Expert-system for an INtelligent Supply of Thermal Energy in Industry
and other Large Scale Applications

EINSTEIN Show Case

"DemoTFC"

Demonstration of EINSTEIN Functionality

EINSTEIN Show Case “DemoTFC”

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1 Description of the Show Case

1.1 Motivation for the Design of the Show Case

A show case for demonstration of the EINSTEIN functionality has been built around one of the i-ThERM pilot projects for heat to power conversion, as those pilot projects are currently at the most advanced stage.

Waste heat to power conversion with relatively low conversion efficiencies (25 % or less) in most cases is not competitive with direct heat recovery, whenever there is an appropriate demand for heat at sufficiently low temperature and comparable amount of energy (although limit cases may arise due to too large distances between the origin of waste heat and the heat consumer, which would lead to a too high additional investment for piping).

Therefore, in our show case we suppose that there is a waste heat stream appropriate for heat to power conversion (HTP), but no corresponding appropriate and nearby low temperature heat demand. As possible alternative system we consider the use of the waste heat in a high temperature heat pump (HP), for providing saturated steam at a temperature well above the temperature of the available waste heat.

The outcome of a comparative analysis of those systems depends on the relative index (cost, ratio of environmental parameter: primary energy, CO2, etc.) between the fuel saved (e.g. natural gas) and the electricity saved (in the case of waste heat to power) or consumed (in the case of a high temperature heat pump). Following Figure 1 (see Annex 2 for the mathematics behind), and depending on the conversion efficiencies for both technologies, the break-even is between a relative index electricity/fuel of 1,5 (for high efficient HTP and low efficiency HP) and 2,5 (vice versa). Furthermore, economic analysis of course in addition depends on the relative investment costs of both technologies.

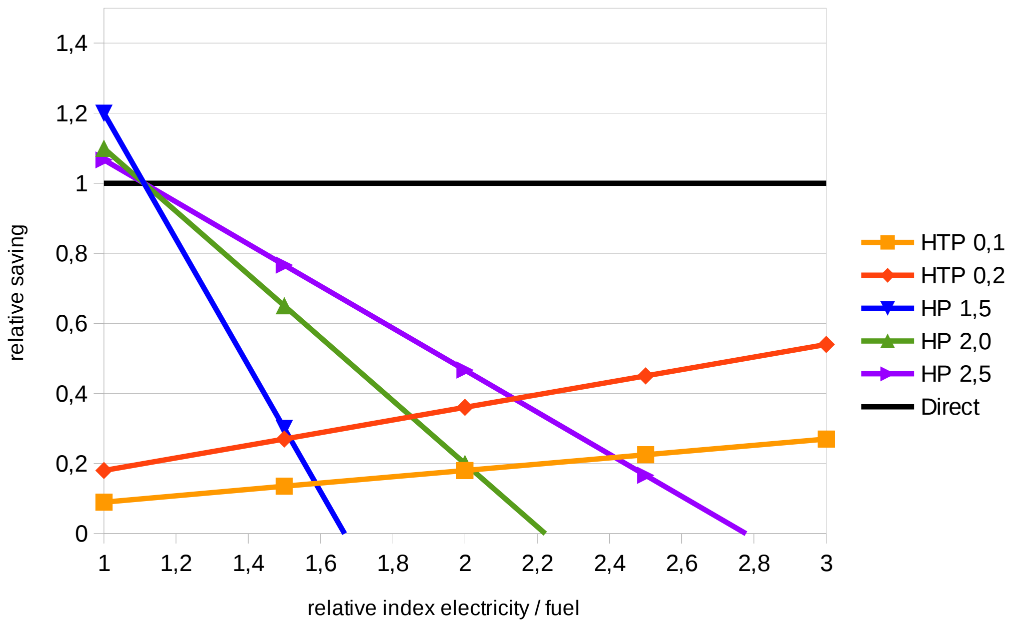


Figure 1. Relative saving (cost, primary energy, CO_2, etc.) per unit of available (waste) heat as a function of the relative index of electricity vs. fuel used. HTP: heat to power conversion with net electric efficiency 0,1 and 0,2. HP: heat pump with effiencies 1,5, 2,0 and 2,5 (COP for heating). Reference conversion efficiency for heat generation: 0,9. Direct heat recovery is used as reference defining the level of relative saving = 1,0.

In the following sections some of the most important tool features are demonstrated for the use case system design (energy audit).

1.2 Collect Data: Building a Model for the Base Case Scenario

The first step in energy assessment is the collection of available data:

- an inventory of utilities and processes including all the relevant technical data
- operating and boundary conditions (e.g. production volumes, etc.)

a) an inventory of utilities and processes

The scheme of the base case scenario is shown in Figure 2. In the system there are three heat consuming processes:

- "***process_WH***": a process consuming some high temperature heat at 170 °C and generating waste heat in form of hot cooling water at 90 °C.
- "***steam_LP***": a process consuming low pressure steam at 120 °C (2 bar).
- "***buildings heating***": Space heating demand for buildings

Heat supply is provided by a steam boiler generating high pressure steam at 180 °C and 10 bar, supplying heat to the processes "***process_WH***" and "***steam_LP***", and a hot water boiler providing hot water for space heating. Both boilers are fired by natural gas. The full data set (list of input parameters) describing this base case is given in Error: Reference source not found.

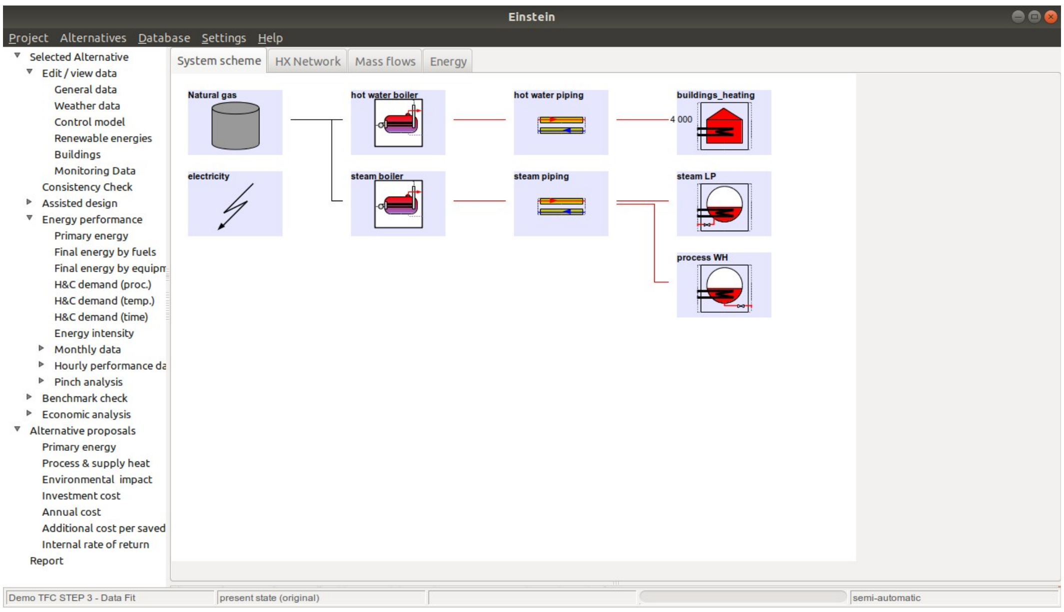


Figure 2. Scheme of the system (base case scenario)

Table 1. Listing of input parameters for the EINSTEIN model.

Parameter	Unit	Value
Processes		
Process WH (process generating waste heat)		
heat demand (maintenance)	kW	2 649
process temperature	°C	170
minimum temperature difference for heat supply	K	0
residual heat: cooling water	medium	water
cooling water flow rate	kg/h	30 347
cooling water outlet temperature	°C	90
Steam LP (process consuming low pressure steam)		
heat demand (maintenance)	kW	1 600
process temperature	°C	120.5
minimum temperature difference for heat supply	K	0
heat demand (inflow of feed water)	medium	water
feed water flow rate	kg/h	2617
feed water inlet temperature	°C	60
Building		
yearly heating demand for space heating	MWh	4 000
yearly demand for cooling and air conditionning	MWh	0
daily demand for domestic hot water	m3	0
period for space heating		from 01.10 to 31.03
required temperature level for heat supply	°C	55
indoor temperature	°C	20
Heat supply and distribution		
High pressure steam	medium	steam_10bar
type of boiler / fuel		steam boiler / natural gas
nominal power (heat output)	kW	10 000
boiler efficiency	%	90
steam temperature (forward / return)	°C	180.0 / 80.0
rate of recirculation of condensate	%	100
piping length (one way)	m	800

Table 1. (continued)

Parameter	**Unit**	**Value**
Hot water (space heating)	medium	water
type of boiler / fuel		hot water boiler / natural gas
nominal power (heat output)	kW	4 000
boiler efficiency	%	90
hot water temperature (forward / return)	°C	70.0 / 55.0
rate of recirculation	%	100
piping length (one way)	m	10 000
Other information		
Fuel and electricity tariff		water
Natural Gas	€/MWh	40.0
Electricity (purchase / sales)	€/MWh	100.0 / 100.0
Products		water
Some product	t	n/a
Period of operation of the plant		water
Days per year	d	365
Hours per day	h	12.0

b) operating and boundary conditions

In the present show case it is supposed that the only available information on the schedules of processes in time are available monitoring data, which nevertheless are not directly monitoring the processes' operation.

The available monitored data are:

- the steam generation in the steam boiler supplying both processes
- the hourly production volume of the final product

The latter one can be correlated to the cooling water flow of process "***process_WH***".

In order to build a base case scenario it is furthermore supposed that production will increase by about 25 %.
Monitoring data are available in form of a csv-data file and can be automatically imported and scaled up, accounting for the expected growth rate.

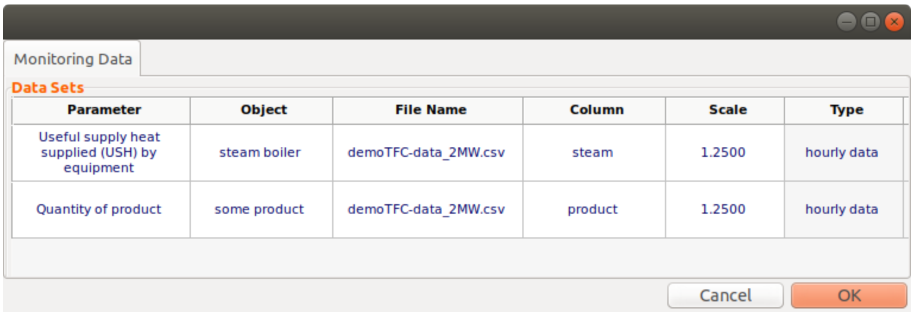


Figure 3. Association between monitoring data and the corresponding quantities in the system model as defined in the EINSTEIN GUI: steam flow rate provided by the steam boiler and quantity of product "some_product" produced. A scaling factor of 1,25 is applied in order to account for an increase in production volume in the future.

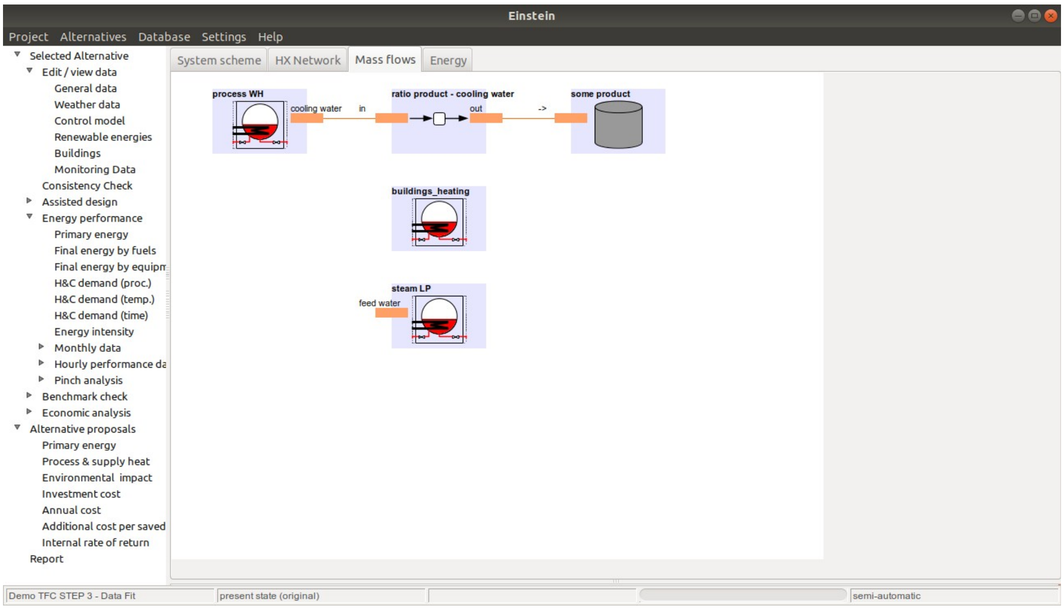


Figure 4. Correlation between cooling water flow (output of process_WH) and quantity of product "some_product" in the mass flow editor within EINSTEIN.

Operation schedules of the processes are then calculated by automatic parameter fitting. The estimation of the time schedule of process "process_WH" in this example is trivial, as the process heat demand is proportional to the production quantity specified within the data.

$$UPH_{process\,WH}(t) = c * m_{some_{product}}(t) \qquad (1)$$

The estimation of the time schedule of process "steam_LP" nevertheless even in this simple example is more complex, as it is related to the 2 data sets and – in addition – to the heat losses in the steam piping defining the distribution efficiency η_{dist} with some degree of uncertainty:

$$USH(t) = \eta_{dist} * (UPH_{process\,WH}(t) + UPH_{steam\,LP}(t)) \qquad (2)$$

With Eq. 1 for $UPH_{process\_WH}$ this gives

$$UPH_{steam\,LP}(t) = \frac{USH(t)}{\eta_{dist}} - c * m_{some\ product}(t) \qquad (3)$$

The resulting time schedule for the heating demands can be seen in Figure 5.

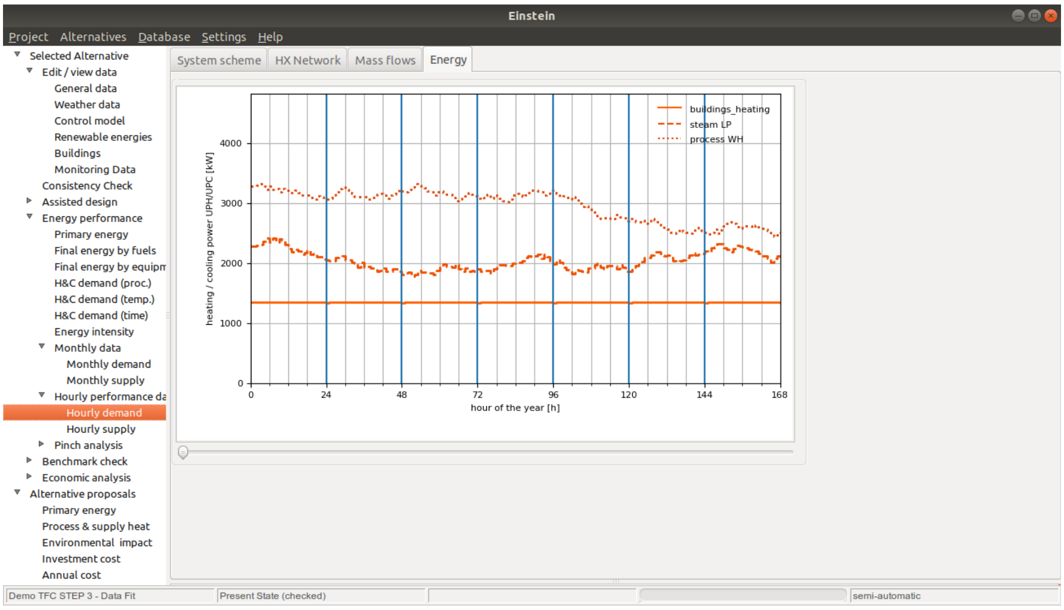


Figure 5. Hourly heating demand for the three processes as a result of data fitting. Shown for the first week (168 hours) of the year.

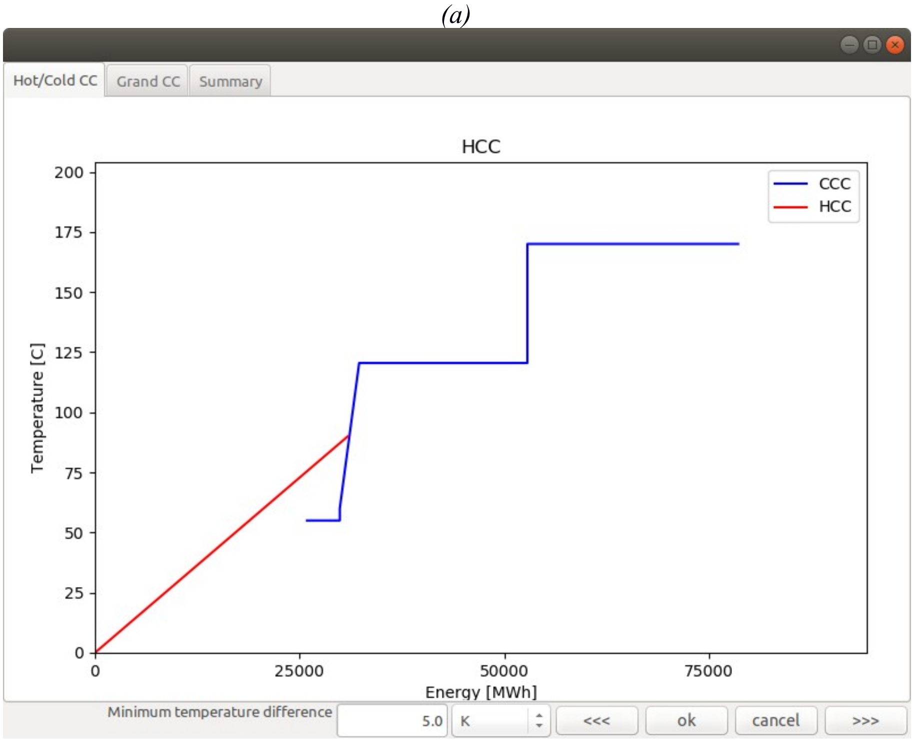
1.3 Proposal for Heat Exchanger Network

a) analysis and detailed breakdown of present state

One of the most important data to be used as starting point for evaluation the potential for heat recovery and designing a heat exchanger network is carrying out pinch analysis for the present state situation. This is done automatically by EINSTEIN once the model for the base case scenario is completed (Figure 6).

From Figure 6a a theoretical heat recovery potential for covering all heat demands below 85 °C can be seen, this is part of the preheating demand for process “steam_LP” and the building heating demand. The lower part of the Grand composite curve in Figure 6b shows the amount and quality (temperature level) of waste heat which would still be available even after all the heat recovery potential has been exploited.

(a)



(b)

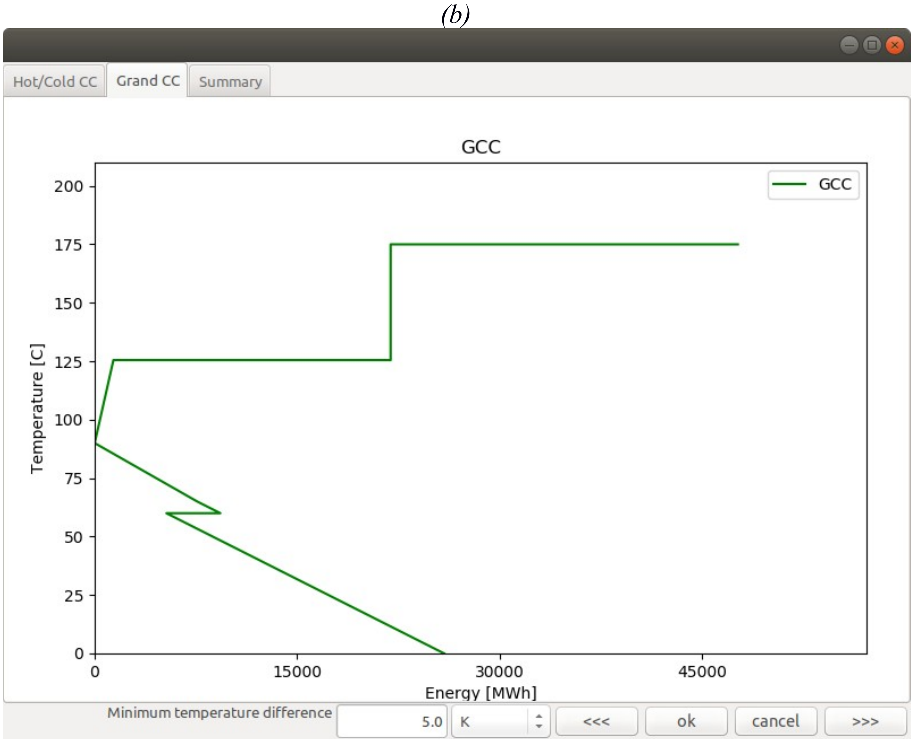


Figure 6. Results of pinch analysis. (a) Hot and cold composite curves; (b) Grand composite curve. ΔT = 5K.

b) first approach: automatic design of HX network

EINSTEIN design assistants provide tools for (semi-) automatic pre-design of energy saving options. In this case the automatic pre-design of a heat exchanger network is demonstrated.

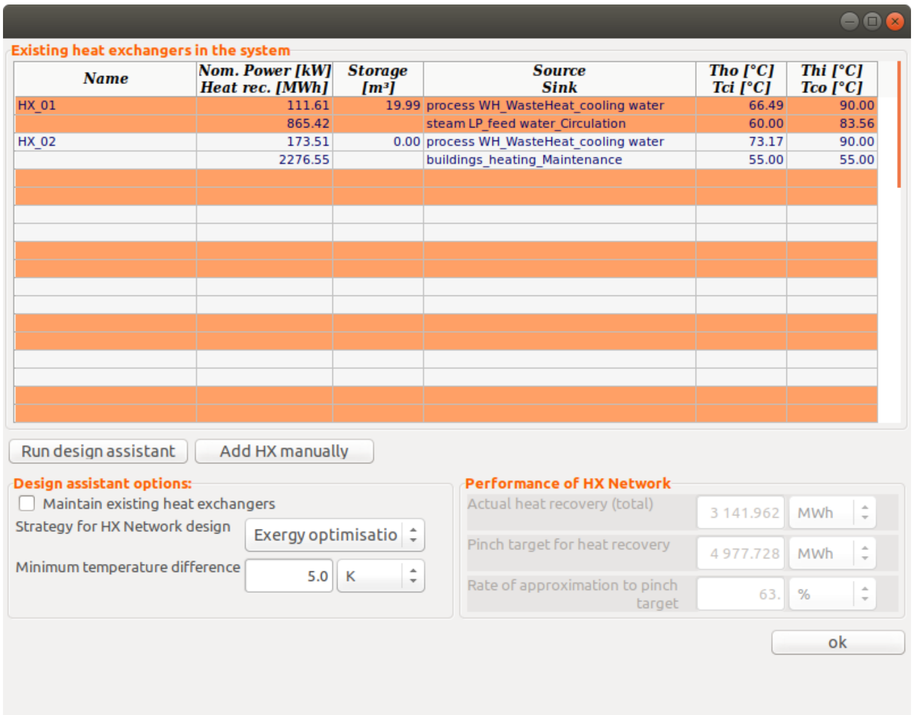


Figure 7. EINSTEIN design assistant showing results of the automatic pre-design of a heat exchanger network.

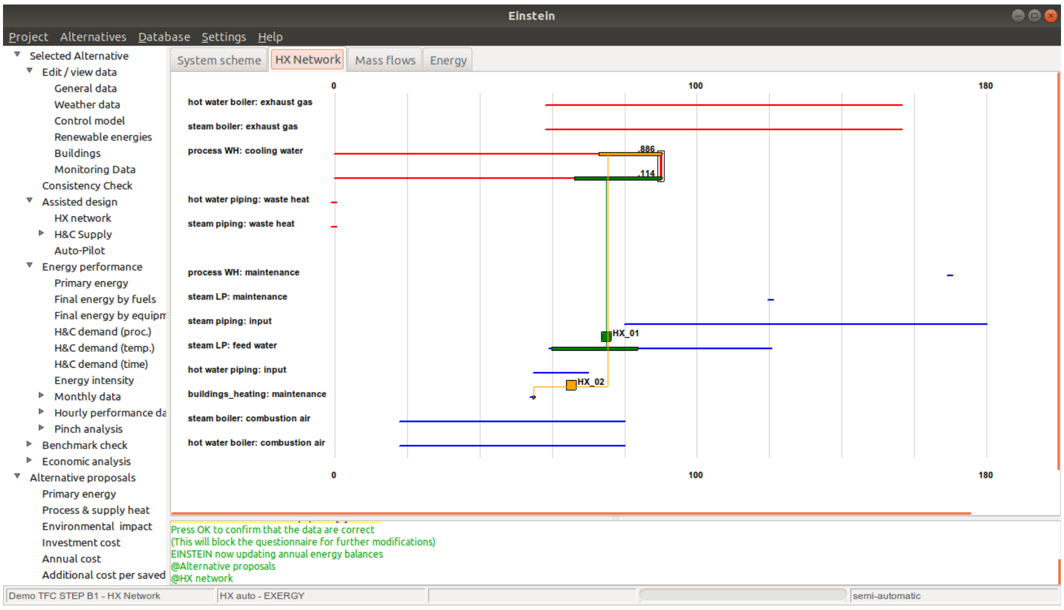


Figure 8. Scheme of the resulting heat exchanger network

c) manual fine tuning

Supposing that – e.g. due to non technical reasons, such as cost of piping, contractual issues, etc. - feeding recovered heat for providing space heating in buildings is not possible, the corresponding heat exchanger can be manually deleted from the system, maintaining only the proposed heat exchanger for feed water preheating.

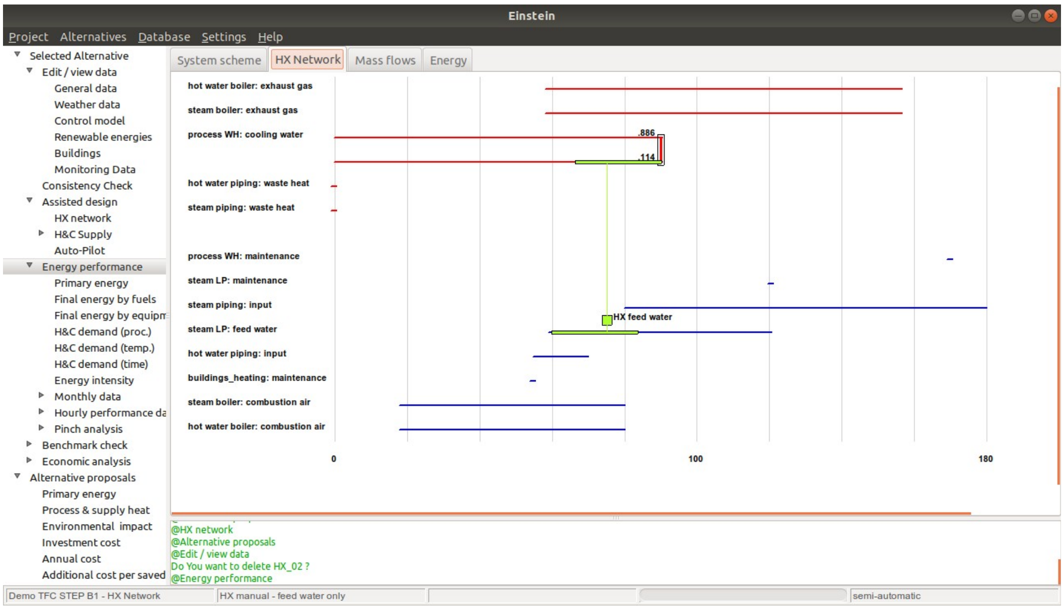


Figure 9. Scheme of the remaining heat recovery after manual fine tuning

1.4 Proposal for Waste Heat to Power Conversion

a) design of the alternative scenario and analysis of energy performance

In a new alternative scenario, a waste heat to power (HTP) conversion unit using a low temperature heat source can be manually added to the system (Figure 10). Figure 11 and Figure 12 show the points of operation of the system (electric efficiency as a function of driving tempearture and part load behaviour).

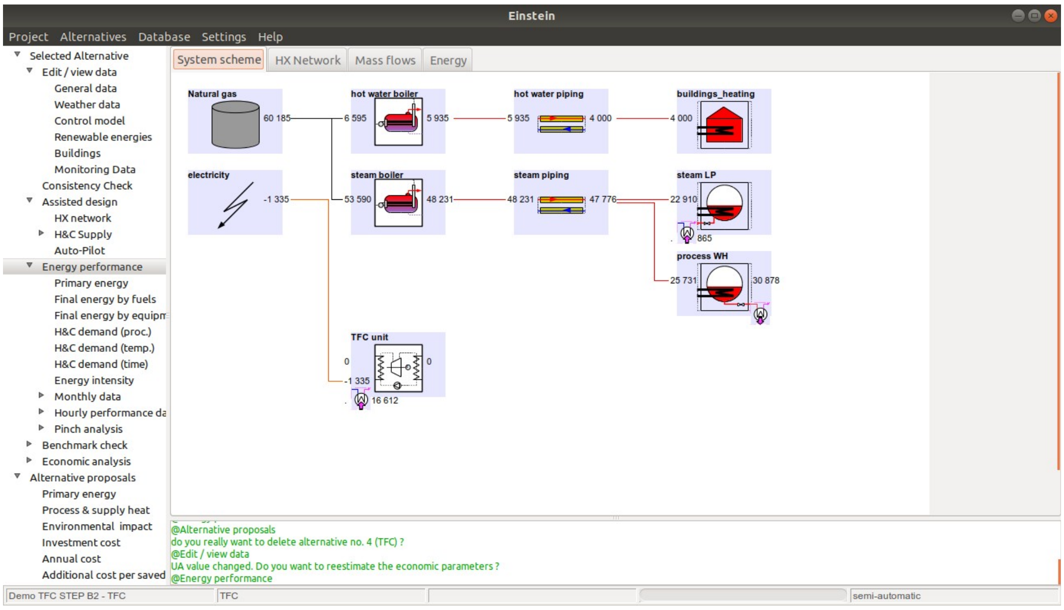


Figure 10. Scheme of the new system including a HTP unit

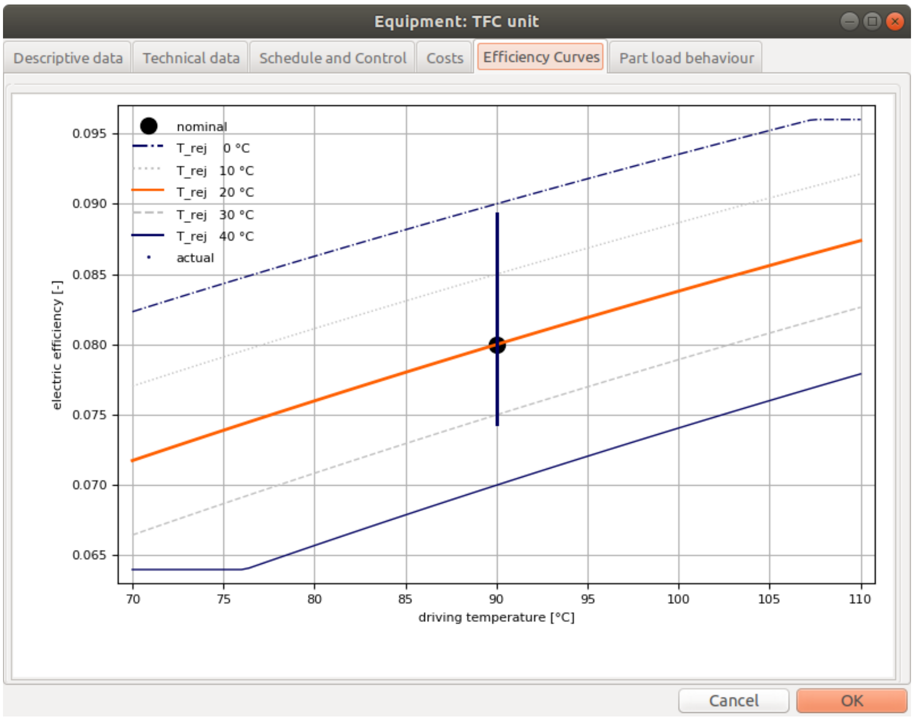


Figure 11. TFC unit. Electric efficiency as a function of the driving temperature. Region of operating temperatures in the example.

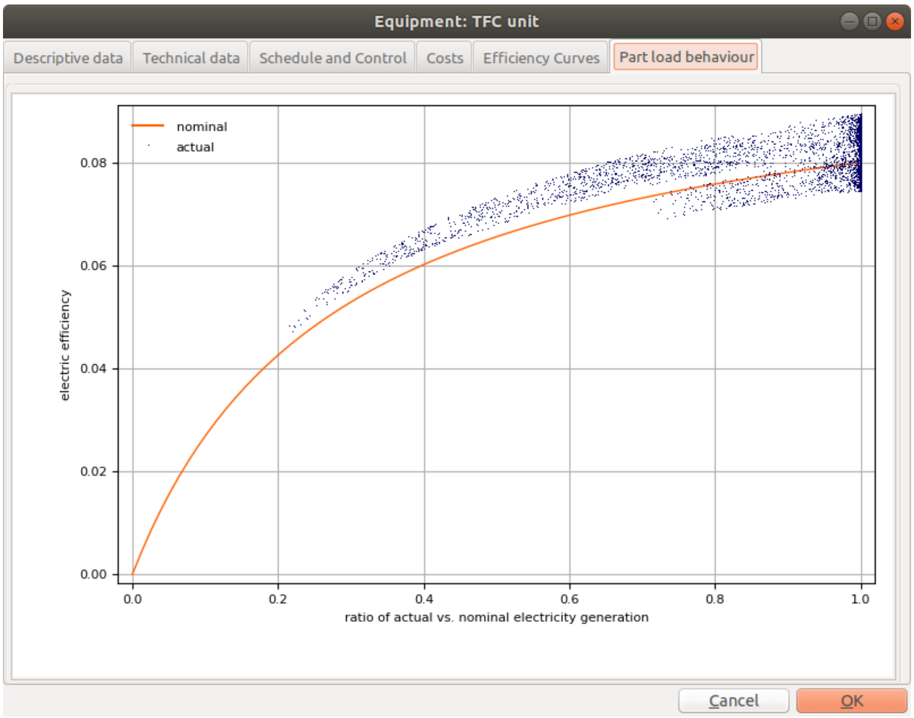
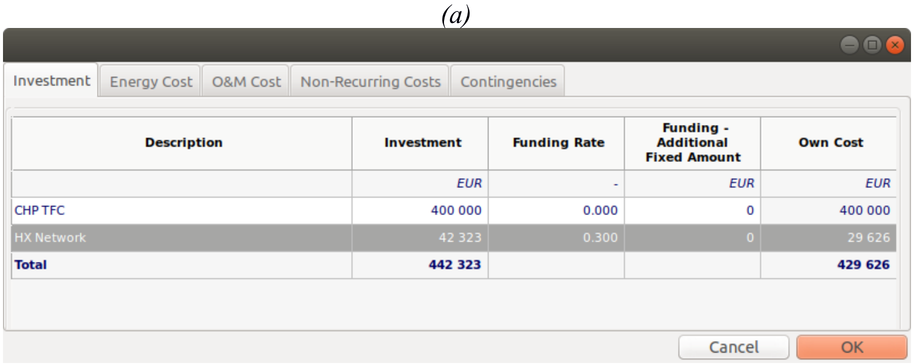


Figure 12. Electric efficiency as a function of the part load ratio. Dots indicate the range of actual operating conditions in the example.

b) economic analysis

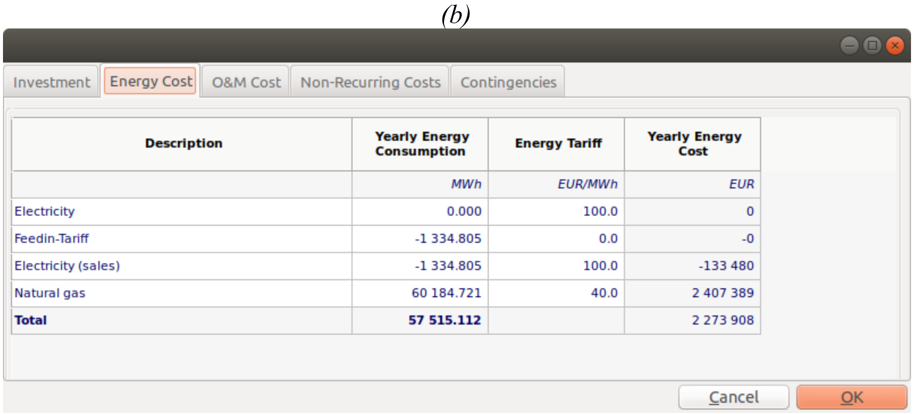
EINSTEIN allows also for economic analysis. Some details for the given example are shown in the following figures. Figure 13 shows some of the cost details (here: investment cost and subsidies, energy costs) for the alternative scenario with a TFC unit. The resulting summary of economic performance is given in Figure 14.

(a)



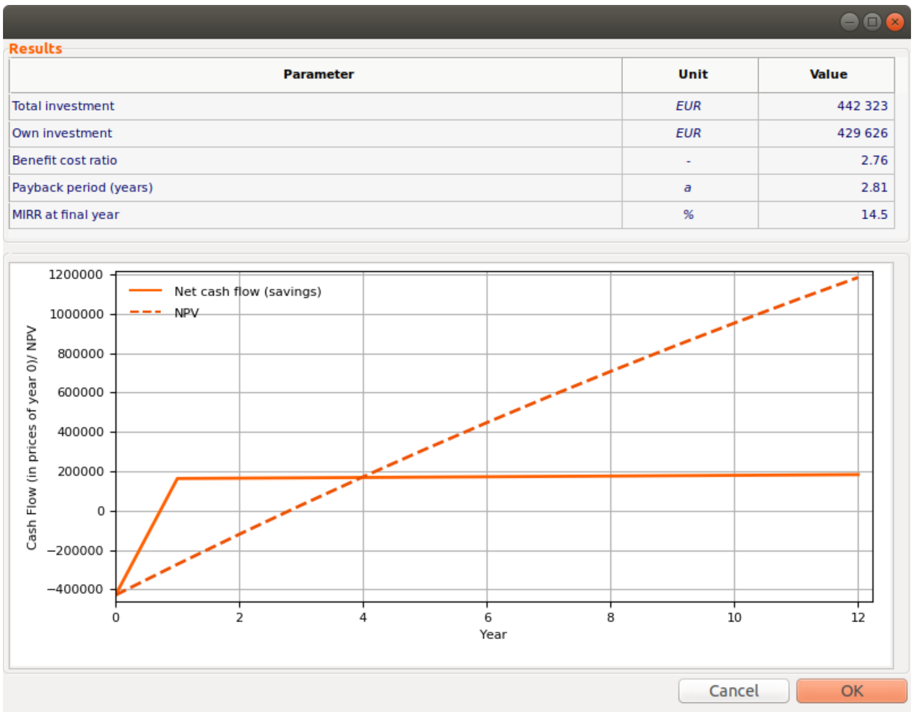
Description	Investment	Funding Rate	Funding - Additional Fixed Amount	Own Cost
	EUR	-	EUR	EUR
CHP TFC	400 000	0.000	0	400 000
HX Network	42 323	0.300	0	29 626
Total	**442 323**			**429 626**

(b)



Description	Yearly Energy Consumption	Energy Tariff	Yearly Energy Cost
	MWh	EUR/MWh	EUR
Electricity	0.000	100.0	0
Feedin-Tariff	-1 334.805	0.0	-0
Electricity (sales)	-1 334.805	100.0	-133 480
Natural gas	60 184.721	40.0	2 407 389
Total	**57 515.112**		2 273 908

Figure 13. Cost details for the alternative scenario with TFC unit: (a) investment cost and subsidies; (b) energy costs and revenues from electricity sales.



Parameter	Unit	Value
Total investment	EUR	442 323
Own investment	EUR	429 626
Benefit cost ratio	-	2.76
Payback period (years)	a	2.81
MIRR at final year	%	14.5

Figure 14. Economic performance for the alternative scenario with TFC unit.

1.5 Proposal for a High Temperature Heat Pump

The installation of a high temperature heat pump could be a possible competing technology for the previously proposed heat to power conversion. In this case a heat pump would rise the temperature of the available waste heat from below 90 °C to above 120 °C in order to reuse the energy for process heating.

A preliminary design can be done for example with the semi-automatic design assistant for heat pumps in EINSTEIN. Figure 15 shows the scheme of the new system with heat pump and Figure 16 shows the contribution of the heat supply equipment to the total heat demand.

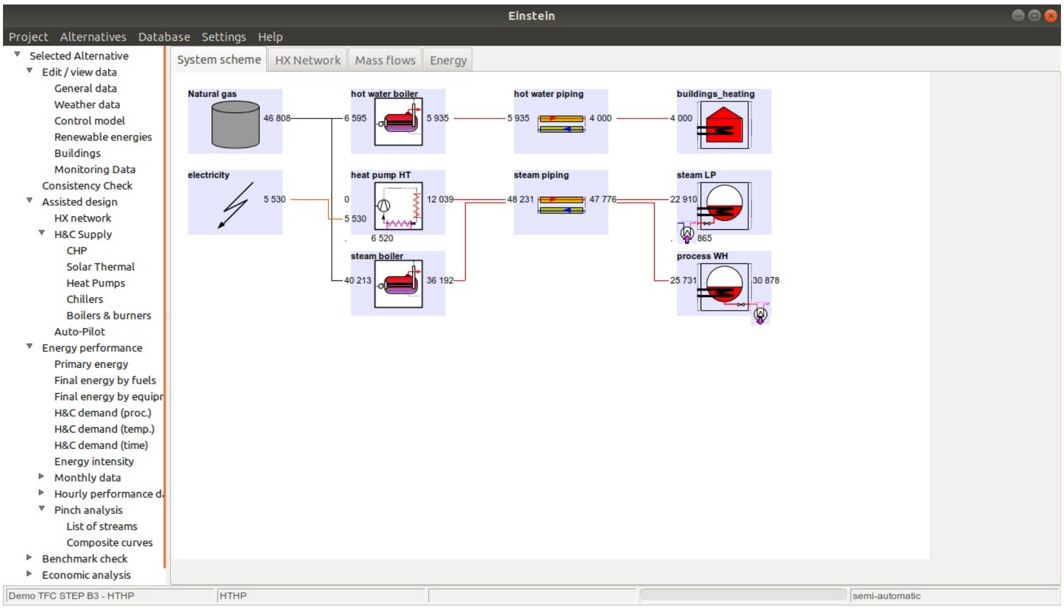


Figure 15. Scheme of the system with high temperature heat pump.

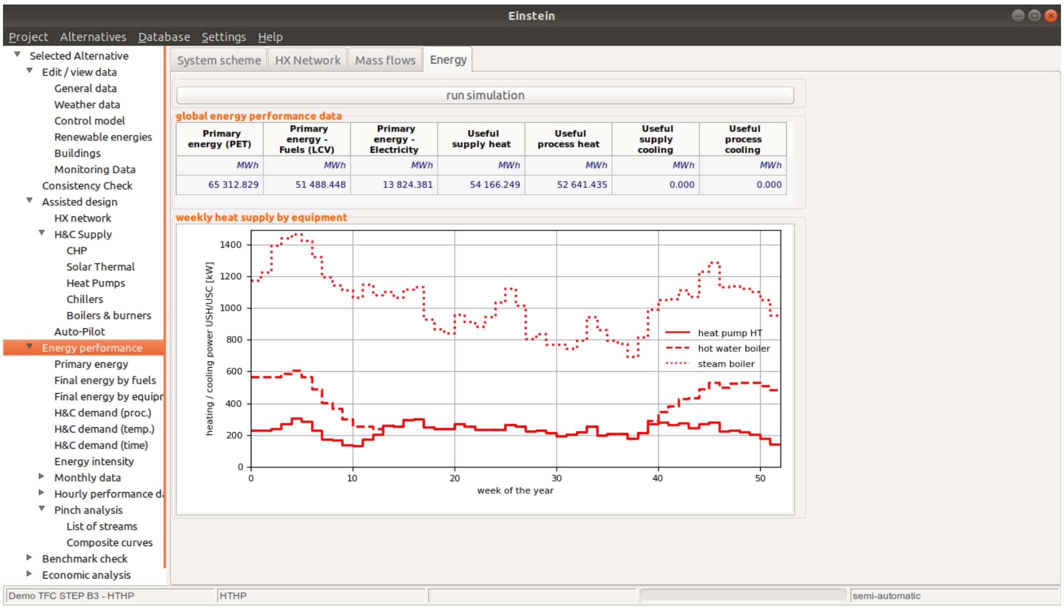


Figure 16. Contribution of equipment to the total heat supply.

1.6 Compare and Select the Best

The overall performance of the systems can be compared with regard to energy (Figure 17), environmental and economic (Figure 18) performance. With regard to economic performance, also the influence of a reduced energy tariff (reduction from 100 to 80 EUR/MWh, corresponding to a ratio of 2,5:1 and 2,0:1 of electricity and natural gas tariffs) has been studied. From Figure 19 it can be seen, that in the system with TFC the total yearly energy system costs slightly increase, as revenues from electricity sales are lower. On the contrary, for the system with high temperature heat pump energy costs are significantly lower, as the cost for electricity driving the heat pump is reduced.

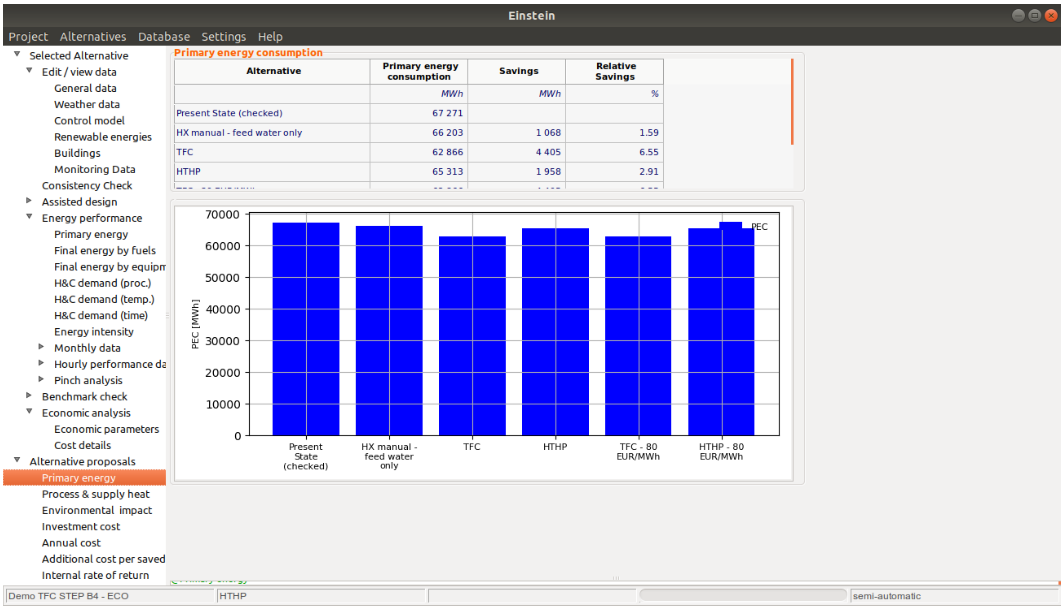


Figure 17. Comparative study: primary energy consumption

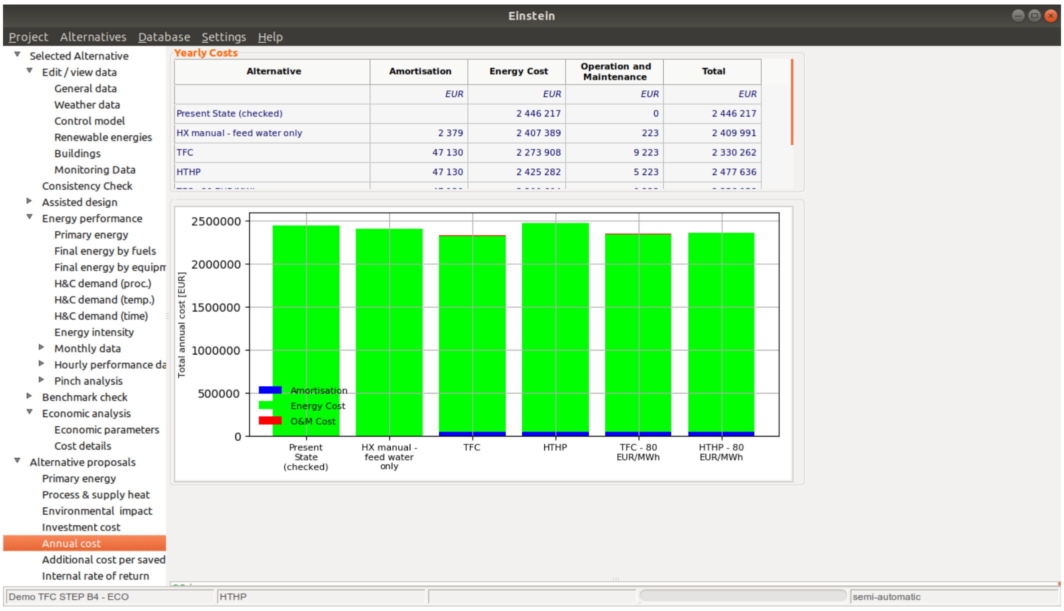


Figure 18. Comparative study: total yearly energy system costs composed by amortisation of initial investment, energy costs and revenues, and O&M costs.

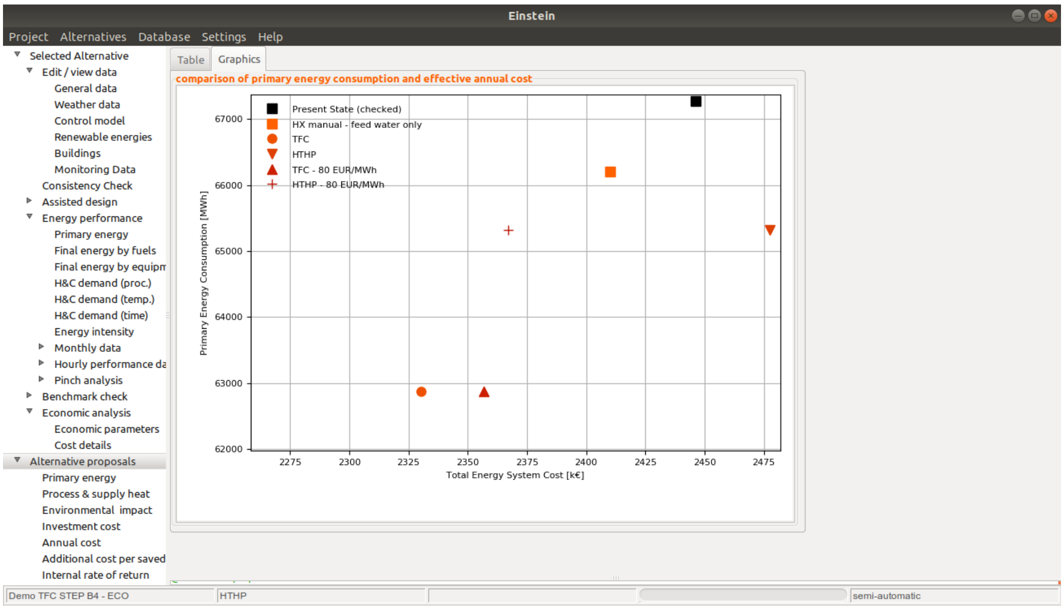


Figure 19. Comparative study: two dimensional graphical comparison of alternative proposals: primary energy and yearly total energy system cost.

1.7 Convince Decision Makers: EINSTEIN Audit Report

After concluding the analysis, EINSTEIN automatically generates an exhaustive audit report. As an example the summary of the global results is given in Figure 20.

Show Case Demo TFC

EINSTEIN thermal energy industry audit

Summary

		Present state	Proposed alternative	Savings
Total primary energy consumption (1)				
Total	MWh	67.271	62.866	6,55%
-Total fuels	MWh	67.271	66.203	1,59%
-Total electricity	MWh	0	-3.337	-
Primary energy saving due to renewable energy	MWh			-
CO2 emissions	t/a	15.289	14.379	5,95%
Total annual energy system cost (2)	€	2.446.217	2.330.262	4,74%
Total investment cost(3)	€	-	442.323	-
Pay-back period (4)	a	-	2,8	-

(1) Including primary energy consumption for non-thermal uses

(2) Including energy cost (fuel and electricity bills), operation and maintenance costs and annuity of total investment.

(3) Total investment cost (own investment + subsidies)

Figure 20. Example page of the EINSTEIN audit report

2 Before You Start: How to Use this Show Case

2.1 Requirements

For fully using this show case, you need the version EINSTEINplus (Version 3.0plus or higher).

You can also work with the free (standard) version of EINSTEIN (V3.0 or higher), but some functionalities will not be available and, therefore, numerical results may be different.

2.2 Download Example Projects and Data Files

Download and unpack the file "showCase demoTFC.zip" into some folder on your computer (e.g. (...)/Documents/MyFolder/). Within this folder you then will find the example projects which you can use as a starting point for the different parts of the tutorial.

Copy the required data file "demoTFC-data_2MW.csv" into the APPDATA folder of EINSTEIN.

(See the user manual (einstein.sourceforge.net), section "Basics: Application Data Folder and Log-Files" on where to find the APPDATA folder on your computer, depending on your operating system)

3 Follow the Tutorial Step by Step

You can follow the Tutorial starting from scratch (empty project) following the parts one by one.

Alternatively you can work with a single part of this tutorial, loading the example project (xml-file) defined as *starting point* for each of the parts.

In the following sections the operations to be carried out with EINSTEIN are described step by step. The relevant EINSTEIN menus or windows to be selected are indicated in [brackets], using the following abbreviations (in capital letters):

- MAIN MENU: the main menu options in the EINSTEIN main window, e.g. [MAIN MENU – Project -> Import]
- TREE: the tree at the left of the EINSTEIN main window. e.g. [TREE – Some item. subitem. sub-subitem].
- TAB: the tab visible in the EINSTEIN main window (System Scheme, HX Network, Mass Flows, Energy), e.g. [TAB System Scheme]. If these four tabs are not visible, first select [TREE – Selected Alternative. Edit / View Data]

For the detailed sequence of the actions to be carried out see the video tutorials.

3.1 Part 1: Data Entry and Consistency Checking

Starting point: new project created from scratch (see below)

In the first part of this tutorial we will show You how to build the model in EINSTEIN for the present state and to check for consistency and completeness.

3.1.1 Step 1: How to build a simple project

Create a new project [MAIN MENU Project -> New] and give it a name (e.g. “Demo TFC Tutorial”)

Data entry – general data

Fill in some general data of the project [TREE Selected Alternative. Edit / View Data. General Data]:

- The plant operates in a shift of 12 hours, during 365 days a year, without break for holidays.
- The plant produces only one product, without having information about the quantity produced
- The yearly O & M costs for the heat and cooling supply system in the present state are set to zero. It is supposed that the real costs for the existing equipment remain constant for all possible alternative scenarios and, therefore, do not have an effect on potential savings
-

Process “Process WH”: process generating waste heat

Add a process to the system which is generating waste heat. Adding a process is done by right-clicking on the free space in the system scheme [TAB System Scheme]

Waste heat is available in form of cooling <u>water</u> at a temperature of <u>90 °C</u> and a flow rate of <u>30.347 kg/h</u>.

This process has also a *heat demand* of <u>2649 kW</u> at constant temperature (<u>170 °C</u>). Add a heat demand for maintenance (see the EINSTEIN Audit Guide for the definition of heat demands for maintenance, circulation and start-up).

We suppose that the heat transport medium can be directly used within the process, without need for a heat exchanger, so that the minimum temperature difference between heat supply medium and process medium is 0.

With regard to the operation schedule of the process for the moment we keep the default values: 12h in 1 cycle per day, during 365 days a year. This will be modified later on.

We confirm the information we entered by clicking ok

Process “Steam LP”: demand for low pressure steam

Now we add a second process consuming low pressure steam. Again we right-click on the system scheme and select Process.

Heat demand now is composed by two parts. The sensible heat for preheating water to the evaporation temperature, and the latent heat for evaporation.

First we enter the preheating part, adding an inflow to the process.

- flow rate: 2617 kg/h
- inlet temperature: 60°C
- process temperature: 120.5 °C
- minimum temperature difference supply / process medium: 0 K

Then we enter the power required for latent heat (maintenance heat demand): 1.600 kW

As before, also for this process for the moment we use the default operation schedule (12 h/day x 365 days/year), and then confirm the data by clicking OK.

Process "Building_Heating": space heating demand for buildings

A third heat demand is given by the space heating requirements of buildings. Building heat demands, unlike other heat demands, are not directly defined as processes, but indirectly by adding a building to the system [TREE - Selected Alternative. Edit / View Data. Buildings].

The building is supposed to have only demand for space heating, and none for air conditioning or domestic hot water:

- Yearly demand - heating: 4.000 MWh
- Yearly demand – cooling: 0
- Dailly demand – domestic hot water: 0

The required temperature for the heating system is 55 C and the target indoor temperature is 20 C.

The occupation of the building is 12h a day during 365 days a year.
The heating period is from 1st of october to 31st of march

After having added the building, in the system scheme we can now see that a third process has been added describing the building space heating.

Heat Supply for Processes: Steam Boiler and Steam Piping

For the heat supply to the processes we add a steam boiler to the system.
[right click in the system scheme, select "Equipment]

The nominal power of the boiler (heat output) is 10 MW, and the conversion efficiency is set to 0,9.

The boiler is fired by natural gas. Therefore, we add the fuel natural gas to the system [right click on system scheme, select "Fuel"], and connect the fuel as input to the steam boiler.

A steam piping is required in order to supply heat from the boiler to the processes [right click on system scheme, select "Pipe/Duct"].

We suppose a closed circuit with 100 % recirculation, a forward temperature of 180 °C and a return temperature of 80 °C. The heat transport medium is steam at 10 bar pressure. The length o the steam piping is 800 m.

Now we connect
- the output of the steam boiler to the input of the steam piping
- and the output of the steam piping to the input of the first two processes (Process WH and Steam LP)

Heat Supply for Space Heating of Buildings: Hot Water Boiler and Hot Water Piping

Space heating is provided by a separate boiler (add as described above, select equipment type: hot water boiler). The boiler has a nominal power (heat output) of 4 MW and an efficiency of 0,9

Also this boiler is fired by natural gas.

Heat is distributed in a hot water piping (add piping as described above). The forward and return temperatures are 70 and 50 °C respectively, and a fully closed loop with 100 % recirculation is supposed (medium: water). The piping length is 10.000 m.

As before we connect
- the boiler to the hot water piping
- and the piping to the process "building_heating"

Economic Information: Electricity and Fuel Tariffs

Finally we enter the electricity and fuel tariffs as economic information (click on the corresponding icons for Electricity and Natural Gas).

The natural gas tariff is 40 EUR/MWh and the electricity tariff – both for consumption and for sales – is 100 EUR/MWh.

For the electricity mix – defining the environmental parameters associated with electricity consumption – we select one of the default mixes provided in the EINSTEIN data base: "*Generic PE 2.5*", with a primary energy ratio of 2,5 MWh primary energy per MWh of electricity.

3.1.2 Step 2: Consistency and Completeness Checking

Now we are ready for checking our data for consistency and completeness [TREE - Selected Alternative. Consistency Check].

First let us assure that standard level of accuracy is defined.

Then we run the basic check. As a result we see that there are some parameters which are not defined with sufficient accuracy.

In order to solve this, we could either enter more detailed information for some of the components of the model, or we could try to automatically estimate missing parameters. For the moment we do not yet worry about this, as in the following step we still will enter some additional information.

3.2 Part 2: Link with Monitoring Data and Data Analysis

Starting point: Demo TFC STEP 1 – Base Case.xml

In this second part of this tutorial we will show You how to complete the data collection by adding information from available monitoring data. Furthermore we will show which results are available in order to analyse the present state energy consumption.

3.2.1 Step 3: Use of Data Files

In the present show case it is supposed that the only available information on the schedules of processes in time are available monitoring data, which nevertheless are not directly monitoring the processes' operation. The available monitored data (data file "*demoTFC-data_2MW.csv*" are:

- the steam generation in the steam boiler supplying both processes (column STEAM)
- the hourly production volume of the final product (column PRODUCT)

Load the Data File and Associate Data Columns with the Corresponding System Parameters

First we load the available data for steam generation. We open the tree item monitoring data [TREE - Selected Alternative. Edit / View Data. Monitoring Data] and add a new entry / data row [right-click on the table, select "add below"].

We load a new data file into our project [right-click on the table, select "load new datafile", chose the copy of the file "*demoTFC-data_2MW.csv*" in the location on your computer].

Select the column STEAM in this data file. The input data correspond to the system parameter "Useful Heat Supplied by Equipment" [column "Parameter"] of the equipment "steam boiler" [column "Object"].

For loading the available information on production volume we add a new row. We can use the already loaded data file [select in column Data File], and select the column PRODUCT. The input data correspond to the system parameter "Quantity of Product" [column "Parameter"] of product "some product" [select in column "Object"].

In order to take into account that in the future the volume of production will grow by 25% with respect to the recorded data from the past, we can scale the monitoring data by the factor 1,25 [column "Scale" in both data rows] ... .

.. and finally confirm the data by clicking OK

Establish the Correlation between the Production Volume and the Flow Rate of Waste Water

Now we link the production volume of "some product" to the quantity of cooling water from the waste heat generating process. We suppose that they are correlated by a constant ratio.

We open the editor for mass flows in the system [TAB Mass Flows], add a node by right clicking on the white space, and select scale/mixer. We enter the ratio of product to cooling water of 0,503 ... and we delete the unused entries of the mixer.

Then we connect the cooling water (output of Process WH) to the input of the new node, and from there – after scaling – to the product quantity of some_product.

As a last step we modify the operation schedules of the processes. [TAB System Scheme, open Process WH by clicking on the icon). Instead of using the simple default schedule, we select the schedule type "*fit to data*". Confirm by OK, and repeat the same for the process Steam_LP.

Consistency checking

Now we can run again our consistency and completeness check [TREE - Selected Alternative. Consistency Check], button "Basic Check" and – as a result - see that everything is OK.

We now can confirm the data as a valid reference scenario for the present state by clicking OK

3.2.2 Step 4: Analysis (Break-down) of Present State Energy Consumption

Now we will show you some of the detail information you can obtain from EINSTEIN on the present state energy consumption [-> click through the sub-menus in TREE – Selected Alternative. Energy Performance, from "Primary Energy" to "Pinch Analysis"]

First of all you see the share of each of the processes in the total heat demand [-> H&Demand (proc.)]. In a second break down you see the cumulative heat demand by temperature [-> H&Demand (temp.)] and by time [-> H&Demand (time)].

You can see the heat supply and the final energy consumption by equipment [-> Final Energy by Equipment], by fuels [-> Final Energy by Fuels] and the corresponding primary energy consumption [-> Primary Energy].

An overview of the yearly energy flows in the system is given in the system scheme [TAB System Scheme] and you can see the monthly breakdown of demand and hourly data [TREE – Selected Alternative. Energy Performance. Monthly Data and (...).Hourly Performance Data].

Pinch analysis is automatically carried out [submenus of -> Pinch Analysis]. You can see an overview of the hot and cold streams in the system [-> List of Streams], the hot and cold composite curves, the grand composite curve, and some aggregate summary results of the heat recovery potential [-> Composite Curves].

3.3 Part 3: Design of a Heat Exchanger Network

Starting point: Demo TFC STEP 3 – Data Fit.xml

In this third part of the tutorial we will show You how to generate and design alternative proposals for heat recovery and to compare them with respect to primary energy consumption.

3.3.1 Step B1: Alternative Proposal for a Heat Exchanger Network

Use of the Automatic Design of a Heat Exchanger Network

First we want to show you the automatic design of a heat exchanger network. For this purpose we first have to define a new alternative scenario in our project. Select the tree item “Alternative Proposals”, right-click on the table and select “generate new”. We give a short name (e.g. “HX auto”) and a description to our proposal by writing directly into the table.
Then we go to the tree item [TREE - Selected Alternative. Assisted Design. HX Network] and press the button “run design assistant” to activate the automatic design of a heat exchanger network.

As a result we see that two heat exchangers are proposed. The technical data and the recovered heat by each heat exchanger are given in the table, and can also be seen in the system scheme [TAB System Scheme].

We can see the heat exchanger network also in the graphical editor [TAB HX Network], in matrix view or in linear or logarithmic temperature scale [-> right click and select the corresponding view].

Manual Fine-Tuning

In a successive step we can do a manual fine-tuning of the automatically generated proposal. For this first we generate a copy of the current heat recovery proposal: [TREE – Alternative Proposals], right-click and select “copy proposal”, and then rename the new proposal (e.g. “HX manual”).

Then we go to the editor of the HX network (TAB HX Network). We delete the heat exchanger for space heating by right-clicking on the corresponding symbol (motivation: this heat recovery for example may be impossible in practice due to a large distance between the process and the buildings), and we rename the remaining heat exchanger (e.g. into “*HX feed water*”) by left-clicking on the symbol.

After having generated some possible alternatives, we can compare their performance, e.g. with respect to the required heat supply [TREE Alternative Proposals. Process and Supply Heat] and to primary energy consumption [TREE Alternative Proposals. Primary Energy].

3.4 Part 4: Heat to Power Conversion and Economic Analysis

Starting point: Demo TFC STEP B1 – Heat Recovery.xml

In this part of the tutorial we will show You how to generate an additional proposal adding a heat to power conversion equipment to the system; and you will see some basic features of the economic analysis module.

3.4.1 Step B2: Alternative Proposal for Heat-To-Power Conversion

Manually Adding a Heat-To-Power Conversion Equipment to the System

Like in the previous step (B1), we generate a new alternative proposal, in this case as a copy of our manually tuned heat exchanger network (alternative proposal “HX manual”), to which we want to add the new equipment:

- Go to [TREE – Alterantive Proposals]
- Right-click on alternative “HX manual” and select “Copy Proposal”.

We go to the system scheme and add a new equipment [right click and select “Equipment”]. We select the equipment type “CHP and heat-to-power” and the sub-type HTP-TFC for a trilateral flash cycle unit, and we give it a name (e.g. “TFC”).

As technical data we enter the following data:

- nominal electric power output: 160 kW
- nominal conversion efficiency: 0,08
- driving temperature (nominal): 90 °C
- temperature for heat rejection (nominal): 20 °C

We can see the efficiency curves behind the EINSTEIN model - the efficiency as a function of temperature [form for equipment data, tab “Efficiency Curves”] and as a function of the part load ratio [form for equipment data, tab “Part Load Behaviour”]

Finally we confirm by OK.

Connecting the Heat-to-Power Conversion Unit to the Waste Heat Stream

We add a heat exchanger in order to connect our waste heat stream to the input for driving heat of the TFC equipment [TAB HX Network, connect the streams “*process WH: cooling water*”, unused subbranch with the higher mass flow ratio of 0.886, and “*TFC unit: driving heat*”].

We define the following parameters for the new heat exchanger:

- UA value: 2.000 kW/K
- Economic parameters: investment cost 20.000 EUR, yearly O&M (fix): 1.000 EUR, yearly O&M (variable): 0.

We confirm by OK and then we run the EINSTEIN system simulation for the new system: [TREE – Selected Alternative. Energy Performance; press button “Run Simulation”, if not activated automatically].

View and Analyse the Results

After this we can see power generated by the system:

- in the system scheme (as yearly data: negative input of electricity for the TFC equipment)
- as hourly values [TREE Selected Alternative. Energy Performance. Hourly Performance Data. Hourly Supply].

Viewing the equipment parameters again [TAB System Scheme, click on icon for TFC equipment) we can see the efficiency curves of the equipment with the dots indicating the operating conditions in the present system [form for the equipment, tabs "*Efficiency Curves*" and "*Part Load Behaviour*".

We can compare the primary energy savings to the alternatives with heat recovery only [TREE – Alternative Proposals. Primary Energy].

Economic Analysis and Manual Editing of Economic Parameters

Defaults for parameters required for economic analysis, which are not explicitely introduced during system design, are automatically generated by EINSTEIN in the background.

These parameters, nevertheless, can be edited manually. We select the tree item [TREE – Selected Alternative. Economic Analysis. Cost Details]. For investment costs, by default a funding rate of 30% is assumed [tab "Investment Cost"]. We change this ratio to 0 % for the TFC equipment by writing the appropriate value into the table, supposing that for this type of equipment there is no funding available in your country.

Other parameters could be changed manually, too, but for the purpose of this tutorial we keep the default values for the rest.
As a result we can see the net yearly cash flow, the net present value of the cumulative cash flow and the global indicators for economic performance [TREE – Selected Alternative. Economic Analysis]:

- Total and own investment cost
- Benefit-cost ratio
- Pay-Back period
- (Modified) internal rate of return

Alternatives can now be compared also with respect to economic parameters [TREE Alternative Proposals; click through sub-menus from investment to IRR]. The trade-off between energy saving and economic saving can be seen in a two-dimensional comparison [TREE Alternative Proposals] in tabluar and graphical form.

3.5 Part 5: High Temperature Heat Pump and Comparative Study

Starting point: Demo TFC STEP B2 – TFC.xml

In this part of the tutorial we will show You how to generate an additional proposal using automatic design for adding a high temperature heat pump to the system. Furthermore, we will show how to use the economic analysis module in order to study the influence of the electricity tariff on the (relative) performance of the different alternative proposals.

3.5.1 Step B3: Alternative Proposal for a High Temperature Heat Pump

Adding a High Temperature Heat Pump to the System Using the Design Assistant

Like in the previous steps, we generate a new alternative (name e.g. "HTHP"), in this case as a copy of our manually tuned heat exchanger network (alternative "HX manual"), to which we want to add the new equipment (see description in Part 4).

We add a new equipment now using the design assistant for heat pumps: [TREE – Selected Alternative. Assisted Design. H&C Supply. Heat Pumps].

First we configure the design assistant selecting the following parameters:

- Minimum desired yearly operating hours: 2.000 h
- Maximum desired condensing temperature: 150 °C
- Minimum desired evaporation temperature: 50 °C
-

Then we click on the button "*Run Design Assistant*" in order to activate the auto-design.

A table will appear in which a heat pump with a nominal power of 2.000 kW is proposed. We can confirm by double-clicking on this equipment and then by clicking OK within the window of the design assistant.

We rename the new equipment [TAB System Scheme; open the equipment form by clicking on the icon]

Manual Adjustments after Auto-Design

By default, in automatic design the new heat pump will be connected to all heat consumers with an appropriate temperature range. If we want the new heat pump to supply heat only into the steam piping, we have to manually disconnect the equipment from the second piping (hot water).
For doing this go to the system scheme, select the connection to be deleted by clicking on it, and choose "delete connection".

In a next step we manually connect the heat pump with a heat exchanger to a specific heat source. We go the the editor of the heat exchanger network and add a new heat exchanger [TAB HX Network, connect the streams "*process WH: cooling water*", unused sub-branch with the higher mass flow ratio of 0.886, and "HTHP*: low temperature heat source*"].

We define the following parameters for the new heat exchanger:

- UA value: 2.000 kW/K
- Economic parameters: investment cost 20.000 EUR, yearly O&M (fix): 1.000 EUR, yearly O&M (variable): 0.

We confirm by OK and then we run the EINSTEIN system simulation for the new system: [TREE – Selected Alternative. Energy Performance; press button “Run Simulation”, if not activated automatically].

This done, we can analyse the resulting energy flows as described in the corresponding section in Part 4.

As with the proposal for heat to power conversion, also here we change the funding rate in the economic analysis to 0 and we compare the results to that of the previous alternatives.

3.5.2 Step B4: Influence of the Electricity Tariff on Relative Performance

Finally we want to check which impact a different electricity tariff may have on the relative performance of the alternative proposals.

For this purpose first we generate a copy of the proposal for the TFC unit [TREE – Alternative Proposals] and we reduce the electricity tariff to 80 EUR/MWh [TREE – Seleted Alternative. Economic Analysis. Cost Details; tab “Energy cost”]

We repeat the same for the alternative with the high temperature heat pump.

We compare the final result [TREE – Alternative Proposals; tab “Graphic”].

We see that:

- the cost savings for heat to power are reduced with a lower electricity tariff
- in the case of the heat pump, with a lower electricity tariff now there are also high cost savings.
- due to this changes in opposite direction, the relative performance of both systems depends strongly on the electricity tariff used as a basis for comparison.