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sweet swiss energy research for the energy transition

Summary

The energy required for heating and cooling in many production plants accounts for a major part of their total energy demand. Therefore, in-process heat recovery is essential for improving energy efficiency: “Process waste heat” is converted into useful heat and as a result energy costs are reduced. However, heat recovery requires investments on the plants side, for example for new heat exchangers and piping systems. Through Pinch Analysis (PA), the optimal combination of streams can be found which meets the objectives of minimum total investments and energy costs. Strategic plans are then made with the results of the analysis. These plans look to introduce measures for the improvement of energy supply and heat recovery. “Targets before design” is the basic philosophy of PA. This means that first the energy and cost targets are determined. Once these are determined then the system can be designed in detail. In this deliverable, “targeting” using Composite Curves (CCs) and Grand Composite Curve (GCC) is briefly introduced. Then, the GCC for selected companies are presented at the end.

1 Introduction

The aim of Work Package (WP) 4 is to enhance the understanding of the energy demands from industry to facilitate successful integration of energy efficiency measures, and renewables within the process energy supply. The WP adopts Process Integration (PI) methodology to characterize process energy demands, aiming at both company and sectorial levels. Determining industrial energy demand profiles (quantity, quality, temporal), based on real data analysed using state-of-the-art PI techniques, is a crucial precursor to supporting integration of renewable heating and cooling (henceforth termed “renewables integration”), and excess heat use (e.g. in thermal grids), as they form the basis for accurate characterization and eventual matching of demands with suitable renewables technologies emerging and currently on the market.

The Swiss Federal of Energy (SFOE) has been promoting the performance of pinch analyses in Swiss industry for years. To date, more than 100 pinch analyses have been carried out. PA provides important insights into the absolute energy saving potential of an overall system and with which measures this can be correctly exploited, e.g. heat recovery, optimization of the energy supply, use of energy conversion systems, energy storage. Often, not all measures proposed in a PA are implemented due to different considerations.

Therefore, to achieve the aim of WP4, the purpose of Task 4.1 is to collect, collate, and evaluate plant data of industrial companies, to understand and obtain the temporal profile of energy demand in terms of both quantity and quality (energy profiles) at the company level. Task 4.1 builds upon the solid body of existing knowledge; industrial energy usage data collected during previous Swiss energy research activities (especially those of the SCCER EIP); through systematic evaluation of selected data from PAs conducted in Switzerland. Thereby, real plant data exclusively from Swiss industry is used to form the energy profiles, taking note of the scale of production, and handled according to the data management plan. Where real data cannot be sourced, previous SCCER EIP studies and literature, as well as data from well-known processes, best available techniques, and statistical data will be used to complete the energy profiles. In this deliverable report, the aim is to present GCCs of a few selected industries.

2 Background on Pinch Analysis

Process Integration is a holistic approach to design operation which emphasises the unity of the process [1]. PI tools and methods have been used to analyse the use of energy and other resources in the multiple industries and to identify ways to increase productivity, decrease costs and address environmental issues. PI, which includes PA, is a method to reduce energy use and emissions in industrial plants and has been successfully applied across many industries. It achieves this by providing a framework for systematic and rigorous systems analysis to understand the intrinsic thermodynamic requirements of industrial production systems with a special emphasis on the efficient use of energy and water, and the minimisation of environmental impacts.

2.1 Pinch Analysis

PA is a graphical approach and is the most important and advanced tool in energy PI. The principal tools of PA are the pinch point(s) insights and the graphical representations of CCs, shifted CCs, and the GCC. PA is a systematic technique for analyzing heat flow, process requirements, through an industrial process and is based on fundamental thermodynamics. Based on the process requirements, it makes it possible to calculate the minimum necessary external energy under the constraint of minimum annual total costs (energy and cost targets) and to develop an optimal plant design. PA allows to determine the (absolute!) energetic optimization degree of a plant and to identify economically reasonable optimization potentials.

In PA, the process material flows to be heated and cooled are combined into two composite curves (CCs). The "cold CC" reflects the heat demand and the "hot CC" reflects the heat supply (Figure 1, left). The "pinch" is the closest approximation of the hot and cold composite curves, characterized by ΔT_{min}. Heat recovery (HR) is possible in the overlapping region. Moving the CCs horizontally changes the minimum temperature difference, ΔT_{min}, between the curves, the HR potential, and the heating and cooling required (hot utility HU, cold utility, CU). With the objective of minimum annual total cost, the optimal temperature difference $\Delta T_{min,opt}$ (Figure 1, right) can be identified. The larger the ΔT_{min}, the smaller the overlapping area and thus the potential for HR. At the same time, more heating and cooling utilities are needed, which leads to higher energy costs, and vice-versa is true for the investment costs for the HR system: the smaller the in ΔT_{min}, smaller heat exchangers are required.

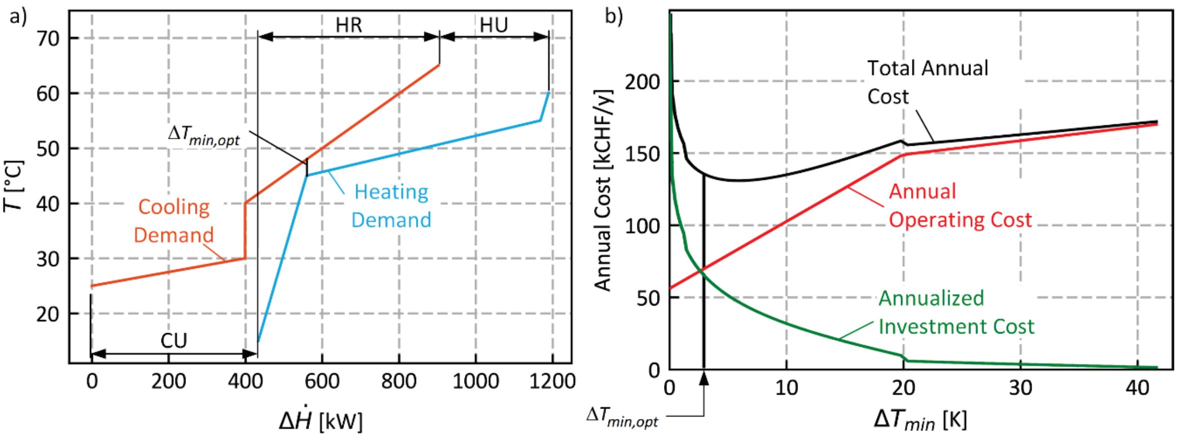


Figure 1: Composite curves and cost curves (example metal processing plant). Left: CCs of the cooling (red curve) and heating (blue curve) demands. The arrows indicate the HR and the area to be covered by the hot utility (HU) and by the cold utility (CU). Right: cost curves showing annual total cost (black curve), annual operating cost (red curve), and annualized capital cost (green curve). The minimum total annual cost shows the optimal temperature difference $\Delta T_{min,opt}$.

This is followed by the design of the heat exchanger network (HEN), with which the energy and cost targets from the CCs are achieved as well as possible while complying with $\Delta T_{min,opt}$. The following three main rules ("Golden Rules") must be observed in a PA: (1) no external cooling above the pinch, (2) no external heating below the pinch, and (3) no heat transfer across the pinch, i.e., do not take heat above the pinch and give it below, and vice versa. PA systematically leads to the goal of an energetically and economically optimized overall plant. The implementation of a PA is already worth-while for relatively "simple" plants. As soon as complex plants with dozens of flows are involved, PA is the only viable tool for plant design.

In addition to the CCs, the overall composite curve (Grand Composite Curve, GCC, cf. Figure 2is of particular importance. The GCC can be derived from the CCs and shows how much heat deficit (heating demand) and heat surplus (cooling demand) exists depending on the temperature level. Above the pinch there is a heat deficit, below a heat surplus, just at the pinch point there is neither a deficit nor a surplus.

The temperatures read from the GCC, the so-called "shifted" temperatures, do not correspond to the real temperatures: these are higher above the pinch by $\Delta T_{min}/2$ and lower below the pinch by $\Delta T_{min}/2$ than the temperatures shown in the diagram (see e.g. [2]). The gray areas are called "pockets", which illustrate that there is the possibility of transferring heat internally within the process. Here, neither external heating nor cooling is necessary.

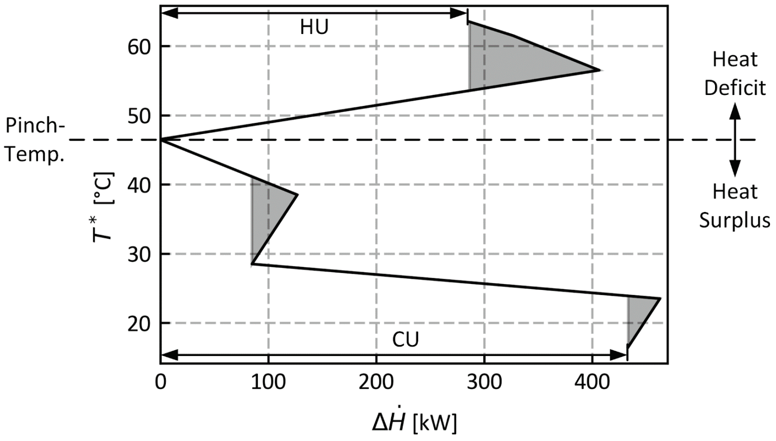


Figure 2: GCC from a pinch analysis (example metal processing plant). The GCC shows the heat deficit and surplus depending on the temperature level. Above the pinch there is a heat deficit and below a heat surplus. The "shifted" temperatures are read on the y-axis.

2.2 Heat Transfers

2.2.1 Direct Heat Transfer

Direct heat transfer refers to the heat transfer between the processes which takes place directly between two streams, usually via a HEX. The main operational conditions for direct heat transfer between processes are listed below. The various processes shall:

- operate (almost) always simultaneously in their actual state,
- operate (almost) always simultaneously in the foreseeable future (i. e. a process does not require flexible operating hours),
- be spatially close to each other,
- be technically combinable (i. e. control systems must be able to communicate with each other) and
- be combined with quality and safety taken into consideration (e. g. no re-cooling of hydraulic oil with milk, no pairing of corrosive substances,etc.).

Whether or not the direct heat transfer is energetically justifiable can be made clear with the CCs and a comparison of the HR. The comparison should be done on the basis of a realistic ΔT_{min}.

2.2.2 Indirect Heat Transfer

Indirect heat transfer is the transfer of heat between two or more streams through an intermediate loop (IL). An IL can be, for example, a circulating system specifically installed for HR and which can optionally support hot or cold utilities. It can also be an existing utility network (e. g. hot water loop, steam network) that is used for indirect heat transfer. The hydraulic separation is a pipe connection that can be flowed through in both directions depending on the volume flow rate on the charging/discharging side of the IL (and thus the charging and discharging side are separated).

The capital costs for indirect heat transfer are higher in comparison to direct heat transfer (two HEXs instead of one, reduced ΔT through the IL resulting in larger heat transfer area with the same output, pumps, lines, etc.) and the implementation of indirect heat transfer systems can be technically complex.

For these reasons indirect heat transfer is mainly used only when the conditions for direct heat transfer between processes are not fulfilled (non-continuous processes) or for any other reason that direct heat transfer between the processes is not desired.

2.3 Integration of energy efficiency measures and renewables using GCC

2.3.1 Heat pump integration

PA provides a systematic design and correct integration of energy efficiency measure, e.g. heat pumps (HPs). From the "Golden Rules" it can be deduced that a HP should absorb heat below the pinch (where there is a heat surplus) and release heat above the pinch (where there is a heat deficit). It is said that "the heat pump operates across the pinch." (Figure 3). If a HP operates only below the pinch, the heat surplus is increased, and additional compressor power must be dissipated through the CU. Integrating a HP only above the pinch results in a reduction of the HU by the compressor power – energetically an electric heater.

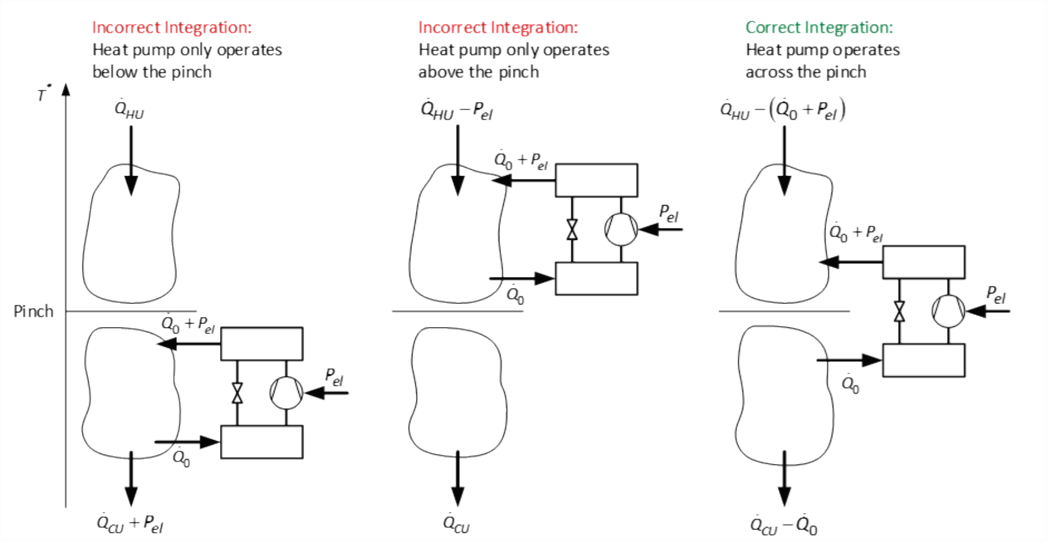


Figure 3: HP Integration into a continuous process (adapted from [3], [4]).

One of the reoccurring mistakes in industry is that HPs are not correctly integrated. The position of the pinch point and the shape of the GCC indicate whether it makes sense to integrate a HP or whether an existing HP is correctly integrated into the process. With a correctly integrated HP, the heating and cooling requirements and the associated energy costs can be reduced simultaneously (Figure 4).

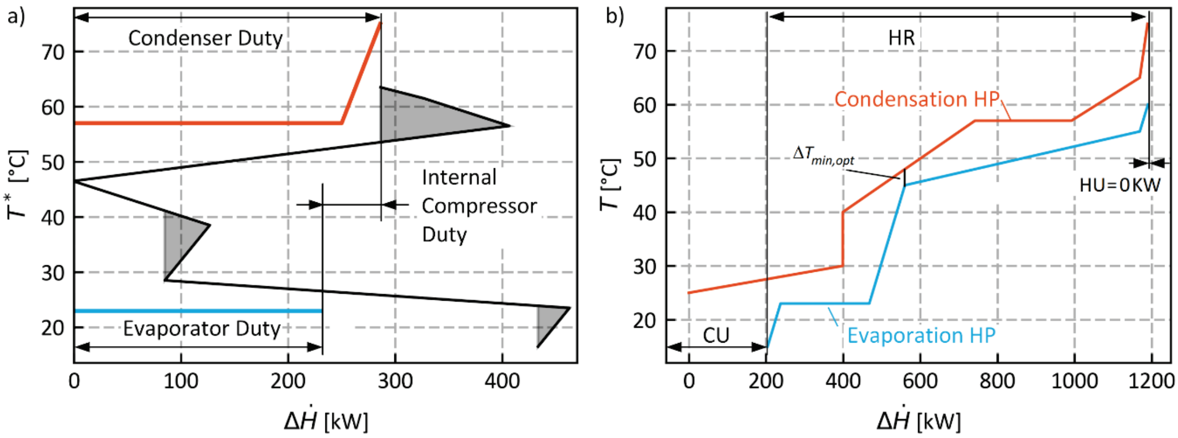


Figure 4: Heat pump integration in metal processing plant. a) GCC with evaporating and condensing temperature of WP. b) CCs with integrated heat pump streams.

2.3.2 Renewable and district heating integration

A key element in the integration of renewable energy integration into industrial processes is the GCC [5]. The GCC shows the difference between the available heat of the hot streams and the heat required by the cold streams, based on the respective temperature levels. It is assumed that all heat recovery (HR) has been implemented in the process. With this information about the heat deficit, possible energy supply systems can be selected and designed. For the integration of solar heat, it can thus be read directly from the GCC at which temperature level the solar thermal system must be operated in order to be able to cover the corresponding heat deficit. Furthermore, it follows from the three main rules that the integration of solar heat must always be carried out above the pinch point. In Figure 3 shows an example of the temperature level at which the solar thermal system must be operated in order to cover the heat deficit of the process.

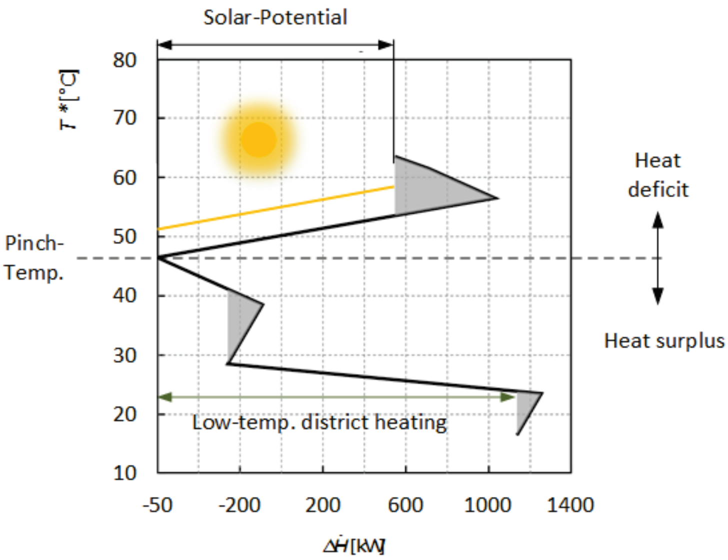


Figure 5: GCC from a pinch analysis (example metal processing plant) with solar and low temperature district heating potentials.

2.3.3 Integration of thermal energy storage systems

In non-continuous processes, heat sources and sinks do not occur simultaneously, and the temporal change of the heating and cooling demand is sometimes high. HR can often only be achieved by integrating thermal energy storage (TES), which is referred as Indirect Heat Recovery (IHR).

Pinch analysis can be used to determine which heat sources and sinks should be considered, how storage capacities and temperatures should be selected, and whether the storage solution is economical. In practice, tools based on time-averaged methods have proven to be effective (Time Average Model, TAM). In the TAM, a representative of one repetitive period of the process is considered at a time. The heat duty of each process stream is averaged over this period, giving the maximum HR potential, neglecting time constraints.

The Indirect Source Sink Profile (ISSP) is based on the TAM approach and allows for the integration of TES into non-continuous processes (see, e.g., [6], [7]). It shows the whole heating and cooling demands over the batch process in cycles. When batch processes are delivered in a cyclic manner, (periods in which streams occur in a repeated order appear), these periods are called Stream-wise Repeated Operation Period (SROP). As a difference to continuous processes the ISSP displays the needs of heat load in kilowatt hours instead of the heat rate in kilowatts. The ISSP method ensures that the resulting storage system is technically feasible, the heat balance is guaranteed, and the complexity is as low as possible. The temperature-enthalpy regions where placement of storage is feasible are termed as Assignment Zones (AZs). Abdelouadoud et al. [7] introduced the AZs graphically on the ISSP to represent the ISSPs constraints and degrees of freedom that apply when designing the HESN that can achieve the target heat recovery, given by ISSP overlap. Figure 6shows an example of an ISSP and its associated TES system. The ISSP is reminiscent of CCs, but the thermal requirements are shown as heat quantity (in kWh over the period) rather than heat output (in kW). The black line between the red source profile and the blue sink profile shows the transferred heat quantity (IHR) and temperature levels of the storage tank and the Intermediate Loops (ILs), respectively. The method is well established, it is used today by engineers for the dimensioning of TES systems with the software PinCH.

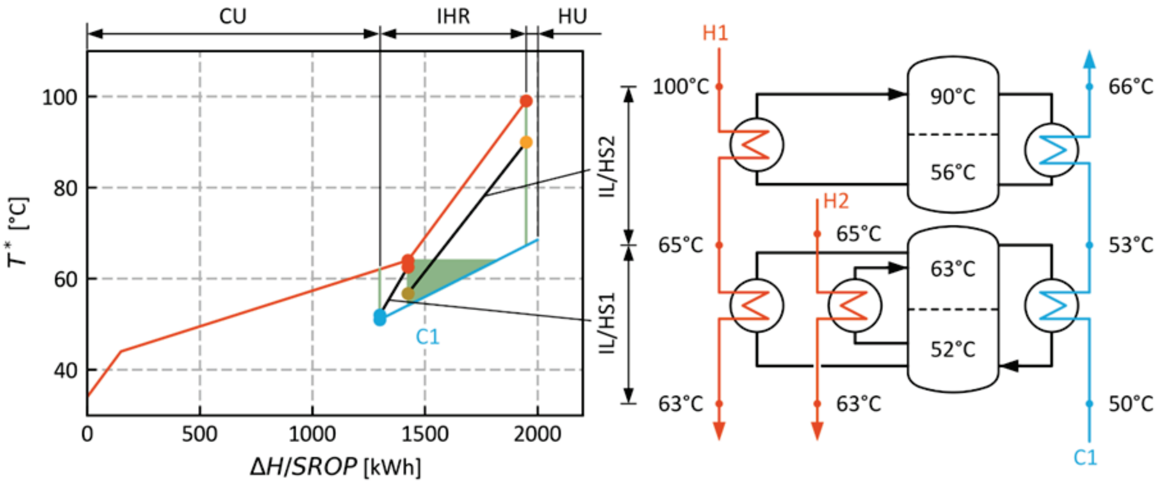


Figure 6: Storage integration in non-continuous processes using ISSP. HS represents Heat Storage.

In addition to non-continuous processes, TES can be integrated to help stabilize the volatility of the renewable energy supply system.

3 Profiles

In the PA context, there are two types of processes: continuous and non-continuous processes, where non-continuous can be further divided into batch or multiple operating case processes.

1. Continuous process: processes consisting of at least one stream but generally multiple streams that occur simultaneously, as well direct heat transfer amongst the streams is possible. A process can consist of several process stages up to and including an entire process plant.

2. Batch process: processes in which various unit operations are executed sequentially. This step-by-step execution (a batch) is performed repeatedly. This typically occurs in a time frame of hours or days.

3. Multiple operating case (MOC) process: The plant is operated in different operating cases, e.g. product changes, or cleaning cycles. This often occurs within a day but may extend beyond that time frame.

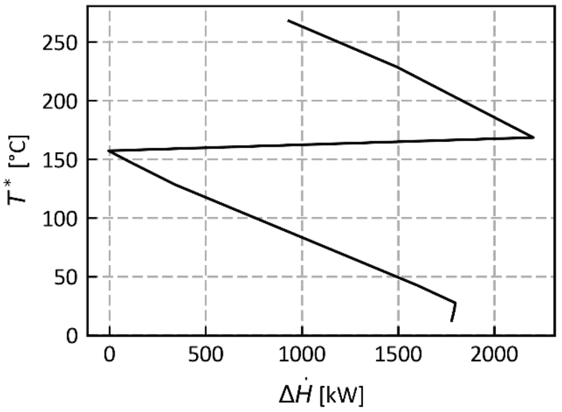
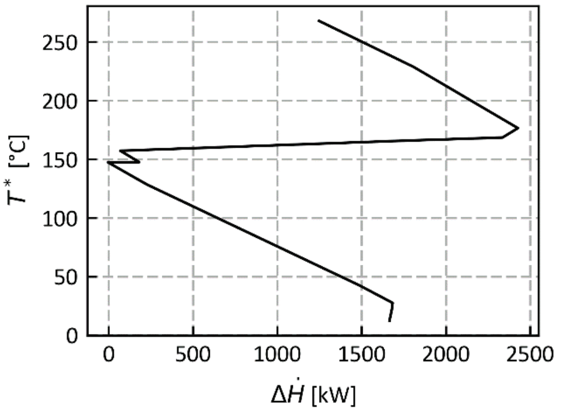
Different profiles from various industrial sectors are presented to show the difference different type of processes.

3.1 Multiple operating case processes

3.1.1 Case 1: Product change

A potato chips production plant from a Swiss food company, producing snacks such as potato chips. The frying process (Fritter Line) for the potato chips has a heating demand of around 64% of their total heating demand. The Fritter Line is used to fry two varieties of potato chips: (Operating Case, OC1) Regular chip and (OC2) cractive chips.

Information		
Production Line	Regular Chips	Cractive Chips
Production Hours	4’410 h	2’610 h
Pinch-Temperature	163.3 °C	°C
Heat Recovery (kW)	1’843	1’834
Hot Utility (kW)	1’527	1’254
Cold Utility (kW)	1’960	1’671

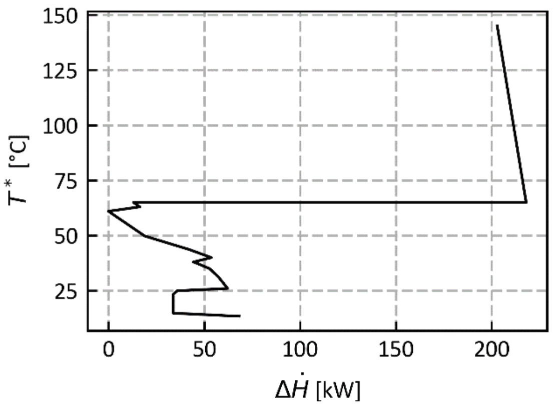
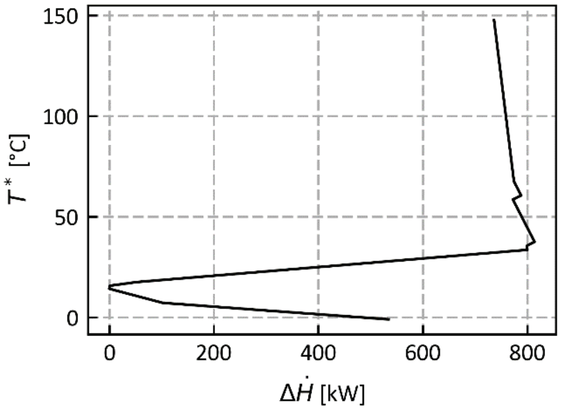
Diagrams	
Production Line	Grand Composite Curve
Regular Chips	
Cractive Chips	

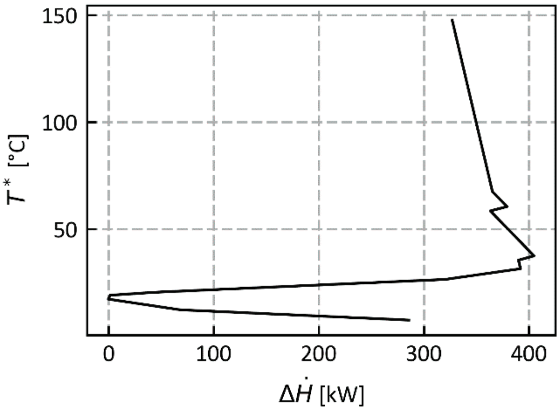
Due to the different heat recovery potential and heating and cooling demands of the two chips production using the same equipment, the resulting HEN needs to be able to ensure feasible heat transfer in each operating case. Stampfli et al. [8] developed a two-level genetic algorithm and differential evolution algorithm to retrofit existing HEN for this MOC.

3.1.2 Case 2: Seasonal change

This company produces cutting -edge technology in the galvanic field. This case shows the GCCs for different seasons of the year. In a SFOE project, BillySolar [9], this galvanic industry was used as a case study for the integration of solar thermal.

Information			
Season	Summer	Winter	Transition Period
Dates	01.06. – 31.08.	01.12. – 31.12. 01.01. – 28.02.	01.03. – 31.05. 01.09. – 30.11.
Production hours	900 h	900 h	1'800 h
Weekly profile	Monday - Friday	Monday - Friday	Monday - Friday
Production time	06:00 - 21:00	06:00 - 21:00	06:00 - 21:00
Pinch-Temperature	63.5 °C	17.5 °C	9.2 °C
Potential for solar heating (kW)	387	441	490
Heat recovery (kW)	95.4	139.5	144.3

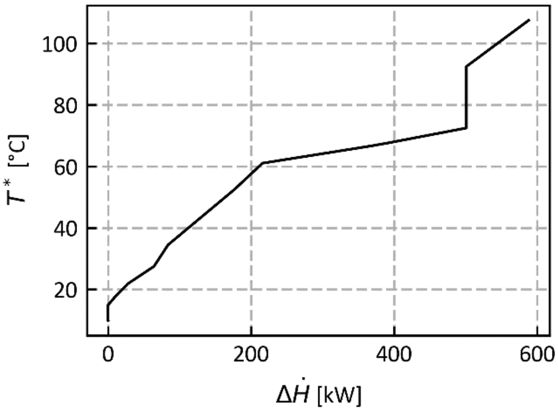
Diagram	
Season	Grand composite curve
Summer	
Winter	

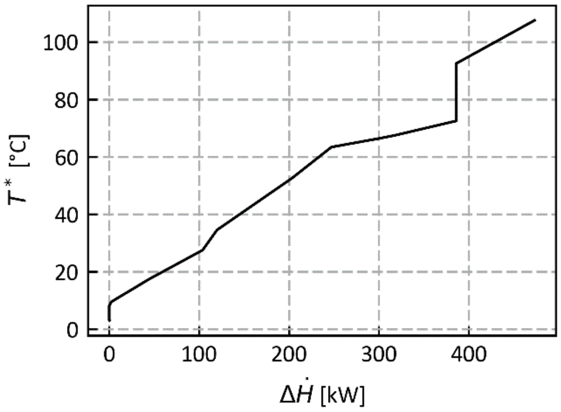
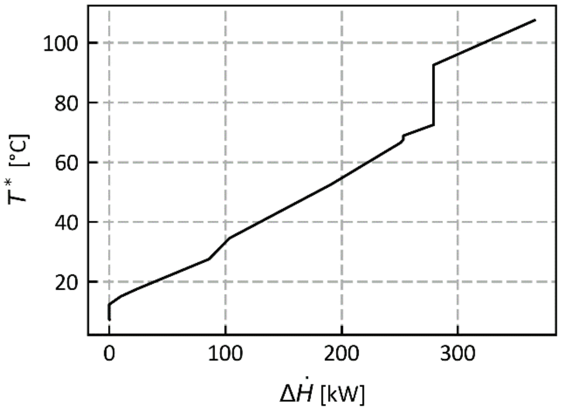
Transition	

3.1.3 Case 3: Seasonal change

This company produces sweets, fruit gums, and instant drinks for local and international wholesaler. Around 5.1 GWh of heat is obtained annually from the local waste incineration plant. This case shows the GCCs for different seasons of the year. In a SFOE project, BillySolar [9], this food industry was used as a case study for the integration of solar thermal.

Information			
Season	Summer	Winter	Transition Period
Dates	01.06. – 31.08.	01.12. – 31.12. 01.01. – 28.02.	01.03. – 31.05. 01.09. – 30.11.
Production hours	550 h	550 h	1’100 h
Weekly profile	Monday - Friday	Monday - Friday	Monday - Friday
Production time	06:00 - 14:00	06:00 - 14:00	06:00 - 14:00
Pinch-Temperature	37.4 °C	35.5 °C	36.1 °C
Potential for solar heating (kW)	588	366	473
Heat recovery (kW)	95.4	139.5	144.3

Diagram	
Season	Grand composite curve
Summer	

Winter	
Transition	

3.1.4 Multiple operating case with overlap

A major milk processor in Switzerland. The site focuses on the production of fresh cheese, processed cheese, and fondue. For a period during the winter months, due to increased demand, fondue production occurs in two shifts 03:30 to 21:00 on weekdays (Mon-Fri). A single shift occurs on Sat (03:30-12:00). In January, fondue is produced in one shift during weekdays (07:00-15:00). This period of increased production is referred to as “maximal production”. From February on, fondue production is reduced to between two and four production days per week. This period of operation is termed “reduced production” and occurs throughout the rest of winter and the summer months. Fresh/Processed cheese is produced during a single shift on weekdays throughout the year. In a SFOE project, Integration of Heat Pumps and Thermal Energy Storages in Non-Continuous Industrial Processes, HPTES [10], designed HP and TES for the process. The work used the process streams that occur in every single operating case and the GCC for that is presented in Figure 7.

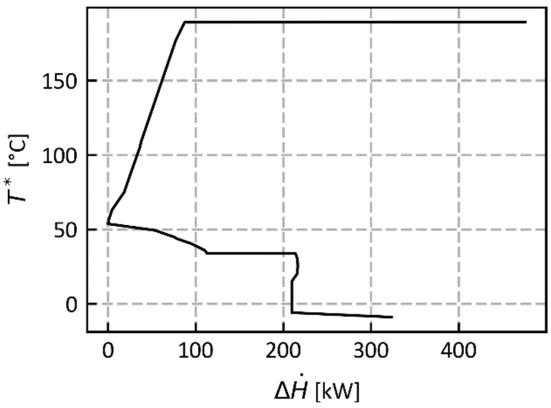


Figure 7: Repeating streams in every OC.

3.2 Case 5: Batch process

The case study comes from the PA of a large Swiss cheese factory. Each stream occurs only during a certain time period. The duration of the batch cycle is 24 hours. According to the production schedule, the process is in operation for 339 days/year.

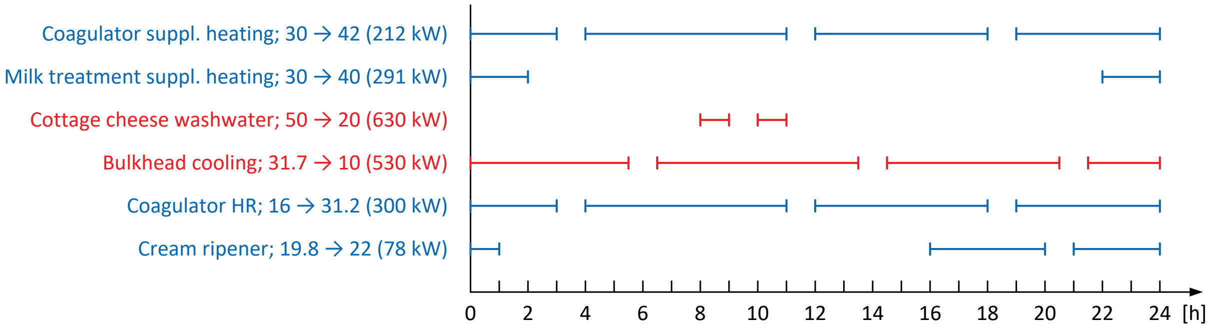


Figure 8: Gantt chart of the representative production day of the batch process of a large Swiss cheese factory selected as a case study.

Figure 9 shows the TAM of the process.

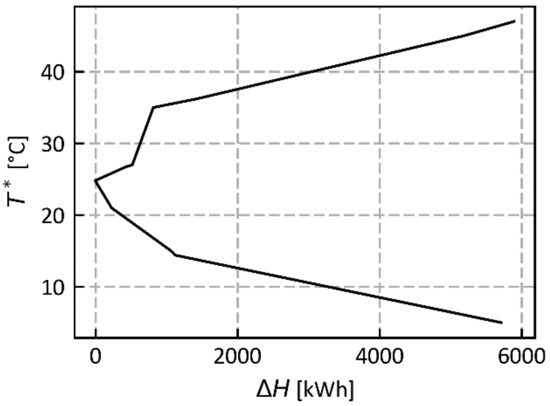
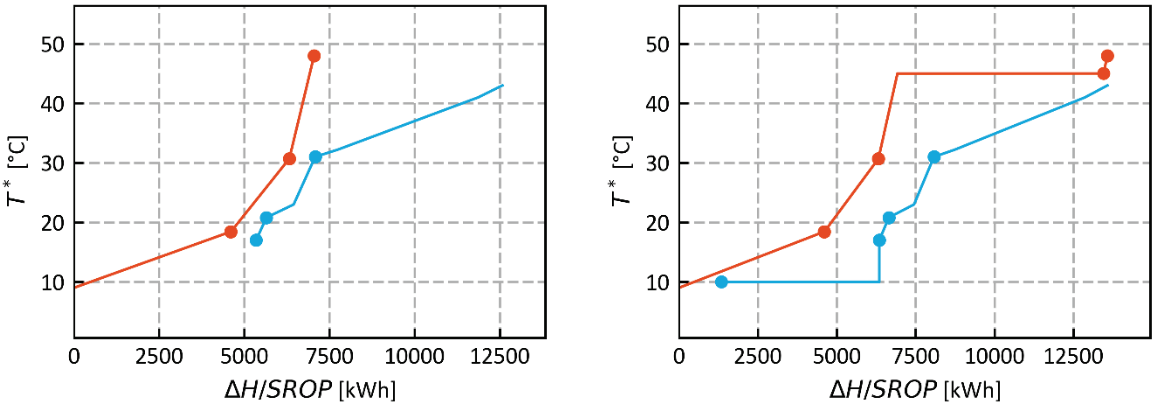


Figure 9: TAM of the process.

Using the ISSP, it was identified that the IHR potential is up to 2’400 kWh/day. However, according to the HPTES project for the design of IHR system, the IHR of 1’700 kWh/day proved to be the most economical and technically feasible.



(a) (b)

Figure 10 (a) Indirect heat recovery of Case 5 with a IHR of 1’700 kWh/day, (b) Case 5 with an integrated HP evaporator and condenser streams.

4 Conclusions

This deliverable report introduced the basics of Pinch Analysis and the associated graphical representation of energy demand in industrial processes, as it is basis for the next outputs from WP4. In the next reporting period, the important step to achieve in WP4 is the construction of exemplary energy profiles (GCCs) that represent the energetic demands and excess heat at company level for various industrial processes in Switzerland, using statistical analysis, in T4.3. This is important for scoping studies to be used within the consortium for any further research. It will allow members of the consortium, and also practitioners, to scale the exemplar energy profile according to their production size to explore their potential renewables integration opportunities. This exemplar energy profile will facilitate the development and assessment of solutions for the optimal integration of energy efficiency measures (EEMs; closely linked with WP05), renewables, as well as negative emission technologies (NETs, WP12), as shown in the report. The work carried out in Task 4.3 will feed into Task 4.2. The aim of task 4.2 is to identify a company’s potential to integrate renewables as well as the external use of excess heat. GCCs are essential. The developed tools and methods in T4.2 should function with minimal plant data (e.g. production volume), and include and expand existing techniques that shorten the analysis where limited data can nonetheless be used to predict reliable values of unmeasured streams and process requirements). Understanding of frequently encountered processes, infrastructure, and energy supply systems are to be incorporated, to identify where data recording can be minimized and where it is unavoidably required. The methods and tools should allow users to determine the profiles rapidly and with minimal time commitment, so that such undertakings become feasible for SMEs as well as more attractive to larger companies.

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