EINSTEIN – Expert system for an Intelligent Supply of Thermal Energy in Industry. Audit methodology and software tool

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Abstract
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 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.

The main features of EINSTEIN are: (1) a basic questionnaire helps for systematic collection of the necessary information with the possibility to acquire data by distance; (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) the data processing is based on standardised models for industrial processes and industrial heat supply systems; (4) semi-automatization: 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 creates a standard audit report.

The software tool includes modules for benchmarking, automatic design of heat exchanger networks, and design assistants for the heat and cold supply system.

The core of the expert system software tool is available for free, as an open source software project. This type of software development has shown to be very efficient for dissemination of knowledge and for the continuous maintenance and improvement thanks to user contributions.

Introduction
The *EINSTEIN methodology for thermal energy audit* that is described in this paper has been developed in the framework of the European (Intelligent Energy Europe - IEE) project EINSTEIN (www.iee-einstein.org). This project has been the result of the previous collaboration of the project partners *Joanneum Research (Austria)*, *Sapienza University of Rome (Italy)* 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 (5^{th} Framework Programme) project POSHIP (The Potential of Solar Heat for Industrial Processes) and of the Austrian national project PROMISE (Produzieren mit Sonnenenergie).

Based on the practical experience of a large number of energy audits in different industrial sectors, 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. For the development of this methodology, also a detailed screening of the available methodologies and tools has been carried out, that is available for the public on the EINSTEIN project web page (Vannoni et al., 2008).

Furthermore several tools have been developed that allow for a fast access to the required information and for a semi-automatization 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 project 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 industry, and that the present version can be continuously enriched with new experiences and contributions from the community.

In November 2008 and March 2009, about 250 energy auditors in 7 countries have been trained on EINSTEIN, and some of them currently are elaborating 90 thermal energy audits in industries of the food and beverage, wood processing and metal surface treatment sectors in Austria, Czech Republic, Italy, Poland, Slovenia and Spain. The results of this audit campaign will be available in August 2009 at the end of the IEE-EINSTEIN project.

EINSTEIN thermal audit methodology – the basic ideas

THERMAL ENERGY IN INDUSTRY

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 and 21% of the CO2 emissions in Europe[2]. 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 reasons, such as lack of knowledge, high costs or little reliability of / trust in energy audits, etc. 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.

AREAS OF APPLICATION – INDUSTRIAL AND NON-INDUSTRIAL USERS

The EINSTEIN thermal audit methodology focuses on industries with a high thermal energy (heat and cold) demand in low and medium temperature ranges up to 400ºC, such as food and beverage industry, metal surface treatment, wood processing industry and many other industrial sectors (paper, chemical, pharmaceutical, textile, 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.

Even if the EINSTEIN methodology is focused on *industrial* heat and cold demand, a big part of the developed methodology can also be applied to other medium and large scale consumers of heat and cold, such as:

- district heating and cooling networks, including also the integration of demands in form of centralised generation of power and heat for industrial areas or networks with industrial and non-industrial users
- buildings in the tertiary sector, such as large office buildings, malls, commercial centers, hotels, hospitals, convention centres, schools, spas, etc.
- other installations consuming thermal energy, such as seawater desalination, plants for water treatment, etc.

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, cogeneration, heat pumps), **including** the use of **renewable energies** (especially relevant for thermal use are biomass and solar thermal energy); and the consideration of the given economic constraints.

THE EINSTEIN TOOL-KIT

The EINSTEIN tool kit 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, de-

1. English, Czech, German, Italian, Polish, Slovenian, Spanish

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 CO2

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).

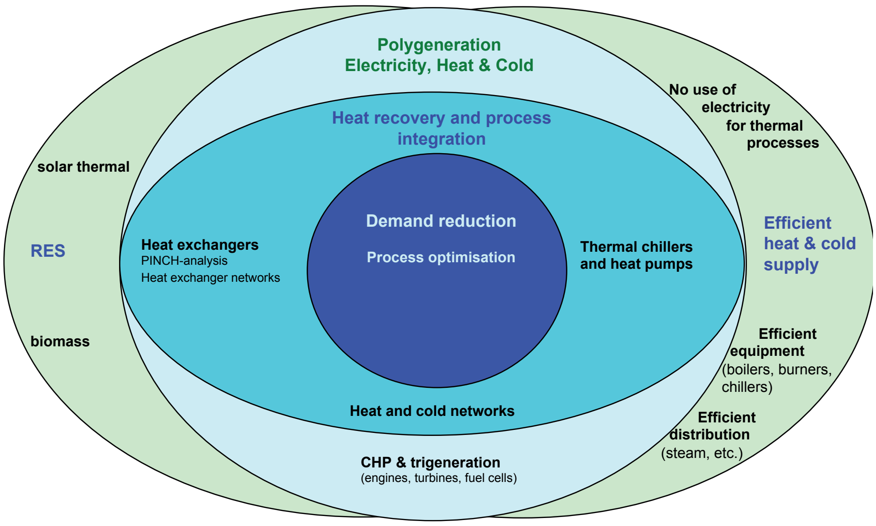

Figure 1: Holistic approach for thermal energy audits ("the view with EINSTEIN's eye"), combining demand reduction, heat recovery and process integration and an intelligent combination of supply technologies.

sign 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 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 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 the present guide for thermal energy auditing with recommendations and best practices, make the tool-kit accessible also for non-expert users.

The advantages of the EINSTEIN audit procedure

In contrast to many aspects of industrial electricity consumption such as pumps, motors, 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 SME's 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 is in contrast 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:

- **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 based on the template for data collection that allows data collection in situ and, if the case, it can be easily completed by means of telephone calls.
- **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 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 uncompleted, frag-

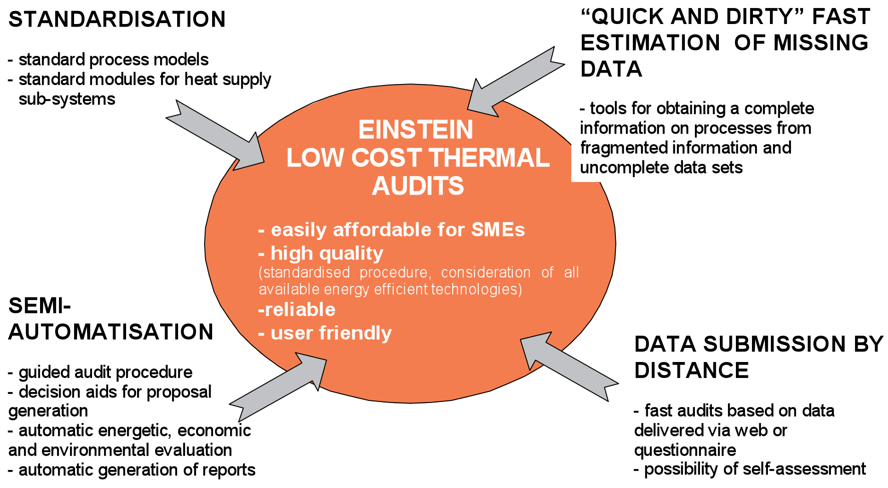

Figure 2: Overview of the EINSTEIN thermal auditing functions for obtaining fast and cheap, but high quality thermal energy audits

mented, and sometimes only qualitative – information collected in the visits and interviews with the technical staff in a company. The 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, 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 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 by distance

The EINSTEIN questionnaire for data acquisition is available in both an electronic version, forming part of the software tool, and in a spreadsheet version that can be filled in either directly (electronically) or printed out, filled in manually and sent by fax.

The questionnaire contains sheets on: general data of the industry (administrative data, production volume, etc.); total energy consumption; details on processes; system for energy supply and distribution; existing heat recovery; data relevant for the use of renewable energies (surface areas, biomass availability, etc.); buildings; economic and financial parameters.

The set of data in this questionnaire is just the minimum necessary and sufficient for realising a standard EINSTEIN thermal energy audit in the company. But the submission of data does not have to be complete. In many cases already with only about 10% of this information it is possible to do a rather accurate first fast assessment. E.g. in some cases it is sufficient to know the details of the most energy consuming process in an industry, whereas for the processes with minor energy consumption some basic information is sufficient.

Data acquisition in EINSTEIN in the present version is conceived as a snapshot at a certain time, with the objective of structural improvements (before/after implementation of energy efficiency measures). Consideration of continuous monitoring and controlling is a possible extension of the concept to be included in future versions.

"Quick and dirty" fast estimation of missing data

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.

There are often several ways to determine the same information. Some examples for this are:

- 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 the energy consumption is obtained using the fuel's LCV.
- 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.

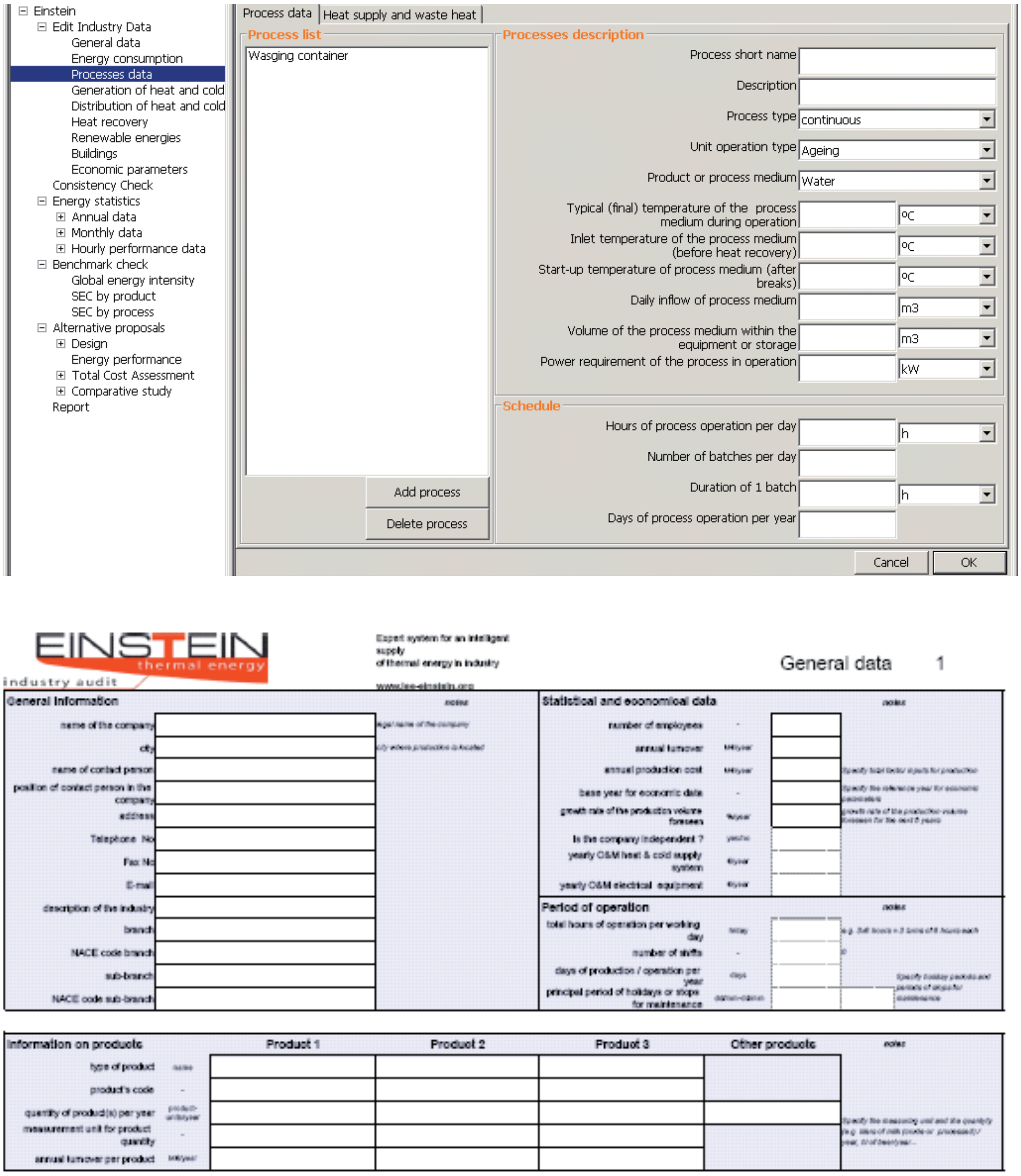

Figure 3. (left) electronic questionnaire in the EINSTEIN software tool; (right) printable spreadsheet.

In gathering data on the status-quo (present state energy demand, etc.) one 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, one has two or more different ways to determine or to calculate the same parameter. If the different ways lead to the same result, it is fine: this just gives 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 the problem of selection arises (which is the right one, which the wrong one ?) and – whatever one decides - as a consequence of the uncertainty one may doubt of both.
- *Lack of information.* One may not have all the detail information available that one would like to have for a detail calculation. E.g. one 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 lengthy task. In general there are 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 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.
- *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 something like 0.7 ... 0.95 might be considered as a practical limit for non-condensing boilers. Similar reasoning can 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 something like 3 – 5 K for liquid to liquid heat exchangers, and 10 K for liquid to air or air to air heat exchangers. Similar reasoning can be applied for the difference between forward and return temperatures in fluid circuits.
- *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 and the total surface heat loss coefficient, 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 equipments 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 judgment (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, the EINSTEIN methodology distinguishes 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. Nevertheless these automatic features, the tool has to be used by a skilled auditor able to understand the messages produced by the tool and correct data if necessary.

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.

In this case data can be estimated using a *range of typical values* given by engineering knowledge. With the help of these "typical values" most of the data gaps that still exist can be completed, but one has to be aware that these *estimates* may be based on *assumptions* that not necessarily coincide with reality.

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:

- <u>Level 1: Quick&Dirty analysis:</u> For this level it is sufficient to know with a certain minimum accuracy the energy consumption and the main temperature level of the most energy consuming processes in the company.
- <u>Level 2: EINSTEIN standard level of analysis:</u> at least the following parameters should be known with the minimum level of accuracy: the 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; and the waste heat streams from the main energy consuming processes.
- <u>Level 3: detailed analysis:</u> at least the full set of information as given by the EINSTEIN basic questionnaire should be available with the required accuracy.

It is difficult to assess the gains in quality using a lower or a higher level of accuracy, as these depend strongly on the specific cases, and up to now it has not been possible to do a systematic study on this topic. Level 2 is strongly recommended, if the solutions to be adopted are sensitive on the distribution of the heat demand by temperature levels. Level 3 in addition

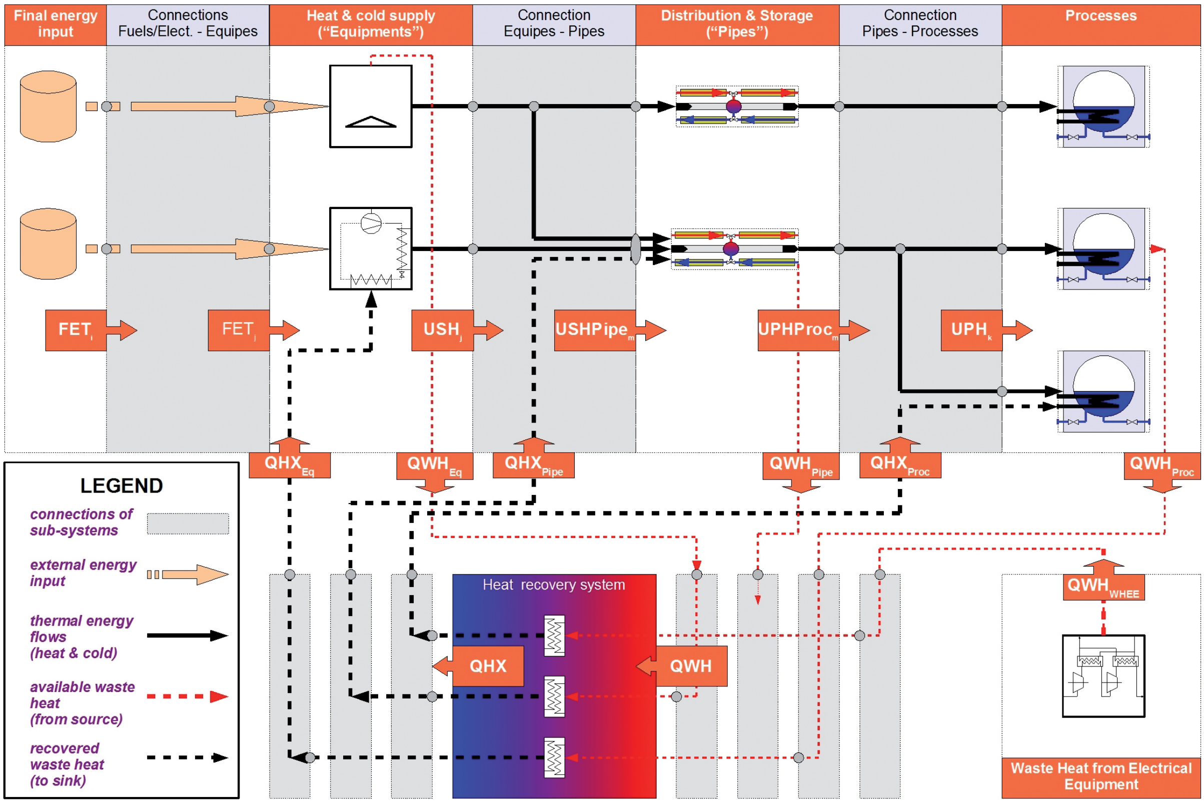

Figure 4: EINSTEIN scheme of energy flows in an industrial heat supply system with heat recovery

includes a more detailed analysis of the time schedules of the different processes.

COMPARISON WITH BENCHMARKS

Benchmarking refers to a structured process of comparing and analyzing 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}.

A basic database with several benchmark data is included in the EINSTEIN distribution, and additional values can be added by the user.

Standardization

SCHEME OF ENERGY FLOWS WITHIN EINSTEIN

The accountancy of all energy flows within the system is done based on the standard EINSTEIN energy accountancy system (Figure 4) that sets clear rules on where to draw the boundaries between the different subsystems. The energy supply system is mainly subdivided in the blocks final energy inputs, supply equipment, distribution, processes and heat recovery. This standard helps for organising the available information in a structured way, and is absolutely necessary for automatic data processing.

THE EINSTEIN PROCESS MODEL

Processes in EINSTEIN are modelled using a standard process model as described initially in Schweiger et al., 2001 (Figure 5). Most processes require both heating of a fluid stream (e.g. hot air streams, hot water, renovation of water in baths ...) and heating of some reservoir (ovens, liquid baths). The latter can be subdivided into pre-heating before the start of operation and into maintenance of temperature (compensation of thermal losses during operation). This disaggregation of the process heat demand is essential in order to assess the temperature distribution and time dependency of the required heat.

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

a) Circulation heat (UPHc)

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

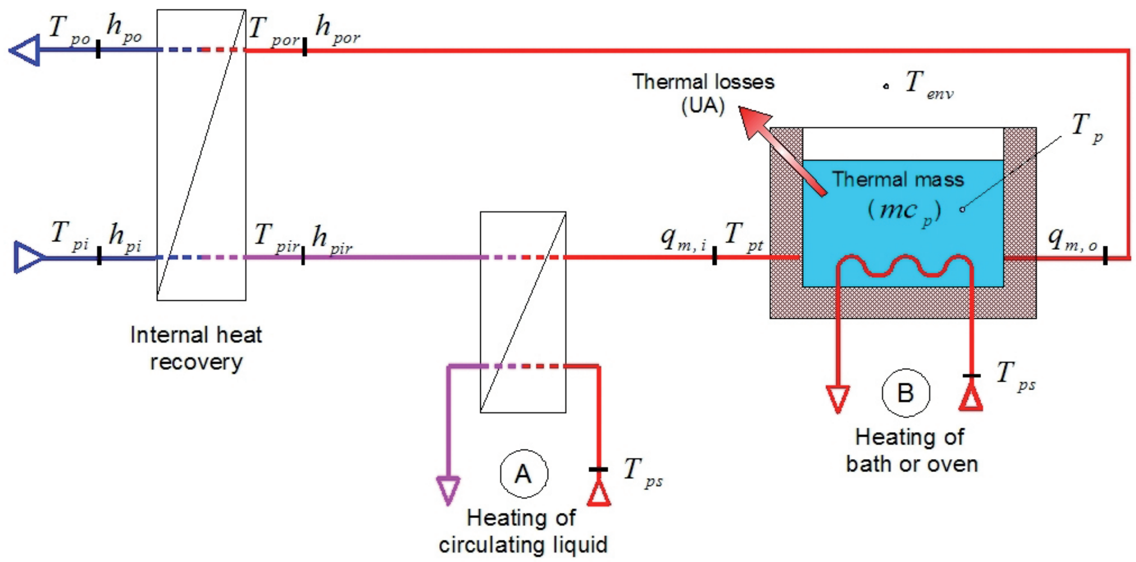

Figure 5: Standard EINSTEIN process model with one incoming and one outgoing stream

$$Q^{gross}_{UPH,c} = m_c c_p \left(T_p - T_{pi}\right) \quad (1)$$

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:

$$Q_{UPH,c} = Q^{gross}_{UPH,c} - Q_{HX,internal} = m_c c_p \left(T_p - T_{pir}\right) \quad (2)$$

b) Initial heating at start-up (UPHs)

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 nighttime or over week-end; breaks between different batches. etc.):

$$Q_{UPH,s} = N_s \left(mc_p\right)_e \left(T_p - T_s\right) \quad (3)$$

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 (UPHm)

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.

$$Q_{UPH,m} = \left[(UA)\left(T_p - T_{env}\right) + \dot{Q}_L\right] t_{op} \quad (4)$$

where (UA) is the termal 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:

$$Q_{UPH} = Q_{UPH,c} + Q_{UPH,m} + Q_{UPH,s} \quad (5)$$

THE STANDARD EINSTEIN AUDIT METHODOLOGY

The EINSTEIN thermal energy audit and design of improved energy systems is based on a standard EINSTEIN audit methodology subdivided in 4 phases and 10 audit steps (Figure 6).

The audit begins outside the company with few quick preliminary activities that can be done in the office. The so called "**pre-audit**" phase is very important because it allows the auditor to improve his/her 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, data can be collected already by distance for a first rough evaluation of the energy demand, and of the areas of potential improvements. This preliminary phase is simple, quick but fundamental to save time afterwards: to prepare the company and the auditor for the **on-site energy audit.**

This second phase (**walk-through audit**) includes two implementation steps: an on – site walk – through visit to the company and an analysis on-site 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 miss-

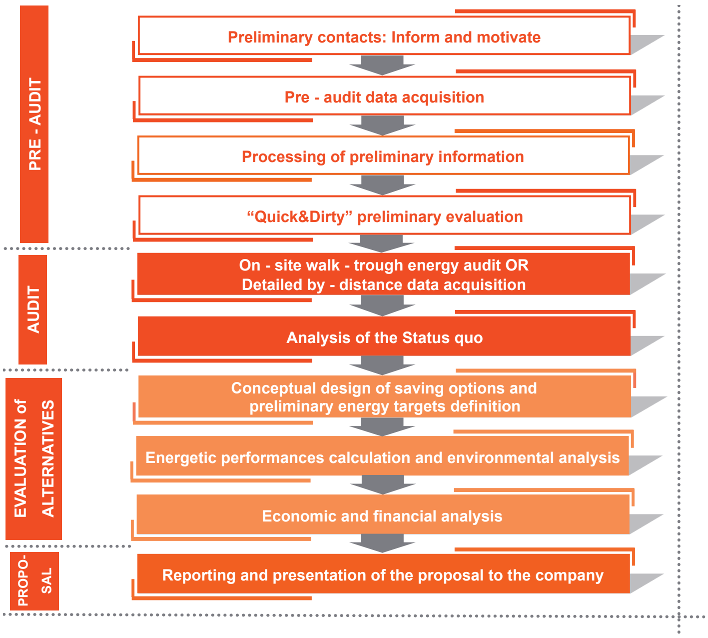

Figure 6. EINSTEIN's ten steps towards energy efficiency

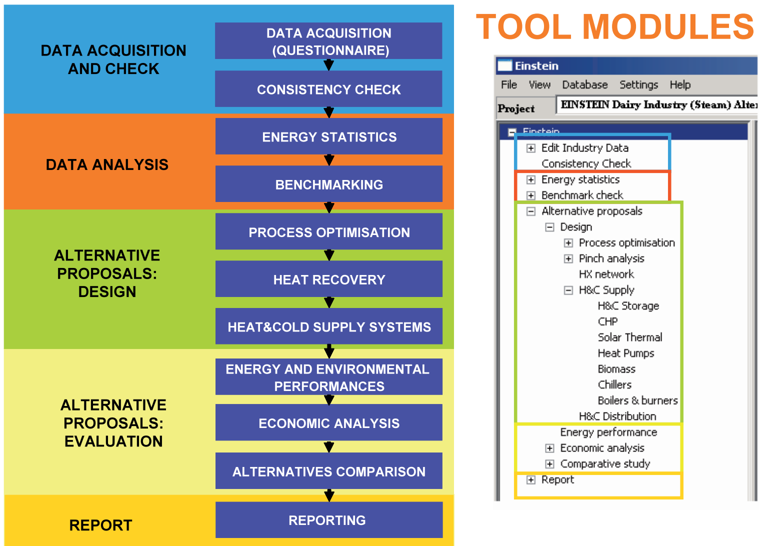

Figure 7. Main functions of the EINSTEIN software tool and their representation in the menu tree.

ing, 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 time.

Back to the office, with the help of EINSTEIN the auditor will be able to check the consistency and completeness of the data acquired; estimate (re-call for) the figures that are still missing; elaborate a detailed breakdown of the heat consumption by process, temperature levels, fuels, etc.; analyse the real operation performance of existing equipments; benchmarking.

Once the auditor has a clear picture of the actual energy flows and inefficiencies of the company, she/he can count on EINSTEIN also for the implementation of the third phase of this auditing procedure: **the design and evaluation of energy efficient alternatives:** 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, there is all the information available required to perform a clear and effective presentation of the results of the audit. **Reporting** with EINSTEIN (the fourth auditing phase) is easy for the auditor and convincing for the costumer.

The four phases of an EINSTEIN energy audit can be subdivided into 10 EINSTEIN **audit steps** shown in Figure 6. Each of these audit steps is described in detail the in the EINSTEIN audit guide (Schweiger et al. 2008). For each audit step the different tasks are described of which it is composed, the indications are given how to carry out each of these tasks, and which of the tools from the EINSTEIN tool-kit can be used.

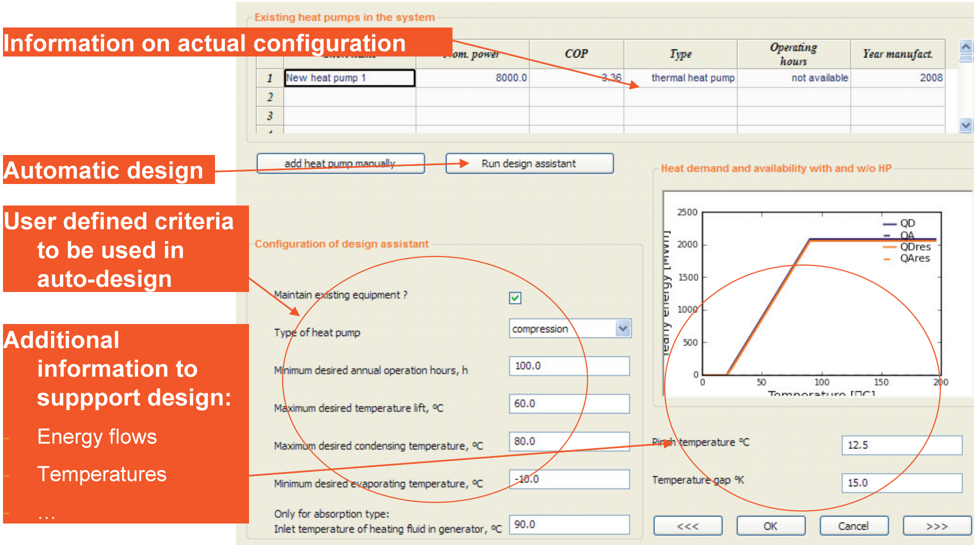

Figure 8. Example of a design assistant for the pre-design of an alternative heat supply system.

THE EINSTEIN SOFTWARE TOOL

Very important for both standardisation and automatization of the audit procedure is the use of the EINSTEIN sofware tool, that includes the following modules:

a. Module 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 a matrix with information on best practice and benchmarks helps to evaluate the state-of-the-art in the company.

b. Module 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. Module for the energetic, economic and environmental evaluation of the new proposal: The energetic performance of the system is determined by a simplified system simulation module. Based on the energetic performance, an economic and environmental evaluation is automatically generated by the *total cost analysis* (TCA) module.

d. Module 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.

Semi-automatization

DECISION SUPPORT FOR THE DESIGN OF SAVING OPTIONS

As already outlined above (**Figure 1**), the systematic analysis of the energy saving potential requires the following steps: reduction of process heat demand by process optimisation; reduction of required heat 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

The EINSTEIN software tool allows for carrying out the system design semi-automatically, based on the so-called **design assistants** (**Figure 8**) that give decision support, and – depending on the configuration of the tool chosen by the user – may even create alternative proposals fully automatically.

The design assistants are based on several data bases that contain technical and economical information on available equipment, such as boilers, CHP, chillers, heat pumps, solar systems, heat exchangers, etc.

Automatic heat exchanger network design

The EINSTEIN tool automatically carries out a determination of the heat recovery potential (*pinch analysis*) of the entire industry (based on the different components of heat demand and available waste heat, the so-called "hot and cold streams"). The heat recovery module furthermore allows for a fully automatic design of an optimised heat exchanger network.

Design of alternative supply system options

An alternative heat supply option or proposal is an alternative set of heat 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 this alternative system involves the selection of the appropriate equipment, and the evaluation of its energy performance considering the heat 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 temperature level of the remaining heat demand (after heat recovery); the quantity of heat demand and waste heat availability; the temporal distribution of heat demand and waste heat availability; the availability of space and the availability of alternative energy sources and their cost (biomass, etc.).

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 mostly 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". In the present version, this step has still 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.

Energy performance calculations

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

The internal energy performance calculation in EINSTEIN is based on the *aggregate* heat demand and the potential output of the supply equipment in the cascade. The calculations in the EINSTEIN tool are carried out by default in one hour 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.

For a more detailed and accurate calculation external system simulation software can be used. At present, within the framework of a national project an interface to a solar thermal system simulation tool is being developed.

Environmental analysis

EINSTEIN uses the following parameters as main indicators for the environmental assessment:

- *Primary energy consumption* as the basic indicator for environmental assessment
- *Generation of* CO_2
- *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 EINSTEIN's 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. [4]

THE EINSTEIN AUTO-PILOT

For purposes of a very fast "quick-and-dirty" preliminary analysis, EINSTEIN disposes of the so-called "auto-pilot", this is a fully automatic mode of running the full audit procedure from data checking to proposal generation and evaluation. Automatically a set of standard technological options is proposed as possible alternative to the existing system.

REPORTING AND PRESENTATION

Once concluded the audit, an *audit report* is written fully automatically by the EINSTEIN software tool. This report is produced as a spreadsheet (OpenOffice) that can be edited and modified, adding manually additional content, etc.

The standard audit report contains the following information:

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

4. Other emissions, such as NOx, SO2 or other greenhouse gases are not yet included, although they might be added in future versions of the tool.

- 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 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. The description of the alternative proposals can optionally 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

EINSTEIN as a collaborative project

Free and open source software

EINSTEIN is a *free and open source software* project under GNU/GPL v3 license (GNU 2008). The tool, including all the source code can be downloaded at www.sourceforge.net/projects/einstein**.** EINSTEIN is built using open source components: *Python* as main programming language, including some python libraries, and *MySQL* as data base server. EINSTEIN is platform independent and can run on Linux, Unix, Windows, McIntosh, etc.

How to contribute

The objective of EINSTEIN is to convert into a platform for energy efficiency, where interested people can freely access and exchange knowledge on energy engineering. In order to achieve this goal, contributions from the community are essential:

Share your experience with the community

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

- 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.
- EINSTEIN is as good as the data bases he can use. User contributions with data sets – e.g. equipment data, benchmark data, good practice examples – can be made accessible to the general public in future updates. References for data should be complete, so that the reliability of those data can be checked and the origin can be tracked back.
- Users help other users: there is an e-mail forum where EINSTEIN users can exchange opinions, get support or give support to others: if You want to participate, subscribe to https://lists.sourceforge.net/lists/listinfo/einstein-users.

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 templates available on the tool or on the EINSTEIN web for reporting bugs, ideas for improvements, etc.

Validation of the results of EINSTEIN in comparison with other tools or methodologies: if You do some comparisons of the outcomes of EINSTEIN with the methods or tools You use at present, please send this information to the EINSTEIN consortium.

Additional languages can easily be added to the EINSTEIN tool. Persons interested in collaborate as translators can send a mail to the EINSTEIN consortium and will receive the pack of text files to be translated.

Organize EINSTEIN trainings or audit campaigns in your country, region or city

The EINSTEIN consortium can give support to public authorities, industry associations or any other entities that want to either organise EINSTEIN audit campaigns or training courses for EINSTEIN energy auditors.

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. Within the limits of its possibilities, the EINSTEIN team will give support to related Diploma, Master and Ph.D. Thesis.

Present state and lessons learnt

The EINSTEIN software tool at present (V1.0.03 – March 2009) is in a beta-testing phase in the Framework of the IEE project EINSTEIN within 90 industrial companies. The feed-back of the auditors that have been trained and are working with the tool has been generally very positive and with high interest. The most important things to be improved are the corrections of several bugs, the improvement of the graphical support and user friendliness in general, and some improvements with respect to functionality, such as a process model extended to more than one incoming and outgoing streams, more complex time schedules, etc. Some of these improvements will be included in the new stable release foreseen for the end of the IEE-EINSTEIN project in August 2009.

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