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

Guide for

E I N S T E I N

Thermal Energy Audits

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Guide for EINSTEIN Thermal Energy Audits

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“It is not enough that you understand about applied science in order that your work may increase man's blessings. Concern for man himself and his fate must always form the chief interest of all technical endeavors, concern for the great unsolved problems of the organization of labor and the distribution of goods - in order that the creations of our minds shall be a blessing and not a curse to mankind. Never forget this in the midst of your diagrams and equations.”

Albert Einstein

From a speech to students at the California Institute of Technology, 1931.

Introduction

Thermal energy (heat and cold) demand in industry constitutes about 20 % of the total final energy demand in Europe. Space heating and cooling in buildings contributes another 27 % to the final energy demand. Even if energy efficiency in industry in Europe has improved the last decades, there remains a large unexploited potential for reducing energy demand that could be achieved by the intelligent combination of existing solutions and technologies. For optimising thermal energy supply, a holistic integral approach is required that includes possibilities of demand reduction by heat recovery and process integration, and by an intelligent combination of existing affordable heat (and cold) supply technologies, under the given economic constraints.

The *EINSTEIN methodology for thermal energy audit* that is described in this document has been developed in the framework of the European (Intelligent Energy Europe - IEE) projects EINSTEIN and EINSTEIN-II. This projects have been fruit of the previous collaboration of the project partners *AEE INTEC (Austria)*, and *energyXperts.NET (Spain)* during the years 2003 – 2007 in the Framework of the IEA (International Energy Agency) Solar Heating and Cooling and SolarPACES Programmes, Task 33/IV on Solar Heat for Industrial Processes (www.iea-ship.org). The basic elements and concepts forming this methodology had already been created in the framework of the European (5th Framework Programme) project POSHIP (The Potential of Solar Heat for Industrial Processes) and the Austrian national project PROMISE (Produzieren mit Sonnenenergie).

One of the interesting aspects of the IEA research group of Task 33/IV was the *interdisciplinary collaboration* of experts in *renewable energy technologies* (solar thermal energy) on the one hand, and *process engineers* on the other. During the work on several case studies in industries in the framework of this Task 33/IV the lack of appropriate audit tools for thermal energy supply in industry have become manifest:

- ✗ The *complexity* of the problem of optimising thermal energy supply requires bringing together knowledge on process technologies, on process integration and heat recovery techniques, and a wide knowledge on the different energy efficient technologies for heat and cold supply including renewable energies.

- ✗ This often is in contrast with both the *lack of time available* for fast audits or first rough quick&dirty feasibility studies, and with the *lack of knowledge* of the technicians involved. In the specific case of the solar process heat projects as studied within the IEA Task 33/IV, this was lack of knowledge of the involved solar thermal experts on process technologies, heat integration and general aspects of industrial heat supply. But the problem is rather general: it is very difficult that one person, especially junior technicians often involved in energy auditing practice, have an overview of the wide range of technological concepts required for designing really integral and optimised solutions.

Therefore, based on the practical experience of a large number of energy audits in different industrial sectors and other large scale applications, such as big buildings in the services sector, the auditing methodologies used by the different partners have been more and more standardised leading to what here is presented as the EINSTEIN audit methodology.

Furthermore several tools have been developed that allow for a fast access to the required information and for a semi-automatisation of the required calculations and design decisions (expert system), from simple spreadsheets to software tools addressing specific parts of the problem. Most of these tools are now integrated into the EINSTEIN software tool on which the EINSTEIN audit methodology is based. The implementation of the methodology in form of a complete auditing tool-kit including an expert system software tool makes it easy to use, easily distributable, and helps reducing time (and therefore cost) and increasing standardisation (and therefore quality) of energy audits.

The EINSTEIN software tool, together with some of the complementary databases, is being developed as a free and open source software project available in all the IEE project partners' languages[1] on the project web page or from any of the consortium members. We hope that this form of distribution will lead to a widespread use in the community of energy auditors, engineers, consultants and researchers dealing with thermal energy supply in large applications, and that the present version can be continuously enriched with new experiences and contributions from the community.

[1] *English, Bulgarian, Czech, French, German, Italian, Polish, Slovakian, Slovenian, Spanish*

1 EINSTEIN thermal audit methodology – the basics

1.1 Thermal energy in industry and other large scale applications

Thermal energy (heat and cold) demand in industry (2002 figures: about 2,300 TWh/8400 PJ) is responsible for about 28% of the total final energy demand (Table 1) and 21% of the CO2 emissions in Europe[2]. Space heating and cooling in buildings contributes another 27 % to the final energy demand [DG INFSO 2008].

Table 1. Distribution of final energy demand in the EU in 2002. Source: EU Green Paper on energy efficiency.

2002	Buildings (residential and tertiary		Industry		Transport		All final demand sectors	
	Mtoe	% of final demand	Mtoe	% of final demand	Mtoe	% of final demand	Mtoe	% of final demand
Solid fuels	12.2	1.1	38.7	3.6	0.0	0.0	50.9	4.7
Oil	96.8	8.9	46.9	4.3	331.5	30.6	475.2	43.9
Gas	155.6	14.4	105.4	9.7	0.4	0.0	261.5	24.2
Electricity (incl. 14 % from RES)	121.3	11.2	91.2	8.4	6.0	0.6	218.5	20.2
Derived heat	22.8	2.1	7.5	0.7	0.0	0.0	30.3	2.8
Renewables	29.0	2.7	16.2	1.5	1.0	0.1	46.2	4.3
Total	437.8	40.4	306.0	28.3	338.9	31.3	1082.6	100.0

Even if energy efficiency in industry in Europe has improved in the last decades, there remains a large unexploited potential for reducing energy demand that could be used by the intelligent combination of existing solutions and technologies. In the EU Green Paper for Energy Efficiency the savings potential in industry (without cogeneration) is estimated to be up to 350 TWh/1260 PJ (European Commission [2005]. The European Commission's energy efficiency action plan indicates that 40% of EU's Kyoto targets must be achieved through energy efficiency, in order to succeed with its goals.

Improvement of energy efficiency not only leads to the obvious environmental benefits, but is also economically attractive for the industrial companies: in many cases pay-back times from some months to few years can be obtained. In a typical small or medium enterprise, energy accounts for between 3% and 12% of the operational costs with an energy saving potential of between 15% and 30% [E-Check 2006]. Nevertheless, frequently the corresponding investments are not realised due to some of the following reasons:

- ✗ Lack of knowledge of the companies about possible energy efficient solutions.
- ✗ Energy costs, although being important, are not the first priority of the companies. Investments in energy compete with investments in the improvement of production and products; this leads to a situation where investments into energy conservation are not being done, although they are economic by themselves but lose competition for available money.
- ✗ In addition, most industrial companies do not perceive energy as a discrete issue, but as a component of broader issues such as cost of manufacturing, environmental compliance, safety and productivity. Energy efficiency competes with other issues for limited resources within a company. While capital is the most often cited resource, staff time may be of equal or greater importance. Corporate downsizing has resulted in less staff available to address all issues.
- ✗ Little (zero) budget available for energy auditing

[2]*Figure including electricity generation in industry. Source: http://ghg.unfccc.int. Total fuel combustion for Manufacturing Industries and Construction in the EU in 2002: 583.070 Mio t* CO_2

- Even in the cases where energy audits are carried out, the auditors often have only a limited knowledge of technological options and do not dare or do not dispose of the means to propose non-conventional innovative solutions.

The EINSTEIN thermal audit methodology aims at overcoming some of the above mentioned barriers and at contributing to a widespread implementation of integral energy-efficient solutions for thermal energy supply.

1.2 Area of application

The EINSTEIN thermal audit methodology focuses on industries and other large scale consumers with a high thermal energy (heat and cold) demand in low and medium temperature ranges up to 400 ºC, such as:

a) industrial sectors:

- food industry
- chemical industry
- paper industry
- construction of machinery, equipment and automobile
-
- plastic processingwood processing industry
- metal surface treatment
- textile industrymany other industrial sectors

b) non-industrial applications

- district heating and cooling networks, including also the integration of demands in form of centralised generation of power and heat for industry groupings or networks that integrate industrial companies with other sectors

- buildings in the tertiary sector, such as large office buildings, malls, commercial centres, hotels, hospitals, convention centres, schools, spas, etc.

- other installations consuming thermal energy, such as sea-water desalination, plants for water treatment, etc.

The advantage of EINSTEIN is especially high in small and medium companies, where costs of conventional audits of a comparable deepness and quality are an important barrier for the introduction of energy efficient technologies.

1.3 An integral approach to energy efficiency

In order to optimise thermal energy supply, **a holistic integral approach** (Figure 1) is required that integrates:

- Possibilities of **demand reduction** by process optimisation and by the application of competitive, less energy consuming technologies.

- **Energy efficiency measures** by heat recovery and process integration.

- An **intelligent combination of the available heat and cold supply technologies** (efficient boilers and burners, co-generation, heat pumps), **including** the use of **renewable energies** (especially relevant for thermal use are biomass and solar thermal energy).

- Consideration of the given economic constraints.

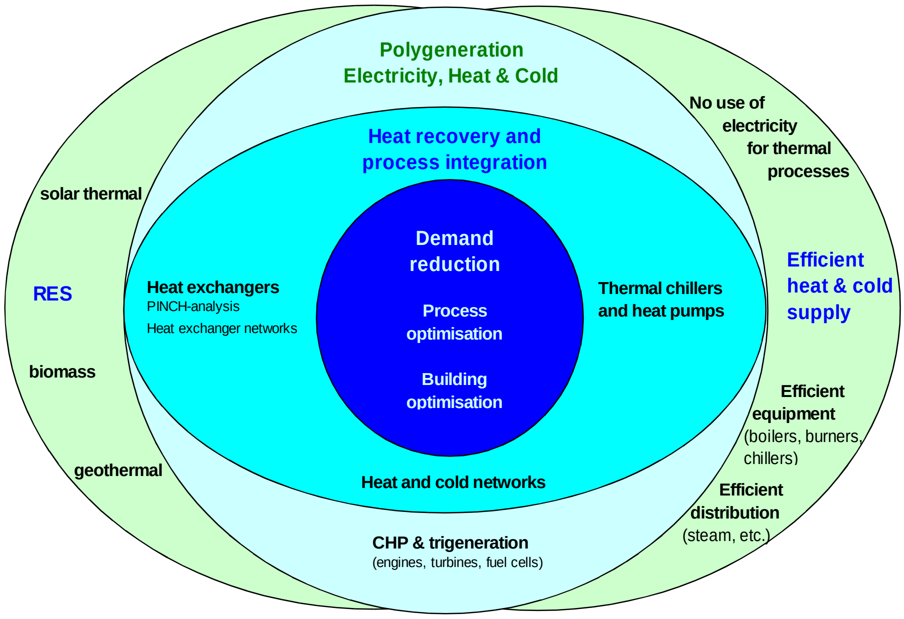

Figure 1: Holistic approach for thermal energy audits ("the view with EINSTEIN's eye"), combining demand reduction, heat recovery and process integration and an intelligent combination of supply technologies.

1.4 The advantages of the EINSTEIN audit procedure

In contrast to many aspects of electricity consumption such as pumps, motors, lighting, etc., where often a list of recommendations and standard measures can lead to good results, the task of optimising *thermal* energy supply in industry is rather complex from the technical point of view:

- ✗ In many companies and especially in small and medium enterprises only very few and aggregate information on the actual energy consumption is available (fuel bills, technical data of boilers, etc.). Consumption of individual processes and sub-processes therefore has either to be estimated or determined by costly and time-consuming measurements.

- ✗ The exploitation of existing heat recovery potentials often requires the integration of several processes at different temperature levels and with different operating time schedules (integration of heat exchangers and heat storage)

- ✗ Different available technologies for heat supply have to be combined in order to obtain optimum solutions

The technical complexity of the problem to be handled contrasts with the need for a low-cost, and therefore necessarily fast assessment methodology. This is one of the main reasons why the energy savings potential for thermal energy is still far less exploited than the electricity savings potential.

In order to overcome these constraints, the EINSTEIN tool-kit uses the concepts described below and allows to process data and to generate proposals in typical small and medium enterprises with medium complexity in 4 – 8 hours of a junior expert working time. The main advantages of the EINSTEIN tool-kit also presented in the Figure 2 are the following:

- ✗ **standardisation of the problem and the possible solutions**: both the data acquisition and the proposal generation are carried out using standardized models for unit operations (processes) representing a generic industrial process applicable to the industrial branches and types of buildings addressed by the project; and standardized modules for the heat and cold supply subsystems.

- ✗ "**quick and dirty" estimates: aids for estimation and calculation of non-available, but necessary data** on heat demand. In many cases, at least approximate figures on the heat demand of the different processes can be obtained by combining several different – often incomplete, fragmented, and sometimes only qualitative – information collected in the visits and interviews with the technical staff in a company. This often lengthy and time-consuming calculations necessary for processing these data can be substantially shortened using a limited data set as input to the standardized procedure. By this way less than one hour of calculation effort can often be a substitute for on-site measurements, with sufficient accuracy also thanks to an internal data cross-check, at least in the pre-design stage.

- ✗ **semi-automatisation of the auditing procedure and proposal generation**: the EINSTEIN software tool incorporates data bases, e.g. including the technical parameters of standard components, and aids for decision making so that also not specially skilled technicians will be able to use the tool for dealing with rather complex problems. Benchmarks will help the user to evaluate the state both before and after the proposed interventions. Lists for quick-check and standard measures are also incorporated. Audit reports are generated automatically from the tool, in a format so that they directly can be delivered by an external auditor to a customer or by the technical staff to the manager of the company itself.

- ✗ **data submission web-based or by a short questionnaire**: Taking into account that in many cases for a first quick-and-dirty assessment it is sufficient to process few data, a *short* questionnaire has been created. It allows data collection in situ and, if the case, it can be easily completed by means of telephone calls. This questionnaire can be also accessed via a web-page for data submission by distance.

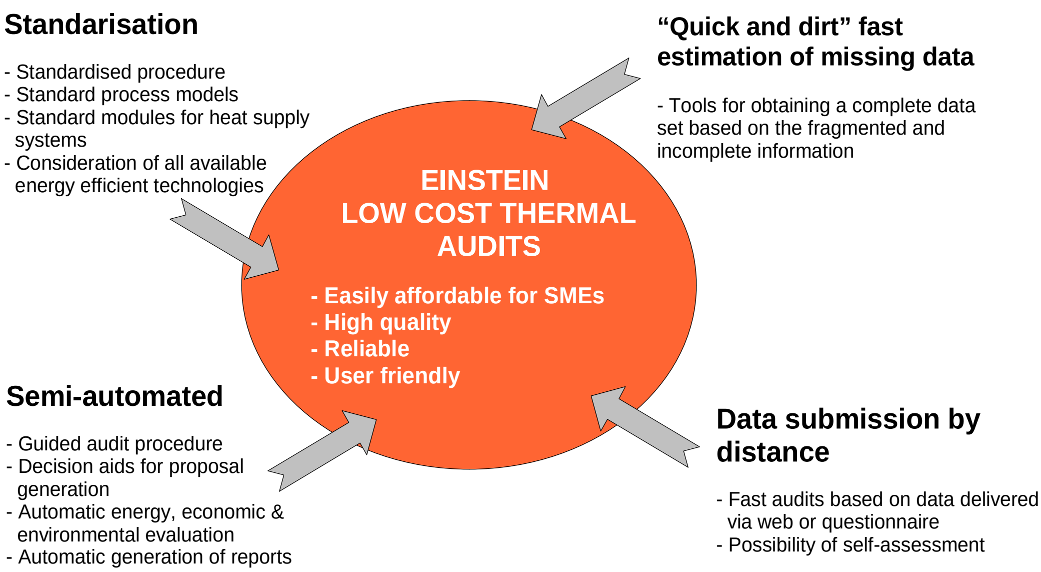

Figure 2: Overview of the EINSTEIN thermal auditing functions for obtaining fast and cheap, but high quality thermal energy audits

1.5 The EINSTEIN tool-kit

The EINSTEIN audit methodology is based on a software tool with decision aids and guidelines forming a complete **expert system[3] for thermal energy auditing.** This easy to use expert system software tool, together with the EINSTEIN audit guide forms an **energy-auditing tool-kit** that leads the consultant through the whole procedure from auditing (preparation of visit and data acquisition), over data processing, to the elaboration, design and quantitative (energetic and economic) evaluation of alternative solutions.

The core of the expert system software tool and the manual is available for free in form of an **open source software project** (www.sourceforge.net/projects/einstein). This type of software development has shown to

[3]*An **expert system** is a "class of computer programs (...) made up of a set of rules that analyse information (usually supplied by the user of the system) (...), provide analysis of the problem(s), and (...) recommend a course of user actions (...)." (wikipedia.org).*

be very efficient for dissemination of knowledge and for the continuous maintenance, bug-fix, update, and improvement of the software by user contributions [FLOSS 2002].

The EINSTEIN tool-kit allows to produce solutions for thermal energy and economic savings on behalf of an expert system software tool with a user friendly and easy-to handle interface.

The expert system software tool includes the following modules:

a) Block for data acquisition and processing

Data acquisition is mainly based on a short questionnaire. An additional module helps the auditor to estimate non-available data. A link to information sources on best practice and benchmarks will help to evaluate the state-of-the-art in the company.

b) Block for the generation of a new proposal

This block is formed by the process optimisation module, the heat recovery module, that helps designing and optimising an appropriate heat exchanger network for heat recovery and process integration; and a heat and cold supply module, that helps to select and to dimension the most appropriate supply equipment and heat or cold distribution systems.

c) Block for the energetic, economic and environmental evaluation of the new proposal

The energetic performance of the system is determined by a system simulation module. Based on the energetic performance, an economic and environmental evaluation is automatically generated by the *economicanalysis* module.

d) Block for generation of reports for the presentation of the new proposal to the company

Automatic reports are generated in a format that can be directly presented to the company. The report contains information on the technical design of the new proposal, the investment cost of the measure, and an economic roadmap for its implementation.

The expert system guides the auditor on any decision to be taken, by help menus, suggestions for best options to be selected, etc. These helps, together with a the present guide for thermal energy auditing with recommendations and best practices make the tool-kit accessible also for non-expert users.

1.6 Overview over this guide

Chapter 2 of the present audit guide gives an introduction to the theoretical concepts used in the EINSTEIN audit methodology. This chapter is essential for the understanding of the details of the audit steps and calculation procedures.

In Chapter 3 the EINSTEIN audit methodology is described step by step, in a chronological order from the first contact to the company until the delivery of the audit report and the follow-up. For each of the audit steps the main aspects are highlighted where attention should be laid on.

In Chapter 4 the application of the EINSTEIN audit methodology to some example case studies is described.

In the annex of this guide You find the EINSTEIN Basic Questionnaire that can be used for data acquisition.

References Chapter 1:

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2 E = mc². EINSTEIN's theoretical concepts

2.1 Energy, energy efficiency and renewable energy sources

2.1.1 Energy consumption by type of energy and by type of use

Energy in industry and large buildings in the service sector is consumed mainly in form of electricity, in form of fuels (fossil fuels, such as natural gas, fuel oil; but also biomass and biogas), and in some cases in form of (externally generated) heat or cold from district heating and cooling.

Energy consumption can be expressed in terms of final energy and in terms of primary energy:

- *Final energy:* is the amount of energy contained in the different energy sources entering the company, independently of their form (The energy content of fuels in EINSTEIN is accounted in terms of their lower calorific value or LCV).

- *Primary energy:* is the total amount of energy necessary for generating this energy supply, taking into account the losses in all the different steps of processing, from mining to conversion and transport. The difference between final and primary energy content is especially high in the case of electricity: at the present state of technology of the electricity supply in Europe, from 2.5 to 3 units of primary energy are necessary for the generation of one unit of electricity.

Energy can be used for *thermal* and for *non-thermal* uses. The EINSTEIN thermal energy audit methodology is concerned with the thermal part of the energy use. *Thermal uses* of energy as defined in EINSTEIN are:

- Process heating and cooling (including energy for chemical reactions, if those are driven by heat)

- Space heating and cooling of buildings (production halls, offices, etc.)

- Sanitary hot water demand (e.g. showers, kitchens, ...)

Non-thermal uses are:

- Electrical (and other) energy consumption for lighting, machinery (e.g. motors, compressors) and other electrical equipment, *excluding* air-conditioning, cooling and electrical heaters, that are included in the thermal energy statistics.

Not considered within EINSTEIN, although important in the global energy balance, are the following uses:

- Non-energetic use of fuels, e.g. as raw materials for chemical processing

- Energy consumption for transport of raw materials and final products and for displacement of workers from/to work.

- Energy contained within the raw materials (from previous processing steps).

Consumption of energy for thermal uses in European industry is nearly 70 % of the total consumption in terms of final energy and more than 50 % in terms of primary energy. Also in buildings, more than 50 % of the final energy is consumed for space heating and cooling and sanitary hot water demands.

2.1.2 Renewable energy

The most relevant renewable energy sources for direct conversion in industrial heat and cold supply systems are:

- Solar thermal energy (including solar thermal CHP: electricity and heat)

- Biomass and biogas
- Geothermal energy

All the other renewable energy technologies are of indirect relevance, as they may reduce the impact of the company's electricity consumption only on a global scale (beyond the boundaries of the company itself). This is valid also for PV systems, even if they are installed on a company's roof, as those systems are usually grid connected and not contributing directly to the company's electricity consumption.

The energy used by the company in form of renewable energy is not accounted for in the primary energy consumption. Nevertheless, it has to be taken into account the difference between the sources of renewable energy and contributions of the different sources therefore in EINSTEIN are accounted separately:

- Solar thermal energy is a practically infinite and infinitely renewable energy
- Biomass and biogas are renewable, but finite energy sources. The use of this energy source for thermal uses may be in competition with the use of the same material in other systems (e.g. power plants, conversion to biofuels) and also with the use of land for agricultural production.

2.1.3 Environmental impact of companies' energy use

Industrial energy consumption in Europe is about 28 % of the total final energy consumption (without taking into account the energy consumption of transport related with industrial production)[4]. Space heating and cooling in buildings contributes another 27 % to the final energy demand

The environmental impact of energy use is due to a lot of diverse factors, such as:

- *Emissions* of different substances due to energy conversion (CO_2, other greenhouse gas (GHG) emissions, NO_x, CO, radioactive emissions, nuclear waste, etc.)
- *Consumption* of finite and non-renewable resources (fossil fuels, raw materials)
- *Risk* associated with the energy supply and conversion system (e.g. nuclear accidents, transport of fuels, ...)
- *Water consumption* (e.g. cooling towers)
- *Land use* (e.g. use of land for biofuels or biomass competing with land use for agricultural production)

It would be beyond the scope of EINSTEIN to make an exhaustive assessment of the environmental impact taking into account all the above mentioned factors. The following parameters are used as main indicators for the environmental assessment:

- *Primary energy consumption* as the main indicator for environmental assessment
- *Generation of CO_2*
- *Generation of highly radioactive (HR) nuclear waste* (associated with electricity consumption)
- *Water consumption*

[4] *Data from EuroStat (2004).*

2.1.4 Demand side and supply side oriented strategies for reduction of energy consumption

Energy consumption in companies (and in general) is not a need by itself, but usually is a *mean* for reaching some objectives, such as:

- ✗ Maintaining some surface or some equipment clean
- ✗ Separating two fluids by distillation

The same objective e.g. of cleaning can often be obtained by very different ways, with very different associated energy consumptions. E.g. a space or some equipment can be maintained clean by:

- ✗ Heating up a large amount of water to 80 or 90 ºC for daily washing
- ✗ Washing at lower temperature, but applying some detergents or with pressure
- ✗ Avoiding excessive need for cleaning by locating a process that generates large amount of dust into a separate space
- ✗ etc.

In this sense, as already outlined in section 1.3, at the very beginning of each EINSTEIN audit one has to look for possibilities of *demand reduction* at its origin. This in general is the economically most cost-effective way, and at the same time the most environmentally friendly way to save energy.

Only the *remaining* heat and cold demand then has to be covered by an energetically and environmentally optimised heat and cold supply system.

2.2 Energy flows – definitions

For the analysis of the thermal energy demand , within the EINSTEIN methodology the following basic quantities are used:

- *Final energy consumption (FEC) and final energy consumption for thermal uses (FET)*: lower calorific value (LCV) of the fuel consumption, heat and electricity consumption (for thermal use).

- *Useful supply heat / cold (USH / USC)*: heat or cold generated in the heat or cold supply system (e.g. boilers, burners, chillers) and that is distributed to the different heat or cold consuming processes in form of steam, hot air, hot water, chilled water, etc.

- *Useful process heat / cold (UPH / UPC)*: heat or cold delivered to a process (measured at the entrance of the process heat exchanger).

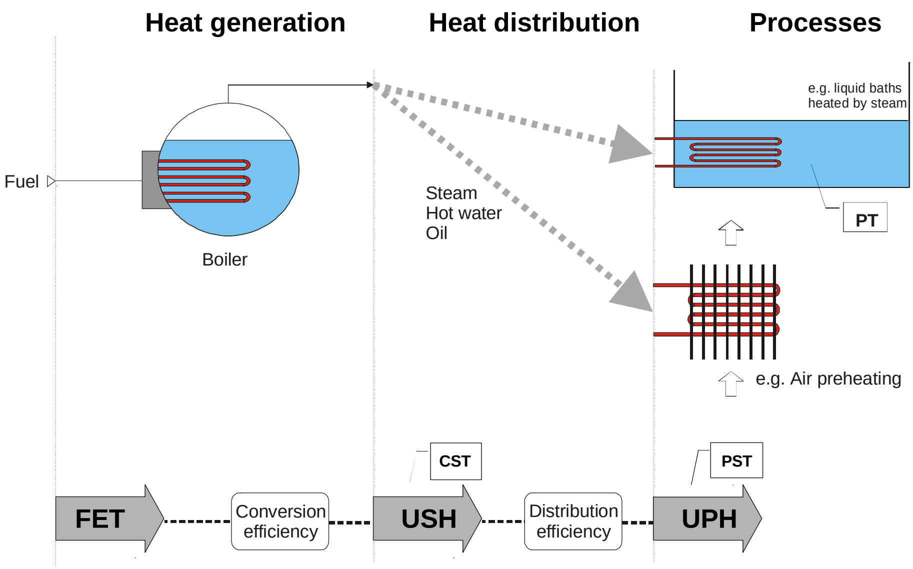


Figure 3: EINSTEIN definitions of energy flows in a heat supply system (anologous for cooling).

The ratios of USH/FET (or USC/FET) and of UPH/USH (or UPC/USC) define the conversion efficiency and the distribution efficiency of the system (Figure 4).

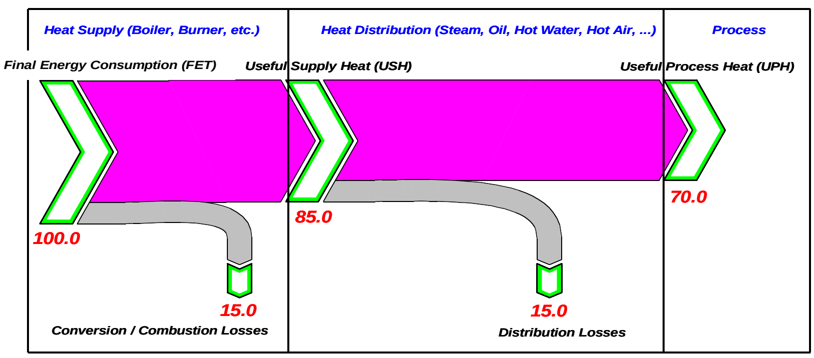


Figure 4: Sankey diagram of energy flows with typical conversion and distribution efficiencies.

If in addition also the different flows of waste heat or waste cold are considered, the scheme of energy flows gets somewhat more complex (Figure 6). An example of an industrial process with different types of waste heat recovery is shown in Figure 5.

In EINSTEIN we denominate as *available waste heat (QWH)* an energy flow produced by any of the subsystems (supply / distribution / processes / other) that is not the main output of that system. Waste heat flows may be for example:

- Heat contained in the exhaust gas of a boiler or in the heat rejection cycle of a cooling machine
- Condensate recovered from a steam piping
- Heat contained in the waste water of a washing process

In an analogous way, there maybe waste cold (QWC) such as e.g. cold exhaust air from an air conditioned space, etc.

On the other hand, we denominate as *recovered waste heat (QHX) or cold (QCX)* an energy flow used as input for any of the subsystems (supply / distribution / processes) that originates from the waste heat recovery system (including ambient air and ground). Recovered waste heat flows may be for example:

- Preheating of combustion air and/or of feed-up water in a boiler
- Preheating of water at the inlet of a washing process
- Preheating of return in a hot water distribution circuit
- Precooling of air at the inlet of a germination process in malt production

In the following sections, a mathematical definition of the quantities used in EINSTEIN energy balances is given.

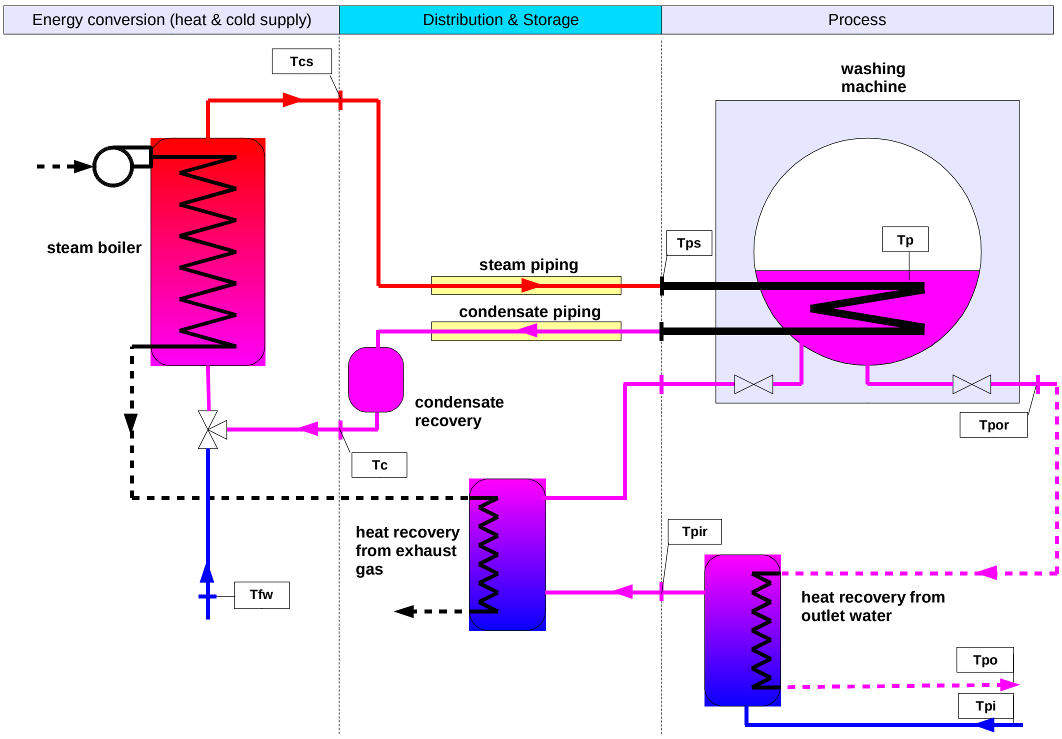


Figure 5: Example of an industrial washing process represented according the EINSTEIN model, with different types of heat recovery: heat recovery from boiler exhaust gas for water preheating; heat recovery from waste water for water preheating; condensate recovery for preheating of boiler feed-up water.

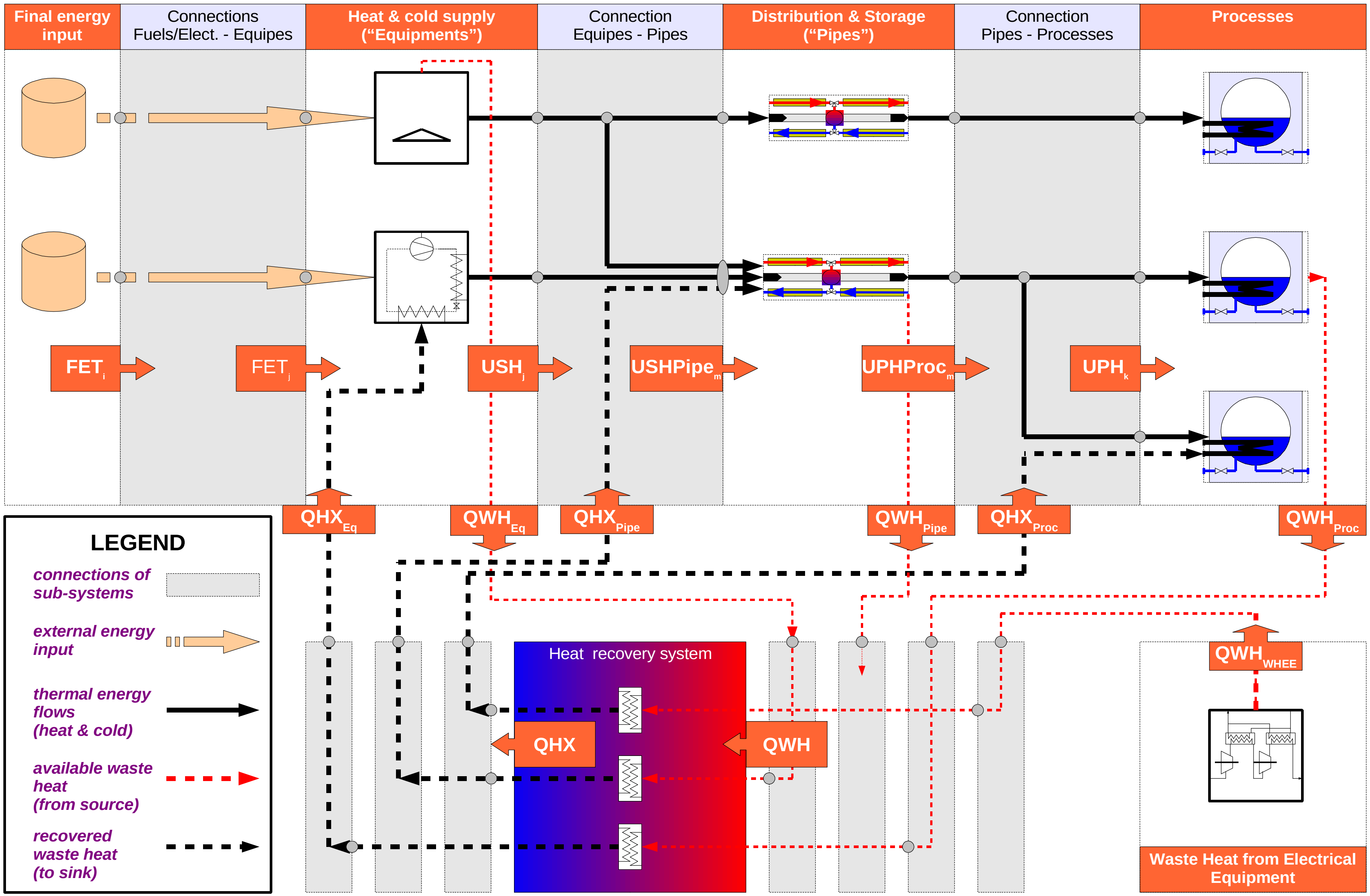


Figure 6: EINSTEIN definitions in a heat supply system with heat recovery (analogous for cooling supply system).

2.2.1 Final and primary energy consumption

The total final energy consumption (FEC) is used to account for the total final energy that enters the company in the form of fuels (expressed in terms of LCV), electricity and district heat.

$$E_{FEC} = E_{FEC,el} + \sum_{i=1}^{N_{fuels}} E_{FEC,fuel(i)} + E_{FEC,heat} \quad (2.1)$$

The primary energy consumption (PEC) is obtained from this, applying the different conversion factors for each of the energy types:

$$E_{PEC} = f_{PE,el} E_{FEC,el} + \sum_{i=1}^{N_{fuels}} f_{PE,i} E_{FEC,fuel(i)} + f_{PE,heat} E_{FEC,heat} \quad (2.2)$$

where $f_{PE,el}$ is the primary energy conversion factor for electricity and $f_{PE,i}$ is the primary energy conversion factor for the different fuel types (see Table 2 for typical values).

Table 2. Typical primary energy conversion factors for different energy sources[5].

Fuel type	Primary energy conversion factor
Wood	0.2
District heat with 70 % natural gas fired CHP	0.6
Natural gas	1.1
Fuel oil	1.1
Electricity	3.0

Energy is consumed for thermal (heating or cooling) and non-thermal uses (lighting, motor drives, etc.). Electricity used in chillers for air conditioning and cooling, and in electrical heating equipment is accounted for as energy for thermal use.

The corresponding amounts of energy are denominated as:

- PET/FET: Primary/Final energy for thermal uses
- PEO/FEO: Primary/Final energy for other (non-thermal) uses

The following equation holds (and in an analogous way for primary energy):

$$E_{FEC} = E_{FET} + E_{FEO} \quad (2.3)$$

The total final energy for thermal uses is the sum of the energy consumed by the heating and cooling equipment in the company:

$$E_{FET} = \sum_{j=1}^{N_{eq}} E_{FET,j} \quad (2.4)$$

where N_{eq} is the number of thermal equipment units in the company (boilers, chillers, CHP engines, etc.)

[5] *Schramek E.-R. (editor), Recknagel, Sprenger, Schramek – Taschenbuch für Heizung- und Klimatechnik 07-08, Oldenburg editions, 2007*

Special case CHP:

From the perspective of EINSTEIN, CHP is treated as a heat supply equipment (see for more detail section 3.7). The final energy consumption of CHP equipment is considered as the net consumption composed by the fuel consumption and the *negative consumption* in form of self-generated electricity:

$$E_{FET,j} = E_{FET,fuel(j)} - E_{FET,elgen,j} \quad (2.5)$$

Note: if the electrical conversion efficiency of a CHP equipment is higher than the reference value of the reference electricity grid, the energy consumption in a CHP equipment in terms of *primary energy* may be negative !

2.2.2 Useful supply heat and cold (USH/C)

Useful supply heat (USH) or cooling (USC) is the energy delivered by the conversion equipment (boilers, burners, etc.), measured at the outlet of the equipment (machine room). The energy balance is obtained as

$$\dot{Q}_{USH,j} = \dot{Q}_{USH,eq,j} + \dot{Q}_{QHX,j} \quad (2.6)$$

being $\dot{Q}_{QHX,j}$ the recovered waste heat used in this equipment (e.g. preheating of combustion air or feed-up water) and $\dot{Q}_{USH,eq,j}$ the additional heat generated in this equipment by conversion from final energy.

The net equipment conversion efficiency is defined as

$$\eta_{conv,j} = \frac{\dot{Q}_{USH,eq,j}}{\dot{E}_{FET,j}} \quad (2.7)$$

The total heat entering the different distribution lines is given by:

$$\dot{Q}_{USH,pipe,m} = \dot{Q}_{USH,m} + \dot{Q}_{QHX,m} \quad (2.8)$$

where $\dot{Q}_{USH,m}$ is the useful supply heat from the conversion equipment to pipe *m* and $\dot{Q}_{QHX,m}$ the recovered waste heat fed directly into pipe *m* (e.g. preheating of return line).

The heat content in heat supplies that are not closed loops (e.g. steam w/o condensate recovery, direct hot water preparation and distribution) is defined based on some default (external) reference temperature (cold water inlet, air inlet):

$$\dot{Q}_{USH,pipe,m} = q_{m,o} h_o - q_{m,ret} h_{ret} - q_{m,i} h_i \quad (2.9)$$

where the sub-indices refer to outlet (o), return (ret) and inlet (i), the latter being the external reference for open loops. For closed loops with $q_m = q_{m,o} = q_{m,ret}$ equation (2.9) simplifies to:

$$\dot{Q}_{USH,pipe,m} = q_m (h_o - h_{ret}) \quad (2.9a)$$

Analogous equations apply for useful supply cooling (USC)

2.2.3 Useful process heat and cold (UPH/C)

The net useful process heat demand (*UPH*) is defined as the difference between the total (gross) heat demand of the process (UPH_{gross}, see section 2.4 below) and the internally[6] recovered waste heat.

[6] *The distinction between an internal and external heat recovery depends on the specification of the process boundaries and is thought to be used for compact equipment with some internal heat exchangers: e.g. gross heat demand in a pasteuriser using cold milk would be the heating up from 4ºC to 72 ºC, whereas net heat demand would be only the*

$$Q_{UPH} = Q_{UPH,gross} - Q_{HX,internal} \quad (2.10)$$

On the other hand, the useful (net) process heat is also obtained as the total external heat supplied to the process, either by the heat supply system ($Q_{UPH,proc}$), or by externally recovered waste heat fed directly into the process ($Q_{HX,proc}$):

$$Q_{UPH} = Q_{UPH,proc} + Q_{HX,proc} \quad (2.11)$$

Here again, similar equations apply for the useful process cold (UPC) and the recovered waste cold (QCX).

2.2.4 Recoverable waste heat / cooling (QWH / QWC) and recovered waste heat / cooling (QHX / QCX)

For the calculation of the heat recovery potential it is important to distinguish between the total amount of waste heat and those waste heat streams that can technically be used. For flows which are used as input to another process, the recoverable waste heat is furthermore limited by the final temperature to which the flow can be cooled down, determining the minimum enthalpy h_{min}. The recoverable waste heat from a certain process ($Q_{QWH,Proc}$) is given by:

$$Q_{QWH,Proc} = m_o(h_{po} - h_{min}) \quad (2.12a)$$

The amount of available waste heat from equipments ($Q_{QWH,Eq}$, e.g. exhaust gas) or from pipings ($Q_{QWH,pipe}$, e.g. condensates) are calculated in an analogous way, based on the inlet temperature of feed-up in open circuits as a reference temperature.

Apart from waste heat *flows*, waste heat can be also contained (stored) in the thermal mass of process equipment or process media that remain within the process. The total amount of waste heat can be calculated as follows, being N_s the total number of start-ups - and correspondingly of breaks - of the process:

$$Q_{QWH,Proc} = m_o(h_{po} - h_{min}) + mc_p(T_p - T_{min}) N_s \quad (2.12b)$$

Analogous equations apply for waste cooling.

In a complex heat recovery system with both heating and cooling demands there maybe the possibility of direct heat exchange between cooling demands at high temperature and heating demands at low temperature. Therefore, the cooling demands of all subsystems (processes, pipes, equipments), $Q_{D,cooling}$, have to be added as potential heat source for waste heat recovery, and vice versa, the heating demands of all susbsystems, $Q_{D,heating}$, have to be added as potential cold source.

The really recovered waste heat Q_{QHX} depends on the configuration of the heat recovery system and is always less or equal than the total available heat and cold sources s

$$\sum_{h=1}^{N_{HX}} Q_{QHX,h} \leq \sum_{source} Q_{QWH,source} + \sum Q_{D,cooling} \quad (2.12c)$$

and the total available heat sinks:

$$\sum_{h=1}^{N_{HX}} Q_{QHX,h} \leq \sum_{source} Q_{QWC,source} + \sum Q_{D,heating} \quad (2.12c)$$

---

residual heating up after heat recovery, e.g. from 50ºC to 72 ºC.

2.3 Temperature levels in heat and cooling supply

In the EINSTEIN analysis, not only the amount (*quantity*) of energy in each of the subsystems is considered, but special attention is given to analyse the temperature level (*quality*) of the energy (demand and supply).

Although this makes the analysis of heat demand much more complex, it is absolutely necessary for the design of energy efficient solutions:

- ✗ The potential of heat recovery and heat integration depends strongly on the temperature levels of demand and supply (available waste heat or waste cooling)
- ✗ Many of the energy efficient conversion technologies such as CHP and heat pumps, and renewable energy sources (solar thermal energy) are (practically) limited to low and medium temperatures. The design of a supply system that makes maximum use of low temperature sources is therefore a necessary precondition for the utilisation of these technologies.
- ✗ Conversion efficiency of conventional heat supply equipment improves, and heat losses of distribution, storage and process equipment are lowered, if temperature levels are decreased.
- ✗ Cold generation is the more efficient, the higher the temperatures at which cooling energy has to be delivered, and the lower the heat rejection temperatures.

Table 3. Classification of the possible heat supply technologies by temperature level.

Temperature interval [ºC]	Temperature level of heat	Applicable heat supply technology
< 60	Low	Low temperature heat pumps Low-temperature solar thermal
< 90	Medium-low	Waste heat from CHP engines (cooling water) Practical limit for flat-plate solar thermal High temperature heat pumps
< 150	Medium	Low pressure steam
< 250	Medium-high	Limit for medium temperature solar thermal
< 400	High	Practical limit for waste heat from gas turbines, biomass…

We have to distinguish between the following temperatures in the processes and the heat supply systems:

- *Process temperature (PT)*: temperature of the working fluid in a process.
- *Process Supply Temperature (PST)*: inlet temperature of the heat transport medium used for heating or cooling of the process (e.g: steam temperature at the entrance of the process heat exchanger).
- *Central supply temperature (CST)*: temperature of the heat transport medium at the outlet of the central heat or cooling supply (e.g. boiler, chiller). The difference between CST and PST accounts for temperature losses in the distribution line.

2.4 Process models and demand curves

2.4.1 Process models

Processes in EINSTEIN are modelled using a generic process model as described initially in POSHIP[7] (Figure 7). The generic process model in the following is presented for heating processes, but the same model – with inverse sign - is also applied for cooling processes. Most processes require both heating (cooling) of a fluid stream (e.g. hot air streams, hot or chilled water, renovation of water in baths, ...) and heating (cooling) of some reservoir (ovens, liquid baths). The latter can be subdivided into pre-heating (pre-cooling) before the start of operation and into maintenance of temperature (compensation of thermal losses during operation).

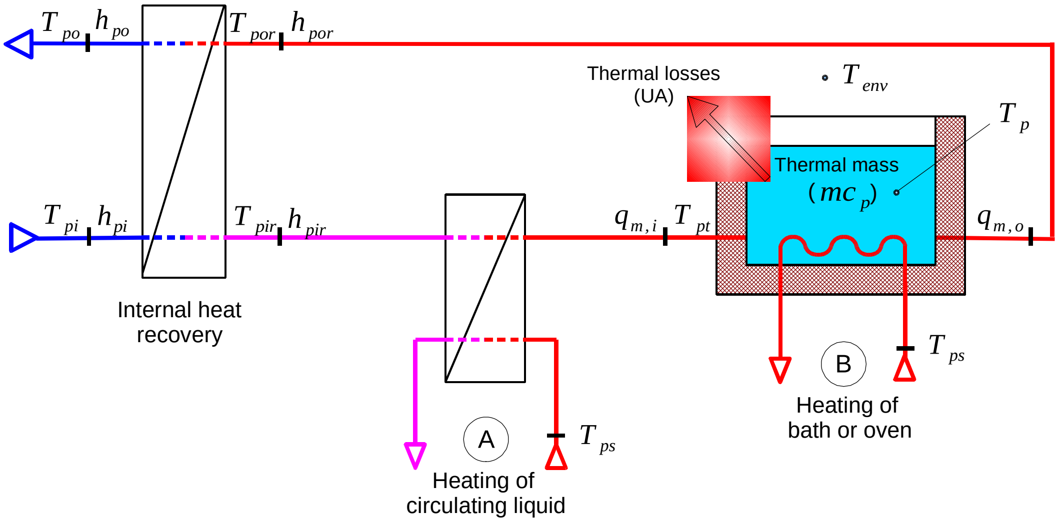


Figure 7: Generic EINSTEIN process model with one incoming and one outgoing stream

The total heat demand of a process can therefore be conceptually split into the three components mentioned above:

a) Circulation heat (UPH_c)

The heat related with the entering medium mass flow (inflow). This is the heat needed to heat-up the entering medium to the process temperature, independently of the physical place where heat is added (prior to or within the process). The circulation heat can be defined for continuous and batch processes, and is conceptually independent from the physical time interval during which the mass flow is circulating. The circulation time can be different from the operation time.

The gross heat related with circulating fluid can be calculated as

$$Q^{gross}_{UPH,c} = m_c c_p (T_p - T_{pi}) \qquad (2.13)$$

where m_c is the total mass of process medium circulating during the period under consideration (one day or one year). The net useful process heat for circulating fluid is obtained by subtracting internal heat recovery:

$$Q_{UPH,c} = Q^{gross}_{UPH,c} - Q_{HX,internal} = m_c c_p (T_p - T_{pir}) \qquad (2.14)$$

[7] *POSHIP: The Potential of Solar Heat for Industrial Processes. Project Funded by the European Commission - Directorate General for Energy and Transport. Programme ENERGIE (5th Framework Programme for Energy, Environment and Sustainable Development), Project No. NNE5-1999-0308.*

b) Initial heating at start-up (UPH$_s$)

The heat necessary to bring the process mass *that remains within the process equipment* (does not include heat added to bring inlet flow to process temperature in either batch or continuous process) to the process temperature after process interruption (e.g. break during night-time or over week-end; breaks between different operation cycles etc.):

$$Q_{UPH,s} = N_s (m c_p)_e (T_p - T_s) \qquad (2.15)$$

where $(mc_p)_e$ is the effective or equivalent thermal mass of the process that considers the thermal inertia not only of the medium itself contained within the process but also the surrounding equipment, and N_s is the number of start-ups in a given period of time.

c) Maintenance heat (UPH$_m$)

The heat necessary to maintain the process temperature constant. It is equivalent to the thermal losses through the process border to the ambient and to the latent heat supply for evaporation or chemical processes.

$$Q_{UPH,m} = [(UA)(T_p - T_{env}) + \dot{Q}_L] t_{op} \qquad (2.16)$$

where (UA) is the thermal loss coefficient of the process equipment, T_{env} is the environmental temperature for the process (usually the indoor temperature of the factory), $\dot{Q}_L$ is the power requirement for phase change or chemical reactions, and t_{op} is the process operating time.

Summarising, the total net useful process heat can be calculated from the three components described above:

$$Q_{UPH} = Q_{UPH,c} + Q_{UPH,m} + Q_{UPH,s} \qquad (2.17)$$

The simple EINSTEIN process model can be easily generalised to processes with several incoming and outgoing process streams (Figure 8).

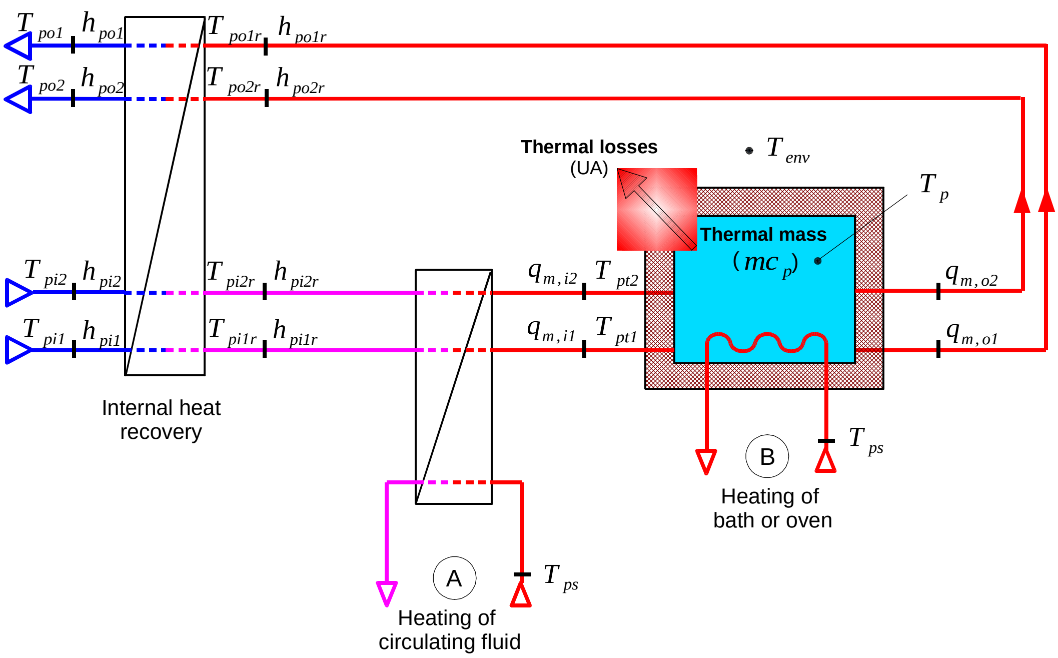


Figure 8: Standard EINSTEIN process model with several incoming and outgoing streams

2.4.2 Simplifying assumptions for EINSTEIN fast audit

For fast analysis and in order to reduce the number of required input data, the general process models in EINSTEIN are simplified as follows:

- constant temperature levels: all inlet, process and outlet (waste heat) temperatures are considered as constant
- time dependence is only given by the schedule of the process. All components of the heat demand vary proportionally in time. (

For most industrial processes this constant temperature level approximation is sufficient. Real processes with variable tempeature can be approximated by splitting the real process into two or several sub-processes in the model.

2.4.3 Standard demand profiles

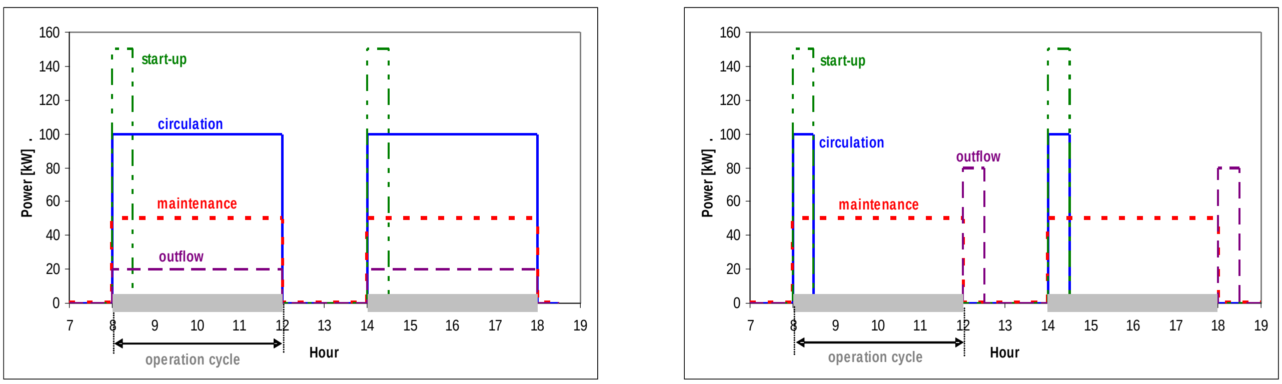
The time dependence of the heat demand and waste heat availability in EINSTEIN generic processes is given by the following time schedules:

- Schedule for the operation of the process: the time during which a constant set temperature T_p has to be maintained
- Schedule for initial heating at start-up: the time when initial heating at start-up begins.
- Schedule for incoming flows
- Schedule for outgoing flows

If no detailed time schedule is given in the detailed annex to the basic EINSTEIN questionnaire (see Annex), default schedules are assumed, depending whether the process is continuous or batch (Table 4)

Table 4. Default process schedules

	Continuous process	Batch process
Circulation (Inflow)	Continuous during t_{op}	The first 20 % of total duration <u>within</u> t_{op}
Start-up	The first 20 % of total duration <u>within</u> t_{op}	The first 20 % of total duration <u>within</u> t_{op}
Maintenance	Continuous during t_{op}	Continuous during t_{op}
Evacuation of waste fluid (Outflow)	Continuous during t_{op}	The first 20 % of total duration <u>after</u> t_{op}



(a) (b)

Figure 9: Standard demand profile for (a) continuous and (b) batch processes. Example: process with t_{op} = 2 x 4h.

2.4.4 Heating and cooling demands of buildings in EINSTEIN

Heating and cooling demands of buildings can be modeled in EINSTEIN as special cases of the generic process model (Table 5).

Table 5. Representation of building heat and cooling demands as processes in EINSTEIN.

Process demand component	space heating	space cooling	sanitary hot water
Circulation (Inflow)	Heating up of fresh air	Cooling down of fresh air Dehumidification of fresh air	Heating up of cold water
Start-up	Initial heating up / cooling down before periods of occupancy		-
Maintenance	energy demand for heating / cooling except air renovation		-
Outflow	exhaust air (useful for recovery in controlled ventilation only)		Waste water
Process temperature	desired indoor temperature		Hot water temperature (points of consumption)
Process supply temperature	Inlet temperature of heat transport medium in heating / cooling system (e.g. water, hot / cold air)		Hot water temperature (distribution)

2.5 Heat integration and Pinch-analysis

The correct way to integrate (waste) heat into a system is described by the pinch theory [Schnitzer, Ferner 1990] that was developed by Linhoff et.al. in the 1970s. With the pinch analysis the heat and cold demand of the whole system is shown in one simple diagram that shows the energy (heating or cooling) demand of the processes and in which temperatures this energy is needed. Some very important statements can be drawn from this analysis:

- How much energy can be theoretically saved by heat recovery ?
- How much external heating demand does the production process have ? At which temperature levels is this heat necessary ?
- How much external cooling demand does the production process have? At which temperature levels is this cooling necessary?

The analysis therefore is a strong tool for a first estimation of the energy saving potential by heat recovery (which later has to be adapted due to practical and/or economic reasons). Second, the analysis shows very well in which temperature demand external heat/cold is necessary – an important information for the ideal integration of new energy supply systems.

2.5.1 Analysing a system with the pinch analysis

The pinch theory separates the heat flows in the system by temperature levels into a cold part with surplus heat energy that needs to be cooled and a hot part that needs to be heated. This process is undertaken by combining the temperature enthalpy curves of all streams that have to be heated (cold composite curve) and all streams that have to be cooled (hot composite curve) into one temperature – duty diagram (See Figure 10 for the combination of “cold” streams). Process streams in this sense are any mass flows that have to be heated up (cold streams) or which have to be cooled down (hot streams). Also streams which are not necessarily required for the process (such as waste water running to the effluent) can be included if they may be used as cooling or heating agent for other streams.

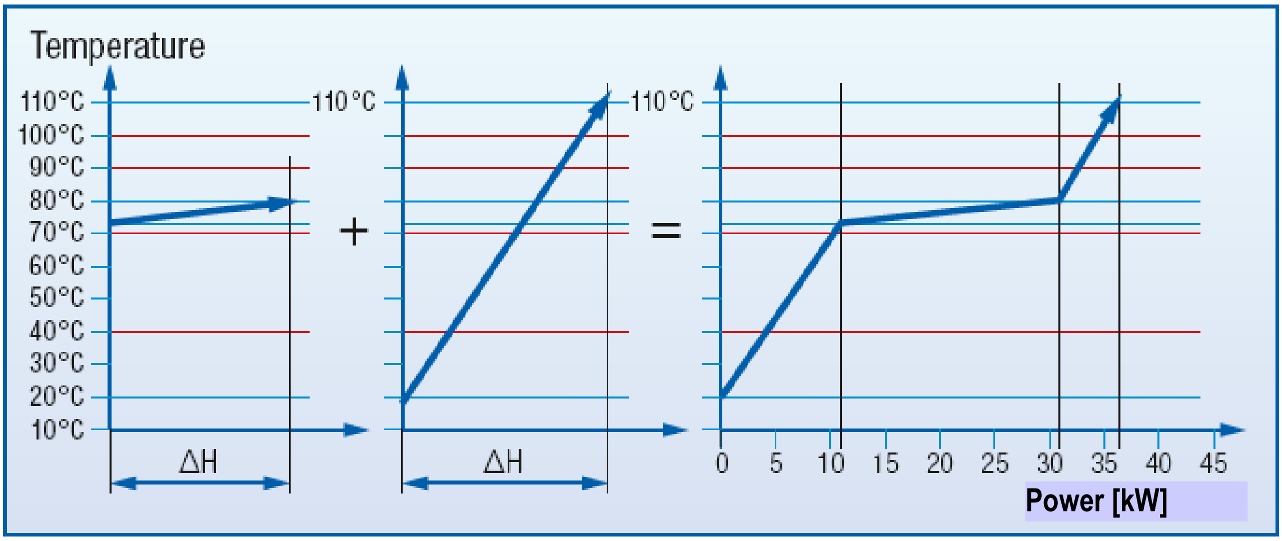


Figure 10. Thermodynamic combination of cold streams. The composite curve is constructed by adding the enthalpy changes of the individual streams within each temperature interval.

The hot streams are combined in the same way. Both curves are then drawn on the same plot in such a way that the cold streams are at a lower temperature than the hot streams everywhere in the diagram. This can be achieved by moving the curves along the power axis (x-axis), as the enthalpy difference always represents a relative and not an absolute measurement.

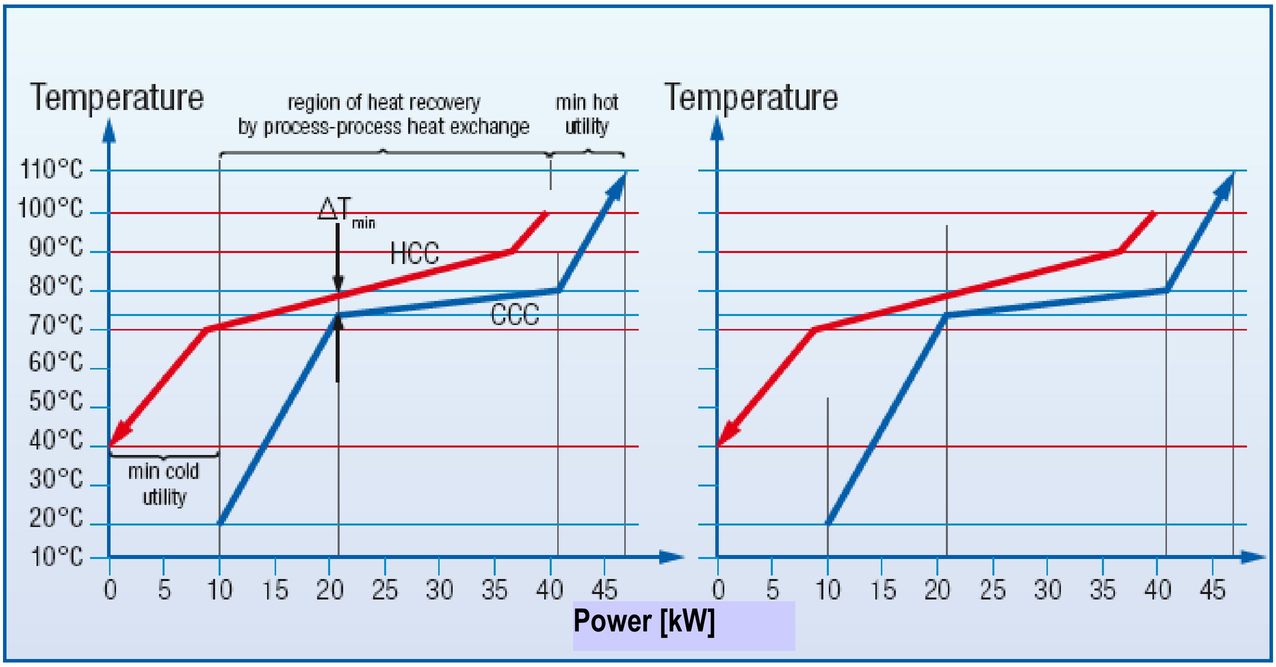


Figure 11. Representation of the combination of the **cold and hot composite curves**.

With the help of these composite curves it is possible to determine some essential facts about the process. The curves are separated by a point of lowest difference in temperature ΔT_{min}, that is chosen by the user as the minimal ΔT over a possible heat exchanger in the system. This ΔT_{min} defines the temperature level in the system that is the thermodynamic bottleneck (See Figure 11) of the process, the so called "pinch".

The pinch temperature cuts the system in two halves: in the area below the pinch temperature there is a heat surplus that has to be removed by cooling or is dissipated to the ambient; and above the pinch temperature there is an energy deficiency that has to be overcome by additional heating. Therefore, three important rules for heat integration follow:

- ✗ No external heating below the pinch temperature (enough waste heat is available)
- ✗ No external cooling above the pinch temperature (cooling can be achieved by heating other process streams)
- ✗ No heat exchange across the pinch: do not use a (waste) heat source above pinch tempeature (a tempeartue range with heat deficit) for heating a sink below pinch temperature (a temperature range which already has a heat surplus).

The overlap of the curves in Figure 11 shows the maximum possible process heat recovery. The minimum heating demand $Q_{H,min}$, and the minimum cooling demand $Q_{C,min}$ can also be identified from the figure. The minimum temperature difference ΔT_{min} is determined by economical optimization, as a lower ΔT_{min} increases the efficiency of heat exchange, but as well increases the heat exchanger surfaces and, therefore, costs. Typical energy differences ΔT_{min} for typical processes in different industrial sectors are shown in Table 6.

Table 6. Typical ΔT_{min} values for various types of processes [Linhoff March, 1998]

Industrial Sector	Experience ΔT_{min} Values
Oil Refining	20 – 40 ℃
Petrochemical	10 – 20℃
Chemical	10 – 20 ℃
Low Temperature Processes	3 – 5 ℃

The theoretical values for $Q_{C,min}$ and $Q_{H,min}$ will be rarely achievable in practice. The reasons for this are the difficulties of handling process streams that are polluted, corrosive or simply out of the way. But the pinch analysis will give a good overview of what is thermodynamically possible.

Another way to demonstrate the heat demand of processes in a system is the **grand composite curve (GCC)**. To construct the GCC curve, the hot composite curve (HCC) and the cold composite curve (CCC) are moved by ½ ΔT_{min} towards each other, so that they touch at the Pinch. The horizontal difference between the two curves is now drawn into a new T-H graph which then gives the GCC. It is another way to show a heat source/sink profile of a process. If the heat flux increases with increasing temperature, the process functions as heat sink (more energy is needed at this temperature than is given). If the heat flux though increases with lowering the temperature, the process can act as a heat source.

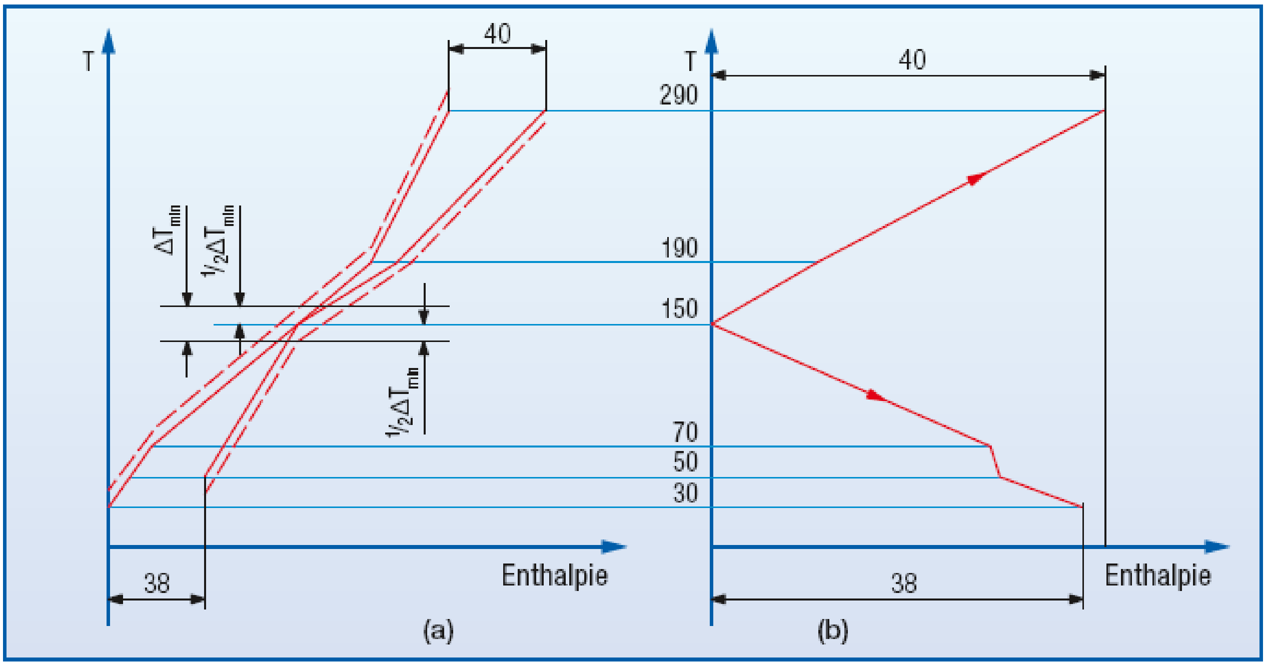


Figure 12: Overlapping of HCC and CCC (a) and design of the GCC (b)

The main aim of the GCC is to identify the ideal external energy sources that are necessary to heat up or cool down different streams. By analysing which heat sources can transfer heat to heat sinks of the processes, the remaining heat demand is only covered by external energy sources if no waste heat is available. Also we can see at which temperature the external resource should be supplied (see Figure 13 and Figure 14). It is important to mention that the GCC is crucially dependent on the choice of ΔT_{min}.

2.5.2 Some examples for the integration of external energy supply systems based on the grand composite curve

Heat supply

Most efficiently the heat supply should be placed at the lowest possible temperature level (see figure 13). In the case shown in the figure, 2 temperature levels would be ideal for heat supply H1 and H2.

Cooling machine

A similar situation exists for the cold supply for the ideal temperature levels. Cooling energy should be integrated at the highest possible temperature. The temperature levels of cooling plants should therefore lie at K1 and K2 respectively. (see figure 13).

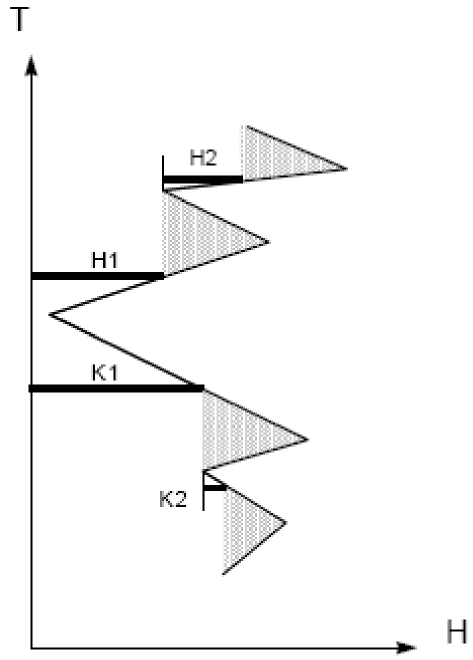


Figure 13: Integration of heat and cold supply (Source: Morand et al., 2006)

Heat pump

The grand composite curve also shows the thermodynamic ideal possibilities to integrate a heat pump. Below the pinch heat is available that can serve as a driving energy for the heat pump. The compressor works to lift the temperature level above the pinch temperature, where energy demand is needed. The compressor of the heat pump, as shown in more detail in section 3.7, therefore works across the pinch. The electrical energy is added to the low temperature heat and results in the high temperature heat delivered above the pinch. From these relations the ideal temperature levels for the heat pump can be identified (see figure 14). A heat pump working at higher temperature would not be ideally integrated in the plant and work with lower COP and higher electricity demand.

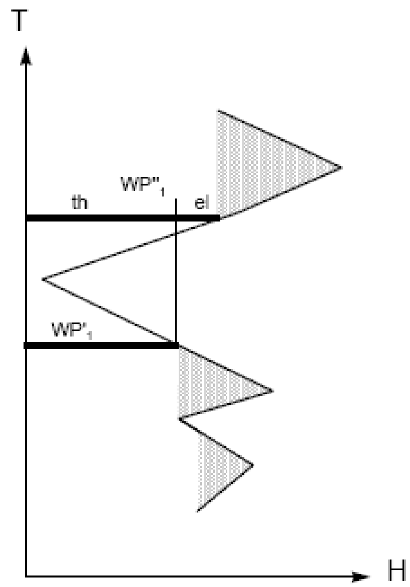


Figure 14: Integration of heat pumps (Source: Morand et al. 2006).

2.5.3 Design of Heat Exchangers

For the design of heat exchangers in the pinch analysis the choice of ΔT_{min} is decisive. The lower ΔT_{min}, the closer the final temperature of the cold stream can come to the start temperature of the hot stream (assuming counter current heat exchange). The following picture should show this more clearly:

- In a counter current heat exchanger the final temperature of the cold stream can maximally reach the start temperature of the hot stream minus ΔT_{min}.
- In a counter current heat exchanger the final temperature of the hot stream can minimally reach the start temperature of the cold stream plus ΔT_{min}.

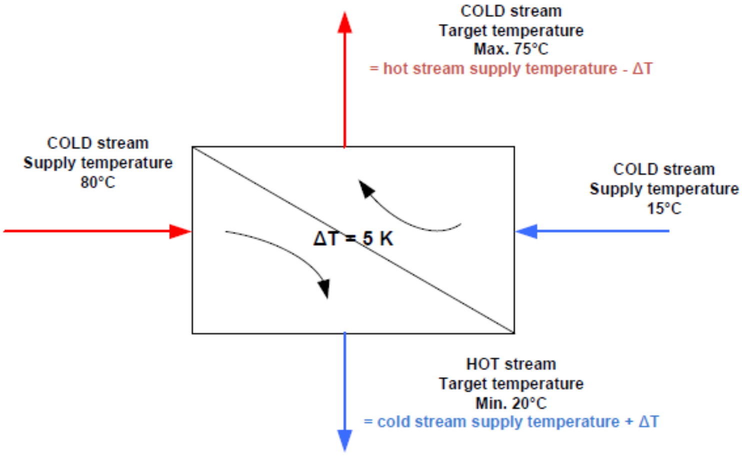


Figure 15: Influence of ΔT_{min} on heat exchanger design

Obviously the power exchanged between the hot and the cold stream has to be the same.

$$\dot{Q} = m_{hs} c_{p_{hs}} \left(T_{\text{supply}_{hs}} - T_{\text{target}_{hs}} \right) = m_{cs} c_{p_{cs}} \left(T_{\text{target}_{cs}} - T_{\text{supply}_{cs}} \right) \quad (2.18)$$

Supply = Start temperature / Target = End temperature
Index hs: hot stream = heat source
Index cs: cold stream = heat sink

The basic formula for the calculation of the necessary area for the heat exchange is given by:

$$\begin{aligned} &\dot{Q} = UA\Delta T_m \\ &A = \text{heat transfer area} \\ &\Delta T_m = \text{temperature difference} \\ &U = \text{heat transfer coefficient} \end{aligned} \quad (2.19)$$

2.5.4 Influence of ΔT_{min} on the pinch analysis

Influence on (thermodynamic) heat exchange

As explained above the choice of ΔT_{min} is crucial to the design of a heat exchanger network. The lower the ΔT_{min} value, the closer the end temperature of a cold stream can come to the start temperature of a hot stream. This becomes obvious in a simple example: Waste water at 50℃ can heat fresh water to a temperature of (50- ΔT_{min})℃. The lower ΔT_{min}, the closer can be the temperature of the fresh water to the 50℃ after the heat exchange. (This example is of c ourse only valid if the mass flow of the fresh water is the same or less than the waste water).

It becomes clear that the change of ΔT_{min} can change the heat exchanger design considerably. Going on with the example of the fresh water heating by waste water the explanation follows: If ΔT_{min} is set to 5 ℃, fresh water can be heated to 45℃. In case the target tem perature of the fresh water is 60℃, another hot st ream should be found that is best suitable to heat the fresh water from 45℃ to 60℃. If ΔT_{min} is now changed to

7℃, the criteria for this hot stream now change, because now the fresh water needs to be heated from 43℃ to 60℃. This can influence the ideal solution for the hot stream that could satisfy this heating demand considerably. This is the reason why a mathematical heat exchanger network should always be calculated from scratch, if the ΔT_{min} value is changed.

Influence on heat exchanger area and costs

In the pinch analysis, the graphs of the hot and cold composite curves usually are displayed on the basis of one general ΔT_{min} value. Later in the design stage of the heat exchangers, the ΔT_{min} value is set according to the characteristics of the streams. A gaseous stream will have a higher ΔT_{min} value than a liquid stream, as liquids usually have better heat transfer coefficients. It was shown in the section "Design of Heat Exchangers" that the specific ΔT_{min} value of a heat exchanger has influence on the necessary area for the required heat exchange. Thus, also the investment costs are affected.

Usually in the final design stage for the area of heat exchangers ΔT_{min} is set as a trade off between investment costs and savings of operating costs. The higher ΔT_{min}, the lower the area of the heat exchanger and the lower its investment costs, but as well the lower the energy savings (Figure 16).

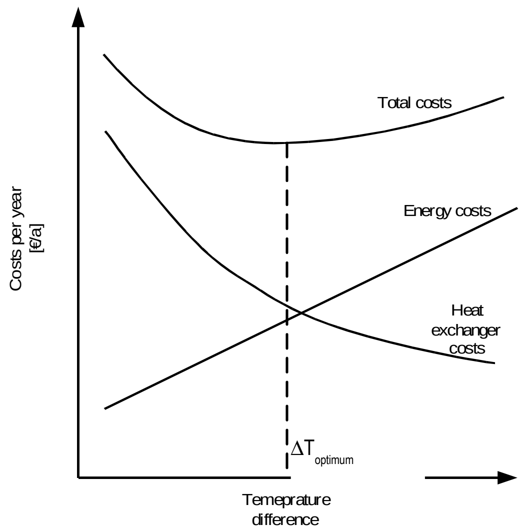


Figure 16: : Total costs as a function of ΔT_{min}

2.6 Total cost assessment - TCA

Total cost assessment is a method that enables a conventional economic analysis based on the micro-economic parameters, but as well may be used for a more complex analysis taking into account also macro-economic parameters for an economical analysis for a longer time frame, taking into account e.g. environmental and safety issues as well. This means that a TCA can take into account other cost categories than a conventional cost analysis and might integrate macroeconomic aspects (such as long term costs that become decisive within the life cycle of the investment object).

A total cost assessment therefore has the following features compared to a conventional analysis:

- ✗ *Cost categories:* besides all costs that are considered in conventional analysis, as well all indirect costs, savings and revenues are taken into account, such as costs that arise through image losses etc.
- ✗ *Cost allocation:* all costs are exactly allocated to the investment and not considered overheads.
- ✗ *Time horizon:* The considered time of a total cost analysis is longer than in conventional analyses, to take into account long term influences.
- ✗ *Indicators:* In TCA economic indicators are used that can also demonstrate the long term economic performance of an investment.

It becomes obvious, that a method for a TCA can as well be used for a conventional analysis, if a few parameters are changed. Due to this fact, EINSTEIN integrates a method that is applicable for a conventional analysis, but can be extended to consider macro-economic parameters if required.

In EINSTEIN generally economical analyses compare the costs of the existing process (existing heat and cold supply) with the expected investment and other costs of the proposed alternative energy supply system. In general the time horizon of the economic calculation is set to the life time of the project (life time of the equipments of the energy supply system), however can be changed to any value.

Conventional cost analysis in EINSTEIN (micro-economic analysis)

The economic calculation is based on the costs of the existing heat and cold supply system to be replaced and those of the new proposed alternative(s). The main costs categories include the investment, energy costs, operating and maintenance costs, contingencies and other non reoccurring costs.

Contingencies are possibly occurring costs or revenues that have an effect on the economic analysis, such as increase in market shares, expected tax benefits etc. Other non re-occurring costs include costs that arise once throughout the lifetime of a project, such as costs from legal allowance for the investment realisation.

For each proposal of a new heat and cold supply system, the cash flow will be calculated year by year during the project lifetime from the equation:

$$CF_t = \sum_{i=1}^{n} EX_i^t - \sum_{i=1}^{n} S_i^t \qquad (2.20)$$

Where:

t = the year of calculation

CF_t = cash flow at the time of calculation

n = number of cost categories

EX = the net expense of the project, which is calculated from the costs of the proposed process

S = the savings of the project which is calculated from the costs of the existing process to be replaced.

Then the net present value of the project during the project lifetime will be calculated from the following equation:

$$NPV_t = \sum_{i=0}^{t} \frac{CF_i}{(1+r)^i} \quad (2.21)$$

Where now:

t = the year of the calculation

NPV_t= the net present value of the project at the year t

r = the real interest rate of external financing

One of the most important economical parameter of any project is the internal rate of return (IRR). The IRR is defined as the annualized effective compounded return rate which can be earned on the invested capital and determined as any *discount rate* that results in a *net present value* of zero of a series of cash flows. For each proposal, the *internal rate of return* (IRR) is calculated for each year of the project lifetime after the payback period:

$$\sum_{i=0}^{t} \frac{CF_i}{(1+IRR_t)^i} = 0 \quad (2.22)$$

Where:

t = the year of the calculation

IRRt = the internal rate of return of the year t

In the EINSTEIN TCA calculations, the *modified internal rate of return* (MIRR) is used in order to determine the efficiency of various alternative choices. More preeminent than the IRR parameter, the MIRR takes into account the reinvestment potential of intermediate positive cash flows. For each alternative, the MIRR is calculated for each year of the project lifetime after the payback period:

$$MIRR_t = q_t^{1/t} - 1 \quad (2.22a)$$

Where:

q = the value at the year t of the positive cash flows, computed according to the reinvest rate (here we have the company specific discount rate), divided by the net present value of the negative cash flows, computed according to the finance rate (here we have the interest rate of external financing):

$$q_t = \frac{\sum_{i=0}^{t} CF_i^{+} (1+d)^{t-i}}{-\sum_{j=0}^{t} CF_j^{-} (1+r)^{j}} \quad (2.22b)$$

Where:

CF^+ = the positive cash flows

CF^- = the negative

d = the company specific discount rate (real rate)

r = interest rate of external financing (real rate)

In the TCA module of EINSTEIN tool, the payback period (PBP) is also resulted for each alternative. The payback period refers to the period of time required for the return on an investment to "repay" the sum of the original investment and calculated as followings:

$$\sum_{i=0}^{PBP} \frac{CF_i}{(1+r)^i} = 0 \quad (2.23)$$

Other parameter also taken into account for each alternative is the Benefit Cost Ratio (BCR).

As an alternative approach, the total (yearly) energy system cost is calculated as the sum of the energy cost for fuels and electricity, the operation and maintenance (O&M) costs and the annuity of investment.

$$C_{Total} = C_{el} + C_{fuels} + C_{O\&M} + a\, I_0 \qquad (2.24)$$

The annuity of investment is obtained hereby as the fraction $a = A/I_0$ of the (constant) yearly payment A required, so that after the given period all the debt and the corresponding interest payments for the initial investment have been returned[8]:

$$\sum_{i=1}^{N} \frac{a}{(1+r)^i} = 1 \qquad (2.25)$$

where the parameters are defined as follows:

a: Annuity of investment

N: Economic depreciation period

Extension of macro-economic parameters for a TCA

For taking into account macro-economic aspects the cost categories operating and maintenance costs, contingencies and other non reoccurring costs can be extended to include any possible macro-economic aspects.

For the contingency cost category for the new energy supply system this might include market share increase through macro-economic improvements of the region due to more sustainable production. Non re-occurring costs for the current energy supply system might be re-mediation activities for environmental hazards that would occur if the energy supply would not be changed but left as it is.

Company's or micro-economic point of view vs. social or macro-economic point of view

One of the main differences between the macro-economic or *social point of view* and the micro-economic or *company point of view* is the consideration (or not) of subsidies[9] and externalities in the economic calculations:

- ✗ Whereas for the company's cost-benefit analysis the *net investment* (= gross investment – subsidies) is the relevant investment cost parameter, from a social point of view the total (gross) investment cost should be considered, as subsidies *are* an effective cost for society. In the case of not realising the proposed investment, the amount of subsidies could be dedicated to another alternative energy saving or environmental protection measure.
- ✗ On the other hand the cost of externalities (environmental hazards, etc., see above) does not appear in a company's balance, but has to be considered in a social balance.

See Table 7 and Table 8 for a comparison of the different points of view for optimization.

[8] *This is equivalent to say that the net present value of the series of yearly payments is identical to the initial investment. Equation (2.25) is strictly valid only if all the investment is realised in one year (year 0).*

[9] *In an analogous way the same reasoning applies also to other public support mechanisms such as tax reductions, feed-in tariffs, etc.*

Table 7. Most relevant cost parameters in micro- and macro-economic analysis

	Micro-economic analysis (company's point of view)	Macro-economic analysis (public administration point of view)
Investment	Net investment (gross investment minus subsidies/fundings)	Gross investment (money for funding otherwise could be used for other environmental protection measures)
Energy costs	Energy costs including expected rise of energy costs	
Other operation and maintenance costs	Utilities, maintenance, labour, legal compliance etc.	
Contigencies	e.g. positive impact on market share, saving of CO2 emission certificate fees etc.	
Non-reoccurring costs	Saving repair costs that would occur without changing the energy supply systems; costs for authorization (construction permits)	

Table 8. Most relevant indicators and objective function subject to optimization in micro- and macro-economic analysis

	Micro-economic analysis (company's point of view)	Macro-economic analysis (public administration point of view)
Main objective	Energy cost reduction (yearly costs and annuity of own/net investment)	Saving of primary energy consumption
Relevant indicators	IRR / MIRR Pay-back period NPV BCR	Additional yearly energy system cost per unit of primary energy saved. (Minimum required IRR as **INPUT**)
Impact of economic constraints on optimisation criteria	Maximum absolute saving vs. Maximum IRR/MIRR	Maximum absolute primary energy saving vs. Minimum additional cost per unit of primary energy saved

References Chapter 2:

R. Morand, R. Bendel, R. Brunner, H. Pfenninger (2006): Prozessintegration mit der Pinchmethode, Handbuch zum BFE-Einführungskurs. Bundesamt für Energie, Bern, 2006.

Schnitzer H., Ferner H. (1990): Optimierte Wärmeintegration in Industriebetrieben DBV Verlag, Graz, 1990.

3 How to implement an EINSTEIN energy audit

The EINSTEIN thermal energy audit and design of improved energy systems begins outside the company with few quick preliminary activities that you can start to carry out while sitting in your office. The so called „**pre – audit“** phase is very important because it gives you the opportunity to improve your knowledge on the status quo (i.e. on the actual energy demand profile, thermal processes in operation, equipments in use, energy bills, etc.) and to get ready before going to the company. After a preliminary telephone call to the customer, you should only send to your contact person an electronic questionnaire for the data acquisition. Once that it has been filled in, this template can be automatically imported in a calculation software tool for a first rough evaluation of the energy demand, and of the areas of potential improvements.

Therefore, what you have the opportunity to do in this preliminary phase is simple, quick but fundamental to save time afterwards: to prepare the company and yourself for the **on-site energy audit.**

This second phase includes two implementation steps:

- ✗ an on – site walk – through visit to the company
- ✗ an analysis of the results calculated running the Einstein software tool

The aim of the walk – through audit at the company is mainly to acquire the information still missing, through interviews and direct measurements; to inspect plants and hydraulics schemes, etc. Thanks to the preliminary assessment and definition of the auditing priorities, the visit on-site shall require no more than few hours of your time.

Then, coming back home, you have simply to access the EINSTEIN calculation tool. It will help you to elaborate the information gathered and to estimate the energy and economic savings. With the help of EINSTEIN you will be able to:

- ✗ check the consistency and completeness of the data acquired
- ✗ estimate (re-call for) the figures you still miss
- ✗ elaborate a detailed breakdown of the heat consumption by process, temperature levels, fuels, etc.
- ✗ analyse the real operation performance of existing equipments
- ✗ compare with available benchmarks

Once you have a clear picture of the actual energy flows and inefficiencies of the company, you can count on EINSTEIN also for the implementation of the third phase of this auditing procedure: **the design and evaluation of energy efficient alternatives.** This task drives you towards the comparison of different options through the following steps:

- ✗ preliminary design of integral energy and cost saving measures, and energy targets definition;
- ✗ calculation of the energetic performance and analysis of the environmental impact of the feasible solutions;
- ✗ analysis of economic and financial aspects.

Finally, you will have on your laptop all the information required to perform a clear and effective presentation of the results of your study. **Reporting** with EINSTEIN (the fourth auditing phase) is easy for you and convincing for the costumer.

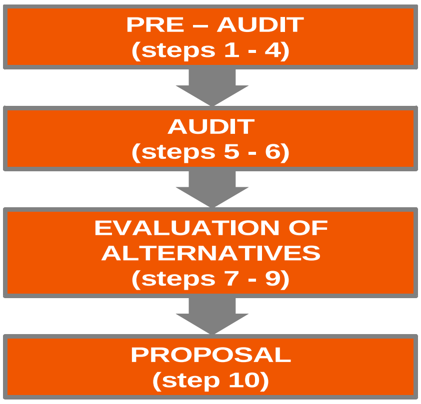


Figure 17. Phases of an EINSTEIN energy audit

The four phases of an EINSTEIN energy audit can be subdivided into 10 EINSTEIN **audit steps**, that are shown in Figure 18. Each of these audit steps is described in detail the following sections. For each audit step you can find the different tasks it is composed of, the indications how to carry out each of these tasks, and which of the tools from the EINSTEIN tool-kit you can use. For detailed instructions on the use of the EINSTEIN software tool please consult the EINSTEIN Software Tool – User Manual.

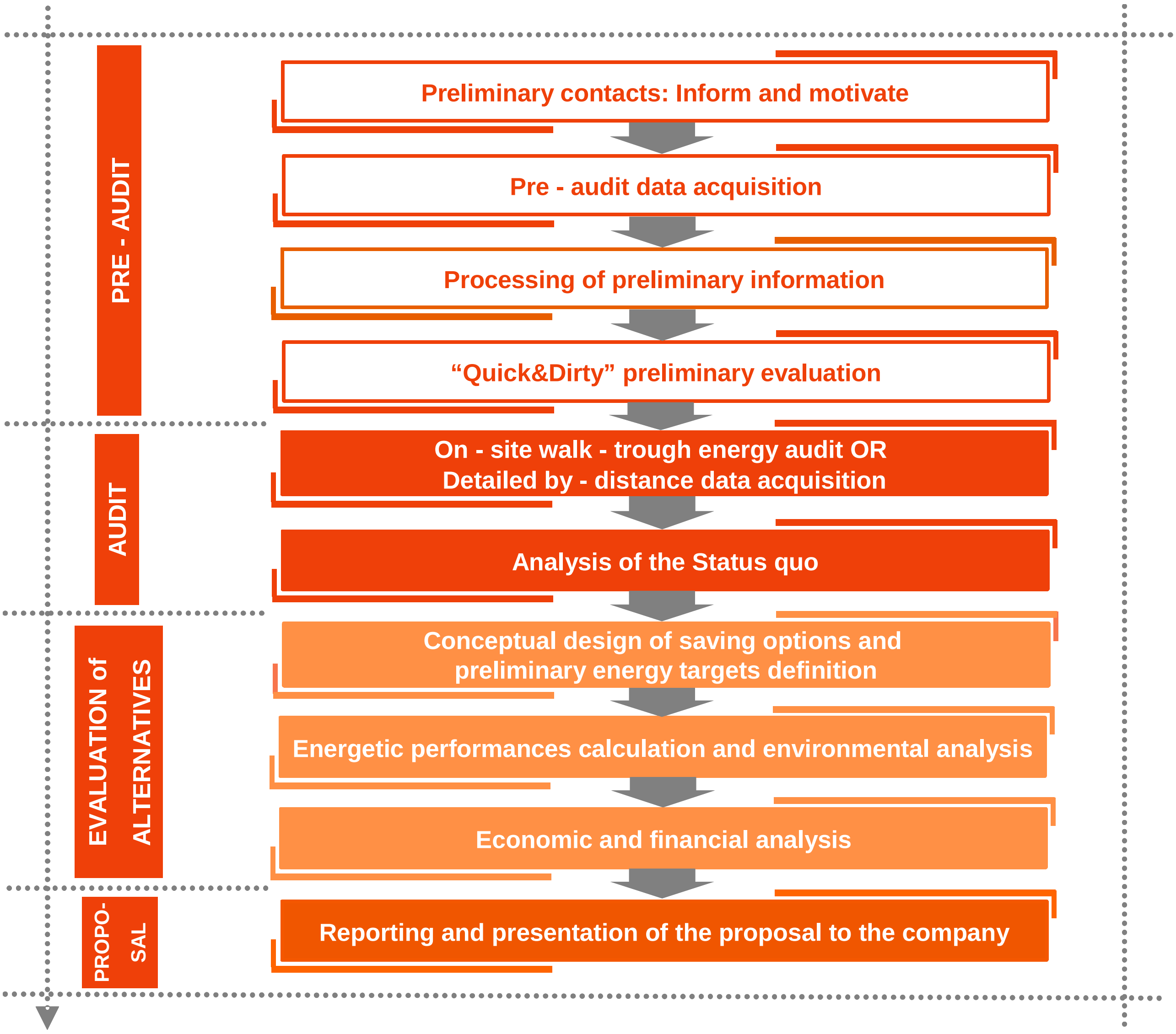


Figure 18. EINSTEIN's ten steps towards energy efficiency

3.1 Preliminary contacts: motivate

3.1.1 Initial contact

The target of the first contact is to arouse interest in the client, to get the intention to give some information in advance and to make an appointment.

One of the best possibilities to arouse interest are personal contacts you already have. Probably you already know companies that want to improve their thermal system or want to enlarge, restructure or change their installation.

Furthermore you could mention EINSTEIN at public presentations or within discussions, distribute the EINSTEIN brochure and get some new contacts e.g. at fairs, trainings you participate, events on energy savings in industry. You could also get into contact with local branch associations or chamber of commerce, if they are interested to support your work (e.g. by an article in their newsletters, by sending out your offer to their member companies…)

You should send out some information material to your contact persons or energy managers of a specified group of companies. (e.g. to the industrial branches: food industry, metal industry, chemical industry, paper industry, wood industry, textile industry and so on). As the EINSTEIN Audit will be a new product for your consulting company you can start with your regular customers.

This information material should include the main aspects of EINSTEIN (as mentioned in the EINSTEIN brochure, incl. e.g. some energy costs statistic), but also the possibility of financial support you can probably offer, e.g. by financial support of some public institutions, chamber of commerce and so on.

After one or two weeks you should contact the person you have sent the information to per telephone. Your target must be to persuade the company to proceed further and send you first data, that you can check if the company is a possible candidate for a EINSTEIN audit. You should also try to get a personal meeting at the company and/or the intention to fill in the basic questionnaire.

First check if the person is the right person. This could also be done in advance by collecting information on the web, or in business or environmental reports, press articles and so on. You should know the function, name, title, telephone number of the contact person and products and size of the industrial site before you call the relevant person.

You should define the first sentences, advantages and think of answers for counter-arguments like: “I have not time, not interested, please send us more information…”

3.1.2 Preliminary appointment (optional)

If the company is quite near to your office you should think of a preliminary site visit just to get in personal contact and present your company and the EINSTEIN instrument. Otherwise you would have to get into a closer telephone conversation. For the appointment check that the relevant persons are there (e.g. the plant manager, boiler attendant, chief technical officer…). You also could send the basic questionnaire in advance. (for details see 3.2)

Usually for the first appointment you should collect as much information as possible from the web. You should also try to understand who the client is, and what he/she could expect (e.g. he/she has technical problems, the energy costs are too high, to fulfil legal requirements of the company, to distinguish him/herself …). Then you can define the main advantages and your target of the meeting: Start the EINSTEIN audit, make a quick tour within the plant

For this first meeting you should ask the client if he/she wants to start with his presentation of the company or to introduce your own company. Then you should ask the customer about the specific situation, wishes, problems, expectations. You could discuss problems you already know or ask e.g.: Did the energy costs increase, and why? Are there any technical or organisational problems with the thermal system, e.g. with the public authority or neighbours, or the utilities? Who is responsible for the maintenance? How old is the boiler? Is there a shortage of time, budget, know how? Are there any plans for the future? Who will be responsible for a possible project?

For the presentation of the EINSTEIN tool you can use the EINSTEIN road show, the EINSTEIN promotional brochure and EINSTEIN technical brochure (included in the EINSTEIN tool-kit). But also some results of the quick- and dirty study, if already available.

Some general tips:

- ✗ Start the conversation with some information you got from the website or say "very interesting webpage, who is responsible for that…"
- ✗ Never reply to an objection directly but ask if you got them right, take a note and think of it first. Try to define other main advantages.
- ✗ Try to ask many open questions, so you learn as much as possible.
- ✗ Do not talk a lot on your own. Just present precise and short information on the main advantages the company could get.

EINSTEIN Step 1: Preliminary contacts. Inform and motivate

> Promotional material

> Possibility of self-assessment

3.2 Pre-audit data acquisition

Before starting an energy audit in an industry (which usually requires previously a contract between the company and the auditor) it is very helpful to gather some preliminary information. This preliminary information may help to decide whether it is worth while going further on in the auditing process.

Preparing the user for which data You will ask him for, in time *before* a visit or a detailed telephonic interview, helps saving time both for the user company and for the auditor. In addition, by this way it is more likely to get a rather complete and detailed set of data.

In many cases acquisition of data by distance may be already sufficient in order to make a first quick-and-dirty fast assessment and generate some ideas of possible energy saving measures.

3.2.1 Preparation of the user company

In order to prepare the user company tell them which type of data is required, so that they can collect the required information. as a first step a check list for the most relevant data is given:

- general situation of the company:

  - economic situation (past and present)
  - future prospects (evolution of production volume foreseen, other important changes or projects)

- fuel and electricity bills:
  - get a quantitative overview of present energy consumption and tariffs paid
  - historical data for the previous years if available
  - monthly data if available, or qualitative information about seasonality of the demand

- description of the production process (flow chart):

  - which production lines exist in the company
  - which are the product flows and the different processing steps

- description of the different processes:

  - which of the processes are consuming heat and cold
  - which quantities of product are processed
  - which temperature levels are used (in the heat supply, in the process itself)
  - how many times operates the process and during how much time

- description of the heat and cold supply system

  - technical data of the equipments (boilers, chillers, etc.)
  - temperature and pressure levels in the heat distribution and in the processes

- description of the buildings, production halls and stores:

  - data on consumption for space heating and cooling if available
  - surface area, occupancy

This pre-audit check-list is also available in the EINSTEIN tool kit and can be sent to the company. If you opt to make a preliminary visit, you could use this to ascertain some of the above information that is readily available. A brief walk through may also be useful at this stage.

3.2.2 Preparation of the auditor

Usually the EINSTEIN energy auditor is an expert in energy (heat and cold supply) systems, but cannot be expert for all the different industrial sectors she/he probably will get in touch with. Nevertheless it is important to gain a basic insight about sector specific problems, at best already before getting in touch with the company, or at least before going there to the first visit.

A large amount of information is available for most industrial sectors and subsectors, but in many cases access to the right information is difficult and time-consuming.

The EINSTEIN tool-kit helps here giving useful links for easy and fast access to a basic information in most sectors, that then can be deepened depending on the time available and on the specific needs, following the large amount of web-links and bibliographic references given in the additional documentation.

The auditor should gain a basic insight in the following topics:

- ✗ which are the most relevant processes in terms of energy consumption in a typical company of the specific industrial sector or type of building ?
- ✗ which are the existing options for process technologies (best available technologies - BAT), and it's main advantages and disadvantages ?

3.2.3 Check-list and basic questionnaire for data acquisition by distance

The EINSTEIN audit methodology uses a check list (see section 3.2.1) and/or a basic questionnaire for data acquisition, that later on can be completed with more detailed information ("detailed annexes"). This check-list and questionnaire can be sent to the company, together with an explanatory text, so that some technician of the company can fill in the data. The questionnaire is available both in printable and in electronic format (see Annex).

It is important to take into account, that a first rough assessment can be carried out semi-automatically already with very few data, although – as a general rule – the reliability of the analysis and the corresponding recommendations will improve, the more complete the data set is.

Feeding the EINSTEIN tool with incomplete data, it tries to estimate the missing parameters as far as possible, carries out those calculations that are possible with the available information, and generates a check list with the most relevant additional data that should be obtained by the auditor (See description of the menu "consistency check" in the user manual).

EINSTEIN Step 2: pre-audit data acquisition

> prepare the company

> prepare yourself

> collect basic data by distance

3.3 Preparation of audit: Processing of preliminary information

3.3.1 Processing of pre-audit data

A simple pre-checking of the data delivered by the industry can be carried out with the help of the EINSTEIN software tool. Once the available data is introduced, the statistics of energy demand and supply is automatically created, , the available information is evaluated, and consistency of data is checked.

At this stage of a first processing of pre-audit data the following information can be obtained:

- a list of severe inconsistencies within the data (e.g. consumption of a fuel type is specified, that is not used in any equipment, ...)

- a list of necessary data that are missing and can neither be computed nor estimated from other available information.

3.3.2 Complete information by telephone interviews or e-mail

If during the processing of the pre-audit data there have been detected serious inconsistencies or a lack of very basic data, that are indespensable even for a first rough assessment, telephone or e-mail contact with the company may help to acquire some additional data or for clarifying some doubts.

After changing the basic data set, the consistency checking (previous section) should be repeated.

After this step at least the following information should be available:

- the main products and the produced quantities should be identified
- the amount of total energy consumption in the company for thermal uses
- the major heat and cold consuming processes should be identified, and at least a rough estimate of the energy consumption of each should be available
- the main heat and cold supply equipment should be identified and at least nominal powers should be available; a rough layout of the heat and cold distribution system should be given (which boiler supplies heat to which process, etc.)
- temperature levels in the heat supply and in the main heat consuming processes should be known

3.3.3 Acquisition of benchmark data

As at this stage we already have some more detailed information on the industry, on the processes it applies, and on the products, we can obtain reference values from other similar industries (benchmarks).

The sources of information for doing this are the following:

- the EINSTEIN software tool contains a benchmark data base, that helps you find quickly reference values for many industrial sectors

- further information can be obtained in the documents referenced in the EINSTEIN report on thermal energy auditing practices and tools [Vannoni et al., 2008)]

For some more details on benchmarking see section 3.6.5.

References chapter 3.3.3:

C.Vannoni et al. (2008): EINSTEIN Report: Review of Thermal Energy Auditing Practices and Tools.IEE Project EINSTEIN, Project deliverable D2.2. Available for download on www.einstein-energy.net

3.3.4 Acquisition of basic knowledge on the specificindustrial sector or type of company

With the information you have available now on the specific industrial sector or type of company You can deepen Your knowledge on the specific types of processes and machinery you will find during the audit, as already outlined in section 3.2.2.

- ✗ Get information on the specific machinery used and possible technological alternatives
- ✗ Get information on the specific supply equipments and systems used and possible technological alternatives

3.3.5 Identification of possible measures

With the information you already have available on the company You probably can carry out already a complete auditing cycle from data acquisition to proposal generation.

Even if data are still very incomplete and therefore the results You can expect can not be very precise, You should do this in order to get already a first idea about orders of magnitude of possible savings, approximate dimensions of possibly necessary investment, etc. , that may be very useful for a first discussion with the company during the audit.

It doesn't take You much time, as the EINSTEIN software tool can do it (nearly) automatically by itself.

When thinking about possible improvements, You should also consult the available documentation on best available technologies (BAT) for the specific sectors and problems. The EINSTEIN tool-kit helps You to get easy access to the available information.

3.3.6 List of priorities for further inquiry and data acquisition

If You want to do a *fast* audit, You have to focus on the essential. If You want to do a *high-quality* audit, You should not forget the important data. In some cases there might be a conflict between one objective and the other. Therefore, once You have in mind what You probably want to propose to the company, You should fix a list of priorities of which information You should look for first during the audit, and where You should insist, even if access to the information might be difficult.

After the audit You should have all the information necessary to assess the feasibility of the technologies and solutions You might propose (or exclude), and You should avoid to collect unnecessary data, especially if accessing them is difficult. For example, if You want to propose a solar thermal system for process heat production, You *should* obtain all the information on available roof and ground surfaces, possible shading problems, structural details of the roof, etc. necessary for assessing this technology; whereas if the probable solution is a heat exchanger for improving heat recovery in some process, it might not be the best strategy to bother the company with looking for architect's drawings of roof details ...; in the same sense, it might not be worth while asking for lots of technical details of a process that consumes only 0.3 % of the total energy demand).

EINSTEIN Step 3: Ppreparation of audit. Processing of preliminary information

> process pre-audit data

> call the company to check data

> compare with benchmark data

> learn about specific processes/companies

> identify possible measures

> fix priorities for audit

3.4 Quick-and-dirty pre-evaluation

As a result of the processing of the preliminary information, a first “quick-and-dirty” pre-evaluation report can be generated. This report should give information on:

- ✗ identification of the most relevant heat and cold consuming processes and approximate quantification of the energy consumption
- ✗ first quantitative analysis of heat and cold demand by temperature levels and time schedules; cumulative heat demand curves

and based on this analysis of the heat and cold demands:

- ✗ identification of possible technological options for efficient heat and cold supply
- ✗ order of magnitude of dimensioning of required equipment
- ✗ estimation of energetic and economic performance to be expected

This first sketch of “*what possibly might be done*” in the industry can help both the auditor and the user company to focus from then on on the specific information required for assessing the most promising technological options.

3.4.1 How to create the “quick & dirty” pre-evaluation report ?

The EINSTEIN “quick-and-dirty” pre-evaluation report can be automatically generated using the “report”-function of the EINSTEIN software tool.

Economic estimates for proposed system designs that are given by the EINSTEIN software tool are only as good as the data on equipment and sub-system costs that previously have been fed into the corresponding data bases. These data can vary strongly depending on local and national conditions, and the given default values should be interpreted only as rough and orientative figures.

3.4.2 Do not promise too much at the beginning !

As already mentioned before, in some cases the presentation of a first pre-evaluation report to the company can be very useful in order to inform them about possible options and the necessary future steps to be gone through. Estmiative figures from pre-evaluation may help the technical staff or local directives to convince the company direction to go ahead with the audit and to deepen the analysis or even to ask for some funding.

Nevertheless care should be taken not to present too much detailed data (especially economic data !) that still have not a solid basis. In any case you should explicitly advise the company that the presented figures are only first order-of-magnitude estimates that can change strongly in a more detailed analysis.

EINSTEIN Step 4: “quick & dirty” pre-evaluation report

> create pre-evaluation report

> optional: present to company

3.5 Visit on site (or alternatively: second detailed by-distance data acquisition)

3.5.1 Optional: present and discuss quick-and-dirty study

If You decided to present some preliminary results from your first quick&dirty study to the company, then maybe this is the moment to start discussion on a visit. You can summarise the results You could gather up to now by distance, and explain Your preliminary conclusions to the company.

3.5.2 Interviews and visit of site for detailed data gathering

3.5.2.1 Data collection in the office

The first step when You arrive in a company should always be to sit down in the office, to introduce Yourself and what You can offer to the company, and to collect the basic information. If possible, during this first meeting already some technical staff of the company should be present, who knows the technical details of the processes and equipments in the company.

You can use the structure of the EINSTEIN basic questionnaire or EINSTEIN data check list (You should take a copy on paper with You, eventually already prefilled with the information You gathered in the previous stages) in order to structure the interview, asking for the following information:

- *general information* on the company: what and how much do they produce; how is the production process; what are the global figures (turnover, energy consumption, number of workers); what are the shifts and holiday periods, etc. In this context it is also important to obtain information on the future prospects of the company: possible expansion plans that might completely change the demand data, or, on the contrary, risk of shutdown of some production lines or the whole factory due to pressure of competition.

- *fuel and electricity bills and energy tariffs*: try to get information for several years, and, if available already detailed information on which share of consumption corresponds to which equipment / process / production line

- *data on the processes*: as in many industries only the overall energy consumption is known, but not the split-up into the different processes, a detailed information on the processes is often the only way to determine the distribution of the heat demand (the generally possible ways to obtain this information is shown in Figure 19) it is important that You get a general understanding of how a certain process works; which are the operation schedules and the process temperature;

  Furthermore it is desirable to gather additional information about the different components that contribute to the process heat demand:

  - fluid inflow and outflow: volume or mass and temperature levels (inlet/outlet)

  - mass or volume to be heated (or cooled) at start-up of a process, number of operation cycles or breaks, and initial temperature from which the equipment has to be heated up (cooled down)

  - thermal losses of the process equipment in operation: the power required to maintain the process at a given temperature. This may be composed by power requirement for the compensation of thermal losses, power requirement for phase change of working fluids (boiling, drying) or power requirements for chemical reactions. This is often the most difficult part to be determined, as e.g. usually no thermal loss coefficients for process equipment are known. You can get some hints indirectly that allow You to make some calculations, e.g. if You know that the equipment after some period Δt (e.g. during night time) cools down from process temperature T_P to a certain final temperature T', You can estimate the corresponding thermal loss coefficient; or if You know the approximate size of the equipment and the insulation thickness, You can try to calculated it; in drying processes, the difference of humidity in the wet and in the dry product gives You an idea of how much heat You have to input for evaporation, etc.

The EINSTEIN software tool gives You some aids for doing this type of auxiliary calculations in some of the most frequent cases.

- ✗ *data on the heat and cold supply equipment*: make an inventory of the existing equipment and the most relevant technical data (incl. age and state of conservation, in order to decide whether it makes sense to suggest a substitution); try to get at least indicative information not only on the nominal *power*, but also on the *energy* (heat or cold) produced by this equipment (operating hours, part load factor), even if it's something very qualitative like "we use it only some few hours a year, is mainly for back-up" or "the two boilers work nearly always at full load and sometimes we are getting short of steam ..."; and do not forget to make a clear block diagram of which equipment supplies heat or cold to which process.

- ✗ *data on the heat and cold distribution and storage*: length and diameters of pipes and ducts; temperature and pressure levels and flow rates; wherever You can get this additional information, this can help You to make You a more precise image of the consumption in the factory; identify heat storage wherever existing (volume, temperature and pressure levels, insulation).

- ✗ *existing heat recovery systems*: identify existing heat exchangers for heat recovery, including the technical data and the (typical) real operation conditions (flow rates and temperatures at hot and cold side).

- ✗ *renewable energies*: identify available area (roof and ground surfaces) for a possible use of solar thermal energy (size, orientation, static capacity of roof, distance from the machine room and / or the processes); assess the availability of biomass or biogas (either residual biomass from the production process itself, or from other nearby suppliers); is there any motivation for the use of renewables besides the possibility of economic saving (e.g. contribution to protection of environment, marketing aspects, ...)?

- ✗ *building heat & cooling demand*: heat & cooling demand for buildings in some companies may be an important part of the total; make an inventory of the existing buildings, the heating and air conditioning system used; temperature levels and schedules of use, etc.; sketches of the buildings should be asked for whenever possible.

- ✗ *economic and financial parameters*: what are the O&M costs in the company (in addition to the energy bills); how are investments in the energy supply system financed (externally, internally); what are the requirements regarding pay-back or return rates.

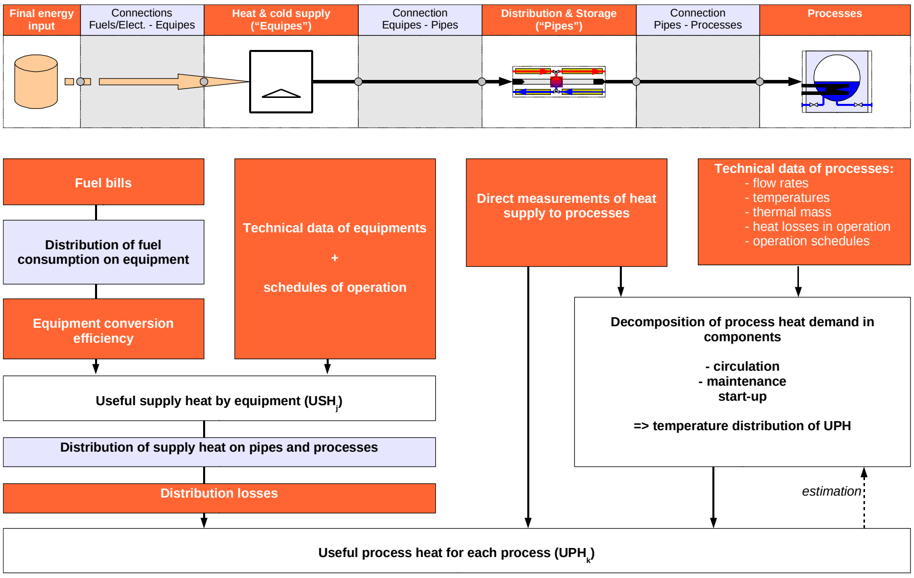


Figure 19: Possible ways to obtain information on the heat & cold demand of the different processes

You should have these different blocks of data in Your mind as a mental check-list (and best also on paper), in order not to leave the factory without having asked all the relevant questions. But in most cases the interview does not follow Your (mental) order, but usually You get information piece-wise and unstructured in an informal talk.

For keeping the overview it helps making Your notes during the visit already in a structured format, grouped by the blocks mentioned above. So after half an hour or an hour of informal talk, when You learnt a lot of the different processes and equipments, but also on the family relations of the maintenance technician and problems with the competition that the factory owner faces, You can still keep the track and rapidly check if You got all the necessary data, or if (and *where*) there is something important still missing.

3.5.2.2 Walk through

Once You have the impression, that You got all You could get in the office, let You invite for a walk through the factories installations. Make sure that You see at least all the relevant process and heat supply equipment. Whenever possible take a digital camera and make pictures, that later on help You remind the details.

Use the visit for deepening Your insight in how the different processes work, and ask all the detail questions You did not think about during the talk in the office.

Try to anticipate possible problems that might have to be solved for the modifications of the systems You might already have in mind:

- ✗ possible points of connections for new heat and cold distribution lines or equipments
- ✗ available space for new equipments or storage

If in the office You talked only with the technical director, try to use the walk-through for getting in touch with the maintenance staff in the company that can give You valuable information from everyday practice (e.g. ask questions like "*.. in the morning when You enter the factory, at which temperature do You find this storage tank*", etc. ...).

3.5.3 Fast on-site completeness- and consistency check

If You used Your laptop during the interview and had the opportunity to enter already some data into the EINSTEIN software tool, You can use the "*consistency check*" option of the EINSTEIN software tool in order to check:

a) if the data are consistent, or if there are contradictions in the informations You got (e.g. confusion of units)

b) if there are relevant data missing (and which data), so that You can ask explicitly for *those* data.

Maybe You have even already enough information in so that You can run the automatic proposal generation tool, that gives You already an idea of orders of magnitude of possible alternative supply systems (e.g. if You know how much additional storage You might need for some system, during the visit You can already have a look if there's enough space ...).

3.5.4 Measurements during visit

In many production processes the total yearly (and often even monthly) energy demand is known based on the utility bills of the company, but the demand can not be allocated to the specific equipments and processes. However, this knowledge – at least for some crucial processes and for the main heat and cooling supply equipment - is essential for applying the EINSTEIN methodology.

Any data available from on-site measurements of the company itself can help to analyse the detailed energy profiles including energy demand and waste heat availability schedules. It is therefore important to check, together with the company, which data are already monitored and which combination of data sets can be used for analysing the energy flow.

In many companies some additional measurements will be necessary to overcome the existing lack of data. Depending on the variations of the processes, some of the measurements can already be done during the first visit at the company. Fast and easy measurements for calculating heat and cold flows during the visit at the company's site include:

Temperature measurements

Infra-red pistols applied for (non insulated) vessels or pipes can give a first estimate of the temperatures during the operation. In case the process temperature is changing quickly thermocouples with data loggers can be quickly installed for recording the data during the duration of the visit. Applied on insulated vessels or ducts the temperature measured gives a basis for the calculation of heat losses.

In case the mass flow of pipes (heat supply flows, product stream or cold supply flows) is known, measuring the flow, forwardand return temperature of the pipes during some hours can already give sufficient information for calculation the heat or cold supplied by the pipe.

Mass flow measurements

Contact-less measurements of water/medium flows using e.g. ultrasonic measurement principles can easily be installed without interfering with the processes. In combination with temperature measurements energy flows can be quickly calculated. Please be aware that short measurements (e.g. for some hours) only give You a small picture of the whole production especially if there is a big time dependency of the production processes.

Metering of energy flows can be either done on the primary side of the energy supply (hot water, condensate line) or on the secondary side (process medium measurement). Usually the choice of this depends on the availability of possible measurement points (access to the pipes, insulation, status of the pipe, regulation etc.). A short list of possible measurements (not complete) shall give the user an idea of possible measurement points:

1. *Measurements at the side of the process medium ("secondary side"):*

   - Measurement of *process medium* (water, air, product flow) that is heated within the process
   - Measurement of *fresh water* added in a vessel, that is constantly heated to a temperature (e.g. in washing plants)

2. *Measurements at the side of the heat supply ("primary side"):*

   - Measurements of hot water supply line and temperatures before and after the heat exchanger (for indirect energy supply)
   - Measurements of hot water supply line and temperature of hot water (for direct energy supply)
   - Measurement of condensate line of one process (or several processes, if their regulation pattern is such, that the measurement data can be allocated to each process afterwards)
   - Measurement of fresh water added in the steam supply system (for identification of energy used as direct steam)

3.5.5 Measurement programme for the user

If You saw that there is information missing, that You can not be obtained instantaneously by meteringon-site, you can leave some "homework" for the company:

- Register of temperatures, pressures or counters of already existing sensors in some periodic intervals

- ✗ You may also leave some measurement device that You brought with You and ask the company to register the measured values during some period
- ✗ You can define some simple “experiments” that can be carried out by the user company (e.g. determine heat-up or cool-down curves of some equipment, etc.)

3.5.6 Discuss insights from visit

After the visit, You should give some information to the company on which impression You got and how You think to proceed:

- ✗ Define and decide together with the company which of the possible measures You want to analyse in detail, and which options You exclude a priori.
- ✗ Fix some schedule for the future steps: deadline for the delivery of additional information by the company; deadline for the delivery of the audit report.

EINSTEIN Step 5: on - site walk - through audit

> present to company quick-and-dirty study

> make interviews and visit the site

> fast check of new data

> take measurements

> define measurement program

> discuss new understanding

3.6 Analysis of status-quo

3.6.1 Consistency and completeness checking of data

A systematic analysis of the status-quo is the starting point for the further identification of energy saving opportunities for a company. However breaking down the total energy consumption into different components and defining the main energy streams, sources and sinks usually requires the acquisition of a rather large number of data. Besides the quantity, also the accuracy and the consistency of the available data affect significantly the reliability of the alternative solutions envisaged.

As already outlined in the previous section, there are often several ways to determine the same information. Some examples (see also Figure 19):

- ✗ the fuel consumption in a company can be given directly in form of energy; or it can be available in form of the quantity of fuel consumed (in m^3, litres, etc.), then You can calculate energy consumption from this using the fuel's LCV.

- ✗ the heat produced by a hot water boiler may be determined on the one hand by the fuel consumed, and on the other also by the amount of hot water consumed; furthermore there may even be a heat meter measuring directly the delivered heat at the outlet of the boiler.

In gathering data on the status-quo (present state energy demand, etc.) You may face – and have to solve – one or both of the following problems:

- ✗ *Redundancy* of information and possible *conflicts* between data: Redundancy exists if, like in the examples above, You have two or more different ways to determine or to calculate the same parameter. If the different ways lead You to the same result, You are fine: this just gives You more confidence that the obtained value is the right one. But in the opposite case, if different ways of calculating something lead to different results, then You have the problem of selection (which is the right one, which the wrong one ?) and – whatever You decide - as a consequence of the uncertainty You may doubt of both.

- ✗ *Lack of information.* You may not have all the detail information available that You would like to have for a detail calculation. E.g. You may know the total heat demand (calculated from the fuel consumption) and the demand of the most heat consuming process, but there may be no information on how the remaining demand is shared by two other small processes.

Checking both redundancy and completeness in a complex system may be quite a difficult and time-consuming task. In general You have the following tools available for doing this job:

a) *mathematical and physical relationships* between the different quantities obtained from basic physical laws (energy conservation, second law of thermodynamics) and *physical properties* of materials.

- ✗ *energy and mass balances* on equipments and subsystems (input = output + losses). Efficiency parameters or mass flow ratios in many cases have to be between 0 and 1 due to conservation laws.

- ✗ *second law constraints*: heat flows only from hot to cold. This may help you to define minimum and maximum possible values for certain quantities (e.g. temperatures).

- ✗ *physical properties of materials,* especially fluid and fuel properties. For example: the energy transported by a fluid is related with the mass flow and the specific enthalpy difference between forward and return, which depends on the specific heat capacity and on the steam fraction and the latent heat of evaporation (in the case of phase change).

- ✗ *operating hours* of processes and equipment are constrained by the duration of a day (24h) and a year (8760 h) and by the holiday and week-end periods specified.

b) *engineering knowledge* on typical values or practical limits for certain quantities:

- ✗ mathematically a boiler efficiency has to be between 0 and 1 (or between 0 and something like 1.1, if the LCV is used as reference). But in practice it will be very strange to find a boiler with an efficiency such bad as 0.1, and also 0.999 in practice might be never reached. So something like 0.7 ... 0.95 might be considered as a practical limit for non-condensing boilers. Similar reasoning might be applied for distribution efficiencies in pipes and ducts.

- ✗ *temperature drops* in heat exchangers (LMTD) theoretically (by second law of thermodynamics) have to be greater than 0 K. But in *engineering practice* the limit is even higher, something like 3 – 5 K for liquid to liquid heat exchangers, and something like 10 K for liquid to air or air to air heat exchangers. Similar reasonings can be applied for the difference between forward and return temperatures in fluid circuits: no one will design a circuit with a heat transport fluid circulating at such a high mass flow that there is only 0.1 K difference between forward and return. Practial limits also here might be something like 1 - 2 K.

- ✗ *heat losses* of some process equipment are difficult to determine exactly. But there is some upper limit given by the total surface area of the equipment (that can be estimated easily from the size) and the fact that total heat transfer (radiation + natural convection) from any non-insulated body and at not too high temperatures (below 100 ºC) is lower than about 8 W/m^{2}K indoor and 20 W/m^{2}K outdoor (incl. wind), if there are no additional losses due to phase change or chemical reactions (e.g. boiling ...).

- ✗ *time for heating-up or filling/emptying* of some process equipment will be rarely more than 50 % of the total batch duration in batch processes or more than 2 – 3 hours in continuous processes that are shutdown during night.

Whereas mathematical limits give a sharp and clearly defined judgement (yes/no) on whether some parameter value (in the context of the whole data set) is possible or not, the limits from engineering knowledge are diffuse to a certain degree. For these engineering constraints, in EINSTEIN we distinguish between:

- ✗ *practical limit values*: this is the wide range of possible values (from an engineering point of view) that includes 99.9 % of practical cases.

- ✗ *range of typical values:* this is a much narrower range of values that should be valid for about 90% of practical cases (but having in mind that there may be 10 % of situations *out* of this range).

Basic consistency checking in EINSTEIN is understood as the check that the data set of a given company is consistent with respect to *mathematical and physical relationships* and with respect to *practical limit values* given by engineering knowledge.

With the help of the EINSTEIN software tool this basic consistency checking can be done automatically. If there is some conflict between the data set introduced and the given limits, the data will be automatically corrected and a list of error messages will be produced.

Basic consistency checking with the EINSTEIN software tool furthermore *completes* all the data that are not explicitly given in the questionnaire, but that can be calculated from the same correlations and constraints.

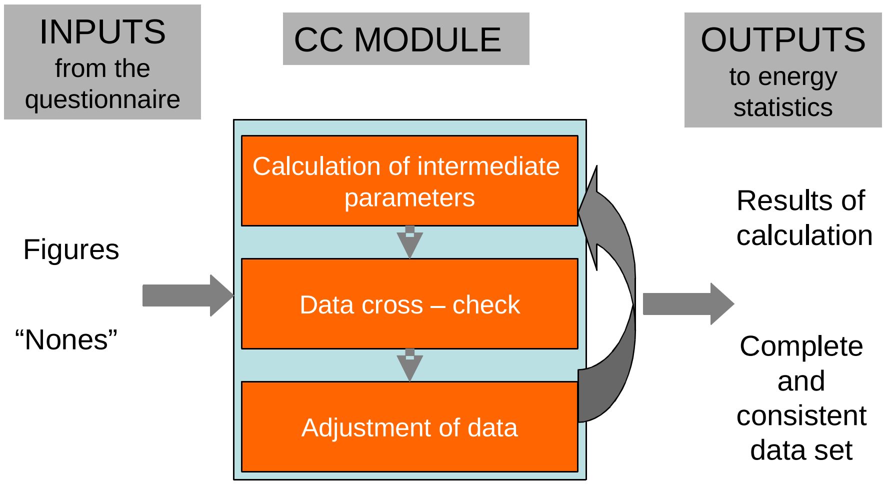


Figure 20: Scheme of the basic consistency check procedure in the EINSTEIN software tool. “Nones” stands for unknown data (blank cells).

3.6.2 Acquisition of missing information

The quantity of information and the level of accuracy necessary for an energy audit depends on the thoroughness of the energy audit. For the purpose of preliminary evaluations (quick&dirty studies) the information needed is less, while for a detailed analysis a large number of parameters have to be taken into consideration.

However, in many cases, not all the figures which are theoretically required can be easily known. Sometimes, especially in small companies, even very basic data may be difficult to acquire, and therefore after basic consistency checking and data completing there still may be leaks in the data set, or data that can be determined only with a very low degree of accuracy.

If this is the case, for the still unknown parameters we can use what we denominated the *range of typical values* given by our engineering knowledge. With the help of this “typical values” we will be able to complete most of the leaks that are still existing, but we have to be aware that using this *estimates* we are making *assumptions* that not necessarily have to be in coincidence with reality.

So, whenever we do this, this should be clearly reflected and highlighted in the reports we produce:

> “*conclusions only valid under the assumptions A, B and C ...*”

And, whenever possible, we should confirm at least a posteriori, whether the assumptions made were correct or not.

If even with all Your engineering knowledge You are still not able to get at least estimates for the basic data You absolutely need for Your analysis, You can do two things:

a) call the company and tell them that with the few information You have it is absolutely impossible to make any reasonable proposal.

b) make some hypothesis or scenarios on the missing information: just suppose some numbers that at least seem reasonable. You can try to catch the limit cases: one scenario that is very good (for the system what You want to propose), one very bad, and one in between.

This sometimes is better than doing nothing, but all the cautions mentioned above in this case should be given twice, and still be more highlighted in **bold letters**.

Quantity and accuracy of data required for different levels of analysis

The EINSTEIN methodology distinguishes between three levels of analysis with increasing level of detail and accuracy:

- *Level 1: Quick&Dirty analysis*

  For quick&dirty analysis it is sufficient to know with a certain minimum accuracy[10] the energy consumption and the main temperature level (process temperature) of the most energy consuming processes in the company.

- *Level 2: EINSTEIN standard level of analysis*

  For the EINSTEIN standard level of analysis at least the following parameters should be known with the minimum level of accuracy:

  - energy consumption of the main energy consuming processes and it's decomposition in heat&cold demand for circulation, maintenance and start-up

  - all temperature levels (inlet, process, outlet) and hours of operation of those processes and the corresponding heat & cold supply equipment

  - waste heat streams from the main energy consuming processes

- *Level 3: detailed analysis*

  For a detailed level of analysis at least the full set of information as given by the EINSTEIN basic questionnaire should be available with the required accuracy.

The accuracy of the available data, both in the qualitative sense of level of reliability (do You trust them or not) and in the quantitative sense of the margin of error (± xy %), depends strongly on the following factors:

- *The source of information.* Sometimes in big companies the figures on energy consumption are directly measured by accurate metering equipments and stored in sophisticated energy management systems, while, on the opposite, small companies often know only the average operating conditions of the plants and global energy consumption from energy bills. One year or even single month data may not be very representative for the average consumption in the future.

- *The procedure for data acquisition.* Mistakes may easily come out while filling in a data sheet or when copying figures, when entering data in a calculation tool, etc. (e.g. did You/the company enter properly the data into the questionnaire ? May there be a confusion with measurement units ? Has the questionnaire been filled by the company, or did You assist them ? etc.).

- *The level of detail.* The deeper the level of the analysis, the more detailed and specific are the data required, and therefore the higher may be the risk to acquire less accurate figures (e.g. do you need figures on annual base? Or on hourly base? Are you interested in the overall energy consumption? Or in the breakdown by different processes ? Etc.).

If there is any parameter where You have a doubt on its validity, You should highlight this in the report, in the same fashion as outlined above for estimated values and for values set by assumption in your scenarios.

3.6.3 Detailed breakdown of consumption

The breakdown of the energy consumption by processes, equipment, fuel and temperature level is very important in order to have in view all the aspects related with the energy usage in the analysed industry. The resulting statistical information for the present state is a starting point for decisions over application of energy saving measures and technologies.

[10] *As minimum accuracy we consider an error margin of less than +/- 30 % !*

The overall energy consumption permits to rapidly situate the auditor about the rate of the energy consumption and the possibilities (a priori) for energy savings, when compared with available reference data for the industrial sector (benchmarks). When different alternative proposals for energy efficiency improvements are considered, the present energy demand and its composition is used as the reference for analysing the effect of the proposed measures for improvement.

Here the most important energy statistics are outlined, and the usage of the data is commented.

- *Breakdown of the energy by processes, equipment and fuel type*: Identifies the principal energy consuming processes, equipment, and the fuel types responsible for the highest energy bill. Improvement efforts focused on them will have the highest impact.

- Analysis of the energy consumption by *temperature level*. Permits to evaluate the potential for waste heat recovery and for the application of efficient low-temperature technologies such as solar thermal, heat pumps, cooling water from combined heat and power (CHP) engines, etc.

- Analysis of the impact of the energy consumption in terms of *primary energy consumption,* CO_2*- and other emissions*: permits the evaluation of the environmental impact of the industry.

- Breakdown by specific energy consumption ratios: energy intensity (EI) and specific energy consumption (SEC): permits the comparison with reference benchmark data and fixing realistic energy consumption targets.

The energy statistics (breakdowns) in different temporal scales is very useful for obtaining further insight:

- *Annual data* show the main energy consuming processes, equipments and energy types, and give general indications where the energy efficiency measures should be aiming first.

- *Monthly data* are necessary for considering seasonal or ambient temperature-dependent variations in demand (such as space heating, drying processes, seasonal variations of production as e.g. in the beverage industry, ...) and in supply (e.g. solar thermal systems) and are required for assessing the feasibility of specific technologies.

- *Hourly data* scale of heat demand and supply is important for determining peak power consumption, analysing possibilities for waste heat recovery, and especially for determining the requirements of accumulation of heat and cold.

All these breakdowns of the companies' energy demand can be created automatically using the EINSTEIN software tool, both for the present state of the industry and for the future scenarios given the different alternative proposals.

3.6.4 Analysis of real operation of existing equipment

Technical data of equipments are very important for assessing the energy system performance. The most relevant performance parameters are energetic conversion efficiencies and heating / cooling capacities.

In most cases the only accessible information on these data are the nominal values given in the technical data sheets of the equipment manufacturers or on the data given on the equipments themselves.

Nevertheless actual performance of equipment may be quite different of these data due to fouling and malfunctions, due to some extreme operation conditions in specific applications, and to possibly a series of other factors. Therefore, whenever data are available that allow for doing this, it might be interesting to compare actual performance of the equipments with nominal performance data.

One possibility of assessing actual performance is input/output measuring. E.g. if the fuel consumption and the heat production of a boiler is known by measurements, the mean conversion efficiency can be determined by calculation.

For combustion equipment, measurements of the exhaust gas are another way to obtain information on the equipment conversion efficiency, as the heat contained in the exhaust gases and incomplete combustion are the dominant factors for energy conversion losses.

If measurement data are available, the necessary calculations are carried out automatically by the EINSTEIN software tool, and in case of significant differences between nominal and actual equipment performance corresponding warning messages will advise the auditor.

3.6.5 Comparison with benchmarks

3.6.5.1 What is benchmarking ?

Benchmarking refers to a structured process of comparing and analyzing business practices, in order to improve business processes by identifying, sharing and using best practices. The aim of benchmarking is to enable the evaluation of the energy efficiency in a company with respect to defined benchmarks or targets.

In EINSTEIN the following reference values are used:

- ✗ *A benchmark* is a range given by a minimum and maximum value (B_{min}, B_{max}) that describes the state of the art energy consumption of existing industries in a given sector.

- ✗ A *target* is a target value (B_{tar}) for energy intensity or specific energy consumption that can be reached if economically feasible best available technologies are used. Where no explicit target values are given, the assumption is made that the industries with a good practice are those with energy consumption in the lower 10 % of the range between B_{min} and B_{max}.

- ✗ *Good practices* are documented strategies and tactics employed by successful companies. They can be identified from in-depth interviews with energy managers, thorough review of companies' documents, analysis of literature and secondary sources.

3.6.5.2 Classification of indicators by reference quantity

For benchmarking in EINSTEIN three types of reference ratios are systematically used depending on the quantity used as a reference:

- ✗ *Energy intensity*: As energy intensity we understand the energy consumption per monetary value of the product. The product value can be either expressed in terms of turnover (sales price) or in terms of production cost (approximately the sales price minus the industrial benefit). If not specified explicitly, the turnover (sales price) is used. As those benchmarks refer to monetary units, the currency and the year of the data should be clearly specified.

- ✗ *Specific energy consumption per product unit.* The specific energy consumption per product quantity is the energy consumption associated with the production line under analysis, with respect to the product quantity produced with it (measured in units, tons, liters, etc..; for example the total energy consumption per kg juice of concentrate, energy consumption per liter of chemical product, etc.).[11]

- ✗ *Specific energy consumption per intermediate products in a unit operation:* Besides of the ratios for final products, energy consumption ratios for unit operations are also of interest. The specific energy consumption per quantity of processed intermediate product is the energy consumption associated with this unit operation with respect to the product quantity (measured in units, tons, liters, etc.; e.g. the energy consumption per kg or liter of distilled solution). Where these ratios are found, the reference base is mentioned (e.g. in a drying process the energy consumption can be indicated per kg of humid product or kg of dry product, which can lead to very different numeric values).

3.6.5.3 Classification by types of energy

- ✗ *Electricity vs. fuels*: In the benchmarking module, data for energy consumption is classified into electricity and fuels, as this data is more easily available in practice (from the electricity and fuel bills in a company) than the distinction into energy used for thermal and non-thermal uses.

[11] *General energy consumption in the company that can not be associated to a given production line or product should be taken in consideration proportionally with respect to the value of a given product in total turnover.*

- *Total final energy consumption:* Data on total energy consumption is obtained by adding up final energy contained in electricity and final energy contained in fuels.

- *Total primary energy consumption:* Total energy consumption in terms of primary energy. This parameter should be used whenever available for global inter-company comparison.

3.6.5.4 Benchmarking procedure in EINSTEIN

Comparisons of energy efficiency of a company is made by comparing the actual value of specific indicator I (e.g. specific energy consumption per ton of product) with a reference target B_{tar} that is based on the given sector structure. This means that both the actual I and the reference B_{tar} are similarly affected by changes in sector structure.

The reference target B_{tar} is defined as indicated above. The difference between the actual I and reference B_{tar} is used as a measure of energy efficiency, because it shows which energy efficiency level would be achieved in your company when best practice plant technologies would be used. The smaller the difference, the better the energy efficiency is. The ratio between actual I and reference B_{tar} (called energy efficiency index *EEI; Eq. 3.1)* can be compared between companies.

$$EEI = \frac{I}{B_{tar}} \cdot 100\,\% \qquad (3.1)$$

where I is the specific indicator of energy consumption and B_{tar} the reference target value.

If only best plant technology is used within a sector, the EEI would equal 100. An EEI of 105 means that I on average is 5 % higher than the reference level, so that 5 % of energy could be saved at the given process structure by implementing the reference level technology.

3.6.5.5 Sources of data for benchmarks

Some data on benchmarks have been selected from the existing BAT reference documents[BREFs] and other literature and sources, in order to form a basis for defining indicators and benchmarks/targets and are available in the default data base of the EINSTEIN software tool. For each benchmark in this database the reference of origin is specified.

Benchmarks are also available in literature either for *industrial sectors or sub-sectors*, for certain *products*, or for certain *unit-operations*.

a) classification by industrial sector and sub-sector

The EINSTEIN default database includes some benchmarks for the following industrial sectors, identified by their NACE code. Other sectors may be included in the future or can be added by the user.

b) Classification by unit operations

In industrial production of goods, a unit operation is a basic step in a production process. For example in milk processing, homogenization, pasteurization, chilling, and packaging are each unit operations which are connected to create the overall production process. A production process may have many unit operations to obtain the desired product.

*Referenc**es chapter 3.6.5:***

BAT Reference Documents (BREFs) for different industrial sectors.Published by the European Union on http://eippcb.jrc.es/pages/FActivities.htm.

Vannoni et al. (2008): Review of Thermal Energy Auditing Practice and Tools. IEE Project EINSTEIN, Deliverable D2.2, 2008. Available for download on www.einstein-energy.net

EINSTEIN Step 6: analysis of status quo

> consistency check of data

> estimate and/or acquire missing information

> breakdown of consumption

> real equipment performance

> comparison with benchmarks

3.7 Conceptual design of saving options and draft energy targeting

As already outlined in section 1.3, the systematic analysis of the energy saving potential requires the following steps:

- Reduction of process heat and cooling demand by process optimisation
- Reduction of required heat and cooling supply by heat recovery and process integration
- Cogeneration and polygeneration
- Supply of the remaining heat and cold demand by energy efficient technologies, as far as possible using renewable energy sources

As a first step the design and dimensioning of an alternative heat and cold supply system has to be created. Different possible alternatives have to be elaborated, that then in the following steps will be compared by their energetic and economic performance, in order to finally select the optimum solution.

The analysis of heat and cold demand and the potential of heat recovery / process integration allows also for fixing energy targets a priori, that can be used as a reference for evaluating calculated real system performance.

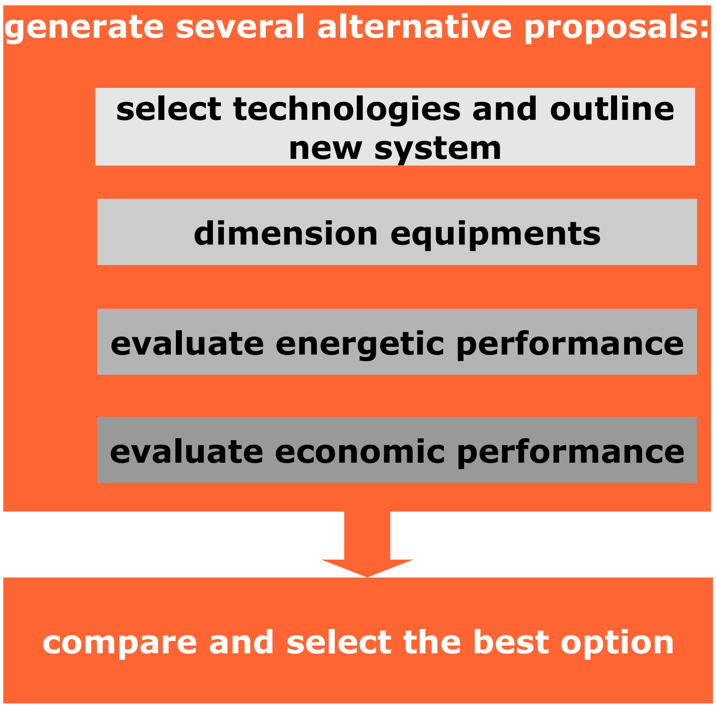


Figure 21: Steps for generation and evaluation of alternative proposals (EINSTEIN audit steps 7 – 9).

3.7.1 Check-list of recommendations for potential energy savings

After the energy demand data has been collected and documented, the first step after the analysis and the benchmarking step is to show to the user the possibilities with which energy savings measures the production processes could be energetically improved.

Many energy efficiency manuals and reports of case studies exist that show the possibilities of different measures for demand side savings. A large list of relevant documents has been put together in the EINSTEIN report *Energy Auditing Practices and Tools [Vannoni et al. 2008]*. In this document measures have been listed by sectors, as well as by heat and cold supply technologies to give a structured overview of saving potentials.

Implemented housekeeping opportunities are energy management actions that are done on a regular basis and never less than once a year. The following are typical energy saving opportunities:

- adjust and tighten damper linkages, with particular attention to outdoor air dampers, multizone unit zone dampers and heating ciol face and by-pass dampers
- check and adjust motor drives on fans and pumps for belt tension and coupling aligment
- replace air system filters to prevent restriction of air flows
- shut off exhaust and make up air systems to airs such as kitchen and laundries when the processes are not required
- shut off lights and other heat producing equipment when not required
- check and recalibrtae control components such as room thermostats, air and water temperature controllers and verify settings of time clocks
- replace damaged or missing insulation on piping and duct systems
- replace or repair crushed or leaking ducts in air systems
- clean heat exchanger surfaces, heating units and heating coils
- consider rules on use of building space to permit reduction of outdoor air intake
- establish minimum and maximum temperatures for heating and cooling and readjust controls accordingly
- adjust air flow rates to suit changing occupancy conditions and use of building space

References:

C.Vannoni et al. (2008): EINSTEIN Report: *Review of Thermal Energy Auditing Practices and Tools*. IEE Project EINSTEIN, Project deliverable D2.2. Available for download on www.einstein-energy.net

3.7.2 Process optimization: list of efficient technologies for specific unit operations, possibilities for demand side savings

3.7.2.1 Process optimization in industry

A second deeper step to analyse the possibilities for demand side savings is the consideration of each process. Each processing unit can be evaluated on its effectiveness and efficiency. Possible measures to improve the processes are:

- change of the technology in place
- improvement of the process via improved regulation

Many literature sources exist that describe energy efficiency measures for various sectors and new developments that are continuously ongoing by plant engineers, operators, technology suppliers and research. The European Union has developed documents for each sector that summarize the current *best available techniques*[12] aiming –among others – at efficient use of energy.

These BAT Reference Documents (BREFs) for different sectors and specific are published by the European Union on http://eippcb.jrc.es/pages/FActivities.htm. Of particular interest for the scope of this project are the BREF reports on:

A. *Energy efficiency:*

- Integrated Pollution Prevention and Control, Draft Reference Document on Energy Efficiency Techniques, June 2008

B. *Heat and cold supply systems:*

- Integrated Pollution Prevention and Control (IPPC), Reference Document on the application of Best Available Techniques to Industrial Cooling Systems, December 2001
- Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques for Large Combustion Plants, July 2006

C. *Sector specific documents for different industrial sectors.*

Within the IEA Task 33/IV on *Solar Heat for Industrial Processes* a *matrix of indicators* has been established, that serves as a tool that systematically includes process engineering and energetic information of industrial sectors with a potential for application of solar thermal systems. This decision support system gives the user a large information database for all crucial steps that have to be taken when designing a solar heating system for industrial processes. These steps include the overview of the processes, important parameters of the energy supply of unit operations, benchmark data on energy consumption, **competitive technologies**, hydraulic schemes for solar integration and successful case studies. Within the section on competitive technologies of the matrix, energy efficient technologies are listed for different unit operations. This matrix has been further developed by AEE INTEC and Graz University of Technology and it is now accessible as a broad data base via internet on http://wiki.zero-emissions.at.

The EINSTEIN tool now builds on these existing information sources (partly collected within the EINSTEIN project). A database is integrated in the EINSTEIN tool where the user can browse:

a) General energy saving measures
b) Specific saving measures documented for the unit operations applied in the production system.

The structure based on unit operations and linked by relevance to different sectors allows screening the database for efficient technologies or methodologies applied for specific unit operations, or for energy

[12] As defined in the in the Article 2.11 of the IPPC Directive "best available techniques" shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole. "Techniques" shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned; "available" techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator; "best" shall mean most effective in achieving a high general level of protection of the environment as a whole.

savings measure for specific technologies. Table 9 presents some example datasets of the database in order to show its structure (excluding the allocation to relevant sectors in which these technologies and saving measures are already applied).

Table 9: Example datasets from the EINSTEIN database of general saving measures and best available technologies for the food industry

UNIT OPERATION	TYPICAL PROCESS	TECHNOLOGY	ENERGY EFFICIENCY MEASURE
01-CLEANING	0101-Cleaning of bottles and case	General measures	Install heat exchangers to recover thermal energy from condensate in its bottle washing section and fuel oil heater condensate
01-CLEANING	0101-Cleaning of bottles and case	Methodology	Cascaded use of wash water
01-CLEANING	0103-Cleaning of production halls	General measures	Low temperature detergents in washing: Use of final rinsing water for pre-rinsing, intermediate rinsing or the preparation of cleaning solution (often used in CIP systems); turbidity detectors can optimize the reuse of water
05-PASTEURISATION	0501-Pasteurization	Flash pasteurization	Reuse pasteurizing overflow water
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Use store heat / solar heat for heating system for start up
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	High efficiency pumps, VS drives
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Preheat incoming containers (ambient air, solar)
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Local generation of hot water
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Use of hot water instead of steam (no distribution losses, no HEX losses etc.)
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Insulating high temperature zones of unit
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Thinner glass / more conductive materials lower the driving temperature (temp drop across glass now: 5-15°C)
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Even heating/cooling increase heat transfer and shorten process times
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Immersion, spraying from below, or other heat transfer systems may increase internal convection and allow process time to be shorter
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Aiming at very little temperature increase of containers leaving the unit (normally +20°C compared to entrance temp)
05-PASTEURISATION	0501-Pasteurization	Turnel pasteurization	Evaporatively cooled water, absorption or ejector cooling with waste heat or other strategies may be used for cooling, if necessary Reuse pasteurizing overflow water
05-PASTEURISATION	0501-Pasteurization	Microwave pasteurization	Possible use in conjunction with heat recovery or at variable basis to achieve specified temperatures where variable heat sources are available or flow rates vary. Efficiency at 90% (conversion from electricity). Power from cogeneration can enhance economic/ecological performance.
05-PASTEURISATION	0501-Pasteurization	Mechanical pasteurisation	Reducing pressure drop over filters is decisive. Strategies using centrifuges
05-PASTEURISATION	0501-Pasteurization	Irridation for pasteurisation	
05-PASTEURISATION	0501-Pasteurization	Ultrasonic pasteurisation	
05-PASTEURISATION	0501-Pasteurization	Ultraviolet radiation for sterilization	
05-PASTEURISATION	0501-Pasteurization	Microfiltration for sterilization and clarification	
07-COOKING	0701-Cooking and boiling	General measures	Use of vapour condensers in wort boiling to collect hot water from condensate
07-COOKING	0701-Cooking and boiling	Wort boiling with mechanical vapour recompression	
07-COOKING	0701-Cooking and boiling	Wort boiling with thermal vapour recompression	
07-COOKING	0701-Cooking and boiling	Steineker Merlin wort boiling system	
07-COOKING	0701-Cooking and boiling	Brewing at high specific gravity	

The database is set up to summarize best available technologies and process optimization possibilities for different unit operations from different sectors. This allows the user to learn from other solutions applied in other industry sectors for similar process engineering problems.

For further information on the proposed technologies and efficiency measures proposed, a link to a *Wiki Web on Energy Efficiency* can be followed. On this *Wiki Web* the *Matrix of Industrial Process Indicators* (developed within the IEA Task 33/IV) is published, and the sections on competitive technologies is continuously extended to include more details on efficient technologies and best available techniques.

Tools of the process optimization module

- ✗ Database of best available technologies and process optimization measures for different unit operations
- ✗ Identification tool for optimization possibilities for the technology and equipment used for the processes

3.7.2.2 Demand reduction in buildings

Main energy improvement measures in buildings can be divided into BASIC and ACTIVE measures (see Figure 22).

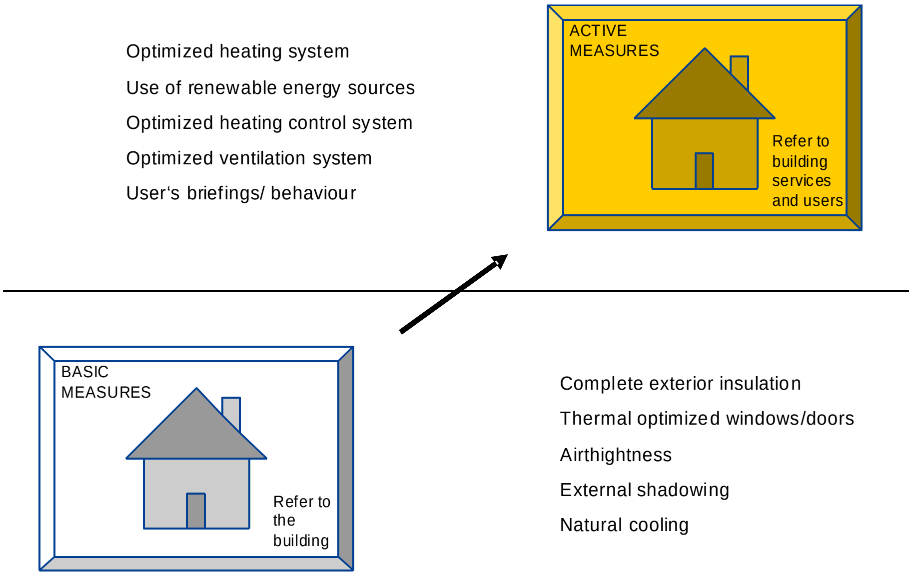


Figure 22: Two levels of improvement measures – BASIC and ACTIVE MEASURES are leading to energy efficiency and good indoor environment (Reference: AEE INTEC)

Depending on the location of the buildings in a warm, temperate or cool climate zone (regulated by the lowest and average outside temperature during heating period, average outside temperature during summer, heating degree days and solar radiation) six main measures can be suggested in order to gain an optimisation in the field of heating and cooling the buildings (suggested measures for climate zones in Europe [Knotzer and Geier, 2010].

Complete exterior insulation

In all climates there is a need for insulated buildings; the thickness of the layer is ranging from 5 cm in the South to 40 cm in the North part of Europe. Before insulation it is crucial to investigate building components (ground touching walls, ceilings…) thoroughly for capillary rising and absorbed moisture. If there is one it should be dehumidified immediately. For building physical reasons the insulation layer should be positioned at the exterior side of the load bearing structure. Hereafter it is easier to avoid thermal bridges, to cover window frames with insulation, to keep heat storage mass and humidity buffer of the building components inside the thermal building shell. Interior insulation is mainly used for historic buildings, but it is more difficult to manage the building physical challenges there. With these measures the heat transmission losses are reduced and thermal bridges can be avoided leading to a reduction of the energy demand of the building up to 70%. Also the thermal comfort within the building can be improved.

Thermal optimized windows and doors

In all European climates we have the need for better insulated glazing, windows and doors. This is very important for the temperate and cool climates, but also getting more common in the warm climates. Not only the value of insulation of windows and doors itself is very important to improve the energy efficiency of buildings, but also the fixing of them into the cladding – the exterior insulation layer should cover a big part of the window frame (on site) to make it more heat protected and the joints more draught-proofed, etc. Therewith heat transmission losses are reduced and "passive" solar energy is gained leading to a reduction of the energy demand of the building up to 25%. The indoor environment is improved by a higher thermal comfort, decreased draught and cold surfaces and a decreases risk of condensation.

Airtightness

In all European but mainly in cold and temperate climates, we have the need for an airtight building envelope. The most important thing is to decide where the airtight envelope will be situated (inner side of the exterior wall or between old and new façade, etc.) and how windows, doors and building breaches are integrated into that airtight envelope. With these measures infiltration / ventilation losses can be reduced and the indoor environment is positively influenced by improved thermal comfort, decreased draught and cold surfaces as well as decreased risk of condensation.

External shadowing

This measure is necessary to keep indoor thermal comfort during warm season. Of course it is important in warm climates, but its importance even in cool climates is noticeably increasing. There are various reasons for that like higher inner heat load (technical equipment, lighting), big window areas without countable shading possibility, etc. With external shadowing the cooling demand as well as the power consumption for artificial light by combined daylight use can be reduced. Furthermore, the indoor environment can be improved by avoiding over-temperatures during summer and using daylight lighting.

Natural cooling

In warm European climates vented roof and light coloured roof and façade is very useful to protect the building from heat. Natural cross ventilation and night free-cooling, combined with external insulation and interior heat storage mass, are used to hold suitable indoor climate during summer season also in cold temperate climates. Therewith the cooling demand can be reduced and over-temperatures during summer can be avoided.

User‘s briefing/ behaviour

Every retrofit process of residential buildings is first of all a technical and organisational effort, but also a social and communicational one, guiding residents (the users) to energy improvement and high indoor environment. The users' understanding of the actions during and the use of the building after renovation is very important for a comprehensive performance of the process. It is very important to give residents tools and information so that they can learn what they are dealing with (building services, electricity demands of different devices, ventilation system, etc.). Therewith the final energy use decreases, the efficiency increases and the indoor climate becomes more stable.

Solar space heating of factory buildings

In a factory building the specific heating energy demand varies depending on the temperature in the building, the air exchange rate, the quality of the insulation and internal gains. Within the IEA Task 33/IV AEE INTEC simulated different scenarios for a reference factory building in Austria (heating demand 70 kWh/(m^2a), 1,000 m^2 area, 6 m high, 1 shift operation, 15 workers and an internal gain by lighting of 5 W/m^2). It was shown that compared to the reference building the heating demand increases up to 105 kWh/(m^2a) by reducing the insulation and even up to 150 kWh/(m^2a) when in addition to the reduced insulation also the air exchange rate is increased. By internal gains from machine operation inside the building the heating demand can be reduced down to roughly 50 kWh/(m^2a). Based on the work conducted in IEA Task 33/IV solar thermal energy can be named as a good solution for space heating of industrial buildings if there is not enough waste heat available form the company's operations (for further Information see Jähnig and Weiss [2007].

Further reading and references:

Knotzer, A., Geier, S. (2010): *SQUARE - A System for Quality Assurance when Retrofitting Existing Buildings to Energy Efficient Buildings, Energy Improvement Measures and their Effect on the Indoor Environment,* SQUARE project (EIE/07/093/SI2.466701), Work Package 5 Energy Improvement Measures, Deliverable 5.1 report, AEE INTEC, Gleisdorf, Austria

Jähnig, D., Weiss W.(2007): *Design Guidelines – Solar Space Heating of Factory Buildings – With Underfloor Heating Systems*, Booklet prepared as part of the IEA Task 33/IV – Solar Heat for Industrial Processes, published by AEE INTEC, Gleisdorf, Austria

3.7.3 Pre-design of heat exchanger and storage network

After having gathered all relevant data and having analysed the potential for energy savings through the use of energy efficient process technologies, the next step within the audit methodology is a structured analysis for the potential of further energy savings by heat recovery. This is highly important as the application of any energy efficiency measures prior to the change of an energy supply system ensures an efficient overall concept for a sustainable supply of energy in the future and avoids over-dimensioning of supply equipment.

Heat integration is a well developed methodology for the optimisation of thermal processes since the 1970s [Linnhoff and Hindmarsh 1983]. With the *pinch analysis* (as described in detail in section 2.5) the potential of heat recovery can be shown within a system of energy streams. Based on the acquired data of processes and supply equipment of the company and based on the energy balance, “enthalpy streams” can be defined that show the energy demand or the energy availability of a process respectively.

As an example, the energy streams within a bottle washing machine with the following parameters are given in Table 10:

- ✗ Volume of the vessels inside the machine: 5 m³ in total
- ✗ Temperature of the cold water = 10°C
- ✗ Temperature of the water within the machine = 60°C
- ✗ Cold water input during continuous operation = 10 m³/d
- ✗ Heat input during operation (heating of input water and thermal losses, evaporation negligible) = 90 kW
- ✗ Operation schedule: Start-up from 6:00 to 6:30, continuous operation from 6:30 to 16:00.
- ✗ Waste water temperature = 50°C
- ✗ Temperature to which the waste water can be cooled down: 5°C

Table 10: Enthalpy streams for the example of a bottle washing machine.

Name	Start Temperature	End Temperature	Mass flow	Required Power / Waste Heat	Operation schedule
	°C	°C	kg/h	kW	
Start-up	10	60	10.000	582	6:00 – 6.30
Heating continuous inflowing water	10	60	1.053	61	6:30 to 16:00
Additional heat input during operation for thermal losses	60	60	-	29	6:30 to 16:00
Waste water	50	5	1.053	55	6:30 to 16:00
Waste water after machine stop	50	5	10.000	524	16:00 – 16:30

Such streams can be defined for any processes and equipments. Focus will lie on the thermally most relevant streams. Based on such a stream table, the hot and cold composite curve can easily be drawn and show the theoretical maximal potential for heat recovery for a defined ΔT_{min} over the heat exchangers (see also section 2.5).

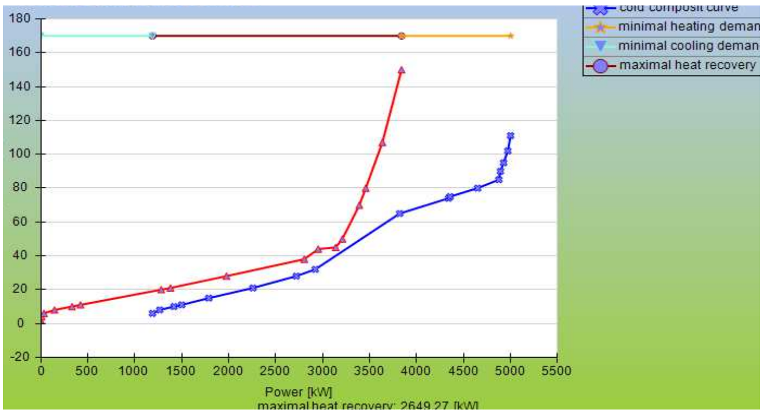


Figure 23: Hot and cold composite curve for a dairy with milk, cheese, curd and butter line)

The grand composite curve shows the heat recovery potential of the process in a slightly different form, but based on the same input data (see section 2.5 for details). Here the difference between the hot and the cold composite curve is drawn, and in this way the necessary external heat/cold supply at the different temperature levels is shown.

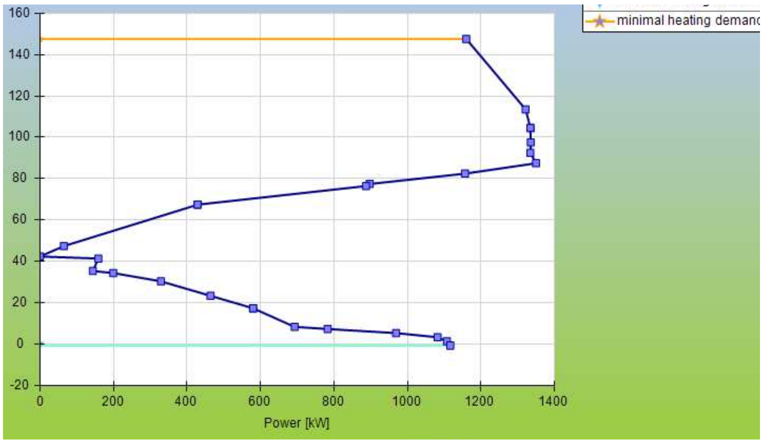


Figure 24: Grand composite curve of a dairy (with milk, cheese, curd and butter line)

Based on the theoretical potential, a technical and economical sensible heat exchanger network has to be identified. Here, some general criteria have to be taken into account:

- Use of heat at a certain temperature level for heating other streams to a similar temperature level (destruction of high value energy - at high temperatures - for low temperature applications should be avoided)
- Power of heat exchange
- Total transferable energy over the heat exchangers
  - Operation schedules of processes – When are which streams in operation and can be used for a direct heat exchange ?
  - Storages – Are storages necessary for a certain heat exchange between two streams ? How big are the storage losses and how much energy can be transferred in total ?
- Heat integration within the same process should be given priority - direct use of waste heat
- Use of heat that has to be cooled down by a cooling machine for heating up processes increase the energy savings by the heat exchange, as the external energy supply of the heat source and the heat sink can be saved
- Distance between the heat source (hot stream) and heat sink (cold stream)
- Practical issues, such as fouling factors, necessity of indirect heat exchange via a heat transfer media, temperature and pressure aspects etc.
- Investment costs and saved energy costs

These calculations can be done by hand, but for complex systems this step might be quite time-consuming. Algorithms for an automatic proposal of heat exchanger networks have been developed by different research groups, however the consideration of time schedules and storage design has hardly been integrated. Also, the focus on giving internal heat recovery higher priority and aiming in general at highest energy savings of the overall network are not usually considered.

Within EINSTEIN a method based on the strategy of the maximum energy recovery network [Kemp, 2007] that uses basic elements of the *pinch design method* [Linhoff and Hindmarsh 1983] is applied for an automatic design of a heat exchanger network. Heat exchangers are selected based on the nominal $q_m c_p$ values of the energy streams. Later within the heat exchange network simulation, the heat exchanger performance is simulated with the varying enthalpies and temperatures over time. In this simulation, also the size of an approximate storage tank is calculated.

Storage concepts

Important for the development of heat recovery networks in industry is the consideration of batch processes and storage concepts. First of all, the general operation schedules of the different processes have to be

defined for a typical week. Here, not only start and end time of a shift is relevant, but as well how many batches are done, the duration of one batch etc. to indicate the real operation schedule. Figure 25 gives an example for a cheese fermenter.
In a cheese fermenter, first hot milk is preheated, then the milk stays in the fermenter while preheated wash water is added and at last the whey is extracted and cooled down. For this delicate process we assume a cleaning of the fermenter after each 2nd batch. In case two fermenter line operate in parallel the schedule becomes more continuous, as the parallel lines can operate timely shifted.
It is obvious that operation management and intelligent planning of heat demand can not only reduce peak loads but as well increase the continuity of streams.

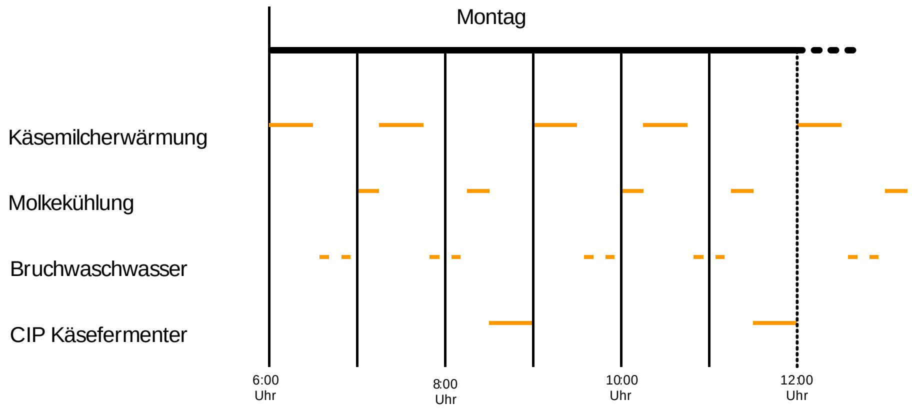


Figure 25: Time schedule of a cheese fermenter

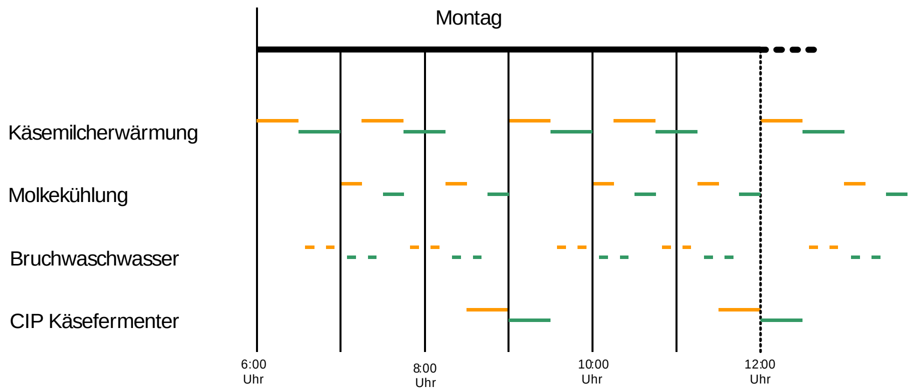


Figure 26: Time schedule of two cheese fermenters running timely shifted

However, many examples exist where a full continuity of processes cannot be reached. In our example of the fermenter, we can see that we still have breaks in the production schedules. Assuming we would like to exchange heat between the milk to be preheated and the whey to be cooled down, we cannot satisfy our heat exchange without storage.

A time slice model can now be applied. Time slices are defined by start and end times of processes. Four kinds of time slices can follow:

1. Only the heat source is available
2. Only the heat sink needs energy
3. Both, source and sink run simultaneously
4. No stream is running

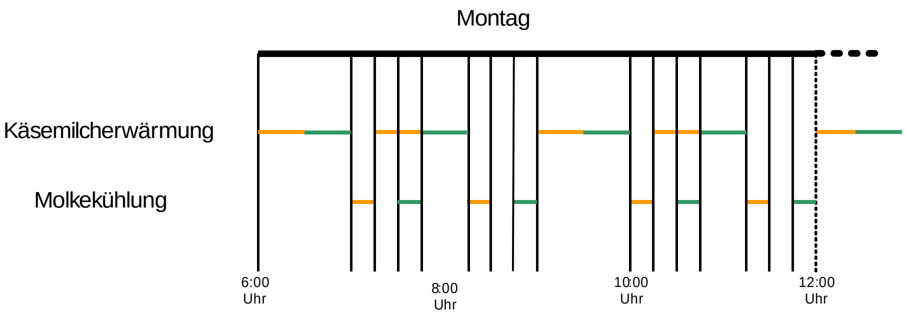


Figure 27: Time slice model applied for cheese milk preheating and whey cooling

Some methodologies exist that apply time slices to the overall network of streams and then calculate heat exchanger networks for each time slice. Here, a different methodology is proposed that first selects two streams for a heat exchanger according to some of the criteria mentioned above, calculates their storage capacity over the time slice model and finally calculates the total transferable energy between the two streams. This is done for many combinations of streams and finally the best one (highest energy savings with one heat exchanger) is selected.

Within each time slice the difference in energy demand and availability can be calculated. These energy surplus or energy demand forms the basis for the storage design. The design is done in a simulation that takes into account cumulation, appropriate size of the storage, current volume of the storage and respective losses in each time period.

It is important to state that this first pre-design of storages is only based on energetic simulation for a standard storage tanks and shows the storage capacity proposed for each heat exchanger. On this basis the expert can choose how many storages with which temperature levels should be installed in practice.

Proposed heat exchangers and design

Aiming at highest possible energy transfer, the heat exchangers proposed in this conceptual stage will be all counter-current heat exchangers.

For a first estimate on the investment costs of heat exchangers the area of the heat exchanger needs to be defined. As discussed above (see section 2.5) a trade-off between saved energy and investment costs exists, depending on the choice of ΔT_{min}. Here, some standard values exist in literature which ΔT_{min} shall be chosen based on the temperature and the physical status of the mass flow (liquid, gaseous, condensating).

Furthermore, the heat transfer coefficient has to be defined for calculating the necessary area for heat exchange. For a first estimate, average values can be set for different physical statuses of streams, in a further step these need to be re-calculated taking into the account the real flow characteristics.

The following table summarizes some standard values applied in EINSTEIN.

Table 11: Standard values for ΔTmin and the heat transfer coefficient α

Physical state	ΔTmin [°C]	Heat transfer coefficient U [W/m²K]
Liquid	5	5.000
Gaseous	10	100
Condensation	2,5	10.000

In practice, the overall heat transfer coefficients $U = (1/\alpha_1 + s/k + 1/\alpha_2)^{-1}$ depend on the type of heat exchanger and the turbulence created, as well as the material of the heat exchanger. The average heat transfer coefficients of each stream in the heat exchanger given in the table above, however, are the basis good estimates of the total heat transfer coefficients in different heat exchanger types. As a standard value, stainless steel can be chosen as a material for heat exchangers.

Table 12: Heat exchanger types and overall heat transfer coefficients

Heat exchange	Heat exchanger type chosen in EINSTEIN	Overall heat transfer coefficient (material = stainless steel) U [W/m²K]	Average values given in VDI Heat Compendia [W/m²K]
Liquid - Liquid	Plate heat exchanger	2.143	1000 – 4000
Gaseous – liquid	Shell&tube	97	15-70
Condensation – liquid	Shell&tube	2724	500 – 4000
Gaseous – gaseous	Shell&tube	50	5-35
Condensation – gaseous	Shell&tube	99	20 - 60

It is shown that for a first estimate only plate heat exchangers and shell&tube heat exchangers are considered. Once the area for heat transfer is estimated, the selection of the type of heat exchangers is also important for a first cost estimation. Here either cost calculation methods from literature can be used, or data is acquired from suppliers.

Heat demand and availability curves

After designing the heat exchangers and defining the realised savings by heat recovery, the remaining heat demand and availability curves can be drawn as a basis for further design of energy supply systems. Yearly load curves are a good basis for the design of new supply equipment as they show how much heat is required in how many hours of the year. The ideal size of the equipment and its respective full load hours can be determined on this basis.

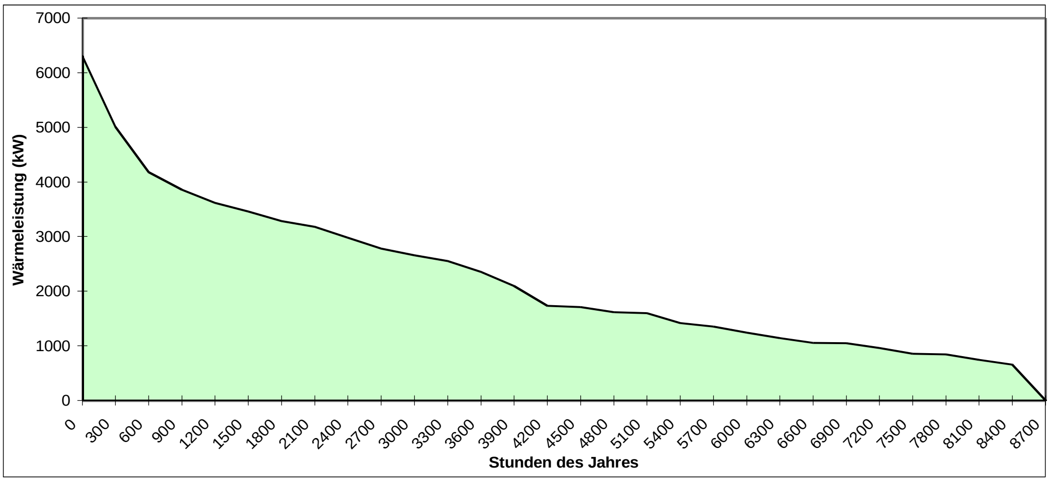


Figure 28: Yearly load curve

Based on the data of energy streams and their operation schedule, such load curves can be drawn after the pinch analysis. As the temperatures are also defined in the energy streams, load curves of heat demand up to different temperature levels can be drawn. In this way, the expert can design suitable supply equipments according to the heat demand that exists in different temperature levels (see section 3.7.4 for details).

Redesign of heat exchanger network due to changing energy supply systems

It might be important in some cases to re-design the heat exchanger network after the energy supply systems have been changed. This might be the case e.g. if a heat exchanger uses the off-gas of the existing boiler which is later substituted by a combination of a biomass boiler and a solar plant. In any case the expert has to check the heat exchanger network proposed after changing the energy supply system. In EINSTEIN it is also possible to re-do the heat exchanger network calculation based on the future energy balance with new supply equipments.

Further reading and references:

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3.7.4 Pre-design of alternative supply system options (including changes in fuels and changes in the distribution system)

The objective

Once the possibilities for heat recovery and process temperature modifications have been examined and applied (these usually require less capital investmen than heat and cooling supply system modifications and may lead to substantial reduction of the energy demand), the next essential part of the EINSTEIN audit methodology is the generation and pre-design of alternative supply options aiming at a further reduction of the energy consumption.

An alternative heat and cooling supply option or proposal is an alternative set of heat and cooling supply equipment and distribution system that can substitute the existing one, offering energy savings, environmental and economic benefits with respect to it. The pre-design of these alternative system involves the selection of the appropriate equipment, and the evaluation of its energy performance considering the heat and cooling demand and availability of the processes and its temporal distribution.

Starting point for the design of the heat & cold supply system therefore is the analysis (breakdown) of the aggregate energy demand after process optimisation, heat recovery and storage pre-design, taking into account the following aspects:

- ✗ temperature level of the remaining heat demand (after heat recovery)
- ✗ quantity of heat demand and waste heat availability
- ✗ temporal distribution of heat demand and waste heat availability
- ✗ availability of space
- ✗ availability of alternative energy sources and their cost (biomass, ...)

Methodological approach

The optimisation of the overall system of heat & cold supply is based on the assumption of a *heat supply cascade* for the aggregate heat and cold demand:

- ✗ the most efficient equipments supply heat at base load (large number of operating hours) and at relatively low temperature levels.
- ✗ the remaining peak load and/or the remaining demand at high temperatures is then covered by less efficient equipment, appropriate for this purpose.

The approach of the heat supply cascade does not lead necessarily to the optimum, and also does not take into account the peculiarities of a specific heat distribution system, but it gives a good first approximation, that then can be manually optimised and adapted to the specific case, depending on the experience of the auditor.

The design process of the overall supply system is carried out in the following steps:

- ✗ Selection of the type of equipment to be used in the heat supply cascade, and order in the cascade. This step has to be carried out manually by the auditor, although the EINSTEIN software tool by default proposes some recommended ordering of the equipment.
- ✗ Dimensioning of the equipment individually for each type of equipment in the cascade. For this purpose, the EINSTEIN software tool offers so-called *design assistants* for several technologies. This automatic or semi-automatic pre-design can then be manually fine-tuned if desired.
- ✗ Selection of the optimum combination of the “whole”. This step has to be done essentially a posteriori by a “trial and error” strategy: different alternative combinations of technologies can be

consecutively designed and finally compared with respect to their energetic, environmental and economic performance.

- In many cases, the optimisation of the sequence heat recovery – heat & cold supply has to be carried out iteratively (repeating the same sequence several times), as a change in the supply system may lead to changes in the available waste heat, and therefore may affect also the waste heat recovery potential.

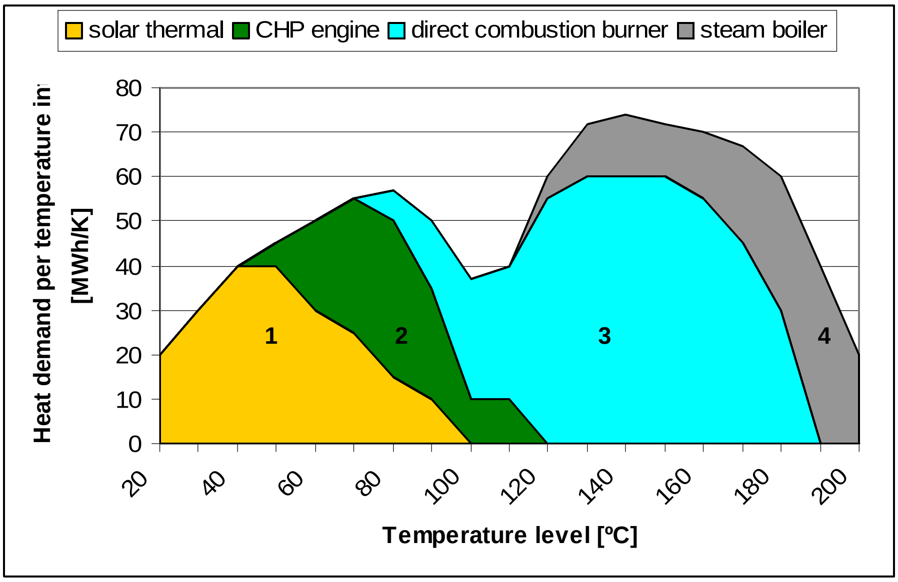


Figure 29: Example: contribution to the aggregate heat demand at different temperature levels by a heat supply cascade formed by different types of equipment.

3.7.4.1 Heat and cold storage

Most of the energy efficient (heat and cold) supply technologies (such as cogeneration, heat pumps, renewable energies that will be described in the following sections) distinguish from (today's) “standard” technologies by:

- Less energy consumption and therefore less operational costs
- Usually higher initial investment costs

Whereas the initial investment is fix (depends only on the type of equipment), the energy savings increase with the annual hours of operation of the equipment. This means, that economic feasibility of these technologies depends strongly on the degree of continuity of operation (number of operating hours).

Therefore these equipments should be typically used for the base load applications, whereas the peak load can be more cost effectively covered by cheaper, although energetically less efficient technologies.

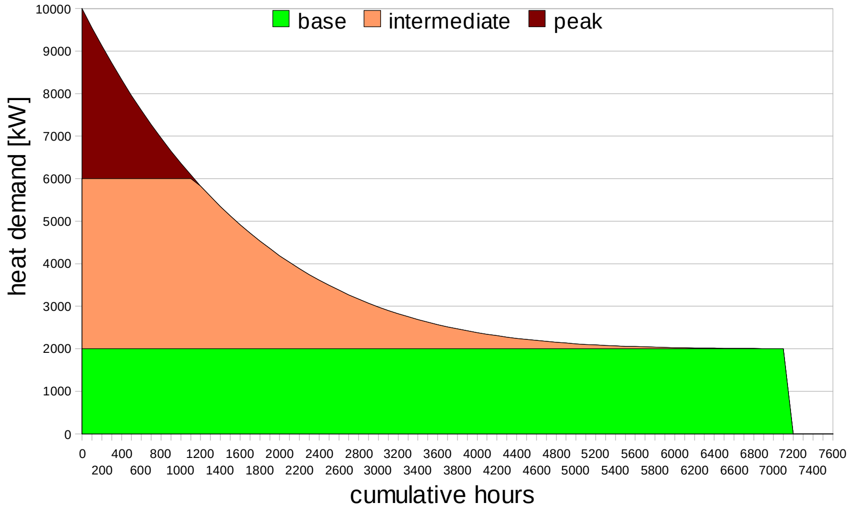


Figure 30. Dimensioning of equipment for base load, intermediate load and peak load

Heat and cold storages can be used in many cases for reducing peak load and increasing the fraction of base load, thereby allowing for a higher fraction of the total demand to be covered by energy efficient supply equipment.

An optimised heat and cold storage system therefore has not to be considered on its own as an independent technology, but as an integral part of all energy efficient heat and cooling (HC) supply options.

Most relevant heat and cooling (HC) storage systems are:

- hot/cold water storages (storing sensible heat; in pressurised tanks storage temperatures of up to more than 150 ºC are possible)
- saturated steam storage tanks
- storage of thermal oil
- solid storages (ceramics, rock beds, ...)
- Latent heat storage with various phase-change materials (PCM storages)
- ice storage and latent cooling storage in other PCM
- thermochemical storages

3.7.4.2 Energy efficient heat & cold distribution

In many cases, a change in the heat & cold distribution may help to reduce energy consumption. Some of the following possibilities should be analysed:

- *reduction of the temperature level*: a reduction of the temperature level in distribution systems may help to reduce losses in piping and storages, and to increase conversion efficiency in the supplying equipment (boilers etc.). The reduction of the temperature level may also be necessary for applying energy efficient technologies (e.g. CHP engines, heat pumps, solar thermal).
- *direct combustion:* in some cases (e.g. drying processes, bath heating) direct combustion or direct use of exhaust gas (e.g. from gas turbines) can increase the system efficiency, on the one hand by eliminating distribution losses, and on the other (e.g in bath heating) by the use of the condensing heat of water vapour contained in the exhaust gas. Direct combustion / direct use of exhaust gas usually is only possible with rather clean fuels, such as natural gas or biogas.

3.7.4.3 Combined heat, cooling and power

Combined heat and power generation at present is the most energy efficient way of generating electricity (except electricity production by means of renewable energy sources) as it optimises the fuel to energy conversion process by producing both heat and electricity instead of heat or electricity-only. In thermodynamic terms it is not possible to be more efficient than with a combined heat and power system since for any amount of fuel input (whether natural gas or biomass, or any liquid fuel), the highly efficient combined heat and power systems will produce heat and electricity with minimal losses (usually in a range from 10% to 25%). Typical electricity-only systems result in conversion losses of at least 45%.

In order to maximise the energy savings, a cogeneration installation should be designed to supply the heat load of the industrial site where it is located. By doing this, the combined heat and power system will be optimised. Any excess electricity produced can be exported to the public electricity network and usually receives a feed-in tariff or certificates (care has to be taken that national legislations often require a certain minimum percentage of own electricity consumption). Operation of CHP plants for electricity generation only by dissipating *excess heat* to the ambient should be avoided from the energy efficiency point of view, unless electrical efficiency of the CHP plant is higher than the mean conversion efficiency of the reference electricity grid.

There are many ways to calculate the primary energy savings achieved by combined heat and power installations: it is possible to compare the amounts of energy saved by comparing with separate heat and electricity production using the same fuel (for example solid biomass if the CHP system runs on solid biomass), or one can use average grid electricity figures (for example the national or UCTE generation mix) for the calculations. Because CHP produces both heat and electricity, the energy savings can be allocated to either the heat produced, to the electricity generated, or in some proportion to both. Currently we find two widespread approaches in Europe:

- ✗ the cogeneration Directive 2004/8/EC approach which compares CHP systems with separate production of heat and electricity (based on reference efficiencies for separate production). This approach is “symmetric” in heat and electricity.

- ✗ the “*equivalent electrical efficiency*” approach used in countries such as Spain and Portugal which subtracts the amount of energy that would be needed to produce the heat in a conventional system from the total fuel input and then calculates a theoretical electrical efficiency (which can be very high, usually well above 60%).

As in EINSTEIN we are concerned mainly with *thermal* energy supply, and – as stated above – energetically optimum operation of CHP plants should be governed by the own *thermal* energy demand, we are interested in the specific net primary energy consumption per unit of heat produced with CHP, given by:

$$\frac{\Delta E_{PE}}{\Delta Q} = \frac{f_{PE}}{\eta_{th}^{CHP}} \left(1 - \frac{\eta_{el}^{CHP}}{\eta_{el}^{grid}}\right) \qquad (3.2)$$

The specific net primary energy consumption can be even negative (!), if the electrical efficiency of the CHP plant is higher than the average electrical efficiency of the power plants used in the electricity grid.

On a medium term time scale this situation nevertheless changes, as the efficiency of the electricity grid itself is getting higher (as power plant efficiency rises and – hopefully – a rising fraction of electricity is generated from renewable energy sources). Compared with a future more efficient electricity grid, the relative savings associated with CHP are getting lower.

As with most energy efficient equipment, an economic operation of CHP system requires a large number of operating hours (typically more than 4000 h/a). Therefore, CHP should be designed for base load and/or in combination with a heat or cold storage.

Apart from heat demand by CHP also cold demand can be covered (so-called *tri-generation*or *combined cooling, heat and power - CCHP*) in combination with thermal chillers (e.g. absorption or adsorption chillers) that convert heat in cold. Thermal chillers usually require a heat input at a temperature level between 80 ºC and 180 ºC, depending on the technology.

The selection of the appropriate technology for CHP depends on the size, continuity and on the temperature level of the heat demand.

Table 13. Available CHP technologies

CHP Technology	Temperature level	Efficiency (el./thermal)
Gas or fuel oil engine	< 95 ºC (cooling water) < 400 ºC (exhaust gas)	(40% / 45 %)
Gas turbine	< 400 ºC	(30 % / 60 %)
Steam turbine	< 250 ºC (practical limit; depending on counter-pressure)	(20 – 30 % / 65 %)
Combined cycle (gas turbine + heat recovery steam generator + steam turbine)	< 250 ºC (practical limit; depending on counter-pressure in steam turbine)	(50 - 55 % / 35 - 40%)
ORC (organic Rankine cycle) turbine	< 250 ºC	*(27- 50% / 30-55 %)*
Stirling engine	*<90 °C*	*(10-25 % / 60 – 80 %)*
Fuel cell	*<80 °C (PEM technology)* *<400 °C (SOFC technology)*	*(45-60 % / 30 – 50 %)*

For further reading:

OPET: Combined heat and power and district heating project. www.opet-chp.net.

COGEN*challenge:* The European information campaign on small-scale cogeneration. www.cogen-challenge.org.

COM 2004/8/EC: Directive on the promotion of cogeneration based on a useful heat demand in the internal energy market. www.managenergy.net/products/R81.htm.

UK Department for Environment, Food and Rural Affairs: Action in the UK - Combined heat and power. www.defra.gov.uk/environment/climatechange/uk/energy/chp/index.htm.

American Council for an Energy Efficient Economy: CHP – Capturing wasted Energy. www.aceee.org/pubs/ie983.htm.

3.7.4.4 Heat pumps

Heat pumps are used for increasing the level of temperature of some waste heat source (or heat extracted from the environment: ambient air or ground) to a level high enough so that it can be used within the heat supply system.

Heat pumps may vary in both size and concept, but the most relevant types of heat pumps used in industrial applications are:

- *mechanical vapour compression* heat pumps, usually using electrical energy as driving source
- *absorption heat pumps*, using thermal energy in form of hot water or steam
- *steam jet pumps*, using steam as a driving source

Typical industrial applications are process water heating and cooling, drying processes, space heating, evaporation and distillation processes, and waste heat recovery.

Important points to be considered about heat pumps application are:

- *Temperature of heat delivery.* It depends on the type of heat pump and working fluid, but it is normally between 55 and 120 ºC. Some compression type applications using water as a refrigerant can be used in higher temperatures, typically in the range of 80 - 150ºC. Temperatures up to 300ºC have been achieved in test plants.

- *Temperature lift.* The coefficient of performance (COP) of the heat pumps strongly depends on the temperature lift, i.e. the temperature difference between the heat source and the heat delivered, with higher COPs being obtained at smaller temperature lifts. Typically temperature lifts are in the range of 20 – 40 K in most applications.

- *Hours of operation.* Heat pumps, like other energy efficient technologies save energy and operation cost, but are intensive in initial investment. Therefore, their application will be more appropriate where the heat demand is continuous and assures larger utilisation factors.

- *Pinch temperature.* The pinch temperature (see section 2.5) divides the aggregate heat demand into two parts: at temperatures above pinch external heat input is required, whereas below pinch there is excess of (waste) heat. The appropriate placement of a heat pump is "*across pinch*", this means: using heat at a temperature below the pinch (where there is excess availability) and releasing it at a higher temperature level above the pinch, where external heat input is required.

- *The form of the heat supply and heat demand curves.* Heat pump application may be appropriate, if after application of heat recovery there is still some overlap in aggregate heat demand and waste heat availability, or if the temperature gap (required temperature lift) is sufficiently small.

For further reading:

Information on heat pump technologies and suppliers is available on the web site of the IEA Heat Pump Centre: www.heatpumpcentre.org.

3.7.4.5 Solar thermal energy

Coupling the solar thermal system to the processes

Existing heating systems based on steam or hot water from boilers are often designed for much higher temperatures (150–180℃) compared to those needed in the process (100℃ or even lower). On the contrary, solar thermal should always be coupled to the existing heat supply system at the lowest possible temperature. Nevertheless, the solar heat should be supplied to the heat carrier only after preheating by waste heat. In fact, the combination of both systems yields better results than a solar thermal system at lower temperature but without heat recovery. The solar thermal system may be coupled with the conventional heat supply system in several ways, including direct coupling to a specific process, preheating of water and steam generation in the central system.

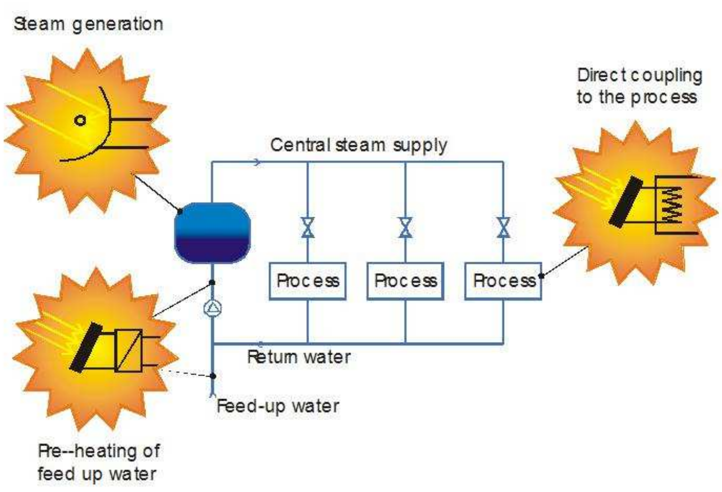


Figure 31. Coupling the solar thermal system with the conventional heat supply [Schweiger et al. 1999]

Whenever possible, a *direct coupling* of the solar thermal systems to one or several processes is preferred, as the working temperatures are lower. Direct coupling to a process can mainly be done in the following two ways:

- *Preheating of a circulating fluid* (e.g. feed-up water, return of closed circuits, air pre-heating etc.). In general, in this application, the mean operating temperature of the solar thermal system is lower than the required final process temperature. If circulation is discontinuous, a storage tank must be also considered.

- *Heating up of baths, vessels and/or hot chambers (e.g. drying)*. Thermal energy is required for heating-up the fluid at the operational start-up temperature and also for maintaining the process temperature constant. The existing heat exchangers integrated into the process vessels generally are designed to operate at temperatures that are too high for a solar thermal system. Where machinery changes are not possible, due to technical constraints, an external heat exchanger coupled to a circulation pump can be used. If the process baths are well-insulated, they can be used for solar heat storage. For example, maintaining the temperature during the process shutdown (typically during weekend) by the solar thermal system can reduce the heat demand for start-up.

The most suitable unit operations for an integration of a solar thermal system are cleaning, drying, evaporation and distillation, blanching, pasteurization, sterilization, cooking, painting, degreasing and cooling. In addition to the manufacturing processes, space heating and cooling of factory buildings should be included among the target applications that require energy at low and medium temperature. Further on solar thermal systems can also be linked to thermally driven chillers (solar cooling).

In almost all industries, *coupling of a solar thermal system to the boiler* is also feasible. This can be done either by preheating the feed-up water of the steam boilers or by a solar steam generator. In the first case, the solar heat can be used either to preheat the fresh water at lower temperature (if no other heat recovery option is feasible) or to further increase the condensate temperature. The generation of solar steam is viable only on sites with high solar radiation and if concentrating collectors are used.

Solar thermal collectors for process heat

The instantaneous efficiency (η) of a solar collector is defined as:

$$\eta = c_0 - (c_1 + c_2 \Delta T) * \frac{\Delta T}{G_T} \qquad (3.3)$$

where c_0 is the optical efficiency, c_1, c_2 are the linear and quadratic heat loss coefficients (c_1 [W/K m^2]; c_2 [W/K^{2}m^2]), ΔT [K] is the difference between the average temperature of the solar heat carrier and the atmospheric temperature and G_T [W/m^2] is the amount of incident solar radiation on the solar collector.

Based on this definition, it can be easily derived that the yield depends strongly on the site (i.e. the irradiation) and on the operating temperature, due to thermal losses in the collector and in the piping.

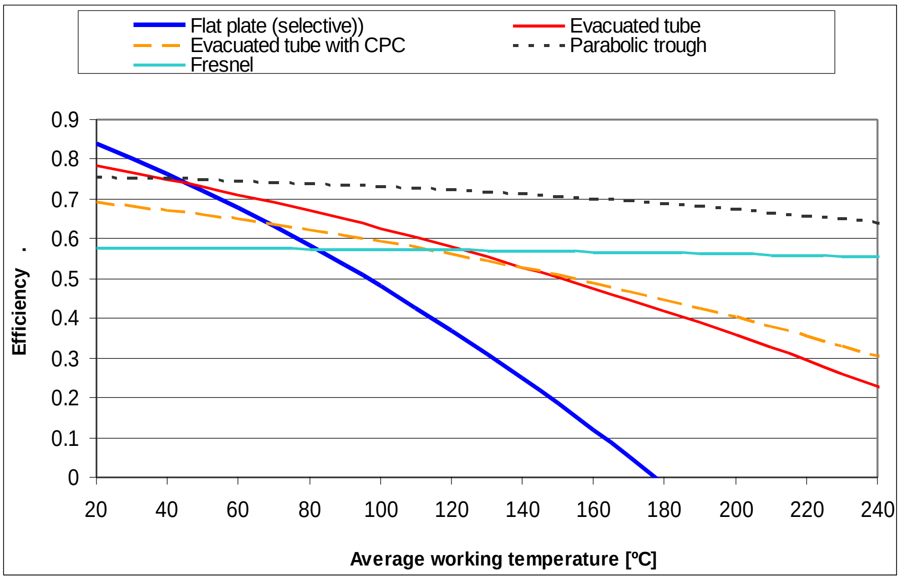


Figure 32. Instantaneous efficiency for different solar collector types (referred to aperture area, beam radiation at normal incidence, G_T = 1000 W/m²) [energyXperts 2010]

At present time, for low process temperatures (up to about 80 ℃), flat plate collectors (with or with out selective absorbers) are the most viable solution. Other collector types, currently used mainly at temperatures above this range (up to 250℃), are: h igh efficiency flat plate (e.g. with double anti-reflection glazing), evacuated tube, stationary low concentrating CPC, small parabolic trough and linear concentrating Fresnel collectors. Beyond these, other concentrating technology such as the collectors with stationary reflector are currently under development.

Dimensioning of the solar thermal plant

In general there is an opposite relation between the solar fraction (i.e. the solar contribution to the overall heat demand) and the specific solar thermal yield of the system (solar heat generated per installed thermal power, or per unit area of solar collectors). Therefore, when dimensioning a solar thermal plant a techno-economic optimum needs to be found. As a rule of thumb, With increasing solar fraction the specific energy yield decreases due to increasing operating temperatures of the solar collectors and due to an increased frecuency of situtations (specially in summer) where the availability of solar energy exceeds the demand.

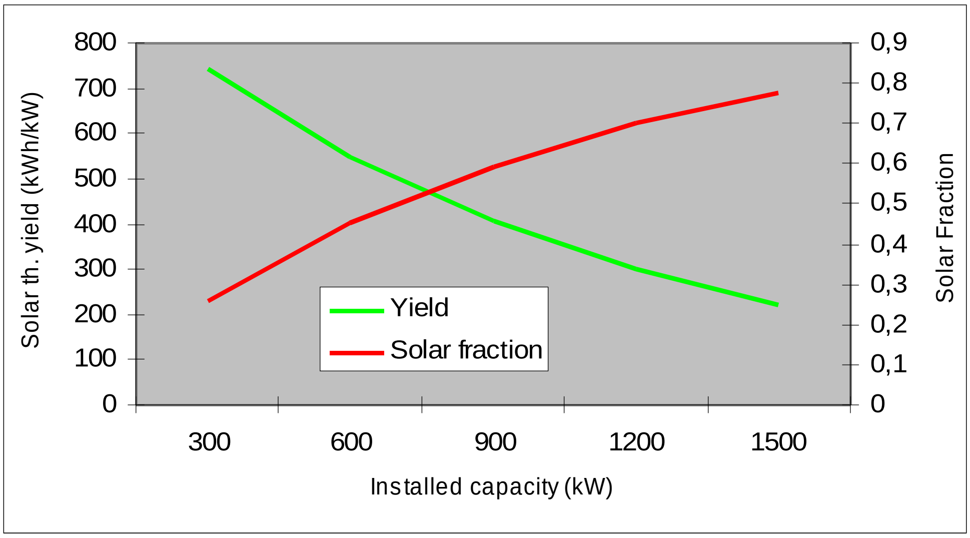


Figure 33. Solar fraction and solar thermal energy yield for different plant size

Load profile and solar heat storage

When the process heat demand is continuous during the day and during the week (e.g. with no weekend breaks), the solar thermal plant does not need any heat storage and the solar heat can be supplied directly to the final user (process or heat supply system). This is the most favorable situation since the simpler the system design, the higher is the overall energy yield and the lower is the investment cost.

In cases where the load is continuous during the week, but there are strong fluctuations in the daily demand, a heat storage of 30 – 120 l/kW of collectors is recommended. If the load profile shows significant breaks (e.g. during the weekend), then the recommended storage size is 120 – 200 l/kW. Storage for longer periods (seasonal storage) can only be considered for very large systems (> 3 000 kW).

Lessons learned

For the feasibility of a solar process heat plant do not forget to check:

- ✗ The process temperatures
- ✗ The load profile (batch, continuous)
- ✗ The availability of process intrinsic heat storages (e.g. baths, pipings)
- ✗ The possibilities of coupling solar to the existing industrial equipments (e.g. heat exchangers, machineries, etc.) and of connection to the conventional heat supply systems
- ✗ The potential for heat recovery
- ✗ The availability of roof and/or ground area for installation (satellite images can be used as additional support)

Concerning the latter, experiences show that the installing area available in the industrial sites is one of the most limiting factor for the feasibility of large scale solar thermal plants. So, remember to survey all the surfaces potentially usable for installation!

Table 14. Design criteria for solar industrial process heat plants.

Criterion	Influence on the energy and economic performance of solar thermal systems
Operating temperature	Operating temperatures not higher than 200℃, best performance below 100 ℃
Climate	Very good conditions in the southern and central European Countries
Continuity of the demand	
Annual variation	Breaks in summer reduce system performance. Losses in solar gains are more than proportional to the time interval of the break.
Daily variation	Continuous demand or demand with peaks at daytime are favourable. Short interruptions (several hours) can be compensated by low volume storage with little increase in system cost
System size	The economic performance of solar thermal systems depends strongly on the system size. Resulting solar energy costs are up to 50 % lower for large systems than for small systems
Annual energy yield	The annual energy yield of a solar system should be at least about 600 kWh/kW for economical profitability.
Solar fraction	Systems should be designed for solar fractions not higher than about 60 % (for continuous demand)
Available roof or ground area	Sufficient roof or ground area should be available in order to obtain solar fractions from 5 to 60 %. Orientation to the south with inclination of about (latitude – 10°) is the optimum to maximize the ann ual energy generation. Small deviations from these values are tolerable (±45° from south orientation, ±15° from optimum inclination). Long piping should be avoided.
Roof structure	The need for reinforcement of roof structures increases system cost and therefore reduces economic performance. The additional static load of solar collectors is 25 – 30 kg/m^2 for standard collectors.
Waste heat recovery	First, improving possibilities to increase energy efficiency by waste heat recovery should be explored. Solar systems should be designed to cover (part of) the remaining heat demand.

References on solar thermal technologies for process heat:

C.Vannoni, R. Battisti, S. Drigo (2008): *Potential for Solar Heat in Industrial Processes.* Published by CIEMAT, Madrid (Spain) 2008. Website: www.iea-shc.org/task33/index.html

D. Jaehnig, W.Weiss (2007): Design Guidelines – Solar space heating of factory buildings. With underfloor heating systems. Published by AEE INTEC with financial support of the Austrian Ministry for Transport, Innovation and Technology, Gleisdorf (Austria) 2007. Website: www.iea-shc.org/task33/index.html

energyXperts.NET (2010): Elaboration based on manufacturer data for group of best market available solar collectors in Spain.

ESTIF (2008): Solar Thermal Action Plan for Europe (STAP). ESTIF Website: www.estif.org/281.0.html

H.Schweiger et al. (2001), POSHIP (Project No. NNE5-1999-0308): *The Potential of Solar Heat for Industrial Processes*, Final Report. Available for downolad at www.energyxperts.net/docs/POSHIP_FinalReport.zip

W. Weiss, M. Rommel (eds., 2007): *Process heat collectors*. State of the art within Task 33/IV, Editors:, Published by AEE INTEC with financial support of the Austrian Ministry for Transport, Innovation and Technology, Gleisdorf (Austria) 2007. Website: www.iea-shc.org/task33/index.html

3.7.4.6 Biomass and biogas

Biomass and biogas are both resources that can have the potential of supplying large parts of the industrial process with renewable energy. Biomass used for industrial burners mainly includes wood chips and pellets. Straw is used as well, but requires more sophisticated technical equipment. Any other biogenic residues from the production process can be used, however its use will largely depend on the calorific value achievable. This again is highly dependent on the water content and the efficiency of the drying process of the biomass.

In general, biomass burners for hot water applications and superheated water applications are state of the art. There is less experience with biomass fired steam boilers but also these types of boilers have been sucessfully applied in the past years.

The fermentation of biogenic residues to biogas opens new possibilities for its use. One large advantage is that the necessity of drying the biomass prior to the combustion, does not exist for biogas. Here, the efficiency depends on the conversion process, the methane yield in the gas phase, and the necessary cleaning of the biogas (especially important for use in engines). Beyond heat generation, biogas can also be used in different technologies like gas (or combined gas-solid) boiler CHP, gas turbine and fuel cells. .

Details on biogas

Biogas is a mixture of methane, CO_2, H_2S, water and other trace gases which is produced oout of organic materials under anaerobic conditions and with the support of microorganism . The process of the production of biogas is complex and follows several fermentation steps. The product quality depends on the kind of feedstock, the used micro-organisms, the process parameters (especially temperatures and pH-level) and the treatment of the produced raw biogas.

In recent biogas plants the combination of different feed stocks is state of the art (co-fermentation). This means the fermentation of organic fertilizers like liquid manure together with other biogenic raw- and waste materials. For industrial applications the use of these additional materials has a big potential for the production of biogas on site and for decreasing the dependency of external energy supply. In Table 15 possible feed stocks from different sources are listed:

Table 15: Biogas feed stocks from different sources

Agriculture industry	Slaughter houses	Industry (e.g. food)	Canteen kitchen	commune
•Residues of harvesting •Energy plants •Liquid manure •Solid and liquid dong	•Slaughter house waste water (grease,..) •Slaughter house solid waste (bowels)	•mash •Brewer grains •yeast •Fruit pulp	•Food residues •Kitchen waste •Waste grease	•grass •Biogenic waste •Sewage sludge

Table 16: Pretreatment technologies of biogas

Pre-treatment	**examples**
Mechanical/physical	Milling, chaffing, ultra sonic
chemical	Acids, base, wet oxidation
Bio-technological	Enzymes, fungi,
Thermal	Steam explosion, thermal pressure hydrolysis

Table 17: Biogas composition out of different feed stocks

components	Wood gas		Sewage gas	landfill gas	biogas	Biogas av.
	air	steam				
CH_4	3 – 6 %	9 – 11 %	60 – 75 %	45 – 55 %	50 – 75 %	**55 %**
CO_2	*12 – 16 %*	20 – 25 %	30 – 40 %	30 – 40 %	25 – 45 %	**43,9 %**
H_2S			< 1 %	50 – 300 ppm	0 – 1 %	**0,05 %**
H_2O			saturated	saturated	saturated	saturated
H_2	11 – 16 %	33 – 40 %	traces		0 – 1 %	**0,5 %**
O_2			< 1 %		0 – 1 %	**0,1 %**
N_2	45 – 60 %	< 3 %	< 4 %	5 – 15 %	0 – 3 %	**0,4 %**
NH_3					0 – 0,5 %	**0,05 %**
CO	13 – 18 %	25 – 30 %	traces		-	-
Heating value [kWh/m³]	**1,1 – 1,7**	**3,3 – 4,2**	**6 – 7,5**	**4,5 – 5,5**	**5 – 7,5**	**5,5**

* Vol% on dry gas

Different process technologies like a one or two step fermentation process, mesophile or thermophile conditions and a wet or dry fermentation have influence in product quality and quantity. The pre-treatment of the feed stock, especially for celluloid and hemi-celluloid materials, has a big positive influence on the biogas yield. State of the art pre-treatment technologies are shown in Table 16.

In order to increase the "energetic value" of biogas and depending on the future use of the gas, the raw biogas need to be conditioned in most cases. Mainly the removal of CO_2, H_2S and H_2O raises the heating value of the biogas and makes it therefore applicable to different areas. Natural gas has an average heating value of around 10 kWh/m³ whereas biogas typically has a heating value of approximately 6 kWh/m³. This means, that for the production of the same amount of energy (equivalent conversion efficiencies of the equipment assumed) 1.7 times more biogas is needed than natural gas.

For further reading:

Ross, Charles C.; T. J. Drake (1996): Handbook of Biogas Utilization Vol. III, Second Edition.; Environmental Treatment Systems, Inc. July 1996

3.7.4.7 Energy efficient boilers and burners

In order to evaluate the overall performance of an existing boiler, during a walk – through energy audit it is recommended to check: the year of installation; the technical data (manufacturer, nominal power, etc.); the state of insulation; possible leakages; the control strategy of the boiler.

Several measures can be implemented to reduce the energy consumption of a new or existing heat generation system (e.g. boilers, steam boilers, condensing boiler, etc.). In particular, the following items should be considered:

- The use of electricity for heating of processes is very inefficient. The conversion efficiency of primary energy to electricity used in the process (including distribution losses) is about 30 %, compared with up to more than 90 % in highly efficient gas boilers or burners.

- Hot water boilers have a higher conversion efficiency than steam boilers, and for low temperatures even condensing boilers may be used. Thermal losses in the distribution are also reduced. Furthermore a hot water circuit allows the use of other energy-efficient technologies such as CHP, heat pumps and solar thermal energy.

- A lower steam pressure (and temperature) level leads to a reduction of thermal losses and costs.

- The use of natural gas or LPG allows the application of energy efficient technologies such as condensing boilers, direct combustion, etc.

- The efficiency of a boiler rapidly decreases when it works at load lower than 30%. Therefore, it can be appropriate to install two or more boilers in cascade to supply the total heat demand. Over-dimensioning of boilers should be avoided. In particular higher efficiency boilers should be used as base-load boilers while the less efficient ones should cover only the demand peaks.

- Optimizing the control may help to increase the efficiency.

- If boilers or furnaces are regularly shut down because of change of load, the heat loss caused by the chimney effect drawing cold air through the boiler can be significantly reduced by the use of dampers.

- The main factors influencing the efficiency are the flue gas losses and the radiation of the shield. Decreasing the flue gas temperature and insulating the boiler always lead to an increase in efficiency. Adjusting the excess air ratio helps also to reduce flue gas losses and improve thereby boiler efficiency.

- The return of the condensate to the steam boiler allows the recovery of the energy contained in them (up to 15 % of the energy required for steam generation).

- In order to minimize the blow-down waste heat the blow-down stream should be reduced (by preliminary treating the feed up water) and the heat contained in the blow-down should be recovered. Treated fresh feed-up water furthermore reduces the deposition of limestone, maintaining thereby a good heat exchange between the combustion gas and the fluid to be heated.

- The installation of a economizer (an additional heat exchanger for preheating of boiler feed-water by waste heat recovery from flue-gases) and/or an air preheater (recuperator) increases the overall efficiency by recovering the waste heat in the off gases.

For further reading:

The Energy Research Institute Department of Mechanical Engineering University of Cape Town. H*ow to save money and energy in boiler and furnaces systems.* Website: http://www.3e.uct.ac.za

Lawrence Berkeley National Laboratory Washington, DC for DOE, Improving Steam system Performance a sourcebook for industry. April 2004. Website: http://www1.eere.energy.gov/industry/bestpractices/pdfs/ steamsourcebook.pdf.

Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques for Large Combustion Plants. July 2006. Website: http://eippcb.jrc.es/pages/FActivities.htm

Ralph L. Vandagriff. Practical guide to industrial Boiler systems. 2001. Marcel Dekker, Inc. Website: www.dekker.com

V. Ganapathy ABCO Industries. Industrial Boilers and Heat Recovery Steam Generators Design, Applications, and Calculations. 2003 Marcel Dekker, Inc.Website: www.dekker.com

3.7.4.8 Energy efficient cold generation

Industrial chillers are used for controlled cooling of products and factory machinery, or for providing cooling for air conditioning of production areas. There are two groups of chillers according to the refrigeration cycle principle they use:

- *Vapour-compression chillers* use mechanical energy for their operation and are powered either by electric motors (most commonly used) or bysteam or gas turbines. Depending on the type of compressor they use vapour-compression chillers can be classified into reciprocating, scroll, screw and centrifugal chillers. The energy efficiency ratio (EER) of large vapour-compression chiller applications is typically 4.0 or more.

- *Thermal chillers* use thermal energy for their operation, delivered in form of steam, hot water or exhaust gas from combustion. The most commonly used thermal chillers are the *absorption chillers*. The EER's of absorption chillers are in the range from 0.5 – 0.8 (single-effect) up to 1.0 – 1.3 (double effect)[13].

Chillers release the absorbed energy from the cooled medium to the environment. They can release the energy to the air (air-cooled) or to water (water cooled). Water-cooled chillers usually use wet cooling towers which improve their thermodynamic effectiveness compared to air-cooled chillers due to a reduction of the temperature level of heat rejection, but add additional cost and water consumption to the system.

Important points to be considered in chiller applications and design:

- *Temperature of cold supply*. The conversion efficiency of cold generation depends strongly on the evaporating temperature (or the temperature at which cold is produced). Higher evaporation temperature will result in a higher energy efficiency. In many applications one chiller unit supplies cold to different processes. If processes with different levels of cold temperature exist, group them by temperature and supply cold with the highest possible temperature to each of the groups. A higher chilled water temperature will also allow an increased use of free-cooling (see below).

- *Temperature difference between evaporation and condensation*. Lower temperature difference between the cooling produced and the temperature level of heat rejection results in a higher EER. An appropriate design of the cooling tower and re-cooling circuit can improve the efficiency. In the case heat from chillers is rejected to the ambient, the condensation temperature or the temperature of the cooling water flowing through the dry or the wet cooling towers do not need to remain at a constant level. Instead, the temperature level of the fluid can be adapted in function of the outdoor temperature, in order to reduce the difference between evaporation and condensation of the chiller.

- *Reduced part-load operation - use of equipment cascades*. Most of the chillers usually see their efficiency drop at part-load operation. If the cooling loads are strongly variable, e.g. for the air-conditioning of a building, it might be useful to use one or more chillers working at nominal power to cover the base load, and use one chiller (preferably using a turbo-compressor, which has a better behaviour at part-load) to cover the cooling peak demand. Part-load opearation can also be reduced and operation hours can be increased by using cold storage (elimination of demand peaks).

[13] *Take into consideration the absorption chillers use thermal energy instead of electrical or mechanical energy in the case of mechanical vapour compression chillers. Therefore the COP – values can not be directly compared.*

- ✗ *Availability of low temperature heat in the range from 80 - 90 ºC.* Heat in this temperature range may be available from waste heat recovery, from CHP plants (e.g. engines) or from a solar thermal system. In these cases the application of thermally driven chillers should be taken into consideration, especially in large scale applications with high utilization factors.

- ✗ *Possibility of free cooling.* Chillers should be applied only in cases where the necessary temperature of cooling can not be achieved directly releasing the heat to the environment. In many climates the environmental temperature may be lower than the cold demand temperature for considerable periods of time (during night and/or winter period). Different chiller designs exist that permit free cooling in periods of low outside temperatures, creating a direct loop between the medium to be cooled and the outside air. The use of this type of chillers may result in considerable energy savings. Good candidates for free cooling chiller applications are processes with relatively constant loads in climates with low winter or night temperatures.

- ✗ *Use of environmental friendly and natural refrigerants.* When selecting vapor-compression equipment the environmental aspects with the used refrigerant should be considered, having in mind the international agreements in this area. It is preferably to use refrigerants without ODP (Ozone Depletion Potential) and low GWP (Global Warming Potential) and natural refrigerants as ammonia, carbon dioxide, which also have excellent thermo-physical properties assuring high operating efficiency.

- ✗ *Use of waste heat from chiller.* Waste heat from the condenser of chillers, and in certain cases from the cooling of the compressor, that generally is dissipated in the cooling towers, can instead be reused for (pre-) heating of fluids at low temperature (up to about 50 ºC, operating the chiller as a *heat pump*; temperature lifts of up to 40 K between the chilled water temperature and the condenser temperature are possible). The temperature level of the rejected heat can be further increased by using an additional heat pump.

For further reading:

EU BREF *Reference Document on the application of Best Available.Techniques to Industrial Cooling Systems.* December 2001. The European Comission.

ASHRAE Handbook - HVAC Systems and Equipment. ASHRAE, 2008.

EINSTEIN Step 7: conceptual design of saving options and preliminary energy targets definition

> check list of recommendations for potential energy savings

> process optimization and demand side opportunities

> analyse the theoretical heat recovery potential

> pre-design heat exchanger and storage network

> pre-design of alternative supply systems

3.8 Energy performance calculation and environmental analysis

In order to assess the energy consumption of a proposed heat and cooling supply system, a model calculation (simulation) of the system has to be carried out. For this purpose, within the EINSTEIN software tool a system simulation module is available for all technologies.

3.8.1 EINSTEIN system simulation module

The internal energy performance calculation in EINSTEIN is based on the heat and cooling demand of the different supply pipes or ducts in the system, and the potential output of the supply equipment ordered in form of a heat and cooling supplycascade.

The heat demand for each equipment $\dot{Q}_{D,j}=\dot{Q}_{D,j}(T,t)$ is temperature and time dependent according process characteristics and schedules.The potential power output P_{nom} of the different thermal supply equipment is generally dependent on supply temperature levels and, furthermore, in the special case of heat pumps, also on the availability of waste heat $\dot{Q}_A=\dot{Q}_A(T,t)$ .The useful heat supplied by each equipment at a given position *j* in the heat supply cascade then can be calculated from the heat demand and the nominal power:

$$\dot{Q}_{USH,j}(T,t)=min[P_{nom}(T),\dot{Q}_{D,j}(T,t)] \qquad (3.4)$$

where

$$\dot{Q}_{D,j}=\dot{Q}_{D,j}(T,t)=\sum_{connected\ pipes}\dot{Q}^{res}_{D,m}(T,t) \quad . \qquad (3.5)$$

and $\dot{Q}^{res}_{D,m}(T,t)$ is the residual heat or cooling demand at pipe or duct *m*, after having received already the heat or cooling supply from the previous equipments in the cascade, equipments 1 to (j-1).

The calculations in the EINSTEIN system simulation tool are carried out by default in 1h time steps for the whole year, taking into account the variation of demand in time and temperature during the different hours of the day, seasonal variations, week-ends and holiday periods.

The main limitation of this internal calculation tool is the "*heat and cooling supply cascade*" approach used: the details and peculiarities of the real system regulation and control strategy are not considered within the energy calculations[14], and can only be approximated by an appropriate ordering of the equipments in the cascade

For a more detailed and accurate calculation external system simulation software can be used.

3.8.2 System simulation with specific external software

For those cases, where the internal system simulation module of EINSTEIN may not be accurate enough, external system simulation software has to be used. Some references of existing simulation tools can be found in the EINSTEIN review of thermal energy auditing practices and tools[Vannoni et al., 2008]. .

3.8.3 Environmental analysis

As already outlined in Chap. 2.1., EINSTEIN uses the following parameters as main indicators for the environmental assessment:

- *Primary energy consumption* as the main indicator for environmental assessment
- *Generation of CO_2*

[14] *Thermal losses in distribution are approximately taken into account in the calculations using an overall average distribution efficiency.*

- ✗ *Generation of highly radioactive (HR) nuclear waste* (associated with electricity consumption)
- ✗ *Water consumption*

The quantity of the environmental impact parameters is directly obtained from the composition of the final energy consumption in the industry that results from the energy performance analysis described in the previous sections.

The conversion parameters to be used can be configured by the user in the EINSTEIN databases for fuels and for the representative electricity mix to be applied.

Generally speaking it can be said that *primary energy consumption* is the preferred parameter to be used as main indicator, and that should be minimised, as it represents a (somehow weighted) mean of the different types of emissions.

The parameter CO_2 emissions – frequently used as environmental indicator – neglects other types of emissions such as radioactive waste, and therefore underestimates the (usually negative) environmental impact of a shift from fuels to electricity especially in countries with a high contribution of nuclear energy to electricity generation.

References chapter 3.8.2

C.Vannoni et al. (2008): EINSTEIN Report: Review of Thermal Energy Auditing Practices and Tools.IEE Project EINSTEIN, Project deliverable D2.2. Available for download on www.einstein-energy.net

EINSTEIN Step 8: Energetic performance calculation and environmental analysis

> fast calculation

> system simulation with specific external software

> energetic and environmental analysis

3.9 Economic and financial analysis

For the company itself the economic analysis of the proposed energy supply is one of the most crucial questions. Therefore emphasis has to be put on this step and the more detailed data can be acquired for this analysis, the higher will be the reliability of the results.

For the economic analysis of a new energy supply systems, operating (energy) costs have to be compared with the current equipment. Therefore, a suitable methodology is to calculate all costs that will occur in the future with the existing heat and cold supply and compare those with the expected investment and other costs of the proposed alternative energy supply system. The difference in costs gives the expected cash flow that occurs due to the change of the supply equipment.

In general the following cost categories need to be considered:

- ✗ Investment costs:

  - offers from suppliers or use of 2nd hand equipment
  - subsidies and funding
  - revenues that can be achieved through the sale of the replaced equipment

- ✗ Operating costs:

  - energy costs incl. expected increase in energy prices
  - maintenance, labour costs, insurance, utilities etc.

- ✗ Contingencies

  - in case the current supply system is not changed: tax disadvantages, costs for remediation activities, costs for compliance with legislation, negative impacts on market share, affection by CO2 emission trading etc.
  - in case the energy supply system is changed: tax benefits, positive impacts on markets share, amelioration of company image

- ✗ Non re-occurring costs

  - repair works for equipments, exchange of collectors, irregular maintenance, permits, legal costs, prevention costs etc.

In conventional cost assessments the focus l on the investment costs and operating costs. However, for a consideration of the overall true costs also contingencies and non-reoccurring costs have to be considered and they can have an important impact on the final result. The cost analysis should be suitable for detection of all parameters that influence the economic performance of energy efficiency and the installation of an energy supply systems in industrial processes, besides the energy costs.

For a total costs assessment (TCA) that looks at a longer time period and takes into account macro-economic parameters as well, contingencies and non-reoccurring cost are the categories for their consideration.

It is obvious that the following parameters are crucial for the result of the cost assessment:

- ✗ Nominal interest rate of the external financing
- ✗ Company specific discount rate
- ✗ Expected development of energy prices
- ✗ General inflation rate
- ✗ Chosen time frame for the economic analysis

The result of the economic analysis includes the investment, the payback period and the benefit cost ratio, but should also include economic parameters that show the economic performance in a longer time period. Here, the internal rate of return and the development of the net present value over the years are highly important. (For details on calculation see section 2.6.

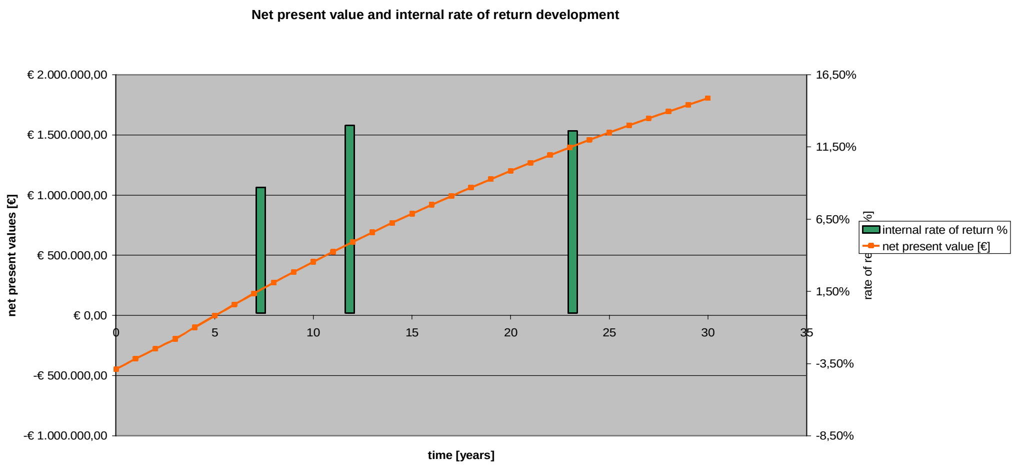


Figure 34: Result of the economic analysis

EINSTEIN Step 9: Economic and financial analysis

> calculate main economic parameters

> assess possibilities of funding and financing

> elaborate an appropriate financing scheme

3.10 Reporting and presentation

3.10.1 Content of the report

Once concluded the audit, an *audit report* has to be written as the main document being produced during this process.

The audit report should contain (at least) the following information:

- ✗ An *executive summary* highlighting the main results of the audit

- ✗ The data that have been collected and/or estimated during the auditing process and have been used as a starting point for the analysis. Especially *estimations* and *hypothesis* made by the auditor and that are not supported by collected data should be clearly highlighted.

- ✗ The breakdown of present state energy consumption as outlined in chapter 3.6 and it's comparison with benchmark reference data.

- ✗ A description of the different alternative proposals analysed, highlighting the necessary modifications with respect to the present state, and the differential features of each of the alternative proposals. Each of the alternative proposal should be named by a short but self-explaining acronym that can be used for identification in comparative tables and graphics.

  The description of the alternative proposals should best be accompanied by schematic drawings (block diagrams and/or hydraulic schemes) that clearly illustrate the position of the new equipment in the existing system.

- ✗ Comparative tables and figures with the main results (energetic, environmental, economical) of the different alternatives studied

- ✗ Presentation of a detailed financial analysis of the finally proposed solution (or solutions: in some case it may make sense to propose more than one "best" alternative to the company, and leave the final selection to them). Here You should also mention the possibility of third-party financing of necessary investments, possible sources of funding and other types of incentives.

- ✗ A clear statement and identification of the necessary uncertainties that still exist after concluding a fast audit, especially if these may have a critical impact on the feasibility of the proposed systems. Highlight the aspects that should be analysed in more detail before taking a decision on a change in the system.

The EINSTEIN software tool automatically generates a standard audit report containing all of this information. This report is produced as a spreadsheet (OpenOffice) that You can edit and modify, adding manually additional content, etc.

3.10.2 Presentation to the company

The presentation of the report to the company should be always personal, if possible, as so You have the possibility to explain Your proposals, avoid misunderstandings and highlight the advantages of Your proposal to the decision makers in the company.

Nevertheless, the EINSTEIN audit report should be clear enough that it can be also sent by mail or e-mail, in case that a personal presentation is not possible (e.g. large distance to the company and low budget doesn't allow for a second visit, ...).

EINSTEIN Step 10: reporting and presentation to the company

> elaborate short-and-clean audit report

>present to the company

3.11 Collective learning

3.11.1 Share your experience with the community

Each case study You carry out is a new experience, with own peculiarities, that should be incorporated into the stock of experience that can be accessed either by You or by other auditors in future audits. This process of collective learning can be by different ways and on different levels:

- ✗ Share the information within Your company, institute or network. The data, once introduced in the EINSTEIN data base can be accessed for future audits, e.g. for being used as an additional benchmark for similar industries, as a source of ideas on which type of measures can be proposed, etc.

- ✗ Share the information with the community of EINSTEIN users. In the subsequent updates of the EINSTEIN tool-kit, new projects developed by the users will be incorporated. Aspects of confidentiality can be taken into account by making data anonymous (the EINSTEIN tool for this offers different options / levels of confidentiality that automatically eliminates certain data from the projects). The submission of the projects can be done via the EINSTEIN web-page www.einstein-energy.net, or sending a copy by e-mail to the EINSTEIN developers at: info@energyxperts.net.

- ✗ Users help other users: there is a e-mail forum for EINSTEIN users where You can exchange opinions, get support or give support to others. Just subscribe at the web site of the EINSTEIN tool: https://lists.sourceforge.net/lists/listinfo/einstein-users

3.11.2 Help to improve the methodology and the software tool

EINSTEIN is nearly perfect, but not completely. There's always something that can be improved; new technologies or data that arise; things that have not been considered; special cases that cannot be represented well within the EINSTEIN standard schemes, etc.

Use the EINSTEIN web (einstein.sourceforge.net) for reporting bugs, ideas for improvements, etc.

3.11.3 Become an EINSTEIN developer

The EINSTEIN tool is being further developed as a free and open source software project. You can download and modify the source code, develop and contribute your own modules.

After quality and compatibility checking by the EINSTEIN team these modules will be incorporated into the next EINSTEIN distribution.

How ? Just send a request for getting EINSTEIN developer to the EINSTEIN team by some of the above mentioned channels.

3.12 Follow-up

3.12.1 From the audit to the installation of the new system

As important as the audit itself is the follow-up afterwards. The main objective, of course, is to convince the company to realise the proposed investment and install the new energy efficient systems.

But also from negative responses You can learn and increase Your experience: try to get information on why a proposal, that You considered energetically and economically feasible, was not realised. If in this specific case the decision can not be reversed, at least You can consider this knowledge in the way You present the next study.

3.12.2 Predicted and real performance of new systems

If everything went well and You did a good job, finally the company will improve its heat & cold supply system by installing (more or less) the new system You proposed. You can lay down, relax, enjoy your success, and then after some time ... start working in the next audit.

But You should best keep track and make use of this practical experience at least during several years after start-up of the new systems (some problems of certain technologies may reveal only after some time). The best way to do this is carrying out a systematic follow-up:

- ✗ Best try to sign a maintenance contract and so get in direct touch with the plant during the first years of operation.
- ✗ Call the company in periodic intervals and ask them for their experience.
- ✗ If You can get even some measurement data on the performance of the system, the better. Use these data in order to compare Your predictions with real behaviour.
- ✗ Keep a register of the contacts carried out, the problems reported, your insight about how this problems could have been avoided, etc.

4 Examples

4.1 Overall procedure

Starting point:

After a presentation about energy efficiency measures and renewable energies in industry You have a short talk with the technical director of the company EINSTEIN Container Washing Ltd., Ms. Cleanton. She tells you that she is very interested in the potential that renewable energies offer for reducing her energy costs, that since the recent rises in energy tarriffs have started to be a significant cost factor for the company.You exchange visit cards and promise her to send her further information.

4.1.1 EINSTEIN Step 1: Motivate

Once You arrive in Your office, You send a short e-mail to Ms. Cleanton with the EINSTEIN information material attached.

After some days You phone her, and she tells You that she is very interested in an EINSTEIN energy audit and proposes You to come to visit the company, which unfortunately is located in Railway City at about 150 km distance from Your office. You agree with her, that she will send some data and some sketches of the factory in advance, so that You can elaborate a preliminary proposal prior to the visit.

4.1.2 EINSTEIN Step 2: Pre-audit data acquisition

You send the “EINSTEIN check list for the company” to Ms. Cleanton in order to give her an idea, which information You will ask her for during the visit. You send this check list together with the EINSTEIN basic questionnaire, asking her to fill in the data she can get easily and send it back to You by fax or by e-mail.

Some days later You get the questionnaire back, filled with very few data:

some general data on the company: administrative data, turnover, etc.

period of operation:	260 days/year, 10 hours/day, 2 shifts/day, only one process: container washing
hot water demand:	100 m^3 / day at 80 ºC
heat supply equipment:	steam boiler, no further data specified
fuels used:	natural gas, no data on consumption specified

Although the case of EINSTEIN Container Washing Ltd. seems to be a rather simple one, You try to get some information on similar industries, and check the EINSTEIN BAT recommendations whether You can find some ideas on possible improvements. Among some other recommendations the ones that best fit to your case are:

process optimisation in washing processes:

- “check if water consumption and/or water temperature can be reduced by using other detergents”
- “check if waste water reuse or a closed water circuit is possible”

recommendations on the heat supply side:

- “check possibility of heat recovery from waste water”
- “hot water heating at low temperature is appropriate for application of solar thermal energy”

4.1.3 EINSTEIN Step 3: Processing of preliminary information

First of all You enter the data in the EINSTEIN software tool in order to see to what level of detail You can say already something with the data You have up to now. From Your experience, You know that apart from the information You got from the company, You will need to make some estimations about the possibilities of waste heat use and also make some assumptions about energy tariffs. For a first approximation, You suppose the following (although You are aware that these data may have a big error and have to be confirmed before making a proposal to the company):

- quantity of waste water = the same quantity as the hot water consumed: 100 m^3 / day
- temperature of waste water: 50 ºC

- You assume the following energy tariffs based on experience You have for other industries of similar size: natural gas price: 30 €/MWh; electricity price: 85 €/MWh

- heat distribution: steam at 2 bar, forward temperature 140 °C, return temperature 60 °C, 100% condensate recovery

(see example project *EINSTEIN Guide 41 Preliminary step*)

As You want only a very fast first orientation, You set the accuracy level for consistency checking to "quick&dirty" and then You run the EINSTEIN audit procedure in the automatic mode ("Autopilot"):

- you are lucky: data are sufficient for a first quick&dirty study and are consistent
- for a more detailed analysis, the nominal power of the currently installed boiler would be necessary
- the estimated yearly process heat demand is 2.118 MWh and the fuel consumption is estimated to 2552 MWh; 71 % of the heat demand or about 1500 MWh are below 60 ºC
- the required external heat supply can be reduced to 1327MWh with heat recovery
- as suitable additional energy efficienct solutions you get the following proposals
  a) a solar thermal system with a nominal capacity of 693 kW covering 51% of the residual heat demand
  b) a CHP engine of nominal thermal power of 333 kW covering 70% of the remaining heat demand
  c) a heat pump with nominal capacity of 300 kW covering 20 % of the remaining heat demand
  d) new boilers with higher efficiency

  In all cases, the old boiler has been substituted by more efficient ones. The results are showed in Figure 35.

(see example project *EINSTEIN Guide 41 Auto-Pilot Results*)

Primary energy consumption (PEC)

	Alternative	Primary energy consumption [MWh]	Savings [MWh]	Savings [%]
1	Present State (checked)	3386.97		
2	Heat recovery (HR)	2319.71	1067.26	31.51
3	Solar thermal	1493.73	1893.25	55.90
4	CHP	1577.49	1809.48	53.42
5	Heat pump	2170.66	1216.31	35.91
6	Boiler cascade	2279.67	1107.30	32.69

Relative comparison of PEC

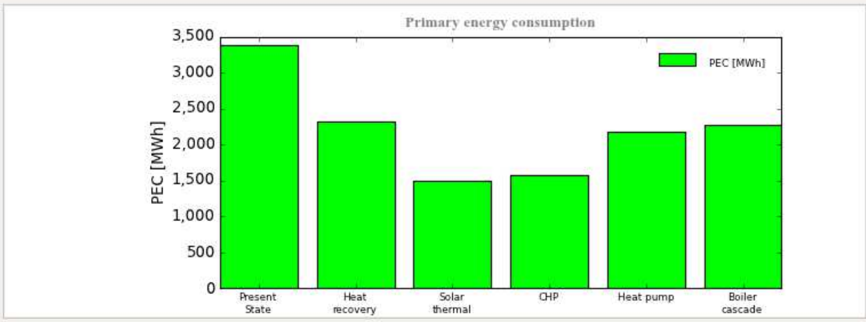


Figure 35: Comparison of estimated present state primary energy consumption, and reduction potential with different energy efficiency measures.

In order to confirm the preliminary assumptions made and the results obtained, You call the company and ask for the nominal power of the boiler installed. They tell You that they have a 3 MW steam boiler installed in the factory.

As You are not very expert in renewable energies, You call some colleague who is working in this field in order to get some further information.

Now as You have an approximate idea about the energy consumption in the company, You can look for benchmark data, in order to know whether the present energy consumption is within the good-practice range.

As a result of the possible measures that you could identify during the fast preliminary study, you fix the following priorities for further data acquisition:

– determine temperature of waste water and degree of contamination (possible problems for heat recovery)
– determine the available surface areas and structural characteristics of the roofs for a possible installation of a solar thermal system
– determine the energy conversion efficiency, age and state of conservation of the existing boiler in order to decide on a possible substitution of the steam boiler

4.1.4 EINSTEIN Step 4: Quick&dirty pre-evaluation

In the present case the available data are sufficient in order to make a first quick&dirty proposal that can be presented to and discussed with the company. Therefore, You print out the standard audit report of the EINSTEIN software tool. You decide not to send it by e-mail but to present it personally during the visit at the site.

4.1.5 EINSTEIN Step 5: Visit on site

At the company You are received by Ms. Cleanton, accompanied by an operator of the washing plant. You present and explain the preliminary study, and get the confirmation that there is a big interest of the company in applying the proposed measures for energy saving, especially the options that seem to offer the highest saving potential: heat recovery and solar thermal energy.

Therefore, You focus in the following on gathering further information, especially on the topics on your priority list. You get the following additional information:

- the existing steam boiler is very old, and the company is already thinking about a possible substitution. Ms. Cleanton in the meanwhile succeeded to collect information from the company's energy bills: the natural gas consumption during the past three years was between 2700 and 3100 MWh per year.
- the company disposes of a flat concrete roof of about 2000 m^2 without any static problems regarding the installation of a solar thermal system.
- all the waste water is collected in a small reservoir before being treated in a waste water treatment plant in order to separate chemicals and other contamination. You cannot get further information about its temperature. You learn that the waste water is not corrosive, and does not contain a significant amount of other contamination such as fibres that could be a problem for heat exchangers.

(see example project *EINSTEIN Guide 41 Visit On-Site*)

As You brought Your laptop to the company for making a presentation, You use the opportunity to feed in the new information You just collected into the EINSTEIN software tool and check whether they are consistent with the preliminary information. In this case it is confirmed that they are. Nevertheless, the new data on energy consumption let You suggest that the existing boiler is very inefficient (You get an estimate for the boiler conversion efficiency of 74% !).

During the walk through the installations in the company, You measure the waste water temperature in the waste water collector. You take two different measurements, one at the beginning of the walk through, and another one at the end of the visit, just before leaving the company. You get the following values:

- Waste water temperature measurements in the reservoir: (a) 51.3 ºC (while there were three washing processes running in parallel); (b) 42.8 ºC (at that moment there was only one washing process active).

The values are not too far away from Your initial estimate. But anyway You suggest that the company should monitor and register this temperature during a week, together with the start and stop time of the washing cycles and the water consumption.

After the walk through You shortly comment Your observations to Ms. Cleanton. You tell her that in Your opinion the main aspects of the initially presented pre-feasibility study continue being valid. You suggest to wait for the missing data measurements. The operator of the washing line promises to do this during the following week, so that You promise to Ms. Cleanton to deliver the final audit report within two weeks.

4.1.6 Einstein Step 6: Analysis of Status Quo

After analysing the results of the company's measurements, that You finally received by fax, You obtain a mean waste water temperature of 45.2 ºC, so You decide to correct your initial estimate from 50 to 45 ºC in the final study for the company. You obtain the breakdown of process heat consumption by temperature as shown in Figure 36.

Furthermore You get a confirmation that the existing heat supply system is working with a low efficiency (about 75 %).

Heat demand (UPH) and supply (USH) by temperature

heating/cooling: heating

	Temperature levels [°C]	Heat demand (UPH) by process temperature (PT) [MWh]	[%]	cumulative [%]	Heat supply (USH) by central supply temperature (CST) [MWh]	[%]	cumulative [%]
1	< 60 °C	1513.06	71.43	71.43	1241.13	57.14	57.14
2	60 - 80 °C	605.22	28.57	100.00	620.57	28.57	85.71
3	80 - 100 °C	0.00	0.00	100.00	310.28	14.29	100.00
4	100 - 120 °C	0.00	0.00	100.00	0.00	0.00	100.00
5	120 - 140 °C	0.00	0.00	100.00	0.00	0.00	100.00

Distribution of heat demand (UPH) and supply (USH) by process temperatures

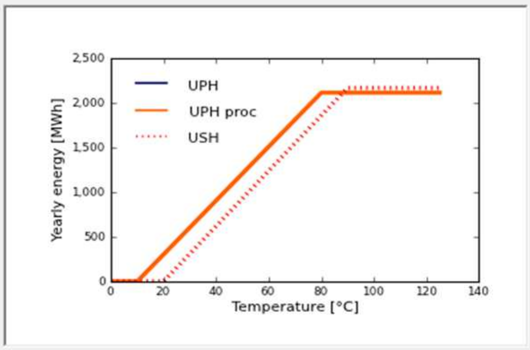


Figure 36: Break down of energy consumption (example): process heat and supply heat by temperature level (Note: minimum required temperature is given in the case of supply heat and not the actual steam supply temperature).

4.1.7 EINSTEIN Step 7: Conceptual design of saving options

4.1.7.1 Process optimisation

After discussing in the company You come to the conclusion that in this case there is no possibility of improving the washing process itself. So You decide to focus on heat recovery and supply optimisation.

4.1.7.2 Heat recovery

As first measure for improving energy efficiency You suggest to the company to recover heat from the waste water and from the exhaust gas from the boiler for preheating of the fresh feed-up water. You use the EINSTEIN software tool for a quantitative estimation of the heat recovery potential. The remaining heat demand then is used as a basis for all the optimised heat supply proposals.

4.1.7.3 Heat supply

As You want to do only a fast audit, You decide to take over mainly some of the automatically generated options of the EINSTEIN software tool. Nevertheless, You do some fine-tuning of the proposal combining heat recovery, a solar thermal system and the substitution of the existing inefficient and oversized boiler by a new and smaller one.

The automatically created proposal foresees a 624 kW solar thermal system with evacuated tube collectors (ETC). You decide to manually change this:

– You round the results to 600 kW and 40 m3 storage
– You compare different collector types: flat plate (FPC) and evacuated tube collectors (ETC)
– You study a 3rd solar thermal proposal with a smaller solar system (FPC 300 kW)

(see example project *EINSTEIN Guide 41 Detailed*)

Based on the auto-design of the EINSTEIN software tool, a new boiler with a nominal power of 650 kW is proposed for all three types / sizes of solar system.

Primary energy consumption (PEC)

	Alternative	Primary energy consumption [MWh]	Savings [MWh]	Savings [%]
1	Present State (checked)	3770.00		
2	Heat recovery (HR)	2428.87	1341.13	35.57
3	Boiler cascade	2444.85	1325.15	35.15
4	ST-ETC-600	1731.46	2038.54	54.07
5	ST-FPC-600	1964.28	1805.72	47.90
6	ST-FPC-300	2167.62	1602.38	42.50

Relative comparison of PEC

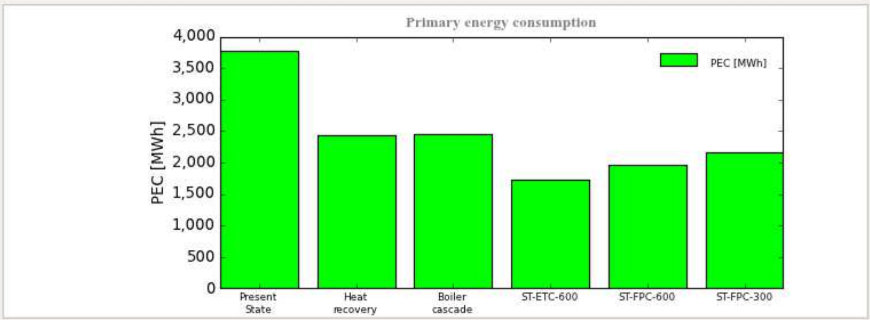


Figure 37: Comparison of present state primary energy consumption, and reduction potential with different energy efficiency measures. All solar thermal proposals are based on the alternative “Heat Recovery” and include also heat recovery and renewal of the boiler.

4.1.8 EINSTEIN Step 8: Energy performance calculations

Figure 38: Weekly heat supply by the different equipment. Alternative "ST-ETC-600".

In order to learn about the seasonal performance of the system You carry out a system simulation with the internal energy performance calculation tool of EINSTEIN. From the results You can see the weekly performance of the system (Figure 38).

4.1.9 EINSTEIN Step 9: Economic and financial analysis

Finally You carry out an economic comparison of the proposed alternatives. For a fast assessment you take over the automatically calculated investment and O&M costs as availabe in the EINSTEIN database and add manually estimated values for the heat recovery system[15].

As a result of the economic analysis You get the data as listed in Figure 39, Figure 40 and Figure 41, In Figure 39 the values for the investment cost and subsidies are plotted.

[15] *The values used for the economical analysis in this example are: operation and maintenance costs (for thermal uses in the status quo system): 1500 EUR; annual inflation rate: 2%; rate of increment of energy prices: 4%; nominal rate of interest for external financing installations: 8%; time of economic amortization of installations: 15 years. Manually added estimated investment costs for heat recovery system: 50.000 €*

Investment cost

	Alternative	Total cost [EUR]	Own cost [EUR]	Subsidies [EUR]
1	Present State (checked)			
2	Heat recovery (HR)	50000.00	45000.00	5000.00
3	Boiler cascade	320000.00	234000.00	86000.00
4	ST-ETC-600	570537.00	409375.90	161161.10
5	ST-FPC-600	536195.00	385336.50	150858.50
6	ST-FPC-300	411680.00	298176.00	113504.00

Investment cost comparative

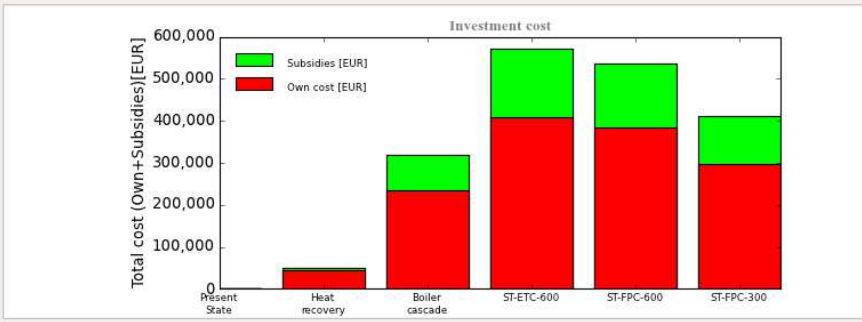


Figure 39: Comparison of the investment costs of the different set of energy efficiency measures. All solar thermal proposal are based on the alternative “Heat Recovery” and include also heat recovery and renewal of the boiler.

Figure 40 shows the total yearly energy system cost of the different alternatives composed by energy costs, operation and maintenance costs, and an annuity of the initial investment. The minimum of total yearly energy system cost is obtained for the alternative “Heat recovery” with moderate primary energy savings, whereas for the alternatives with large solar systems and corresponding high primary energy savings total energy system cost rises again, due to the contribution of the annuity on investment.

Annual cost

	Alternative	Amortization [EUR]	Energy cost [EUR]	ration and maintena (O&M) cost [EUR]
1	Present State (checked)		104000.00	1500.00
2	Heat recovery (HR)	5148.14	66753.20	4000.00
3	Boiler cascade	32948.08	67957.13	4000.00
4	ST-ETC-600	58744.07	48498.96	6142.00
5	ST-FPC-600	55208.12	54628.00	6142.00
6	ST-FPC-300	42387.71	60395.85	5071.00

Annual cost comparative

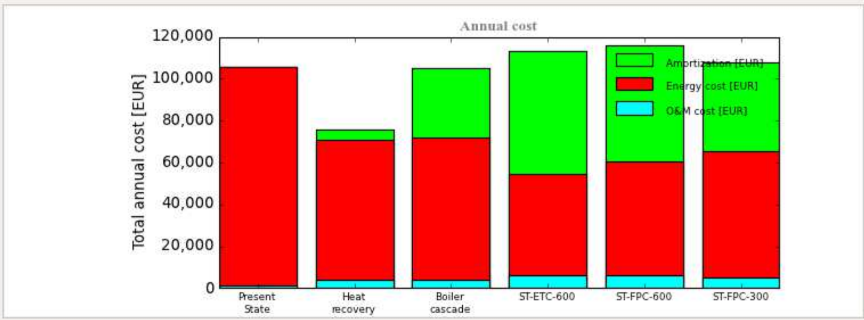


Figure 40: Comparison of the annual costs (including annuity of total investment) of the different energy efficiency measures. All solar thermal proposals are based on the alternative “Heat Recovery” and include also heat recovery and renewal of the boiler.

Figure 41 shows the additional cost per saved energy. The heat recovery alternative supposes both a reduction of primary energy consumption and a reduction of the total yearly energy system costs. The alternatives including solar systems (ST) lead to higher primary energy savings, but at the price of a higher yearly cost. The alternative ST-FPC-300 leads to very high primary energy savings being nearly cost-neutral.

Additional cost per saved primary energy (PE)

	Alternative	Total energy cost cl.O&M and invest.) [EU	Additional cost [EUR]	Additional cost per saved PE [EUR/MWh]
1	Present State (checked)	105500.00		
2	Heat recovery (HR)	75901.34	-29598.66	-22.07
3	Boiler cascade	104905.21	-594.79	-0.45
4	ST-ETC-600	113385.03	7885.03	3.87
5	ST-FPC-600	115978.12	10478.12	5.80
6	ST-FPC-300	107854.56	2354.56	1.47

Comparative of additional cost per saved primary energy

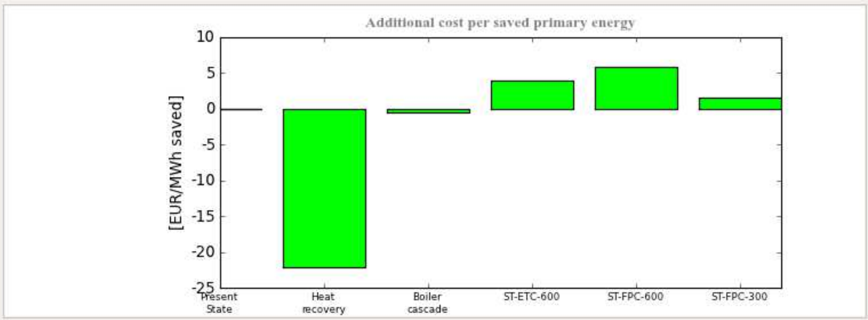


Figure 41: Comparison of the additional total yearly cost per saved energy of the different energy efficiency measures. All solar thermal proposal are based on the alternative "Heat Recovery" and include also heat recovery and renewal of the boiler.

4.1.10 EINSTEIN Step 10: Reporting and presentation

You are happy with this result. It seems that with the alternative ST-FPC300 You have an attractive proposal to be presented to the company that allows for 42,5% of primary energy savings. You print out the EINSTEIN audit report, that is automatically generated by the tool, and call Ms. Cleanton in order to make an appointment for the presentation of the results.

4.2 Consistency checking and data estimation

In this section You will find some examples on how to use the EINSTEIN tool for consistency checking of the data. A simplified model of a dairy with only three processes will be used in order to demonstrate the most relevant options of the EINSTEIN tool. The examples described are included in the default data base of EINSTEIN release package.

4.2.1 Description of the model dairy

4.2.1.1 Processes

Three typical processes of a dairy are considered:

- pasteurisation (process 1)
- coagulation (curdling) (process 2)
- mozzarella spinning (process 3)

Pasteurisation is the most energy consuming process. The model dairy operates 280 days per year, producing mainly two products: normal cheese and mozzarella. Intermediate products are: pasteurised milk (from pasteurisation), whey and curd (both from coagulation)

Pasteurisation

Pasteurisation is a controlled heating process used to eliminate viable forms of any micro-organism, i.e. pathogen or spoilage causing, that may be present in milk. High temperature short time (HTST) pasteurisation uses a temperature of 72 to 75 ℃ for 15 to 240 seconds. For continuous pasteurisation, flow-through heat-exchangers, e.g. tubular, plate and frame, are applied. These have heating, holding and cooling sections.

Pasteurisation foresees internal heat recovery and external heat supply for heating up and cooling down a circulating fluid (milk). The daily volume of milk being pasteurised is 400 m^3. The process is continuous and it lasts 5 h/day from 6 to 11 o'clock. The external heat supply medium is hot water.

Milk enters into the equipment at 4℃, then it flows though an internal counter-flow heat exchanger where the outgoing hot milk preheats the incoming cold milk up to 38℃. The preheated milk is then further heated up to 72℃ by hot water, remains at that temperature for some time while passing through the heat exchanger, and is then cooled down again to 38℃. The energy demand due to heat losses of the pasteuriser and to start-up is assumed here to be negligible.

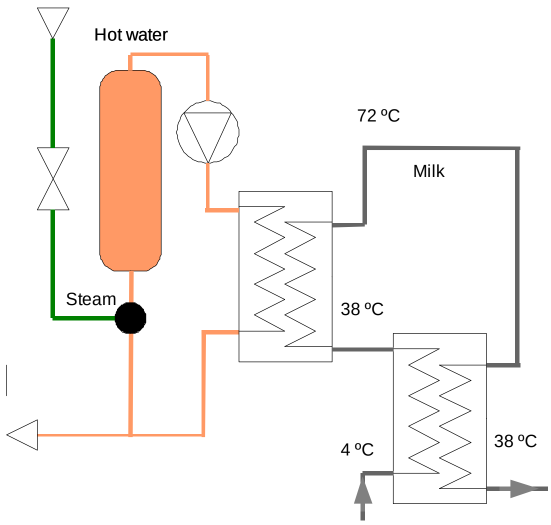


Figure 42: Simplified scheme of the pasteurizer

Coagulation

Coagulation is used in milk processing to separate the curd from the whey, and it is also called curdling. Curdling is carried out in suitable vats or tanks where starters and other ingredients are added to the milk for the production of a *coagulum*. The curd is produced by the separation of the whey, which is then gathered and sent for further processing as appropriate. Temperature is one of the key factors that influence milk curdling. The required temperature is obtained by using either heat-exchangers or by direct injection of steam into the curdling vat.

Curdling is a batch process and, in this case, each batch lasts 1,5 h. 4 batches per day are run from 10:00 to 16:00. Heat is required at the beginning of the batch in order to heat up the pasteurised milk from the inlet temperature (37℃) up to the process temperature (4 0℃). During the coagulation process, thermal energ y is required to maintain the process temperature constantly at 40℃.

The total daily milk volume of 400 m^3 is passing to coagulation after having been pasteurised. By separation, as an output of the process 240 m^3/day of whey at 37℃ are obtained.

Mozzarella spinning

Mozzarella spinning involves heating and melting. The curd is put into a processing kettle and mixed up with hot water at high temperature, typically 75 – 95℃. Hot water is mainly used for melting the *coagulum*. A given percentage of the process water is also absorbed by the curd in order to increase its elasticity. Hot water is obtained by using either heat-exchangers or by direct injection of steam.

Spinning is also a batch process and, in this case, each batch lasts 1 h. 4 batches per day are run from 12 to 18 o'clock. Thermal energy is required here to increase the process water temperature from 10℃ up to 90℃. 50% of the daily pasteurised milk is used aft er coagulation to produce mozzarella. Assuming that for 100 l of milk 26 l of hot water are required to produce 13 kg of mozzarella, for 200 m^3/day of pasteurised milk 50 m^3 of water at 90℃ are required daily. The outlet te mperature of waste water is 70℃ while the flow is assumed to be the 80% of the inlet daily quantity, i.e. 40 m^3.

4.2.1.2 Heat supply and distribution

Figure 43 shows the scheme of the heat supply and distribution, formed by two natural gas fired steam boilers and three independent pipings to each of the three processes.

Boiler B1 (nominal power 3 MW) feeds only the pasteurization process (P1). The average efficiency is 80% while the mean utilisation factor is 80% and the nominal natural gas consumption is 301.8 kg/h. Boiler B1 runs 6 hours per day from 5:00 to 11:00.

Boiler B2 (nominal power 2 MW) feeds all three processes (P1: pasteurisation, P2: coagulation; P3: mozzarella spinning). The average efficiency is 88% while the mean utilisation factor is 59.4% and the nominal natural gas consumption is 182.9kg/h . Boiler 2 runs 8 hours per day from 10:00 to 18:00.

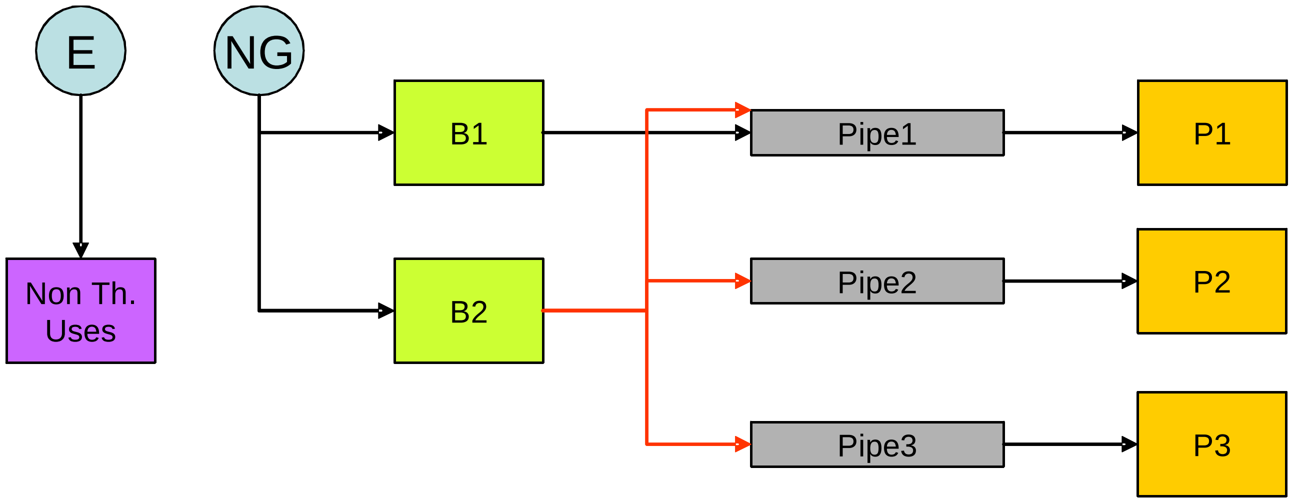


Figure 43: Block diagram of the heat supply and distribution system and thermal processes in the dairy.

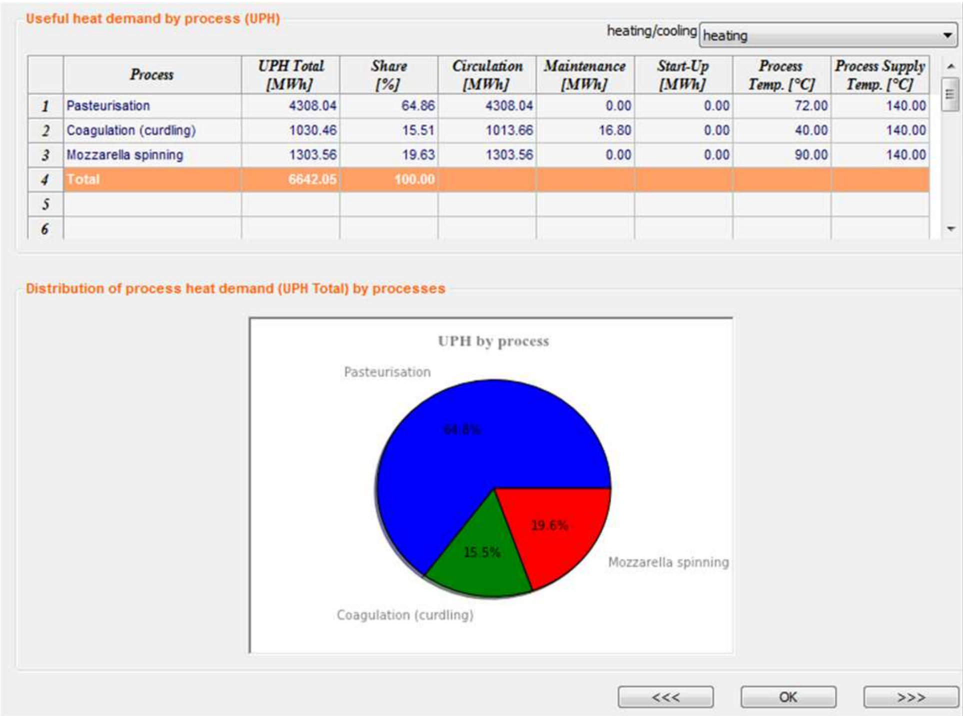
The heat supply medium used is low-pressure steam (2 bars) at 140°C and the condensates return at 60ºC. The length of the piping is 200m (one-way) for pipe 1, while pipe2 and pipe3 have a length of 100m.

From the energy bills the annual quantity of fuel (natural gas) is known to be 811200 m^3. The final energy consumption of natural gas (NG) for thermal uses (i.e. the annual consumption (LCV)) is 8 063 MWh.

Electricity is needed only for non thermal uses and it's consumption is approx. 400 MWh: 300 for running machineries and 100MWh for lighting.

4.2.1.3 The base case: breakdown of energy consumption with the EINSTEIN software tool

After entering all data into the EINSTEIN software tool and running the consistency check, the results as shown in Figure 44 are obtained.



	Process	UPH Total [MWh]	Share [%]	Circulation [MWh]	Maintenance [MWh]	Start-Up [MWh]	Process Temp. [°C]	Process Supply Temp. [°C]
1	Pasteurisation	4308.04	64.86	4308.04	0.00	0.00	72.00	140.00
2	Coagulation (curdling)	1030.46	15.51	1013.66	16.80	0.00	40.00	140.00
3	Mozzarella spinning	1303.56	19.63	1303.56	0.00	0.00	90.00	140.00
4	Total	6642.05	100.00					
5								
6								

Figure 44: Break down of process heat consumption for the model dairy (Example project "EINSTEIN Audit Guide 42 Base Case").

If the data are entered correctly into the EINSTEIN software tool, You can obtain a full breakdown of the energy consumption with the data as specified above (Figure 44). The main energy flows in the system are shown in Figure 45.

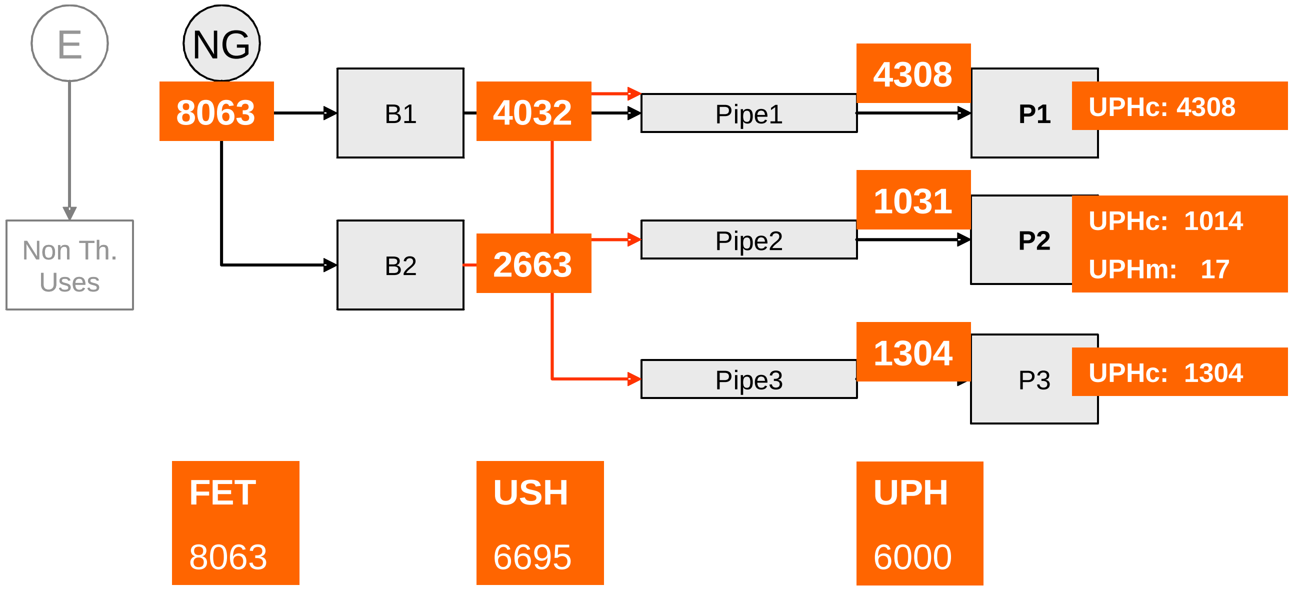


Figure 45: Energy flows in the system (base case).

4.2.2 Detecting conflicts in data

As already outlined in chapter 2, one of the first steps in data checking is to see whether the available data are consistent, or if there are some contradictions between the data. This will be illustrated in two examples.

4.2.2.1 Conflicts in two data directly specifying the same quantity

An example for a very simple conflict in input data can arise e.g. due to errors in units (e.g. the use of kWh instead of MWh). The total energy consumption of 8063 MWh in our example corresponds to a natural gas consumption of about 811200 m^3. If the user due to some error in reading the units enters 8063 *kWh* instead of 8063 *MWh*, then this error will be easily detected by the EINSTEIN tool (Figure 46).

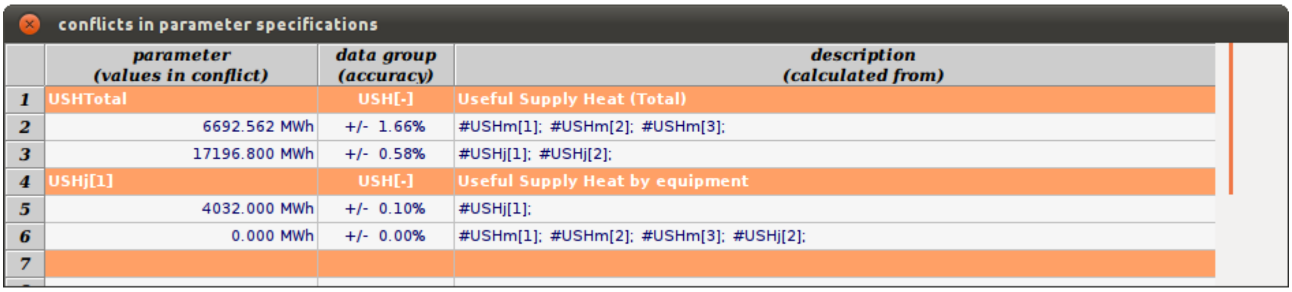
conflicts in parameter specifications

	parameter (values in conflict)	data group (accuracy)	description (calculated from)
1	FECFuel	Fuel[1]	total own fuel consumption (LCV)
2	8.063 MWh	+/- 0.10%	FECFuel;
3	8063.328 MWh	+/- 0.00%	MFuelYear;
4	MFuelYear	Fuel[1]	annual consumption
5	648960.000 kg	+/- 0.00%	MFuelYear;
6	648.934 kg	+/- 0.10%	FECFuel;
7			

Figure 46: Error message of the EINSTEIN software tool in the case of contradictory data on fuel consumption (Example project “EINSTEIN Audit Guide 42 1a”).

4.2.2.2 General conflicts of system data

Not all the data conflicts are so easy to detect as the example mentioned above. Sometimes detecting contradiction requires the calculation of system energy balances or the evaluation of flow rates, temperature levels, etc. As a second example we can enter a total fuel consumption that is much larger than the sum of all the process heat demands (taking into account reasonable values for conversion and distribution efficiencies).



conflicts in parameter specifications

	parameter (values in conflict)	data group (accuracy)	description (calculated from)
1	USHTotal	USH[-]	Useful Supply Heat (Total)
2	6692.562 MWh	+/- 1.66%	#USHm[1]; #USHm[2]; #USHm[3];
3	17196.800 MWh	+/- 0.58%	#USHj[1]; #USHj[2];
4	USHj[1]	USH[-]	Useful Supply Heat by equipment
5	4032.000 MWh	+/- 0.10%	#USHj[1];
6	0.000 MWh	+/- 0.00%	#USHm[1]; #USHm[2]; #USHm[3]; #USHj[2];
7			

Figure 47: Error message of the EINSTEIN software tool in the case of contradictory data on energy balances – total useful supply heat (Example project “EINSTEIN Audit Guide 42 1b”).

4.2.3 Data completing with EINSTEIN

In the base case example above, a complete data set has been entered into the EINSTEIN tool, this means that for the determination of several parameters even redundant information is available (which may lead to conflicts, as shown in the previous sections).

But, as we already learnt, EINSTEIN is an intelligent guy and does not need all the data in order to know what to do. He is able to calculate what is missing by his own. Calculated or estimated data nevertheless have only a certain degree of reliability, which is shown to You in the consistency-check analysis windows. Before You accept them and proceed with the audit, You should evaluate and decide whether the uncertainty is acceptable for Your purposes or not.

In this section it will be shown how to use the EINSTEIN consistency check module in order to complete the information on the industry based on a reduced and incomplete data set.

4.2.3.1 Process heat consumption is known only for the main processes

A very frequent case in practice is that energy consumption is known only for the main heat consuming processes, but that there are one or several minor processes with unknown heat demand. In order to show how to proceed in this case, we modified our example so, that the energy consumption of process 2 (coagulation) is undetermined:

– the circulation heat demand of the process (flow rate of process medium at inflow) was left unspecified. This means that Q_{UPHc} may have any – even a very large – value.
– the part load factor of boiler B2 was left unspecified. This means, that also the heat supplied by boiler B2 is unknown. Nevertheless in this case, the total heat supplied by this equipment is *limited* by the total energy consumption of 8.063 MWh and also by the known nominal power of the boiler and by the maximum operating hours.
– The length of pipes 2 and 3 are also unspecified.

The general situation is slightly undetermined: an exact solution of the problem can not be found, as the piping heat losses are not exactly known. But the problem is constrained, as the total energy consumption is known, and therefore EINSTEIN can estimate the missing parameter, the heat demand of process 2, by difference. In this case the process heat demand of process 2 can be determined to 467 MWh with a very big error of almost 100%, which is due to uncertainties in the piping heat losses.

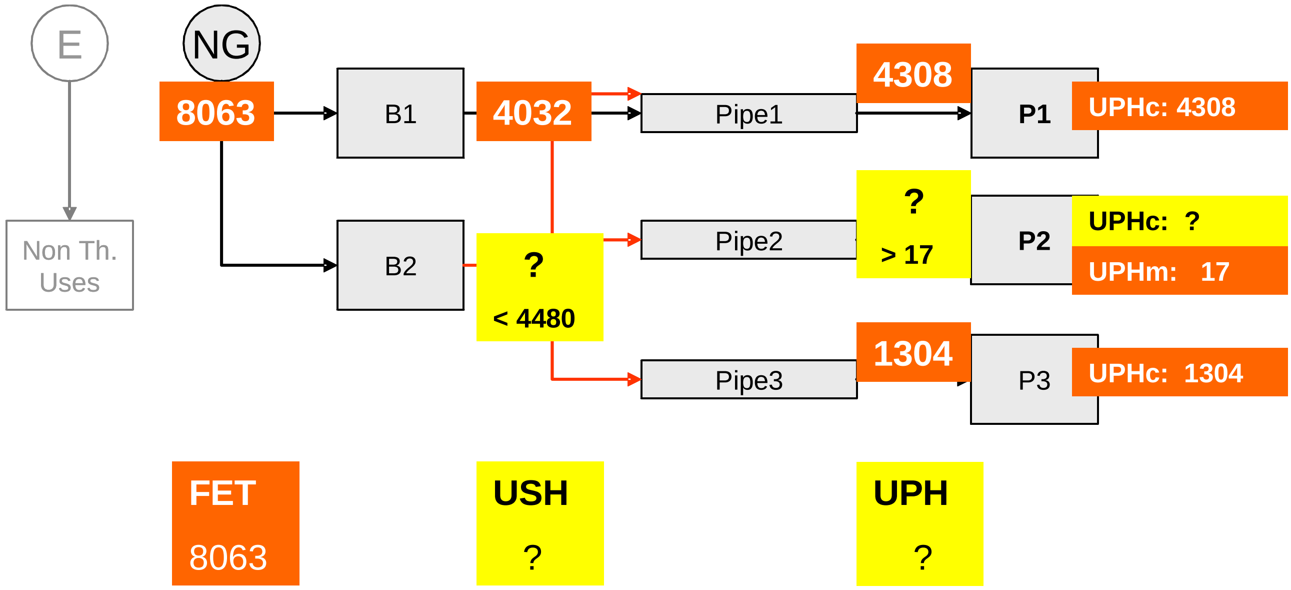


Figure 48: Starting point of analysis: energy consumption unknown for small process (Example project "EINSTEIN Audit Guide 42 2a").

4.2.3.2 Total heat demand is unknown

The problem gets more undetermined, if we do not have any information on the total final energy consumption and also, like in the previous section, the heat demand of process 2 is unknown. But also in this case the problem is *constrained*, as the nominal power of boiler 2 still imposes an absolute maximum.

Now only very rough limits can be given for the process heat demand of process 2 in the range of 1244 MWh still with a very big error of close to 100$.

Nevertheless, the relative uncertainty in the *total* heat demand (*USH*) is much less (8342 MWh ± 32 %). This means, that even with one of the processes' demand completely undetermined, there still can be made a very reasonable first estimate of the total heat demand.

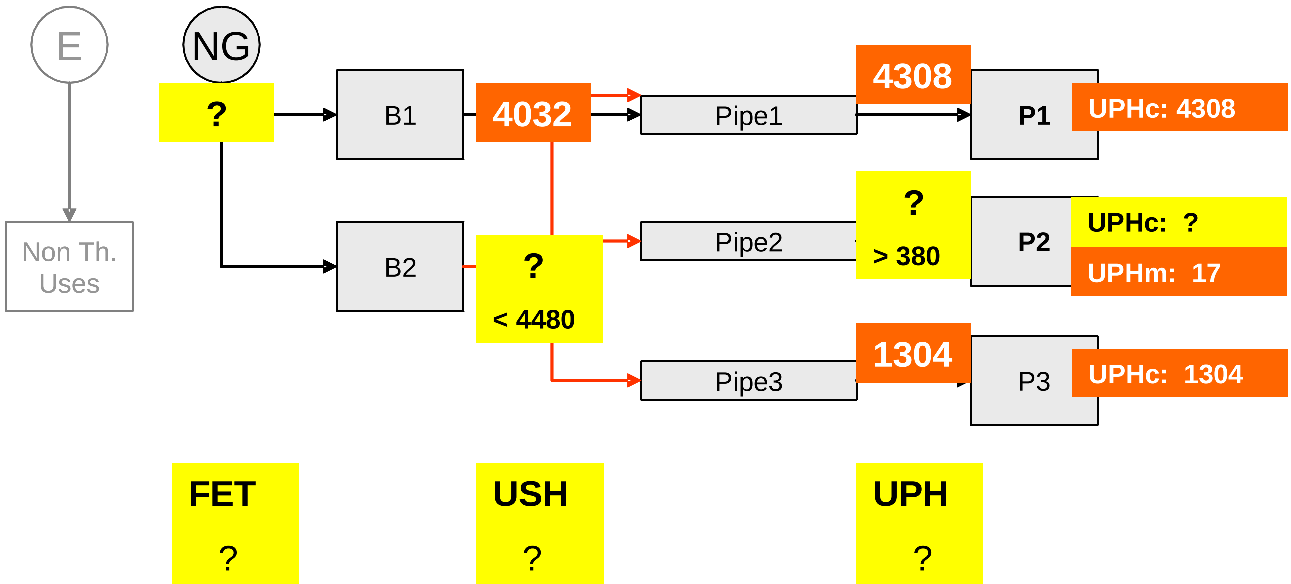


Figure 49: Starting point of analysis: both total energy consumption and energy consumption for a small process unknown (Example project "EINSTEIN Audit Guide 42 2b").

4.2.3.3 Total heat demand and technical data of boilers are unknown

The situation gets completely undetermined, if also the nominal boiler power is unknown, and therefore no reasonable constraint can be made for the process 2 heat demand (Example project “EINSTEIN Audit Guide 42 2c”).

4.2.4 Using data estimates

Some of the results of the examples from the previous section can be improved, if apart of the mathematical relationships (energy balances) also estimations based on engineering knowledge are used.

In our examples this can be for example:

- ✗ it can be supposed that boiler part load factors are in a narrower range than from 0 to 100%, as both extremes are not very likely in practice.

- ✗ Even if data regarding the length of the pipes are missing, at least an order of magnitude can be estimated.

Using the data estimation – option in the EINSTEIN tool this can be done automatically, and in the case of example 2b the process heat demand of the coagulation process (process 2) can be determined with sufficient accuracy (< 30% error) to 745 MWh. Only the circulation heat demand of this process remains still undetermined (due to uncertainty in the mass flow rate of the inflowing process medium): Q_{UPHc} = 737 ± 37 %.

4.3 Heat recovery: Dairy example

A dairy is chosen to serve as project example for the practical use of the heat recovery module.

As a data basis for pinch analysis and heat exchanger network design, the data from the processes is converted to so called *energy streams* that can be either cold (have to be heated up, thus requiring energy demand) or hot (can be cooled down, thus serving as energy source for other processes). These streams are then matched through an algorithm that results in the suggestion of heat exchangers for the system aiming at maximum energy savings over the year.

4.3.1 Flow sheet and process description

The example project is a dairy, in which the most energy intensive processes are the fermenter processes and the evaporation of whey for whey powder production. Figure 50 shows the processes in a flow sheet. Initially cold milk is pasteurised and stored. For cheese production the milk is preheated and added in the fermenter, where hot water at 65℃ is added. Additi onally external heating is supplied to the fermenter. The whey is extracted and, after some cleaning steps, cooled down from about 45℃ to storage temperature. For the evaporation the whey is heated up externally and as a next step enters the evaporation, which is in this case a thermal re-compression evaporator. The whey is dried from about 6% to 60% dry weight within the evaporation process, thus the outgoing whey concentrate is a tenth of the mass of the whey entering the evaporation. The hot condensate collected at 75℃ a nd is the largest waste heat of the process compared to the heat that leaves the process via the hot whey concentrate. The hot concentrate leaves the evaporator and is consequently dried to its final dry mass in a spray dryer.

As the pasteurisation is already well equipped with internal heat exchange, the highest priority for energy savings is seen for the fermenter as well as for the whey evaporation. Therefore only these processes are considered in the following example.

For heat recovery it is important to consider the time schedules of the streams. The following operation schedules are assumed for the project:

- Fermentation: 10 batches per day, each lasting 2 hours, 5 days per week
- Milk preheating: 30 min prior to each batch
- Wash water: 20 min during each batch
- Evaporation: continuous process, 14 hours/day , 5 days per week

4.3.2 Entry of process data in EINSTEIN

In EINSTEIN the following processes are thus defined in the data entry module (Table 18):

Table 18. Summary of the processes in the dairy example.

Process	Process Type	Incoming process stream	Outgoing waste heat	Power supplied to the process during operation
Milk preheating	batch	Milk, 6℃ to 32℃ 180 m³ per day 10 batches	None (hot milk enters fermenter)	none
Wash water preheating	batch	Water, 10 to 65℃ 18 m³ per day 10 batches	None (hot water enters fermenter)	none
Fermenter	batch	Milk, 32℃ to 45℃ 180 m³ per day 10 batches	Hot whey at 45℃, cooled to 8℃ ~ 170 m³ per day	200 kW
Whey evaporation pre-ehating	continuous	Whey, 8℃ to 100℃ 180 m³ per day	Hot condensate 75℃, 140 m³ per day Whey concentrate 50ºC, 28m³ per day	2 400 kW

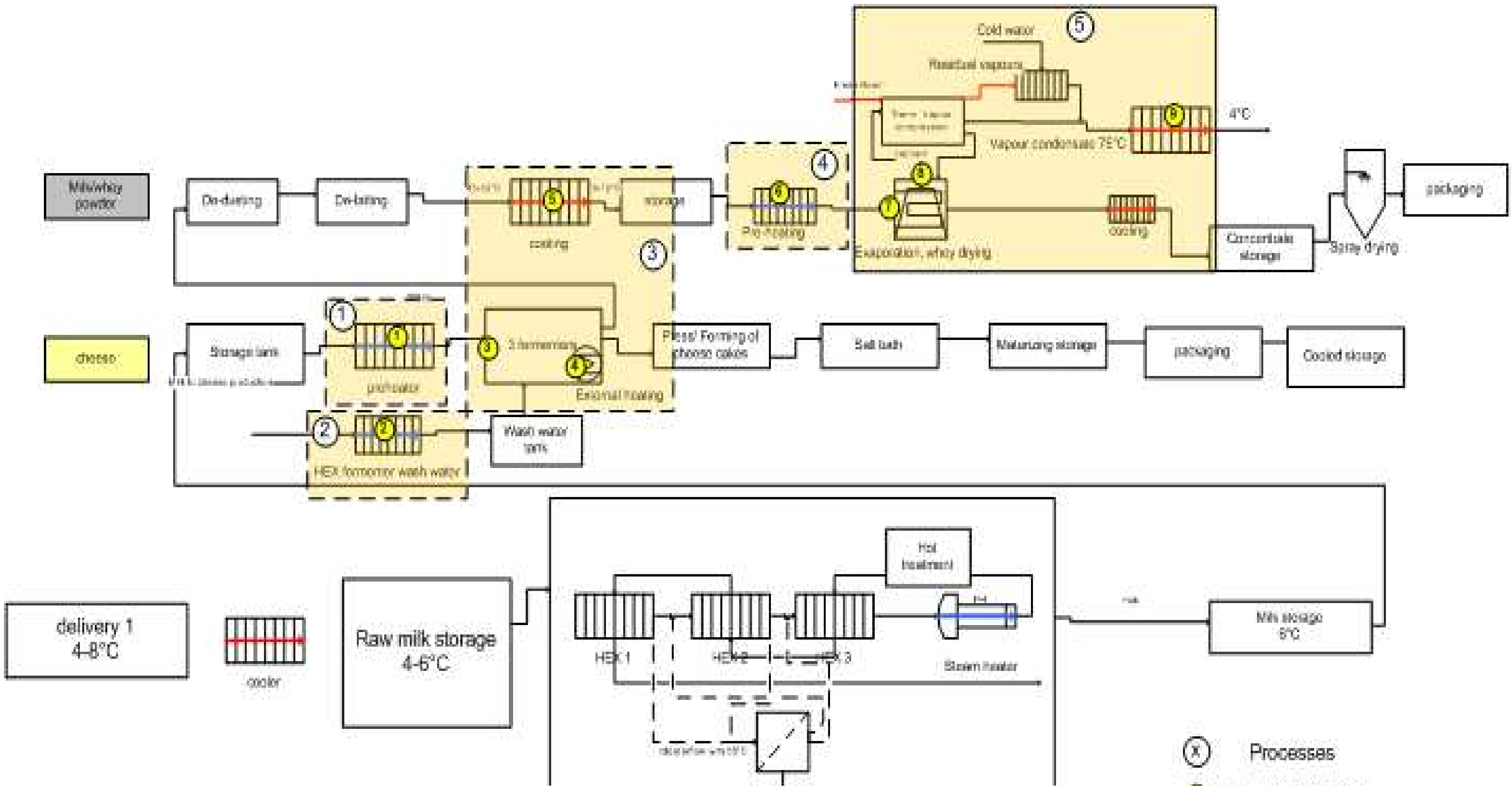


Figure 50: Flowsheet of the cheese and whey powder production of the dairy

4.3.3 Process optimisation

According to the audit methodology and the principle *avoidance before recycling* general saving measures and optimization reached via new / best available technologies should be implemented prior to the considerations on heat integration. In the given project example possibilities to reduce the energy required for evaporation have to be considered, such as reverse osmosis or vacuum evaporation. Reducing the energy demand will reduce the available waste heat at the same time, however lead to a more compact process with overall less energy demand. The applicability of new technologies obviously depends on the process parameters and the willingness of the company to implement such technological changes.

In this example no process optimisation has been included for reasons of simplicity.

4.3.4 Heat recovery calculation

As a first step, the heat recovery calculation generates energy streams based on the process data (Table 19).

Table 19. Energy streams obtained as a result in the calculation:

Stream Nr.	Stream name	description	Start Temperature ℃	End Temperature ℃	Hot/ Cold	Enthalpy kW	Operating hours h/a
1	Milk preheating		6	32	Cold	529	2600
2	Cheese wash water		10	65	Cold	115	780
3	Fermenter start up	Heating milk from 32 to 45℃	32	45	Cold	203	2600
4	Fermenter during operation	Maintaining the temperature at 45℃	45	50 (temperature for maintaining the operating temperature is set 5℃ higher for heat transfer)	Cold	100	5200
5	Fermenter waste heat	Hot whey	45	8	Hot	-753	2600
6	Whey preheating		8	100	Cold	1376	3640
7	Whey evaporation continuous heating	Heating whey further to 100℃	100	100	Cold	2200	3640
8	Condensate from whey evaporation	Hot water generated from condensates	75	4	Hot	-826	3640
9	Whey concentrate from whey evaporation	Whey concentrate leaving the evaporator	50	8	Hot	-98	3640
10	Boiler off gas sensible waste heat	Waste heat in boiler off gas until condensation temperature	140	58	Hot	-138	5200
11	Combustion Air Preheating		25	80	Cold	85	5200

The latent heat of the boiler off-gas at condensation temperature is excluded in this example for simplicity.

The hot and cold composite curves, an addition of all enthalpy/temperature vectors of all cold streams (cold composite curve) and all hot streams (hot composite curve) respectively, show the general possibility for heat exchange.

The large amount of energy needed for evaporation is clearly visible in the cold composite curve. However still, there is a quite large overlap between the available waste heat and the cold streams that have to be heated up. The thermodynamic maximum for heat exchange according to the pinch curves is about 2.400 kW. The pinch temperature is found between 0 and 4℃.

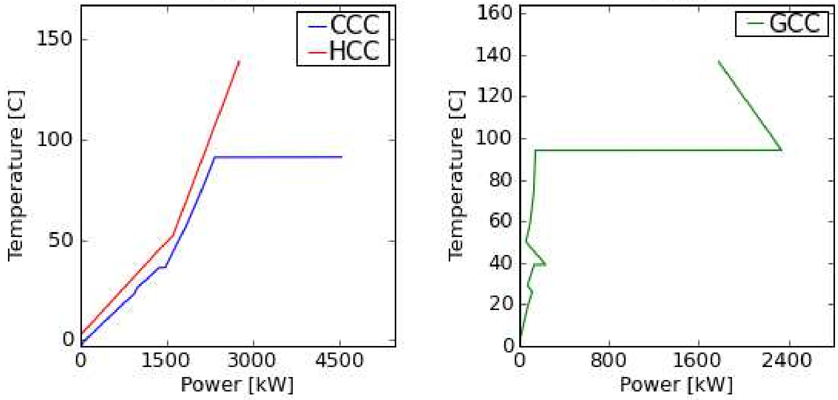


Figure 51: Hot and cold composite curve of the above described process (ΔT_{min} = 5 K)

4.3.5 Results

4.3.5.1 Estimation of heat recovery potential base on pinch analysis

A first estimation of the heat recovery potential can be obtained from pinch analysis by using EINSTEIN estimative mode for heat recovery calculations (Figure 52). The estimated saving potential in useful supply heat is 3.815 MWh.

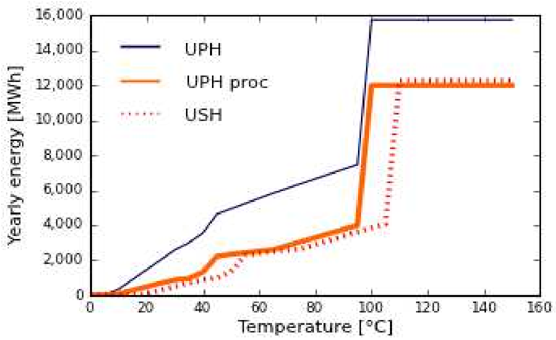


Figure 52: Heat demand before and after heat recovery. Estimation with EINSTEIN (estimate mode).

4.3.5.2 automatic design of heat exchanger network

The algorithm for automatic design of possible heat exchangers within the EINSTEIN software tool takes into account criteria such as suitable temperatures for heat recovery, availability and matching heat capacity flows (m*cp). It is important to know that according to thermodynamic criteria the heat exchanger network above and below pinch are calculated separately. The outcome of the heat exchanger network can depend on a very great extent on small changes in process data that might affect the pinch temperature. The outcome as shown in Table 20 is generated with the default settings for the design assistant:

- Minimal temperature difference = 5K
- Ratio of energy savings to total heat demand > 1%
- Ratio of energy savings to installed heat exchanger power > 200 kWh/kW

The dimensioning of heat exchangers includes the selection of an appropriate heat or cold storage (for the case of non-simultaneous streams). For a correct dimensioning of storage sizes the correct definition of operation time schedules is important (see chapter 2.4.3).

Table 20. Heat exchangers proposed[16]

Heat exchangers	Power	Hot Stream	Thi ℃	Tho ℃	Cold Stream	Tci ℃	Tco ℃	required Storage m³
NewHX Nr.0	529	Fermenter waste heat	45	11	Milk preheating	6	32	11,3
NewHX Nr.1	722	Condensate from whey evaporation	75	13	Whey preheating	8	56	0
NewHX Nr.2	73	Whey evaporation	50	15	Cheese washwater	10	45	1,8
NewHX Nr.3	85	Boiler exhaust gas	140	58	Combustion Air Preheating	25	80	0,7

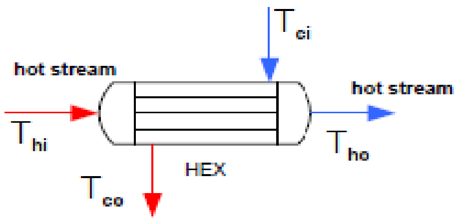


Figure 53: Flows in a heat exchanger

It is obvious to the reader that the waste heat of the evaporation process needs to be well integrated into the demand. EINSTEIN suggests for its use heat exchanger No. 1

From the exergetic point of view, it is sensible using this heat at 75℃ first for heating processes at similar temperature demands. Secondly it is meaningful to use waste heat for preheating streams with similar heat capacity flows (m*cp). This highlights internal heat exchange and ensures that the available temperature difference is used in an ideal way. EINSTEIN suggests to use the hot condensate from the evaporation process to preheat the incoming whey.

The hot whey leaving the fermenter is the second important stream that needs to be integrated in the heat exchanger network. Its use is economically very interesting and its own cooling demand can as well be lowered. This is the case because the whey has to be cooled down for storage. Its use is suggested for preheating the cheese wash water to 32℃. This is a quite common solution found in dairies.

The hot concentrate leaving the evaporator is suggested to preheat the cheese wash water. In comparison with the other heat exchangers its performance is quite low, however it still meets the requirements of the design assistant.

Finally a heat exchanger is suggested to preheat combustion air for the boiler via cooling the exhaust gas of the boiler further down to dew point temperature. The practical possibilities of this measure and the possibility for recovering also the heat of condensation depends on the type of fuel used.

As described above, EINSTEIN offers a first suggestion of a heat exchanger network aiming at maximum energy savings. The heat exchangers given by the automatic design have to be checked according to their technical feasibility depending on regulation, physical distance between energy streams, space required or hygienic aspects.

[16] The results listed in Table 20 correspond to the auto-design in EINSTEIN Version 1.2. Recent updates in heat recovery calculation modules may lead to slightly different results, depending also on the selected heat recovery calculation mode.

On the other hand, it should be checked whether there is still a potential for manual optimisation and fine-tuning of the proposed heat exchanger network. In the given example, the result obtained by the proposed heat exchanger network are savings in useful supply heat of 4.146 MWh, which is already nearly 10% higher than the value suggested by the estimative analysis from the previous section.

Nomenclature

Abbreviations and acronyms

BCR benefit cost ratio
CF cash flow
CST central Supply Temperature
CHP combined heat and power
COP coefficient of performance (ratio of useful heat to input of driving energy)
EHD equivalent heat demand
EEI energy efficiency index
EER energy efficiency ratio (ratio of useful cooling to input of driving energy)
EX net expense of the project
FEC total final energy consumption
FEO final energy consumption for other, non-thermal uses
FET final energy consumption for thermal uses
IRR internal rate of return
LCV lower calorific value
MIRR modified internal rate of return
NPV net present value
PBP payback period
PEC total primary energy consumption
PEO primary energy consumption for other, non-thermal uses
PET primary energy consumption for thermal uses
PSW preheating of Supply Water
PT process temperature
QCX recovered waste cold
QHX recovered waste heat; heat flow over heat exchangers
QWH/C available waste heat/cooling
ST supply Temperature
UPH/C useful process heat/cooling
USH/C useful supply heat/cooling

Symbols

A area
c coefficients of collector efficiency curve
c_p specific heat capacity
d company specific discount rate
E energy
f conversion factor
h specific enthalpy
k thermal conductivity
m mass
N number (e.g. fuels)
Q heat
$\dot{Q}$ heat flow rate
q_m mass flow rate
r real interest rate of external financing
S savings of the project
T temperature
t time
U global coefficient of heat transfer per unit area
α (convection) heat transfer coefficient
η efficiency

Indices

c circulating, condensate
cs central supply; cold stream
e effective
el electric
elgen self-generated electricity
env environment
eq equipment units
Esources energy sources
f final
fue fuels
fw feed-up water
hs heat stream
HX heat recovery heat exchanger
i inlet, incoming, index used for energy source (fuel type, electricity)
j index used for thermal equipment unit
L latent heat (used for evaporation (+), condensation (-), endothermal or exothermal chemical reactions)
m index used for distribution pipes or ducts
o outlet, outgoing
op operating
p process
pi process inlet
pir process inlet after heat recovery
po process otlet
por process outlet after heat recovery
proc process
pt process target
PE primary energy
PS process supply
m maintenance
min minimum
ref reference
ret return
s start-up
tch thermally driven chiller
w waste

Annex: EINSTEIN Basic Questionnaire