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EINSTEIN – Expert System for Thermal Energy Auditing in Industry

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The EINSTEIN methodology and tool-kit for thermal energy auditing in industry and other large consumers of heating and cooling is presented. EINSTEIN has been developed in the Framework of the two European projects EINSTEIN and EINSTEIN-II. The structure of the EINSTEIN tool-kit and the main modules of the are described. The technical key issues forming the backbone of the EINSTEIN methodology are a standard for the definition of temperature levels of demand and supply and a standard for the definition of energy flows and subsystem boundaries. These standards have been documented in the CEN/CENELEC workshop on “Good Practice Thermal Energy Audits (GPTEA).

1. Introduction

For optimising thermal energy supply in industry, a holistic integral approach is required that includes possibilities of demand reduction by heat recovery and process integration, and by an intelligent combination of efficient heat and cold supply technologies.

EINSTEIN (expert-system for an intelligent supply of thermal energy in industry and other large-scale applications) is a tool-kit for fast and high quality thermal energy audits in industry, composed by an audit guide describing the methodology and by a software tool that guides the auditor through all the audit steps (www.einstein-energy.net)

The main features of EINSTEIN are: (1) the data processing is based on standardised models for industrial processes and industrial heat supply systems; (2) special tools allow for fast consistency checking and estimation of missing data, so that already with very few data some first predictions can be made; (3) semi-automatisation: the software tool gives support to decision making for the generation of alternative heat & cold supply proposals, carries out automatically all the necessary calculations, including dynamic simulation of the heat supply system and heat exchanger network, and creates a standard audit report; (4) a basic questionnaire helps for systematic collection of the necessary information with the possibility to acquire data by distance.

The expert system software tool has been developed in the Framework of the European projects EINSTEIN and EINSTEIN-II (EINSTEIN-II, 2012), with the additional support from several national / regional projects in Spain, Catalonia and Austria. In the present paper the main features of the EINSTEIN tool-kit will be presented. Furthermore, some results and conclusions of the experience from 72 energy audits carried out within the EINSTEIN-II project are presented.

2. What is EINSTEIN

2.1 Overview

The EINSTEIN methodology is supported by an expert system software tool that guides the user through the whole auditing procedure spanning from data acquisition, processing and estimation to the design and quantitative (energetic and economic) evaluation of alternative solutions. In practice, EINSTEIN:

- calculates the total thermal energy demand of complex heat and cooling energy consumers, and breaks it down into different components;
- helps to estimate key data. Algorithms for the estimation of missing but relevant information help carry out a preliminary quick assessment based on very little data;
- provides a database on process optimisation possibilities;
- by means of pinch analysis and semi-automatic heat exchanger network design, assesses saving opportunities through heat recovery and process integration;
- based on a reduced heat demand, shows the technical alternatives for the integration of energy efficient and renewable energy supply systems and evaluates them through a dynamic system simulation;
- offers a comprehensive evaluation. The preliminary design of the most promising options also includes the evaluation of environmental impact and economic performance.

The EINSTEIN Software Tool is:

- **Appropriate for both fast and detailed assessments**. Data processing is optimised and allows for quick proposal development.
- **High quality**. The software tool provides quantitative figures on potentially achievable energy and economic savings through refurbished heat supply systems that integrate the most energy efficient technologies (e.g. heat recovery, CHP and renewable energies).
- **A Comprehensive Package**. EINSTEIN combines features from pinch analysis tools to system simulation tools for specific technologies within one comprehensive package. So, a detailed simulation of complex systems is possible, combining different supply technologies and heat exchanger networks, even for users that are not familiar with sophisticated system simulation tools.
- **Reliable**. The data processing includes a completeness and consistency check procedure to detect inconsistencies and missing data.
- **Proven in Auditing Practice**. EINSTEIN has been used successfully for energy audits by project partners from international consortia in more than 200 industrial and non-industrial facilities.
- **Free and open source**. Everyone can freely download, use and modify the standard version of the EINSTEIN software tool under the GNU GPL licence. Users can also contribute to its development and share their experience with the EINSTEIN community.

2.2 Modules of the EINSTEIN software tool

2.2.1 Data Acquisition and Analysis Module

The EINSTEIN software tool contains a questionnaire for structured and systematic data acquisition. Entered data is automatically checked for consistency. A procedure for estimation of non-available data is included. Using a benchmarking database, the current energy consumption of the company is compared with the typical standard values of similar companies or processes.

The tool automatically generates a breakdown of the total energy consumption and supply by processes, utilities, temperature levels and time, both in graphical and in table format.

2.2.2 Process Optimisation Module

As a first step after data acquisition and analysis, the process optimisation module shows the variety of options to reduce process heat and cooling consumption at its origin by selection of efficient process equipment and procedures. The module provides information on best available technologies for important unit operations (e.g. washing, drying, sterilisation etc.).

2.2.3 Heat Recovery Module

The heat recovery module helps in designing and optimising an appropriate heat exchanger network for heat recovery and process integration. For this purpose, EINSTEIN analyses process and utility streams as well as available waste heat, and identifies the potential for heat recovery by pinch analysis. It takes into account energy demand and availability including the time schedules of processes.

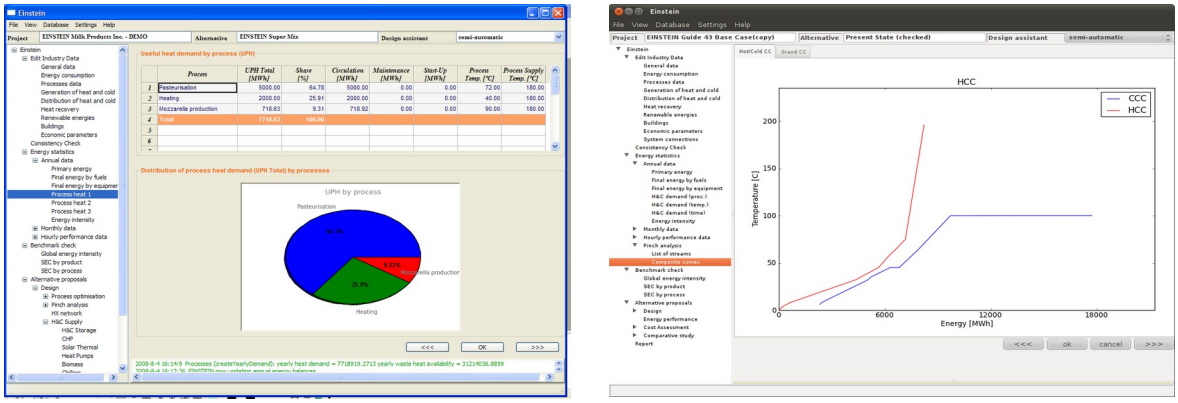


Figure 1: (a) Breakdown of present state energy consumption: process heat demand by processes; (b) Pinch analysis: hot and cold composite curve.

2.2.4 Energy Supply & Renewables Module

The heat and cooling energy supply modules help to select and design the most appropriate energy supply equipment and distribution systems. EINSTEIN analyses the following supply-options: combined heat and power, heat pumps, solar thermal systems and biomass, efficient chillers, boilers and burners.

2.2.5 Simulation and Evaluation Module

EINSTEIN performs a dynamic system simulation (calculations on hourly basis) of the entire system (processes, distribution, heat exchanger network and supply utilities).

Based on the resulting energy performance data an economic and financial evaluation is carried out. This analysis may be based on all parameters that influence the economic performance such as investment costs and depreciation, energy costs (fuels and electricity), operation and maintenance costs, and a lot of other cost concepts such as fees for legal requirements, income from sales of substituted equipment, etc.

As a result of financial analysis the user gets synthetic data on economic performance such as required investment, rate of return (IRR), pay-back and net present value (NPV).

2.2.6 Reporting Module

EINSTEIN automatically creates an exhaustive audit report that summarises the main results of the analysis on both the present state and the energy saving alternatives. The report (a spreadsheet in open document format) can be edited, printed and delivered to the audited company.

3. Technical key-issues addressed by EINSTEIN

In order to quantify energy flows (demand and supply) in general, and under the specific consideration of the associated temperature level (associated quality), it is necessary to recur to a clear definition of the terms used, and specially the sub-system boundaries, to the reference temperatures used for assigning energy quantities to real flows of heat transport media, and to the definition of which temperature is used as quality attribute for which energy flow. Based on the experiences gained in the development of the EINSTEIN approach, EINSTEIN developed conventions of energy flows, sub-system boundaries, definition of temperature levels in view of quantity and quality, and temperature levels as quality attributes of energy flows. Such a consistent and unique system of definitions (or accountancy scheme) is particularly important when it comes to exchange and compare results. The EINSTEIN standards are documented in the EINSTEIN Audit Guide (Schweiger et al., 2012) and in the CEN/CENELEC workshop agreement GPTEA (CEN/CENELEC 2012).

3.1 Quantity and quality: Definition of temperature levels for heating and cooling demands and 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.

The temperatures in the processes and the heat supply systems must be distinguished as to their allocation in the system.

3.1.1 Process Temperature

The temperature of the working fluid (process medium) in a process is the process temperature (e.g. temperature of the water in washing processes, temperature of air in drying processes, required indoor temperature for space heating or cooling, chamber (air) temperature in cooling chambers

3.1.2 Process Supply Temperature

The process supply temperature (PST) is the temperature of the (heat or cooling) supply medium used for heating or cooling of the process at the boundary of the process (process heat exchanger or direct connection without heat exchanger; e.g.: steam temperature of a water bath that is indirectly heated with steam, via heat exchanger; chilled water temperature in a cooling chamber that is indirectly cooled via fan-coil; hot air introduced into a drying chamber). The PST can be distinguished into PST in the current system (the one used in the currently installed and operating system) and a required minimum process supply temperture (PST_{min}).

PST_{min} is the minimum temperature needed in case of applying state-of-the-art good practice. In the case that a direct supply of the (heated or cooled) process medium is possible, PST_{min} is identical to the process temperature. If indirect heating via heat exchangers is required, good practice is defined as:

$$PST_{\min} = PT + / - \Delta T_{\min}$$

where the + sign applies to heating and the – sign applies to cooling. $\Delta T_{\min}$ depends on the type of heat exchange and specific process requirements (e.g., fast heating or cooling required; limited space).

3.1.3 Central Supply Temperature

The central supply temperature (CST) is the temperature of the (heat or cooling) supply medium used for heating or cooling of the process at the boundary of the conversion equipment (e.g. boiler or chiller house; e.g.: steam temperature measured at the steam boiler; chilled water temperature at the chiller). Like in the case of PST, CST can be distinguished into CST (current system) and the minimum required value $CST_{\min}$.

In the case of decentralised heat or cooling generation (e. g. direct combustion in ovens, electrical resistance heaters in water tanks) CST is considered identical to PST.

3.2 Definition of energy flows and subsystem-boundaries

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): LCV of the fuel consumption, heat and electricity consumption (for thermal use).
- Useful supply heat and cooling (USH and USC): heat or cooling generated in the heat or cold supply system (e.g. boilers, burners, and 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 and cooling (UPH and UPC): heat or cooling delivered to a process (measured at the entrance of the process heat exchanger).

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

If in addition the different flows of waste heat or waste cold are also considered, the scheme of energy flows is becoming more complex (Figure 2). The *available waste heat* (QWH) is an energy flow produced by any of the subsystems (supply, distribution, processes, others) that is not the main output of that system, or in other words, whose associated energy is not accounted for within the concept of USH/USC (e.g.: 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). Analogously, there can be QWC, e. g. cold exhaust air from an air conditioned space. The *recovered waste heat* (QHX or QCX) is 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; e.g.: 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).

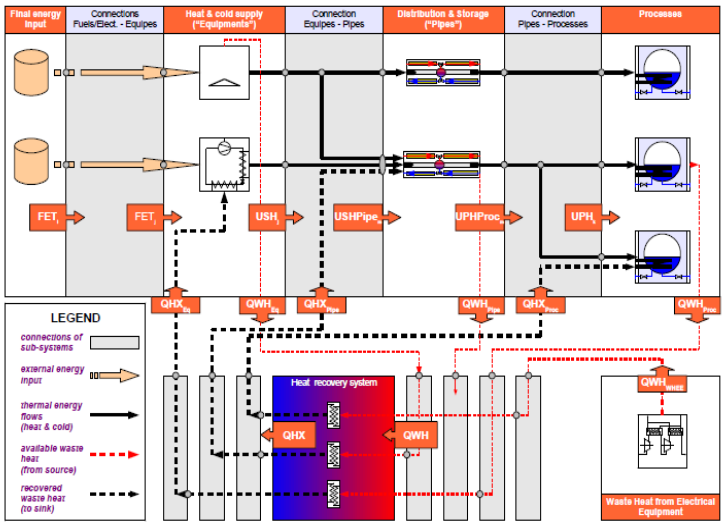


Figure 2. EINSTEIN definitions in a heat supply system with heat recovery (analogous for cooling supply system)

4. Some results of the EINSTEIN-II project

4.1 Energy audits

Of the 72 audits conducted with the EINSTEIN methodology within the European project EINSTEIN-II (EINSTEIN-II, 2012), 67 companies were evaluated in detail (some data was missing for the other 5).The total primary energy consumption of those companies in present state was 1,370 GWh including as main energy carriers natural gas with 617 GWh (45%) and electricity with 701 GWh (51%). The total energy costs were 45.4 million EUR. The proposed measures from the EINSTEIN audit reports would save 259 GWh or 19% of total primary energy consumption. 33 of the energy audit reports recommended measures leading to primary energy savings between 6.2% and 30% (see Figure 1). Heat recovery and combinations of CHP or solar thermal and heat recovery accounted for the bulk of proposed saving measures. The gas consumption would increase by approximately 20%. The electricity consumption would be reduced by 52%. This is due to the fact that, particularly for the bigger plants, combined heat and power plants were suggested which would produce electricity (and deliver the electricity sometimes to the grid) but also would need additional gas.

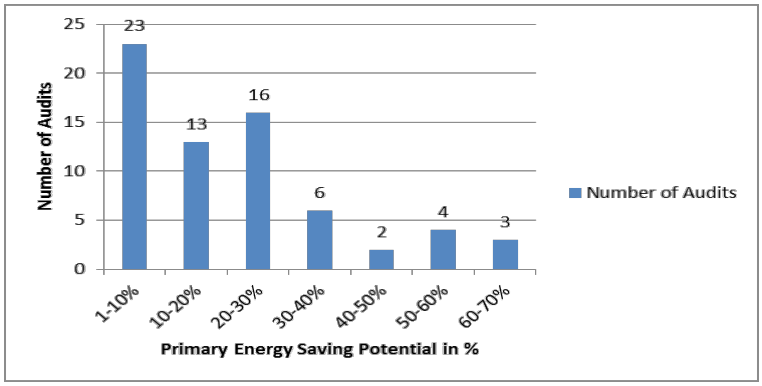


Figure 3: Number of audits as a function of primary energy saving potential

4.2 Trainings for energy auditors

A standard training programme on the EINSTEIN methodology has been developed. This training programme consists of introductory and advanced training courses, together with the possibility for trainees to carry out a project work and obtain certification as an EINSTEIN energy auditor.

The *EINSTEIN introductory course* (21 hours of lecture/practice) is dedicated to the EINSTEIN methodology and software tool application. The content for the introductory training course includes an overview of both the methodology and the software tool itself. Trainees are brought through the individual modules and main features of the tool. Significant time is dedicated to students using the software tool in practice, through a series of examples. At the end of the introductory course, trainees should be in a position to carry out simple audits using the tool on their own. Once trainees have completed the introductory course they can then go on to the *advanced EINSTEIN training course* (14 hours of lecture/practice). This course gives trainees the opportunity to deepen their knowledge of the possibilities offered by the EINSTEIN methodology. At the end of the training activities, successful trainees, who receive a positive evaluation of their project work (about 100 hours of homework) performed applying the EINSTEIN methodology, obtain the final certificate certificate as an EINSTEIN energy auditor.

Since 2007, introductory and advanced training courses on EINSTEIN, for energy auditors have taken place in Austria, Bulgaria, Czech Republic, France, Germany, Ireland, Italy, Luxembourg, Poland, Slovakia, Spain and the UK. The contact details of certified EINSTEIN energy auditors are listed at the project website.

5. Conclusions

With the EINSTEIN methodology and tool-kit a very versatile and comprehensive tool is available that allows for carrying out thermal energy auditing and system optimisation in an efficient and standardised way.
The methodology has been successfully applied in more than 200 energy audits around Europe and more than 500 energy auditors have been trained in its use.
As one of the main results of a large number of energy audits carried out it can be stated that there is still a very large potential for improvement of energy efficiency in the industrial sector, with potential primary energy savings of more than 20% in many cases.

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