Lucerne University of
Applied Sciences and Arts

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Engineering & Architecture

Industrial Energy Efficiency and Renewables Integration using Process Integration

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Competence Center Thermal Energy Systems and Process Engineering (CCTEVT)

23. September 2021

UNIGE, SÉMINAIRE ÉNERGIE – ENVIRONNEMENT, Conférences 2021-2022

Agenda

1) Competence Center Thermal Energy Systems and Process Engineering

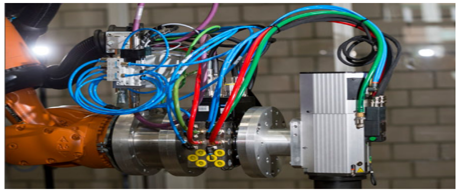
2) Process Integration and Pinch Analysis in Swiss Industry
   - Fundamentals, benefits, results and workflow
   - Case studies from industry
   - Actual research
   - Waste heat usage
   - Integration of renewables

3) Energy Efficiency Improvement Potential in Swiss Industry

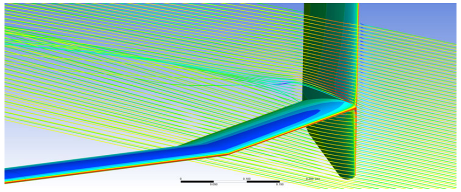
1) Competence Center Thermal Energy Systems and Process Engineering

Institute of Mechanical Engineering and Energy Technology

Our tasks: Education, Research & Development and Knowledge and Technology Transfer



CC Mechanical Systems



CC Fluid Mechanics and Numerical Methods

CC Thermal Energy Storage

CC Thermal Energy Systems and Process Engineering

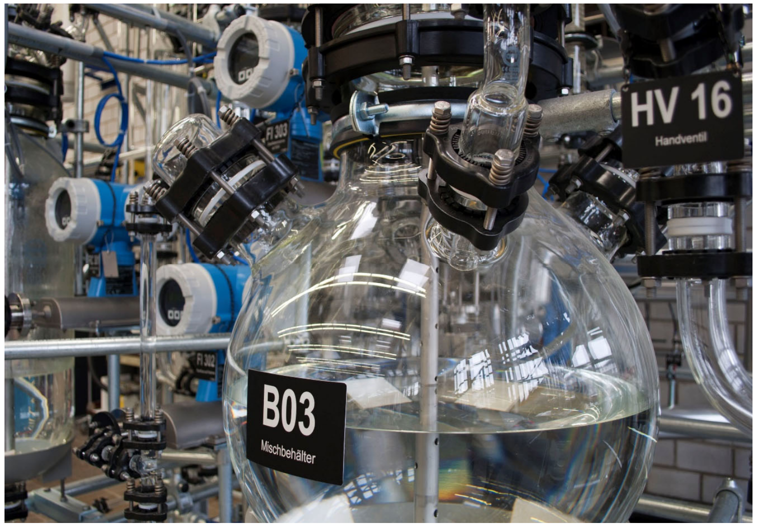
Facts & Figures: 140 employees, 7.5 Mio CHF p.a. revenue in R&D, 75% external funds

CC Thermal Energy Systems and Process Engineering

Applied R&D in the field of energy technology, process and environmental engineering. Research Topics:

- Heat Pumps and Cooling Systems (some project examples on next slide)
- Process Integration and Pinch Analysis
- Process and Environmental Engineering
- Sorption Processes (Prof. Mirko Kleingries)
- Bioenergy Processes (Prof. Thomas Nussbaumer)

Impressions from our lab: test rig for heat pumps/chillers (up to 600 kW) and multi-stage distillation plant



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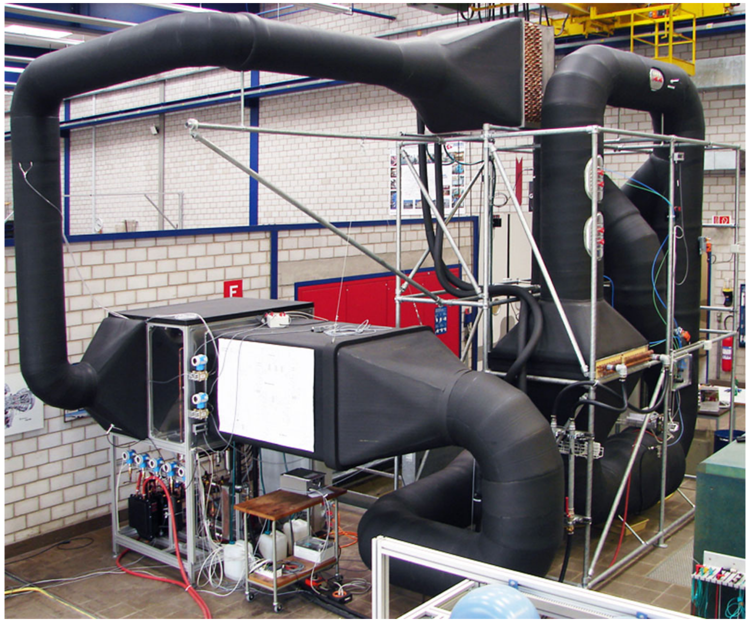
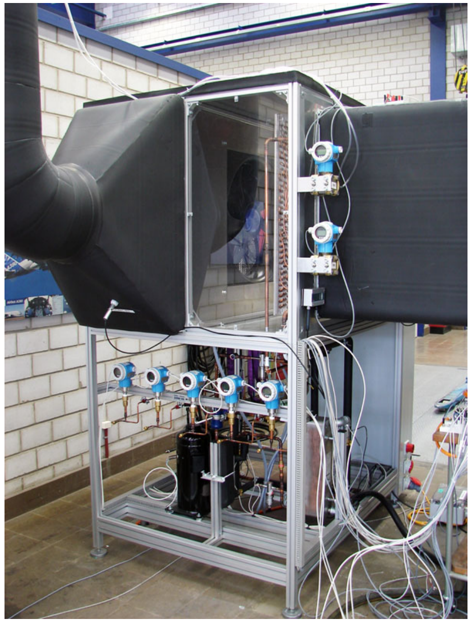
Project example: **Optimal capacity control of heat pumps** (A/W-, B/W- and W/-HP; SFOE projects)


- Significant increase in efficiency due to optimal capacity control
- Field measurements in single-family house of B. Wellig (A/W-HP, fresh water station): SPF = 4.2 – 4.4

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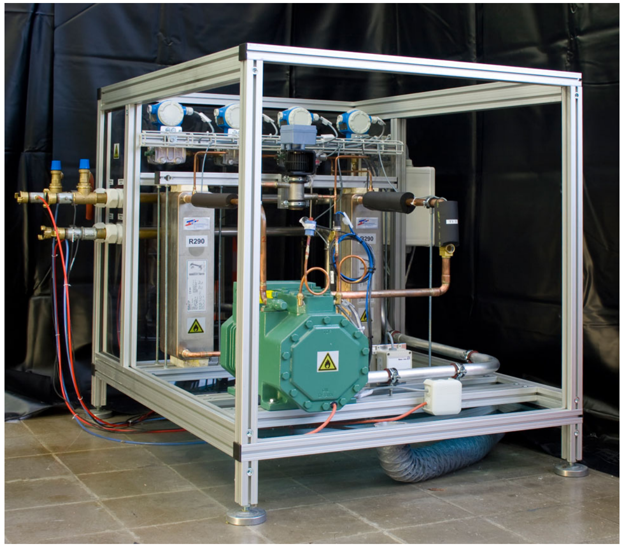
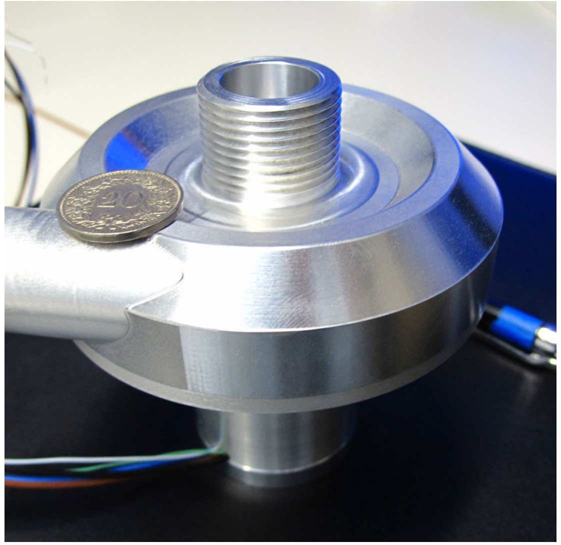
Project example: **Small-temperature lift heat pumps and chillers** (BS2 AG, Celeroton AG)





- Substantial energy savings possible through consistent use of low-lift systems
- Achieved energy efficiency in optimized building cooling and heating systems:
  – building cooling EER > 13
  – building heating COP > 8

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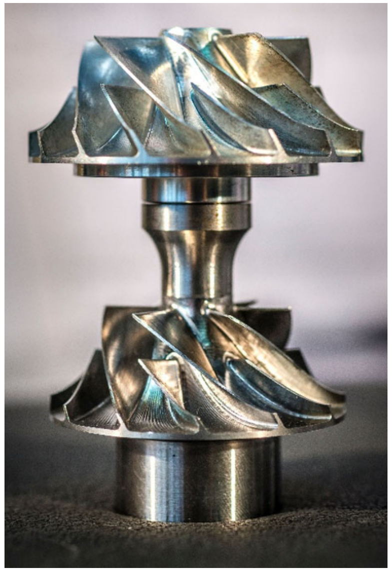
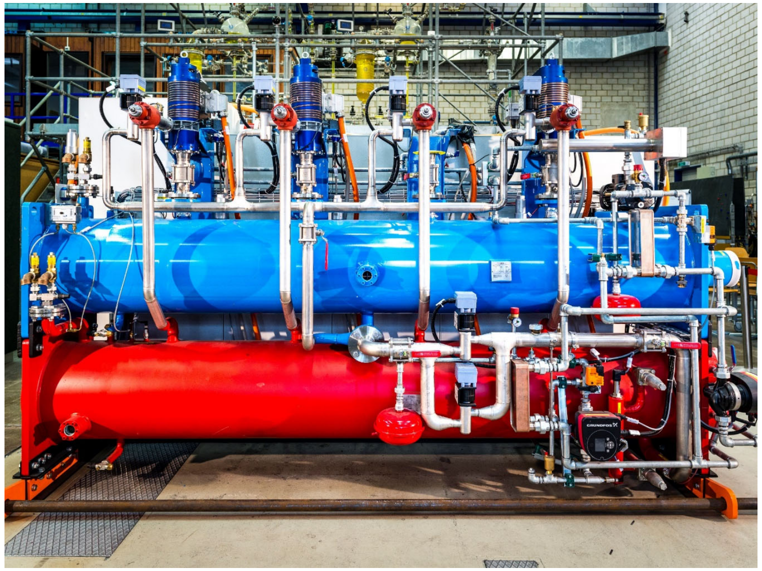
Project example: **Oil-free, gas-bearing turbo compressor for chillers and heat pumps** (Teqtoniq GmbH)





400 kW prototype in HSLU lab

- 2-stage gas-bearing turbo compressor for high-efficiency chillers and heat pumps
- Achieved energy efficiency in the lab:
  – building cooling EER = 11.2 … 5.5 throughout the year (conditions according to EN14511).
  – building heating COP = 8.5 … 6.1 throughout the year (conditions according to EN14825).

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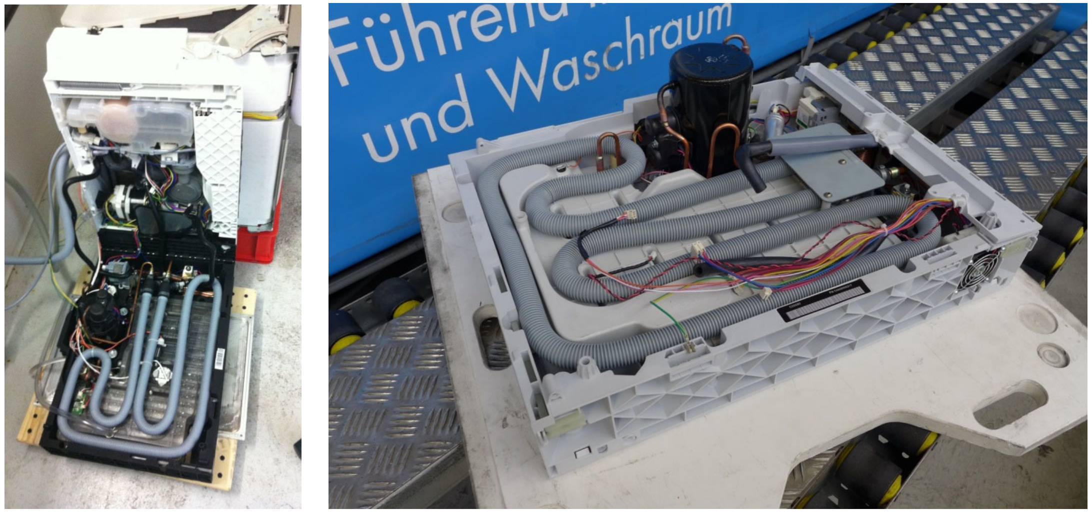
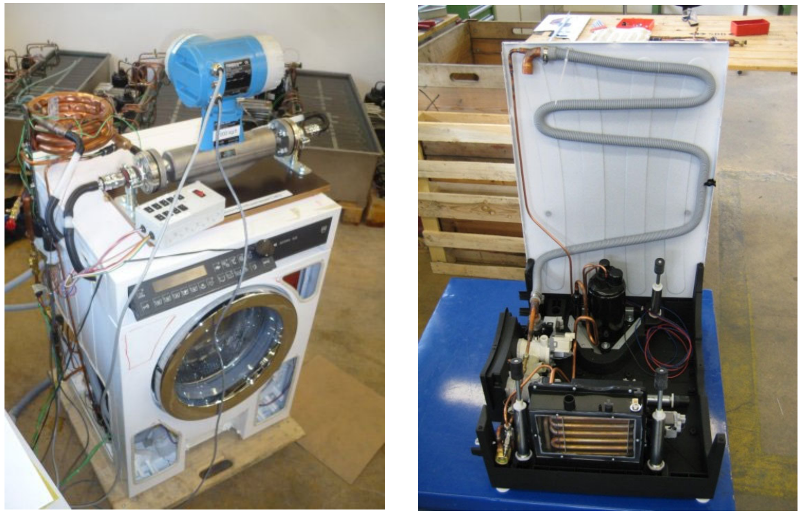
Project example: **Household appliances with heat pumps** (V-ZUG)
Tumble Dryer, Dishwasher, Washing machine, etc. with integrated heat pump



Dishwasher with heat pump


Washing machine with heat pump

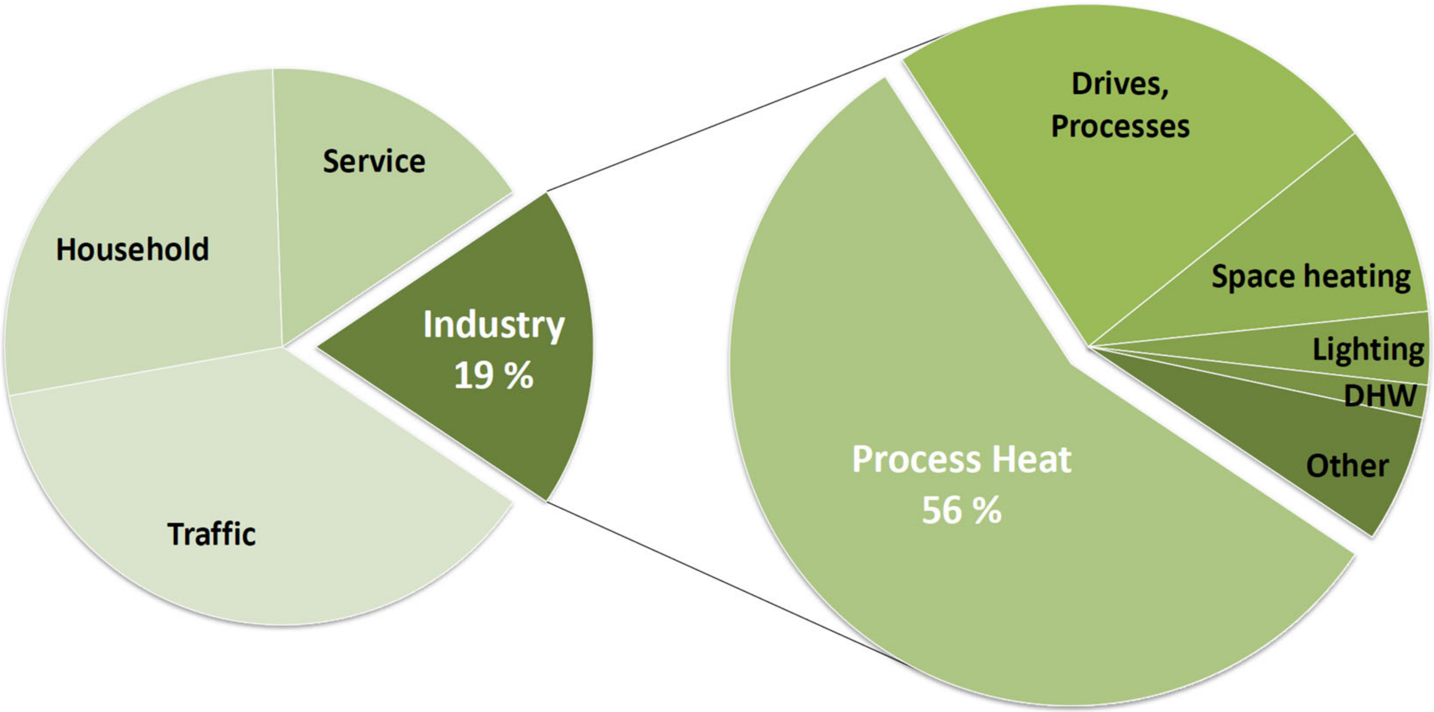
- Dishwasher: “World champion in energy saving”: **A+++ minus 40%**, around 50-60% less energy required than conventional dishwashers (field measurement B. Wellig: average eco-program with HP **390 Wh**, -50% to -70% compared to conventional dishwashers)
- Washing machine: energy consumption reduced by around 50%

2) Process Integration and Pinch Analysis in Swiss Industry

- **Fundamentals, benefits, results and workflow**
- Case studies from industry
- Actual research
- Waste heat usage
- Integration of renewables

Energy use in Swiss industry

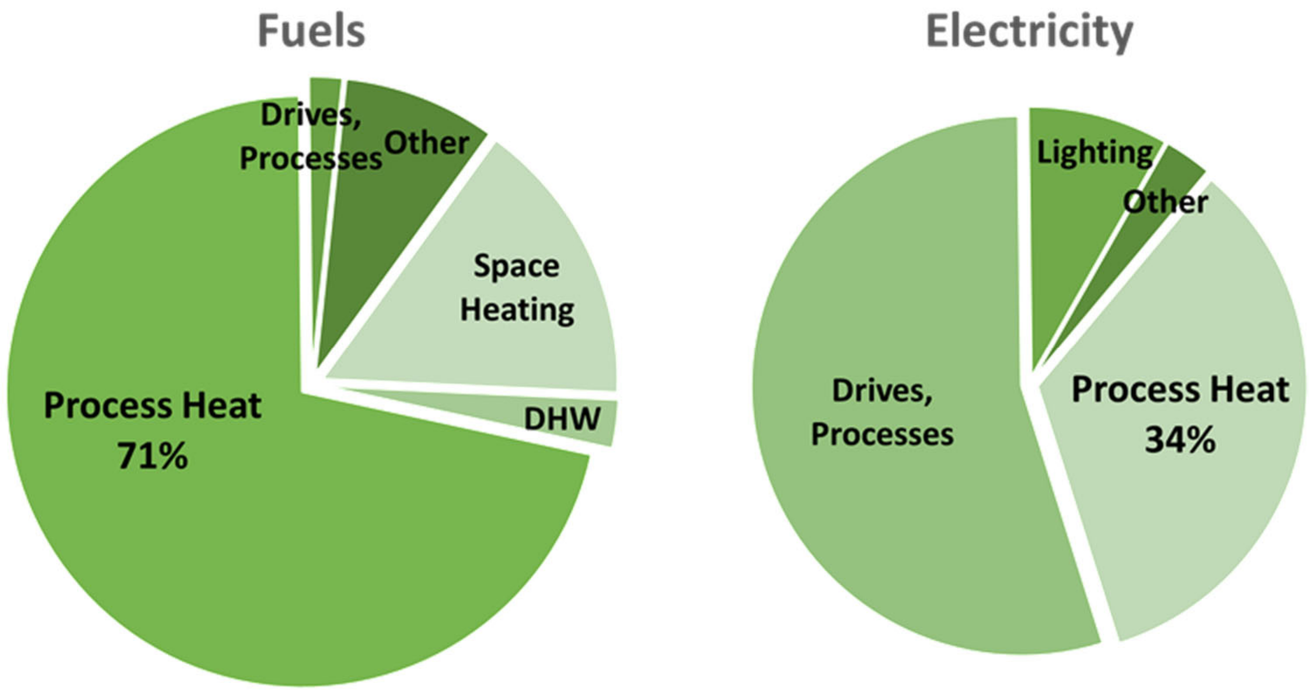
Approximately **19%** of Switzerland's total energy use is for industry. More than half is for **process heat**.



Source: Swiss Federal Office of Energy SFOE (2019)

Energy use in Swiss industry

Approximately **59%** of the total final energy demand is provided by fuels, **41%** by electricity:



Source: Swiss Federal Office of Energy SFOE (2019)

Challenges in industrial energy optimization

- How energy efficient is the industrial process?
- What is the energy demand if the process was already fully optimized?
- How can a heat pump, CHP system, solar energy system, etc. be properly integrated?
- Where is the economic optimum for the investment and operating costs?
- How can this optimum be achieved?

Process Integration using Pinch Analysis provides the answers!

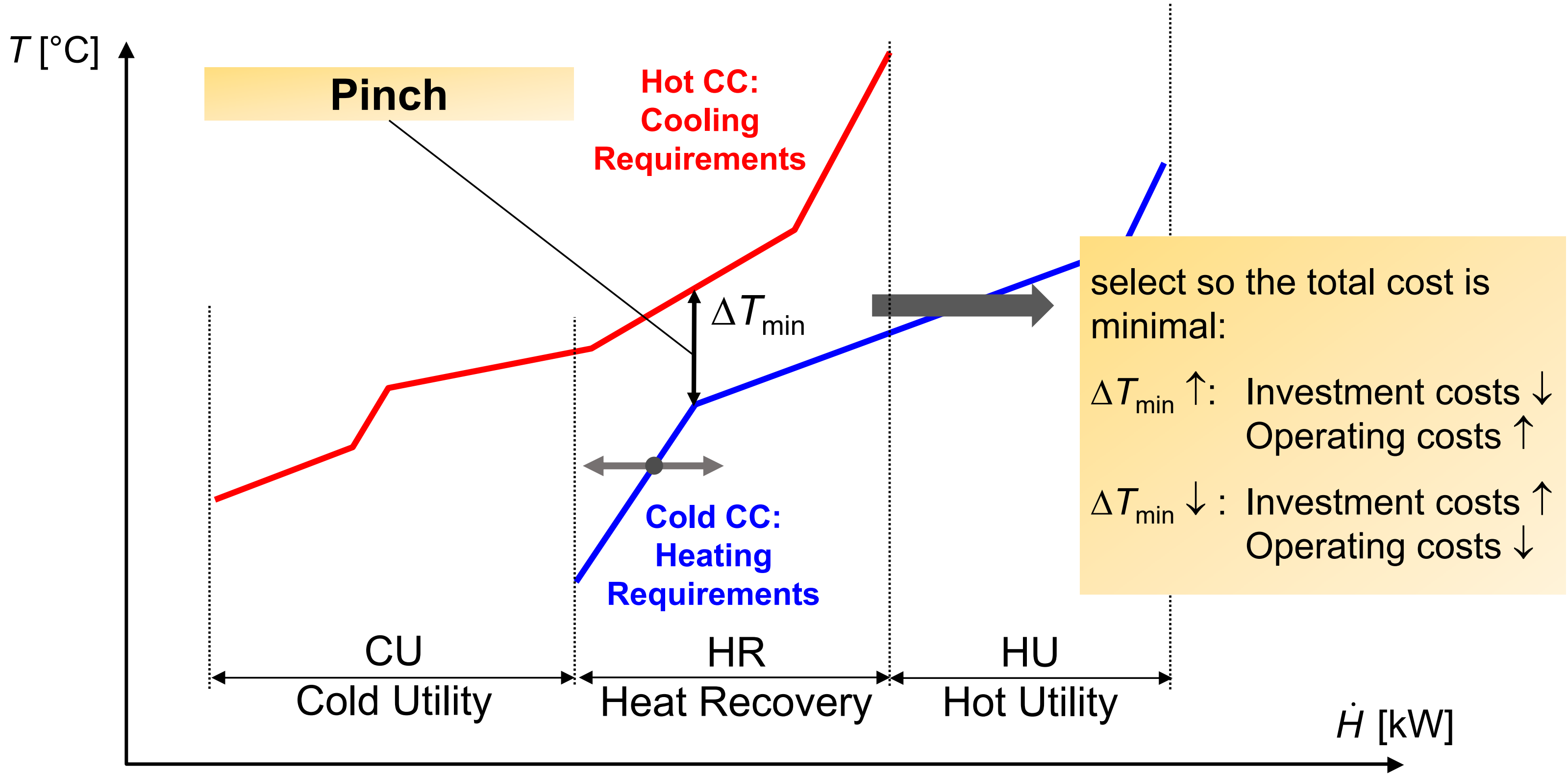
What is energetic Process Integration?

- **Another perspective** on industrial production and infrastructure processes
- **System orientated method** to determine the optimal energy input and plant design under the condition of minimal cost (investment and operation)
- «Energy optimization based on a **systematic approach** instead of Trial-and-Error.»

Pinch Analysis (PA): Most important **tool** for energetic Process Integration (PI)

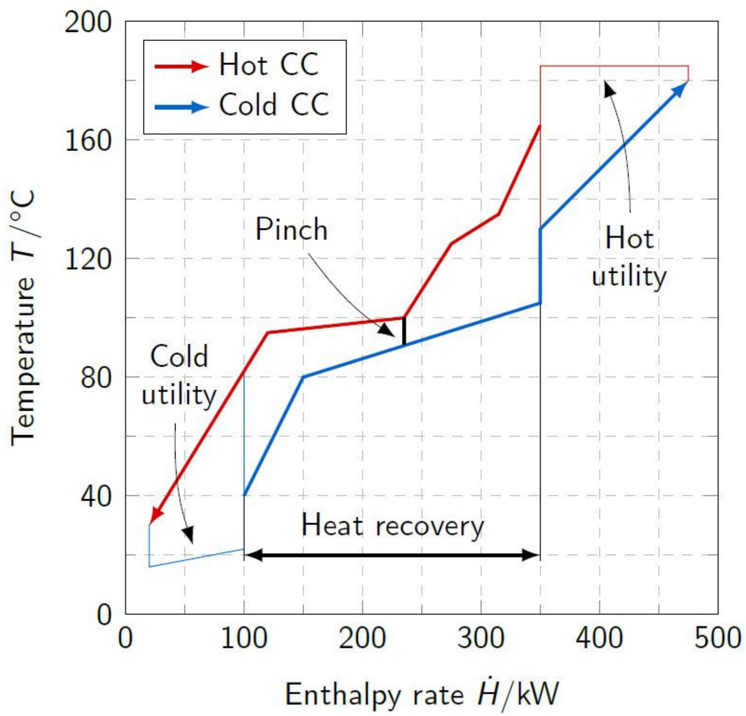
Principle of Pinch Analysis: the Composite Curves

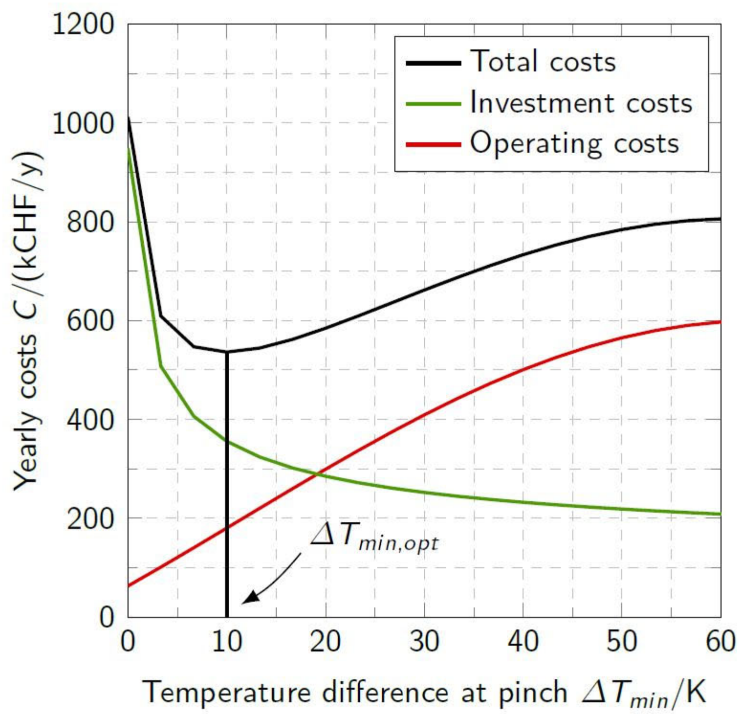
A process is abstracted into “streams” that have heating requirements (cold streams) or cooling requirements (hot streams) → the **Composite Curves** are the basis of PA.



Principle of Pinch Analysis: supertargeting

Philosophy of Pinch Analysis: "Targets before Design!" – Ensures a proper systematic approach to first determine the pinch and energy targets before starting detailed design.





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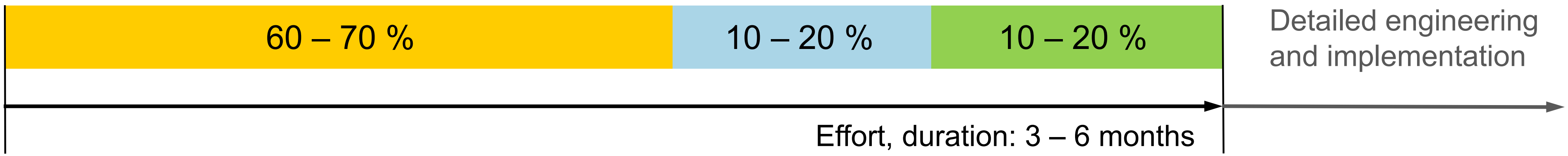
Benefits of Pinch Analysis

- Holistic optimization of
  - plant design
  - energy efficiency
  - utility systems
  - investment and operating costs (Capex/Opex)
- Comprehensive cost/benefit analysis and strategic planning of measures
- Reduction of the energy demand typically 10–40%

Results from a Pinch Analysis

- Determination of the absolute energy savings potential (retrofit and new plants)
- Optimized heat recovery and utility systems (steam, cold, renewables integration, etc.)
- Catalog of measures with technical and economic assessment

Workflow of a Pinch Analysis



Analysis of present situation, data extraction, energy modelling, definition of process requirements

Conducting of pinch analysis with software PinCH

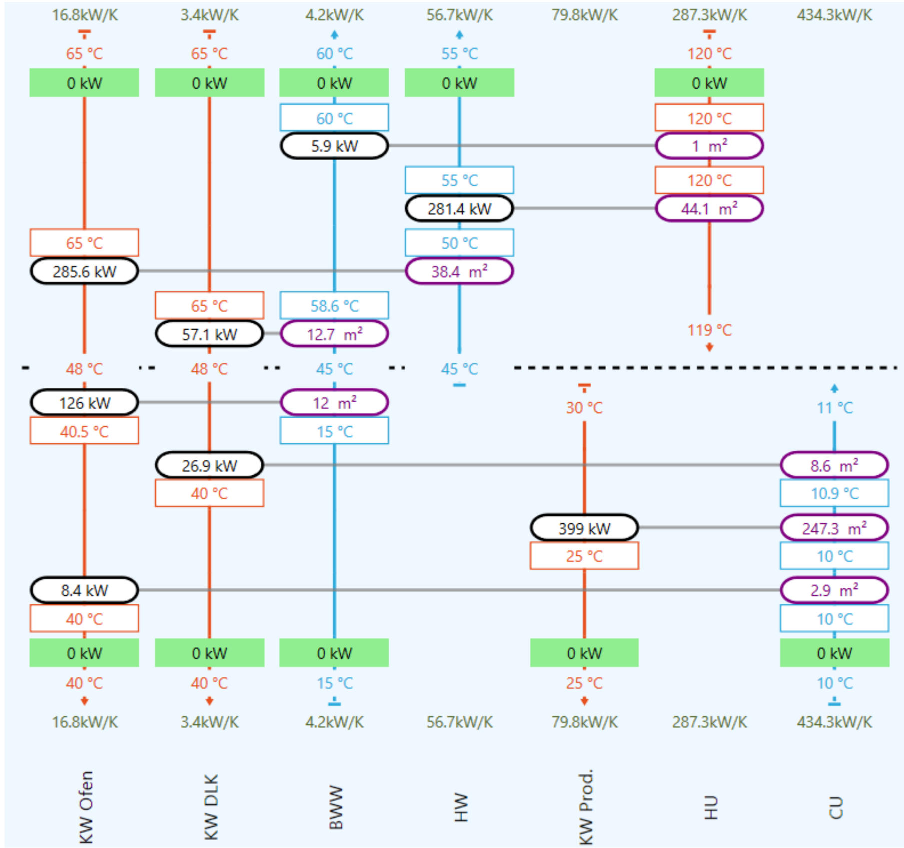
Elaboration of measures (efficiency, utilities, renewables, etc.), economic evaluation, prioritization

- A **suitable software tool** is necessary for the efficient completion of a Pinch Analysis project.
- The **definition of the process requirements** has the most far-reaching influence on the HR potential.
- Excel-based tools to **simplify the energy modelling** of unit operations are available («E-Modules»).

Support from the Swiss Federal Office of Energy (SFOE)

The SFOE supports financially two phases of a Pinch Analysis (PA):

- **Rough Pinch Analysis**:
  - rough quantification of saving potentials
  - identification of possible measures
  - recommendation detailed PA yes/no
- **Detailed Pinch Analysis**:
  - development of measures (efficiency, energy supply, renewables, etc.)
  - technical and economic evaluation
  - recommendations for strategic planning of implementation etc.



Heat Exchanger Network (HEN) metal processing company (PinCH 3.2)

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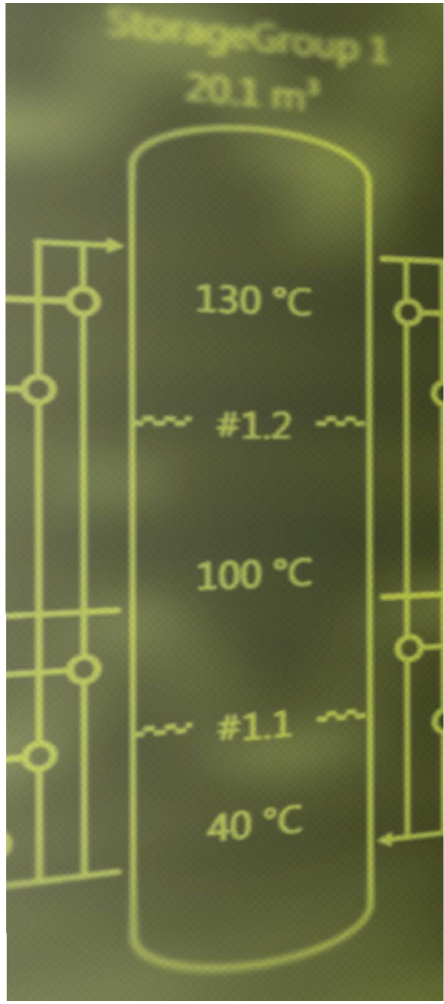
SFOE Process Integration/PinCH Center at HSLU

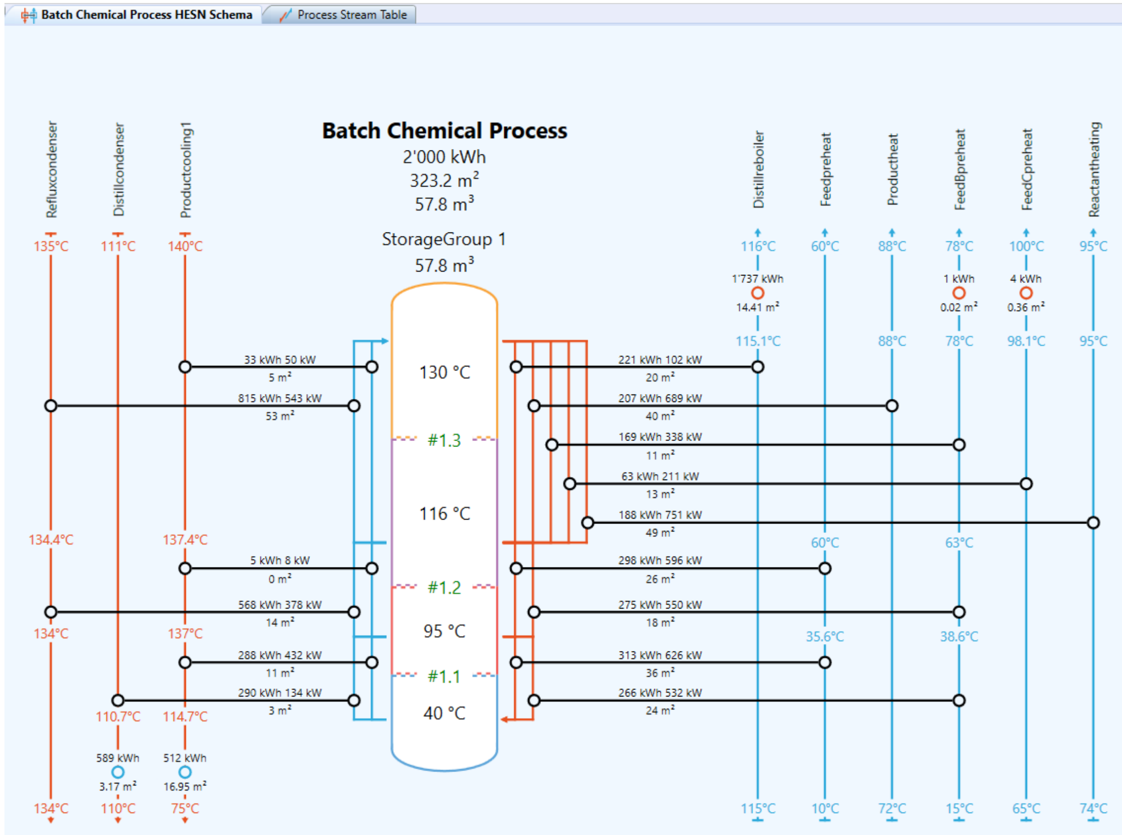
- PinCH software development, maintenance and user support
- Consulting for industrial companies and engineering firms in the area of process integration and pinch analysis
- Continuing education courses, customized company training courses and individual coaching



www.pinch.ch

PinCH software

- A user-friendly software for the practical application of pinch analysis
- Guides the engineer step by step through the optimization
- Enables the rapid evaluation of different designs and scenarios



Heat Exchanger and Storage Network (HESN) of batch chemical process (PinCH 3.2)

The development of PinCH is supported by the SFOE (EnergieSchweiz, Industrie und Dienstleistungen)

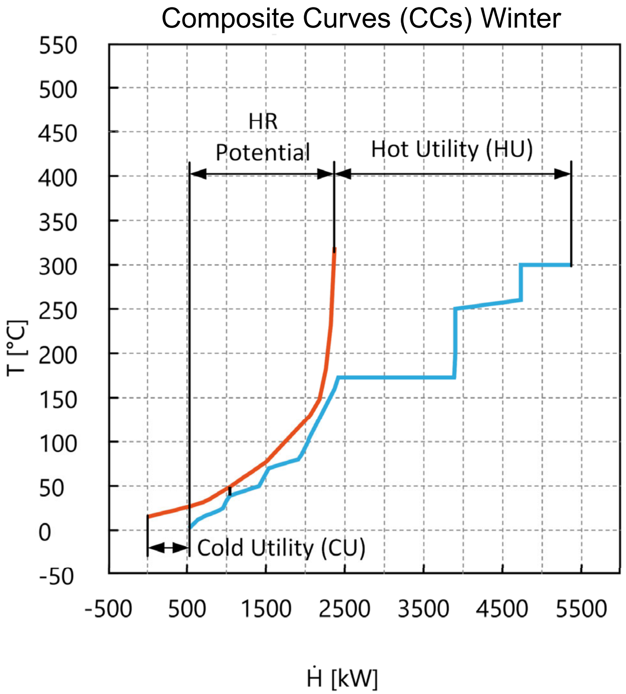
www.pinch.ch

2) Process Integration and Pinch Analysis in Swiss Industry

- Fundamentals, benefits, results and workflow
- **Case studies from industry**
- Actual research
- Waste heat usage
- Integration of renewables

Example 1: Textile finishing

Identifying heat recovery potential and measures of production processes and infrastructure systems:



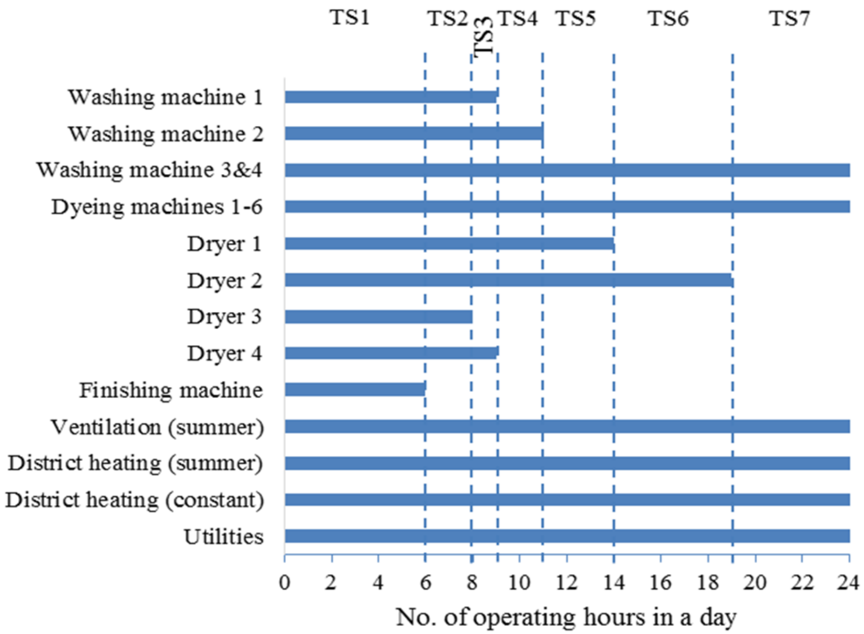
- Pinch analysis with 55 energy streams (typical situation in Swiss Industry)
- Heat recovery potential: winter 1‘800 kW, summer 1‘300 kW

Example 2: Multi-product batch process

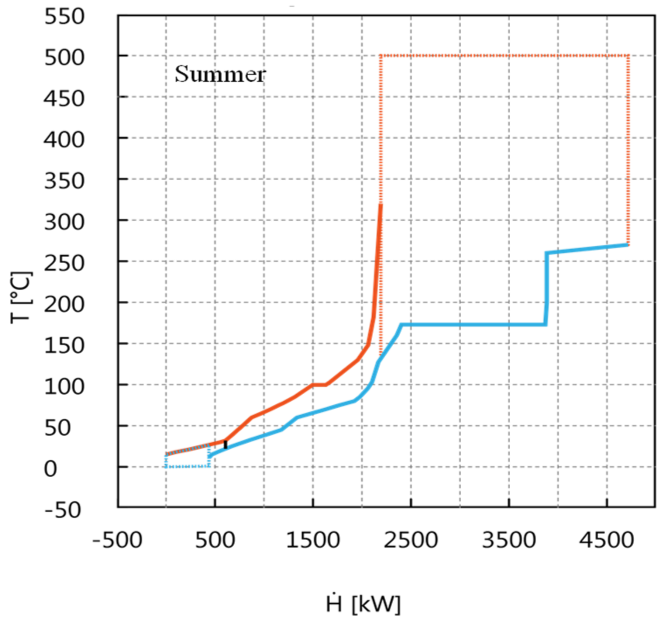
Collaboration with Research Group Prof. Martin Patel, UNIGE

Approach: First optimize for direct heat recovery (DHR) and then for indirect heat recovery (IHR) using thermal energy storage (TES)

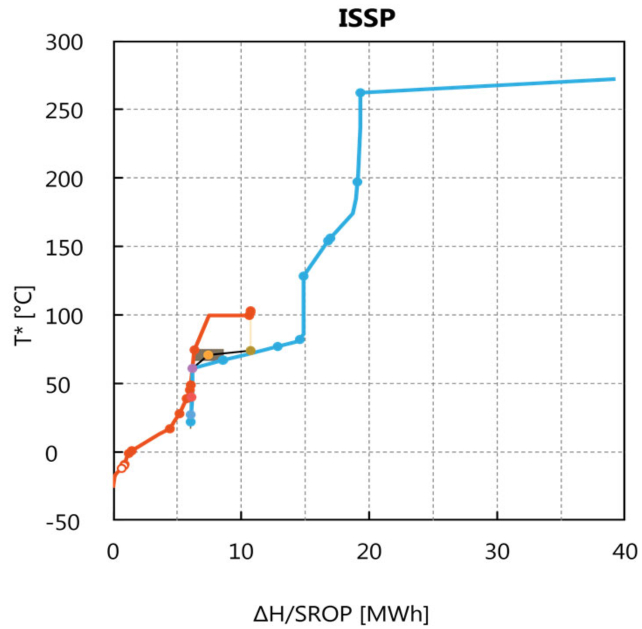
Operating Cases Summer



Composite Curves for TS1:
Direct Heat Recovery (DHR)



Indirect Source Sink Profiles:
Indirect Heat Recovery (IHR)



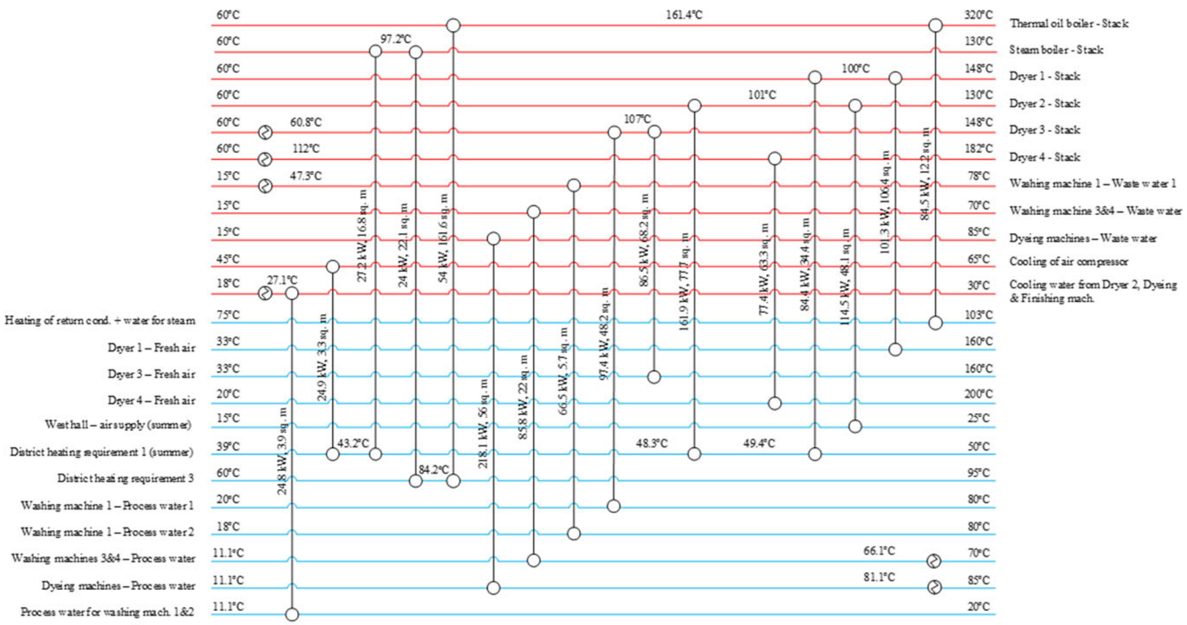
Example 2: Multi-product batch process

Collaboration with Research Group Prof. Martin Patel, UNIGE

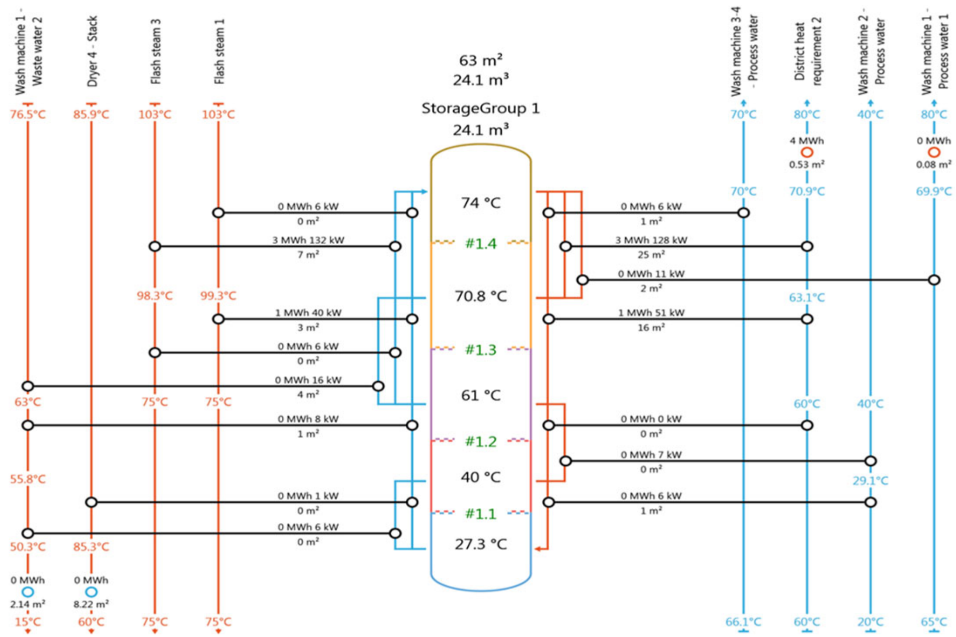
For example energy savings for OC Summer:

DHR = 23.6 MWh/day = **25%** / IHR = 4.7 MWh/day = **5%** of the daily thermal energy demand of the overall process, **total energy savings = 30%**

DHR (heat exchanger network HEN)

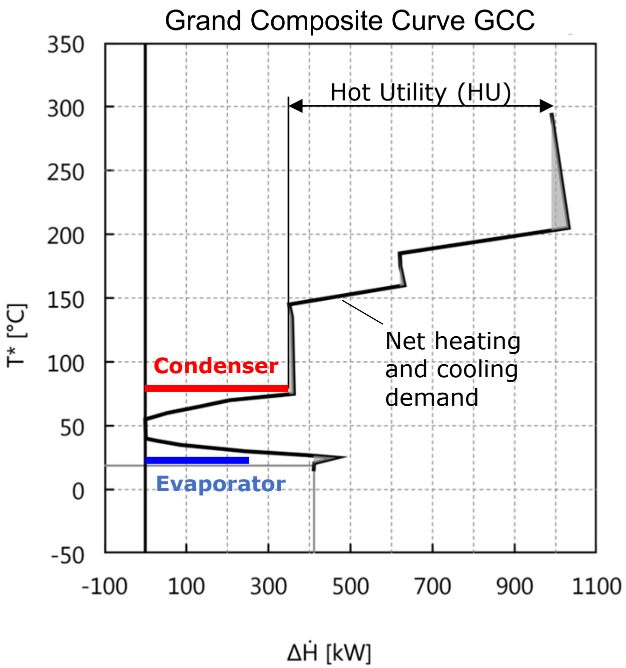


IHR (heat exchanger and storage network HESN)



Example 3: Paint shop

Pinch analysis is key to ensure the correct integration of a heat pump:

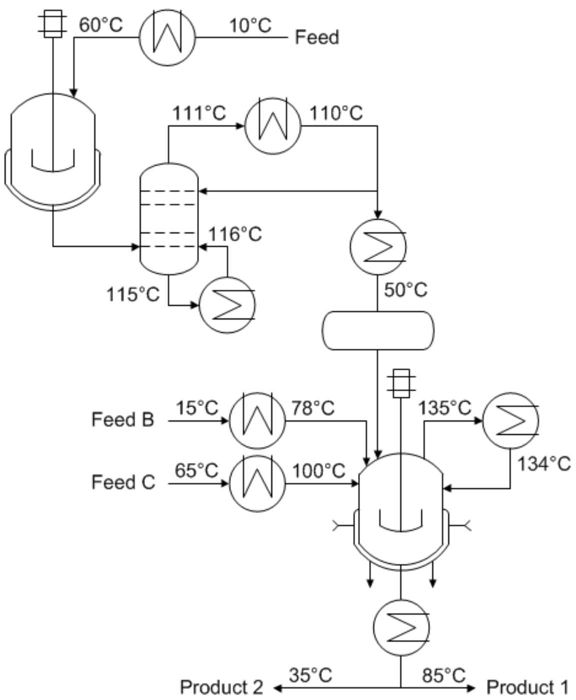


- Reduction in natural gas demand ca. 1.3 GWh/a (-30%)
- Payback approx. 5.5 years (for infrastructure acceptable)

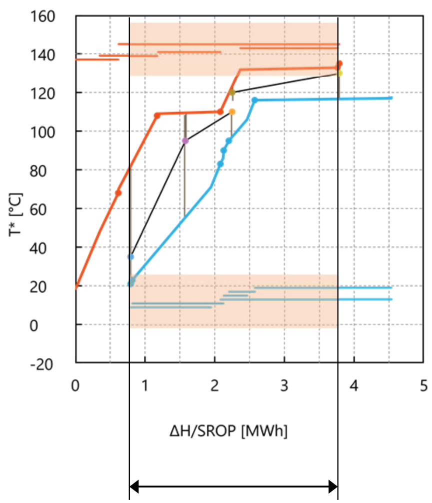
Example 4: Batch process in chemical industry

Demonstration in the PinCH Software

Batch plant

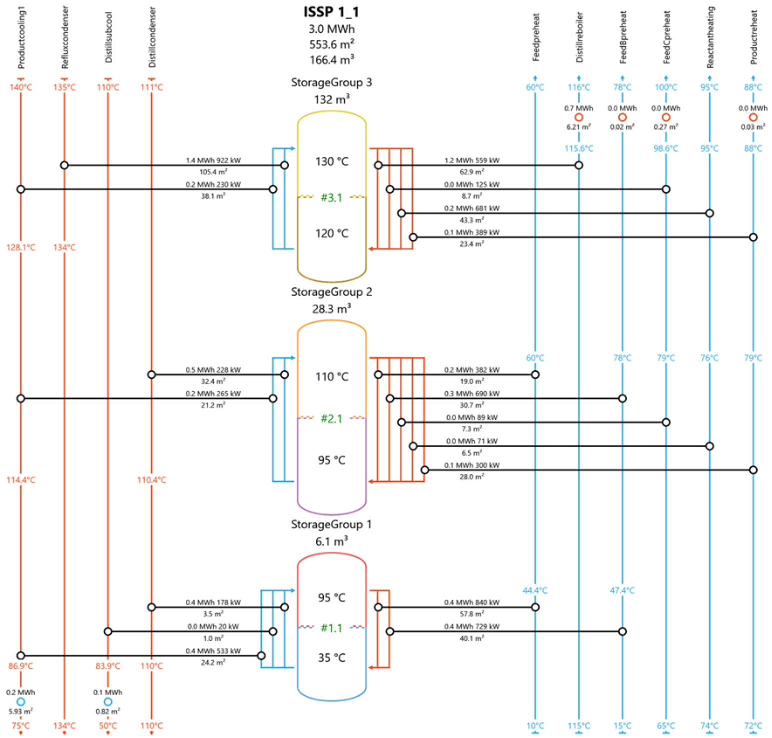


Indirect Sources and Sinks Profiles (ISSP)



Indirect
HR potential
(storage)

Storage integration



- Design thermal energy storage system: number, capacity, temperatures, HEN design, profitability, etc.
- HR Potential 3‘000 kWh/batch, static payback 3.6 years

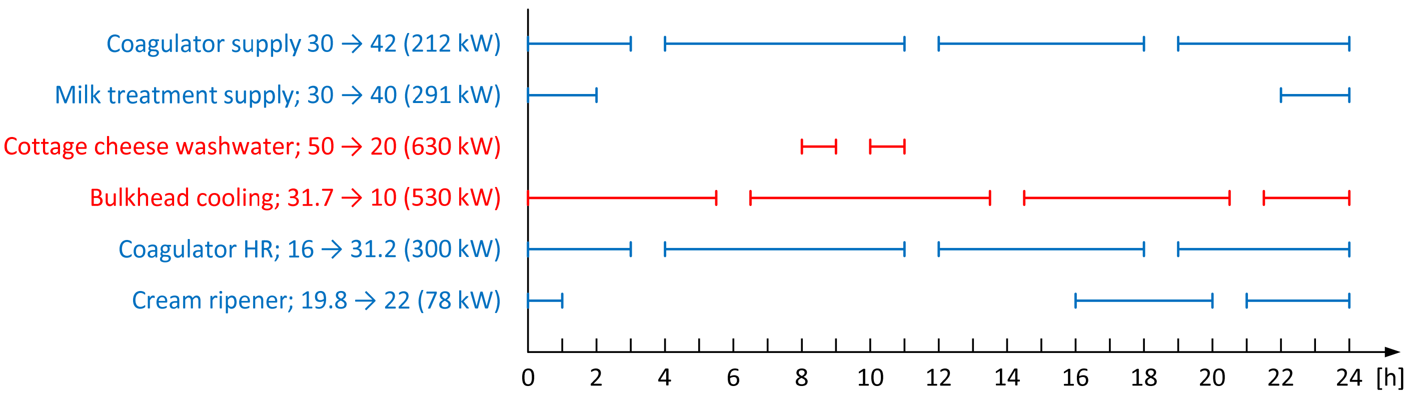
2) Process Integration and Pinch Analysis in Swiss Industry

- Fundamentals, benefits, results and workflow
- Case studies from industry
- **Actual research**
- Waste heat usage
- Integration of renewables

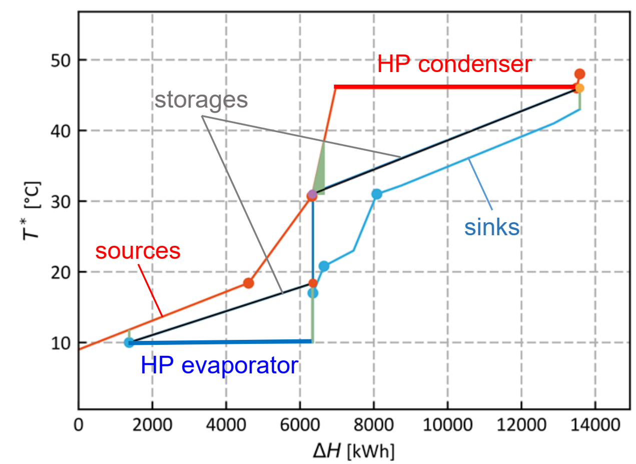
Integration of heat pump and storage systems in non-continuous processes

- The vast majority of processes in Swiss industry are non-continuous → heat storage solutions are often the only possible optimization strategy (Indirect Heat Recovery, IHR)
- Development of a practical method for cost-optimal integration of heat pump and storage systems in non-continuous processes
- Workflow extends available practical Pinch Analysis tools (e.g. Indirect Source Sink Profiles, ISSP)

Case study cheese production plant:

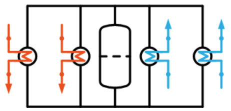
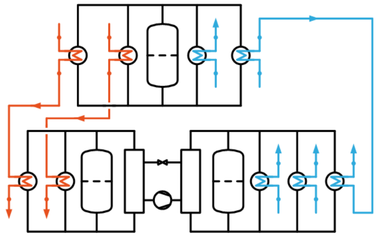
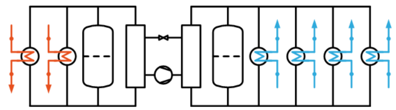
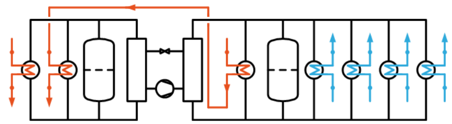


ISSP (variant 4 on next slide)



Integration of heat pump and storage systems in non-continuous processes

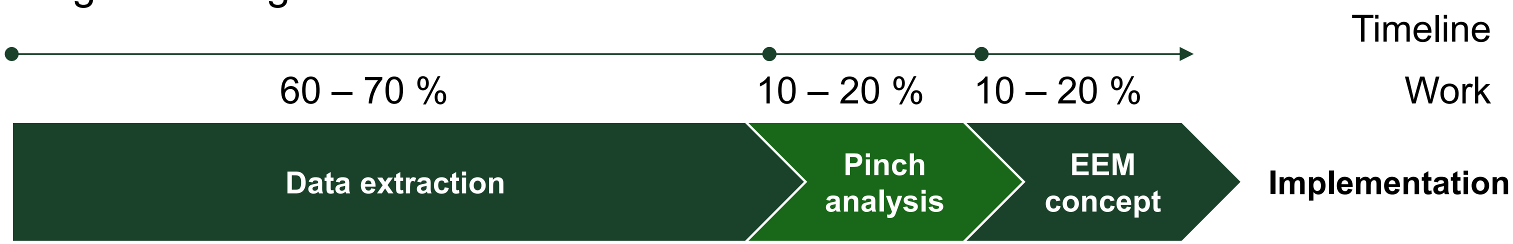
Case study cheese production plant: variant study

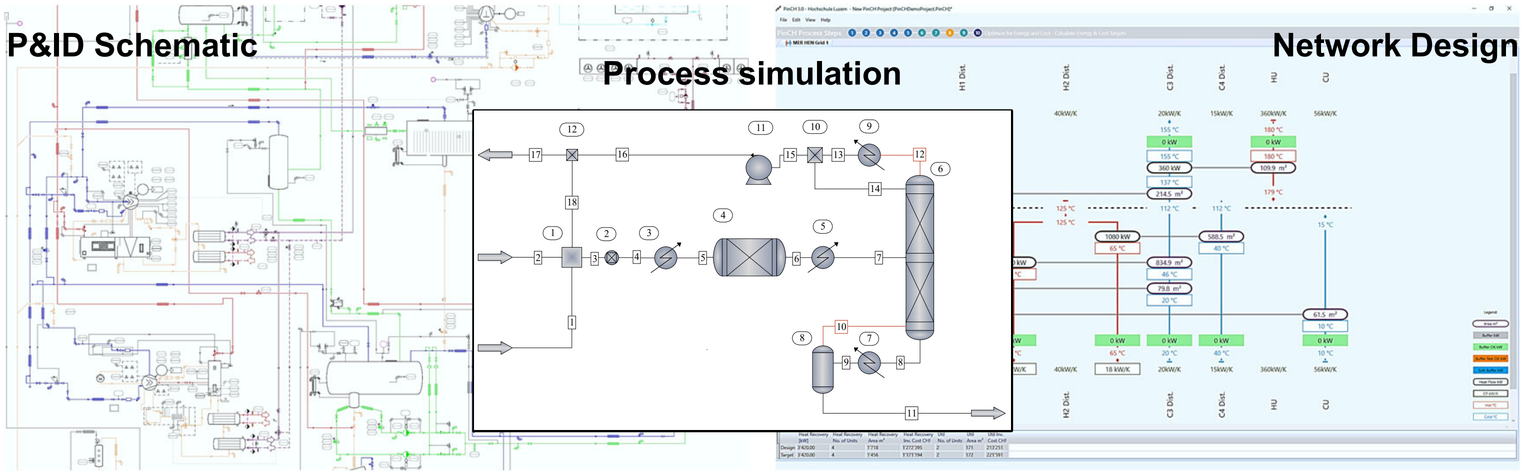
	Variant 1: **IHR only**	Variant 2: **IHR + HP split**	Variant 3: **HP only**	Variant 4: **IHR + HP combined**
				
Investment	280 kCHF	767 kCHF	659 kCHF	703 kCHF
Energy Cost Savings	44 kCHF/y	150 kCHF/y	131 kCHF/y	143 kCHF/y
Static Payback	6.4 y	5.1 y	5 y	4.9 y

- System design, hydraulics, key component sizes and costs are computed automatically.
- Tradeoff between these systems are the economic efficiency and the complexity of solutions.
- Recommendation: Variant 3 likely is preferred due to less complexity.

Extending Pinch Analysis with Process Simulation and Ecological Impact Assessment

Development of a general workflow to guide the engineer in accelerating data extraction, energy modelling and design validation





Existing or new plant

- Process understanding and accelerating data extraction through process simulation

Validated and accepted design

- Design validation through process simulation
- Cost and environmental impact assessment: **Eco-Targeting**

2) Process Integration and Pinch Analysis in Swiss Industry

- Fundamentals, benefits, results and workflow
- Case studies from industry
- Actual research
- **Waste heat usage**
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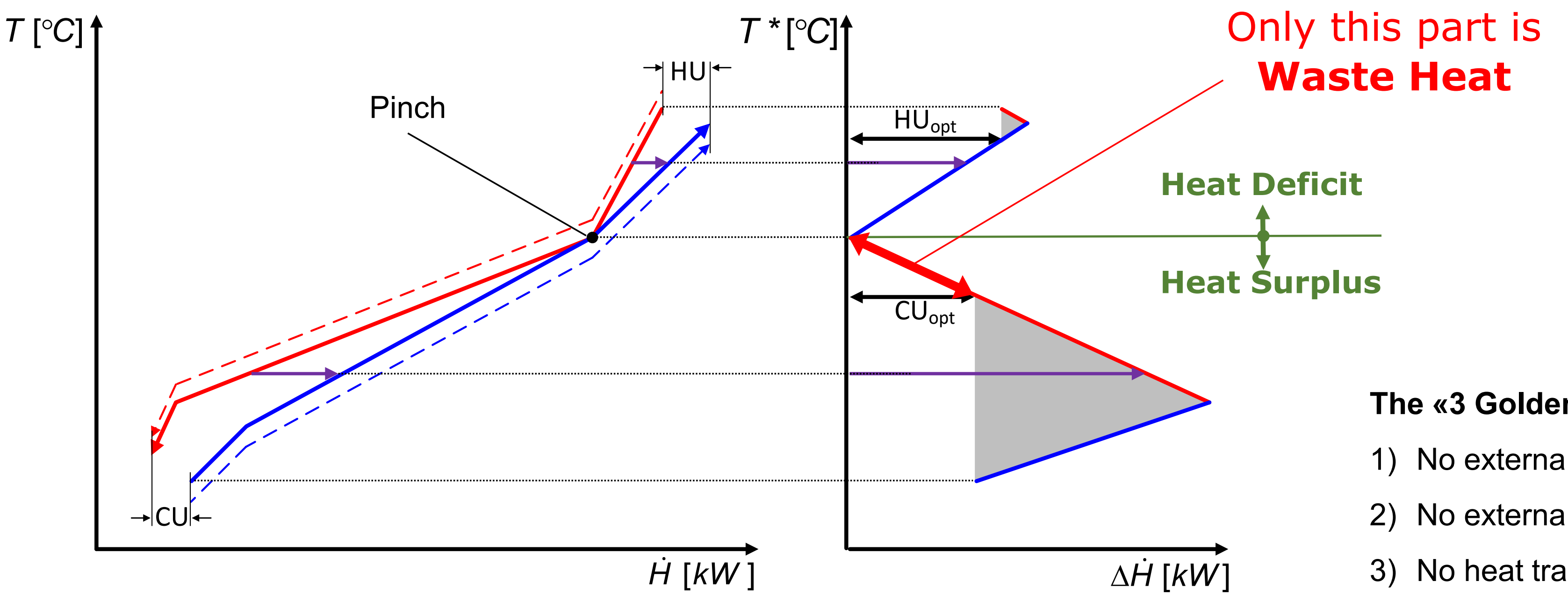
Grand Composite Curve (GCC)

- Shows the heat deficit and surplus as a function of temperature
- Enables the optimization of the utility supply system (HU_{opt}, CU_{opt})
- **Identifies and characterizes the waste heat** (and excess heat)

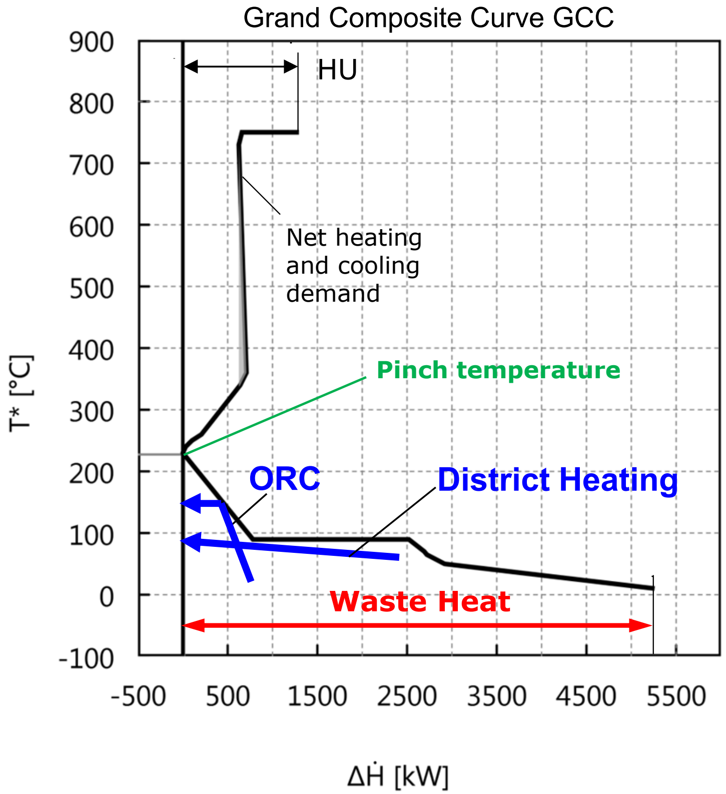


The «3 Golden Rules» of Pinch Analysis

1) No external cooling above the pinch
2) No external heating below the pinch
3) No heat transfer over the pinch

Example: Mineral processing

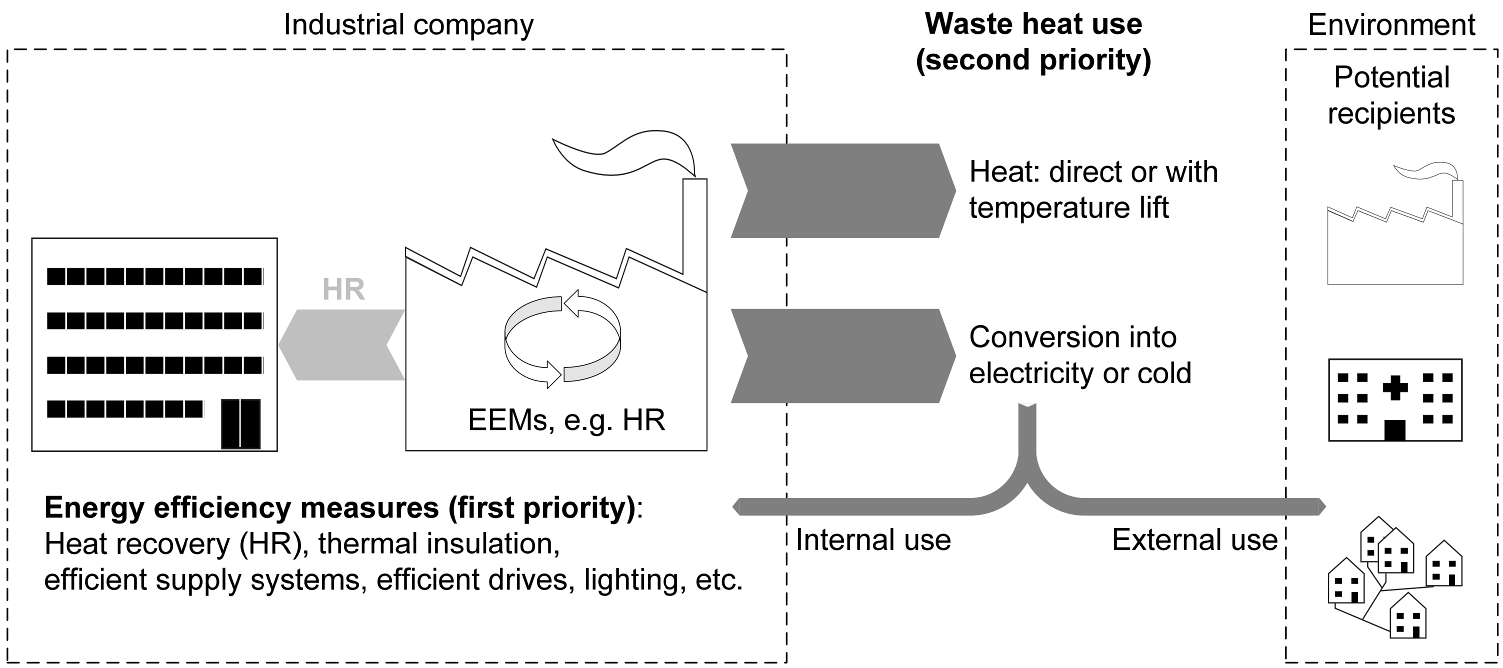
Pinch analysis is the only feasible method in the praxis to identify and characterize waste and excess heat:



Comparison of an ORC plant vs. district heating: Expansion of district heating was implemented.

Guidelines for the use of industrial waste heat (SFOE)

- Guidelines for the proper use of industrial waste heat
- Support the analysis of the waste heat potential and the conception of suitable technical and commercial solutions (incl. business models)



2) Process Integration and Pinch Analysis in Swiss Industry

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- **Integration of renewables**

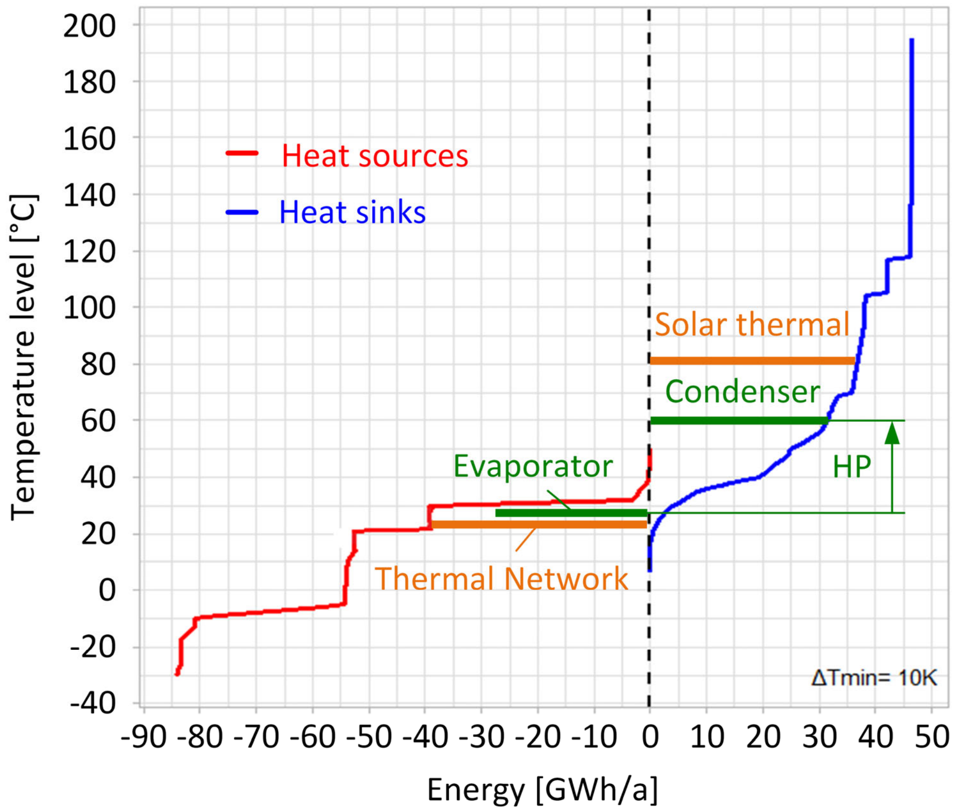
Role of Process Integration for renewables integration

Process Integration as basis for the optimal integration and implementation of
- energy efficiency measures
- **renewable energy sources**
- fuel substitution
- Negative Emissions Technologies (NETs)
- waste/excess heat use (e.g. in thermal grids)

SWEET project DeCarbCH:

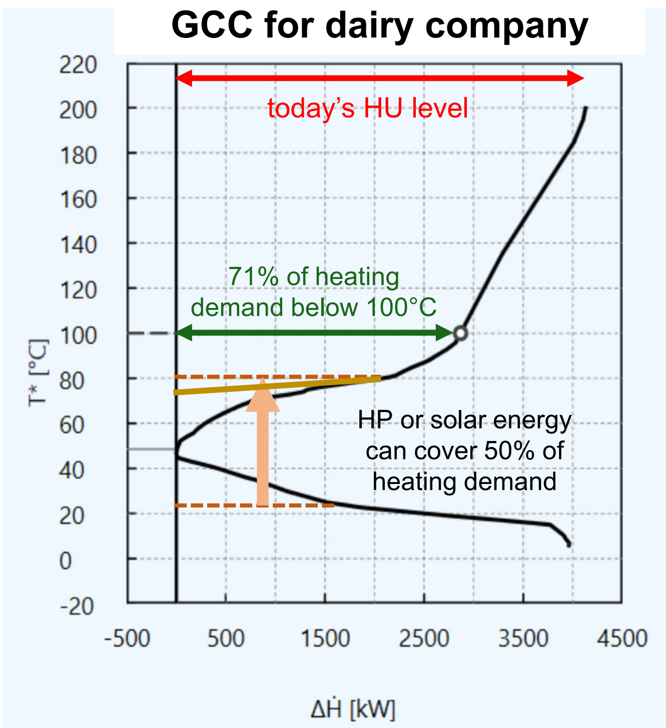
- Determination of **energy demand profiles** at company level and sector level
- Development of **practical methods and tools** as well as of decision-making tools based on PI methods

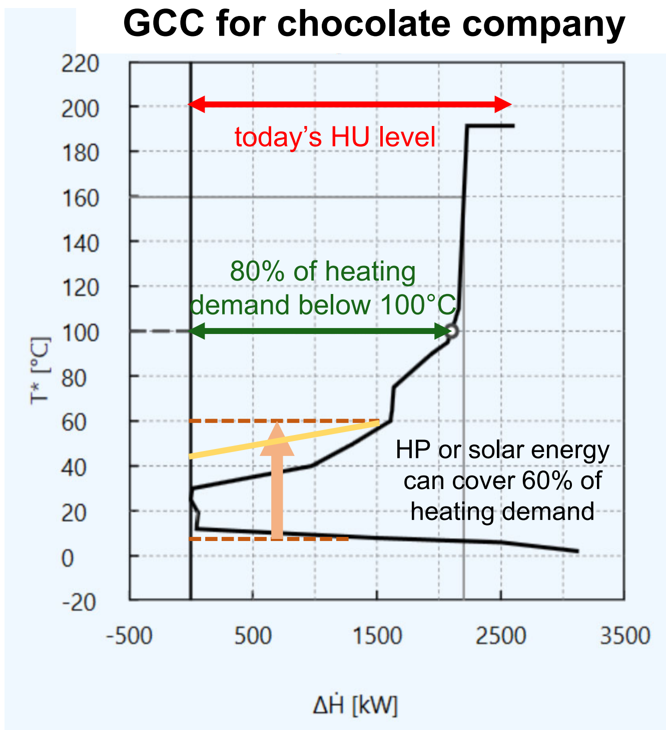
Energy demand profile for sub-sector «Meat»
after implementation of energy efficiency measures



Examples: Food industry

- GCC shows transparently the real process requirements. → “What do the processes *really* need?”
- Integration of different types of renewables can be evaluated
- Systematic approach supports a well-informed decision-making process





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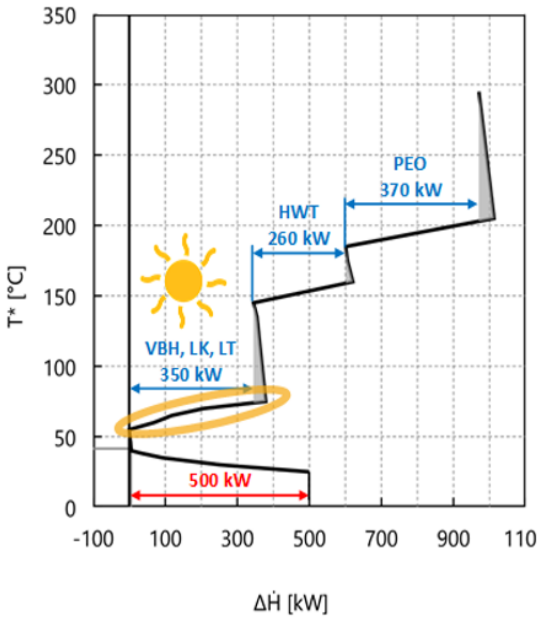
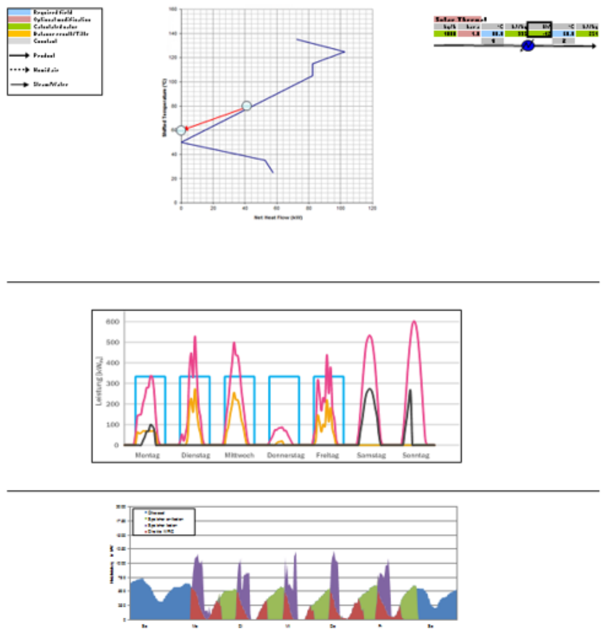
Example: Paint shop

- Identification and characterization of solar thermal energy potential based on the GCC of the process
- Design of solar thermal energy plant using the “PinCH E-Modul Solar Energy”
- Optimal integration and system design systematically done with Pinch Analysis

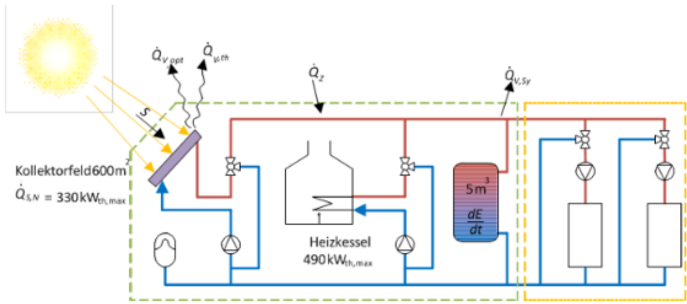
Pinch Analysis Paint Shop



Energy-Modul Solar Energy



Integration and Implementation



- Optimal system design
- 248 MWh_{th} solar energy p.a.
- 20% savings in natural gas
- 50 t CO_2 reduction p.a.

3) Energy Efficiency Improvement Potential in Swiss Industry

Economic energy efficiency improvement potential using Process Integration

Conservative estimate for the Swiss industry sector:

Energy Savings [1]	min. 3 TWh/a
Reduction CO_2 emissions [2]	0.54 Mio. t CO_2/a
Net savings per reduced tonne CO_2 [3]	385 CHF/t CO_2

[1] only economic energy efficiency measures (EEMs) under today's conditions (investment costs, energy prices, CO_2 levy); saving potential including waste heat use measures (i.e. extended system boundary) at least double.

[2] only economic EEMs, without potential for renewable integration

[3] negative CO_2 abatement costs for a mean economic lifetime of 10 years, static calculation

Process Integration is (by far) the most effective method to save energy in industry. With the use of additional methods and tools, Process Integration can also be applied in SMEs, i.e. the potential will be increased markedly in the future.

Bottom-up modelling of industrial energy efficiency

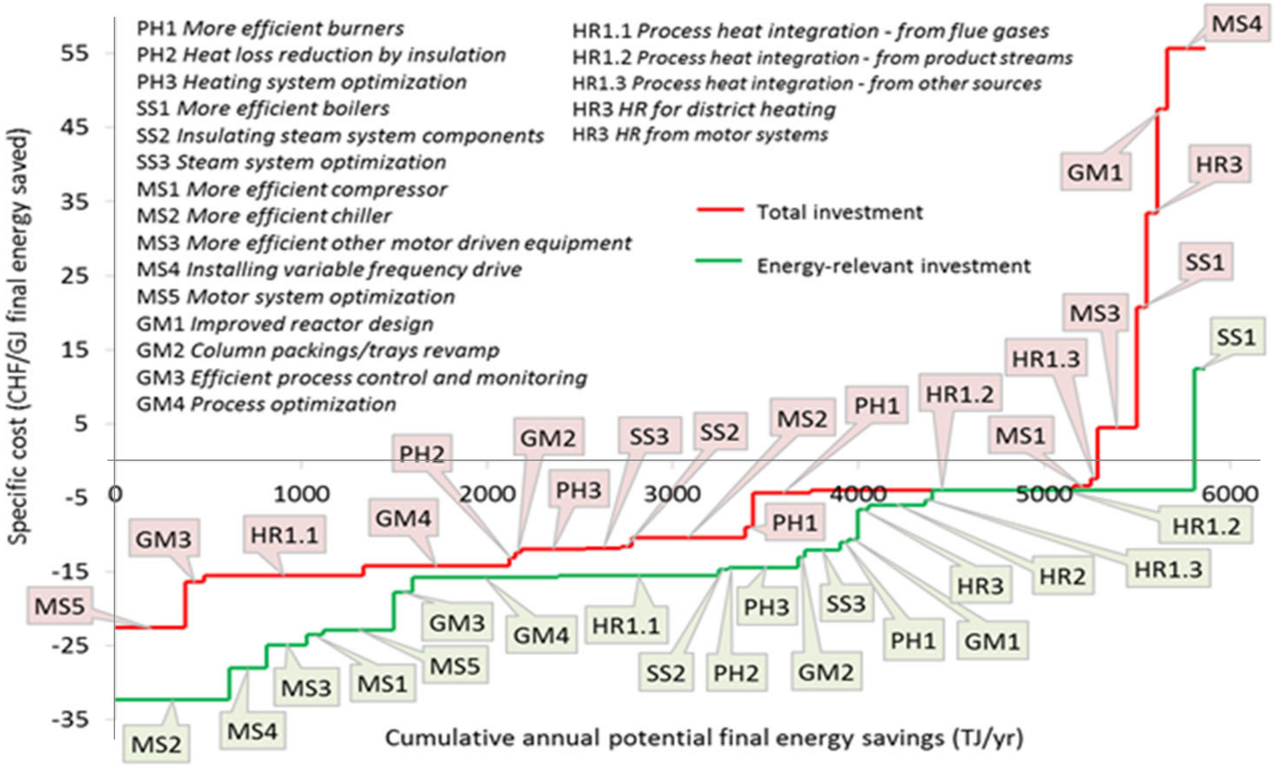
Source: SCCER EIP, Research Group Prof. Martin Patel, UNIGE

Analysis of selected sectors

- Example for the **chemical sector** (diagram right):
  economic EE potential: 21%

- **Other investigated sectors**:
  cement, metals, food
- **Cross cutting technologies**:
  Electric motor driven systems (EMDS): econ. EE potential 17%

  Waste heat recovery:
  econ. EE pot. 14%



Economically feasible EE and CO2 saving potential

Source: SCCER EIP, Research Group Prof. Martin Patel, UNIGE, and HSLU (Process Integration)

Today, Swiss industry uses approx. **43 TWh/a**, of which **24 TWh_{th}/a** is used for process heating. The estimated economically feasible EE and CO2 saving potential relative to today's energy consumption is:

Research	Economically feasible EE potential (of 43 TWh/a)	Potential energy savings (GWh/a)	Potential CO2 savings ($MtC0_2$-eq)
EE Improvements [1]	6 – 7 %	2'520 – 2'915	0.45 – 0.52 [2]
Process integration and heat recovery [3]	9 % (16 % of thermal energy demand)	3'930	0.71
Multiple Benefits [4]	Increases above values 10 – 20 %	645 – 1'370	0.12 – 0.25
Total	**approx. 16.5-19 %**	**7'095 – 8'215**	**1.27 – 1.47**

(1) Research at UNIGE estimates the **total economic EE potential** across all sectors at **6-7% excluding heat recovery.** [a]

(2) CO_2 savings based on Swiss industrial energy consumption weighted average: **0.180 $kgCO_2$-eq/kWh.** [b]

(3) Assuming realization of all pinch analyses in Swiss industry. **Process integration is (by far) the most effective individual measure.**

(4) Monetized Multiple Benefits decrease payback periods markedly, increasing the number of economically feasible EEMs.
A conservative estimate places this **increase at approx. 10-20 %.**

[a] M.J.S. Zuberi: Improving Energy Efficiency in Swiss Industrial Sectors, PhD Thesis, UNIGE, 2019
[b] SCCER EIP Requirement Report, CER, 2019

Hochschule Luzern
Engineering and Architecture

Thank you for your time!