirect steam generation. These collectors are best suited for very sunny regions/countries, such as in Latin America, India or the MENA (Middle East/North Africa) region. They operate exclusively with direct sunlight, which is bundled onto a heat exchanger using reflector systems. Thermal oils are used as a heat transfer medium, alongside water and steam. Highly concentrating collectors were developed to generate power for solar thermal power plants during the mid-1980s. These systems have been adapted for process heat applications. They are smaller and lighter so that they can be installed on the roofs of industrial factory buildings in a modular manner. The collectors differ mainly according to the arrangement of the concentrating reflector. The most widely used collectors of this type are line focus systems, particularly parabolic trough collectors.

With these systems, the radiation collected is concentrated on a receiver tube along the focal line of a reflective trough with a parabolic profile. Here, the radiation is transformed into heat and transferred to the flowing heat transfer medium. The steel tube is selectively coated and surrounded by an evacuated glass envelope tube. The in-
Individual collectors are erected in rows on the mounting system and are connected with one another so that they are torsionally stiff. The line focus alternative to parabolic trough collectors are Fresnel reflectors.

Here, reflector segments made of glass which are positioned close to the ground are installed instead of a parabolic concentrator. These follow the path of the sun, while the receiver tube has a fixed position. Additionally, a secondary reflector is attached over the receiver, which reflects back imperfectly focussed radiation onto the absorber tube. Due to the slim design and the position of the primary reflector, which is exposed to lower mechanical loads, as well as to the use of simpler standard components, Fresnel reflectors are cheaper than parabolic trough collectors both in terms of production and maintenance. Due to the higher optical losses resulting from their structure, around 30% lower annual yields are achieved even with a similar size.

Point focusing systems, especially so-called “dish concentrators”, are also used as highly concentrating collectors. These are rotationally symmetric, parabolic curved hollow reflectors with short focal lengths, which bundle the radiation onto a “punctiform” receiver with the aid of biaxial tracking. Temperatures of up to 300 °C can be achieved, depending on the size of the reflector and the number of collectors. These systems are particularly common in India, where they are used for cooking, baking and milk production, as well as in the paper and textile industry.

Solar energy for the automotive industry

How can the automotive industry and its supplier companies exploit solar process heat? To find out, scientists headed by the Institute of Thermal Engineering at University of Kassel are analysing 20 locations as part of the German-Austrian SolarAutomotive research project (project number 0325863). At production sites from different companies including Opel, Volkswagen and MAN, they are analysing individual processes and developing concepts for the use of solar heat. They are also analysing processes in supplier companies for leather, textiles, conductor plates and surface finishing.

Solar energy can be used for the operation air handling units, for example. Their task is to keep the temperature and humidity constant during car production. At the supply level, warm and hot water networks offer potential integration points within the companies. In paint shops, air handling units and heated baths are used. These are also found in galvanic operations in the pre-treatment stage of cathodic dip-paint coating, and in component washing facilities. These processes are also be assessed by the scientists. In addition, they are investigating possibilities for combining solar thermal energy with other heat generation technologies, such as large-scale heat pumps, cogeneration plants or micro gas turbines.

At the sites in Germany and Austria, the analyses are focussing on the provision of heat below 120 °C. During the second half of the project, sites of companies in other countries will also be investigated, such as in Spain, South Africa, India or Mexico. Here, the researchers are also considering the integration of concentrating collectors, which provide steam or hot water at a higher temperature.
There is a large number of initiatives throughout the world which are working to promote the use of solar process heat. From February 2012 to June 2016, an international working group of the International Energy Agency (IEA) worked on ways of providing solar heat for industrial applications. IEA-working groups of this kind are built of representatives of industry, research and development, and work on an area of application in thematically subdivided groups, known as subtasks. As part of Task 49, “Solar Process Heat for Production and Advanced Applications”, the members focussed in three subtasks on developing methods and tools which can be used to simplify and therefore also accelerate project development and the planning and implementation of solar process heat in the future.

As part of Subtask A, “Process heat collector development and process heat collector testing”, the experts analysed how process heat collectors and solar circuit components can be further improved. They compared the different types of collector, taking technological and economic criteria into account, and formulated recommendations for standardised test procedures. The results of this work are now partially available to the general public. For example, information on the stagnation behaviour of large-scale solar heating plants has been compiled for a technical report. It is precisely in industrial applications that controlling the stagnation behaviour plays an important role, since here, large-scale collector arrays are frequently installed which are usually not used for solar heat during the weekend.

A key challenge when it comes to solar process heat is to integrate the solar heat into the existing system. The members of Subtask B (Process integration and process intensification combined with solar process heat) worked on this problem. Here, the focus lay on the process chains that are used in industry, the plant technology used, and the conventional heating equipment. The experts examined the possibilities and limits of integrating solar process heat, and derived the related tools from their results. During this process, a database for specialists in the field covering industrial sectors and their typical industrial processes was comprehensively expanded and supplemented by potential integration concepts for solar heat. Additionally, a comprehensive report was published with the so-called “Integration Guideline”, which is oriented towards energy consultants and managers, plant manufacturers and process technicians, as well as solar planners. The guideline contains all the key information as to how solar heat can be integrated into existing structures in industrial companies, and what special features should be taken into account.

Members of Subtask C, “Design guidelines, case studies and dissemination”, focussed on the solar heating plant as a whole and the implementation of solar process heat plants. In order to promote the use of this technology, and above all to offer a valuable tool for acquisition and project development, a database was created, among other products, which presents solar process heat plants across a range of different sectors worldwide.
**In practice**

**Fossil steam generators supported by renewable energy sources**

In the SolSteam project funded by the German Federal Ministry for Economic Affairs and Energy (project number 0325545), the Institute for Solar Research at the German Aerospace Center (DLR), together with its German industry partner Industrial Solar GmbH, is researching different concepts for the direct integration of solar steam in steam circuits. If solar steam is used, the consumption of fossil energy decreases when conventional firing is reduced accordingly while the solar heat is being fed into the steam generator.

The experts are currently testing a new concept for integrating solar steam at “RAMPharma”, a manufacturer of pharmaceutical products in Amman (Jordan). The plant is the first solar heating plant used to produce process steam in the MENA region (Middle East/North Africa).

When the sun is shining, the system achieves a solar coverage share of 100 %, and no conventional steam generation is required. When the solar irradiation is no longer strong enough during the early evening, the plant is driven using diesel. The Fresnel collector array (396 m² aperture area) feeds saturated steam directly into the steam network at the company. The pressure in the network is 6 bar, and the temperature is 166 °C. The steam is used primarily to dry tablets. The plant went into operation in March 2015, and has since been running without interruption. A monitoring procedure will be conducted by 2017 as part of the SolSteam project. The results can be used for similar hybrid systems.

**Cooling with solar heat**

Solar energy can be used not only to generate heat, but also to provide cooling. The particularly interesting aspect here is that the heat requirement and the heat supply are usually available at the same time. In more moderate climate zones, the solar cooling systems are usually used to air condition non-residential buildings. Cold stores in southern climates and many process cooling systems also require considerable energy when the sun shines intensely. The use of solar cooling systems instead of electric chillers also eases the grid, particularly at peak load times. With the aid of solar energy, the air is cooled and the air humidity is controlled with solar air conditioning. The drive energy source of a cooling machine or air conditioning method is driven from the power grid using solar heat instead of electrical energy.

With solar heating plants, a differentiation is made between closed and open methods. Closed methods use ab- or adsorption chillers to provide chilled water that is used, for example, in chilled ceilings. The chilled water temperature depends on whether devices are supplied that are also used for dehumidification, or whether the connected room-side components are only used for removing sensitive loads, i.e. to control the temperature. Open sorption methods, on the other hand, condition the supply air. Here they not only reduce the temperature but also ensure a pleasant indoor air humidity. The refrigerant is water and is in direct contact with the atmosphere, which is why it is described as an „open system“.

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**En passant**

**Fig. 23** Solar-driven air conditioning: The regeneration of the dehumidification rotor is driven directly by a 100 m² air collector array. Source: Fraunhofer ISE

**Fig. 24** Solar-driven open, desiccant evaporative cooling system for seminar rooms. Source: Fraunhofer ISE
Outlook

Despite its great potential, solar process heat continues to be a niche market. To reduce the impediments to using this technology, experts at national and international level have developed sector concepts, guidelines and databases in order to provide further information on the subject. In this way, interested companies can conduct a feasibility assessment and receive assistance for the practical realisation of plants.

Solar thermal energy is just one of many options for covering process heat requirements in companies. It competes with measures such as the use of exhaust heat, CHP solutions or fossil energy sources. Increasing energy efficiency is also an important issue. In many cases, saving process heat is extremely profitable. Specific aspects are reducing the demand, the use of exhaust heat, innovative and coordinated components and efficient control and regulation of operating processes.

The ETA model factory at the Technische Universität Darmstadt, is one example of how an energy efficient industry might look in the future, and what challenges solar process heat might face. In the project funded by the German Federal Ministry for Economic Affairs and Energy, scientists researched how the industrial sector might use energy more efficiently by connecting all building and production components. By considering the entire system – consisting of machines, energy storage systems, building services technology and the building envelope – the intention is to reduce the primary energy requirement in production by 40 percent. As well as improvements in the energy requirements of the individual production plants, their energy networking also has a role to play.

While exhaust heat is being used, the machine peripherals, building services technology and the factory building are also incorporated alongside the production plants. For example, the waste heat from the machine tools is used to provide other plant systems with heat or to heat a 550 square-metre hall. The waste heat from heat treatment plants can be used to heat cleaning baths or provide cooling using sorption technology. The production building can serve as a heat sink for low-temperature waste heat. It can also be used for generating solar heat or cold water by releasing heat to the environment.

One future challenge will be to integrate solar thermal energy as a component of an energy-efficient technology concept, in which the different technologies are combined and supplement each other in a beneficial way.

Links

▷ Website with general information on solar process heat: www.solare-prozesswaerme.info (in German)
▷ Institute of Thermal Engineering, University of Kassel | www.solar.uni-kassel.de
▷ Institute for Solar Energy Research in Hamelin GmbH | www.isfh.de
▷ AEE- Institute for Sustainable Technologies | www.aee-intec.at
▷ German Aerospace Center, Institute for Solar Research | www.DLR.de/sf

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