

PinCH Tutorial 2

Welcome! The PinCH team of the Lucerne University of Applied Sciences and Arts offers tutorials for the PinCH software to present to you the possibilities of the software and how to use it. In five tutorials, you will learn the basics of using PinCH for energy and cost optimization in industrial processes:

PinCH Tutorial 0	Quick Overview
PinCH Tutorial 1	Continuous Production Plant
PinCH Tutorial 2	Production Plant with Multiple Operating Cases
PinCH Tutorial 3	Discontinuous Production Plant
PinCH Tutorial 4	Integration of Thermal Energy Storage

The tutorials are sequential. If you are using PinCH for the first time, we recommend that you start with Tutorial 0 entitled "Quick Overview".

The tutorials and the associated "finished" PinCH files can be downloaded from the website www.pinch-analyse.ch. The tutorials can be solved with the trial version of PinCH (full version, but limited to eight process streams). To obtain the trial version, please send an E-Mail to pinch@hslu.ch.

The tutorials are available in German, English and French. The labels in process flow charts and the names of processes, streams, etc., as well as software-related terms, are always kept in English. The used currency is Euro.

Energy and cost optimization with PinCH is carried out in [10 Steps](#). You will find an overview of the [10Steps](#) and a list of symbols and abbreviations in [Tutorial 0](#).

The tutorials focus on using the PinCH software. It is assumed that you are familiar with the basic principles of the pinch analysis. We recommend the following books as an introduction or for a deeper insight into the pinch method:

- F. Brunner, P. Kruppenacher: Einführung in die Prozessintegration mit der Pinch-Methode – Handbuch für die Analyse von kontinuierlichen Prozessen und Batch-Prozessen. Swiss Federal Office of Energy SFOE, 2017 (available from www.pinch-analyse.ch)
- R. Smith: Chemical Process Design and Integration. 2nd Edition, John Wiley & Sons, 2016; Pinch Analysis from Chapter 15 onwards (ISBN 9781119990130)
- I. C. Kemp: Pinch Analysis and Process Integration – A User Guide on Process Integration for the Efficient Use of Energy. 2nd Edition, Elsevier Butterworth-Heinemann, 2007 (ISBN 978-0-7506-8260-2)

You are currently working on [PinCH Tutorial 2](#). It is about analyzing and optimizing a production plant with multiple operating cases (MOCs). [Tutorial 2](#) is structured as follows:

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I Introduction to [Tutorial 2](#)

Learning objective: To perform energy and cost optimization for production plants with multiple operating cases in [PinCH](#).

Duration: 2-3 hours

While optimizing the energy and costs of production plants with multiple operating cases, further aspects of [PinCH](#) are presented. These include the configuration of equipment and the definition of MOC processes. In this [PinCH Tutorial 2](#), you will be guided through the optimization process in the following steps ([Steps 7](#) and [9](#) are not required for this case study):

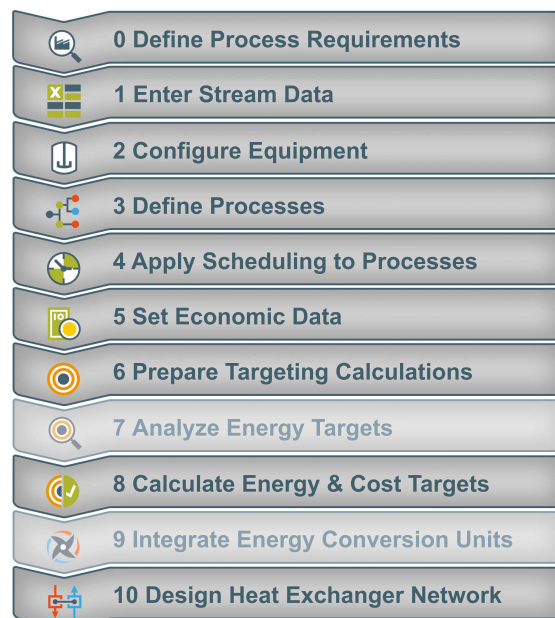


Figure 1: Sequence in [PinCH](#) for optimizing a process with multiple operating cases

The PinCH team of Lucerne University of Applied Sciences and Arts hopes you find this tutorial instructive and wishes you every success!

II Case Study: Production Plant with Multiple Operating Cases

Process Description

We are considering a planned production plant in a chemicals company. In the future, it should be possible to make two different products with the same reactor using this plant.

In the first operating case (Operating Case Product C, OC Product C), the two educt streams Reactant A and Reactant B react to Product C in the reactor (Figure 2). Both educt streams must be heated to 100 °C so that the endothermic reaction can take place. The product must be cooled to 40 °C.

In the second operating case (Operating Case Product F, OC Product F), Reactant D and Reactant E react to Product F (Figure 3). Only Reactant E has to be heated to 90 °C during this exothermic reaction. Product F, meanwhile, must be cooled to 40 °C. A heat transfer coefficient α of 1'000 W/(m² K) is used for all process streams.

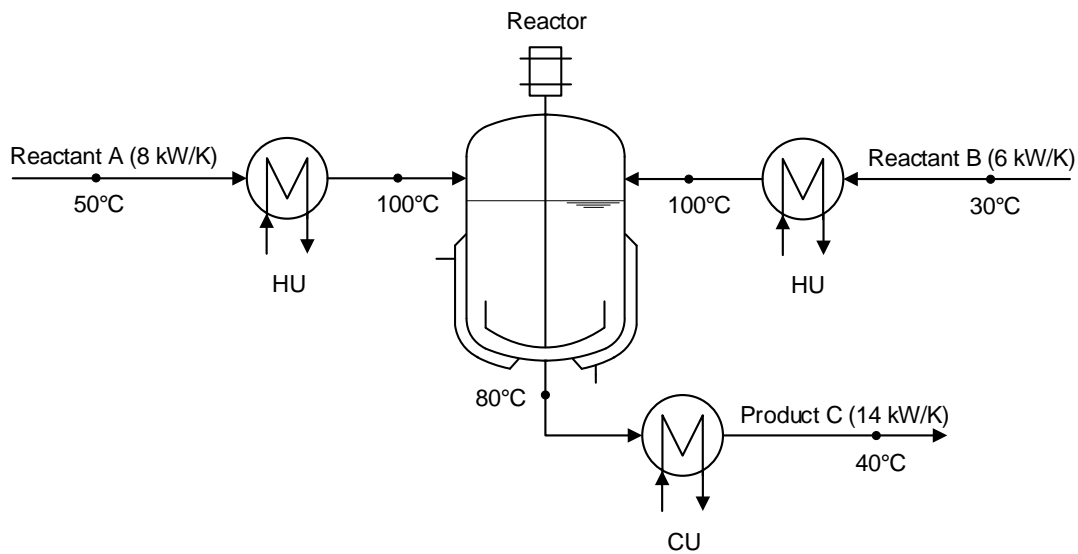


Figure 2: Process flow chart for OC Product C (endothermic reaction)

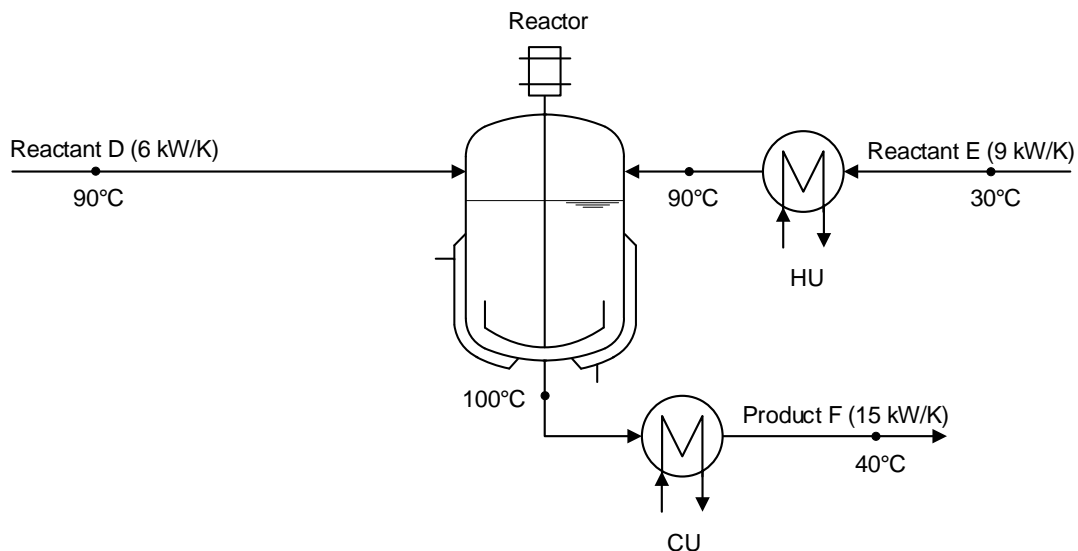


Figure 3: Process flow chart for OC Product F (exothermic reaction)

Scheduling

The two operating cases take place at staggered intervals. Any interruptions to production are disregarded. As shown in Figure 4, the operating time of OC Product C and OC Product F is 3'000 h/a and 4'000 h/a respectively. Production runs for 7'000 h/a in total.

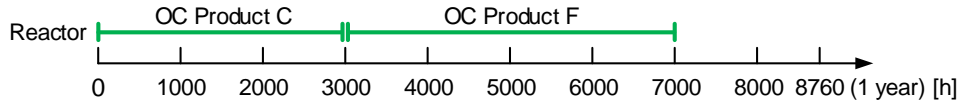


Figure 4: Gantt chart

Utilities

The Utilities from Table 1 are available for heating and cooling the process streams. Heating steam is used as a hot utility (HU) for heating. The heating steam is available as saturated steam, so the pressure p and – instead of the inlet temperature (T_{in}) and outlet temperature (T_{out}) – the steam content x are specified. The cold utility (CU) is made up of cooling water, which is provided from a cooling tower.

Table 1: Utility data

Utility Stream	T_{in} [°C]	T_{out} [°C]	p [bar(a)]	α [W/(m ² K)]	c [€/MWh]
Heating Steam (HU)	$x=1$	$x=0$	4	5'000	70
Cooling Water (CU)	26	32	3	2'000	18

The total annual operating costs C_{Op} [€/a] are made up of the annual operating costs per OC. The total annual operating costs are calculated as follows using the annual operating hours τ [h/a], the requirement \dot{Q} [kW] for HU / CU, and the specific costs c_{HU}, c_{CU} [€/MWh] of the HU / CU:

$$C_{Op} = \sum_{OC} C_{Op, OC} = \sum_{OC} \tau_{OC} \cdot \left(\dot{Q}_{HU, OC} \cdot c_{HU, OC} + \dot{Q}_{CU, OC} \cdot c_{CU, OC} \right) \quad (1)$$

Table 2: Utility services and operating costs of the process without heat recovery (HR)

Operating Case	\dot{Q}_{HU} [kW]	\dot{Q}_{CU} [kW]	τ [h/a]	C_{Op} [€/a]
OC Product C	820	560	3'000	202'440
OC Product F	540	900	4'000	216'000
Total	-	-	7'000	418'440

Investment Costs

You are already familiar with the process of calculating investment costs from Tutorial 1. Since only the investment costs C_{HEX} of the heat exchangers (HEX) for heat recovery (HR) and the utilities have to be taken into account, the following applies to calculate the total investment costs C_{Inv} :

$$C_{Inv} = \sum_{HEX} C_{HEX} = \sum_{HEX} \left(C_0 + C_b \cdot \left(\frac{A_{HEX}}{A_b} \right)^m \right) \quad (2)$$

whereby $C_0 = 0$ (HEX basic costs), $C_b = 110'000$ € (HEX reference costs), $A_b = 100$ m² (reference HEX heat transfer surface) and $m = 0.71$ (degression exponent, see Tutorial 1). These values are used in

the cost calculation for all heat exchangers based on the specific heat transfer area A .

The two heat exchangers "HU Reactant B" and "HU Reactant E", as well as "CU Product C" and "CU Product F", are found in the same pieces of equipment (lines). Here, the design (and therefore the cost calculation) of the HEX in question follows the process requirement with the biggest HEX area. The heat exchangers from OC Product F are taken into account.

When using the cost function (equation 2), you get the following costs for the two HU heat exchangers and the CU-HEX:

Table 3: Costs of the individual heat exchangers using equation 2

Heat Exchanger	\dot{Q} [kW]	ΔT_m [K]	k [W/(m ² K)]	A [m ²]	C_{HEX} [€]
HU Reactant A	400	65.9	833.3	7.3	17'132
HU Reactant E	540	80.3	833.3	8.1	18'419
CU Product F	900	34.2	666.7	39.5	56'894
Total				54.9	92'445

Note: The condensation temperature of water vapor at 4 bar(a) (approx. 144 °C) is used to calculate the mean logarithmic temperature difference ΔT_m of HU1 and HU2.

The k value is calculated according to Tutorial 1 from the two α values of the respective streams (all process streams have an α value of 1'000 W/(m² K)): $\frac{1}{k} = \frac{1}{\alpha_1} + \frac{1}{\alpha_2}$

Total Costs

The annual total costs C_{tot} [€/a] are calculated from the annual investment costs $a \cdot C_{Inv}$ [€/a] and the annual operating costs C_{Op} [€/a], where a is the annuity factor, see equation 3:

$$C_{tot} = a \cdot C_{Inv} + C_{Op} \quad \text{mit} \quad a = \frac{Z \cdot (1 + Z)^n}{(1 + Z)^n - 1} \quad (3)$$

The following data is given:

- Interest rate: $Z = 5\%$
- Pay-off period: $n = 4$ a

The annuity factor is $a = 0.282$. In this tutorial, planning of a new plant is considered and the corresponding investment costs can be found in Table 3. The reactor's investment costs are disregarded, because they have to be incurred regardless of energy and cost optimization. Therefore the result is annual total costs of roughly $C_{tot} = a \cdot C_{Inv} + C_{Op} = 444'510$ €/a.

Problem

- Determine the **energy and cost targets** for the two OCs.
- Create a **MER HEN** (maximum energy recovery heat exchanger network) for both of the OCs.
- Combine the two MER HENs to form a single process flow chart which can be used for both OCs.



Step 0: Define Process Requirements

Define the **process requirements** by extracting the relevant data (for data extraction, see [Tutorial 1](#)). Reactant D is not a process requirement, because the process stream is already at the desired temperature of 90 °C.

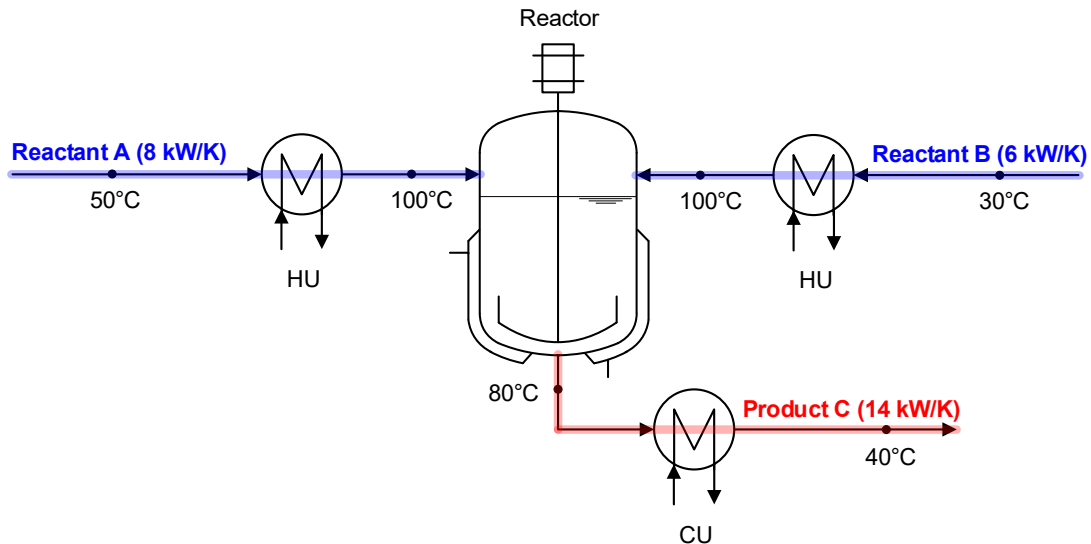


Figure 5: Process requirements for OC Product C (endothermic reaction)

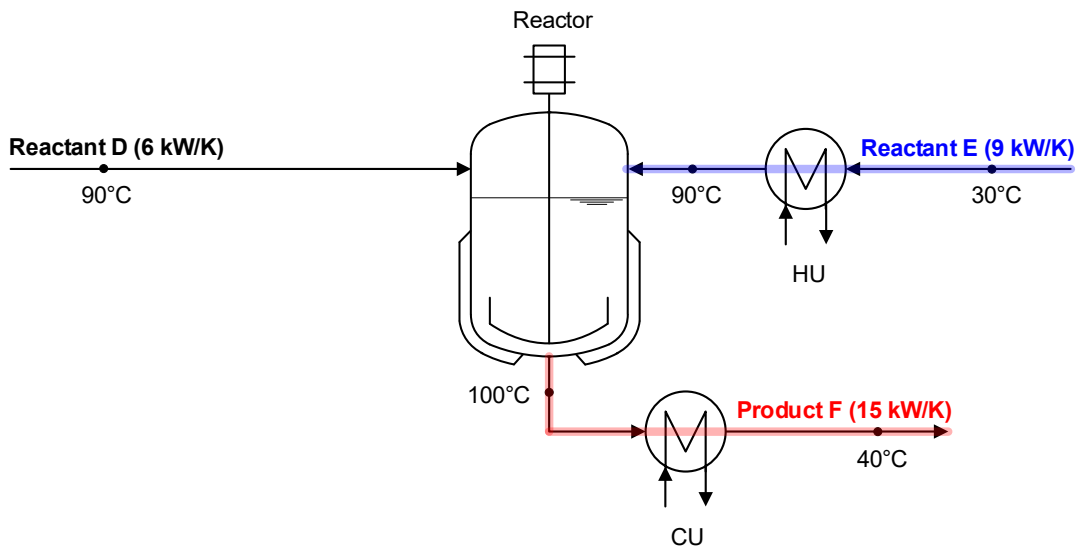


Figure 6: Process requirements for OC Product F (exothermic reaction)

Table 4: Process requirements

Operating Case (OC)	Process Stream	T_{in} [°C]	T_{out} [°C]	α [W/(m ² K)]	CP [kW/K]
OC Product C	Reactant A	50	100	1'000	8
OC Product C	Reactant B	30	100	1'000	6
OC Product C	Product C	80	40	1'000	14
OC Product F	Reactant E	30	90	1'000	9
OC Product F	Product F	100	40	1'000	15

III 10 Steps in PinCH

Let's get started!

Open [PinCH](#) to start the pinch analysis. Before we start with the actual project, it is advisable to adjust the basic settings in [PinCH](#). Because the costs are specified in € in this tutorial, you must adjust the currency in the settings before you start. The units kW and MWh are also used in this tutorial. An explanation of how to proceed is provided in [Tutorial 0](#).

The tutorial follows the [10 Steps in PinCH](#). First of all, create a new project and give it a suitable name.



Step 1: Enter Stream Data

The process requirements are entered in the [Process Stream Table](#). The finished Process Stream Table looks like this:

+/-	Name	Hot/Cold	Tin °C	Tout °C	m kg/s	cp kJ/(kg K)	Phase Change kJ/kg	α W/(m ² K)	Pressure bar(a)	CP kW/K	ΔH kW	Fluid	Humidity Ratio In kg/kg	Soft	tstart h	tstop h
	Reactant A	Hot	50	100	2.66667	3	-	1000	-	8	400	Simple	-	<input type="checkbox"/>	-	-
	Reactant B	Hot	30	100	2	3	-	1000	-	6	420	Simple	-	<input type="checkbox"/>	-	-
	Product C	Cold	80	40	4.66667	3	-	1000	-	14	560	Simple	-	<input type="checkbox"/>	-	-
	Reactant E	Hot	30	90	3	3	-	1000	-	9	540	Simple	-	<input type="checkbox"/>	-	-
	Product F	Cold	100	40	5	3	-	1000	-	15	900	Simple	-	<input type="checkbox"/>	-	-

Figure 7: Process Stream Table

The [Utilities](#) (HU and CU) are entered in the [Utility Stream Table](#). The finished Utility Stream Table looks like this:

+/-	Name	Hot/Cold	Tin °C	Tout °C	cp kJ/(kg K)	Phase Change kJ/kg	α W/(m ² K)	Pressure bar(a)	Utility Cost EUR/MWh	Fluid	Humidity Ratio In kg/kg
	Heating Steam (HU)	Hot	x1	x0	-	2133.77	5000	4	70.000	Water	-
	Cooling Water (CU)	Cold	26	32	4.2079	-	2000	3	18.000	Water	-

Figure 8: Utility Stream Table



Step 2: Configure Equipment

In our case study, the same pieces of equipment are used for both OCs. In the Project Explorer under **Equipment Individual**, you can see that an individual piece of equipment is assigned to the start of each process stream. To change this, proceed as follows:

- Right-click on **Shared**
- **Create New Shared Equipment** (twice)
- Rename the newly created pieces of equipment "Reactants B, E" and "Products C, F".
- Now select the "Reactant B" stream in the Process Stream Table.
- Click on Properties below the Target Explorer.
- Open the Equipment tab and select "Reactants B, E".
- Assign the "Reactant E" stream to the "Reactants B, E" equipment in the same way.
- Now assign the "Product C" and "Product F" streams to the "Products C, F" equipment.
- Rename the "New Process Stream 1 Eq" equipment under Individual "Reactant A". This is an individual piece of equipment because it only occurs in OC Product C.

In the Project Explorer, you will find the "Products C, F" equipment, for example, under Shared. When you click on this, the assigned streams in the Process Stream Table are highlighted blue.

Name	Hot/Cold	T _{in} °C	T _{out} °C	m _{in} kg/h	c _p J/(kg·K)	Phase Change	α	Pressure bar(a)	CP kW/K	ΔH kW	Fluid	Humidity Ratio In kg/kg	Soft	t _{start} h	t _{stop} h
Reactant A	Hot	50	100	2	2566.8	3	-	1000	6	800	Simple	-	-	-	-
Reactant B	Hot	30	100	2	2566.8	3	-	1000	6	800	Simple	-	-	-	-
Product C	Hot	80	40	4.66667	3	-	1000	14	560	Simple	-	-	-	-	-
Reactant E	Hot	30	90	3	3	-	1000	9	540	Simple	-	-	-	-	-
Product F	Hot	100	40	5	3	-	1000	15	900	Simple	-	-	-	-	-

Figure 9: The "Products C, F" equipment includes the "Product C" and "Product F" process streams highlighted in blue








Step 3: Define Processes

To define a production plant with multiple operating cases, the process streams must be split between the two OCs:

- Right-click on **Processes**
- **Add Continuous Process**
- Rename the two processes, "Process 1" and "Process 2", to "OC Product C" and "OC Product F" (use F2).
- Add the process streams (Reactants and Product) to the associated OC (OC Product C or OC Product F).

Note: Two process streams cannot flow through the same piece of equipment at the same time. Therefore, process streams which are assigned to the same piece of equipment cannot be assigned to the same OC. Corresponding process streams are highlighted in gray in the Process Stream Table.

Now create a Multiple Operating Cases Group (MOC Group) and add OC Product C and OC Product F to it:

-  Right-click on Processes
-  Add Multiple Operating Cases Group
-  Rename the "MOC Group 3" process to "Chemical Process".
-  Right-click on "Chemical Process"
-  Assign Process and select "OC Product C" and "OC Product F".








Step 4: Apply Scheduling to Processes

The scheduling of our production plant is specified in Chapter II. OC Product C runs for 3,000 h/a, and OC Product F for 4,000 h/a.

Open the [OC Schedule 1](#) tab and enter the operating hours for the "Chemical Process" defined in [Step 3](#).

Note: PinCH naturally takes the fact that several process streams for the same OCs cannot exist at the same time. If you make changes to the duration of OCs, you must ensure that the OCs never overlap. Otherwise, the change is not applied.

-  Click on the + sign in front of "Chemical Process" (under OC Schedule 1 in Continuous Processes).
-  In the [CW Start](#) column, change the OC Product C start week to 1. For OC Product F, change the start week to 43. This prevents any overlapping between the two OCs.
-  In the [Timebase](#) column, select "Cont. Year" for both OCs.
-  Adjust the [Duration](#) of both OCs in the Duration column.
-  To ensure that there is no interruption between the two OCs, you can set the start day ([Mo](#) to [Su](#) columns), the start time ([Daytime Start](#) column) and the start week ([CW Start](#) column) of OC Product F as close to the end of OC Product C as possible (e.g. start on Monday at 7:00 in week 19). This isn't mandatory, however.

Additional information: The Production Campaign Start column specifies the time at which the OC starts relative to the start of the year. The Production Campaign End column accordingly specifies the time at which the process ends. The Gross Operation Time specifies the OC's operating time including interruptions (difference between production campaign start and production campaign end). The Net Operation Time specifies how many hours the OC is effectively in operation (takes overnight and weekend interruptions into account, etc.). The net operation time corresponds to the total operating hours per year and is used for calculating the energy costs.

For our case study, the "OC Schedule 1" tab looks like this:

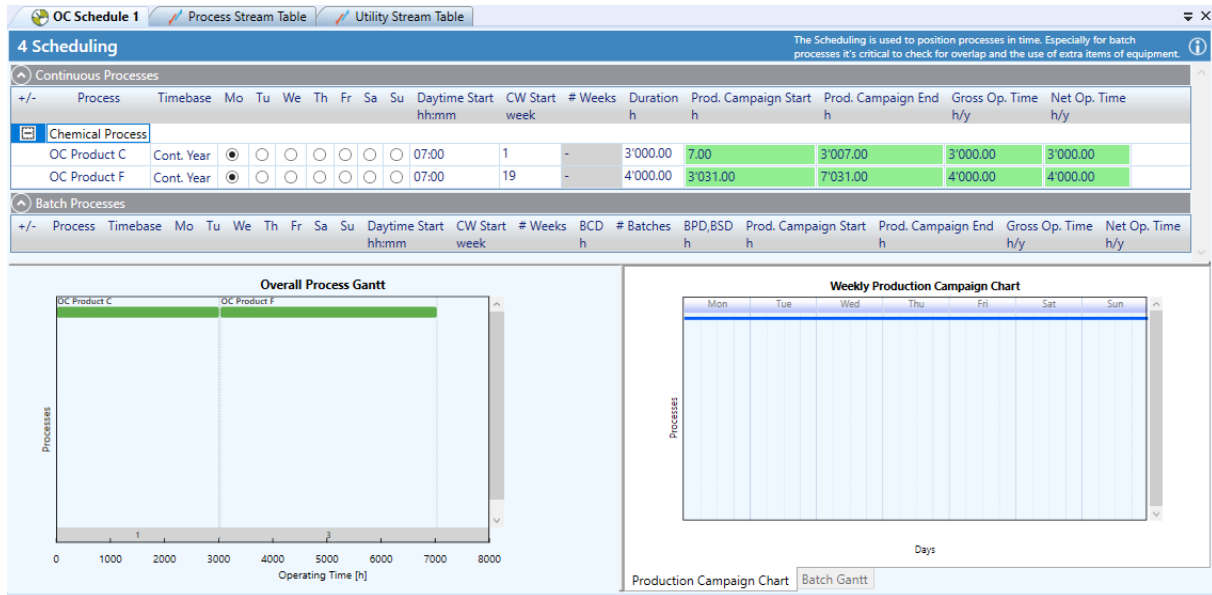


Figure 10: Operating cases scheduling

The two OCs are shown along with their duration in the [Overall Process Gantt](#) chart. It is clear that OC Product F starts straight after OC Product C. The production time of the chemical process in one week (continuous production, in our case) is shown in the [Weekly Production Campaign Chart](#).



Step 5: Set Economic Data

You already learned about the economic parameters in [Tutorial 1](#). The costs for the heat exchangers are calculated in [PinCH](#) as described in the section entitled "Investment Costs" on page 4. In addition to the information on the reference HEX (heat exchanger costs in Figure 11), the amortization parameters are defined in [Step 5](#).

Change the "Heat Exchanger Costs" and the "Amortization Parameters" according to the information in Figure 11.

Additional information: Costs for electricity, independent fixed costs, and staff and maintenance costs can be entered as required. The electricity costs in particular are highly significant when integrating a heat pump. But this is not relevant to determining the optimum ΔT_{min} , because it is a (constant) amount which is independent of the ΔT_{min} .

Your finished data record should now include the following values:

5 Economic Data The economic Data data is used throughout the software PinCH for calculating the main costs associated with an heat exchanger network

Heat Exchanger Costs i

$$C = C_0 + C_b (A/A_b)^m$$

A = Heat Exchanger Area in m²

Type	Fixed Cost C ₀ EUR	Base Cost C _b EUR	Base Area A _b m ²	Exponent m
Process Heat Exchanger	0	110'000.0	100	0.71
Hot Utility Heat Exchanger	0	110'000.0	100	0.71
Cold Utility Heat Exchanger	0	110'000.0	100	0.71
ISSP Heat Exchanger	0	110'000.0	100	0.71

Storage: Tank Costs i

$$C = C_0 + C_b (V/V_b)^m$$

V = Tank Volume in m³

Storage	Fixed Cost C ₀ EUR	Base Cost C _b EUR	Base Volume V _b m ³	Exponent m	Storage Type
FTVM	0	150'000.0	100	0.71	FTVM
Stratified	0	150'000.0	100	0.71	Stratified

Storage: Media Costs and Media Properties

$$C = C_b \cdot m_{sm}$$

m_{sm} = Mass of Storage Media in kg

Media	Base Cost C _b EUR/kg	Density kg/m ³	α W/(m ² K)	c _p kJ/(kg K)
Water	0.0010	1000	2000	4.18789
Heat Transfer Oil	5.0000	800	1000	2.00000

Amortisation Parameters i

Pay Off Period y Independent EUR

Interest Rate % Personnel %/y Investment Costs

Annuity 0.282 1/y Maintenance %/y Investment Costs

Electricity i

Note: Utility Costs are set on Utility Stream Table Electricity Cost EUR/MWh Electric Power kW

Figure 11: Economic Data

After economic data is recorded in [Step 5](#), the production plant is completely characterized in PinCH. In [Steps 6-10](#), the energy and cost optimization now takes place based on the data entered in the Project Explorer. Your Project Explorer should now be structured as follows:

Project Explorer The Project

1-5 Project Explorer

- ▲ **Chemical Process**
 - Process Stream Table
 - ▲ **Equipment**
 - ▲ **Shared**
 - Reactants B, E
 - Products C, F
 - ▶ **Individual**
 - ▲ **BaseCase**
 - ▲ **Processes**
 - Chemical Process
 - OC Product C
 - OC Product F
 - Operating Cases Scheduling
 - OC Schedule 1
 - ▲ **Economic Data**
 - Economic Data

Figure 12: Project Explorer

Step 6: Prepare Targeting Calculations

To examine a scenario, create a new target group and assign it to the "Chemical Process" defined in [Step 3](#). Add the hot utility and cold utility defined in [Step 1](#) to the target group. You will find additional information about assigning processes, utilities, etc., in [Tutorial 1](#). Your Target Explorer now looks like this:

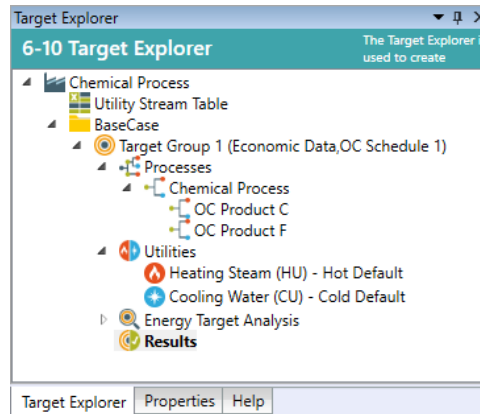


Figure 13: Target Explorer

Step 7: Analyze Energy Targets

The Energy Target Analysis (ETA) tool allows the user to investigate and assess any combination of selected and overlapping processes. The goal is to see which of the combinations offer the most benefit, from an energy perspective, using process integration.

Additional information: In addition to analyzing the potential of individual processes on total heat recovery, the Energy Target Analysis (ETA) tool allows the analysis of simultaneous (direct) and time dependent (indirect) HR potential typical of batch processes. However, the ETA tool has far more to offer. It is particularly helpful for more complex systems where several multiple operating cases have to be optimized.

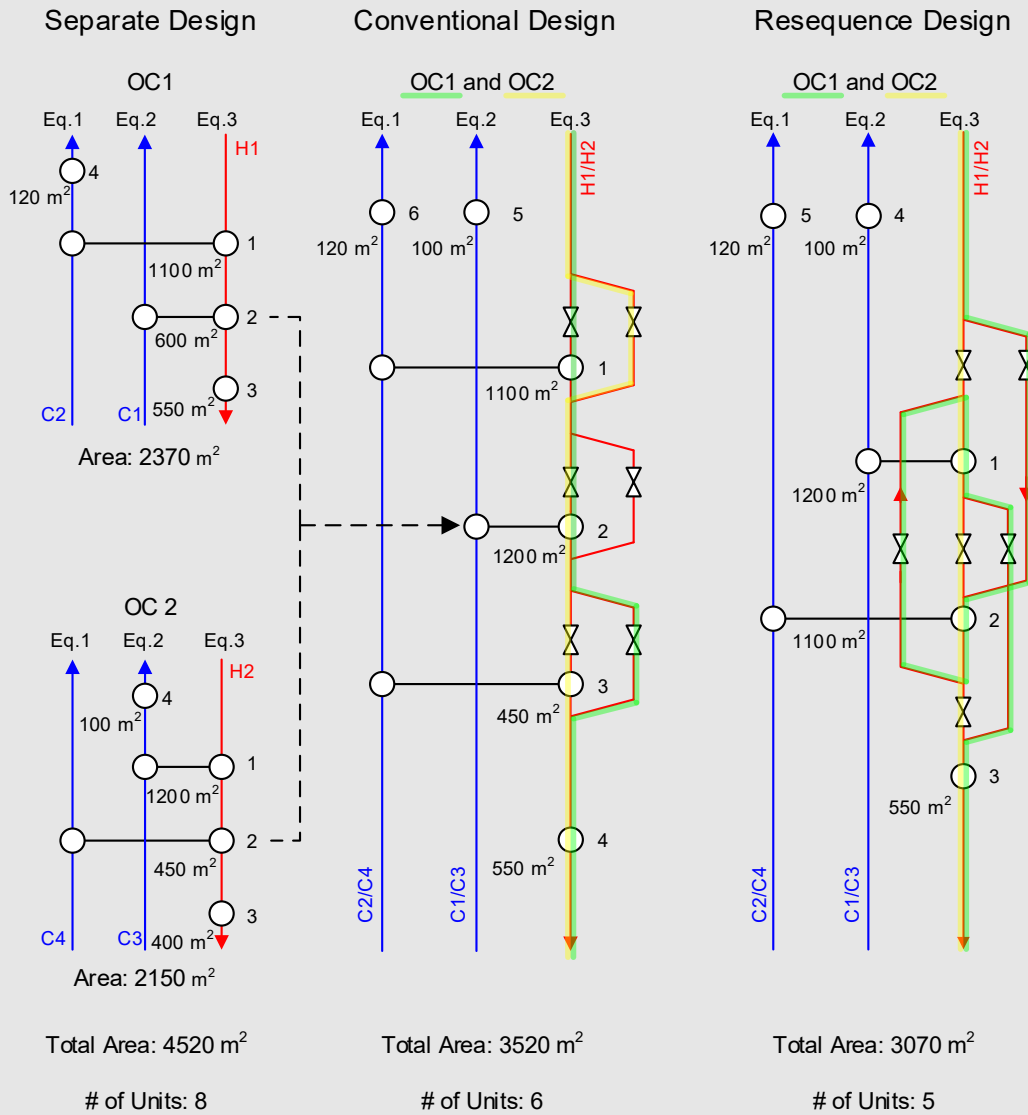
For our case study with two OCs a detailed analysis in [Step 7](#) is not necessary.

Step 8: Calculate Energy & Cost Targets

In [Super Targeting](#), the design types "Separate Design", "Conventional Design" and "Resequence Design" can be compared with one another. A separate heat exchanger network (HEN) is created for each OC with the Separate Design option. Conventional Design and Resequence Design are based on the use of heat exchangers in multiple OCs. The number of heat exchangers in the overall system can be reduced as a result (see references on page 1). In our case study, we are performing super targeting with the Conventional Design option.

Additional information: Compared with the "classic" pinch analysis of an individual continuous process, MOC Super Targeting / HEN Design is also about maximizing the reuse of the HEX area between different OCs. This is a complex optimization problem. The freedom to reuse a HEX is understood as giving the possibility to reuse the same HEX of an OC in another OC between any process streams. The two design types Conventional Design and Resequence Design limit the freedom

to reuse heat exchangers and therefore simplify the optimization problem. The three design types are explained briefly using a three-stream case (separate from our case study).



The **Separate Design** considers each OC separately. No HEX area is used between the OCs (so there is no freedom to reuse any HEX). The number of heat exchangers in the Separate Design is therefore higher than in the other design types. In the example above, eight heat exchangers with a total area of 4520 m² are required.

The **Conventional Design** enables reuse of the HEX area between the OCs. However, the freedom to reuse the heat exchangers is limited by two restrictions:

- (1) The heat exchangers in the overall design can be used at most between the same pieces of equipment (pipes): In the Separate Design, the HEX2 in OC1 (600 m²) and the HEX1 in OC2 (1'200 m²) use the same equipment (Eq.1 and Eq.3). In the Conventional Design, these two heat exchangers can be reduced to one heat exchanger by simply using the one with the greater area (HEX1 from OC2 with a HEX area of 1'200 m²).
- (2) Additionally, in the Conventional Design, there is the restriction that each process stream has to stream through the heat exchangers in the same order as in the respective OC itself. This results in the condition that only one heat exchanger can be used for all OCs together at all times for each equipment. The total HEX area has reduced by 1'000 m² compared to the Separate Design, and two fewer heat exchangers are required.

In the case of the **Resequence Design**, the heat exchangers are used between the same two lines, just like with the Conventional Design. Unlike the Conventional Design, the Resequence Design permits streaming through the heat exchangers in any order. The heat exchangers can therefore be used more flexibly and the total HEX area of the overall design can be reduced by a further 450 m² compared to the Conventional Design. Furthermore, only five heat exchangers are required.

You will find further information in the references on page 1.

Start Super Targeting:

 Right-click on [Results](#)

 Calculate Target Result with...  Select [Combined Supertargeting \(Advanced\)](#)

To get a better overview, hide the Time Charts by deselecting the "Processes" and "OCs" boxes and maximize the "OC Charts" window by dragging the top edge of the window as far up as possible.

In the OC Charts window, we want to analyze the [CCs](#) (Composite Curves) and [Costs](#) (Cost Curves) diagrams (see Figure 14). To switch between the two OCs, on the right-hand side you can click on the eye in front of the desired OC under "OCs". You can also view both of them at the same time (see Figure 14).

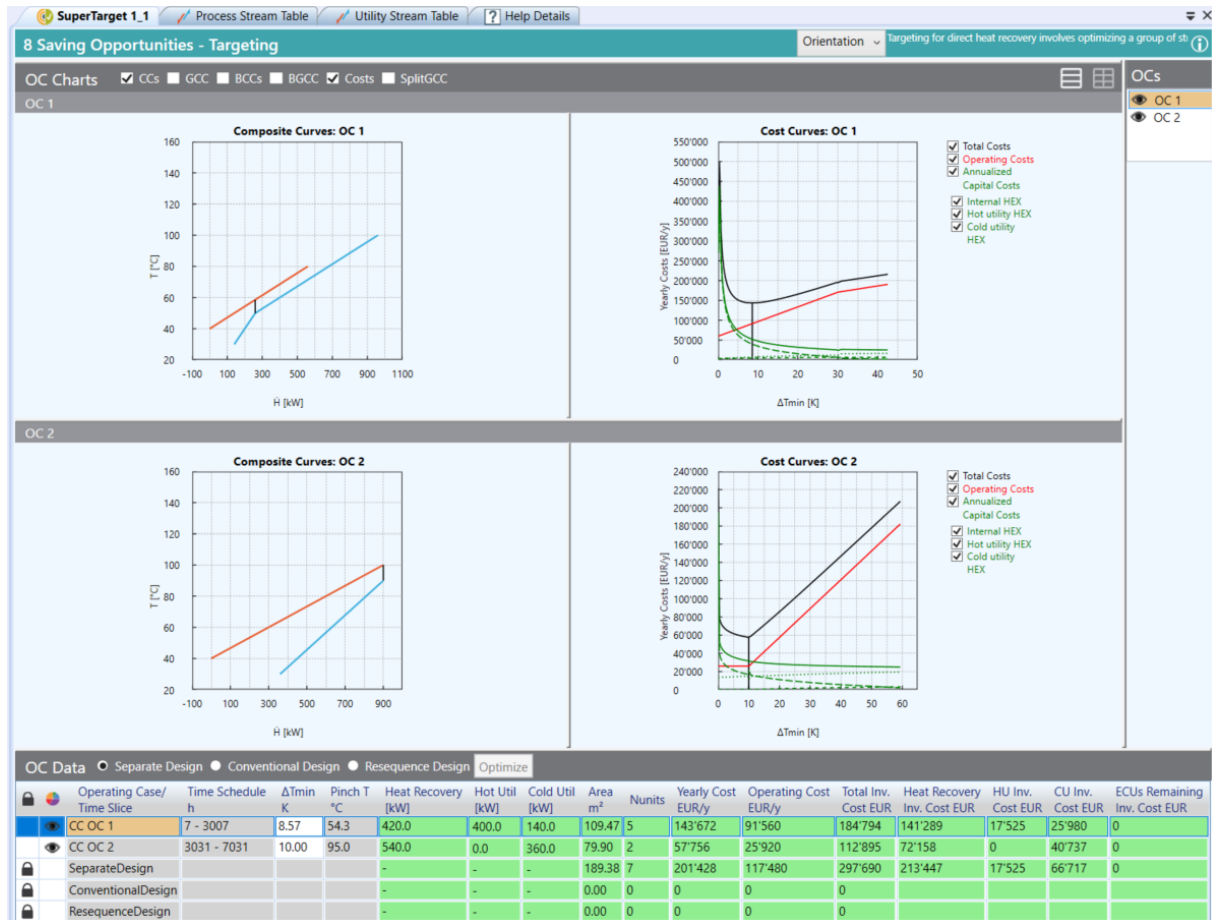


Figure 14: Composite curves, cost curves and OC data for the two operating cases

In Figure 14, the designation OC 1 corresponds to our OC Product C, and the designation OC 2 corresponds to OC Product F.

To optimize energy and costs, proceed as follows:

- Select **Conventional Design** in the OC Data
- Click on **Optimize**

The ΔT_{min} of OC1 has changed from 8.57 K to 7.48 K (" ΔT_{min} " column) due to the optimization. For the next steps, we are setting the ΔT_{min} of OC1 in the Conventional Design to 7.50 K and in the Separate Design to 8.50 K.

In Figure 14, it is clear that OC2 is a "Threshold Problem": If the Cold CC is moved to the left, the ΔT_{min} reduces and the CU requirement falls below the pinch point. However, moving also creates the simultaneous need for a CU above the pinch point. The overall CU requirement remains constant on the whole. Moving the Cold CC to the right would only cause the CU requirement to increase. The ΔT_{min} must therefore be set to 10.00 K for the Separate Design and the Conventional Design.

Table 5 compares the design of the production plant without HR, the Separate Design and the Conventional Design.

Table 5: Comparison of the design without HR with the Separate Design and the Conventional Design

	HU		CU		HEX Area	Invest. Costs	Energy Costs	Total Costs
	[kW]	[MWh/a]	[kW]	[MWh/a]	[m ²]	[€/a]	[€/a]	[€/a]
Design without HR								
OC 1	820	2'460	560	1'680	-	-	202'440	-
OC 2	540	2'160	900	3'600	-	-	216'000	-
Total	-	4'620	-	5'280	54.9	26'070	418'440	444'510
Optimized Design - Separate Design								
OC 1	399	1'197	139	417	110.3	52'375	91'296	143'671
OC 2	0	0	360	1'440	79.9	31'836	25'920	57'756
Total	-	1'197	-	1'857	190.2	84'211	117'216	201'427
Optimized Design - Conventional Design								
OC 1	385	1'155	125	375	-	-	87'600	-
OC 2	0	0	360	1'440	-	-	25'920	-
Total	-	1'155	-	1'815	136.5	61'684	113'520	175'204

The design without HR has the smallest HEX area of 54.9 m² and therefore the lowest investment costs of 26'070 €/a. However, the annual energy costs are the highest, amounting to 418'440 €/a, because heating and cooling is completely taken over by the utilities. This is why the annual total costs are also the highest, amounting to 444'510 €/a.

The Separate Design considers HR for each OC separately. As a result, the HEX area and the investment costs increase compared to the design without HR. But due to HR, around 72 % of the energy costs can be saved compared to the design without HR. The annual total costs are reduced by 55 %.

The Conventional Design takes into account the option of reusing the HEX area between the OCs. For this reason, the total HEX area can be reduced compared to the Separate Design, which is the reason for the slightly lower investment costs. The annual energy costs incurred are slightly lower than with the Separate Design. Overall, the Conventional Design appears to be the most advantageous design type from an efficiency point of view, with annual total costs of 175'204 €/a. With the Conventional Design, 1.08 million € can be saved compared to the design without HR, even during the four-year pay-off period, thanks to the energy and cost optimization with [PinCH](#).

Let's finally look at the GCC (Grand Composite Curve) in Figure 15.

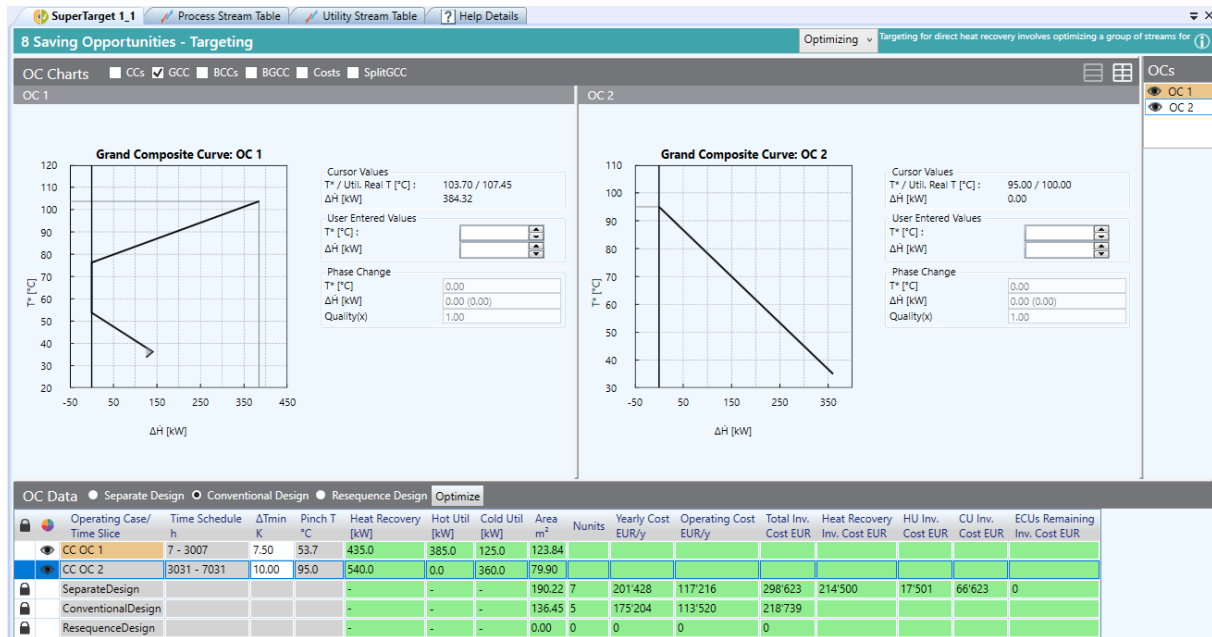


Figure 15: Grand Composite Curve of the two operating cases

The GCC is explained in [Tutorial 1](#); only a brief description of potential optimizations is given here. In OC1, there is a high heat requirement above the pinch point. Here, it can be interesting to expand the system boundary and examine production operation for other heat sources that have not yet been recorded (keyword: Total Site Analysis, or TSA for short).


Step 9: Integrate Energy Conversion Units (ECUs)

In OC1, there is a heat requirement of 384 kW between 80 °C and 107 °C (see Figure 15), so the possibility of integrating an ECU (e.g. combined heat and power plant, CHPP) would have to be checked. If an ECU is integrated in a production plant with MOC, the additional difficulty of the ECU having to be designed for both OCs arises. To evaluate the benefits of an ECU, further examinations are necessary, which go beyond the coverage of these tutorials.

Step 10: Design Heat Exchanger Network (HEN)

Congratulations! You have successfully completed targeting as the basis of energy and cost optimization of the process. The last step in PinCH now involves designing a MER HEN (Maximum Energy Recovery Heat Exchanger Network) for both OCs. Because it is not clear at this point which heat exchangers are overlapping between the OCs, a MER HEN must be created for each OC first of all. The engineer can decide afterwards during the overall design which heat exchangers can be omitted.

As already explained in [Tutorial 1](#), add a MER HEN to the "Super Target 1_1". Ensure that the "Conventional Design" is activated in the "Super Target 1_1".

 Right-click on "Super Target 1_1"

 Add HEN...  Add MER HEN

Note: You can view the HEN of the desired OC by selecting the OCs above the MER HEN.

First of all, let's consider OC1 and start with the sub-system below the pinch point. According to the design rules on creating a MER HEN (see references on page 1), we start with the highest heat capacity stream (highest CP) in the direction of the pinch point. In our case study, this is the Reactant B stream ($CP = 6 \text{ kW/K}$), the heat requirement of which we want to meet with as large a heat exchanger as possible. The Product C stream ($CP = 14 \text{ kW/K}$), which has a sufficiently large heat level, is suitable for this purpose. To complete the MER HEN in the sub-system below the pinch point, we link the Product C stream to the Cold Utility stream.

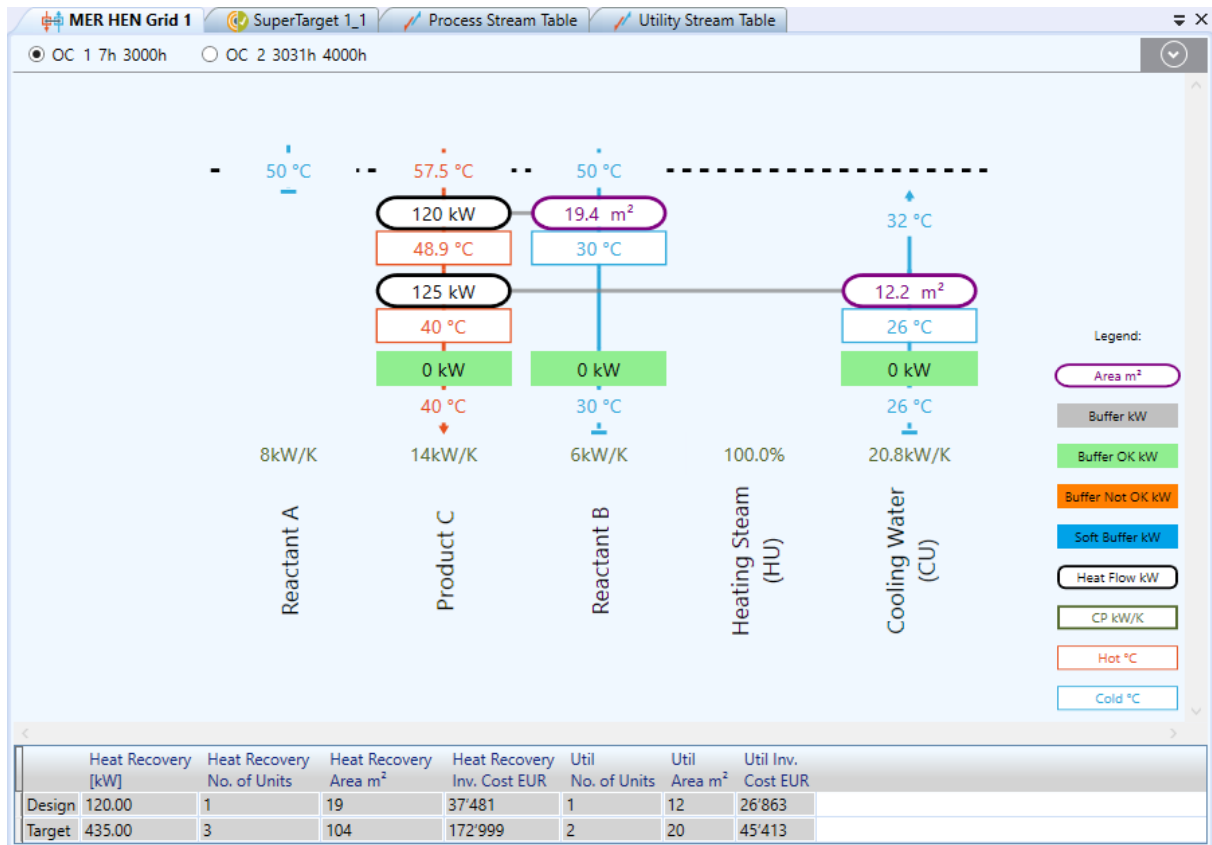


Figure 16: MER HEN in the sub-system below the pinch point for OC1

Note: Below the MER HEN, you can continuously track the heat recovery achieved (Heat Recovery column), the HEX area already used (Heat Recovery Area and Utility Area) and their costs (Heat Recovery Inv. Cost and Utility Inv. Cost) in the "Design" row. The target data for the HEN without reuse of heat exchangers is specified in the form of comparative figures.

Let's turn our attention to the sub-system above the pinch point: Try to position the required heat exchangers yourself.

As you have surely noticed, the flows cannot be readily connected here. The CP rule is violated; the Product C stream to be cooled has to be split. Split the heat capacity streams into 8 kW/K and 6 kW/K (CP of Product C must not be greater than the CP of Reactant B).

Let's continue with the highest heat capacity stream in the direction of the pinch point. Connect one

sub-stream of Product C to the Reactant A and Reactant B streams. Before we use the remaining heat exchangers, the branches of the split Product C are reconnected.

To complete the MER HEN, connect the two streams, Reactant A and Reactant B, to the HU utility stream.

The complete MER HEN of OC1 is as follows:

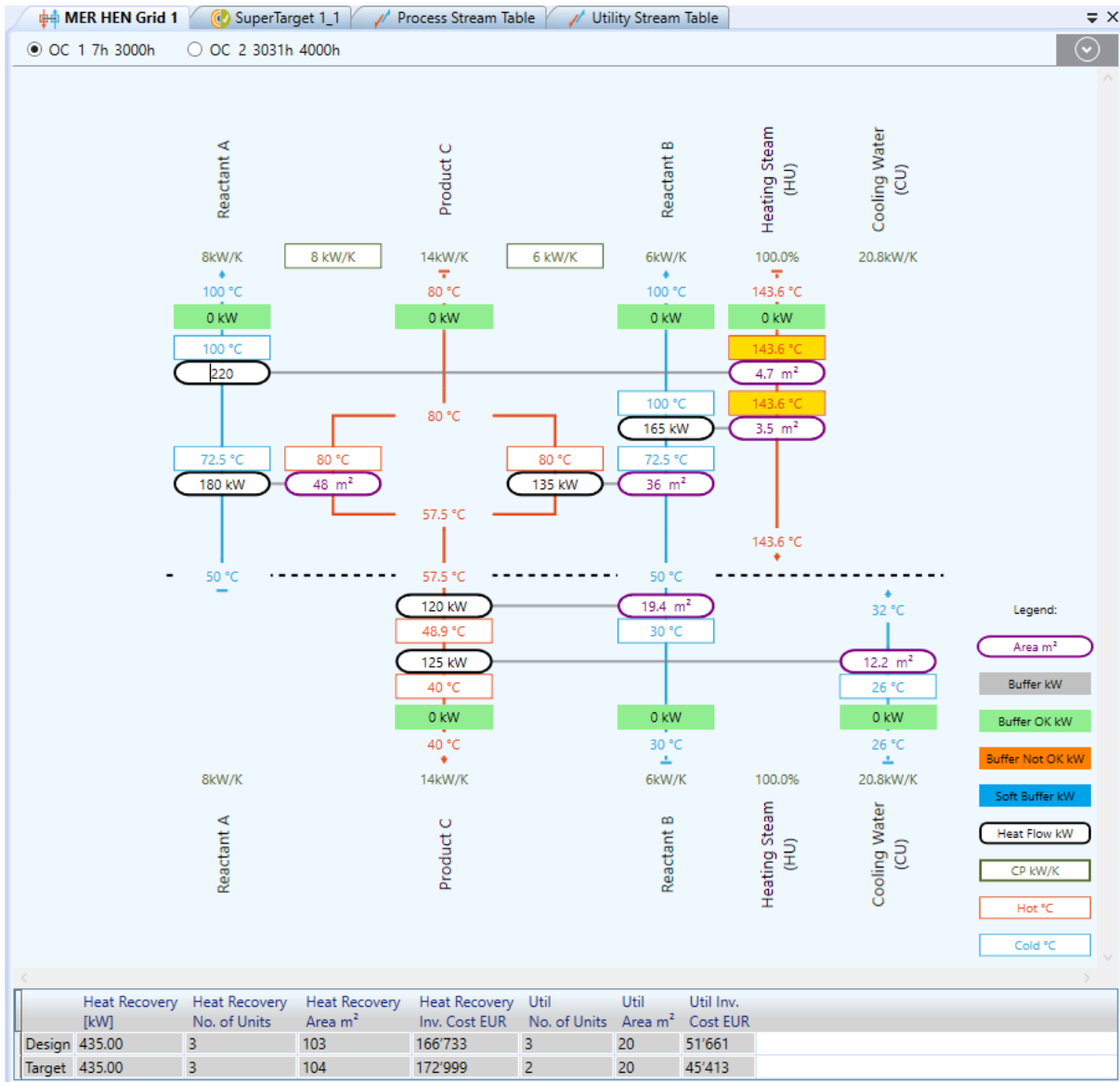


Figure 17: MER HEN of operating case OC1

Now try to create the MER HEN for OC2 by yourself.

The complete MER HEN of OC2 is as follows:

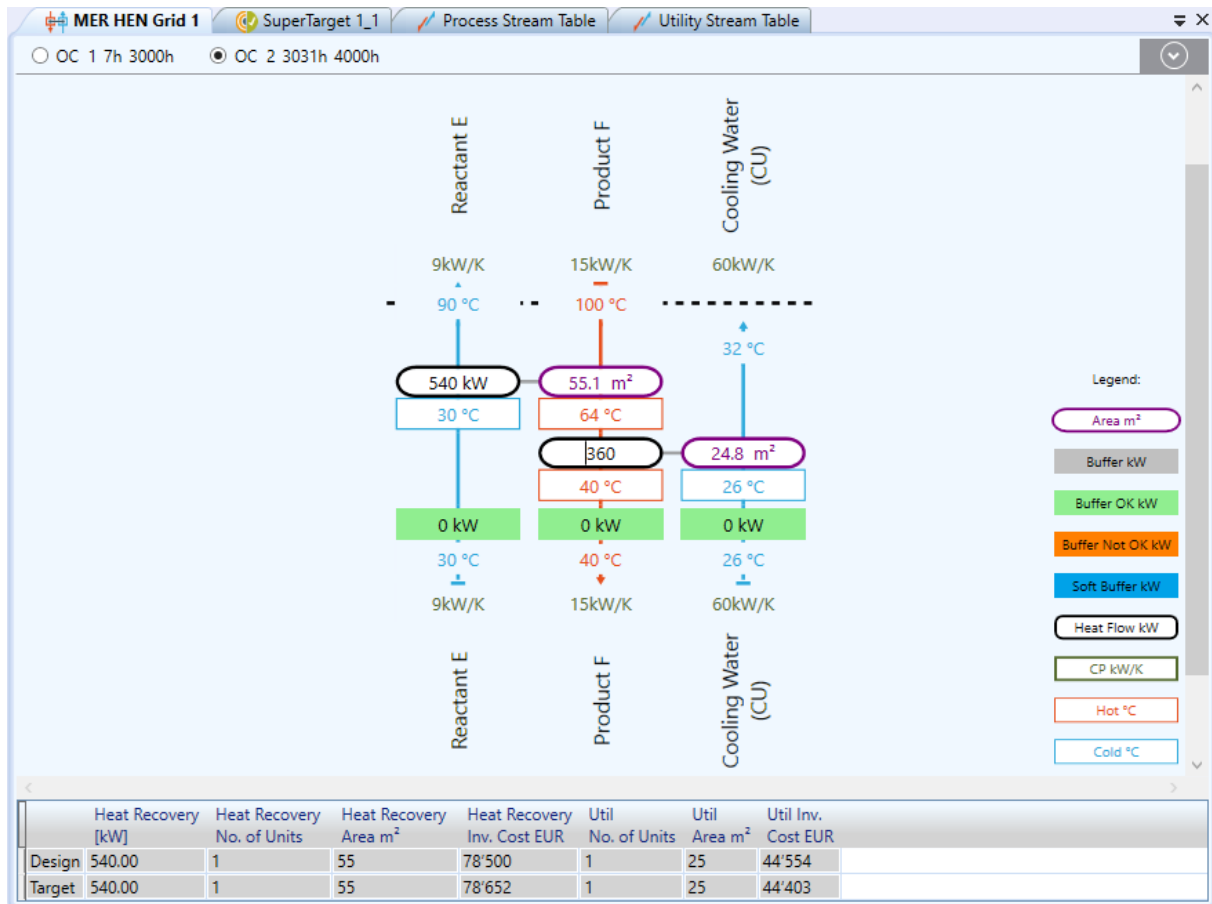


Figure 18: MER HEN of operating case OC2

Once the MER HENs have been created for both OCs, the comparison between "Design" and "Target" can be performed:

For OC Product C (OC 1), investment costs of 218'394 € are incurred (total of Heat Recovery Inv. Cost and Util Inv. Cost). This almost corresponds to the target investment costs (difference of only 18 €).

For OC Product F (OC 2), investment costs of 123'054 € are incurred, which almost exactly corresponds to the target investment costs (123'055 €). These two MER HEN designs come very close to the target values from [Step 8](#).

IV Optimized Production Plant

A process flow chart which covers the two OCs can now be created from the combination of the two MER HENs. The aim in this regard is to use the heat exchangers in both OCs if possible and thereby reduce the number of heat exchangers. In our case study, this affects the heat exchangers in light green and dark green in Figures 19 and 20. The light-green HEX in OC Product C has a HEX area of 19.4 m^2 determined by PinCH, and in OC Product F a HEX area of 55.1 m^2 :

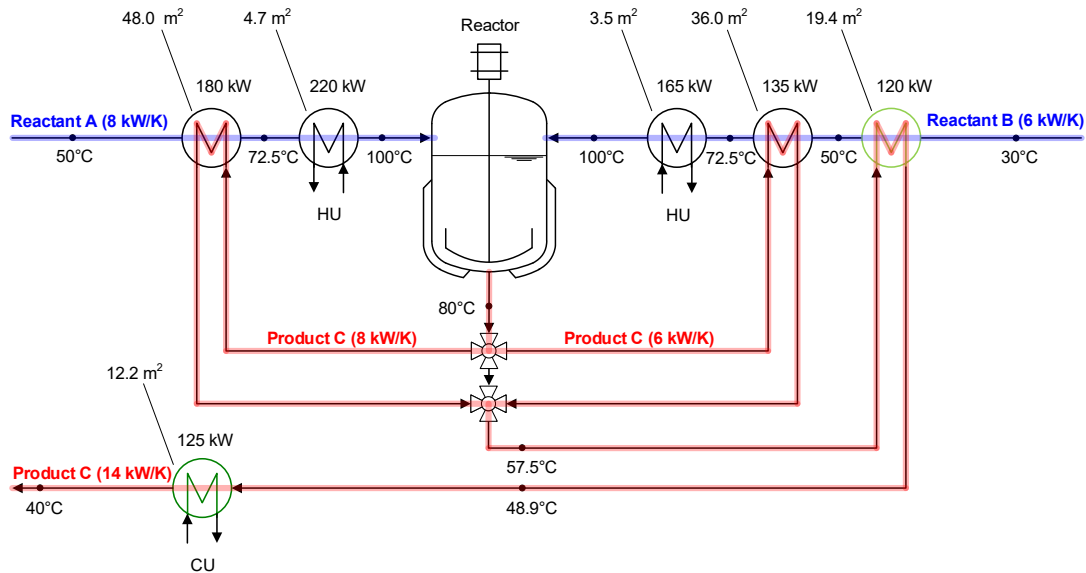


Figure 19: Process flow chart of the optimized production plant. The process requirements of OC Product C (OC 1) are colored.

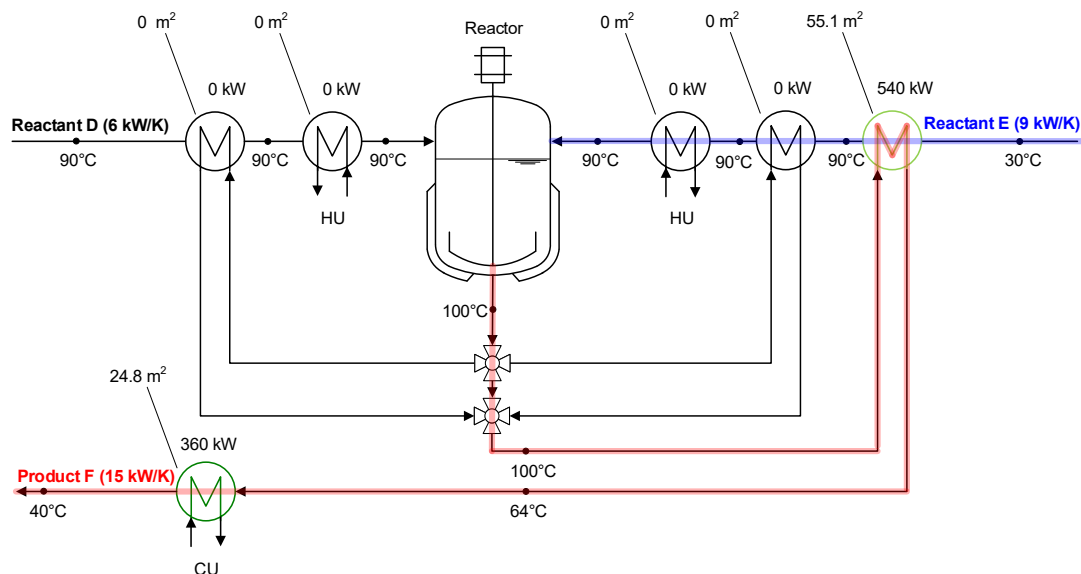


Figure 20: Process flow chart of the optimized production plant. The process requirements of OC Product F (OC 2) are colored.

To meet the process requirements of both OCs, the light-green HEX with the larger area (55.1 m², OC2) is now used, and the other area (19.4 m², OC1) is omitted. This results in a cost saving of 24'701 € due to the omission of the combined light-green HEX.

The HEX in dark green with an area of 12.2 m², which would incur costs of 34'335 €, can be omitted. The HEX from OC2 can therefore be reused in OC1. By reusing the HEX area, investment costs of 24'701 € + 34'335 € = 59'035 € are saved compared to the Separate Design.


In Table 6, the design without HR is compared with the optimized design.

Table 6: Comparison of the planned plant without HR with the optimized plant

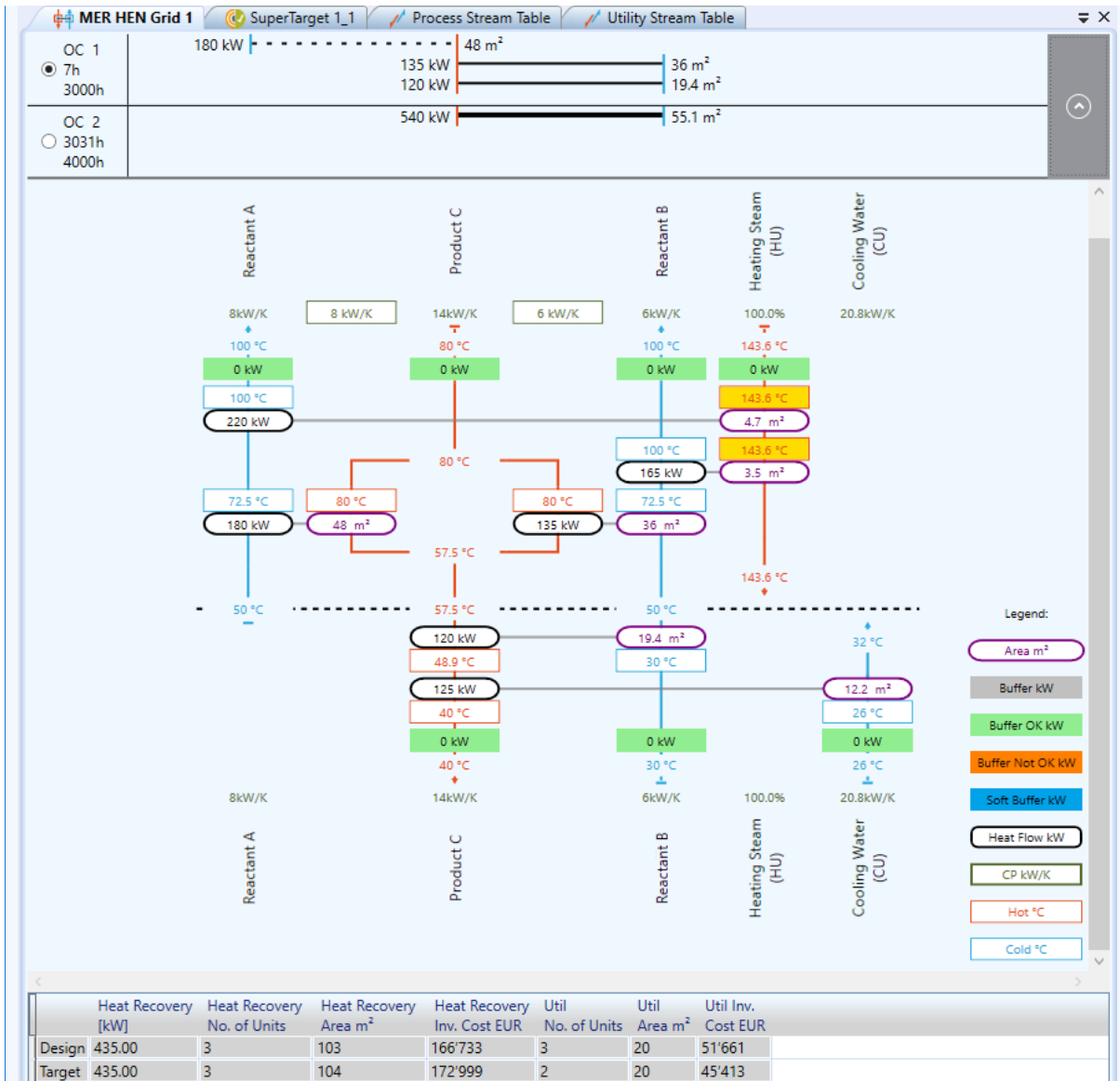
	HU		CU		Invest. Costs [€/a]	Energy Costs [€/a]	Annual Total Costs [€/a]
	[kW]	[MWh/a]	[kW]	[MWh/a]			
Design without HR							
OC 1	820	2'460	560	1'680	-	202'440	-
OC 2	540	2'160	900	3'600	-	216'000	-
Total	-	4'620	-	5'280	26'070	418'440	444'510
Optimized Design							
OC 1	385	1'155	125	375	-	87'600	-
OC 2	0	0	360	1'440	-	25'920	-
Total	-	1'155	-	1'815	79'646	113'520	193'166
Saving							
OC 1	435	1'305	435	1'305	-	114'840	-
OC 2	540	2'160	540	2'160	-	190'080	-
Total	-	3'465	-	3'465	-53'576	304'920	251'344

With the optimized design, the annual total costs can be reduced by 251'344 €/a. This corresponds to a reduction of 57 %.

Note: For creating a process flow chart which covers both OCs, PinCH offers two more HEN design tools to support you:

The **Mini Map Tool** can be found above the HEN if you click on the arrow  when selecting the OCs. It shows the heat exchangers between process streams in the activated OC and also the heat exchangers for the same lines of all other OCs. The heat exchangers are either shown as a dashed black line (if there are no other heat exchangers between the lines used), as a black line (if there are more heat exchangers between the lines used) and as a thick black line (the HEX which has the largest HEX area, if there are one or more heat exchangers between the lines used).

In the mini map in the figure below, you can see that the HEX with a HEX area of 55.1 m² from OC 2 could theoretically be replaced by two more HEX in OC 1. The further analysis starts with the HEX with 19.4 m².



Now, it would be interesting to see what effects increasing the HEX area of the HEX to be replaced from 19.4 m² to 55.1 m² would have. The second tool meets this requirement exactly:

With the **Area-Temperature Calculation Tool**, the inlet and outlet temperatures, the HEX area and the ΔT of a HEX can be examined in more detail. To open it, right-click on the HEX to be examined directly in the HEN and select "Display Area-Temperature Tool". Two HEX temperatures can be fixed by ticking the boxes next to a temperature. In the middle, the HEX area is adjusted from 19.4 m² to 55.1 m². Clicking on the "Calculate" button allows you to track what is happening when the HEX area is increased:

Area-Temperature Calculation Tool

Area-Temperature Calculation Tool

First of all, the HEX falls below the ΔT_{min} ; instead of a ΔT of at least 8.50 K, a HEX ΔT of 1.37 K results. Secondly, due to the increased HEX, heat is transferred over the pinch point (cf. pinch main rules in the references on page 1).

The engineer is responsible for development of the final design. In this case, it should be examined whether a bypass can be used to comply with the temperature requirements.

Thank you for your time!

You are now familiar with the most elementary steps of using PinCH to perform a pinch analysis on a process with different operating cases. Please do not hesitate to contact us if you have any questions. The PinCH team of the Lucerne University of Applied Sciences and Arts and the Centre de Compétence PinCH Francophone of the School of Management and Engineering Vaud are available at your convenience. Please also note the option of coaching to assist with and ensure the quality of your pinch analyses. Learning by doing in this way has already proved to be an excellent experience on multiple occasions. In any case, we hope you have lots of fun and wish you every success with PinCH. Thank you so much for taking the time to join us! For more information, please visit our website www.pinch-analyse.ch. You will find our contact details below.

Kind regards,
the PinCH team of Lucerne University of Applied Sciences and Arts

English and German Contact:

Lucerne University of
Applied Sciences and Arts
Competence Center Thermal Energy
Systems and Process Engineering
Technikumstrasse 21
CH-6048 Horw
Prof Dr Beat Wellig
T +41 41 349 32 57
pinch@hslu.ch

French Contact:

Haute Ecole d'Ingénierie et de
Gestion du Canton de Vaud
Institut de Génie Thermique
Centre de compétence PinCH francophone
Avenue des Sports 20
CH-1401 Yverdon-les-Bains
Dr Pierre Krummenacher
T +41 24 557 61 54
pinch@heig-vd.ch



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