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Evaluation of innovative integration concepts of combined solar thermal and heat pump systems for efficient thermal supply of industrial processes – based on case studies and the results of the project EnPro

J. Fluch[1], V. Wilk[2], D. Lange[3], D. Wertz[3], C. Brunner[1], A. Grubbauer[1], P. Königshofer[1], F. Veynandt[1], T. Fleckl[2], K. Ponweiser[3],

[1] AEE – Institute for Sustainable Technologies, Feldgasse 19, A-8200 Gleisdorf

[2] AIT Austrian Institute of Technology GmbH, Giefinggasse 2, A-1210 Wien

[3] TU Wien - Institute for Energy Systems and Thermodynamics, Getreidemarkt 9/E302, 1060 Wien

Abstract

Solar thermal energy and heat pumps are key technologies to increase the share of renewable energy in industry. In order to spread these technologies, integration barriers should be reduced, such as high investment costs, lack of experience, missing integration schemes and planning guidelines or lack of knowledge about technological developments. Within the Austrian research project EnPro appropriate guidelines for manufacturers, users and planners are being developed. Therefore, in total 12 case studies in food, paper, metal production and processing, laundries and insulation industry have been performed, three of them selected and presented in this paper. Based on a detailed assessment of the processes, their process parameters and energy demand as well as the energy supply of the industry, integration concepts of solar thermal and heat pump systems and their combinations have been developed. Possible integration concepts include the parallel use and three different variations of serial integration of solar thermal and heat pumps. As variation I solar thermal is integrated first in the supply cascade (heating demand of a process or the supply system), followed by the heat pump. Variation II is the reversal of the order while as variation III solar thermal is used as source for the heat pump. Integration points for all possible combinations have been detected in the assessed companies. The concepts will be economically evaluated. The focus is set on generalized integration schemes for solar thermal and heat pump systems and the combination of both followed by the identification of upcoming R&D topics to push the implementation of identified solutions.

Keywords: *solar thermal, heat pumps, combined integration, industry, energy efficiency, process heat, renewable energies*

1. Introduction

In order to address the challenge of climate change and global warming the European Union agreed on the ambitious targets to reduce greenhouse gas emission by 40 % and to increase energy efficiency and renewable energy by 27 % by 2030. Special emphasis is placed on energy efficiency and renewable energy in industrial processes as industry accounts for 30 % of the final energy demand in Austria (Statistics Austria, 2014). Solar thermal energy and heat pumps are considered as important measures to reach these targets. Therefore they play an important role in European guidelines as well as in national regulations (European Parliament, 2009).

Solar thermal systems and heat pumps are state of the art for covering heating and hot water demand in the building sector. Combined systems including solar thermal and heat pumps also play a considerable role

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within this sector. However, these technologies are not yet wide spread in industry, as there are still significant barriers although the potential is high. The main reasons for these barriers are high investment costs, lack of experience or skepticism regarding the reliability of these technologies, lack of planning guidelines and integration concepts, as well as lack of users' knowledge of ongoing technological developments, such as high-temperature heat pumps or advanced solar collectors. Several studies and projects have proven that the required temperature range of industrial processes with a heating demand is suitable for the integration of solar thermal systems, heat pumps and the combination of both technologies. These industry sectors include for instance food and beverage, insulation, paper, metal processing and laundry (Hummel et al. 2013; IEA Heat Pump Centre, 2014; Wolf et al. 2014). The Austrian research project EnPro[1] aims to reduce these barriers, hence appropriate guidelines for manufacturers, users and planners are being developed. The bases for the guidelines are twelve case studies that are carried out in the project in different industrial sectors.

The choice of sectors ensures high potential for application of solar thermal energy and heat pumps and guarantees a high degree of replicability. In the companies, the current situation of energy supply and consumption is analyzed based on the European standard EN 16247. The aim is to identify and classify processes, that are suitable for the integration of solar thermal energy and heat pumps and their combination and to detect available waste heat streams and other suitable heat sources for heat pumps. Based on the energy demand of the respective process, integration concepts for solar thermal energy and/or heat pumps are developed to reach more energy efficiency and to increase the amount of renewable process energy. Special focus is set on efficient and cost effective integration concepts for solar thermal energy, heat pumps and the combination of both technologies. Within the framework of the project four different integration concepts for the combination of solar thermal energy and heat pumps are considered as basis for specific adaptions. The EnPro guidelines will consist of generalized concepts for the studied industrial sectors and a calculation tool that allows for basic planning of solar thermal and heat pumps for industrial use.

1.1 Solar thermal systems

Solar thermal systems use solar radiation for the supply of process heat, mainly hot water, but also process steam. Process heat collectors and their application can be divided into three temperature ranges: low temperature (<100 °C), medium temperature (100-250 °C) and high temperature (>250 °C) (Frank et al. 2012). The available technologies can be subdivided into concentrating and non-concentrating collectors, which show differences in design and in optimal operating temperatures. With increasing collector temperature, the efficiency of concentrating systems does not decrease as strongly, compared to non-concentrating collectors. Therefore flat plate collectors and vacuum tube collectors with reflectors are used to provide low temperature levels, vacuum tube collectors and low concentration systems are used for medium temperature levels, while stronger concentrating systems are used for high temperature levels.

1.2 Heat pumps

Heat pumps use low temperature streams to provide heat at a higher temperature level. In the building sector ambient air, ground water or the ground are commonly used as heat source for heat pumps, they usually supply hot water for domestic heating.

In industrial processes, waste heat streams often cannot be reintegrated into the production process or the energy supply of the process because of the inadequate low temperature levels. Therefore low temperature waste heat is released to the environment in many cases. This often goes along with additional cooling demand. Heat pumps allow for re-integration of waste heat streams into the production processes at a higher, useful temperature level and thereby increase energy efficiency. Currently heat pumps that provide temperatures from 90 to 125 °C are available on the market (IEA Heat Pump Centre, 2014; Wolf et al. 2014). Heat pumps that provide temperatures up to 160 °C have been in scope of research since several years. The mentioned temperatures can already be reached in experimental heat pumps and it can be assumed that heat pumps providing temperatures up to 160 °C reach market maturity in the next few years (Fukuda et al. 2014; Fleckl et al. 2014).

[1] The project EnPro (project number 848818) is an R&D service on behalf of the Austrian Climate and Energy Fund, financed by the Energy Research Programme 2014.

2. Problem statement, methodology and project introduction

2.1 Problem statement

There are different integration barriers for solar thermal energy, heat pumps and the combination of both technologies to increase market penetration. The most important barriers are high investment costs, lack of experience, missing best practice examples, missing integration schemes and planning guidelines and lack of knowledge about technological developments. When evaluating the technical integration of the technologies in an industry, several challenges related to the process and energy supply system can be identified such as:

- Heat supply of production sites are often grown structures (based on steam or hot water…) that do not allow a standardized integration
- Due to different used technologies the heat demand varies significantly:
    - Batch or continuous processes
    - Different load profiles and operating hours
    - Different requirements in process parameters (e.g. temperature…)

Another challenge is the choice of the suitable integration point and the development of an integration concept, defining how renewable energy is integrated in the production site. There are different levels for the integration of solar thermal and heat pump systems, on process level (direct supply of one selected process) or on supply level (integration in existing system). Requirements concerning storage and heat exchanger systems result from the defined integration concept. It has to be emphasized that not only the integration concept is important. With regard to the selection of the type of solar collector and the hydraulic connection (charging and discharging strategies of the solar storage), the needed temperature in the collector loop is essential aside from the chosen integration concept and the control strategy. Furthermore, the location of the production site (solar irradiation), its available areas (ground or roof), and static requirements to carry collector weight, orientation or shading are important to gain a maximum solar yield. (Muster et al. 2015) Regarding the integration of heat pumps also the required temperature of the process is an important parameter, as it relates to the refrigerant agent of the heat pump, the temperature of the heat sources, as it has a strong influence on the efficiency of the heat supply, the simultaneity of heat source and demand, as it decides whether storage is necessary. The available space to erect the heat pump and the distances to available heat sources also have to be considered.

Based on the results of IEA Task 49/IV, the main challenges for solar process heating systems are the achievement of a high solar cover ratio and the close alignment with process demands up to the development of "solar process technologies". Also the best possible combination of solar thermal systems with other technologies gets more and more important. This is precisely where the potential of combined solar thermal and heat pump systems can be seen: for example, the achievable temperature of the solar thermal system could be increased with a heat pump to meet process demands.

2.2 Methodology and project introduction

In order to identify and evaluate possible integration concepts in industrial sectors, a total of twelve production sites from different industrial sectors were chosen within the project EnPro. For the selection of the sectors, branches identified in a preceding project were considered and ranked based on high replicability (Hummel et al. 2013) Especially branches with a high number of companies and a high energy demand were selected. The chosen sites were analysed based on the European standard EN 16247. The current situation of energy supply and consumption of the industrial sites were evaluated and the thermally relevant unit operations were identified. The unit operations were classified to ensure high replicability of the integration concepts. The mentioned classification provides information concerning process technology, process and supply temperatures, process medium, load profiles and operating hours.

Also optimization potentials on process and system level were evaluated as basis for the integration of renewable energy. Pinch analysis was used as methodology to identify heat recovery potentials.

This was followed by the identification of processes that are suitable for the integration of solar thermal energy, heat pumps and their combinations to reach more energy efficiency and to increase the amount of renewable process energy in the industry. The basis was the classification of the unit operations and the evaluated parameters. Within this step, concepts and different schemes for the combined usage of the technologies were created, accompanied by site-specific simulations. Considering the classified processes and the integration concepts the achieved information are generalized resulting in general applicable integration points for the different branches and general combination schemes. A main focus of the project EnPro is the development of guidelines and a basic planning and calculation tool.

The final guideline and tool will be designed as a basic planning instrument consisting of a decision tree that compares the different possible combinations for a specific case study. By the combined use of tool and planning guideline recommendation on the implementation of solar thermal energy and or heat pump technologies can be made. The tool includes the following features:

- stop/go criteria – pre-assessment of the integration potential
- definition and evaluation of the energy related status quo
- branch specific process definition possibilities and process optimization suggestions
- systems optimization including pinch analysis for the deduction a heat exchanger network
- generic integration concepts and
- assessment of solar thermal energy, heat pumps and the combination of both technologies

As a final step, based on the assessments and the developed integration concepts the project EnPro is defining upcoming R&D advices, taking also existing international R&D advices and roadmaps into account (e.g. "renewable heating and cooling technology platform" roadmap or results from IEA networks).

3. Case studies

In this paper, three of the twelve performed case studies are presented. A special focus is set on integration concepts for solar thermal and heat pump systems and the combination of both technologies.

3.1. Bakery

The audited production site is a large scale bakery. The main products are typical Central European bakery goods (i.e. bread, rolls, fine pastry…). Typical process steps for all products are shown in Fig. 1. First, the ingredients are processed followed by the fermentation step. There are different operation modes for the fermentation step in a bakery. For direct fermentation the step is finished before baking. The other way is to cool the piece of dough and process it later on. In this case a controlled heating step is necessary before the fermentation step. Rack ovens (batch-mode) or continuous baking machines (conveyer) are used for the baking process. Depending on the type of product the baking step is finished, the product gets packaged, stored (cooled) and distributed or it is pre-baked, deep frozen and distributed.

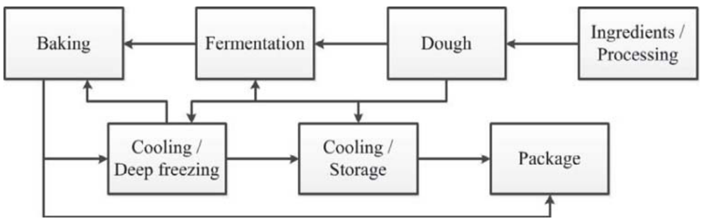

Fig. 1: Process steps with high energy demand in bakery

3.1.1 Energy supply and energy demand

The energy supply of the company is based on fuel oil, natural gas and electricity. Electricity is used by the cooling devices (approx. 40 %) and the bakery ovens (26 %). The rest is consumed by small consumers, pressurized air and the ventilation system. Natural gas is consumed by four boilers supplying the baking ovens as well as for supplying steam (process steam and heating system). The fuel oil is partly consumed by a thermal oil boiler and a steam boiler and partly distributed to directly fired baking ovens in the production hall. A detailed analysis of the last years shows a significant shift from fuel oil to natural gas.
Process steam is needed beside the demand of process heat (160 – 270 °C) during the baking process depending on the product type. Humidification of the baking goods ensures good heating transfer within the baking step. Simultaneously quality and taste of the product are influenced. The steam, provided by the steam boilers is also used for covering the space heating demand.

The cooling demand is a large part of the total energy demand of a bakery. Firstly the unbaked pieces are deep frozen (-4 to -23 °C) to stop the fermentation process. Secondly the ingredients (before the doughmaking-process) and the finished products have to be stored (deep) frozen. Hot water for cleaning is needed at a temperature level between 40 and 60 °C. Hot water storages support the heat distribution.

3.1.2 Optimization potentials and integration of solar thermal systems and/or heat pumps

Within the energy audit short term optimization measures have been identified. Partly due to the age of the baking ovens and due to the high energy demand high potential for process optimization has been identified. The primary direct fired baking ovens (including internal heat recovery) will be substituted by more efficient and central supplied (thermal oil) baking ovens step by step in the next years. High losses (mainly space heating and cooling) caused by high flow temperatures could be reduced by the integration of a central distribution system. The biggest potential was identified within heat recovery of cooling devices. The fuel oil boilers could be substituted step by step by optimizing the existing heat distribution network and integrating thermal energy in existing storages for the preparation of hot water for cleaning.

The baking process is suitable for the integration of solar thermal energy only to a limited extent due to the demand of high temperatures. Nevertheless two potential integration points have been identified. Firstly, the supply of hot water for cleaning in combination with the heat recovery from the cooling devices shows potential. The needed temperature of 60 °C is optimal for supplying the demand via flat plate collectors with a high efficiency. The existing storage infrastructure also supports the integration of a solar thermal system. Secondly, solar thermal energy could be integrated on system level for pre-heating of boiler feed water and for pre-heating of thermal oil.

There are two possibilities for the integration of heat pumps. The first possibility is to use the waste heat from the cooling devices as a heat source and to heat the cleaning water instead or in parallel to solar thermal system. The second possibility is a combination of solar thermal and heat pump system. Within this combination the solar thermal energy is used first for heating the cleaning water and a heat pump is used for increasing the temperature level provided by the solar thermal system using waste heat from the cooling devices as the heat source.

3.2. Metal surface treatment

The metal company analysed in the project produces hardware for windows and doors. The audit focuses on the thermal energy demand and was mainly done for the production area of metal surface treatment which consists of a barrel plant and a rack plant (rotating barrels or racks are used for the transportation of work pieces between different process baths). The process temperatures are in a range between 40 and 80 °C. This offers a potential for the integration of solar thermal and heat pump systems.

The surface treatment process steps can be divided into pre-treatment, main treatment and post-treatment as shown in Fig. 2.

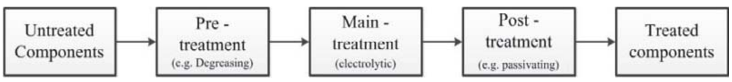

Fig. 2: Main process steps in metal surface treatment

The work pieces are pretreated to be clean from dust, grease and oil and to ensure uniform application and permanent adhesion of the surface treatment. Furthermore oxides are removed to ensure a chemically active surface. Pretreatment processes applied in the assessed company are degreasing, electrolytic degreasing, pickling and descaling. Rinsing is carried out between the processes steps with varying temperatures. For degreasing temperatures of 70 °C are necessary. The other pre-treatment steps do not have any heating demand. After pretreatment the core activities follow. In the audited company zinc coatings are used for the electrolytic surface treatment. During the exothermal electrochemical reaction, heat is released. It is necessary to cool the solution in order to keep the process baths within the required temperature range (23 to 26 °C) to ensure high quality of the products and minimize the breakdown of chemicals in the process bath. Afterwards the work pieces are post treated by brightening, passivation and sealing. Finally the work pieces are dried in order to avoid staining and corrosion. In the barrel plant centrifugal drying is used, whereas in the rack plant the dryer operates with circulatory air. The temperatures of the post-treatment are in a range from 40 to 80 °C. For centrifugal drying a temperature of 130 °C is provided by electric heating.

3.2.1 Energy supply and energy demand

The energy supply of surface treatment is based on natural gas (53 %) and electricity (47 %). Natural gas is consumed by a thermal gas boiler supplying heating process baths (25 %) and dryers (28 %), heating of production halls (46 %) and domestic hot water (1 %). During summer less natural gas is consumed as a result of increasing ambient temperatures. The process baths have to be heated up before the process starts and a constant process temperature (cover also heat losses) has to be kept to ensure the product quality. Two chillers are operated in the area of surface treatment to provide cooling water for the zinc baths.

3.2.2 Optimization potentials and integration of solar thermal systems and/or heat pumps

Within this energy audit process optimization measures have been identified mainly in the field of the heating of production halls. There air curtains are an effective way to prevent the intrusion of cold outdoor air. In order to reduce energy losses of the process tanks, insulation can be applied at the tanks. Furthermore the surface of the process baths can be covered with a blanket of plastic floating spheres which reduce evaporation without restricting the access of work pieces, jigs or barrels.

For integration of solar thermal energy and heat pumps potential processes have been identified. First of all, solar thermal energy can be used on process level to heat up the process baths at temperatures between 40 and 80 °C. Flat plate collectors and vacuum tube collectors reach high efficiency in this temperature range. Secondly, solar thermal energy could supply the heating demand of domestic hot water.

For integration of heat pumps especially the process baths have been identified as appropriate integration points on process level. The return flow of the cooling water from the process baths could be used as a heat source for heat pumps. The upgraded energy can heat up other process baths. The advantage arising from this integration point is that heat sink and source occur at the same time, so far not used heat streams are utilized and the processes operate constantly over the whole year.

A combination of solar thermal and heat pump systems can be implemented on the one hand in a parallel integration in one storage tank supplying the above mentioned processes 24 hours a day. Furthermore, the decreasing solar thermal energy yield in winter months could be compensated by the heat pump. On the other hand, a possibility is rising up the temperature level provided by the solar thermal energy system with a heat pump using the waste heat from cooling the process baths as a heat source.

3.3. Laundry

This laundry is specialized on the cleaning of work wear. Fig. 3 shows the most important process steps concerning energy demand. The dirty laundry is delivered, sorted, manually loaded into washer extractor machines and washed. Depending on the type of fabric the clothing gets pre-dried via gas- or steam heated driers. Afterwards the clothing is straightened in a gas heated tunnel dryer (finisher) or pressed and dried. The dried clothes are sorted, packaged and delivered to the customers.

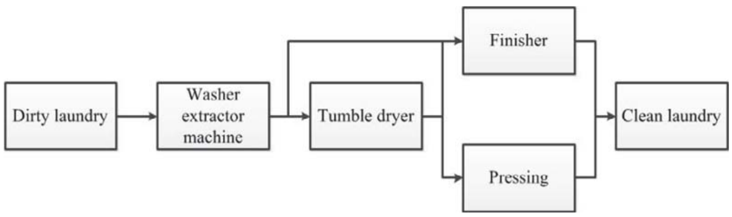

Fig. 3: Process steps in the laundry

3.3.1 Energy supply and energy demand

The energy supply of the company is mostly based on natural gas (83 %) that is used for steam generation. A total of 17 % of the energy demand is covered by electricity. The gas supplied steam generator provides up to 2 t/h of steam with 11 bar (saturated steam, 185 °C).

The most important consumers of thermal energy are the washer extractor machines, the driers and the finisher. The fresh water is preheated via heat recovery from waste water. Steam is injected directly to increase rapidly the temperature of the fresh water to the required washing temperature. The temperature range of the prewashing (30-70 °C) and the main washing step (40-70 °C) depends on the material and the degree of soiling. Two steam heated drum dryers and a gas heated drum dryer are used for the pre-drying step. Concerning the steam heated drum dryers steam increases the temperature of the air via heat exchanger up to 160 °C and is drained as condensate. The dryer operates with circulatory air. The drying air absorbs the moisture of the clothing and leaves the dryer as waste air with a temperature of around 70 °C. Concerning the gas heated dryer the hot exhaust gas of the burner is used for the drying process. The finisher is a continuous tunnel dryer. First, the clothing is sprinkled with steam. The following drying zones are heated with three gas burners to ensure an air temperature of around 130 to150 °C. Circulating fans ensure the circulation of air for straightening the clothes. The saturated air passes an exhaust air system and is replaced by fresh air. The exhaust air has a temperature level of about 80 °C and is not used any further.

3.3.2 Optimization potentials and integration of solar thermal systems and/or heat pumps

The exhaust gas of the boilers has a temperature level of 140 °C. A further exhaust gas heat exchanger could be integrated to lower the exhaust gas temperature. In order to maintain the induced draft effect the described measure has to be coordinated with the boiler manufacturer. About 40 % of steam in the washer extractor machines and the finisher are used directly are replaced by fresh water. Preheating of the boiler feed water also increases the efficiency of the steam boiler

An integration potential of solar thermal energy could be the preheating of the boiler feed water or the process water for the washing machines. Integration for space heating is not possible in this laundry due to the existing heating system.

For the integration of heat pumps several waste heat streams were identified as possible heat sources that are currently released unused. Exhaust air streams of the dryers and the finisher are relevant streams for this concept. Possible heat sinks are preheating of the dryer air or preheating of the boiler feed water. The advantage of preheating the dryer air is that waste heat and heat demand occur at the same machine at the same time. The steam boiler is also an interesting heat sink as it has the longest operation time per day compared to the other processes. However, the distances between source and sink are significantly higher.

4. Integration concepts of combined solar thermal systems and heat pumps

Based on the case studies the following simplified integration schemes have been developed. Although ambient heat is a potential source for heat pumps supplying industrial processes on low temperature level, the focus was set on available waste heat streams from processes or utilities supplying heat pumps. The chosen combination possibilities and integration schemes are inspired by the IEA SHC Tasks 44 (system combinations of solar thermal systems and heat pumps for residential buildings) and IEA SHC Task 49 (different integration schemes and systems for solar thermal in industry). Within this paper only schemes for integration of combined solar thermal systems and heat pumps systems are presented. For the combination of the technologies, it is crucial to have a significant process heat demand that can be supplied with available solar irradiation and a suitable waste heat source.

The following four combination concepts have been identified within the project:

- Parallel combination - heat pump and solar thermal system supply in parallel
- Serial combination
    - Serial variation I - the process stream is heated first by the solar thermal system and then by the heat pump
    - Serial variation II - the process stream is heated first by the heat pump and then by the solar thermal system
    - Serial variation III – the solar thermal system is used as heat source for the heat pump supplying the process stream

4.1 Parallel combination

Solar collector and heat pump provide heat independently from each other as shown in Fig. 4. The combination can be operated with storages or the heat can be transferred directly to the process. Available waste heat (from processes or energy supply devices) is used as heat source for the heat pump. This combination is able to balance the lower yield of a solar system in winter and vice versa the operating time of the heat pump is reduced in summer because of the high solar yield. By an optimized system design the efficiency of both technologies van be optimized having also positive effects on the lifetime of the systems. (Hadorn, 2015a, 2016b)

Examples for possible integration points have been identified in the three case studies. Generally, the solar thermal and heat pumps systems supply the processes via an optional storage. The source for the heat pump is defined:

The parallel combination of both technologies offers the individual optimization of each system without any influence on the other. One option is that the heat pump provides heat when the collector does not deliver due to seasonal or time of day. The other option is that the heat pump valorizes a waste heat stream that is available all the time and the solar collector adds more heat and by this fossil fuel consumption is further reduced. Which option is the most suitable has to be determined by a technical and economical evaluation for the specific industrial site. A disadvantage of this combination is that the provided maximum process temperature is limited by the technologies itself. This integration might be seen comparably easy concept and the R&D demand has to focus on maximum achievable temperatures of both technologies.

An example for this integration concept can be found in the bakery evaluated. A solar thermal collector and a heat pump supply heat via a storage for space heating and cleaning water demand. The source for the heat pump is the waste heat from a chiller.

Further examples - the source for the heat pump is defined:

- Metal surface treatment – heat pump source: return flow of cooling water
    - Heating of process baths
- Laundry – heat pump source: exhaust air streams
    - Space heating
    - Fresh water for washing machine

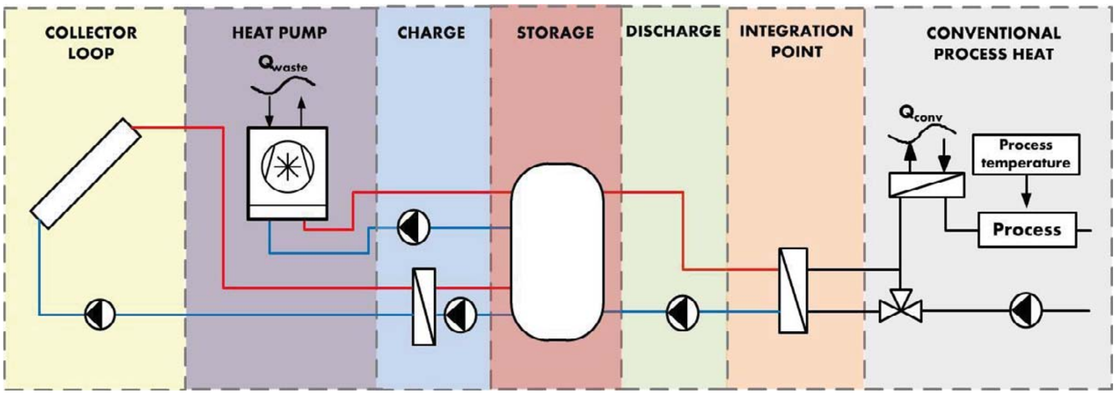

Fig. 4 Parallel combination of solar thermal systems and heat pump

4.2 Serial combinations

4.2.1 Serial variation I

In this combination first the process stream is heated by a solar system followed by the heat pump to reach higher temperatures (shown in Fig. 5). Available waste heat is used as heat source for the heat pump. Storages can be integrated to balance temporary deviations between heat supply and heat demand. If the solar thermal system supplies the total heat demand at necessary temperature, the heat pump is bypassed and the process is supplied only by the solar thermal system.

A clear advantage of this integration concept is the significant higher temperatures provided by the serial combination of the technologies. The solar thermal collector is operated in a suitable temperature range for flat plate and vacuum tube collectors offering high efficiencies. Heat pumps are able to provide temperatures up to 120 °C. To achieve high efficiency, a comparable warm heat source exceeding 40 °C is preferable. This waste heat has to be mentioned as a challenge. The upcoming R&D demand has to focus on the further development of heat pumps providing heat up to a temperature of 160 °C.

An example for this concept can be found in the metal surface treatment company. There the solar thermal collector could preheat the process baths or the air needed for heating the dryer up to a temperature of 70 °C. The heat pump, using the waste heat from the cooling system can further increase the temperature of this process stream up to a level of 100 – 120 °C.

Further examples - the source for the heat pump is defined:

- Bakery - heat pump source: waste heat chiller
    - Hot water for cleaning
    - Heating of thermal oil
- Laundry – heat pump source: exhaust air streams
    - Preheating of the dryer air

- Preheating of the boiler feed water
- Potentially space heating in case of hot water based heating system

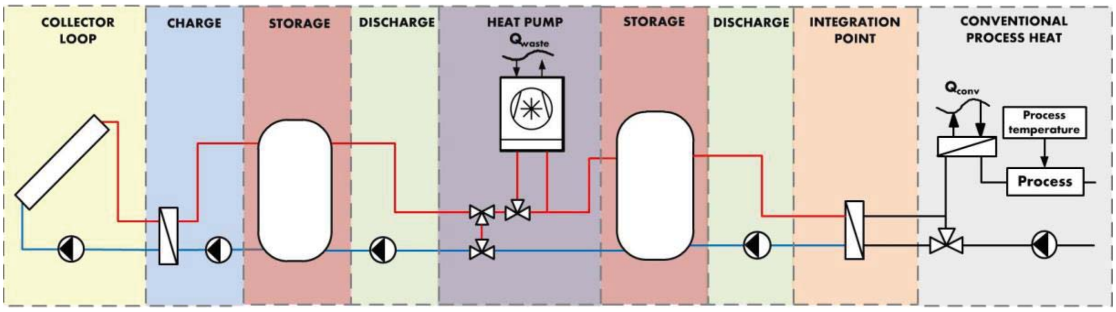

Fig. 5 Serial variation I of solar thermal system and heat pump

4.2.2 Serial variation II

First the process stream is heated by the heat pump followed by the solar system to reach higher temperatures (shown in Fig. 6). The heat pump uses available waste heat as heat source. If a process stream, that has to be cooled, can be used as heat source, a double benefit of the system occurs. Storages can be integrated to balance temporally deviations between heat supply and heat demand.

This serial integration concept is more suitable for low temperature heat sources from process waste streams or if available ambient air or ground water. A disadvantage is the demanded supply temperature (> 100 °C) of the solar thermal system and following low efficiencies of the flat plate and vacuum tube collectors. Furthermore, especially in Central European regions the direct solar irradiation is not sufficient to supply concentrating collectors and the limited maximum temperature is by this a challenge for this concept that has to be part of upcoming R&D activities.

An example for this combination concept can be found in the assessed laundry. There, the spent and cooled water from a washer can be used as heat source for the heat pump. An advantage is that the waste water is further cooled before charged into the sewage system. The process supplied is the fresh water for the steam boiler, which is preheated first by the heat pump followed by a suitable solar thermal system up to 80 – 110 °C to further decrease the fossil fuel demand of the boiler.

Further examples - the source for the heat pump is defined:

- Bakery - heat pump source: waste heat chiller
  - Heating of thermal oil
- Metal surface treatment – heat pump source: return flow of cooling water or chiller
  - Hot water for cleaning

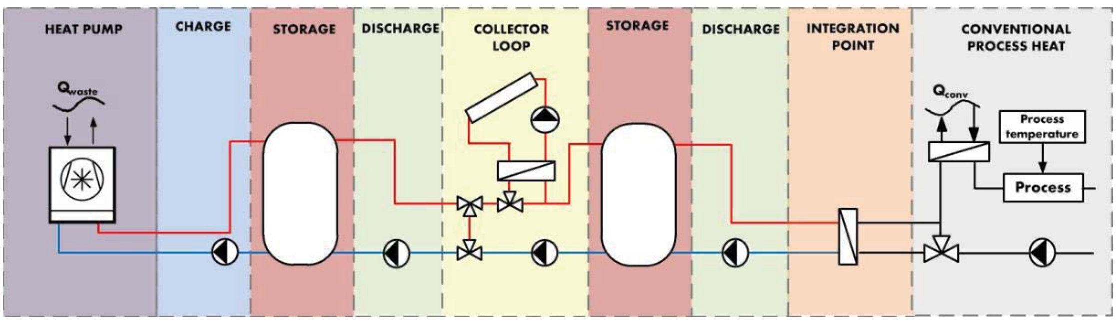

Fig. 6 Serial variation II of solar thermal system and heat pump

4.2.3 Serial variation III

In this integration concept the heat pump uses solar heat as heat source (shown in Fig. 7). Solar heat can be used directly by the heat pump or via storage. As the solar thermal system is used to provide temperatures up to 50 – 80 °C, flat plate and vacuum tube collectors operate at high efficiencies.

An advantage of this concept is that the solar thermal system provides heat for the heat pump at a higher temperature than ambient sources in case that no waste heat streams are available. Additionally available waste heat streams above 50 °C in the assessed industry were limited and this concept could overcome this challenge. By this the demanded temperature lift of the heat pump is reduced and the efficiency (also for higher temperatures) increases. In this concept a storage can be seen as mandatory. An upcoming R&D focus should be set on the further development of heat pumps providing heat above 120 °C.

An example for this concept can be found in the bakery. Available waste heat streams are already well integrated in the heat recovery system with only limited access for a heat pump concept. The integration of this stream as source for the heat pump is competing with this solution (a disadvantage in serial variation I). The solar thermal source for the heat pump addresses this challenge- A possible integration of the concept would be in the existing thermal oil based supply system. The solar thermal system supplying the heat pump that is providing heat above 100 °C.

Further examples:

- Metal surface treatment
    - Heating of process baths
- Laundry
    - Preheating of the dryer air
    - Preheating of the boiler feed water
    - Potentially space heating in case of hot water based heating system

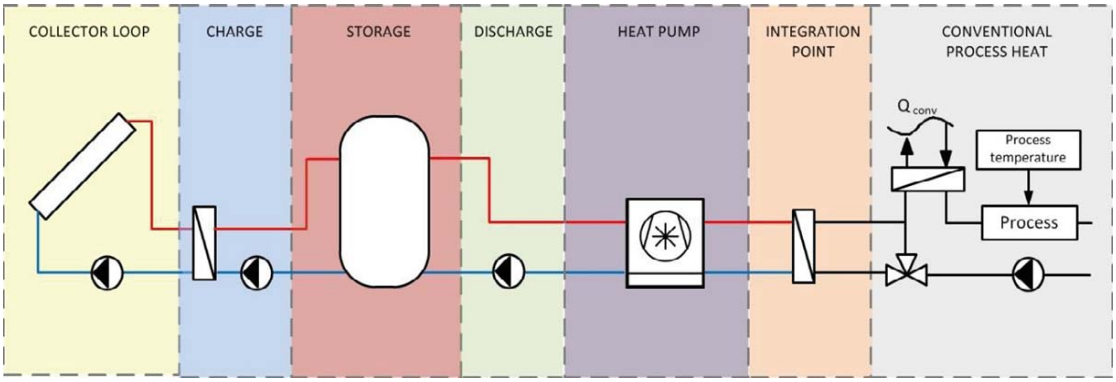

Fig. 7: Serial variation III of solar thermal system and heat pump

5. Conclusion

For assessing the energy supplies of an industrial company the energy demand on process level and its specific parameters (load profiles, temperature levels, etc.) as well as the type of supply system (media) have to be considered. Considering identified integration criteria different integration possibilities on process and supply level for solar thermal system and/or heat pumps were evaluated from a technical point of view. Examples for integration criteria are load profiles, temperature levels, temporal correlation between demand and supply, efficiency factors, solar yields, quality grades, payback periods or needed storages.

In the assessed industry examples for the single integration of solar thermal or heat pump systems have been identified. In bakeries for example hot water for cleaning is needed on process level, typical for the food and beverage sector with a significant cleaning demand. Hot water is also needed in laundries for the washing process. This demand can be easily supplied by solar thermal system or heat pumps. Especially flat plate collectors are suitable for covering hot water demand with a temperature level of 60 °C (typical for cleaning processes), because of the high efficiency of flat plate collectors in this temperature range. Heat pumps are also suitable for supplying this hot water demand. Available waste heat streams as source are the waste heat of cooling machines (bakery and metal surface treatment) and humid exhaust air streams (laundry). The advantage of integration on process level is that heat sink and source occur at the same time, so far not used heat streams are utilized and the heat source is available at the same time the demand occurs.

An example for an integration of solar thermal system and heat pumps on system level is the integration in steam boiler systems as identified in the case studies bakery and laundry. The usage of direct steam leads to a fresh water demand. Both, solar thermal system and heat pumps could be used for pre-heating the fresh water/boiler feed water. Another option could be the production of steam but only with limited potential due to existing technical constraints further supported by regional difficulties (limited solar irradiation in Central Europe needed for concentrating solar thermal system providing steam). In many cases the needed integration concept for the integration on system level is easier compared to a direct integration on process level, which comes along with several research questions.

Besides the single integration of solar thermal system and heat pump systems, the combination of these offers a huge potential for an optimized system and a further boost of the technologies. The first technical assessment highlights four options as mentioned above parallel operation of solar thermal and heat pump system and three different serial connections.

Parallel combinations could be used for balancing seasonal differences in the solar yield as e.g. for heating of process baths in the metal surface treatment site. This concept offers the individual optimization of each system. One option is that the heat pump provides heat when the collector does not deliver due to seasonal or time of day. The other option is that the heat pump valorizes a waste heat stream that is available all the time and the solar collector adds more heat and by this fossil fuel consumption is further reduced.

Within the serial combination (variation I) first the solar thermal system is used supplying the demand (e.g. for heating the boiler feed water or other streams) and the heat pump technology is used for further increasing the temperature level. Depending on the used collector types and needed temperature level a possibility is also first going through the heat pumps followed by the solar thermal system (variation II). Finally as variation III the solar thermal system can operate as source for the heat pump. In all variations the provided temperature is higher compared to the parallel combination.

In variation I the solar thermal collector is operated in a suitable temperature range for flat plate and vacuum tube collectors offering high efficiencies. Heat pumps use waste heat streams as source in a temperature range between 50 – 70 °C and the system is by this able to provide temperatures up to 120 °C. The demand of a suitable waste heat stream (temperature range > 50 °C) has to be mentioned as a challenge. The serial variation II concept is more suitable for low temperature heat sources from process waste streams or in some cases ambient air or ground water. A challenge is the demanded supply temperature (> 100 °C) of the solar thermal system and following low efficiencies of the flat plate and vacuum tube collectors. In variation III the solar thermal system provides heat for the heat pump at a higher temperature than ambient sources in the case no waste heat streams are available. By this the demanded temperature lift of the heat pump is reduced and the efficiency, also for higher temperatures, increased.

6. Outlook

The case studies show the high potential for the integration of solar thermal system, heat pumps and the combination of both in industrial companies. Due to the fact that the considered process steps and supply structures are typical for each sector the possibilities for the integration can be multiplied and are supposed to be applicable for other companies. Based on the results of the case studies, generalized integration schemes were developed and will be further evaluated. By this, clear recommendations considering technical, ecological and economic evaluations of identified integration concepts will be available.

Further steps will be the definition of selection criteria for the different combinations and based on that the creation of a decision tree. The decision tree will lead the user to the most suitable technology or combination for a certain integration point. For the definition of selection criteria the detailed simulations of the case studies are the basis to identify efficiency ratios, performance numbers, solar yields and quality grades as well as gained energy form heat pumps. Based on that, optimized integration concepts on process- and supply level for the case studies and derived conclusions for the industry sectors will be developed.

Furthermore the derived results will be integrated in an optimized version of a planning and calculation tool. Moreover the sectors and branch specific processes of the tool will be extended and linked to a planning guideline.

One of the main barriers for a market penetration of the technologies is the lack of best practice examples. Based on the selected case studies and developed concepts and a positive economic evaluation this obstacle is targeted to be addressed. Implemented integrations have to act as best-practice examples for other industrial companies. Hence the applicability of solar thermal system, heat pumps and the combination of both technologies is demonstrated.

In correlation with the described actions the need for research and development will be defined. One key aspect is the technological optimization of solar thermal and heat pump technologies. The optimization as well as the development of new refrigerating agents and compressors to increase the maximum condenser temperature of heat pumps is currently part of R&D. For solar thermal systems and components further development is necessary in order to simultaneously increase the efficiency and reduce the costs. Several studies show the need for technologies that supply energy demand at higher temperatures or even supply steam. The efficiency of concentrating solar systems for the supply of steam strongly depends on the regional solar radiation. Heat pumps that supply steam at typically required steam parameters of 5-10 bars are not available on the market yet. A strong need for research has to be seen in this field. The definition of research demand will be carried out after the detailed simulation of the case studies.

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