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Deliverable report

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Table of contents

sweet swiss energy research for the energy transition

Summary

This deliverable reports on the framework developed for the standardised evaluation framework for the industrial energy demands. In this work package, Process Integration methodology is used to characterise industrial energy demands. With the Swiss Federal of Energy promoting the use of pinch analysis in the industry, more than 150 pinch analyses have been carried out. The purpose of Task 4.1 is then to collect, collate, and evaluate plant data of industrial companies to understand and obtain the temporal energy demand profiles at the company level. The framework evaluates the pinch analysis that have been conducted in Switzerland, including their utility data and implemented energy efficiency measures. These evaluations are stored in a database which includes the energetic and economic parameters of the pinch analyses.

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 characterise process energy demands, aiming at both company and sub-sectorial levels. Determining industrial energy demand profiles (quantity, quality, temporality), 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 150 pinch analyses have been carried out. A Pinch Analysis (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, e.g. space constraints or proof of concept.

Therefore, to achieve the objectives 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 [1], [2] and literature [3], [4], as well as data from well-known processes, best available techniques, and statistical data will be used to complete the energy profiles.

Until now, there has only been a holistic compilation of overview of the PA that have been carried out between 2007-2019. There is, however, no database that provides all the data that is needed for the PA. In order to close this gap, a database is created, which will include the energetic and economic parameters of these PAs. The parameters of these PAs (e.g. energy demand, energy sources, energy supply) are systematically evaluated, collected and presented in a suitable form. At the same time, the measures developed in the course of the PA (e.g. energy saving, investment and operating cost reduction, CO_2 reduction) are systematically collected, categorized and evaluated. An additional focus is the development of a systematic evaluation framework based on a top-down/bottom-up approach and covers the important point of data extraction.

2 Current available data

2.1 HSLU-TEVT

The Competence Centre for Thermal Energy Systems and Process Engineering (TEVT) of the Lucerne University of Applied Sciences and arts (HSLU) collected and compiled all performed PAs in the Swiss industry from the year 2007 to 2019. The aim was to record and evaluate the proposed energy efficiency measures in order to show their effects on the energy, cost, and emission situation of the companies. In this effort, respective companies were contacted and existing final reports, presentations, PinCH-files, etc. were collected. A total of 170 PAs were carried out. Of these, documents from 104 PAs (rough and detailed analyses) were collected or made available. The remaining documents were not submitted by the companies for various reasons and could not be used for the evaluation. Of the 104 pinch analyses submitted, four were from waste incineration plants (KVAs). These KVAs could falsely distort the overall result of the evaluation, which is why it was decided to exclude the four KVAs from the evaluation. The 70 detailed analyses were used for the evaluation, as they contain the required detailed information. In addition to the project documentation, 37 PinCH files of detailed analyses were submitted. An overview of the documents received is shown in Figure 1.

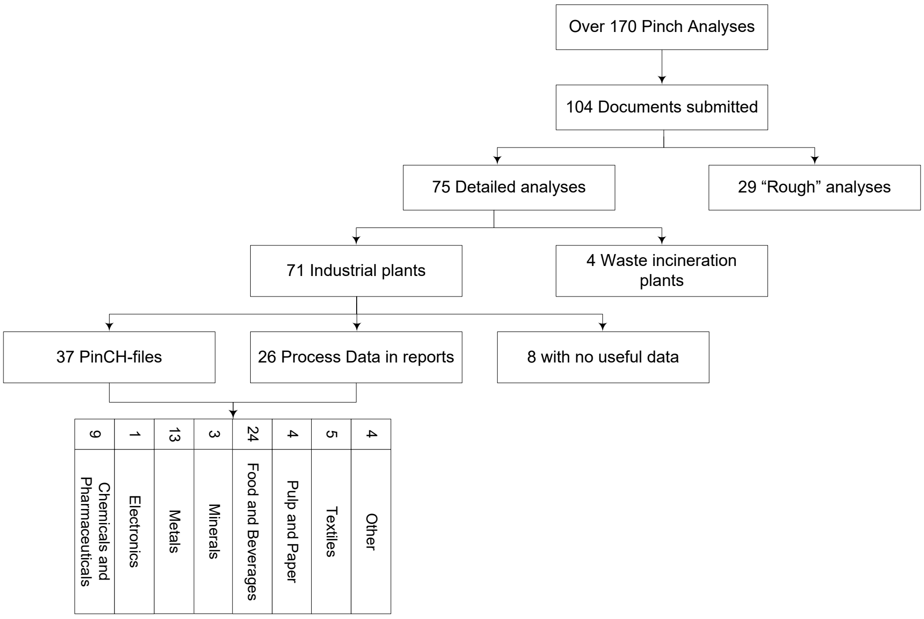

Figure 1: Available data from the Pinch Evaluation project.

The collected data are then systematically classified. Table 1 shows a summarized list of all recorded information per PA.

Table 1: A summary of recorded information and description per performed PA.

Information	**Description**
Company information	Name and location of the investigated company
Year	Year of PA conducted
Detail of analysis	If it is detailed PA or a rough PA
Detail of report	If it is a report, thesis, short report, or presentation
PinCH file	Availability of PinCH files
Consultancy company	The information on the company and contacts
Product detail	Type of products produced and associated NOGA codes

2.2 Core Group

In addition to the data collected above, Task 4.1 formed a “core group for temperature levels”, where the focus is to understand the temperature levels of industrial processes. The members are HSLU-TEVT, UNIGE-EE, OST-IES, OST-SPF, and HEIG-VD-IGT. In this core group, members exchange available information e.g. industrial process stream data, best available techniques, literature reference. The library of the available data is growing as more projects and data are being exchanged.

3 Goals and challenges

The goal of this project is to create a database to systematically store data from all the different PAs from the different sources. A systematic database is needed to properly quantify, assess, and provide the needed information to the consortium, related to the industrial sector. The basis of the database will be in the form of the evaluation that has been carried out by HSLU-TEVT. In the database, the aim is to record the temporal energy demands of the processes and their information (process requirements, scheduling information), the status of the processes focusing on utilities, and the implemented EEMs.

However, the levels detail of the PAs conducted in Switzerland varies, as these are conducted by 19 different companies/institutes. In general, not all processes need to be analysed at the same level. For example, some units may lack sufficient data for the analysis, and some processes do not need a detailed study due to their small size or low complexity.

3.1 Depth of modelling

Generally, in PA, there are three models/depth of modelling, “black-box”, “grey-box”, and “white-box” are used to represent the broad categories in terms of level of details that may be applied to the data extraction of a process [5]. Black-box processes are not to be studied in detail and only the overall utility consumption is considered. This may be because their energy consumption is very small, or heat recovery projects may be difficult to implement, or it is just not the right time for the company to invest in that area. So these processes are simply represented by their existing utility consumption profiles.

Grey-box processes only consider heat transfer that involves utilities. These processes usually have small scope of process–process heat exchange but have significant utility use. In these cases, the process streams that are heated or cooled by utility are considered; however, the process–process heat exchange matches are not considered. In this way, the process/utility interface can be optimized in a site-wide area instead of internal optimization within the process.

White-box processes need to perform a detailed pinch analysis. These are usually complex processes with significant energy consumption. For these processes, grand composite curves are constructed. The source and sink profiles of these white-box processes, together with those of black-box processes and grey-box processes, are further modified to construct the site source sink profile (SSSP) which consists of a site heat source profile and a site sink profile.

In the work that had been carried out in the Pinch Evaluation project, the baseline of modelling differs. Based on these different types of modelling, how do we get to/as close to the process requirements (white-box) with the grey- and black-box modelling?

3.2 Time Modelling

The chemical, pharmaceutical, food, and beverage industries cover 45 % of the total Swiss energy for process heat demand [6]. These processes often have either batch or multiple operating cases (MOCs) due to production of multiple products in the same plant as well as seasonal changes in ambient temperatures. In the SFOE handbook for Pinch Methodology, there are two methods to model the schedule of the processes as shown in Figure 2.

The processes presuppose that these operating times are also known with sufficient accuracy. This representation could be used to analyze not only the direct heat transfer but also, for example, the heat storage between OC1 and OC2 on one day (with 24 hours operating time of the spray dryer and the RTO/RW and 12 hours operating time of the process domestic hot water).

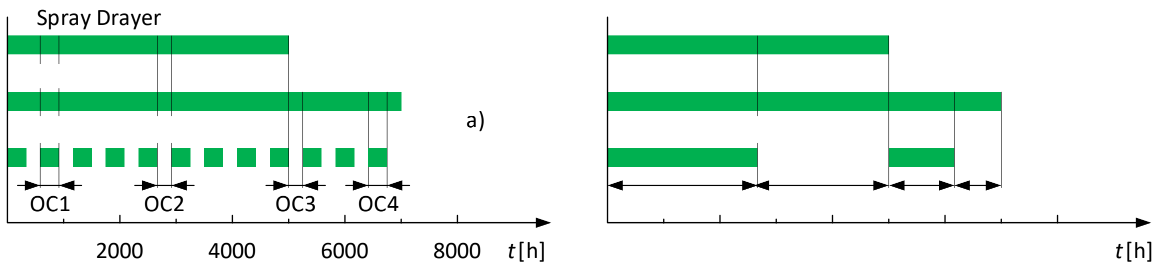

Figure 2: Gantt chart of three overlapping processes, extracted from Brunner and Krummenacher [7].

Scheduling (Figure 2b) represents the domestic hot water process with imaginary start and end times separated into two instances. The OCs according to the case in Figure 2b and also their duration correspond to case in Figure 2a. An optimization of the direct heat transfer by means of MOC supertargeting achieves exactly the same energy and cost targets for both cases. However, the agglomeration of the same OCs (Figure 2b) makes the formation of OCs more manageable. It can also be used, for example, with variable, complicated or not exactly known schedules, if at least the temporal overlap of the processes and thus the OCs and their duration are approximately known. It has the disadvantage that no storage from one OC to the next can be analyzed, and in this case of the DeCarbCH, integration of renewable which has variable source will prove difficult.

In addition, with three or more processes, it is not always possible to represent all OCs in the real plant via an abstracted representation. In Figure 2a, the domestic hot water was defined as a process that is in operation daily from 0-12 h, and this during a "gross operating time" of 7'000 h/a. The interval that is covered by the overflow of the OCs is also not always shown in an abstract representation. The interval created by overlapping the gross operating time of processes is called the scheduling interval.

However, to reduce the complexity of the modeling and optimization, practitioner tend to clusters the OCs to a total net operational hours as shown in Figure 2b. In the case of the database, high percentage of the schedules are modeled in Figure 2b.

4 Methodology

4.1 Database

In this work, Microsoft Access is chosen to as the database for the information. A spreadsheet program like Microsoft Excel has been used for the Evaluation of the PAs. It is a terrific tool for maintaining and calculating small sets of information. Excel is easy to understand and easy to use. Data can be sorted, filtered and formatted quickly and easily. Spreadsheets are ideal for creating one time analysis, they become problematic as the data grows and evolves over time. Spreadsheets are not ideal for handling hundreds of records when creating an important file for reports. It is very easy to make errors in a spreadsheet, which then makes analysing, summing and reporting very challenging.

Microsoft Access is an information management tool, or relational database, that helps store information for reference, reporting and analysis. Access can also overcome the limitations found when trying to manage large amounts of information in Excel or other spreadsheet applications. The value it can provide is to store related information in one place, and then let you connect various parameters together. With Access tables, fields, and relationships set up, data entry forms that use those tables to store the information can be created and later create reports (queries) with the data.

The database that is currently being built will have three categories: (1) the temporal energy demands of the processes and their information (process requirements, scheduling information), (2) the current status of the processes focusing on utilities, and (3) the implemented EEMs. The field that that are included in the database for the temporal energy demands are similar as those in PinCH Software.

4.1.1 Recording of the current status

Relevant parameters on the actual energy status of the respective project are taken from the collected documents, where the parameters of the utilities are collected before the PA is carried out. The description of the current status in the report, as well as the attached system diagrams and energy flow diagrams, were used as sources for these parameters.

The parameters refer on the one hand to the characteristics of the utility (e.g. heat transfer medium, temperature, output) and on the other hand to the energy production (e.g. type of heat/cold production, annual demand for energy sources, economic parameters). The classification is made systematically according to Table 2.

Table 2: Systematic classification of the actual state (utilities).

Classification	Information
Utility	Classification of whether the process is to be heated up (Hot Utility HU) or cooled down (Cold Utility CU). In order to complete the actual energy consumption situation, the electrical power consumption was also included and classified as Electrical Utilitiy (EU).
Medium	Classification of the heat transfer medium (e.g. heating steam, cooling water).
Temperature	Temperature of the heat transfer medium. For steam systems, derived from the steam pressure (by means of a steam pressure table). For heating water systems, for example, the flow temperature was used.
Energy demand	Annual HU/CU/EU energy demand for the process.
Energy generator	Classification of the heat/cold generator (e.g. steam boiler, chiller).
Energy carrier	Determination of the primary energy carrier for the utility system (e.g. gas, heating oil, electricity).
Annual demand for energy carrier	Annual demand for primary energy (e.g. gas consumption, heating oil quantity). If only volume or mass data of the energy carrier are known, the energy quantity can be determined with the help of the calorific value and the density. The annual primary energy demand is directly related to the annual energy demand HU/CU/EU by means of heating/cooling efficiency.
Specific energy price HU/CU/EU	Specific cost of HU/CU/EU taking into account heat losses within the heating/cooling system. Can be calculated from the relation between specific energy carrier price and heating/cooling efficiency.
Specific energy carrier price	Specific cost per kWh of the energy carrier used.
Annual energy cost	Annual energy cost of the heating/cooling system. Calculated from the specific energy carrier price and the annual energy carrier demand.
Use	Classification of energy consumption according to use in the company.

4.1.2 Recording of energy efficiency measures

In the third main step of data collection, the EEMs proposed after conducting a pinch analysis are translated into a list of measures to improve energy efficiency. This information was taken from the reports or presentations based on the available data. All parameters were taken or derived from the individual measure descriptions and the measure summary. There are three classifications of the EEMs, and each EEM is assigned a category, technology and optimization type.

Category: The category "process optimization" includes measures that are directly related to the process. For example, heat recovery between two process flows or optimization of a mass flow by means of a pump. The category "Utilities" refers to the optimization of the energy supply system. For example, replacing an outdated boiler or increasing efficiency by using an economizer. EEMs that can be assigned to the category "Infrastructure" refer to building technology that is not directly related to the process. These are, for example, improvements in the area of building heating or hot water production. The category "waste heat utilization" refers to the utilization of heat that cannot be further utilized outside the industrial enterprise. Examples are the extraction of waste heat via a thermal network (district heating) or the conversion of waste heat into electricity through an Organic Rankine Cycle (ORC). All measures that do not contribute to optimizing the process and cannot be assigned to any of the other categories are assigned to the category "Other measures". Examples are the improvement of thermal insulation or the optimization of lighting.

Technology: The technology describes the (core) technology required for the implementation of the EEM. For example, in the case of heat recovery between two process streams through the use of heat exchangers, the technology "heat exchanger" is selected. Peripheral equipment such as pipes and pumps also contribute to the implementation of the EEM, but are not to be selected as core technology.

Type of optimization: There are six different types of optimizations. “Decommissioning" refers to the decommissioning of equipment. For example, the decommissioning of a steam boiler or the decommissioning of pipelines. EEMs of the optimization type "operational optimizations" refer to measures that improve the operation of existing plants and equipment. These are, for example, temperature reductions in processes or improvements in control technology. The optimization type "New" refers to EEMs that use new systems and equipment. “Replacement" refers to the replacement of an existing plant with a new plant using the same technology. This is, for example, the replacement of an outdated boiler with a new boiler or the replacement of an insufficiently dimensioned heat exchanger with a new, correctly dimensioned one. The optimization type "substitution", on the other hand, refers to a change in the technology used. This includes, for example, the substitution of a boiler with a heat pump. “Thermal insulation" includes all measures that reduce the heat loss of systems and equipment, e.g. thermal insulation of pipes or heat storage tanks.

4.2 Anonymization of data

An ID is given to each of the companies due to the confidentiality issues. The ID given will be based on the NOGA Code. For example, a cheese factory (Company A) will be given an ID as C_1051_1, where C stands for the manufacturing, 1051 stands for operation of dairies and cheese making, and 1 is the identified is given to the Company A. Streams will also be renamed into general terms.

4.3 Reconciliation of data

As mentioned in the Section 3, the questions are:

1) How do we get (or get close) to the process requirements with the available data?

2) How do we get the scheduling information of the process if the time modelling is aggregated to a total net operating hours?

Two approaches are commonly used to reconcile data in PA, top-down and bottom-up approaches [3], or the combination of both. The choice between the two approaches depends on data access, where a bottom-up approach is preferred when detailed process data are available, and the top-down approach can be used in their absence.

4.3.1 Bottom-up approach

Bottom-up approaches rely on gathering primary data from functioning plants in the pertinent industrial sector. In the case of this work, bottom-up approach is used when white-box modelling is used in the PA.

However, if a basic mass balance and temperature of streams are given, bottom-up approach can be used to extract industrial data by building thermodynamic models of the different process units. The models help closing the mass and energy balances while ensuring that the system's thermodynamic constraints are respected, provided that the heat capacity of the streams is known or can be calculated. Top-down approach can be adopted at this stage to validate the data.

4.3.2 Top-down approach

Top-down approaches are also valid for reconciliation of data and produce a similar result, though the deep details accessible for plant operators cannot be leveraged. High-level data such as the best available techniques/reference documents serve as a starting point and provide some process details, depending on which process is being assessed.

Top-down analyses start from the company's energy consumption and determination of the key processing units for a particular plant. This can be compared with literature data, or other plant data to facilitate a common structure exists between industrial processes in the same subsector. Correlation may be used on the energy consumption with production volumes to analyse the possible process requirements.

5 Conclusions

With the above-mentioned database, the hope of Task 4.1 is to be able to deliver necessary temporal energy demands that can be used for the further tasks in WP 4 and other WPs in DeCarbCH. Using Microsoft Access, it will allow the generation of queries easily into subsectors and even sub-process (unit operations) results and their necessary information. An example is shown in Table 3, for the integration of solar power. The following gives the results for recurrent heat sink profiles for typical production plant (with NOGA code: C_2030). The information given is: general information (e.g. operating cases (summer, winter, transition), time profiles, possible solar power, etc.), heat sinks and the residual composite curve (RCC). In the developed RCC, only the heat sinks are shown, as only these are relevant for solar heat integration.

Table 3: Example of possible query.

Information			
Season	Summer	Winter	Transition Period
Dates (Months)	Jun – Aug	Dec - Feb	Mar - May, Sep - Nov
Production Hours	960 h (12 w)	960 (12 w)	1920 h (24 w)
Weekly profile	Montag – Freitag	Montag – Freitag	Montag – Freitag
Production time	06:00 – 22:00	06:00 – 22:00	06:00 – 22:00
Pinch-Temperature	55 °C	55 °C	55 °C
Potential for solar heating	387 kW	490 kW	441 kW
Heat quantity	372 MWh	470 MWh	847 MWh
Annual heat quantity	1'689 MWh/a		

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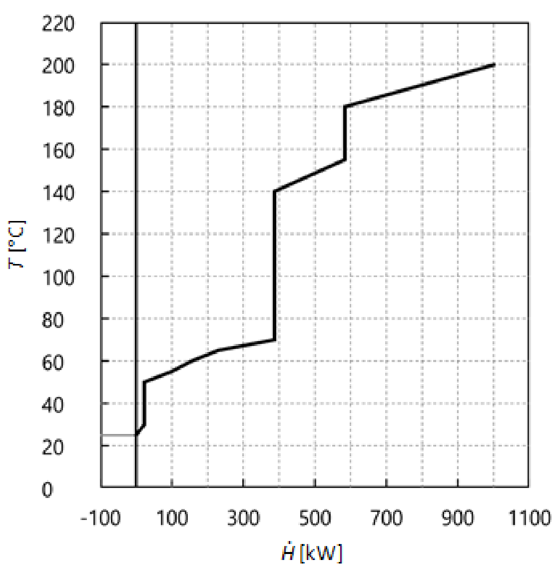
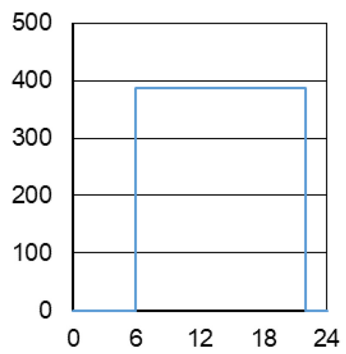
<tr><td>Summer</td><td>
</td><td>
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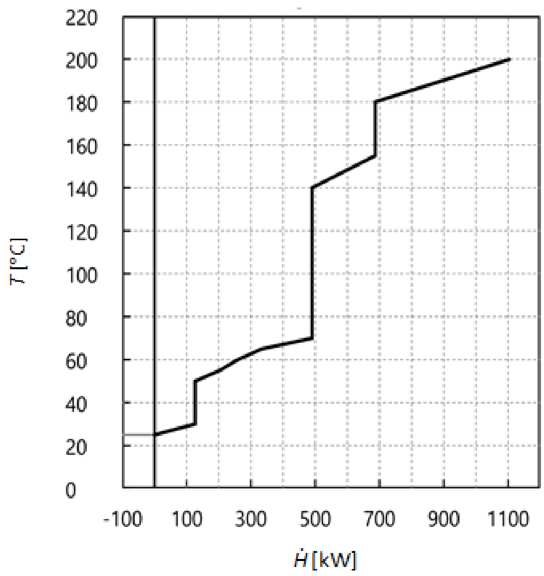
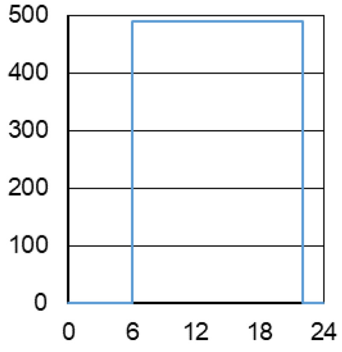
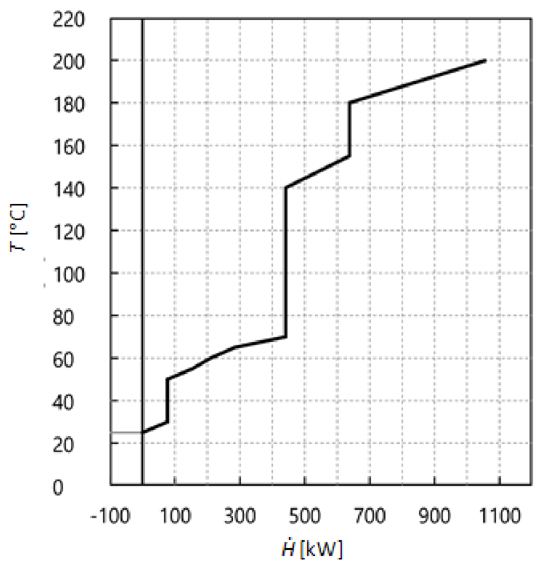
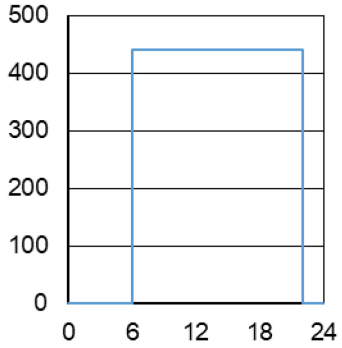
Winter	 
Transition	 

6 References

[1] R. Saxena, M. Santoro, and S. Sulzer, “D1.1.1 Identification, characterization and validation of available data from different sources.,” Swiss Competence Center for Energy Research: Efficiency of Industrial Processes, Horw, Switzerland, 2016.

[2] I. Kantor and F. Marechal, “Potential Impact of SCCER-EIP Work Package 4 Toward Switzerland ’ s ES2050,” Swiss Competence Center for Energy Research: Efficiency of Industrial Processes, Lausanne, Switzerland, 2017.

[3] I. Kantor *et al.*, “Thermal profile construction for energy-intensive industrial sectors,” Proceedings of ECOS 2018 - 31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, June 17-22, Portugal, 2018.

[4] M. Kermani, A. S. Wallerand, I. D. Kantor, and F. Maréchal, “Generic superstructure synthesis of organic Rankine cycles for waste heat recovery in industrial processes,” *Appl. Energy*, vol. 212, pp. 1203–1225, 2018.

[5] B. H. Y. Ong, E. J. Lucas, D. G. Olsen, S. Roth, and B. Wellig, “A user workflow for combining process simulation and pinch analysis considering ecological factors,” *Chem. Prod. Process Model.*, 2021.

[6] A. Kemmler and T. Spillmann, “Analyse des schweizerischen Energieverbrauchs 2000 - 2020,” Bundesamt für Energie, Bern, Switzerland, 2021.

[7] F. Brunner and P. Krummenacher, “Einführung in die Prozessintegration mit der Pinch-Methode, Handbuch für die Analyse von kontinuierlichen Prozessen und Batch-Prozessen, Zweite Auflage,” pp. 1–175, Bundesamt für Energie, Bern, Switzerland, 2017.