# SOLAR THERMAL SYSTEMS FOR THE SWISS PHARMACEUTICAL INDUSTRY SECTOR

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**Abstract**

This study focus on the integration of solar thermal (ST) systems in the Swiss pharmaceutical industry to provide the thermal energy need for their processes. An analysis of the heat demand in this sector showed that around 2 TWh of heat could be supplied with conventional thermal solar systems, such as flat plate collectors or vacuum tube collectors. To identify the obstacles to integrate solar systems and define appropriate solutions, two case studies were considered to assess the technical feasibility and economic viability of these solutions. The two feasibility studies focused on drying processes. The solar heat supplied to the pharmaceutical processes was estimated using the simulation tool Polysun for both case studies. The solar plant sized for case study 1 produces 617 MWh/year with 1060 m² of solar collector (solar field gross surface) and 50 m³ of storage. Whereas for the case study 2, the heat production reaches 382 MWH/year with 684 m² of solar collector and 30 m³ of storage. Finally, the economic evaluation of the ST systems, based on different offers, shows that the price of the heat produced by the solar thermal system reaches almost twice the price of the gas, which allows to determine the competitiveness of the ST system in both cases comparing to conventional heating systems.

*Keywords: Solar thermal systems, industrial process heating, pharmaceutical sector, integration point, Switzerland*

## 1. Introduction

As shown in Fig. 1, the Swiss industry sector accounts for about 19% of final energy consumption corresponding to more than 43 TWh in 2017 (Swiss Federal Office of Energy, 2018). Heat represents the largest part of this energy consumption. 70% of this heat consumption is used for processes (Kemmler et al., 2018). Currently, 66% of this heat is produced from fossil fuels (Swiss Federal Office of Energy, 2018) resulting in an important impact on the environment.

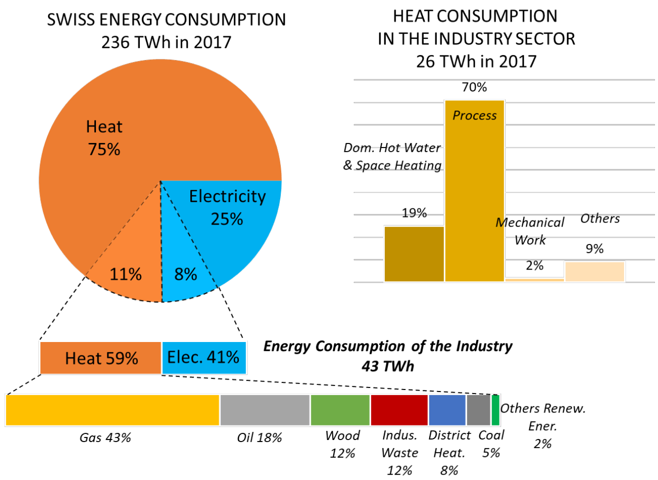


**Fig. 1: Energy consumption of the industry in Switzerland and distribution of the heat consumption by application (own calculation based on Swiss Federal Office of Energy (2018) and on Kemmler et al. (2018))**


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In a previous study, Guillaume et al. (2019) highlighted the large potential for solar thermal (ST) systems to cover low temperature process heat in the Swiss industry. The theoretical potential for conventional thermal solar systems, such as flat-plate collectors and evacuated tube collectors, represents more than 8% of the industry energy consumption, and is equivalent to more than 3 million square meter of installed ST collectors. Some ST systems have been set up in Switzerland to supply process heating applications in different industrial sectors such as in dairy products manufacturing, machinery products manufacturing or bitumen production (Rittmann-frank et al., 2017), but they remain uncommon.

The chemical and pharmaceutical sector has an important place in the Swiss economy since it is leading the export market with 36% of the total Swiss exports reported in 2011 (Scienceindustries, 2018). Despite its potential, no solar systems are currently installed to provide decarbonized energy to this energy-intensive industry. Like many others, this sector has a high heat demand for its processes that can be covered with ST systems. Nevertheless, several incentive indicators such as cost, process integration and matching energy demand and production, which could provide compelling arguments to persuade industries to invest and adopt ST technologies, are no yet available for this sector.

This study aims at estimating the potential of ST systems to cover process heat demand occurring at low temperature (<130°C) in this industrial sector. Feasibility studies have been performed for two pharmaceuticals companies to identify the main barriers for ST system integration in pharmaceutical processes and define adequate solutions. The objective through these case studies is to define simple integration schemes and estimate the solar thermal energy production, corresponding fuel savings and also the levelized cost of the solar heat produced.

## 2. Theoretical potential of the pharmaceutical sector

According to the statistical reports on the energy consumption in Switzerland, published by the Swiss Federal Office of Energy (Sauvin et al., 2018), the chemistry/pharma industrial sector is the highest energy consumer in Switzerland representing 22% of the industry total energy consumption in 2017. Heat consumption accounts for 67% in the Swiss chemistry/pharma industry, mainly produced by fossil fuels such as gas and oil. Renewable energy represents only 0.1% of the heat consumption and is obtained primarily with biomass.

The chemistry/pharma industry is also the sector with the largest share of thermal energy use for process heating. Guillaume et al. (2019) have shown that the amount of thermal energy consumed by the chemistry/pharma sector for this purpose reached 5 TWh in 2016, accounting for 27% of the total thermal energy consumption of the industry sector for process heating. Pardo et al. (2012) provide the distribution of the heat demand by temperature for different industrial sectors in EU-27 countries and the heat demand at temperatures below 100°C represents 40% in this sector. Therefore, a large part of the heat requirement could be covered by ST systems, a technology perfectly suitable to supply heat within this temperature range.

The theoretical potential for solar heat in this sector has been estimated to about 2 TWh, representing 15% of the energy consumption of this sector and 4% of the Swiss industry total energy consumption during the year 2016. This value represents an estimation of thermal energy used for process heating occurring at low temperature and that would be partially provided by ST systems.

This theoretical potential represents 2 million m² installed solar collectors considering an annual yield of 400 kWh/m² and 40% solar fraction. This potential becomes more relevant when considering that ST systems can equally provide heat for hot water production, space heating and replace part of the electricity used for process heating. However, to seize the real potential, the space availability for the installation of ST collectors on industrial sites must also be considered.

## 3. Solar thermal system integration

Given the high heterogeneity of manufacturing processes in the pharmaceutical industry, standard solutions are quite hard to define. Therefore, two case studies were considered to design solutions with a high replicability potential in order to ensure a high success rate for the integration of solar thermal systems in industrial processes. Both case studies are pharmaceutical multinational companies, manufacturing dosage–form products from active drugs substances. These chemical components, conditioned in powder, are generally produced from aqueous solutions mixed in chemical reactors. Firstly, dosing, heating, cooling and mixing operations are carried out to obtain the desired mixture. Secondly, this mixture is dehydrated to obtain powders with a desired granulometry through various drying processes. In case study 1, based in Bulle (Fribourg, Switzerland), the drying operation is done with simple and biconical dryers. In case study 2, based in St-Prex (Vaud, Switzerland), drying is achieved using a fluidised bed dryer.

In both companies, gas boilers are used to produce steam that is distributed to the different processes throughout the site. Therefore, it is not relevant to consider the integration of a conventional solar system, such as flat-plate or evacuated tube, at the energy supply level because the temperature of the steam is higher than the heat that could be produced with the solar system. IEA SHC Task 49 Integration guidelines (Muster et al., 2015) has been used to identify the integration point of the ST system for both case studies. Technical visits to each of the industrial sites were carried out and data (processes heat demand and profile, flows and temperatures) were collected in order to design the solar thermal plants. Discussions with the companies' production managers were also held to gain a proper understanding of how the processes work and how best to integrate the solar system.

### 3.1. Energy consumption analysis

For case study 1, a building where fourteen production processes are implemented is considered. Analyse of the consumption profiles of a typical working day allowed the identification of five processes the most suitable for solar thermal integration. These processes are all drying processes and represent 97% of the total heat consumed by the processes in this building.

The five processes considered have a working temperature below 65°C during around 87% of the time. As show in Fig. 2, except for the charging and preheating phase, the power reaches approx. 350 kW. The load duration curve (red line in Figure 2), shows that 80% of the time, power is below or equal to this value. Therefore, the solar system was sized considering this power and the annual heat consumption equals 1700 MWh/year.

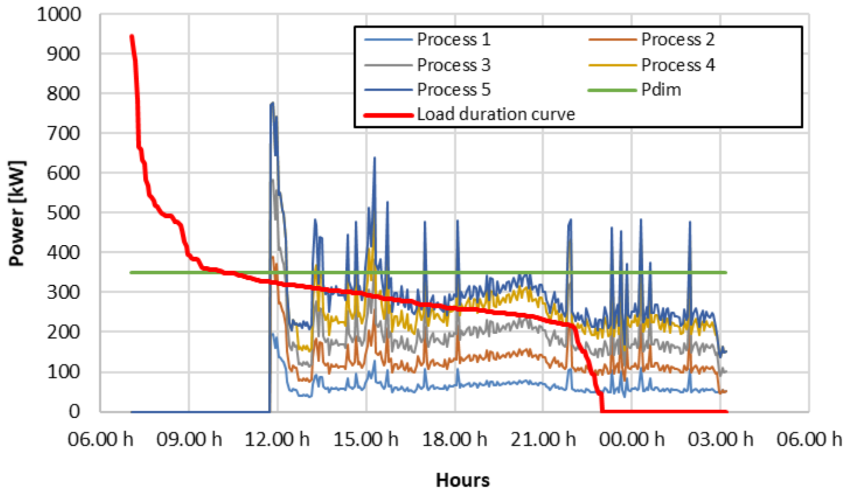


**Fig. 2: Cumulated power during a typical working day (from 24/02/2015 06:00am to 25/02/2015 06:00am) for the five considered processes for case study 1 and with the load duration curve (in red). The green line represents the maximum power supplied by the solar system to the processes that will be used to size the solar system.**

For case study 2, the selected process is a slightly different drying process. Drying is obtained with a fluidised beds in four drying chambers at different temperatures (50, 60, 70 and 100 °C), with air as the heat transfer fluid (HTF). Air is firstly heated with four steam heat exchangers to the desired temperature level before being injected into each drying chamber. The air leaving the drying chambers is then cooled at 25°C to lower its water content (absolute humidity), before returning to the steam heat exchangers. Another air/air heat exchanger recovers heat between the inlet and outlet of the chiller (Figure 3). The heat provided by the solar system is used to preheat air to 50°C according to the process constraints. Based on the consumption profile of the process, the solar system is sized considering a maximum power of 180 kW that could be delivered to the process.

### 3.2. Integration concept

One of the potential barriers to integrating a ST system on the process level is the difficulty for the operator to manage multiple energy sources. The idea, in this project, was therefore to propose simple concepts without any constraints for the operator and with low impact on the maintenance work. Because of the normative aspect of the processes, another important consideration concerns the control and operation of the processes, which must not be altered by the solar system. All these elements have been considered to ensure that they are in adequacy with the control requirements (such as FDA: Food and Drugs Administration, ISO: International Standard Organisation). IEA SHC Task 49 Integration guideline (Muster et al., 2015) was used to identify the integration point of the ST system for both cases.

Solar systems were integrated, in both cases, upstream of the actual heat exchangers (see Fig. 3), allowing the control systems to work without any changes. Although heat exchangers cascade is not optimal from an exergetic point of view, security, simplicity and practicality aspects were considered more important (no hydraulic interferences between circuits allowing to work completely independent). Needs are also secured from conventional heat exchangers and solar gains are there to support the system when solar energy is sufficient (not to replace it).

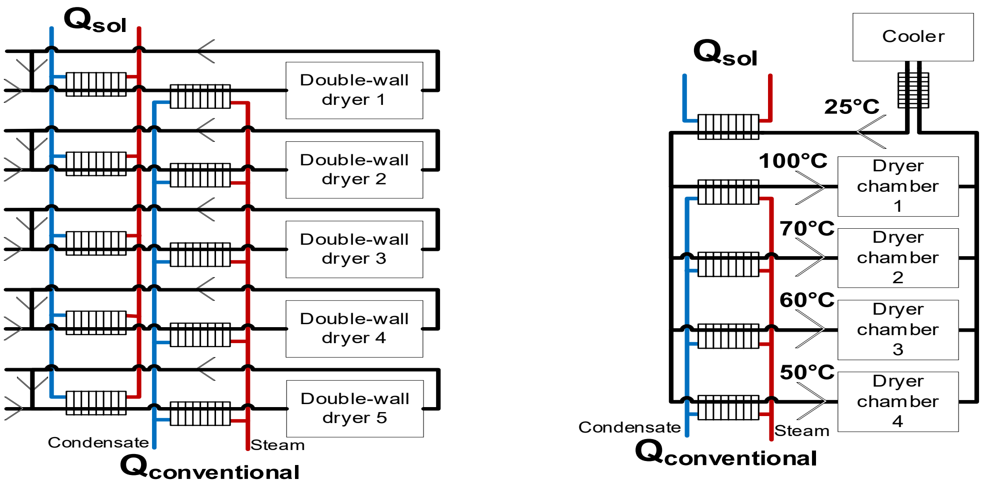


**Fig. 3: Simplified scheme of the integration concept for the solar thermal system for case study 1 (left side) and for case study 2 (right side).**

These solutions correspond to the $P_{L\_E\_IC}$ concept as defined by IEA SHC Task 49 (Muster et al., 2015). This integration concept is simple and allows maximizing the efficiency of the solar system. Another advantage of this concept is that it makes it possible to consider, depending on energy consumption and process temperature levels, preheating or fully meeting the process energy demand.

The detailed integration and control principle for the case studies has been set (see Fig. 4) and used in the simulation environment afterwards. Fig. 4 presents a simplified representation of the integration and control scheme for case study 1. It is quite similar for case study 2, despite that the HTF is different. Upstream of the conventional heat exchanger (1), a two-way valve is installed (2) with a heat exchanger (3) in parallel. If the HTF temperature (4) is below that of the solar system (5), then the two-way valve is closed and the fluid passes through the heat exchanger. If the set point at the exit of the conventional heat exchanger (steam exchanger 6) is not reached, then the steam valve (7) is slightly opened to increase the temperature level and respect the set point. If necessary, in order to have a stable control, a temperature sensor (8), between the two heat exchangers, could be added. If the heat rate of the solar system is too low, then the two-way valve is opened again and the steam valve increases the flow to reach the set point.

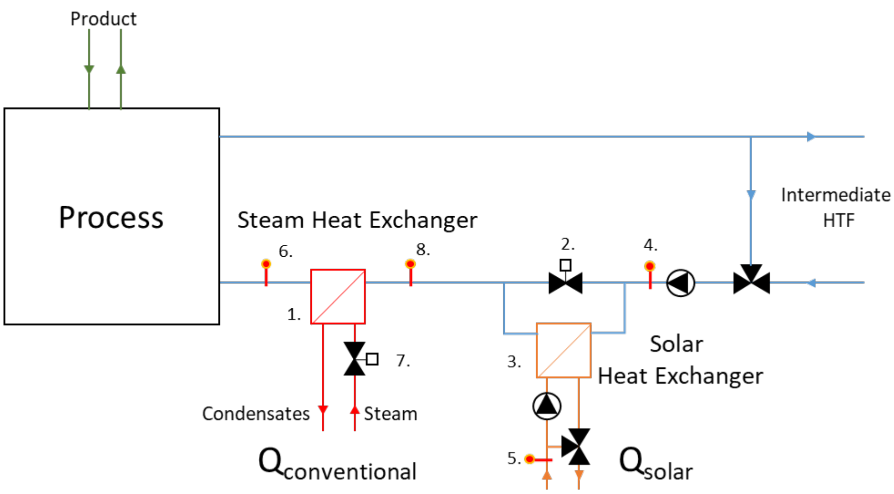


**Fig. 4: Simplified integration and regulation scheme for case study 1**

## 4. Technical assessment

Solutions have been designed for both case studies according to the specific energy needs of the chosen processes and technical constraints (process integration, available space and orientation). Based on several suppliers' quotes, simulations were carried out to estimate the energy production and the energy cost of each system. Simulations were carried out on Polysun (VelaSolaris 2019, POLYSUN V.11.0.12) to assess the energy production of the two solar fields including storage.

To compare the various quotes received, the same Polysun model was used for each case study (see Fig. 5). For each case study, the characteristics of the process, the solar system and the auxiliary boiler were changed to match the design of the installation.

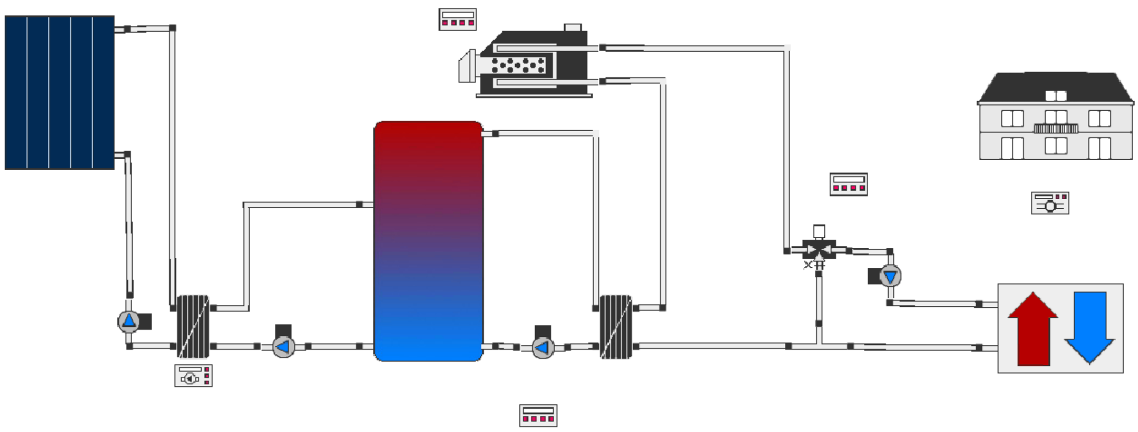

**Fig. 5: Polysun model used to simulate the energy production of the solar system for both case studies.**

### 4.1 Case study 1

The solar thermal plant for the case study 1, located in Bulle, is considered to be installed on the ground, next to the building where the processes are located since this building, as well as the surrounding buildings, have little available roof space. Therefore, implementation of the solar field on the ground was defined in accordance with the company requirements. The ST system was designed with a total collector surface area of about 1000 m² and the solar field south oriented with a 35° inclination. The storage system is a 50 m³ water tank. This storage mitigates the time lag between the consumption profile of the processes and the availability of the solar resource. Five quotes were received for this system with different solar collector models and types but respecting the previous technical requirements of the design. All systems proposed in these quotes were simulated in the Polysun model.

Simulations results depend largely on the type of solar collector installed. Indeed, they have shown that the specific yearly production per m² of collector (solar field gross area) varies from 490 kWh/m² to 783 kWh/m² for the various collectors proposed in the offers received. As the characteristics of the solar system also changes slightly, average values of the solar field area, storage tank and energy production were taken into account. Tab. 1 gives a summary of the technical considerations of the solar thermal plant and the simulation results, taking the average values obtained with all the simulations carried out for this system.

**Tab. 1: Summary of the technical indicators for case study 1**

| Technical indicators | Case Study 1 (Bulle) |
|---|---|
| Solar collector field | 1060 m² |
| Storage tank capacity | 50 m³ |
| Solar resource (on the collector plan) | 1261 kWh/m²/year |
| Annual energy production | 617 MWh/year |
| Specific energy production | 582 kWh/m²/year |
| Efficiency of the solar system | 47% |
| Solar fraction | 38% |

Considering the average results between the different simulations, the ST system produces 617 MWh/year, corresponding to 38% (solar fraction) of the consumption of the processes considered. As show in Fig. 6, the solar fraction is quite steady between April and September, ranging between 44% and 53% of the energy demand.

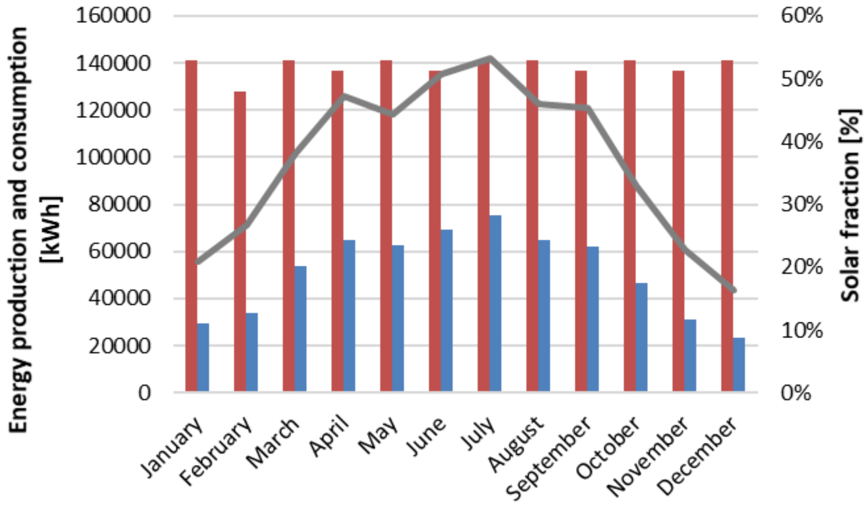


**Fig. 6: Estimated process energy consumption (in red), solar energy production (in blue) and solar fraction (in grey) over the year for case study 1**

As the company of this case study uses gas boilers to supply the heat to their processes, the solar energy produced substitutes part of the gas consumption. To estimate the avoided $CO_2$ emissions with the solar system, only the gas savings are considered. Based on the KBOB database, the greenhouse emissions for the gas boiler is estimated at 0.249 kg $CO_{2\text{-eq}}$ per kWh of useful heat (KBOB, 2017). Therefore, the Greenhouse Gas (GHG) savings with the solar system correspond to 154 t $CO_{2\text{-eq}}$ per year.

4.2 Case study 2

For case study 2, located in St-Prex, the solar collector field is installed on the roof of the building where the manufacturing process is located. Since the available roof area was limited, the area of the solar field could not exceed 700 m². Three offers with this requirement were received. Likewise case study 1, the solar heat production of the solar system changes according to the characteristics of the quotes. Tab. 2 gives the technical indicators of the solar system considering the average values obtained from the three offers received.

**Tab. 2: Summary of the technical indicators for the case study 2**

| Technical indicators | Case Study 2 (St-Prex) |
|---|---|
| Solar collector field | 684 m² |
| Storage tank capacity | 30 m³ |
| Solar resource (on the collector plan) | 1328 kWh/m²/year |
| Annual energy production | 382 MWh/year |
| Specific energy production | 558 kWh/m²/year |
| Efficiency of the solar system | 42% |
| Solar fraction | 28% |

Simulation results show that the ST system for case study 2 produces 382 MWh over the year with an efficiency of 42%, similar to that found for case study 1. The energy produced by the solar system substitutes the gas consumption and therefore the energy saving leads to an estimated GHG saving of 95 $tCO_{2\text{-}eq}$ per year.

The fraction of the process consumption (from the four drying chambers) is covered at 28% by the solar system over the year. This low solar fraction is explained by the fact that the system only provides heat up to 50°C (corresponding to the temperature of drying chamber 4). The heat to reach the temperature required by the other chambers is covered by conventional heat exchangers.

As shown in Fig. 7 the solar fraction reaches a maximum of 45% in June and July. The very high consumption of the drying process makes it possible to consume the amount of energy produced by the solar system, which is also large. This type of process is ideal for ST systems because it operates continuously all year round, allowing large solar fields to be considered without overheating problems during the summer months.

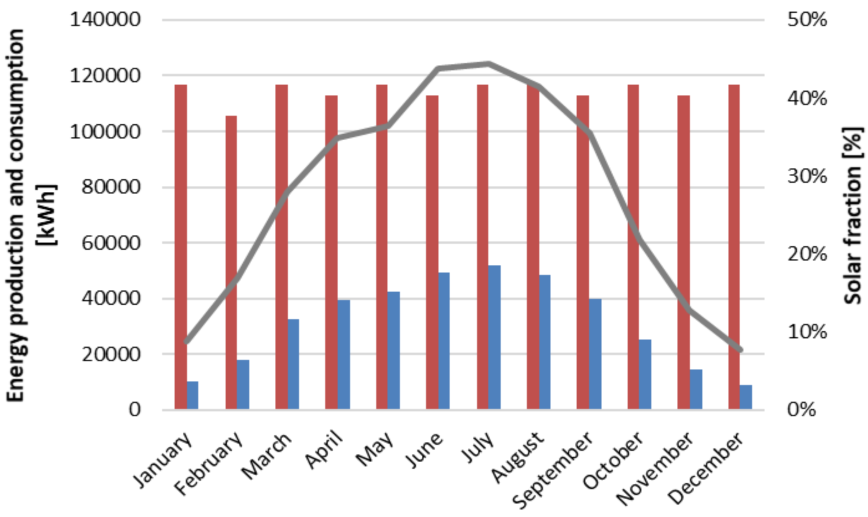


**Fig. 7: Estimated process energy consumption (in red), solar energy production (in blue) and solar fraction (in grey) over the year for case study 2**

The solar systems considered in the two case studies are very similar. Indeed, both the efficiency of the system and the specific production of the solar field have similar values. This is mainly due to the operating conditions, which are almost identical in both cases. Indeed, the required temperatures are very close and the system is controlled in the same way.

## 5. Economical assessment

In order to estimate the financial efficiency of the two solar thermal system, the energy costs of the solar thermal system were calculated based the costs stated in the quotes received and according to the methodology developed on IEA SHC Task 54 (Louvet et al., 2017). Investment costs as well as operation and maintenance (O&M) costs for both case studies were estimated from quotes and the energy production correspond to the results obtained from the Polysun simulations.

### 5.1 Solar thermal system cost

The total investment cost accounts for all costs for the solar thermal system as well as for the distribution line including engineering. Costs of the ST systems correspond to the average costs of the various quotes received (five quotes for case study 1 and three quotes for case study 2) and include equipment for the solar field including the storage, installation and commissioning. Distribution lines correspond to the part of the system between the solar thermal system and the process. Its cost is estimated from various quotes received for the equipment and for the installation and commissioning. Planning costs correspond to the human hours necessary to carry out the study and the design of the solar thermal system, as well as the cost associated with the necessary equipment for the site preparation. Last category, named “Various and unforeseen”, has been added and corresponds to 8% of the total investment value. The following Tab. 3 resumes the total investment cost for both case studies.

**Tab. 3: Initial investment cost by category for case studies 1 and 2**

| Cost category | Case study 1 | Case study 2 |
|---|---|---|
| Solar thermal system | 844’000 CHF | 533’000 CHF |
| Distribution line | 243’000 CHF | 153’950 CHF |
| Planning | 39’500 CHF | 25’000 CHF |
| Various and unforeseen | 81’000 CHF | 57’000 CHF |
| Total investment cost | 1’207’500 CHF | 768’950 CHF |

The investment cost is estimated to 1’207’500 CHF for case study 1 and to 768’950 CHF for the case study 2. In relation to the surface area of solar collectors, the specific cost of case study 1 is 1’040 CHF per square meter of solar collectors (gross area) and is 1’124 CHF for case study 2.

O&M costs correspond to the energy consumption of the pumps and controllers as well as the cost for supervising the installation. For case study 1, the annual O&M cost was estimated to 10’500 CHF and for the case study 2 this cost was estimated to 7’300 CHF, which correspond to about 1% of the initial investment value of the case studies installations.

The breakdown of these costs for both case studies are given in Fig. 8. The O&M costs were compiled over the life span of the solar system, considered to be 20 years. It appears that the cost breakdown is similar between the different solar systems.

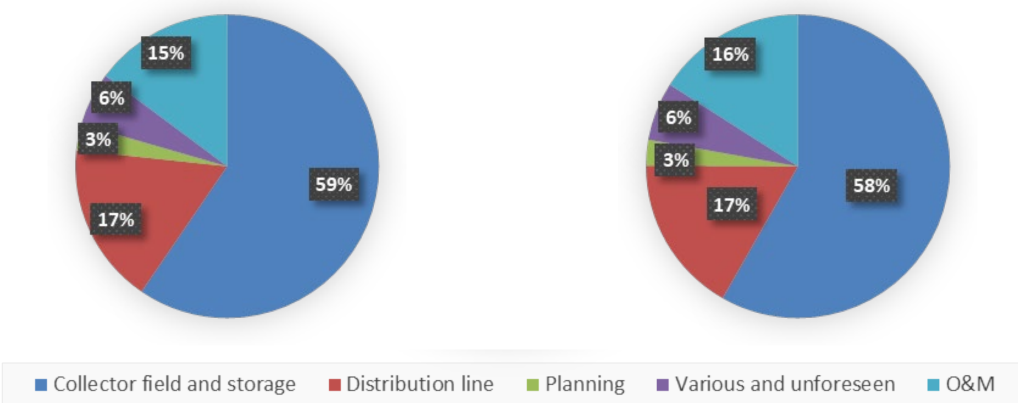


**Fig. 8: Breakdown of the total cost of the solar thermal system for case studies 1 and 2**

### 5.2 Cost of the solar heat

Energy cost has been evaluated using the methodology and the formula as defined in the IEA SHC Task 54

(Louvet et al., 2017). This methodology helps to assess the price of the heat produced with ST systems by determining the levelized cost of heat (LCoH) which is very comparable to the concept widely used to determine the cost of energy in the electrical sector:

$$LCoH = \frac{I_0 - S_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \qquad \text{(eq.1)}$$

No subsidies ($S_0$) were considered for this study because no subsidy mechanisms for the implementation of solar systems for industrial processes is available in Switzerland. The initial investment ($I_0$) and the amount for yearly O&M costs ($C_t$) are as presented in section 5.1 for each case study. The period of analysis (T) is equal to the expected technical life span of the solar thermal system and is considered in this study to be 20 years. The discount rate (r) considered is 3%.

The saved final energy ($E_t$) considered correspond to the gas savings. The efficiency of the boiler is estimated to be 90% for the calculation of the final energy savings. Therefore, the final energy savings for case study 1 and for case study 2 are 686 MWh/year and 424 MWh/year, respectively.

The resulting LCoH for the solar thermal system in case study 1 is 117.9 CHF/MWh. This cost is almost twice as high as the gas cost currently paid by the company, e.g. 60 CHF/MWh. This gas cost is a common value in the pharmaceutical industry in Switzerland and therefore a target value to be achieved for the cost of heat produced by solar systems.

For case study 2, the LCoH is 122.7 CHF/MWh. This heat cost remains too high compared to the cost of gas and is slightly higher than that obtained in case of study 1, but this difference can easily be explained by the fact that this system is smaller and therefore the cost of the system per square meter of solar collector is higher.

## 6. Conclusion

The study of the integration of solar thermal systems into production processes of two pharmaceutical companies was investigated in order to highlight the important parameters to consider for optimising the use of solar energy in this sector of the Swiss industry. The identification of the potential, as well as simple integration and regulation schemes, have made possible to estimate if these systems are interesting for this industry from a technical and also from an economic point of view.

As well as being an important sector of the Swiss economy, the pharmaceutical sector presents the largest consumption of heat for processes. About 15% of the energy consumed by this sector could be met with conventional solar thermal system such as flat-plate or evacuated tube collector. This theoretical potential represents 2 million $m^2$ installed solar collectors that could easily cover the heat demand for process occurring at low temperature (<130°C).

Drying processes are very common in the pharmaceutical industry and are among the largest consumers of energy. The study of energy consumption in case study 1 showed that drying processes accounted for 97% of the energy consumption in a production line involving fourteen processes for the production of a pharmaceutical product.

The two case studies showed that the energy requirements of these processes correspond fairly well to what a solar thermal system can provide with regard to temperature levels and the continuous consumption profile. In both cases, the most interesting integration concept for the solar system was identified as $P_{L\_E\_IC}$, as defined by IEA SHC Task 49. This simple integration concept allows to maximise the solar energy production and to cover a good part of the energy consumption while complying with the operational constraints and the standards for each case study.

The simulation results allow to observe the behavior of the solar thermal system in relation to the processes consumption and to predict the gas savings that could be achieved. The solar plant sized for case study 1 produces 617 MWh/year with 1060 $m^2$ of solar collector (solar field gross surface) and 50 $m^3$ of storage. This energy production corresponds to 38% of the heat requirements for the selected processes, allowing gas savings equivalent to 154 $tCO_{2eq}$ per year. For the solar thermal system in case study 2, the energy production reaches 382 MWh/year with a smaller system (684 $m^2$ of solar collector and 30 $m^3$ of storage), representing a solar fraction of

28% and gas savings equivalent to 95 $tCO_{2eq}$ per year.

The cost assessment show that the levelized cost of the solar heat (LCoH) reaches almost twice the price of the gas, considered to be 60 CHF/MWh for the industry in Switzerland. However, the economic calculation of the installation does not take into account any possible solar incentives or $CO_2$ taxes for the gas consumption that could result in costs reductions of the installation and improve profitability. In addition, the LCoH of the solar system corresponds to that of the heat produced by the system over its entire lifetime, which means a fixed cost for at least the next 20 years.

Despite the costs, the results obtained in this study showed that the integration of a solar system into pharmaceutical industry processes is a technically viable solution. In addition to avoiding the production of steam to supply heat to processes with temperatures below 100°C (energy efficiency), a solar thermal installation also has the advantage of significantly reducing greenhouse gas emissions by substituting fossil fuels which contribute the Swiss Energy Strategy 2050 objectives.

## 7. Acknowledgments

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