SOLAR-THERMAL PROCESS HEAT –
A LOW-TEMPERATURE HEATING NETWORK IN A DAIRY

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1. Introduction

One third of the European primary energy consumption is used for industrial applications. A huge amount of this energy is needed for heating processes. Today's process heating systems are normally fossil fired. Not only the increase as well as the development in fuel costs in recent years requires the industry to reconsider their approach regarding process heat supply but at the same time the finite nature of fossil fuels and the negative impact of CO_2-emissions on the climate.

A very promising option is the implementation of solar-thermal power into the conventional process heat systems. The food industry, especially breweries and dairies, provides consistently favourable conditions regarding their processes and applications as shown in 'Fig. 1'. Additionally to the low process temperatures, there is often a high base load energy demand for production and cleaning processes. In particular, the energy demand in breweries and dairies in summer is higher than in winter times, so it follows the solar radiation. This is a very interesting fact for using solar-thermal energy.

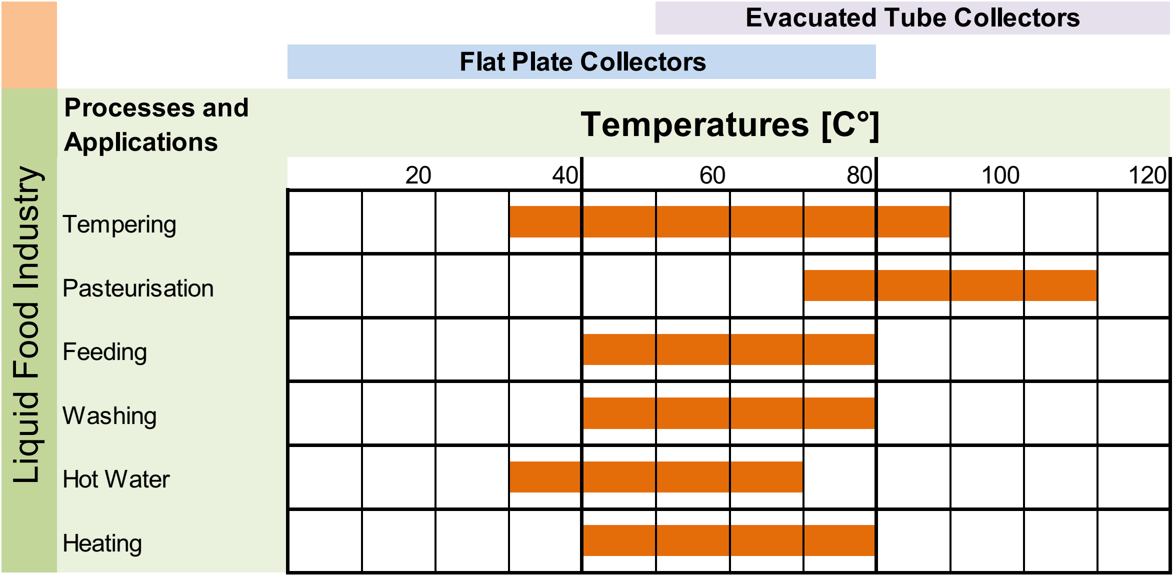

Fig. 1: Process Temperatures of the Liquid Food Industry (especially breweries and dairies)

Several studies within the framework of IEA TASK 33/IV – Solar heat for industrial processes (SHIP) – identified the high potential of this technology. With today's state-of-the-art components (e. g. flat-plate or evacuated tube collectors, storage tanks, …) processes of up to 80 °C can easily be supplied with solar-thermal energy.

For this reason, the *CENTRE OF EXCELLENCE FOR RENEWABLE ENERGY RESEARCH* at *Ingolstadt University of Applied Sciences* carries out a research project with two industrial partners. In cooperation with the brewery *Herrnbräu GmbH & Co. KG* (Ingolstadt, Germany) and the dairy *Zott GmbH & Co KG* (Mertingen, Germany), standardised solutions for the implementation of solar-thermal process heat systems will be developed to boost the distribution of this technology, however, not only in the food industry.

2. Low-Temperature Heating Networks

Nowadays, low-temperature heating networks are known as a part of district heating systems or systems for the heat supply in large social buildings such as hospitals or retirement homes. The supply of energy for space heating and domestic hot water is the central task of such systems. Heat energy supply of these systems is realised by one or more conventional heat generators. Such heat generators are occasionally supported by a solar-thermal system and combined with a short-term or a long-term thermal storage.

As a fact of regional development and an increasing use of waste heat from biogas plants as well as the usage of wood fired heat generators, low temperature district heating systems become more and more important. In urban areas, district heating systems are already more common. The advantage in this situation/case is the ratio between the supplied area and the heating demand which is better than in regional areas. Also, the available space on the roofs of the buildings provides considerably good conditions for solar-thermal systems as a support of conventional heating.

A remarkable number of solar-thermal supported systems were installed and analysed within the framework of the research program SOLARTHERMIE2000 (n. d.). In several studies it was shown that the most challenging topic is the functional integration of the solar-thermal system. Due to an appropriate system configuration and favourable load profiles such systems can reach solar-thermal earnings of 350…550 $\text{kWh}_{\text{th}}/\text{m}^2_{\text{collector area}}$ per year. However, systems with satisfying solar-thermal earnings often could not reach the earnings prognosticated within the previous simulation. Hence, the planning and designing of such low-temperature heating networks will be a major challenge.

The most important fact for satisfactory operation and solar-thermal earnings is the return temperature of the heating network which correlates to the operating temperature of the solar-thermal system. Hofmann et. al. (2009) describes this problem in his study of the urban heating supply of Wanzleben (Germany). 'Fig. 2' shows typical flow and return temperatures for the two collector fields of the solar-thermal system which is directly (without any thermal storage) connected to the local district heating of Wanzleben. The return temperatures are found to be mostly beyond 70 °C which is mainly the reason for solar earnings only about 170 $\text{kWh}_{\text{th}}/\text{m}^2_{\text{collector area}}$ per year.

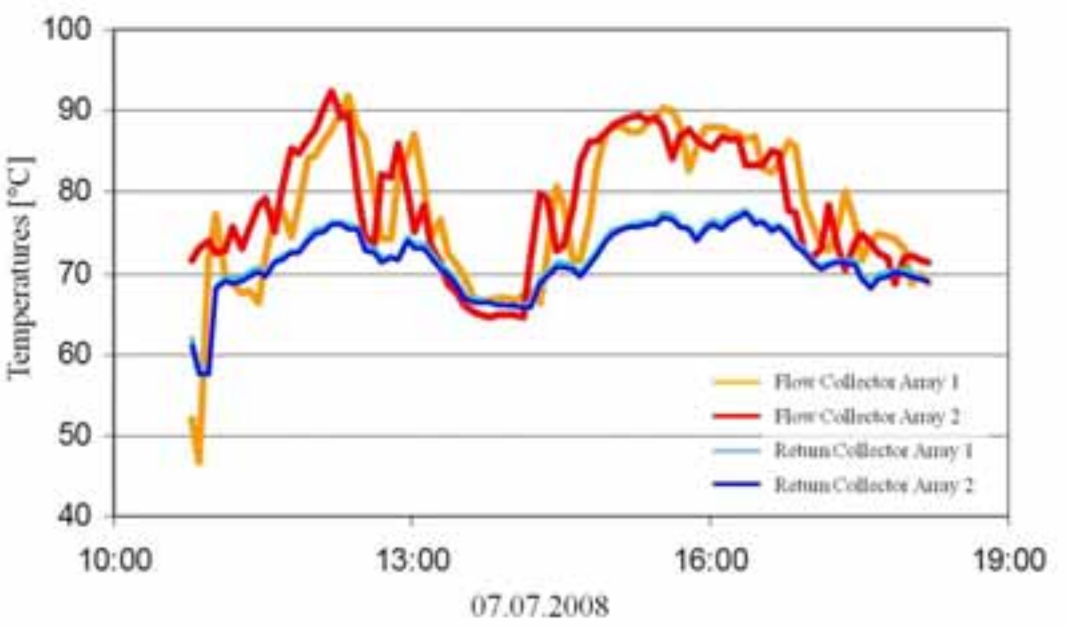

Fig. 2 Flow and Return Temperatures of Collector Fields at District Heating Wanzleben (Hofmann 2009)

Furthermore, the type of thermal storage (long-term or short-term storage) and the direction as well as the angle of the collector array have a significant influence on the annual earnings of a solar-thermal system.

With an energy flow-rate of a few hundred MWh_{th} up to more than five thousand MWh_{th} per year such district heating systems are quite comparable to industrial low-temperature heating networks at medium-sized industry plants of the liquid food industry considering their energy supply. Also the configuration of the heat sources and heat sinks is similar to district heating systems. The most important differences exist regarding the load profiles. Where the heat demand in district heating systems in winter is much higher than in summer the load profile of industrial low-temperature heating networks depends on the supplied heat sinks on a more constant level.

Such low-temperature heating networks are usually supplied by the main heat generator of the industry plant. Moreover, waste heat potentials are used for heat supply if possible, for example the energy of wort cooling in breweries. The flow and return temperatures in most heating networks are determined by the supplied processes and their temperature ranges as well as the temperatures of specific heat sources like the waste heat applications. Industrial low-temperature heating networks are often used also for space heating applications or hot domestic water supply. Further applications are the heating or preheating of water used in production processes (e. g. brew-water for mashing) or thermal energy supply for cleaning equipment (e. g. Cleaning-in-Place). But also the thermal energy demand of production processes can be supplied. This wide range of applications provides generally a huge base load and therefore often continuous heat sinks which is favourable for solar-thermal systems as a heat source.

3. The *Zott* Dairy

The *Zott GmbH & Co. KG* is a large size dairy in Mertingen located in the south of Germany. In 2010 about 1,100 employees processed 430,000 tons of milk. With this processing capacity *Zott* belongs to the ten biggest dairies in Germany. The product portfolio of the main factory in Mertingen ranges from yoghurt, yoghurt and whey drinks up to mozzarella. For processing these products, about 65,000 MWh of thermal energy and more than 50,000 MWh of electrical energy are necessary.

The primary focus of *Zott* is a sustainable thermal energy supply. Several million Euros were invested in improvement measures and modernization of the thermal energy supply and waste heat recovery applications. A wood fired biomass combined heat and power plant (CHP) was commissioned to supply the factory with process steam. The existing fossil fired steam boilers were consequently shut down at the end of 2009. However, there is still a fossil fired steam boiler necessary whenever the steam supplied by the biomass plant is not sufficient. At a central transfer station the process steam line from the CHP is connected to the dairy. The generated condensate from the supplied processes is transferred back to the CHP and reused for steam production. Besides the dairies steam network the industrial low-temperature heating network is partly supplied by the steam of the CHP.

4. Low-Temperature Heating Network at *Zott* Dairy

The low-temperature heating network was originally implemented to use the waste heat of *Zott's* gas fired combined heat and power units. After decommissioning of the combined heat and power units the network was redesigned for heat supply at a temperature level of 65 °C (former 95 °C with the combined heat and power units). This happened in the course of the commissioning of the CHP and the now coming up condensate which has to be cooled before transferring it back from the dairy to the CHP. Thus, the low-temperature heating network is a favourable heat sink.

The present configuration of the heating network is shown in 'Fig. 3'. Currently, the prior heat source for the redesigned heating network is the Condensate Cooling. In times of insufficient energy supply by the Condensate Cooling, additional steam can be delivered by two heat exchangers. Production Processes, Cleaning-in-Place Facilities, Hot Domestic Water and Space Heating are the applications supplied with energy from this heating network. In the network, a Buffer Storage Tank of 160,000 l is integrated. This storage tank is placed outside the dairy buildings. Since the total thermal energy of the condensate is at present consumed, the storage tank remains unused.

With a flow temperature level of 65 °C it is possible to supply the Hot Domestic Water as well as the cleaning equipment with sufficient energy. Also, for Space Heating the temperature level is high enough. For applications in the production, the heating network is only used for preheating the processes whereas the steam network ensures the temperature level needed.

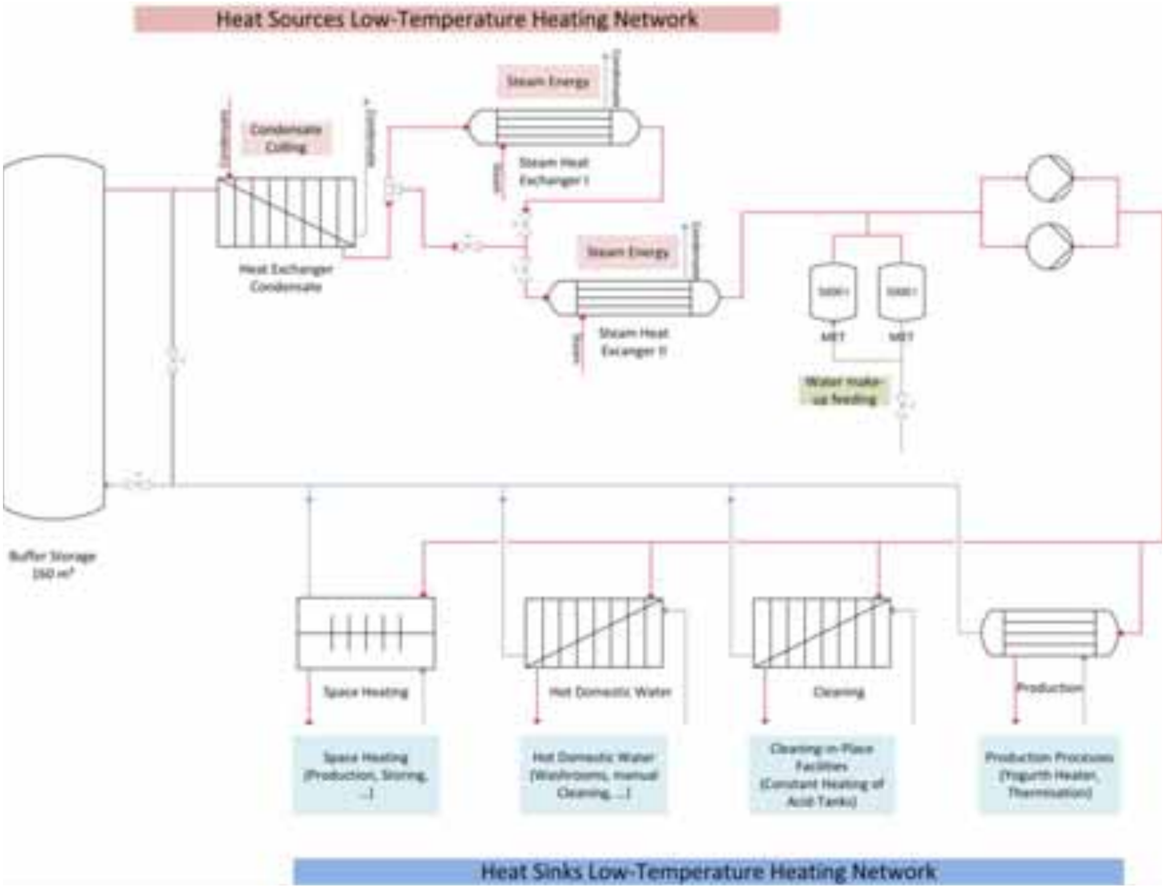

Fig. 3: Configuration of the *Zott* Low-Temperature Heating Network

About 11 % of the total thermal energy demand of *Zott* can be provided by the low-temperature heating network. An extensive analysis of the network in 2010 has shown that the Condensate Cooling contributes about 45 % of the network energy. 3,900 MWh of steam energy were necessary in 2010 to compensate for missing condensate energy as 'Tab. 1' shows.

Tab. 1: Energy of the Low-Temperature Heating Network (2010)

	Condensate Cooling	**Steam Heating**
Energy [MWh_{th}]	3,350	3,900
Proportion [%]	~ 46	~ 54

On average, the Condensate Cooling contributes on a relative constant level about 280,000 kWh each month. Additionally, 325,000 kWh of steam energy are needed. The supplied steam energy is at its minimum level between May and August. During this period, the energy demand drops to 180,000 kWh. The peak energy demand is between January and December with more than 600,000 kWh. As shown in 'Fig. 4', there is a significant increase of energy demand in winter.

A further analysis of the provided heat sinks shows the relation between these load profiles and the total load profile of the low-temperature heating network. 'Fig. 5' shows the heat sinks Production and Cleaning, Hot Domestic Water and Space Heating. Production and Cleaning as well as Hot Domestic Water are relatively constant consumers over the year. Nearly two thirds of the network´s energy is used for these applications. The remaining energy is for Space Heating. This consumer is first of all responsible for the typical load profile of the network.

At first sight, the network´s load profile is not very promising with regard to the use of a solar-thermal system. However, the base load of additional steam energy as shown in ‘Fig. 4’ of about 180,000 kWh in summer is considered to be supplied by a solar-thermal system.

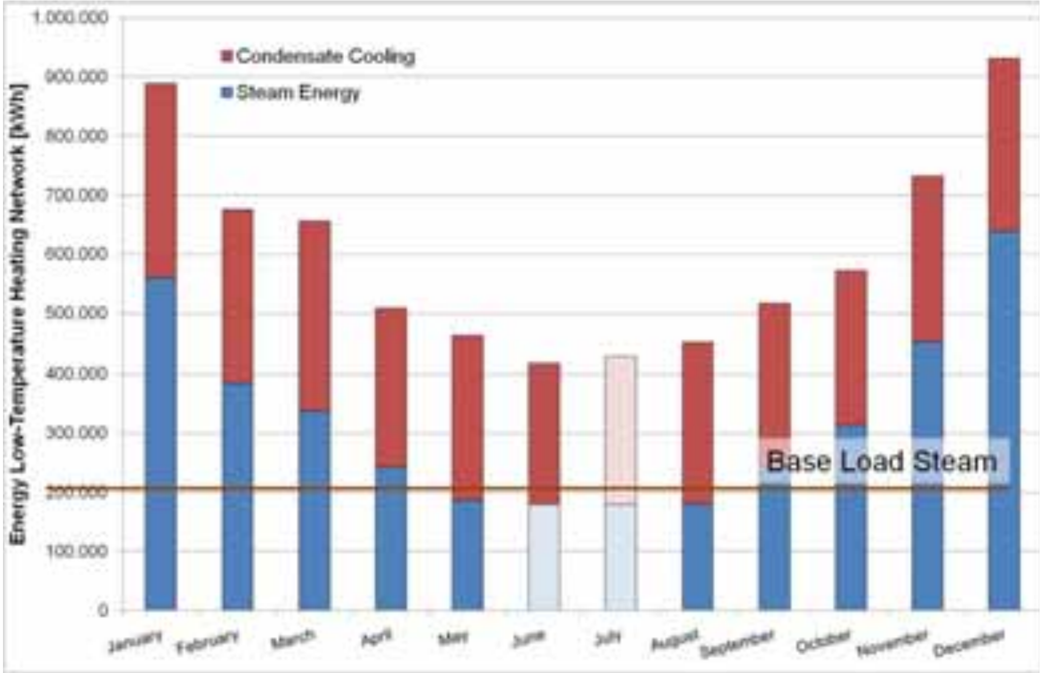

Fig. 4: Load Profile of *Zott* Low-Temperature Heating Network (2010)

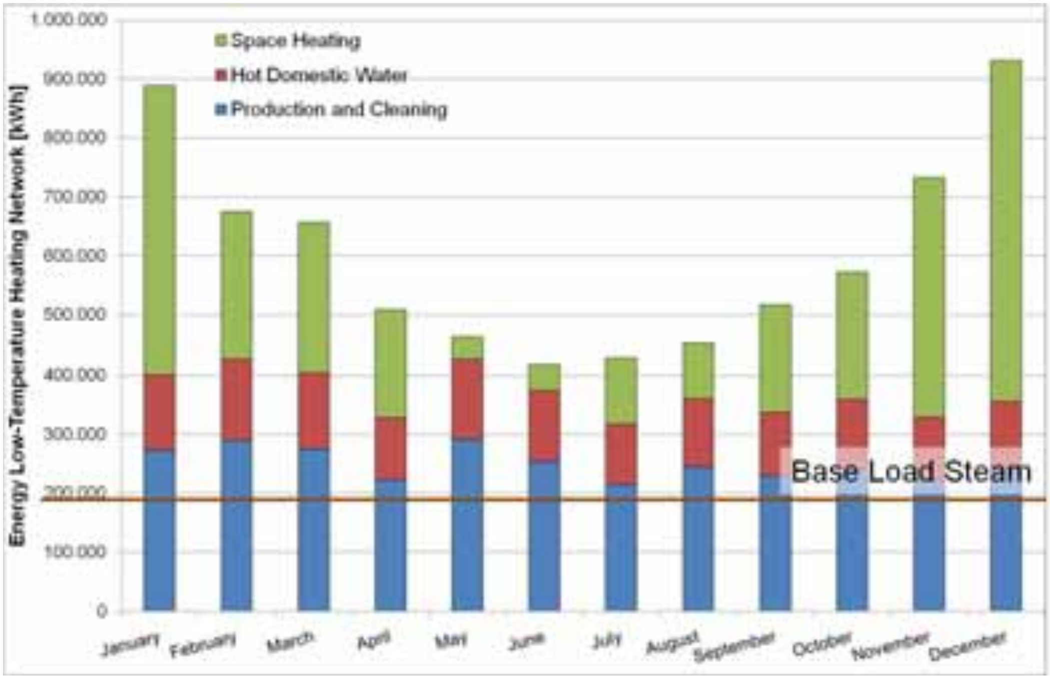

Fig. 5: Load Profile and User Groups of *Zott* Low-Temperature Heating Network (2010)

As a part of the energetic analysis, the flow and return temperatures of the network were considered. As mentioned before, the flow temperature is set at 65 °C. This was confirmed by the measured data which have shown a slightly fluctuating temperature of 65 ± 1.5 °C. More important regarding the solar-thermal system is the return temperature which is at about 61.5 °C in summer and 52.5 °C in winter. The difference between summer and winter is due to the supply of the Space Heating which is a considerable energy consumer. In general, the high return temperatures in the heating network are critical. In case of the *Zott* dairy the reason for this temperature was found to be the high operating temperatures of the Cleaning-in-Place Facilities and the high flow temperature of the Hot Domestic Water.

5. Concepts for a Solar-Thermal Process Heat Integration

In consequence of the energetic analysis of the low-temperature heating network and the result of a base load for steam energy of 180,000 kWh in summer, it is not only possible but also recommendable to analyse the possibilities to integrate a solar-thermal system as additional heat source. Another challenge in the integration of solar-thermal energy is to find the optimum sequence of the three available heat sources: Condensate Cooling, Steam Energy and Solar-Thermal Energy. Therefore, a problem to handle is the cooling of the still necessary condensate. As mentioned before, the condensate has to be cooled down before transferring it back to the CHP. So, there is always the demand to get as much energy out of the condensate as possible by supplying it to the low-temperature heating network. Otherwise, an emergency cooling system will be necessary for reaching the defined temperature level of the condensate.

For the following development of simulation models, three different basic integration concepts as well as a concept for the solar-thermal system are designed.

5.1 Concept 'Reference Model'

The first integration concept is based on prior cooling of condensate. Accordingly, the fist level of heating the network remains the Condensate Cooling. In order to reach the final temperature the steam network will compensate for the missing energy. As shown in 'Fig. 6', the heat exchanger for the solar-thermal energy will be integrated between the Condensate Cooling and the Steam Energy. The major disadvantage of this configuration is the high temperature level of the low-temperature heating network at this stage. As shown in 'Chapter 4', the return temperature of the network is generally at a high level. Downstream of Condensate Cooling it is still higher, sometimes already at 65 °C so that there will be no possibility to supply solar energy to the heating network.

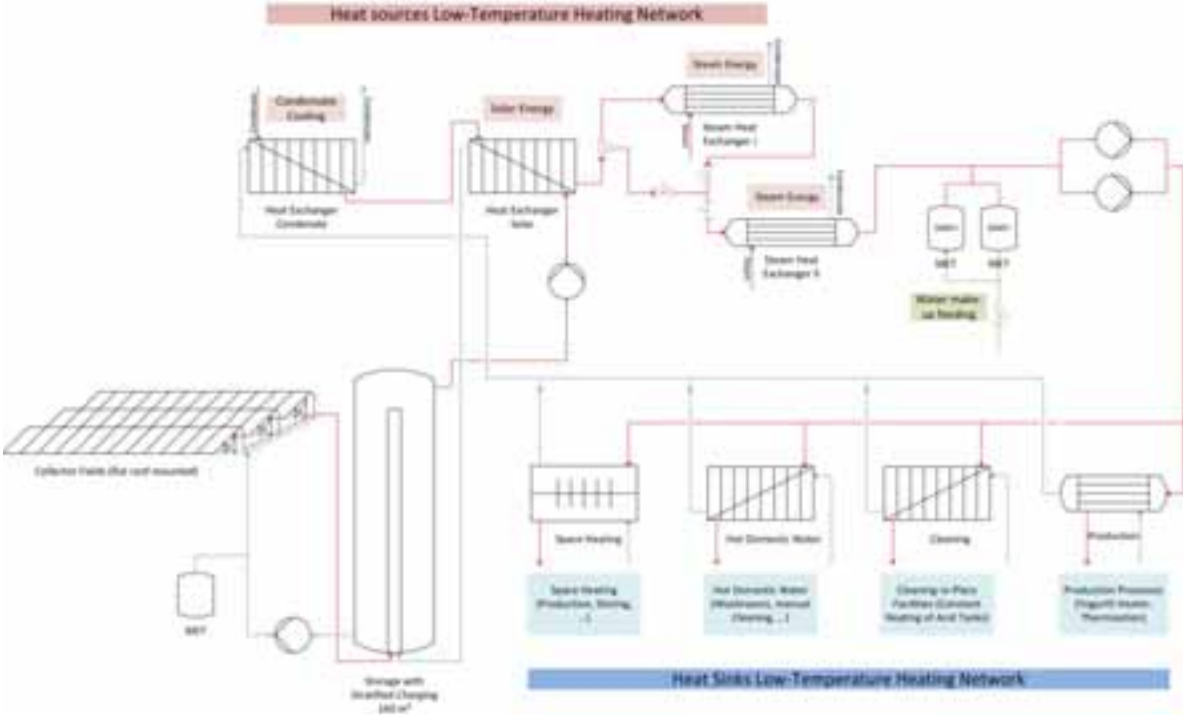

Fig. 6: Concept Design ‚Reference Model'

5.2 Concept 'Solar Priority'

In comparison to 'Reference Model', this model shows the potential of a solar-thermal energy supply at the first stage of the heat exchanger network. First of all, this model is used for an energetic comparison to the 'Reference Model'. The model ensures the possibility of higher solar-thermal due to lower return temperatures at the first stage. To avoid the start of the emergency condensate cooling system, the condensate needs to be cooled to a certain temperature. Further investigations need to be carried out in this matter.

5.3 Concept 'Parallel'

A variation of the two first concepts is based on the idea to integrate the Condensate Cooling and the Solar Energy in parallel and divide the volume flow of the low-temperature heating network before. With the help of an intelligent flow control, the volume can be diverted exactly to the two heat exchangers. This enables the possibility for the solar part of this stage to work at the lower return temperature. Simultaneously, the Condensate Cooling is supplied by a sufficient volume flow for the essential energy output. Challenges with this concept will be the control strategy for the volume flow in connection with the temperatures of solar-thermal energy as well as the temperatures of condensate and heating network.

Economic considerations are not considered important at this phase of conceptual work. First of all, the optimum energetic solution for all the three stages of energy supply to the network is in focus and with this the optimisation of the three designed concepts. As a result, a concept for a solar-thermal system has to be designed too.

5.4 The Solar-Thermal System

Basis for the solar-thermal system integrated to the *Zott* low-temperature heating network is the already existing storage tank. This storage tank with a total volume of 160,000 l was built to store waste heat from CHP-Units. Currently, the storage tank is equipped with a perforated load pipe designed as a ring in the lower part of the storage tank. Tapping of heat energy takes place at the upper part with a connected pipe direct to the storage medium. For the use in a solar-thermal system, the concept design includes, besides the current storage tank configuration (isolation, height, diameter, …), the reconstruction of the tank including the equipment for a stratified charging. Both variations will be simulated within the system simulation for comparison and optimisation.

For the dimensioning of the collector area, the available flat roof was analysed. So, the collector area for the preliminary simulation runs is defined at 2,000 m². Further, a standard flat-plate collector is used within a collector array connected in parallel. The heat transfer medium is water. This enables the possibility to avoid an additional heat exchanger between storage tank and Solar Circuit but requires in further concepts the integration of an anti-freezing system. 'Fig. 7' shows a simplified drawing of the solar-thermal system concept.

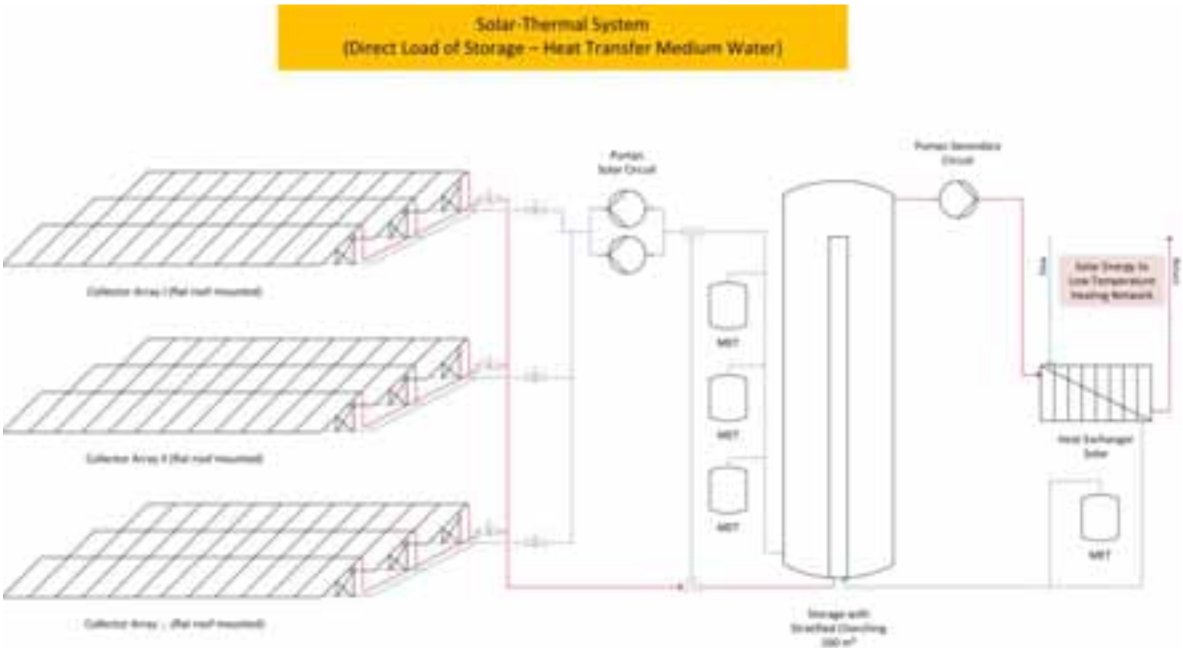

Fig. 7: Concept Design of the Solar-Thermal System

6. Simulation of the Solar-Thermal Process Heat System

MATLAB&Simulink with the CARNOT Toolbox (**C**onventional **A**nd **R**enewable e**N**ergy systems **O**p**T**imization Blockset) is used for the simulation of the systems. This software ensures the necessary flexibility with regard to configuration and development of the system´s components as well as the specification of control strategies.

All the simulation runs in this first phase are carried out as annual simulation to calculate the solar earnings and to analyse the system´s behaviour during a complete year. As basic reference, the real system of the *Zott* low-temperature heating network was also developed as simulation model and simulated based on the measured load profiles, temperatures and energy data. The deviation of the simulation results was found to be at around 2 %. Hence, the model is considered to be close to the real system.

'Tab. 2' shows results of the annual simulation runs of the three basic simulation models with the integrated solar-thermal systems 'Reference Model', 'Solar Priority' and 'Parallel'. Input data for the simulation are the measured load profiles and temperatures of the low-temperature heating network of 2010 as well as weather data of the location Mertingen (REMUND, J.).

Tab. 2: Annual Results of Simulation Models

	'Reference Model'	**'Solar Priority'**	**'Parallel'**
Condensate Energy [kWh_{th}]	3,389,000	3,148,500	3,384,700
Solar Energy to Storage [kWh_{th}]	700,240	776,900	731,100
Collector Earnings (Storage) [$kWh_{th}/m^2_{collector\ area}$ a]	349.2	387.5	364.6
Storage Losses [kWh_{th}]	135,590	121,070	131,790
Solar Energy to Network [kWh_{th}]	564,650	655,830	599,310
Collector Earnings (Network) [$kWh_{th}/m^2_{collector\ area}$ a]	281.6	327.1	298.9
Steam Energy [kWh_{th}]	3,433,600	3,584,800	3,409,300

Focus of these simulation runs is on the results of the solar-thermal system as well as the mutual interference of the solar-thermal system and the Condensate Cooling. Furthermore, the specific collector earnings and the heat losses of the storage tank are compared.

With the 'Reference Model', collector earnings of 349.2 $kWh_{th}/(m^2_{collector\ area}$ a) regarding the storage tank and 281.6 $kWh_{th}/(m^2_{collector\ area}$ a) considering the supply of solar energy to the network are reached. The heat loss of the storage tank is at 135,590 kWh/a which is about 20 % of the energy of the storage tank. Slightly better results shows the 'Solar Priority' model. Here, the specific collector earnings regarding the supply to the heating network are at 327.1 $kWh_{th}/(m^2_{collector\ area}$ a), i.e. about 16 % better than the 'Reference Model'. Besides, the storage losses are minimised. This is a consequence of the lower working temperatures of the solar-thermal system due to its priority to the Condensate Cooling. Solar earnings of the 'Parallel' model are 298.9 $kWh_{th}/(m^2_{collector\ area}$ a), i.e. between the two other simulation models. The same applies for the heat loss of the storage tank. Concerning the demanded steam energy for the heating network to reach the necessary temperature, the 'Parallel' model shows the best results. It is about 25,000 kWh below the 'Reference Model' and about 175,000 kWh below the 'Solar Priority' model.

To summarise, the model with the most promising result is the 'Parallel' model, however, regarding the solar-thermal performance the model is not as good as the 'Solar Priority" model. As a remarkable advantage of the 'Parallel' model the necessary steam energy can be minimised. Since steam energy is the only form of energy in the low-temperature heating network which has to be paid for by the *Zott* dairy, it is important for an economical analysis respectively has to be reduced.

7. Conclusions and Further Steps

The results of the simulation runs show, that the most important problem of all concepts is the high return temperature of the heating network. This fact is difficult to handle. Also, the past activities of *Zott* have shown that there are only limited possibilities for a reduction of this temperature. With specific modifications of the consumers of the production, hence a wider spread of flow and return temperature only a small reduction can be realised. More complex still is a modification of the domestic water heating. The problem here is that the domestic water is preheated by the residual energy of the condensate after cooling within the heating network.

As a result, the energy supply of the low-temperature heating network takes place on a comparatively high temperature level and cannot be modified as the condensate energy must be used. Also, the energy supply of Cleaning- in-Place facility cannot be modified. A constant heating of the acid tank on a temperature level of 55 °C is necessary and therefore a high spread of temperature is not possible. To summarise, there is only limited possibility to modifying the production processes to reach a lower return temperature of the network.

The simulation runs of the three models with the integrated solar-thermal system already show satisfying results with regard to the solar-thermal earnings as well as the interaction with the other heat sources. The next step is the optimisation of the solar-thermal system. With this, two variation studies will be carried out.

The first variation study concerns the storage tank of the system. It will be analysed whether stratified charging as used in the previous simulation and combined with this a reconstruction of the existing storage tank is more energy efficient against simple charging with two connections in the upper part and two in the lower part similar to the current configuration. Also, the volume of the storage tank will be varied to define the optimum storage volume.

The second variation study concerns the collector array of the system. As a result, the first sub-variation will be the collector area. It has to be optimised together with the storage volume. Also, several collectors will be tested in the simulation. Here the various collectors´ performance figures will be used. Furthermore, the flow volume as well as the connection varieties of the collector array will be simulated. With this, the correlation of specific collector volume flow and the method of parallel and serial connection of the collectors are tested.

All the results are finally used for the design of a real system concept for integration in the low temperature heating network. This designed solar-thermal system will be tested concerning technical feasibility and economics.

8. References

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