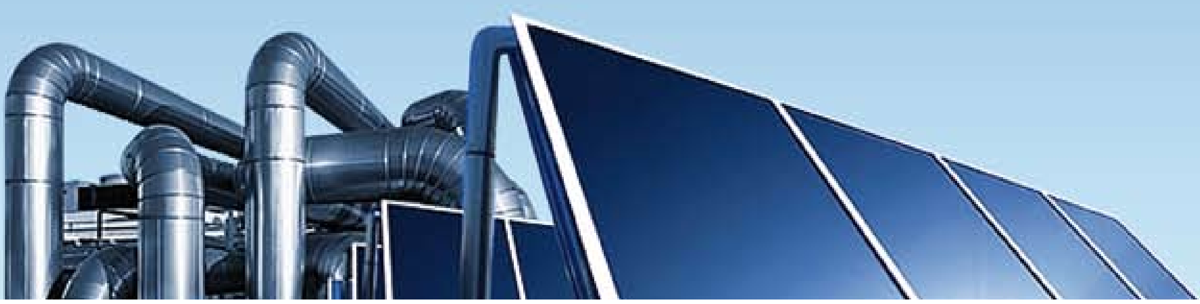
SO-PRO
SOLAR PROCESS HEAT

Solar Process Heat Generation: Guide to Solar Thermal System Design for Selected Industrial Processes

www.solar-process-heat.eu



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Contents

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1 Introduction

1.1 SO-PRO – a European initiative

While solar heat for domestic and service applications has increasing market shares across Europe, solar heat for industrial processes is still in a very early stage of market development. The SO-PRO project, which is supported by the Intelligent Energy Europe programme, aims to trigger the starting up of markets for solar process heat in 6 European regions (Upper Austria, the regions of Castillas y Madrid/Spain, South Bohemia/Czech Republic, North-Rhine Westphalia and Saxony/Germany and the Maribor region/Slovenia).

The project activities include - among others - targeted awareness raising for industrial decision makers, training of professionals, development of checklists and design guides and 12 pilot projects. Comprehensive European dissemination activities ensure that the know-how gained is applied around Europe.

1.2 High potential of solar process heat

In principle, the potential for solar thermal generation of process heat is enormous: In Europe, about 27 % of the total final energy demand is heat consumed by the industry. Herein, about 30 % of the total industrial heat demand occurs at temperature levels below 100 °C and further 27 % between 100 °C and 400 °C. A significant part of this heat, especially below 100 °C, can be generated by solar thermal plants.

1.3 Purpose and use of this brochure

This brochure is addressed to solar companies, installers, specialised planners, energy advisors and researchers. **Regional versions of this guide, adapted individually to each of the participating regions, are available from the project website www.solar-process-heat.eu.** Planning principles for the integration of solar thermal are provided for four selected industrial processes:

- Heating of hot water for **washing or cleaning**
- Heating of **make-up water** for steam networks
- Heating of **baths** or vessels
- Convective **drying** with hot air

These four applications have been identified in the SO-PRO project and were selected because of their favourably low temperature level and frequent occurrence in different industrial sectors.

The guideline in hand is a **short, practice-orientated document** providing technical information **on how solar thermal can be integrated into each of the considered processes.** The main objective is to link the two affected spheres of competence, which are industrial process engineering and solar thermal engineering. No extensive planning principles are provided but a short insight into the four considered processes as well as into the basics of solar thermal engineering is given. A **structured planning approach** with **several consecutive steps is recommended and explained by practical examples.** Extensive information on specific issues arising when dealing with solar thermal process heat can be found in the more detailed planning references cited within this brochure.

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The recommended system concepts and simulated energy gains are only valid for the four introduced specific examples. Although the selected examples are representative for the considered processes, due to the high variety in industrial systems and meteorological conditions, the optimum solar thermal system design and dimensioning will often differ from these examples.

Thus, the **results** shown in this brochure **will have to be adapted individually by own simulations,** taking variations in the individual industrial process systems, process management, resulting load profiles and meteorological conditions into account.

2 Realized examples

Montesano (food industry, washing / cleaning)

In the slaughterhouse of Montesano different kinds of meat products are produced. In 2008, a solar thermal system with 290 m^2 (203 kW) collector area and a buffer storage volume of 23 m^3 was installed. The system provides 45 % of the hot water demand for washing and cleaning, where temperatures between 40 and 60 °C are required. The replaced fossil fuel is oil. Due to the favourable temperature level and location, the system produces 314 MWh / year (1,083 kWh / (year*m^2)). The investment costs were 200,000 Euro.

Fig. 1: Flat-plate collectors on the roof of the Montesano production hall, situated on Tenerife, La Esperanza, Spain

Laguna (textile industry, make-up water and washing)

Laguna is a medium-sized laundry situated at a commercial area in Marburg, Germany. Two gas-fired steam boilers (300 kW each) generate steam which is distributed to the different processes by a steam network. A significant share of the steam is consumed directly. The condensate from the steam which is not directly used returns to the feed water tank. Working time is from 7:30 am to 15:30 pm, the plant is not operated at weekends and usually there are no company holidays.

Fig. 2: Field with prototypes of improved flat-plate collectors (under construction). The collectors are double covered (solar glass and plastic foil) and equipped with external reflectors.

In July 2010, a solar thermal system with 57 m^2 aperture area (40 kW) and 3.3 m^3 buffer storage volume was installed. The solar thermal system supports the partly open steam network of the laundry by pre-heating of demineralised make-up water (20 °C – 90 °C). Also solar pre-heating of feed water (90 °C up to max. 120 °C) is demonstrated. On the process level, soft water for the washing machines is heated (20 °C – 80 °C). The collector field works at temperatures up to 125 °C.

Steinbach & Vollmann (surface treatment, heating of baths)

The metal processing company Steinbach & Vollmann produces locks, fittings and hinges for more than 125 years. By installing a new heating system in 2004, the company reduced its gas consumption by 29 %. In 2008 a solar thermal system with 400 m^2 (280 kW) vacuum-tube collectors and 9 m^3 solar buffer storage was installed. The system (pre-) heats 16 galvanic baths (all together 21 m^3) and also the conventional heating and domestic hot water system, both via return flow boost. The baths act to a certain extent as additional buffer. The required temperatures of the baths range from 60 °C to 80 °C. The total investment costs were 240,000 Euro. From the regional government the company received subsidies of 300 Euro / m^2 (120,000 Euro). The solar thermal system reduced gas demand by further 30 to 35 %. An amortisation time of 7 years is expected (subsidies included).

Fig. 3: Vacuum-tube collectors (400 m^2) on the roof of Steinbach & Vollmann, situated in Heiligenhaus, Germany

Lammsbräu (brewery, convective drying)

The Neumarkter Lammsbräu Gebr. Ehrensperger e.K. is a brewery and malt house in Neumarkt, Germany with a very long tradition. Since 1987, all the ingredients of the beer originate from organic farming. In the year 2000, a 72 m^2 (50 kW) field of single-glazed air collectors was installed. The air-collector system is pre-heating ambient air for the drying process in the malt house. Because the ambient air is used directly, no buffer storage is required and the utilizable temperature is very favourable. The process requires temperatures up to 60 °C.

Fig. 4: Flat-plate air collectors on the roof (hot air ventilation pipe on the right hand side)

3 Preliminary analysis

When an industrial plant is investigated with respect to its potential for the installation of a solar thermal system to support the thermal processes, four consecutive steps have to be performed before designing an appropriate solar thermal system:

- Analysis of **building and boundary conditions**
- Analysis of **process characteristics and heat distribution network**
- Discussion of **future plans of the company**
- Potential analysis **for process optimisation and energy efficiency measures**

The level of detail is highly increasing from the first step to the fourth. Performance, economy and reliability of a solar thermal system depend very much on a proper analysis of the process characteristics and on a sound check of energy efficiency measures. Every industrial plant has to be analyzed individually, since every plant has its own, historically developed heat supply system. Properly carrying out the preliminary analysis discussed in the following ensures a suitable, reliable and sustainable industrial energy concept with predictable energy savings and also provides a good base for industrial decision makers to justify their investment in solar thermal.

3.1 Building and framework conditions

As a first step, the **"SO-PRO Checklist for Industrial Decision Makers" (www.solar-process-heat.eu)** should be filled in. If one of the "knock-out criteria" applies, solar thermal will not be an option for this plant. If the evaluation from the checklist is positive, the industrial plant must be visited to check if solar thermal should be considered further. The following steps are recommended:

a) Explain in a short phone call which data you need on the building, the heat distribution network and the industrial processes. This way, the company can collect the necessary information and a skilled technician or engineer from the plant will be available for the visit. He/she can prepare the information and accompany this first rough analysis.

b) At the visit, make a sketch of the building(s) with their basic characteristics like the dimensions of available unshaded and accessible roof areas with their orientation and slope, crane accessibility (usually necessary), information on statics (if available), etc.

c) Calculate roughly the accessible and unshaded roof area for the collector field, the available area for the storage tank(s) (and the other installations) as well as the distance from storage to collector field and to the potentially supported processes. Indicate these figures in your sketch.

d) Discuss together with the technician and the manager of the plant if there are any legal requirements or other restrictions regarding the installation of a solar thermal plant.

3.2 Thermal processes and heat distribution network

At the visit it is very important first to classify the processes consuming thermal energy into **open or closed** processes as well as into **continuous or discontinuous** processes. Special attention should be paid to continuously running open processes with no mass or heat recovery, since they have the highest potential for the integration of solar thermal.

The **main criteria** of processes suitable for solar thermal are:

- demand more than 3/4 of the year, including summer
- demand at least 5 d/week
- daily demand in summer should not be lower than in the rest of the year

The most important factor for solar heat integration usually is the **available temperature level.** This term means low temperature levels in the plant, at which a significant amount of solar thermal energy could be transferred to the processes by the solar thermal system (e.g. via heat exchanger). The temperature at the heat integration point(s) highly influences the fluid temperatures in the solar thermal system and **should be as low as possible**, because

collector field and storage(s) work most efficient at low temperatures. Also important is the **process temperature** itself. The economical best systems have process temperatures below 50 °C. Process temperatures above 100 °C even in open systems often increase the available temperature level, since heat recovery measures are / should be applied.

Solar thermal energy can be **integrated into the processes directly or into the heat distribution network** (high temperature water network or steam network). Supporting the heat distribution network allows to support the thermal processes indirectly (e.g. by feed-water pre-heating) and to integrate more energy, but except from partly open steam networks usually the available temperature levels are lower when solar thermal is integrated into the processes directly.

The following steps are recommended for the preliminary analysis:

a) Collect the available data on the thermal energy demand of the plant. The most important figures are the temperature levels of the thermal processes and the supply and return flow temperatures of the heat distribution network (if existing). Other aspects are the kind of heating system, the energy source used (i.e. gas, oil or electricity), the energy price, a rough estimation of the heating system efficiency as well as the energy demand of the thermal processes at least on a seasonal basis.

b) Get an overview of all thermal processes in order to examine their feasibility of coupling them with solar thermal. Process schemes are very helpful to understand all mass- and energy flows. The mean inlet and outlet temperatures of the processes should be known and the thermal energy demand of the plant should be split between the processes. Estimate if in case of heat demand for one process the required mass flows are high and varying or if they are constant, which makes it easier to integrate solar thermal. Pay also special attention to very low temperatures (e.g. cold water which has to be heated up), since they are the most promising points both for heat recovery measures and for integrating solar thermal heat.

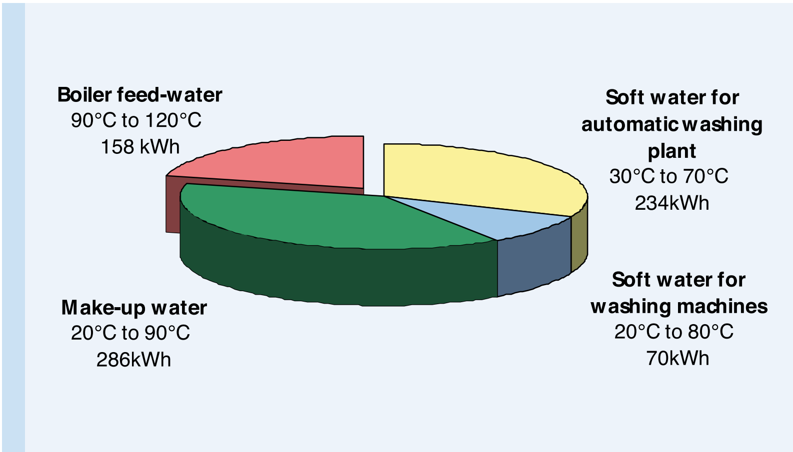

Fig. 5: Example for the heat demand of four processes in a laundry. After measuring in- and outlet temperatures and mass flows for several weeks, the mean daily heat demand of the processes was calculated. In the solar thermal system finally installed, the automatic washing plant is not supported because of the existing internal heat recovery. The solar plant was designed to economically pre-heat the two other low-temperature processes and to demonstrate boiler feed-water pre-heating in the course of a scientific project.

c) The following aspects of thermal efficiency / potential for heat recovery can be investigated during the technical visit:

- Is the insulation of the hot pipes / storages / machines in good condition?
- Is there hot water or other process media wasted in the plant?
- Are there any heat recovery measures applied and what is the intention of the decision makers in this regard for the future?
- When steam is used as a transfer medium, are there existing circuits for condensate return? If yes, are there machines which consume part of the steam directly?
- Are there any processes (e.g. cleaning of equipment or floors) where heat recovery can be technically or economically excluded?

When the first process analysis indicates suitability for solar thermal heat integration, the processes have to be analyzed in more detail. Thermal load profiles have to be generated on a daily, weekly and annual basis (section 4.1). This is also necessary for the energy efficiency measures described in the following.

3.3 Planned changes in the energy system

In the course of the preliminary analysis, **discuss if changes or extensions in the production process or the heat generation network are already planned or will get necessary** for reasons of plant maintenance. When either the thermal load or the load profile (chapter 4) for the solar thermal system is likely to change significantly, such measures will affect the technical and economical performance of the solar installation. This has to be considered in the planning process. If the system can be installed in the course of other necessary installation work at the plant, the installation costs often can be significantly reduced.

3.4 Process optimization and energy efficiency measures

There is a wide variety of approaches for industrial process optimisation. When an optimization of the processes itself is investigated, the intention often may not be energy savings but rather e.g. a reduction of cycle times or raw material input. However, changes in the production process or the production equipment very likely will have a significant effect on the thermal energy demand and temperature levels of the processes. Therefore, whenever it is planned to substantially change the production process within the following fife years, **a solar thermal system only should be designed after the resulting energy demands and temperature levels are reliably known**.

The application of energy efficiency measures (e.g. by heat recovery) usually results in a significant reduction of the thermal energy demand and has a very high economic potential in most industrial sectors. But the topic is also very complex, since measures which change the thermal energy supply may affect the production process itself. When a modernization of production equipment, a replacement of an old heat generation system, combustion gas heat recovery or the implementation of waste heat recovery seem possible or necessary, these measures have to be analysed by specialized experts.

An adequate methodology for the thorough evaluation of measures for waste heat recovery and thermal process optimization is the **"Pinch analysis"**. All thermal processes are analysed and potential heat recovery measures are identified. The theoretically optimal connection between all heat consuming processes by heat exchangers is determined, so that the minimum external energy demand of a plant can be calculated. Most important with respect to solar thermal is a reasonable estimation of the **minimum available temperature after thermal process optimization**. A short explanation of the Pinch Analysis and information on solar heat in energy efficient processes can be found in [3].

An information source concerning energy efficiency in the industry and renewable industrial heat is the project **EINSTEIN** (Expert system for an INtelligent Supply of Thermal Energy In Industry) [4]. An advanced, detailed and software-based **audit methodology** was developed to perform energy audits in the industry. The results are very helpful to both energetically optimize the industrial plant and to integrate renewable heat. Several best practice examples of thermal energy saving measures in the industry are documented.

The measures discussed in this chapter should always be considered prior to the planning of a solar thermal system.

4 Basic steps of system design for solar process heat

From the **preliminary analysis** all the important framework conditions are known and energy efficiency measures have been investigated (chapter 3). For the **design of a solar thermal system generating industrial process heat the following steps are recommended**:

- Calculate the thermal load for the solar thermal system (the thermal energy the solar plant could theoretically provide to the connected processes) and generate an overall thermal load profile (temporal distribution of the thermal load).
- Determine roughly the necessary collector area and storage volume to get a feeling for the resulting size of the installation and to find reasonable starting points for the simulation of the solar thermal system.
- Perform system simulations varying the size of the collector field, the collector type and the storage volume, possibly also the solar thermal system concept and the supported processes.
- Decision for one variant of the solar thermal system considering economical, technical, public relation and future aspects of the industrial company.

4.1 Calculation of thermal load and load profile for the solar plant

For solar thermal system design, the thermal loads and load profiles of the processes likely to be supported by solar thermal should be known on a daily, weekly and annual basis. To generate these load profiles, the initial visit and interviews with the process planners or the staff working at the plant usually are not alone sufficient. It is **recommended to measure** the mass flows and inlet- and outlet-temperatures of all potentially supported processes at least for a typical working day.

It is also very important that the **load profile is calculated after taking off the energy to be saved by the decided energy efficiency measures and considering only the residual temperature lift** after applying these measures.

After deciding which processes should be supported and where the respective points for heat integration should be (section 3.2), the thermal load and load profile for the solar thermal system can be calculated as follows:
For every supported process, the fluid mass flow and the temperature at the integration point (available temperature level) should be known with their variation in time. Also the maximum fluid temperature after solar heat integration (depending on the process or the maximum temperature of the solar system) should be determined. The overall thermal load with its corresponding load profile is calculated by summing up the thermal loads to be supported by the solar plant and by generating an overall load profile.

Example: thermal load and load profile of a cleaning process at a smaller company of the food sector

Let us assume that a process analysis of such a company showed a demand of 10 m^3 cleaning water per working day. The water is consumed at 60 °C. A constant temperature of the cold water of 15 °C was measured (available temperature level). This cold water can be heated up by solar thermal. Heat recovery measures can not be applied, since the water is needed at widely distributed parts of the company and fairly cooled down by the cleaning processes. No waste heat is available at the plant. For the solar installation, the thermal load of this process per working day is without consideration of the water density roughly:

$$Q_{Working\ day} = m_{Working\ day} \cdot \overline{c}_p \cdot \Delta T \approx (10.000\ kg \cdot 4{,}18 \frac{kJ}{kg \cdot K} \cdot 45\ K) / 3600 \frac{kJ}{kWh} = 522{,}5\ kWh$$

$Q_{Working\ day}$ = thermal energy demand per working day for heating up the colc

$m_{Working\ day}$ = mass of the cold water heated up per working day

$\overline{c}_p$ = mean specific heat capacity of the water

ΔT = temperature difference between the hot and cold water

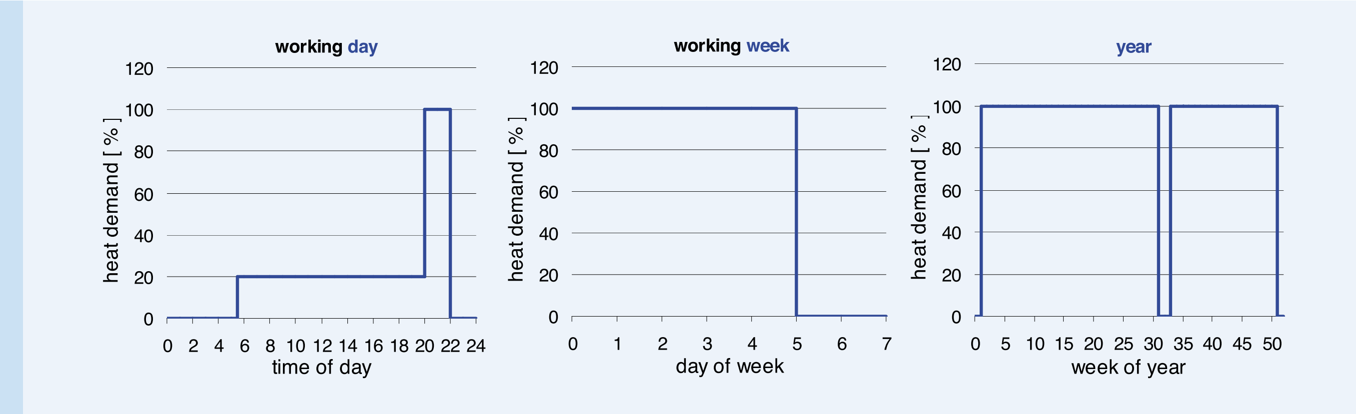

Fig. 6: Example for the discontinuous load profile of the hot water demand for cleaning of production equipment in a smaller company (two shifts)

The thermal load profile of this company is shown in fig. 6. For the generation of the profile, the daily hot water demand was measured over several typical working days. The weekly and the annual profile are based on interviews with the operator of the plant. During the night there is no hot water demand, since the company is only working from 5:30 am to 10 pm (two shifts). There is also no demand at weekends, within the first and the last week of a year and for three weeks in August.

During working hours, there is always a certain demand of cleaning water, but the profile is discontinuous because there is a very high demand of cleaning water from 8 to 10 pm when all the production equipment is cleaned before closing time. The 10 m^3 per working day are distributed as follows: Within the working hours from 5:30 am to 10 pm = 16.5 hours, the maximum load occurs at the two last hours of the working day. At the other 14.5 hours, only 20 % of the maximum load is needed. When the areas under the graph are integrated and compared to the full load, the result is that usually ca. 408 l/h at 60 °C (or 21.3 kWh/h) are consumed during production times. From 8 to 10 pm, 2040 l/h at 60 °C (or 106.5 kWh/h) are needed. During the whole week, 50 m^3 or 2,612.5 kWh/week are needed. When the holidays of three weeks in August and the two weeks in winter are considered, the annual thermal energy demand of the process can approximately be calculated to 122,8 MWh/year (235 working days out of 365 days of the year).

For dimensioning of the solar thermal system it is important to know the mean daily demand of hot water, since the daily or weekly loads can be different. When we assume for our example that the load per working day would always be 10 m^3, the mean daily load for one year is 6.44 m^3.

4.2 Pre-dimensioning of collector field and storage tank(s)

A very rough **pre-dimensioning of the collector field** to find starting points for the simulations without considering the individual framework conditions of the plant can be done by two different methods:

a) Multiply the roof area, which is available for solar collectors, by 500 kWh / m^2_{Ap} estimated annual energy gain and divide the result by the annual thermal load of the supported processes. For flat roofs, the roof area should be divided by 2.5 to estimate the sloped collector area which could be installed. A reasonable starting point for the simulations is a result below 0.6 (solar fraction below 60 %). If this is not the case, select method b).

b) Take 40 % of the annual thermal load of the supported processes, divided by 500 kWh / m^2_{Ap} as a starting point.

Usually, a deviation from south direction less than 20° has no significant influence on the collector performance. A collector tilt angle of 35° is a good starting point. For southern Europe the maximum annual energy gain can be found at slightly lower, for central Europe at slightly higher collector slopes. Of course this depends on the load profile.

For the pre-dimensioning of the storage tank(s), in central Europe usually 50 l storage / m^2_{Ap} are a good starting point for the simulation of a variety of industrial process heat systems. In southern Europe, 80 lstorage / m^2_{Ap} can be used.

The optimal storage volume depends very much on the correlation between the solar gains and the thermal load profile of the process. In case of smaller companies, which do not work at weekends, the storage should usually be able to buffer the solar gains from these two days. Too small storage volumes result in inefficiently high collector field temperatures and might cause stagnation (section 6.2). In southern Europe, the optimal storage volume is usually higher than for central Europe, since the solar gains are much higher than in central Europe and higher storage capacity is needed.

Example: pre-dimensioning of collector field (using method b)) and storage tank(s) for a system supporting the cleaning process introduced in section 4.1:

$$A_{Ap} = (Q_{Year} \cdot 0{,}4) \,/\, 500 \frac{kWh}{m^2_{Ap}} = (122{,}8\ MWh \cdot 0{,}4) \,/\, 500 \frac{kWh}{m^2_{Ap}} \approx 100\ m^2_{Ap}$$

$$V_{Sto} = A_{Ap} \cdot 50 \frac{l}{m^2} = 100\ m^2_{Ap} \cdot 50 \frac{l}{m^2_{Ap}} \approx 5\ m^3$$

A_{Ap} = estimated collector aperture area

V_{Sto} = estimated storage volume

4.3 Selection of the collector type

Before considering the different collector types, it is important to distinguish between the collector's gross area and their aperture area.

The **gross collector area** is the product of the edge dimensions of the collector (length and width), determining the **minimal necessary area for mounting** a collector on a sloped roof. The **aperture area** (index: Ap) equals the light entrance area of the collector. It is the area, through which the solar irradiation enters the collector and hits the absorber either direct or via reflection (e.g. from CPC reflectors). Because of the collector frame, the aperture area is always smaller than the gross area. Usually, **all the specific collector values** like the efficiency curve, collector costs and annual energy gain **are related to the aperture area**.

The **available collector aperture area** (that could be potentially installed) can for a sloped roof be calculated roughly by dividing the available unshaded roof area by the collector gross area. The resulting number of collectors must then be multiplied with the collector's aperture area. In case of a flat roof, the unshaded roof area should be divided by a factor of 2.5 first, to account for the necessary distance between the sloped collectors.

Tab. 1: Comparison of flat-plate and evacuated tube collectors

Flat-plate	Evacuated tube
• Lower costs • Better cost / performance ratio • Able to substitute a conventional roof • Stagnation: better emptying behaviour and lower stagnation temperatures than evacuated tube collectors with a U-configuration piping (section 6.2)	• Higher annual energy gain • Less collector area needed for the same energy gain • Higher efficiency at higher collector temperatures and low irradiation (winter)

Below process temperatures of 50 °C, usually **flat-plate collectors** are the most economic solution. Above this value, always comparative simulations between the different available collector types, considering the available roof area and the price per aperture area should be performed. An overview on commercially available collectors for higher temperatures with basic information on their working principles can be found in [5].

In southern Europe usually flat-plates are applied also at applications with process temperatures quite above 60 °C, because the mean ambient temperatures and the solar irradiation are higher. For examples on the influence of the process temperature and the location on the choice of the collector type please refer to section 5.3.

Dimensioning of collector field, **choice of collector type** and determination of optimal collector slope should always be based on varying system simulations. They depend on many factors like location, load profile, **minimum available temperature**, process temperature, storage volume, system concept and others (see also section 5.3).

A final choice of the solar storage volume should as well always be based on system simulations. The result also depends on the storage type and concept (single buffer storage with good stratification, parallel storages or cascade design), the control strategy for charging and discharging and the connection to the process.

4.4 System Simulations

Only by system simulations a solar process heat system can be designed properly. For the design process, **nomograms** based on system simulations **can be very helpful.** Section 4.5 explains how these nomograms are generated and how they can be used. Exemplary design nomograms for four specific processes are presented in chapter 5. When performing simulations, **only one parameter should be varied to determine the sensitivity** of annual energy gain and solar fraction for this parameter (e.g. storage volume).

There is a variety of software tools to simulate solar thermal systems, but not all of them are suitable for the simulation of solar heat generation for industrial processes. An **important criterion** for the selection of a **simulation program** is the possibility to enter **own load profiles** in the necessary resolution. The program should also be able **to simulate a system concept at least very similar** to the intended one. Another, also very important criterion is the ability of the programme to reliably calculate the stagnation times of the system as well as the stagnation temperatures in the collector field.

Since solar process heat is often used for pre-heating, the **energy gain** of industrial solar plants is **often significantly higher** than for **domestic applications**.

4.5 Nomograms for system design

Every nomogram of this brochure shows results of varying system simulations for different variants of a solar thermal system installed at a certain industrial plant. **In one nomogram, only collector aperture area and storage volume are varied, the system concept and the individual conditions of the plant like the site, the overall thermal load, the load profile, the collector slope etc. are constant.** To vary also the solar thermal system concept, collector type and supported loads, new nomograms have to be generated for each case.

Because only specific values are plotted, the nomograms are fully scalable. This means that solar fraction and specific solar system gains can be plotted for certain ratios of thermal load and installed aperture area, since they are independent from the absolute values of these parameters.

The nomograms shown in this brochure for certain processes with high potential are in principle not sufficient do design solar thermal systems for these applications, because they are only valid for one specific case. But they can be useful to reduce the simulated variants for similar systems and applications. When the supported process and temperature lift as well as irradiation, ambient temperature and collector slope are comparable, starting

points for collector area and storage volume can be identified, the simulated variants can be reduced and tendencies for a reasonable dimensioning can be found.

Fig. 7 shows such a design nomogram, which was simulated for the cleaning process introduced in section 4.1.

There are four different colours in the nomogram, corresponding to four specific storage volumes (litres storage volume per 1 m^2 collector aperture area).

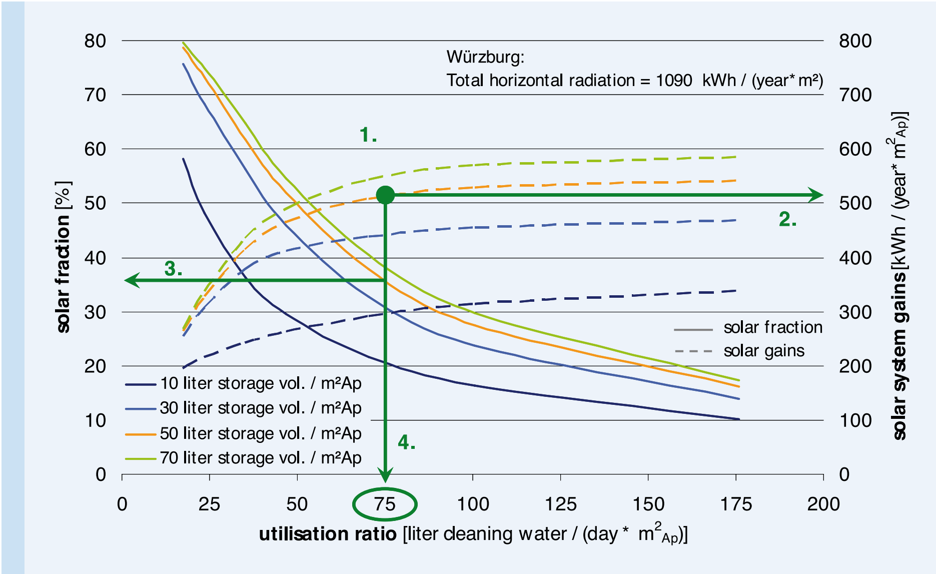

Fig. 7: Example of a solar thermal system design nomogram for a cleaning process in a small company (system of fig. 9, load profile of fig. 6 with temperature lift 15 °C to 60 °C, single-covered flat-plate collector with slope 35°, stratified storage, location: Würzburg)

The **utilisation ratio (x-axis)** indicates how many litres of cleaning water are needed by the process per installed 1 m^2 of collector aperture area. It is the ratio between thermal load and installed collector area. Note that the calculations are based on the mean daily load over the year, not on the load per working day. It is important to remember that the thermal load is constant, so that the utilization ratio directly corresponds to different sizes of the collector field. Of course also other aperture area-related specific energy demand values like the thermal energy demand of a bath can be used (compare fig. 17).

On the **left y-axis**, the **solar fraction** is indicated **(continuous lines)**. It describes, which part of the thermal load (the heat demand of the connected processes, that could maximally be provided by the solar thermal system) is transferred to the processes by the solar installation at a certain ratio between demand, aperture area and storage volume. The continuous lines in the diagram show the solar fraction curves for each of the four specific storage volumes.

On the **right y-axis** the **specific solar system gains** are indicated (energy transferred to the processes by the solar thermal system per year and 1 m^2 aperture area, **dashed lines**). As for the solar fraction, also the specific solar system gains are plotted for certain ratios between demand, aperture area and storage volume. The dashed lines in the diagram show the solar system gain curves for each of the four specific storage volumes.

Example to use the nomogram (fig. 7)

The system design nomograms can be used in a view different ways – there is no standard procedure. When economic viability of the system is the key factor, the specific solar system gains should be the most important criterion. A pre-dimensioning of the system shown in fig. 9 can be done as follows:

- On the 50 l / m$^2_{Ap}$ curve, select a point (1) where you have considerably high specific solar system gains (2: 515 kWh / year m$^2_{Ap}$) and a significant solar fraction (3: 36 %) at the same time.
- Based on the mean daily cleaning water demand, calculate the resulting collector aperture area by means of the utilisation ratio (4). For our example this would be (end of section 4.1):
  Aperture area = (6,440 l cleaning water / average day) / 75 = 86 m$^2_{Ap}$
- Calculate the resulting necessary storage volume. For our example this would be:
  Storage volume = 50 l / m$^2_{Ap}$ storage volume * 86 m$^2_{Ap}$ = 4,300 l

- Calculate the annual energy gain of a solar plant of this configuration either based on the solar fraciton or on the specific solar system gains:
  Annual energy gain = 515 kWh / (year*m²) * 86 m² = 44.3 MWh / year
  Annual energy gain = 122.8 MWh / year * 36 % = 44.2 MWh / year
- Do some variations, for example if you install only 64 m^2_{Ap} collectors (utilisation ratio = 6,440 l / day / 64 m^2_{Ap} = 100) with the same specific storage volume (orange curve), your specific solar system gains will rise to 530 kWh / m^2_{Ap}, but the solar fraction will decrease dramatically to 27 % and the gains of your system will decrease to 122.8 MWh / year * 0.27 = 33.2 MWh / year. If you, for the aperture of 86 m^2_{Ap} (utilization ratio 75) install 70 l storage / m^2_{Ap}, the specific solar system gains would rise to 550 kWh / m^2_{Ap} * year at an increased solar fraction of 38.5 %.

Of course the final design of the solar plant depends on the costs and availability of the components. In our example, pre-fabricated flat-plates with 10 m² aperture area could be installed in three rows on a flat roof, so that 90 m^2_{Ap} would be installed. If, for example, storage tanks with 1.5 m² would be available at low costs and could easily be installed at the plant, a primary storage with 1.5 m³ volume and additionally two secondary, hydraulically harmonized buffer storages with 1.5 m³ each would be possible, resulting in a specific storage volume of 50 l / m².

The nomogram of fig. 8 was generated with exactly the same simulation than for fig. 7, only the **location was changed from Würzburg to Madrid.** A comparison of both nomograms obviously shows how the solar system gains and the economically feasible solar fractions highly depend on the sites with their specific irradiation and ambient temperatures. In southern Europe, higher utilization ratios (smaller solar installations compared to the load) can be chosen. However, the solar fractions that can be achieved (in fig. 8 far above 40 %) are higher than in central Europe and the solar system gains are very high. For our exemplary cleaning process, the solar system gains of a optimized system in Madrid would be nearly twice as high as in Würzburg (for utilization ratios of 75 in Würzburg and 100 in Madrid, both 50 l / m²), and a significantly higher solar fraction could be reached with a smaller system (e.g. 37 % in Würzburg and 51 % in Madrid).

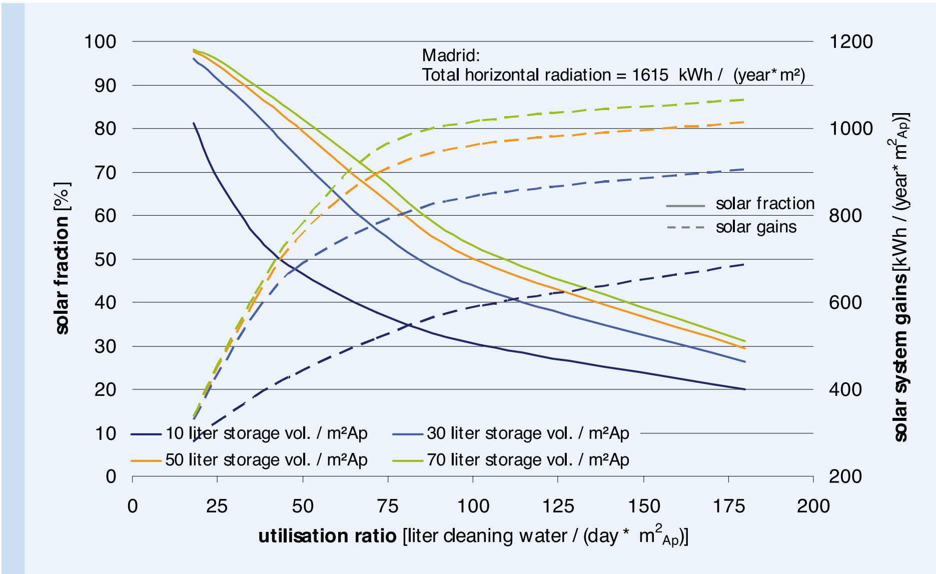

Fig. 8: Example of a solar thermal system design nomogram for a cleaning process in a small company (system of fig. 9, load profile of fig. 6 with temperature lift 15 °C to 60 °C, single-covered flat-plate collector with slope 35°, stratified storage, location: Madrid)

Usage of the nomograms for system design:

Large solar thermal systems compared to the load can be found at low utilisation ratios (left side of diagram). The solar fraction of these systems is very high, but the specific solar system gains per m^2 are low, which reduces the economic viability of the systems. Additionally, very large systems always have the risk of stagnation at weekends or other times with low thermal loads.

Small solar thermal systems compared to the load can be found at high utilisation ratios (right side of the diagram). The specific solar system gains are impressive, since the demand is always much higher than the power of the solar thermal system. On the other hand the solar fraction is low. Since the planning effort and the process analysis is a significant share of the costs for the solar thermal system, very small systems are not recommended. Also, very low solar fractions are no sustainable improvement, since the energy costs of the company are still highly connected to the energy prices and the investment does not offer the possibility to reduce the power of the conventional heat generation system in case of modernization.

Small specific storage volumes (green and blue curve in the diagram) have the risk of longer stagnation times and also the working temperatures in the collector loop are high, which reduces the collector efficiency. They should only be applied when the solar fraction is comparably low and the load profile is very continuous (i.e. demand also at weekends, no holidays). If the storage volume is chosen to be very low or if no storage is applied, a reliable concept to protect the solar installation in case of stagnation due to a low process heat demand has to be applied (section 6.2). From fig. 7 and 8 it gets obvious that for the simulated system concept and load profile 10 l / m^2 are far too less and also 30 l / m^2 especially in Madrid would imply the risk of frequent stagnation at weekends.

High specific storage volumes lead to higher system gains and solar fractions, as far as the storage volume is not too high. Often 50 l / m^2 are a reasonable value, since the storage also increases the costs and space consumption of the solar thermal system. Too big storages may especially in spring and autumn have a lower temperature level to support the process, so that the backup heater might more frequently run at inefficient part-load than for systems with smaller storages. Of course this depends on the storage type and control strategy (section 4.2)

In the following, solar thermal system concepts **for the four considered processes with high potential** are explained and **representative examples for load profiles** are given. For these system concepts and load profiles with their respective temperatures, system simulations in TRNSYS with variation calculations were performed. The results are presented in the exemplary **specific design nomograms of chapter 5**.

5 System design for selected industrial processes

5.1 Heating of hot water for washing or cleaning

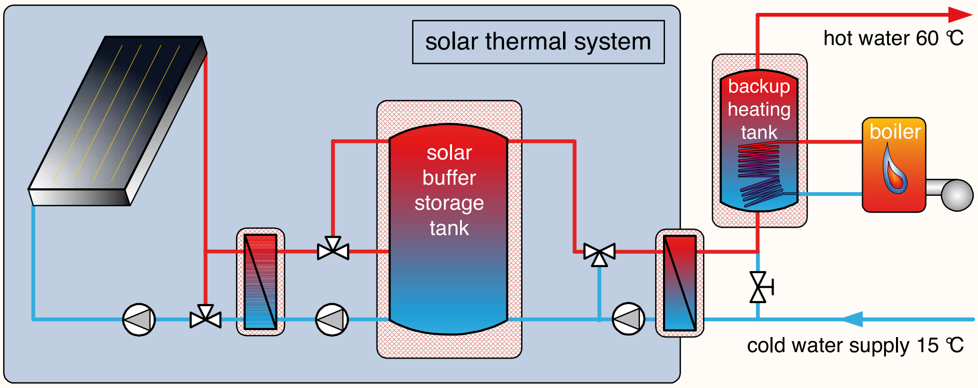

Fig. 9: System concept with heat exchanger and serial boiler (simplified illustration of the conventional hot water preparation system)

The supported system for hot water preparation is an open system without heat recovery, since cleaning water is usually contaminated and cooled down by the cleaning process. Cold water (in this example 15 °C) is heated up to 60 °C. In plants with stochastic cleaning water demand and very high flow rates (cp. fig. 6) the backup heating system is usually equipped with a hot water storage that is heated by a boiler.

With the installation shown in fig. 9, the solar thermal system can be integrated easily via an additional heat exchanger (can be a fresh water module). Whenever cold water has to be heated up, it is (pre-) heated by the solar thermal system before it enters the hot water storage. A cold water bypass at the discharging side of the solar buffer storage prevents the cold water circuit of high temperatures possibly occurring in the buffer storage (temperatures up to 90 °C). At the charging side of the solar buffer storage tank the solar heat exchanger can be bypassed in the collector circuit via a three-way-valve. When the temperature at the bottom of the storage tank is lower than the outlet temperature of the collector, the pump of the collector circuit starts. First, the heat carrier fluid is circulated only in the collector loop and does not enter the heat exchanger. This way the collector circuit is heated up before the pump loading the buffer storage is activated. Otherwise, in the morning or at varying irradiation conditions heat of the storage tank could be lost to the solar loop and there could be a certain risk of freezing of the heat exchanger in winter. When the storage is charged, one or more three-way-valves control the inlet height of the flow in a way that the stratification of the storage is maintained as good as possible. The storage volume of course can also be a cascade of storages or loaded with stratification lances, if available.
In industrial plants with high demand of cleaning water the pre-heating of hot water with low solar fractions can be very economical because of the low temperature of the cold water inlet (cp. "available temperature level", section 3.2).

The simulation results (nomogram) for the system of fig. 9 and the discontinuous load profile of fig. 6 can be found in fig. 7. Fig. 11 shows the same simulation for the continuous load profile of fig 10.

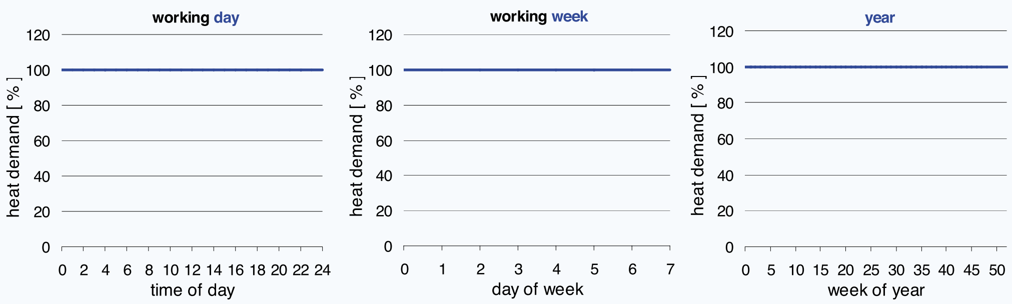

Fig. 10: Continuous load profile of an automated washing process being part of the production in a big company, which works in three shifts without company holidays.

The profile of fig. 10 is valid for a very big company (three shifts), working seven days a week and all over the year. Here the washing process is an automated part of the production and the demand is very constant. A comparison of both nomograms (fig. 9 and fig. 11) shows clearly the influence of the load profile on the solar fraction and the solar system gains. Company holidays in summer result in significantly lower solar gains. For discontinuous load profiles, the storage volume should always be dimensioned large enough to buffer the solar gains at the weekends. Stagnation by reaching the maximum temperature in the buffer storage should be avoided. Anyway the missing heat consumption at weekends reduces the solar gains since the temperature in the solar loop and the storage losses are increasing. From fig. 11 follows that for the continuous load profile not more than 50 l / m² storage volume should be installed. However, to achieve a high solar fraction a storage tank is also in this case still necessary, since the buffer allows the solar installation to still support the process at times with low irradiation or at night.

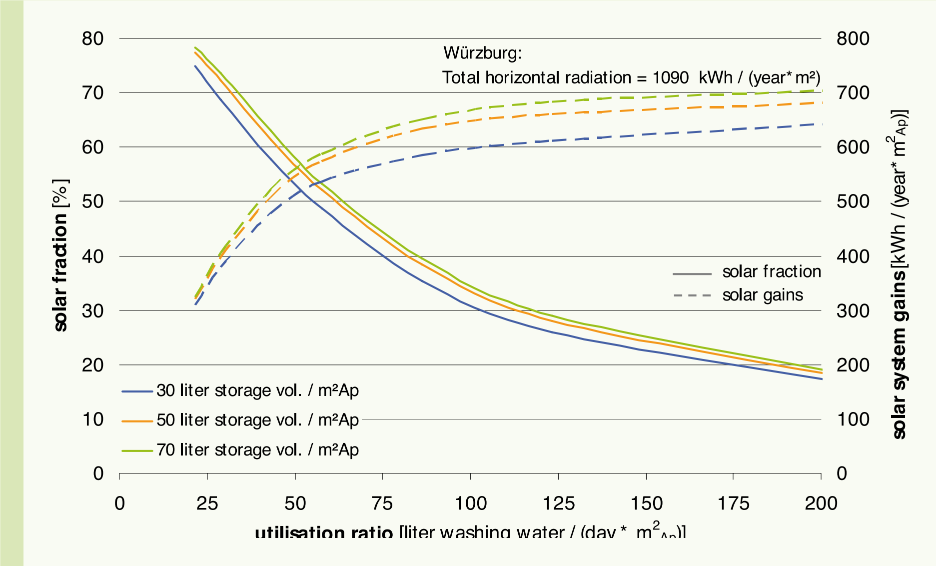

Fig. 11: Example for a solar thermal system design nomogram for a washing process in a big company (valid for the system of fig. 9 and the continuous load profile of fig. 10, temperature lift 15 °C to 60 °C, single-covered flat-plate with slope 35°, stratified storage)

5.2 Heating of make-up water for steam networks

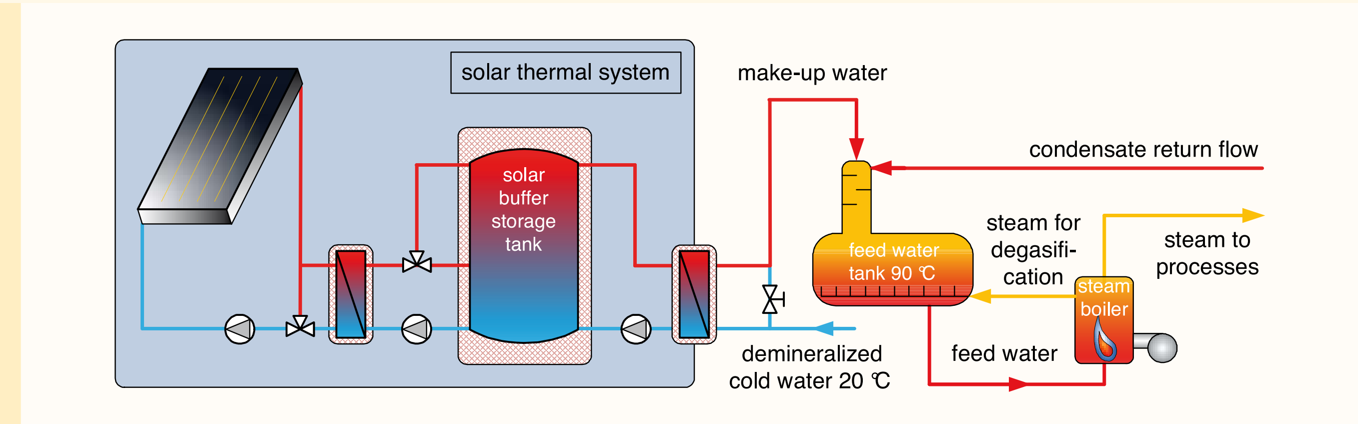

Fig. 12: System concept with cold water heat exchanger, pre-heating the make-up water entering the feed water tank (simplified illustration of the process steam network)

The solar support of process steam generation is usually only economical when a significant part of the steam is used in the processes directly (the steam network is an open or partly open system). Solar heating of the additional, demineralised make-up water can be attractive; heating of the condensate return flow or the feed water directly is more expensive because of the high temperatures. Additionally, at state of the art installations the feed water is usually pre-heated by an economizer.

In (partially) open steam networks the demineralised make-up water is usually mixed with the returning condensate and has to be degassed before it can enter the steam boiler. This degasification is usually done thermally using process steam from the steam boiler. With this steam, the feed water tank has to be heated up to 90 °C, often also up to slightly over 100 °C, when the feed water tank operates at an overpressure of 0.2 or 0.3 bar. It is therefore a good solution to pre-heat the decalcified, additional make-up water before it is mixed with the condensate and before the mixture has to be heated up. This way, less steam is consumed for degasification and since the steam supports many different processes in the factory, the solar thermal system can cover a significant fraction of the overall heat demand very elegant just by adding one single heat exchanger.

The recommended solar thermal system concept is similar as for washing/cleaning, compare fig. 9. The discharging heat exchanger protects the solar buffer storage tank from corrosion and is not bypassed at the solar side, since 90 °C are usually also the maximum storage temperature. No make-up water storage tank is applied, since the make-up water mass flow is usually not varying.

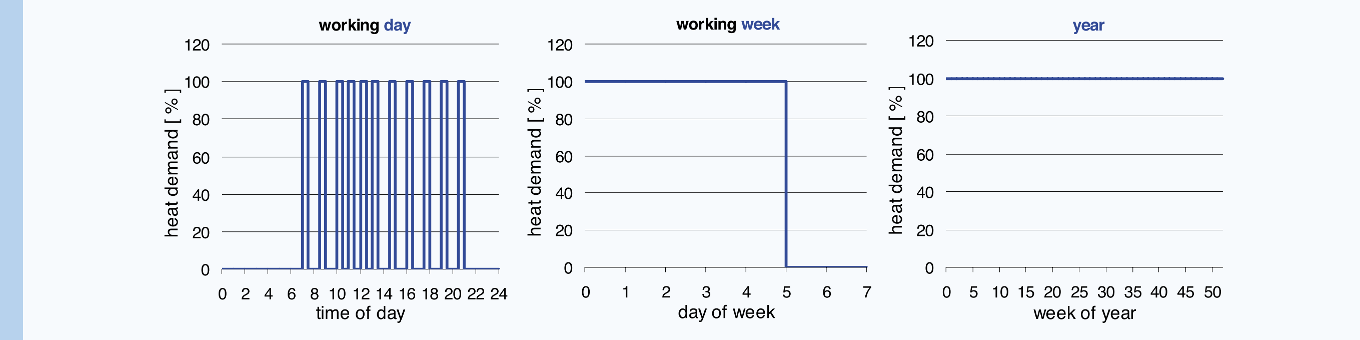

Fig. 13: Example for the make-up water consumption profile of a partly open steam network in a laundry (two shifts, no holidays). The fill-level control of the feed water tank opens the make-up water inlet for intervals of approx. 30 min.

The achievable solar system gains are a little bit lower than for solar plants supporting cleaning / washing applications. This is due to the higher minimum available temperature of 20 °C (compared to 15 °C for washing / cleaning). The cold water is already warming up when it gets demineralised. Also the achievable solar fractions are lower, because the water has to be heated up to 90 °C (the thermal load is always referenced to the temperature lift the solar thermal system could provide). The mass-flow intervals, caused by the fill-level control of the feed water tank, should not have a high influence on the performance of the solar thermal system, since the solar gains only have to be buffered for intervals of one or two hours during the day.

Fig. 14 clearly shows that the utilisation ratio in this case should not be above 75, since the gains of the solar plant are for reasonable specific storage volumes not increasing anymore above this value and the solar fraction gets very low.

In some cases, the available temperature level of the demineralised cold water can rise up to 60 °C after applying heat recovery measures, so that the efficiency of a solar thermal system decreases. This has to be checked individually for every considered plant.

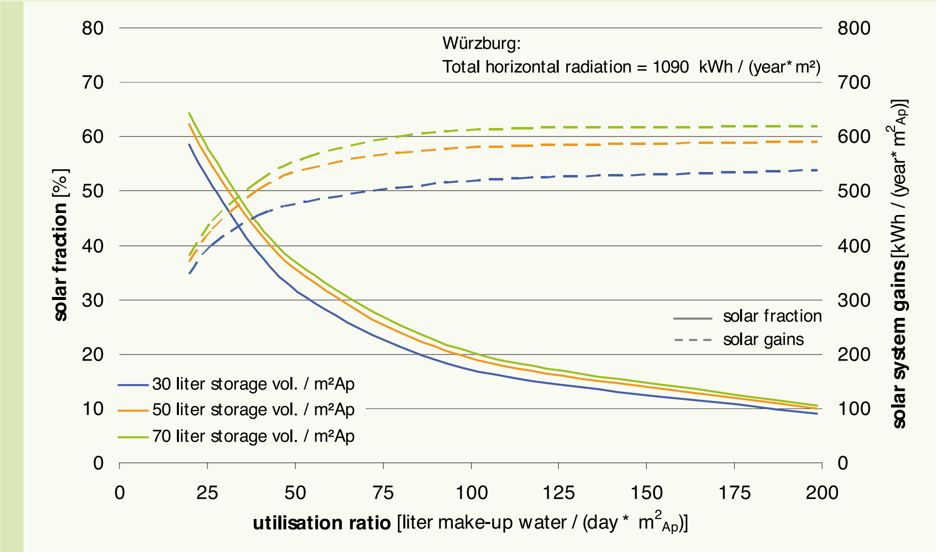

Fig. 14: Example for a solar thermal system design nomogram for pre-heating of make-up water (valid for the system of fig. 12 and the profile of fig. 13, single-covered flat-plate with slope 35°, stratified storage)

5.3 Heating of industrial baths or vessels

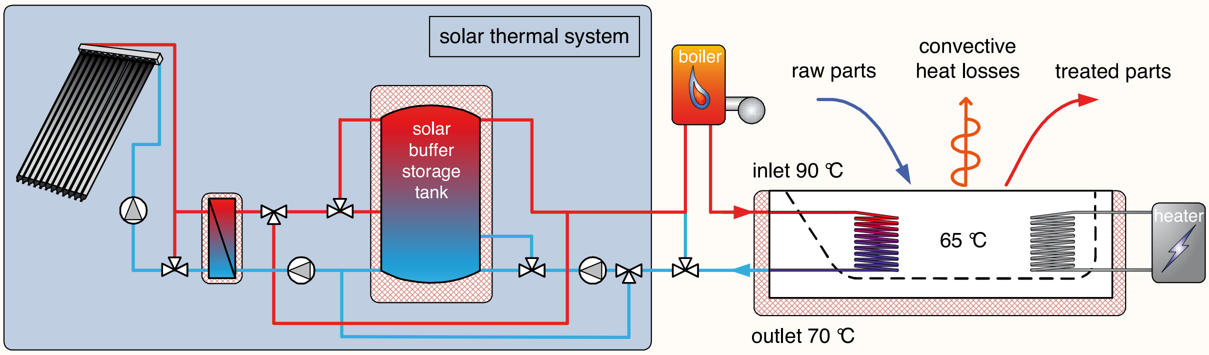

Fig. 15: Example of a system concept for the solar heating of an industrial bath. The backup heating is done serially by a boiler. A bypass of the solar buffer storage tank allows direct solar heating of the bath. The electrical heater is only used for temperature adjustment control of the bath.

In the example of fig. 15 raw parts are treated in an industrial bath at a temperature of 65 °C. Depending on the cycle times, the raw parts cause high heat losses, since they have to be heated up by the bath and usually have a high thermal capacity. The convective heat losses only account for a small share of the heat demand. The solar thermal system heats the bath via return flow boost; a boiler serially provides the necessary backup heat. Depending on the boiler type, a bypass of the boiler has to be foreseen for situations when it is not working.

The energy produced by the solar thermal system is usually significantly lower than the thermal demand of the bath. Since a very high temperature of 90 °C is needed at the inlet of the bath heat exchanger, there is the possibility to bypass the buffer storage tank to reduce storage losses and to prevent the fluid in the heating circuit from being mixed down by lower storage temperatures. This is also important because of the minimum temperature level of 70 °C in the whole system. The control of the boiler has to be able to ensure a constant inlet temperature at the necessary mass flow in this case.

When the storage is discharged, the return flow from the bath can be mixed into different heights of the storage by three-way-valve(s) to ensure a good stratification when the bottom of the storage is colder than 70 °C. When the solar irradiation is not sufficient and the buffer storage temperature is below 70 °C, a three-way-valve enables the boiler to heat the bath directly without heating up the buffer storage tank.

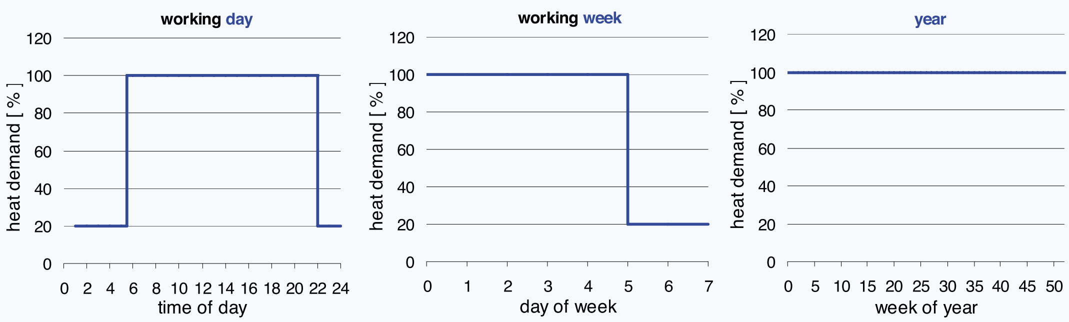

Fig. 16: Example for the continuous heat demand of an industrial bath in a smaller company (since the electrolyte always has to be kept at a certain temperature, there is also a certain heat demand for compensating the convective heat losses at weekends and during the night, when the plant is not operating.)

When heating industrial baths, the solar system gains are usually significantly lower than for heating up cold water. This is because heating of baths is no open process. The gains depend highly on the available temperature level (return flow temperature from the bath) and are lowest when the baths are never or very rarely refilled.

SOLAR PROCESS HEAT

At the examples simulated in this section, the baths are never refilled. In the simulation results of fig. 17, the solar system gains are critically low, even with vacuum tube collectors. This is because of the high return flow temperature of 70 °C, which causes low efficiency in the collectors and high storage losses.

In practice the gains of course can be much higher when the bath has to be refilled regularly and can be heated up by the buffer storage tank. Depending on the bath temperature, also a certain evaporation of water occurs in the bath. The water for refill can be heated up wit a system concept similar to the make-up water system (fig. 12) or from a solar heated hot water tank (fig. 9). Another advantage of bath or vessel heating is, that often only a small storage volume is necessary, since the bath itself can to a certain extend act as a thermal storage (depending on the variations in temperature allowed by the process). For load profiles as shown in fig. 16, also the "stand-by heat demand" at night or during the weekend could be covered by the solar plant completely for some hours. This can reduce the times when due to the low demand the boiler runs at inefficient part load or the electrical backup heater has to provide the energy. These examples illustrate that for the planning of a solar plant heating baths or vessels the preliminary analysis and the development of a well adapted control mechanism is of prime importance.

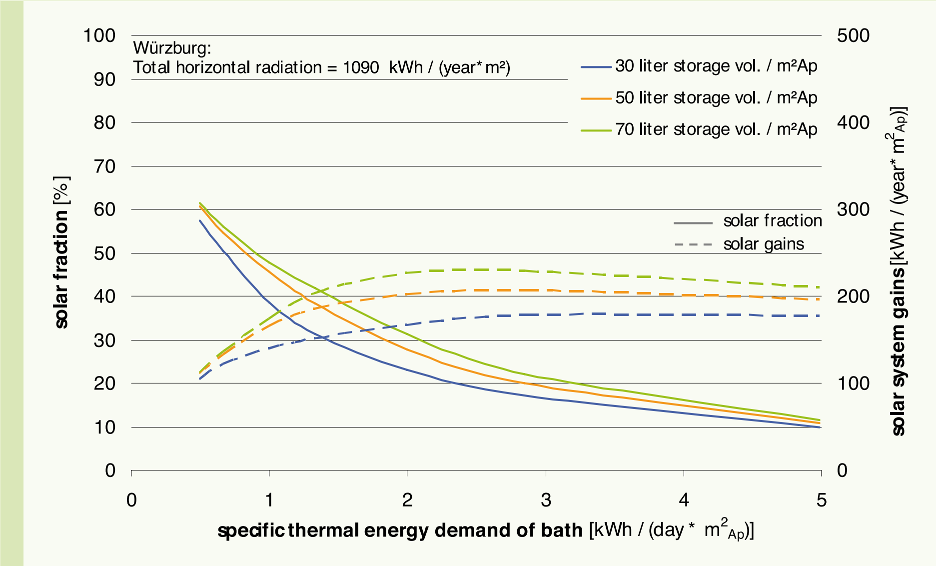

Fig. 17: Example of a design nomogram for the solar heating of industrial baths (valid for system of fig. 15, load profile of fig. 16, evacuated tubes with collector slope 35°, bath temperature 65 °C, inlet 90 °C, outlet 70°C, stratified storage)

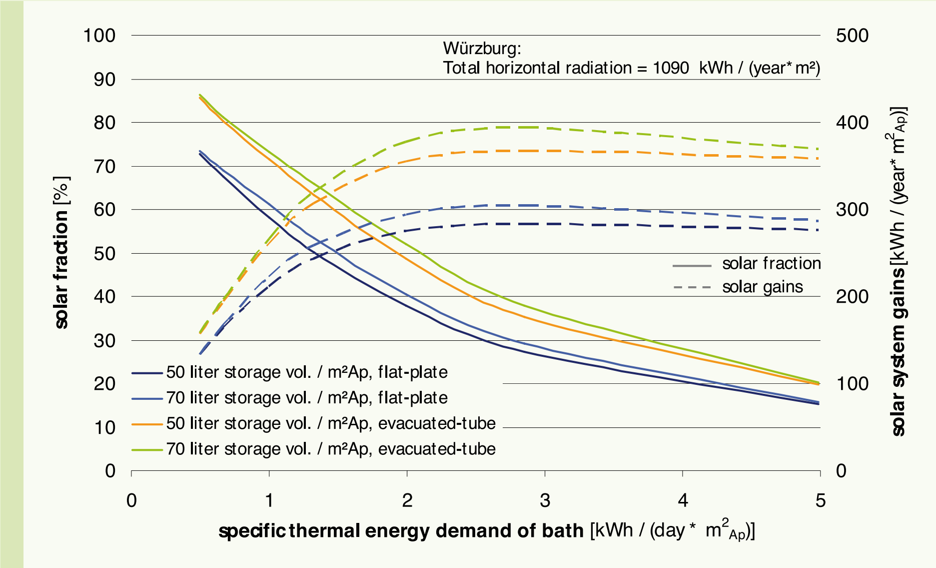

Fig. 18: Example of a design nomogram for solar heating of industrial baths (valid for system of fig. 15, load profile of fig. 16, comparison of flat-plates and evacuated tubes, both collector slope 35°, bath temperature 45 °C, inlet 70 °C, outlet 50°C, stratified storage)

When the bath temperature is reduced from 65 °C to 45 °C, the solar system gains can be nearly doubled for evacuated tube collectors (cp. fig. 17 and 18). In fig. 18 also the solar system gains of flat-plates can be compared to these of evacuated tubes (with the same specific aperture areas installed) for a minimum available temperature of 50 °C (return flow from the heat exchanger). In this case, the difference in collector costs or the available roof area will most likely be the crucial factors for the choice of a collector type. Fig. 19 shows the same comparison for exactly the same installation, but for the system installed in Madrid. The solar system gains are nearly double for this case. Because of the higher irradiation and ambient temperatures the difference between flat-plates and evacuated tubes is much smaller. In this case, most likely flat-plates would be installed because of their lower costs.

A comparison of fig. 18 and fig. 19 shows that the decision for a certain collector type depends not only on the available temperature level, but also highly on the total irradiation and site specifications like the mean ambient temperature.

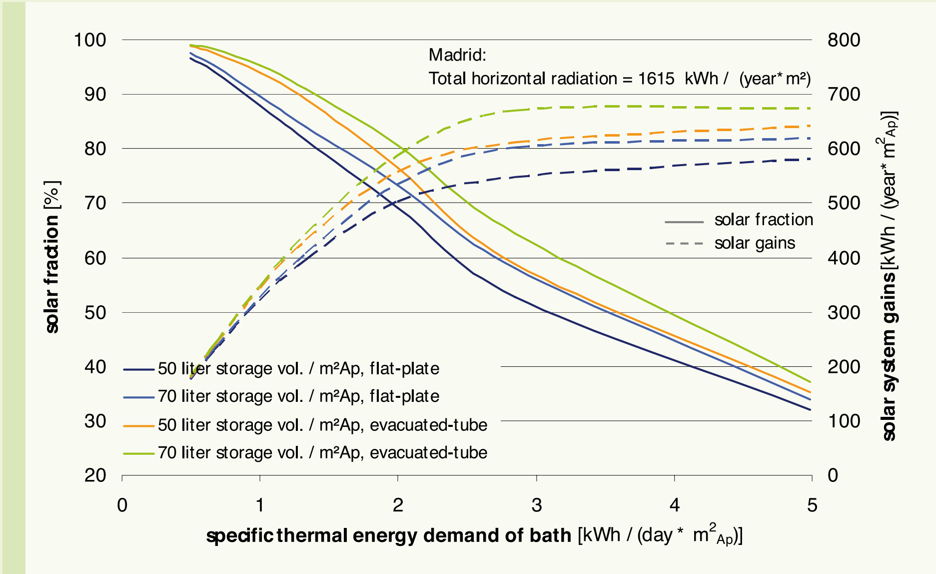

Fig. 19: Example of a design nomogram for solar heating of industrial baths (valid for system of fig. 15, load profile of fig. 16, comparison of flat-plates and evacuated tubes, both collector slope 35°, bath temperature 45 °C, inlet 70 °C, outlet 50°C, stratified storage, location: Madrid)

5.4 Convective drying with hot air

The process supported by the air collectors is an open drying process. In this example, there is no heat recovery from the humidified air. Conventionally, ambient air is heated up to 40 °C by an air / water heat exchanger. The solar air collector system is installed to (pre-) heat the ambient air. Because of the convenient load profile (cp. fig. 21), no storage is installed. The solar fan is at the hot side of the air collectors, so that leakage air flows at the collectors are not lost but used.

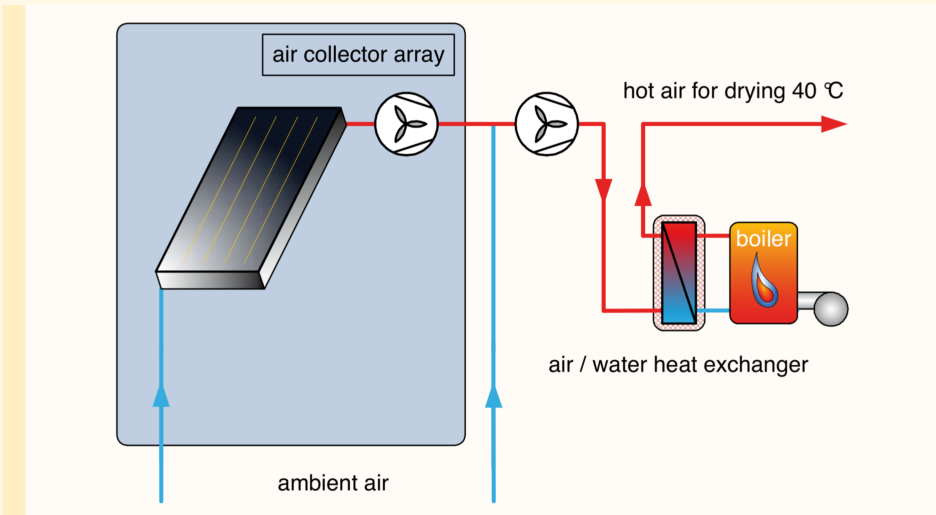

Fig. 20: Exemplary system concept of an open drying process. The open air collector system is serially supported by a boiler (solar fan left, conventional fan right).

Air collectors have different performance characteristics than collectors using water (and glycol) as heat carrier medium. Compared to these collectors, the efficiency of air collectors decreases significantly when the mass flow is reduced. Exemplary, a certain air collector shows an efficiency of 70 % at a mass flow of 100 kg_{Air} / (hour*m²), but only 45 % efficiency at a mass flow of 20 kg_{Air} / (hour*m²) (for collector inlet temperature equal to ambient temperature). As a drawback, the pressure loss at the high mass flow is five to six times higher than for the low one.

Whenever heated ambient air is needed for the drying process, the conventional fan generates the necessary mass flow. This fan compensates all pressure losses in the conventional system. When the sun is not shining, the solar fan is not active and the ambient air is heated by the conventional heat exchanger. When the solar irradiation is sufficient and the absorber temperature exceeds a certain value, the solar fan starts to run and generates its maximum mass flow of 100 kg_{Air} / m^2_{Ap}. For this mass flow, the temperature lift of the solar thermal system is low but the efficiency is high. Depending on the solar irradiation, the residual temperature difference to the 40 °C is added by the heat exchanger. Depending on the size and the internal field connection of the air collectors (collectors of one row often serial, collector rows often in parallel), additional cold ambient air is added automatically by the conventional ventilator running at constant speed to provide always the necessary mass flow for the process. If the solar irradiation is high, the temperature level after the admixture of the cold ambient air (after the conventional fan) can exceed 40 °C. Because of that, the driving speed of the solar ventilator can be modulated. When the speed is reduced the mass flow through the collector field decreases and the efficiency goes down. Because more cold ambient air is added, the temperature of 40 °C can be maintained by controlling the speed of the solar fan. In this case the conventional heater can be switched off and the electrical energy consumption of the solar fan is reduced because of the lower pressure drop in the solar field. With a properly controlled and tailor-made air-collector system for a certain drying process, the air / water heat exchanger can also be bypassed at very sunny days to further reduce the pressure losses of the system.

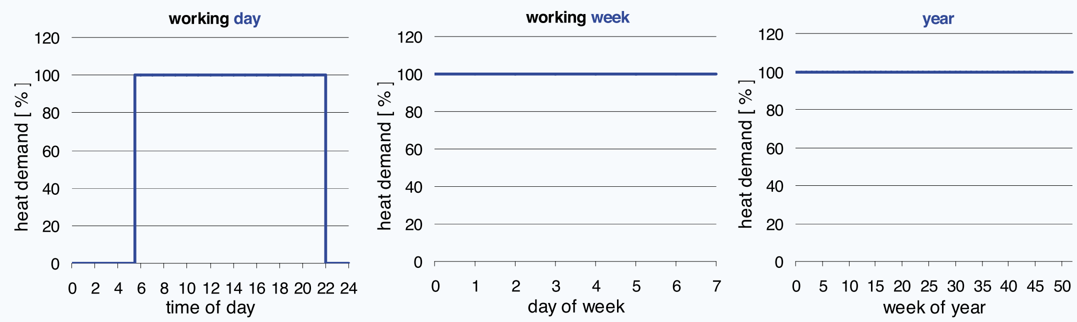

Fig. 21: Load profile for convective drying (application is good for the amortisation of the air collectors, since hot air is needed whenever the sun is shining)

To understand the curves of fig. 22 properly, it is important to remember that the absolute energy demand (and the demanded mass flow) of the process is constant. In the simulations, only the size of the collector field is varied, so that depending on this size of the field different specific energy demands of the drying air are resulting.

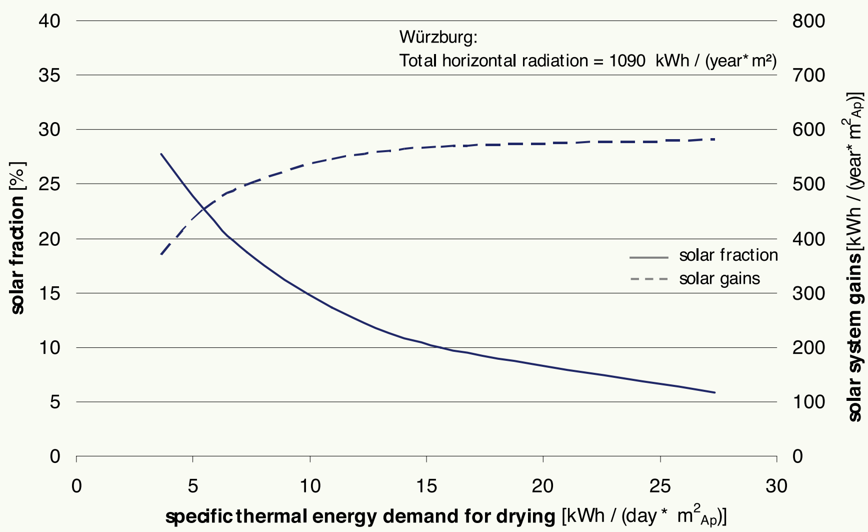

Fig. 22: Solar thermal system design diagram for convective drying, valid for the system of fig. 20 and the profile of fig. 21 (no storage, mass flows automatically controlled between 20 kg / (h*m^2_{Ap}) and 100 kg / (h*m^2_{Ap}))

For high specific energy demands (small collector fields), the collector field can usually be run at high mass flows (high efficiency), since the outlet temperature of 40 °C is usually not reached (to reduce the installation effort, one row of air collectors is usually connected serially). On the other hand, the solar fraction is very low and the backup heater is always running, often at inefficient part load). For large collector areas, the specific system gains decrease since the mass flow in the field often has to be reduced and thus at very sunny days the efficiency of the field is reduced. With this system and load profile, reasonable solar fractions in mid Europe are 15 to 20 %; in southern Europe due to higher irradiation and ambient temperature 25 to 35 % can be reached.

6 Design and maintenance aspects for solar process heat plants

In this chapter only the design and maintenance aspects of solar process heat systems which are especially relevant or can be different from conventional large solar thermal systems are discussed. Detailed **information on planning, installing and dimensioning of the technical components of solar thermal systems can be found in [6], [7] and [8]**.

6.1 Connection of the solar thermal system to the process

For open processes (compare washing / cleaning), the buffer storage tank of the solar thermal system usually has to be connected to the hot water supply system by a heat exchanger. This is because of three aspects:

- **Legionella:** When drinking water is stored in volumes over 400 l, this volume has to be heated up to 60 °C once a day to prevent legionella (fig. 8).
- **Scaling:** Where cold water is heated up to more than 60 °C, scale will be deposited (in storages, heat exchangers, etc.), reducing heat transfer and flow rate.
- **Corrosion:** When e.g. standard steel tanks or copper tubes are regularly in contact with cold water containing high oxygen amounts, they can be damaged by corrosion.

Scaling and corrosion also are the reasons why the make-up water can not be heated in the solar storage directly (fig. 12). In plants with stochastic cleaning water demand and very high flow rates usually an additional storage is installed, since in this case some fresh water modules can only maintain the desired temperature level to a certain extent (fig. 9). Water can only be heated directly (without heat exchanger) in the solar buffer storage tank when it is used as heat carrier fluid, i.e. in a closed circuit (fig. 15, baths / vessels).

6.2 Stagnation

When there is incident irradiation on the solar collectors but the pump of the collector circuit is not operating, the collector field start to heat up until its stagnation temperature. This is the temperature where the energy absorbed by the collector equals its thermal losses. It can be higher than 250 °C, depending on collector type and piping.

The **different phases of stagnation** with can be described as follows: First, the fluid in the collectors is expanding due to the rising temperature. Vapour bubbles are generated when the evaporation temperature of the fluid is reached (depending on the system pressure). The system pressure is rising rapidly. Depending on the construction of the collector piping, the fluid can be pushed out of the collectors by the first vapour bubbles (fig. 23). Steam enters the connecting pipes of the solar field and can reach the other components of the solar circuit (depending on the steam production power of the collector field, correlating with the emptying behaviour in case of stagnation). The remaining fluid in the collectors boils at higher temperatures, because of the now higher system pressure. The steam in the collectors is superheated. When the temperature decreases, the collector field is filled up again by the expansion vessel.

Possible reasons for stagnation with steam production in the collectors are:

- the maximum temperature of the storages is reached and the pump stops (frequency depends on the size of the solar plant compared to the load)
- errors in the control or its sensors, defect of the collector pump or power blackout
- leakages in the solar circuit, reducing the system pressure

The following problems can be caused by stagnation: The heat carrier fluid (if water / glycol) can degrade faster or can even be destroyed. Glycol can be either thermally damaged (at long-term temperatures > 160 °C, depending on glycol type) or degraded by oxygen (in case of leakages). When glycol is destroyed, it can block the collector tubes. Also the components of the solar circuit can be thermally damaged, especially the membrane of the expansion vessel, the valves, deaerators, pump, etc. When the expansion vessel or the safety valve is dimensioned wrong, the collector circuit can blow off from the stagnation pressure. Besides the technical problems, of course also the irradiated energy can not be used in case of stagnation, which reduces energy gain of the system.

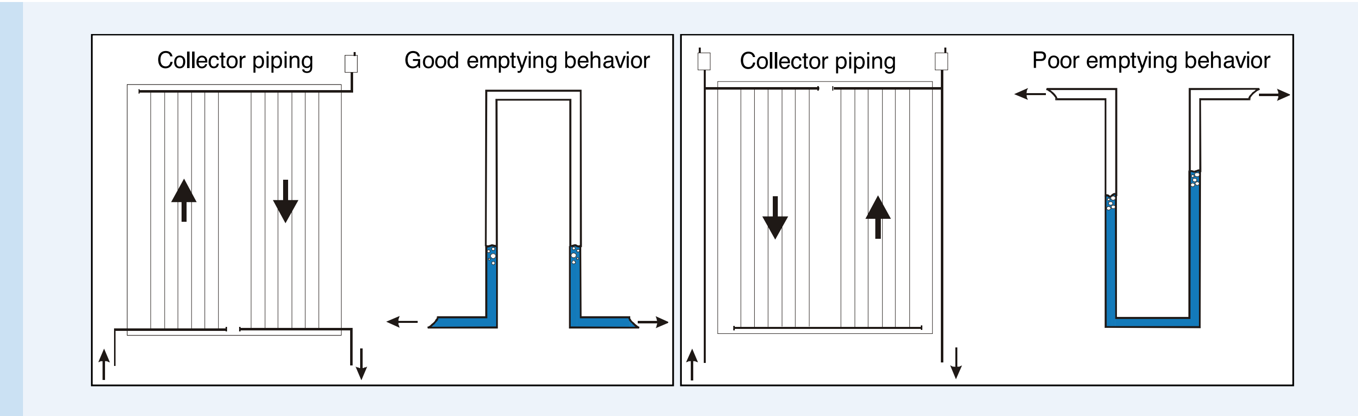

Fig. 23: Comparison of advantageous (left) and disadvantageous (right) pipings. When collectors and collector fields are emptying well (reverse U-configuration), the steam production power and the steam penetration depth are small. For the right piping, all the fluid within the collectors has to evaporate and can be thermally damaged.

Stagnation problems have to be avoided in the planning phase. **Every system has to have a stagnation concept, since stagnation is an occurring operation mode** (e.g. when there is no thermal load at holidays).

Measures to avoid stagnation problems:

- Install **collectors and collector fields with good emptying behaviour** (reverse U-configuration), but ensure that the air in the field can be properly removed.
- Ensure a **correct dimensioning of the expansion vessel**. It should be able to contain the whole volume of the collector piping. Protect the expansion vessel from steam (do not isolate the connecting pipe; also passive coolers can be applied there, depending on the steam production power of the field).
- Do not install a non-return valve between the collector field and the expansion vessel. The non-return valves determine the direction of the penetrating steam.
- Ensure **a correct dimensioning of the safety valve** to withstand the stagnation pressure (usually 6 bar).
- Select **steam- and temperature resistant component**s, if they can be reached by steam; also select a glycol type which can be used at high temperatures.
- Especially for types of vacuum tube collectors where a reverse U-configuration is not possible for the piping, the **steam production power of the field should be reliably known**. It is an important planning criteria e.g. for the expansion vessel.
- Ensure at the system control that the pump can not restart when vapour is inside the collectors (definition of a maximum temperature for operation).
- A **low system pressure reduces the thermal stress of the fluid remaining in the collectors** (but higher steam production must be considered).
- If passive stagnation coolers are not sufficient, use **active cooling**. For flat-plate collectors, heat can be dissipated via the collectors at night. Also active water / air exchangers can be installed at the solar field to cool it down when a certain temperature is exceeded. Have in mind that these measures do not work at power blackout and that they decrease the specific gains and should only applied when absolutely necessary.

- For small plants, **make sure that the storages are large enough** to buffer all the energy irradiated at weekends, when there is no thermal load. This avoids frequent stagnation. Have in mind that the **thermal capacity of the storage depends highly on its temperature level at the bottom** – in case a closed high-temperature process is supported, this temperature regularly might be high (cp. fig. 15).

More detailed information on stagnation aspects can be found in [9].

6.3 Operation of the solar thermal system

Correct system design and installation minimise the maintenance requirements of solar process heat systems. The **most important** aspect for proper system operation is to **give the responsibility** for the periodic inspections necessary (see [8]) to a skilled person of the industrial company (usually a technician), or to a person of the installing company (in case of "solar contracting"). Detailed system concepts and maintenance guidelines should be available for the regular checks.

After the system installation there should be an appropriate adaption of the control parameters to the real behaviour of the process to ensure a maximum efficiency of the solar thermal system. It is also recommended to have an **electronic monitoring** of the solar thermal system parameters and energy gains, so that optimizations can be performed easily and the necessary on-site inspections, e.g. after holidays, can be reduced.

7 System costs and subsidies

7.1 Typical system costs

The costs of solar thermal process heat **installations** in Europe range from **180 up to 500 Euro / m^2_{Ap}**, depending on the system concept, the size of the system, the selected components (e.g. the choice of the collector type) and on country-specific factors (e.g. salaries). Installations for solar drying can have lower costs, since usually no storage is installed. Fig. 24 exemplary indicates the distribution of installation costs for larger solar thermal systems in Germany. The aperture area **specific costs decrease for larger systems**, since the investments for e.g. planning and control do not increase proportional to the costs of the collector field.

As already mentioned, the **annual energy gains** of solar process heat installations **can be twice as high as in the residential sector**, depending on the minimum utilizable temperature, the process temperature and the load profile. This can dramatically reduce the amortization times (dependant if fuel, oil, gas or electricity is substituted).

Properly planned and maintained solar thermal systems can have a lifetime of more than 20 years. The **solar heat generation costs** for low temperature processes can be **between 2 and 8 eurocent / kWh**, highly depending on location, supported processes and temperature levels.

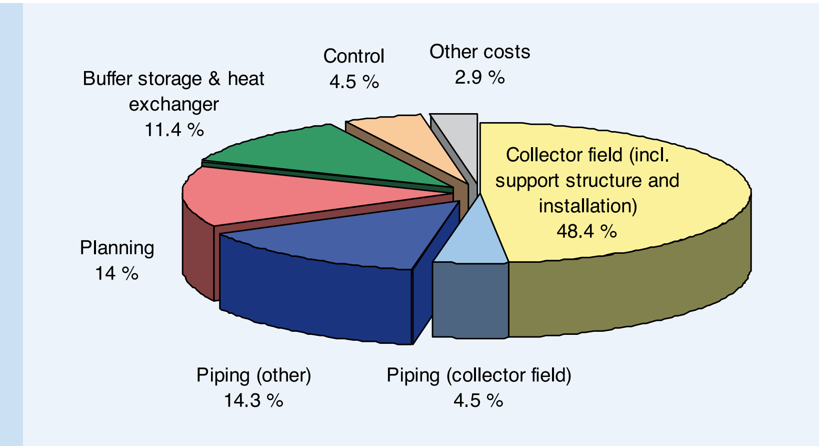

Fig. 24: Distribution of the spezific investment costs for larger solar thermal installations (Solarthermie-2000, reported in [10])

7.2 Subsidy programmes

In almost all European countries subsidy programmes exist, covering also or especially solar thermal process heat installations. **Country-wide, but also regional specific and even technology specific** (e.g. difference between vacuum-tubes and flat-plates) support schemes exist.

Unfortunately, in many regions the subsidy programmes are frequently changing because of short-term political decisions. For further information on up-to-date subsidy programmes for solar thermal process heat installations, please contact the energy agency of your region (see back cover page of this brochure).

8 Literature / further information

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SO-PRO – a European initiative

The SO-PRO project, a project supported by the Intelligent Energy Europe Programme, aims to trigger the starting up of markets for solar process heat in 6 European regions (Upper Austria, the regions of Castillas y Madrid/Spain, South Bohemia/Czech Republic, North-Rhine Westphalia and Saxony/Germany, the Maribor region/Slovenia).

Project activities include – among others – targeted awareness raising for industrial decision makers, training of professionals, development of checklists and planning guidelines and 12 pilot projects. Comprehensive European dissemination activities ensure that the know-how gained is applied around Europe.

Further information is available at: **www.solar-process-heat.eu**

Partners of the SO-PRO project

	Partner	Region
	O.Ö. Energiesparverband (ESV)	Upper Austria (Austria)
	ESCAN	Region of Castillas y Madrid (Spain)
	Energy Centre České Budějovice (ECCB)	South Bohemia (Czech Republic)
	GERTEC	North-Rhine Westphalia (NRW, Germany)
	Sächsische Energieagentur (SAENA)	Saxony (Germany)
	Energy agency of Podravje (Energap)	Podravje region (Slovenia)
	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung (ISE)	(Germany)

Intelligent Energy Europe

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