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STEAM UP

Audit Methodology

STEAM UP Audit Methodology Report

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Deliverable: D3.1 Steam audit methodology document and checklist

D3.2 Recommendations for including energy audit results in energy management systems

D3.3 Database of energy efficiency measures, maintenance practices and purchasing recommendations for steam installations

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Description of the Deliverable:
This document consists of the deliverables D3.1 - Steam audit methodology document and checklist, D3.2 Recommendations for including energy audit results in energy management systems and D3.3 Database of energy efficiency measures, maintenance practices and purchasing recommendations for steam installations.

Summary

This document presents the methodology for carrying out the in-depth steam audit in industrial companies. It includes information on how to reach company management and convince them of the advantages of the steam audit. There is a step by step description of the main elements of the audit and how to process (energy) data with example tables and some attention to non-energy benefits. The document includes a list of typical steam measures that lead to energy savings.

The document also explains how to gradually integrate the steam audit results with an energy management system. The energy management system is considered as a follow-up of the steam audit and the most optimal approach of implementing the measures proposed in the audit in a systematic way.

STEAM UP Audit Methodology Report

Covering

D3.1 Steam audit methodology document and checklist

D3.2 Recommendations for including energy audit results in energy management systems

D3.3 Database of energy efficiency measures, maintenance practices and purchasing recommendations for steam installations

Authors: Michael ten Donkelaar, Šárka Geryková (ENVIROS)

Date: 29 April 2016 (*updated: 17 March 2017*)

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The Steam Audit Methodology

Subject: Development of the in-depth steam audit methodology

Authors: Michael ten Donkelaar, Šárka Geryková (ENVIROS)

Recipient: STEAM UP Consortium Partners

Version: 2.3 (17 March 2017)

This steam audit methodology is divided into a number of sections. After the technical introduction (1), a short description of how to reach top management is given (2) followed by some key questions that need to be answered (3) before starting the work on the energy audit. The main elements of the audit are described in section 4. Section 5 explains the integration of energy management with the energy audit. Section 6 gives a detailed overview of how to process data with example tables and gives some attention to non-energy benefits. Section 7 gives a description of typical steam measures. As a special Annex I, the steam audit template is added.

This report includes the combined deliverables of WP3:

- D3.1 Steam audit methodology document and checklist – section 1 to 4 and section 6
- D3.2 Recommendations for including energy audit results in energy management systems – section 5
- D3.3 Database of energy efficiency measures, maintenance practices and purchasing recommendations for steam installations – section 7

The deliverables will remain work in progress and further updates may be made during the course of the project as the experience of single steam audits will be included.

1. Introduction

An in-depth audit for steam helps an organization to identify opportunities to improve energy efficiency of steam processes. It can be a stand-alone audit or become a part of a site wide energy management system.

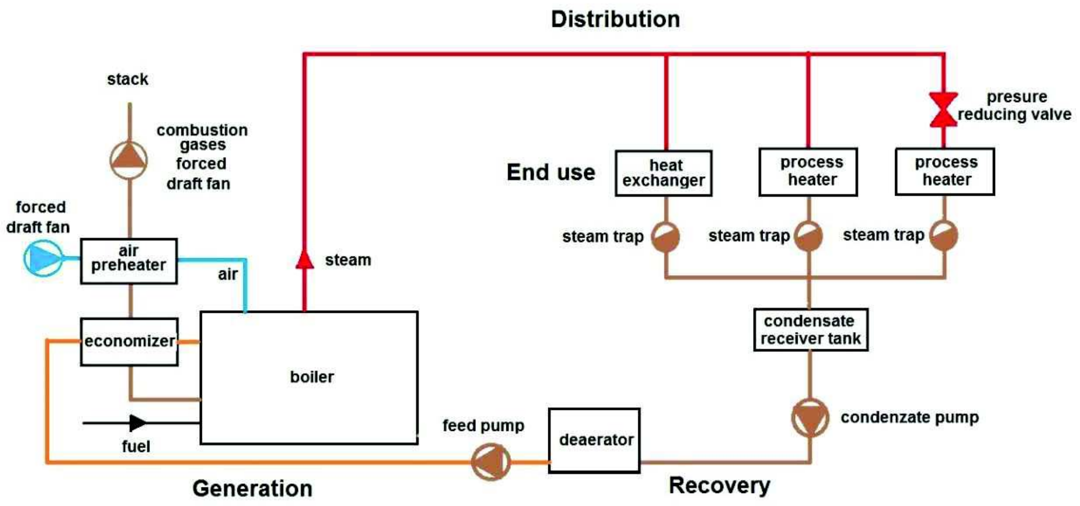
Steam is used by many industries as a useful medium to transfer and deliver heat to industrial and chemical processes. Steam boilers or generators usually form an integral part of a larger steam system. Steam is also used for heating applications in industrial processes to control temperatures and pressures, to remove contaminants and drive mechanical processes. Basically, we can identify four categories of application:

- **Generation –** where steam is generated in a boiler/generator or heat recovery generator;
- **Distribution –** where steam is carried from the boiler/generator to the points of end use;
- **End use –** includes process heating, mechanical drive and moderation of chemical reactions using equipment such as heat exchangers, steam turbines, and chemical reaction vessels;
- **Condensate Recovery –** where condensate is returned to a collection tank.

Steam industrial users can also be classified based on the importance of steam in the production process:

- Heavy Steam Users: Petrochemical, Food & Beverage, Textiles, ...;
- Medium Steam Users: Large commercial heating, Breweries, Bakeries,..;
- Small Steam Users: Electronics, Humidification systems'.

Figure 1 : Steam systems include generation, distribution, end use and recovery of condensate



Source: ENVIROS

These categories will have to be included in the analysis of the energy consumption in order to be able to split energy consumption per process / application.

The main objective of an energy audit, not only steam audit, is to create a systematic overview of the in- and outgoing energy streams, the energy losses and to provide recommendations for improvement.

The EU Energy Efficiency Directive (EED – 2012/27/EU) provides the following guidelines on energy audits (Annex VI of article 8.3 of the EED):

- be based on up-to-date, measured, traceable operational data on energy consumption and (for electricity) load profiles;
- comprise a detailed review of the energy consumption profile of buildings or groups of buildings, industrial operations or installations, including transportation;
- build, whenever possible, on life-cycle cost analysis (LCCA) instead of Simple Payback Periods (SPP) in order to take account of long-term savings, residual values of long-term investments and discount rates;
- be proportionate, and sufficiently representative to permit the drawing of a reliable picture of overall energy performance and the reliable identification of the most significant opportunities for improvement.
- Energy audits shall allow detailed and validated calculations for the proposed measures so as to provide clear information on potential savings.

2. Reach high – level (top) management

According to with EN 16247: Energy Audits, the first step of the energy audit process is to establish a first contact with the management of the enterprise. The aim of the first contact is to create the interest of the client, and to give certain information in advance and arrange an appointment. One of the best ways to attract interest is to use existing personal contacts.

You may know about companies that want to improve or optimize their steam systems or want existing steam installation extended, restructured or changed.

Alternative ways of seeking contacts to industrial companies is though branch associations. They may be of assistance in getting into contact with to single companies.

In-depth steam audits can also be mentioned in public presentations, discussions and gain new contacts for instance at trade fairs, training courses, in which you participate or other events focused on energy savings in the industry. You can also establish contact with local trade unions and chambers of commerce, if they are interested to support your activities (e.g. the publication of an article in their magazine, sending out your offer to their member organizations ...).

You should send information material to their liaison officers or top management in a selected group of companies (e.g. food industry, chemical industry, paper industry, textile industry etc.).

Since the in-depth steam audit is a new product of your consultation, you can begin addressing your regular (industrial) customers. The information material must describe the main aspects of the in-depth steam audit (incl. some statistics on energy costs) and financial options support, you can probably offer.

After a week or two contact the person that you have posted materials to. Your goal should be to convince the company to continue towards the next step and provide you some first data; so that you can verify whether a company is a candidate for in – depth steam audit. Try to arrange a personal meeting in the company and completion of the basic questionnaire.

Make sure you talk to the right person. You can search by collecting the data from the web or business or environmental reports, press articles, etc. Before calling, you should know the position, name, title, telephone number of the person, and you must know the range of products and services of the company. Take Steam-Up flyer with you when visiting the company.

Here it is important to get engagement of top management. This could be during the first talk or when negotiating the steam audit.

There are multiple arguments for addressing the steam system in the energy audit:

- Steam generation is expensive and it is a larger cost item than you may think. So, no reason to ignore possible savings that may be reached. This could be visualised, e.g. with a Sankey diagram, that clearly shows the energy (and financial) losses of processes in the company
- Experience learns that for a number of large companies there could be alternatives to steam generation (e.g. remove/replace steam or produce steam with electricity).

- Addressing so-called non-energy benefits (NEBs) of energy efficiency measures that may lead to competitive benefits to participating companies. Addressing these NEBs may create additional interest in the steam audit than only focusing on energy and cost savings would.

When meeting with top management of the company, it is always a good idea to start asking / talking about more general issues that the company is solving. E.g. asking about the business, the sector, future plans, problems etc. This may give you information for identifying the type of non-energy benefits that the company management may be interested in. This may be another argument for the company to start seriously thinking about the steam audit.

Another argument is the obligation for large companies (non-SMEs) to carry out an energy audit in the framework of the EED (Energy Efficiency Directive). With this argument we need to be careful, however, as companies interested only in the legal obligation may be motivated to have an energy audit carried out according to minimal requirements and not addressing any measures at all.

3. Connect to corporate strategy

Before the first visit in the company is important to get insight in corporate strategy, market and market developments and trends in the sector where the company is operating. Before starting the audit it is necessary to get preliminary information. This preliminary information can help you to identify potential areas that need to be deeply investigated with priority and decide on what scale it makes sense to conduct the in-depth steam audit.

The best way to get general information and data of the company is by preparing a list of questions:

- Market and it's development: competitors, local, national, European and worldwide;
- Annual reports, company website (vision, mission);
- The general situation of the company - the economic situation, future prospects, the expected development of production volumeIs the company certified with ISO 14001 or 9001
- With respect to current system condition and operating parameters, how steam system optimisation and energy efficiency improvement can contribute to the strategic goals and why energy efficiency is a strategic issue;

It is important to get a basic overview about the problems of specific company industries and ideally even before consulting the company or at the latest before the first site visit. In the majority of industrial sectors and sub-sectors there is a lot of available information but access to the right information is in many cases difficult and time consuming.

3.1 The steam system – a systems approach

Several important factors should be considered when industrial companies seek to improve steam system performance and to lower operating costs. Improving steam system performance requires assessing the entire system, identifying opportunities, and selecting and implementing the most feasible and cost-effective projects. In turn, this requires a systems approach. Similarly, proper selection of the best projects requires quantifying the benefits and costs of each project. Successful implementation of these projects requires the participation of all stakeholders within the company including production, maintenance, and management.

There is a need to develop a systems approach in handling the steam system and rather than handling it as a sum of single components. Only a systems approach enables to fully optimize the savings potentials of that system.

This asks for a checklist answering e.g. the following (consecutive) questions:

- Why is steam used (for what purpose)?
- How is it generated?
- How is it used (by what means)?
- How is it distributed?
- How does the steam recovery work?
- Could steam in one or more processes be replaced?

Before starting with the in-depth energy audit, these basic questions should be answered.

3.2 The steam system – an organisational approach

In addition to the system approach, we can also define an organizational approach:

- Who are involved,
- who is the engineer,
- who is knowledge owner,
- who are the steam users,
- who decides about what etc.

These questions should be answered and are part of the in-depth audit.

Before starting the actual audit, it is important to reach all steam-involved personnel. This means: maintenance, users, investment deciders, engineering. In SME’s the investment decision maker is top management. A kind of stakeholder matrix will help to get the broader picture of who decides what and when.

4. Elements of the in-depth audit for steam

In developing the steam audit methodology, the following documentation was used:

- EN 16247: Energy Audits - part 1: general requirements and part 3: processes
- ISO 50001: energy management systems: Requirements with guidance for use
- Methodologies from member states with long-term energy audit experience, such as:
  - Dutch methodology for the Energy Potential Scan (EPS) – especially the part on stakeholder methodology
  - Czech Decree on Energy Audits and Energy Expert Opinion (480/2012 Coll.)
- Additional documentation on the implementation of ISO50001, such as the energy management training packages of UNIDO, checklist of partner IEE.

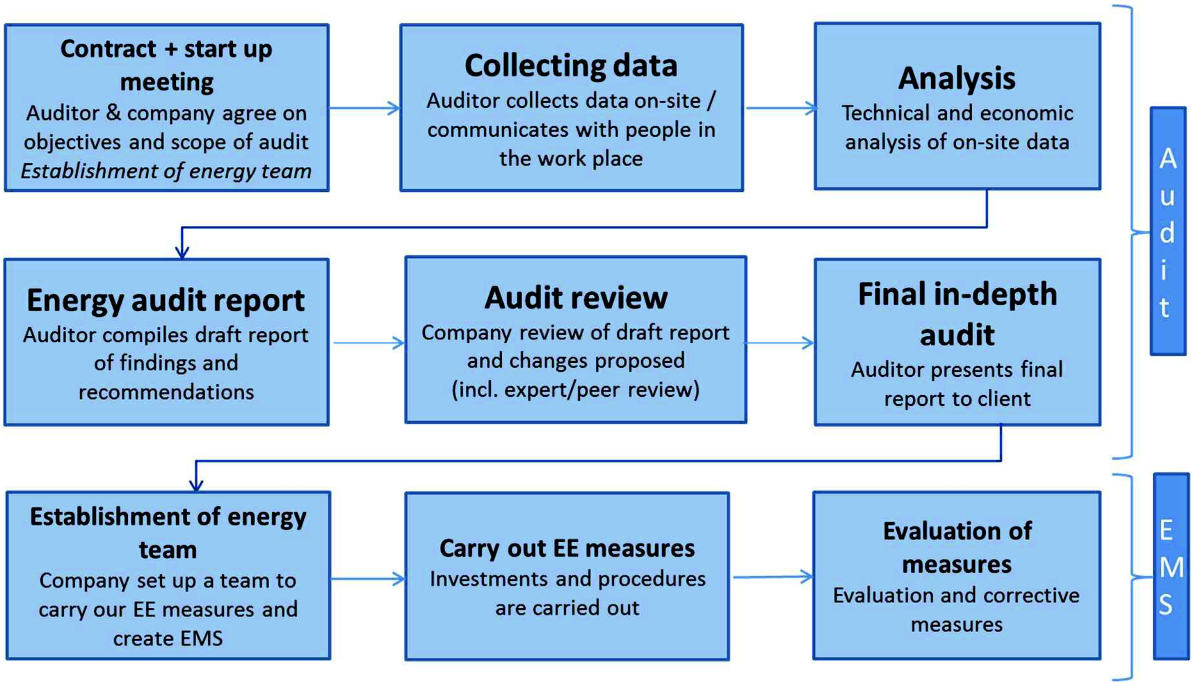
European Energy Audit standard EN 16247

The standard EN 16247 lists the main elements for energy audits. The most important are:

I. The preliminary contract between auditor and client and the start-up meeting
II. Collecting data
III. Field work, that includes site visits, communications with the contract person / management in the company, etc.
IV. (Technical/Economic) analysis of the data and the site visit
V. Reporting
VI. Final meeting / presentation

Audit approach in summary

Figure 2: Audit process followed by energy management



4.1 Preliminary contract

When agreeing with a company on the execution of an energy audit, the energy auditor shall obtain a preliminary description of the site and the process from the organization or from a site visit. The scope of the audit will have to be agreed in this ***preliminary contract***.

You need to assure management commitment at this point. A representative of management should sign and lay down expectation in relation to Steam-Up, mainly related to identification of opportunities. After the in-depth audit more concrete goals can be set. : Dissemination of results, target savings of x GWh.

During the ***start-up meeting*** the energy auditor shall agree with the top management of the organisation on:

- Degrees of thoroughness required;
- Timescale to complete the in-depth audit for steam;
- Criteria for evaluating energy efficiency improvement measures; only standard financial appraisal (IRR, NPV, LCC)
- The type of non-energy benefits (NEB) to take into account
- Expected deliverables and required format of the report;
- Whether a draft of the final report to the organisation should be presented for comment.
- Analyse the steam system from a management point of view, i.e. what are its overall costs and alternatives
- Proposing an energy management system where steam is included
- Steam alternatives
- Ask for internal personnel and time
- Let the management declare that the team is responsible for the result (not only the consultant)

The energy auditor will need to ask for information about management system (environmental, quality, energy management system) in the company. Any other company policy/strategy related to energy / environment that may be important for the energy audit shall be included here as well.

Only projects with a high potential to save money or to increase the production will be accepted by the top management with open arms. And approval by the management is necessary in order to fulfil a project. When starting the in-depth steam audit, the following issues need to be finished or discussed with the management:

- The management is informed about the method and they have expressed their willingness to participate;
- The management agreed on the costs and hours to be spent by their own employees;
- The management agreed about the follow-up.

All employees who will be involved in the project (the energy team) are invited. The management of the company publicly expresses their commitment to the project and informs the participants about the importance of the project.

4.2 Collecting data

Thereafter the project starts with the meeting of the collecting data. In this meeting the consultant explains the working method. Also the project planning will be discussed and agreed.

Data collection is one of the most important tasks within the (steam) energy audit process and should include the following:

a) List of steam using system, processes and equipment;
b) Operational history and past events that could have affected energy consumption in the period covered by data collection;
c) Existing energy audits or previous studies;
d) Status of the energy management system;
e) Verification of the data and information provided by the organization;
f) Obtain any missing data;
g) Check the accuracy of the measuring device;

The collected data can be based on invoices, contracts, measurements, calculation from operating hours and installed capacity, meeting with operations and maintenance personnel.

If requested data are not available, the energy auditor may look for other methods to obtain the necessary information (e.g. through measurements, estimates, modelling, etc.)

Here it is important to consider that steam measurement is generally expensive and complex. Within the framework of an energy audit, steam measurement will be too costly[1].

In general, the data collection strategy focuses on two areas of data collection, design information and operating data.

4.2.1 Design information

Design information is typically used to understand the steam system's capabilities, minimum and maximum operating constraints and limits, energy efficiency parameters, etc. Most often this is gathered from[2]:

- Engineering documents at the plant (if available)
- Equipment / System nameplate information
- Manufacturer's published information
- A combination of the above sources

Design information is also used to compare the current operating conditions and the efficiencies with design. But most times, steam systems are operated at off-design conditions and hence, it doesn't always result in an easy comparison. Nevertheless, it is an excellent data point which should be captured during an industrial steam system assessment.

4.2.2 Operating data

Actual operating data from an industrial steam system are extremely important and have to be collected through calibrated instrumentation with the highest accuracy levels as possible. Actual operating data can be collected in several different configurations, depends on instruments and data system. In addition, it is necessary to find out what data are missing and to make an action point of it.

Operating data frequency is another variable that needs to be properly selected when collecting data during a steam system assessment. Production and steam system loads are not constant (fixed over time) and vary with type of process, seasonality, schedules, etc. Hence, it is very important to

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[1] Steam measurement could be an action point to work out after the in-depth audit

[2] Make a list of all required data and put names of responsible people behind it.

understand load profile of the industrial processes that use steam before defining the time period of data collection as well as the frequency (time-step) of data collection.

In industrial steam systems, operating data measurements of process and utility variables typically consist of:

- Temperature - Temperature measurement is one of the most common measurements for steam system analysis. It can be done in several different ways and depending on the application and location of the measurement it will require different types of temperature measurement equipment. The temperature measurement portable instrumentation equipment required for an industrial steam system assessment is: thermal imaging camera, infra-red temperature gun (or thermometer), hand-held digital thermometer, immersion temperature probe.
- Pressure - Pressure measurement using portable instrumentation in a steam system is much more difficult to do than temperature measurement since the steam or process fluid to be measured has to be in contact with a pressure sensing device.
- Flow - suitable devices include external clamp-on ultrasonic flow meters, electromagnetic flow.
- Combustion analysis **-** flue gas analysis. The main purpose for undertaking a flue gas analysis is to determine the operating combustion efficiency (or flue gas losses) for the boilers. A significant part of the boiler efficiency is dependent on the combustion efficiency and estimating boiler efficiency (using the indirect method) will require calculation of flue gas losses. Flue gas losses are dependent on the net flue gas temperature and the percent oxygen in the flue gas stream. The flue gas analysis allows the steam energy expert to calculate these losses.
- Energy usage – Ultrasonic Leak Detector
- Water chemistry
- Power production

Tables 4.1 to 4.3 are examples of how information on steam generation, steam and condensate distribution and steam use can be summarized in table format. The information included is based on own experience of energy auditors from ENVIROS.

Table 4.1 : Example list of data to be collected

Steam generation	
Description of the facility	Installed capacity, number of boiler
Description of operating mode	Cascade, backup, shutdown, supplementary, etc.
Generator	Commissioning date, power, brand, type, kind of fluid, pressure, outgoing temperatures, nominal flow rate, thermal insulation
Burner	Nature of fuels, age, type, power
Control and measurement equipment	Fuel, boiler
Boiler equipment	Recuperators, superheaters, economizers, air preheaters
Power supply circuits	Feed water, temperature, pressure
Water treatment	Characteristics of water quality, treatment of boiler water
Flue gas	Exhaust flue gas temperature (after Economizer), O_2 level

Annual consumption and production levels

Table 4.2 : Example list of data to be collected

Steam distribution	
Kind of steam	Pressure, temperature, nominal flow rate, real flow rate
Type of network	Above-ground, channels, tunnel, distribution method
Characteristics	Lengths, diameters, flow rates, pressure, temperatures, return systems, etc.
Condensates	Recovery of condensates, pipe sizing, etc.
Steam traps	Type, number and location
Thermal insulation	Description, design
Operating hours	Number
Losses	If it is determined
Networks	Condition and upkeep

Table 4.3 : Example list of data to be collected

Steam use	
General information on the running of the company	Daily/annual production, operating times, start up and shut downs of production, shift patterns
Energy management and monitoring level	Which indicators, who monitors them?
Kind of operation	Drying, heating, cooking, sterilization, etc.
Types of machines using steam	Steam turbine, steam heat exchanger, steam dryer
Steam	Steam consumption, flow rates, pressure, temperatures, return systems, etc.
Condensates	Recovery of condensates, pipe sizing, etc.
Steam traps	Type, number and location
Operating hours	Number

A separate table could be created that includes general company information

- Company information
  - Range of products / production level
  - No. of employees
- Company Strategy (see also workshop results), what are the companies' long term targets:
  - market share, production level,
  - annual increase of turnover or profit
  - environmental policy
- Company context (which markets do they operate in, what market trends, etc.)
  - Main market (domestic market, abroad), main clients
  - Trends on the market (is it a grow market or is it stabilised)

4.3 Analysis

In order to enable a systematic approach of energy use, we will have to view the industrial company as an integrated system. Before starting with the analysis, the following questions should be answered:

- Why is steam used (for what purpose)?
- How is it used (by what means)?
- How is it distributed?
- How is it produced?
- Is steam really necessary and how can it be replaced?

The analysis, based on data collection, site visits and discussions with company representatives (a team engaged in the data collection process) on all different levels includes:

a) Provide an energy balance, incl.:
    i) Analysis of steam generation by sources;
    ii) Analysis of the steam consumption by processes in absolute number and in consistent energy unit;
    iii) Demonstrate an energy balance between steam consumption and steam losses.
b) Calculate the actual energy performance of the process;
c) Compare the actual sizing of process (steam generation, distribution and using) and the energy needs;
d) Investigate the maximum achievable energy performance of the process and benchmark it with the actual energy performance;
e) Evaluate the optimal quantity of energy in steam process.
f) Interview relevant company representatives (EPS participative approach)

If data availability allows it, energy performance indicators should be utilized. The energy auditor could use relevant energy performance indicators detailed in the energy management system. Possible energy performance indicators are explained in section 6.4.

4.3.1 Identify and evaluate energy efficiency improvement opportunities

After the analysis is completed, the energy team proposes a number of energy efficiency improvement opportunities. For each of the proposed energy efficiency improvement opportunity, the energy auditor will calculate the expected energy saving. Standard opportunities are developed for all parts of the steam system: steam generation, steam distribution, end use and condensate recovery. The responsible person for each part of the steam system and the production process will be invited.

There are many different ways to improve steam system performance and identify improvement opportunities in the industrial companies. In general, performance is most effectively optimized when a systems approach is used.

A systems approach analyses both, the supply and demand sides of the system and how they interact, essentially moving the focus from individual components to total system performance. Often, operators are so focused on the immediate demands of the equipment that they overlook the broader issue of how system parameters affect the equipment. Similarly, a common engineering approach is to break a system down into its basic components or modules, optimize the selection or the design of these components, and then assemble these components to form the system. An advantage to this approach is that it simplifies problems. However, a disadvantage is that it often overlooks the interaction of these components. In contrast, a systems approach evaluates the entire system to determine how the end-use requirements can be most effectively and efficiently served.

A systems approach also recognizes that system efficiency, reliability, and performance are closely related.

The energy efficiency improvement opportunities could also be categorized as follows:

a) People based opportunities (training, awareness, etc.);
b) Technical based opportunities (operations, maintenance, replacement of machines);
c) Organizational based opportunities (structure of organization, responsibilities, monitoring).

In order to carry out a complete evaluation, for each (promising) energy efficiency option, the energy auditor should present a short **Business Case** for each (group of) option(s), which includes:

- a brief risk assessment for each of the measures;
- a financial assessment, including all costs (not only investment costs of equipment) like operational costs incl. man hours, production down time, etc.;
- the NEB's
- a short description of how proposed measures support company strategy.

4.4 Proposed measures

A list of proposed measures describes in about 10 pages viable measures that can be taken in the field of steam optimisation. Measures are split into four categories: steam generation, steam distribution, steam use and steam (condensate) recovery. The full list is included in section 7.

In the audit report it is important to give a detailed description per measure: how and who can carry out the measures.

4.5 Energy audit report

The energy audit report combines all findings of the in-depth audit for steam. Here it is important to ensure that:

b) The energy audit requirements agreed with the organisation have been met;
c) The quality of the report before submission to the organization has been checked;
d) All relevant measurements made during the audit are summarised;
e) The method utilized for achieving the results of the analysis is made clear (i.e. whether they have been determined on the basis of calculations, simulations or estimates);

f) The identified energy efficiency improvement opportunities are listed according to agreed criteria (e.g. cost effectiveness ranking)

4.5.1 Content of the report

The report of the in-depth audit for steam is recommended to include:

a) Background:
    a. General information of audited organisation, energy auditor and energy audit methodology;
    b. Context of the in-depth audit;
    c. Description of audited objects;
    d. Relevant standards and regulations;
b) Description of the existing steam installations - see section 3
c) Evaluation of the existing steam installations - see section 3
d) Proposals for measures to energy efficiency improvement

e) Economic evaluation of each measure
f) Environmental evaluation
g) Non-energy benefits / risks and strategies
h) Recommendations steam (energy) specialist

In addition, the report will have to include a (management) summary, so that top management can see on one to two pages what the main recommendations from the audit are with the main financial implications.

In an Annex to the audit report, recommendations can be given to the introduction of energy management. These recommendations will differ company by company, as some may have already introduced some form of energy management (or are even certified) while others are still at the beginning.

4.6 Peer/expert review

The audit process may include a peer review of draft report by a company and changes are made to the report if applicable. The inclusion of such a peer review would either be a requirement of the agreement between the auditor and the client or at the auditor's discretion for internal quality assurance purposes. This review can be done by other steam expert in the consultancy company.

5. Integration with energy management

The proposed energy audit methodology includes the major elements of energy audits according to national and international standards. What is not mentioned here is the link with energy management. Energy management is often mentioned in energy audits as one of the possible energy efficiency measures to be included.

In STEAM UP, we are proposing an alternative approach. Within the in-depth steam audit, the set-up of an energy management system (EnMS) would be the integral measure and other measures will be connected to it.

Figure 3: Standard energy audit approach

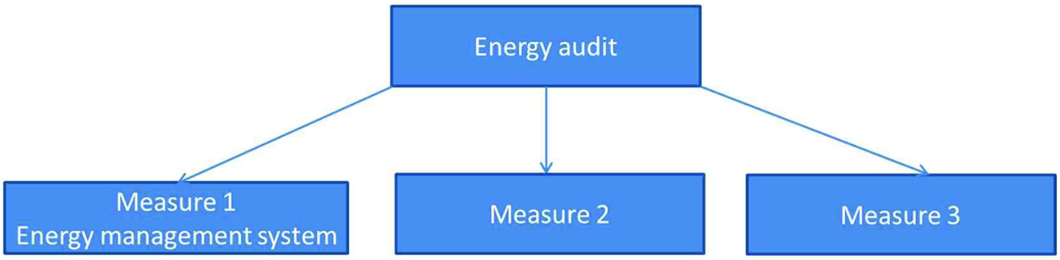
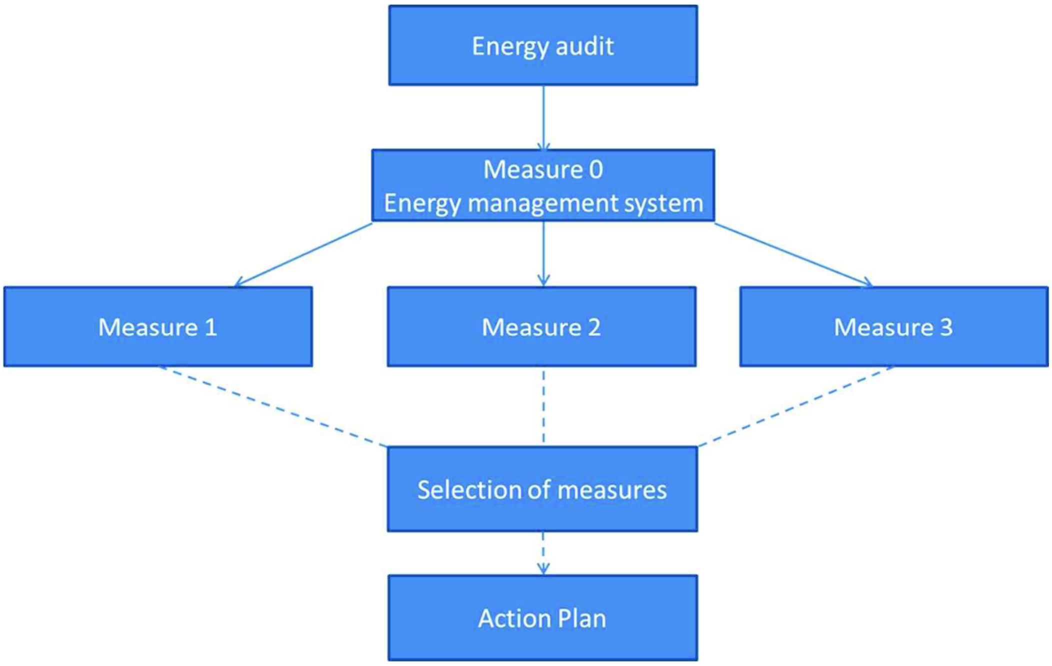


Figure 4: STEAM-UP energy audit and energy management approach



In the second variant, the energy audit proposes the set-up of a certain form of energy management and the technical measures become part of the EMS, although they have been originally identified in the energy audit.

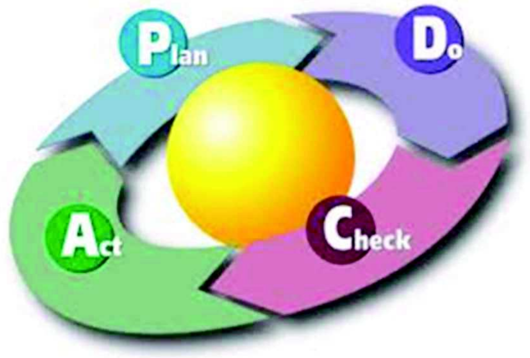
This is the variant we are proposing in STEAM-UP. The energy audit methodology should propose technical measures on one hand, but on the other hand, the implemented measures should be integrated into a (energy) management system.

In its simplest form this would mean that each company should:

- Appoint (a) company representative(s) responsible for the implementation of the agreed measures. In STEAM-UP this person is identified at the beginning of the process.
- This company representative should:
  - check if the measures are implemented and all technologies are working correctly (from a process point of view)
  - after installation, monitor the energy use at regular intervals and compare to the energy use before the measures were implemented
  - Report the energy performance to top management
  - Take corrective measures if needed.

This is a very basic way of working along the PDCA cycle (PLAN-DO-CHECK-ACT) or the cycle of continuous improvement on which all quality management systems are based. The PDCA cycle forms the basis of ISO standards like ISO 9001, ISO 14001 and now also ISO 50001.

Figure 5: PDCA cycle



The PDCA cycle provides a framework for the continuous improvement of processes or systems. It is a dynamic model; the results of one cycle form the basis for the next one. This structure enables you to continuously reassess and optimise the current state.

If we would like to go into more detail, we first have to look what steps the company has to undertake under each phase:

PLAN phase

- Gaining support from top management
- Carry out an energy audit or energy review
- Starts with the developing the energy management system
- Establishes energy saving targets, determining the strategy, identifying measures and responsibilities, providing the necessary resources,
- Prepares an action plan (who, what, when, how)
- The information for setting targets and identifying measures is often gained from an energy audit (usually carried out by an independent energy auditor)

DO phase

The internal energy management system and work plan are developed.

Main activities

- Appointing an energy manager and/or set up an internal energy team with responsibilities
- List external legal obligations and regulations that have to be fulfilled

- Set up internal energy policy regulation and an energy policy statement, through which all employees are informed

CHECK phase
Review of targets and effectiveness of the energy management system

- Apply an energy management checklist, check if all steps have been implemented
- A new internal energy audit (if necessary by external experts)
- Monitoring and targeting, measurement of energy processes (before and after implementation of EnMS)
- Measuring and verifying energy savings of investment projects

ACT phase

- Strategic optimisation by consolidating the current energy data
- Audit results and new information
- Evaluating the progress with the help of current energy market data
- Deriving new objectives

To translate these steps into measures for a systematic implementation of steam measures, we will get the following:

- PLAN: Based on the results of the in-depth steam audit, it is possible to set energy saving targets (based on the potential calculated in the audit)
- PLAN: Prepare an action plan with the measures to implement (in order of priority), necessary resources and responsibilities
- DO: appoint a company representative overlooking the implementation of all measures
- DO: communicate with top management about the action plan
- CHECK: check if all measures have been implemented
- CHECK: monitoring (possibly measuring) the processes where measures were implemented
- ACT: take corrective actions if needed
- ACT: set new targets

6. Possible method of processing the various parts of the in-depth steam audit

Below a number of suggestions are given of how the energy data can be structured in table format, based on existing audit guidelines.

The existing energy performance situation, as described by the energy auditor, becomes a reference against which improvements can be measured. Therefore, it is important that:

a) Energy consumption is included for a certain period (e.g. the last three years) for electricity, natural gas, oil, coal, and biomass.
b) Operational history and past events that could have affected energy consumption in the period covered by the data collection;
c) Own steam source – see table 6.1;
d) Steam distribution – see table 6.2;
e) Using steam – see table 6.3;
f) Review energy management system according to EN ISO 50001:2011

6.1 Energy consumption overview

The following table summarises energy consumption as is done in audits in the Czech Republic. It would be beneficial to complete the table separately for each of three years and a table for an average year, where the prices shall be used from last year.

Table 6.1 : Energy consumption in the steam sources

Last three years and average year					
Fuels and energy input	**Unit**	**Amount**	**Net Calorific value [GJ/unit]**	**Conversion to MWh**	**Annual costs Euro**
Electricity	MWh				
Heat	GJ				
Natural gas	m_n^3				
Other gas	MWh				
Black coal	t				
Brown coal	t				
Coke	t				
Other solid fuel	t				
Heavy fuel oil	t				
Light fuel oil	t				
Oil fuel	t				
Secondary sources	GJ				
Renewable sources	GJ				
Other fuels	GJ				
Total fuel and energy inputs					

6.2 Energy balance in the company

The following tables 5 to 7 show how the energy balance of the different energy / steam sources is given in the Czech energy audit methodology. These tables are a legal requirement in the energy audit.

Table 6.2 : Annual balance of production from own steam source

C.	Title	Unit	2012	2013	2014	Average
1	Installed thermal power	MW				
2	Steam generation	GJ/year				
3	Steam delivery (external)	GJ/year				
4	Sale of steam	GJ/year				
5	Own consumption of heat for steam production	GJ/year				
6	Own energy consumption in fuel for steam production	GJ/year				

Basic technical characteristics of own source of steam

Table 6.3 : Basic technical characteristics of own steam source

C.	Title	Unit	2012	2013	2014	Average
1	Annual overall efficiency of steam generation	%				
2	Fuel consumption for steam generation	GJ/year				
3	Annual operating hours of installed capacity	hours				
4	Specific cost for steam generation	€/GJ				

Also include (make explicit and specify) the cost for steam operation: maintenance, check and audits, steam attendant. This might trigger to assess other options like steam generator or hot water boiler.

6.3 Evaluation of the existing steam installations

This will be an analysis of energy consumption in the own steam sources, steam distributions and steam use. The energy balance shall be representative of the energy input and energy use. It shall be clear which is based on measurement, estimation or calculation.

Table 6.4 : Overall annual energy balance

C.	Indicators	Energy		Costs
		GJ	MWh	€
1	Total fuel and energy inputs			
2	Own steam sources losses			
3	Distribution steam losses			
4	Condensate losses			
5	Steam consumption for technology			

6.4 Energy performance indicators and regression analysis

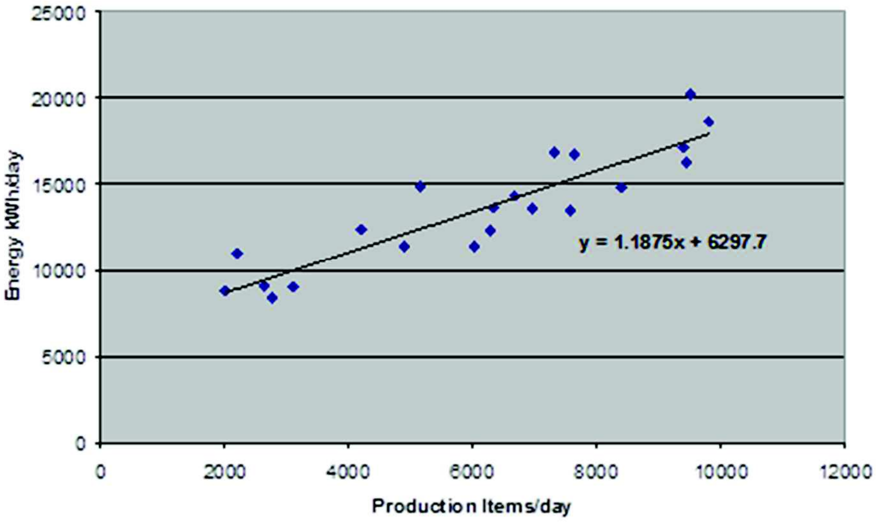
To illustrate the actual energy performance situation, we can use energy performance indicators (EnPI's)[3]. Possible (simple) energy performance indicators to use are:

- Steam requirement per product: tonne of steam (or GJ of steam) required per ton of product
- Energy input for steam production: kWh per tonne of steam produced
- Primary energy consumption (at the entrance of the company) per tonne of product produced
- CO2 emissions per tonne of product manufactured

However, such indicators may not be fully representative. E.g. energy consumption differs per production level, decreasing when less units of product are produced. Nevertheless, as most production processes have some form of baseload, energy consumption will never be equal to zero.

For that reason, regression analysis is a better tool. Regression analysis shows the relationship between variables like production and energy use or heating degree-days and energy consumption. The simplest method of determining the relationship is to plot a series of values of production against associated energy consumption in a production scatter plot.

Figure 6: example of regression analysis – energy consumption versus production level



Source: ENVIROS

The three key features of this graph are:

- Intercept – The implied consumption even if no production took place, this is generally assumed to be the base load of the system. In the picture, when extrapolating the line to "zero production", the baseload energy consumption is approx. 6000 kWh/day

- Slope – the direct relationship between production and consumption, the efficiency of the process can be assessed from the slope.

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[3] See also ISO 50006 on EnPI's and baselines

- Scatter – the degree of variability in the energy performance, this tends to be driven by operational factors

The “intercept” and the “scatter” tend to have greater significance than the “slope” of the graph. Processes may have high intercepts for various reasons:

- The process may have distinctive features that lead to high base loads, e.g. heat input is required to maintain the temperature at a certain level for a certain production process;

- There is a fault in the process which is leading to a high base load, e.g. faults in steam traps, bad insulation

- The intercept represents the capacity of the machine and the variations in production are due to the machine working at full capacity but with different duties.

6.4.1 Energy performance and degree days

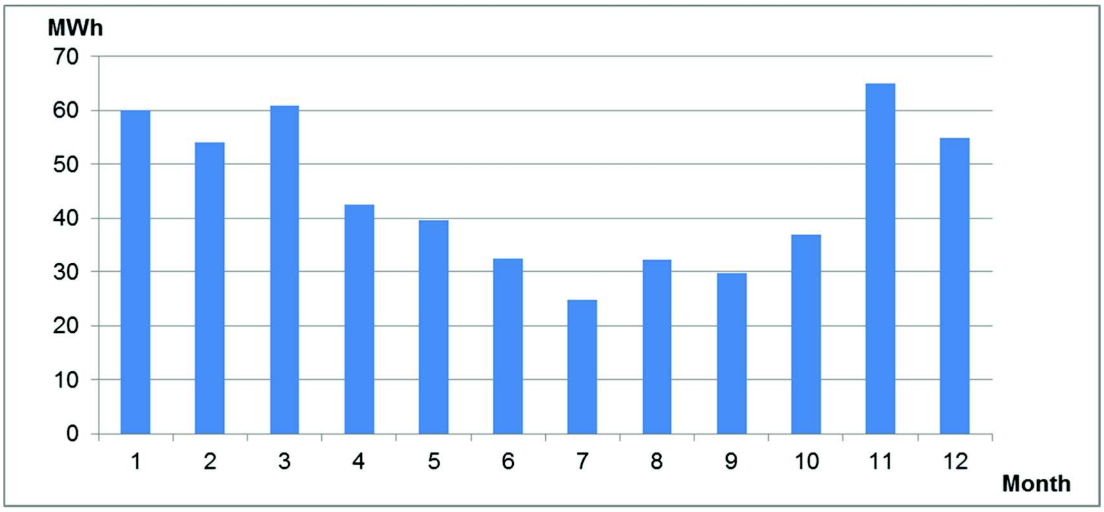
In the case that steam is used for heating purposes, there may be a need to correct energy / steam use for outside temperature. One of the possible correction factors is the correction for Heating Degree Days (HDD). Heating degree day is a measurement designed to reflect the demand for energy needed to heat a building. It is derived from measurements of outside air temperature. The heating requirements for a given structure at a specific location are considered to be directly proportional to the number of HDD at that location.

Heating degree days are defined relative to a base temperature—the outside temperature above which a building needs no heating. The most appropriate base temperature for any particular building depends on the temperature that the building is heated to, and the nature of the building (including the heat-generating occupants and equipment within it). The base temperature is usually an indoor temperature of 18°C or 19°C which is adequate for human comfort (internal gains increase this temperature by about 1 to 2°C).

HDD are often calculated using simple approximation methods that use daily temperature readings. One popular approximation method is to take the average temperature on any given day, and subtract it from the base temperature (e.g. 18°C or 19°C). If the value is less than or equal to zero, that day has zero HDD. But if the value is positive, that number represents the number of HDD on that day. E.g., when the outside temperature is 10°C on a certain day, this means 8 HDD for that particular day (based on an 18°C base temperature). It is possible to calculate HDD for most major cities in the world through websites like: http://www.degreedays.net/.

The energy use for space heating per month can have the following form as shown in the figure below.

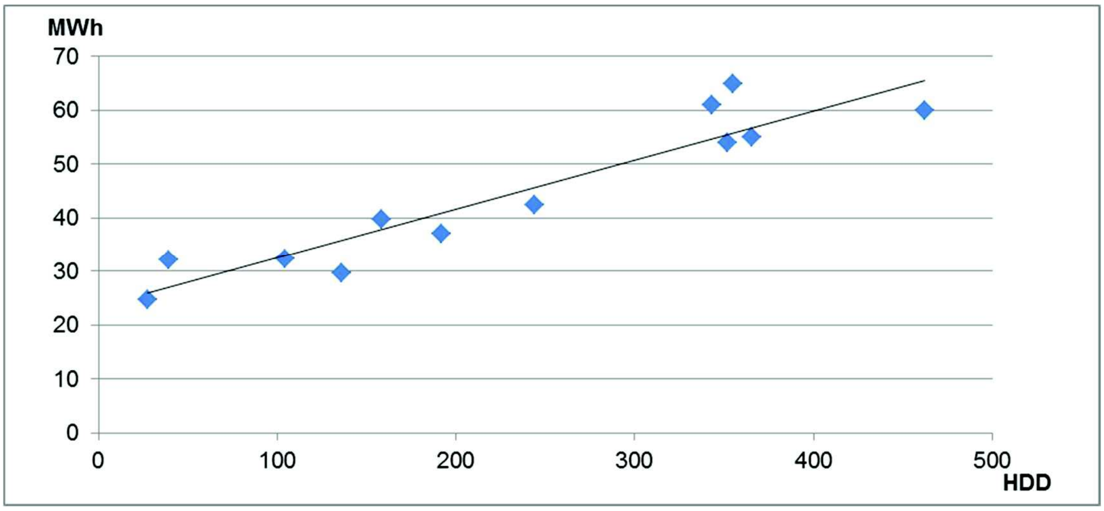
Figure 7: example of energy consumption per month and seasonal influence



Source: ENVIROS

Putting this into regression analysis, leads to the following graph:

Figure 8: example of regression analysis – energy consumption versus HDD



Source: ENVIROS

The baseline is defined by making a diagram where the energy indicator for space heating is correlated to data for HDD representing the same period. The slope defines the baseline.

6.5 Proposals for measures to energy efficiency improvement

The energy audit report will have to contain:

a) proposed actions, recommendations, plan and implementation schedule;
b) assumptions used in calculating savings;
c) appropriate economic analysis;
d) potential interactions with other proposed recommendations.

In section 7, possible energy efficiency measures related to steam have been listed

One of the major goals of the steam system energy assessment is to help industry identify, quantify and implement steam system optimization projects once the steam system assessment is completed. But this always leads into the classic question of what is the return on investment (payback) for implementing the steam system opportunities for the industry.

A basic economic calculation of the proposed measures can be as follows:

Table 6.5 : Calculation of the proposed measures

Indicators	Value	Unit
Description of the measures		
Energy savings		MWh/year
Investment costs		€
Operating costs before measure		€/year
Operating costs after measure		€/year
Reduce costs due to measures		€/year
Simple Payback Period		year
Discounted payback period		year

The table above gives a relatively simple financial calculation of the proposed measures. It gives company representatives the possibility of doing a quick scan of measures (e.g. selecting those with a pay-back time of less than 2 or 3 years).

It does, however, present the risk that it leads to an early (unwanted) selection of measures where only investment costs are taken into account. Therefore, if possible it is recommended to extend the table additional costs items like:

- Man hours before and after the measure is implemented
- Production down time in order to install the measure
- Any other financial benefits, (NEB) e.g. reduced costs for emission charges.

It is expected that one of the deliverables of the steam system assessment is to group the energy savings opportunities into three groups based on their return on investment and capital expense. The three categories are:

- Near-term : improvements in operating and maintenance practices, payback less than one year (by arrangement with the company)
- Mid-term : Require purchase of additional equipment and/or system changes, payback one to two years
- Long-term : New technology or confirmation of performance, payback two to five years

Life cycle cost analysis

The financial indicators mentioned in table 6.5 above are the most common ones in energy audits. Within STEAM-UP we would like to go one step further and include **Life cycle cost analysis (LCCA)**.

Life cycle cost analysis is the process of economic analysis to assess the total cost of ownership of a product, including its cost of installation, operation, maintenance, conversion, and/or decommissioning. By using LCC, total cost of the product can be calculated over the total span of product life cycle. It goes beyond standard pay back analysis and gives more information on what the new measure brings to the company over the whole life time. This may lead to different decisions than when only considering simple / discounted payback.

According to a simple formula LIFE CYCLE COSTS include:

Capital + lifetime operating costs + lifetime maintenance costs + disposal costs – residual value

When calculating LCC of a piece of equipment to be installed, the following steps should be taken

1. Determine lifetime for each cost element, mainly the expected (economic / technical) lifetime of the equipment to be installed
2. Estimate monetary value of each cost element, for every year during the lifetime.
3. Calculate Net Present Value of each element, for every year during the lifetime
4. Calculate LCC by adding all cost elements, for every year,
5. Analyse the results for each separate variant

A number of tools exist that are able to calculate life cycle costs of investments. One such tool is the software COMFAR III Expert or Business Planner[4], developed by UNIDO.

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[4] http://www.unido.org/resources/publications/publications-by-type/o36990/o3470.html

6.6 Non energy benefits

Energy saving projects often creates different side effects in addition to the expected energy savings. These side effects can have significant value and even exceed the value of the saved energy. The side effects are called non-energy benefits (NEBs), and the term refers to all side effects that may arise after implementing an energy saving project.

Examples of NEBs are reduction of waste, maintenance costs, emissions and production downtime as well as improvement of indoor climate, safety, product quality and many more. The NEBs are easily underestimated in the process of an energy saving project and during the evaluation of the project.

According to a recent report of the IEA[5], energy savings in industry can lead to significant improvement of industrial productivity. The value of the productivity and operational benefits derived can be up to 2.5 times the value of energy savings (depending on the value and the context of the investment).

Non-energy benefits are not always taken into account in energy audits, but their benefits may include:

- Environmental benefits and resources
    - Reduced water consumption
    - Reduced waste production (incl. industrial waste, hazardous waste)
    - Reduced amount of waste water (lower amount needs to be treated)
    - CO2 emissions / other GHG emissions
    - Other emissions (e.g. air pollution – SO2, NOx, dust)
    - Security of supply / self sufficiency
    - Other …
- Productivity (increase)
    - Operational costs
    - Maintenance costs
    - Consumption of (raw) materials
    - Necessary work force
    - Product quality
    - Unscheduled down-time
    - Other …
- Sales
    - Unique selling points (such as sustainability)
    - Customer satisfaction / loyalty
    - Publicity
    - Other …
- Work environment / health / safety
    - Internal air quality (e.g. dust / vapours)
    - Draft
    - Noise
    - Light
    - Employee flux / retention
    - Room temperature
    - Safety
    - Other …

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[5] IEA 2014, Capturing the Multiple Benefits of Energy Efficiency

How to value non energy benefits

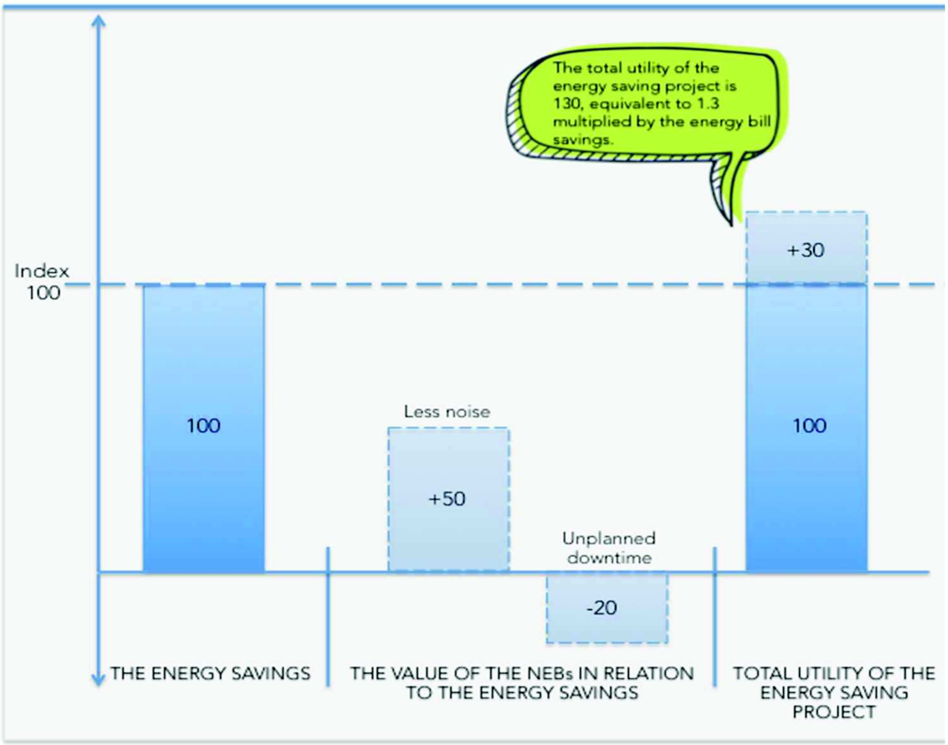
The valuation of NEBs can be a detailed calculation of the side effects using available data or a stated value estimation, where a person who has been closely associated with the project makes the assessment. For the latter, the value is based on a subjective valuation rather than calculations.

Whether results from the calculated or estimated methods will be of higher importance, when considering an investment in an energy saving project, is up to the individual decision maker. Finally, the value of the NEBs is valuated in relation to the economic value of the energy saved.

The saved energy is used as an index of 100 percent – that is, the monetary value of the saved energy, now and in the future, which is an expected and measurable benefit following the investment. The NEBs are valuated relative to this index. The figure below gives an example.

The tool can handle both positive and negative side effects from energy saving projects, as well as estimations and calculations, and one advantage of this method is that it eliminates the need to translate everything into monetary terms (e.g. Euro, Dollars). All of which makes it possible to compare and evaluate a range of energy saving projects that make it possible to include the NEBs in assessments of an energy saving project.

Figure 9: Valuing non energy benefits



Source: http://neb.teknologisk.dk/

This methodology uses indexes based on (expert) estimates. If the possibility is there to quantify each benefit in monetary terms, then this will give better estimates and additional arguments for company management to invest in energy efficiency projects. But it may be relatively difficult to quantify some benefits (e.g. noise).

Non energy benefits can be listed in the following table. For those benefits, where it is possible to quantify, all three columns will be filled in. Where this is not possible, it is sufficient to mention if there is a positive or negative value.

Table 6.6: Listing & quantifying non energy benefits

Type of benefit	**Positive / negative value**	**Unit for measuring the benefit (e.g. EUR, m3, …)**	**Amount**
Environmental benefits and resources			
• Reduced water consumption			
• Reduced waste consumption			
• Other			
Productivity			
• Operational costs			
• Maintenance costs			
• Other			
Sales			
• Unique selling points			
• Customer satisfaction			
• Other			
Work environment			
• Internal air quality (e.g. dust / vapours)			
• Draft			
• Other			

6.7 The economics related to steam system improvement

The main output of the in-depth energy audit is the recommendation of the auditor in cooperation with the team to implement one or a combination of multiple types of measures. According to Annex VI of article 8.3 of the EED (Energy Efficiency Directive) the in-depth audit for steam, whenever possible, shall be based on life-cycle cost analysis (LCCA) instead of Simple Payback Periods (SPP) in order to take account of long-term savings, residual values of long-term investments and discount rates. In the investment costs try to be as complete as possible to avoid a high discount rate because the assumption of hidden costs like: production down time, additional study, man hours; so not just the purchasing price of the new equipment.

Table 6.7 : Example – Calculation of the variants

Recommended opportunities	**Energy savings**	**Investment costs**	**CO_2 reduction**	**Estimated project costs**		**Simple payback period**
				Low end	High end	
	MWh	€	tons	€	€	

In order to go further than only SPP calculation, for each measure or variant (often combinations of measures) the following table should be completed.

Table 6.8 : Economic evaluation of the selected variants

Indicators	Recommended Variant	Unit
Investment costs		€
Energy costs savings		€/year
Maintenance costs savings		€/year
Personal cost savings		€/year
Operational cost savings		€/year
Emission cost savings		€/year
Running cost savings		€/year
Total project benefits		€
Time rating		years
Price development for energy		%
Discount rate		%
SPP - Simple Payback Period		years
RPP - Real Payback Period		years
LCCA – Life-cycle cost analysis		€
NPV – Net Present Value		€
IRR – Internal Rate of Return		%

6.8 Other issues covered in the energy audit

Environmental evaluation

The environmental evaluation mainly includes the impact of the proposed measures on the environment. This mainly includes CO2 emissions and emissions of air polluting substances like SO2, NOx, CO and PM (particulate matter).

In steam systems, water savings will play an important role, same as use of chemicals for water treatment.

Selection of optimal variant

Selection of optimal variant is made based on the results of the economic evaluation and how it contributes to corporate strategy, with respect to size savings or according to the criteria grant programs.

The final selection of the optimal variant will have to be made in cooperation with the company management. During a meeting with company representatives it is necessary to discuss possible variants, what is the most optimal from the energy / economic point of view and how this fits into company strategy.

The final selection of the optimal variant is made in agreement between energy auditor / energy team and client (top management of the company). Especially in the case that there are numerous possible measures to be taken (e.g. tens of measures), then It is important that the auditor and client sit together to come to an optimal mix of measures, taking into account:

- Energy savings reached
- Economic evaluation of each measure, but often more important, the economic evaluation of a mix of measures. Often a mix of measures with low to medium pay back is chosen in order to reach a more beneficial economic evaluation that single measures would not have.
- Impact on the environment and with that impact on e.g. environmental permits, CO2 emission trading
- The value of other NEBs, e.g. related to safety, employment etc.
- How it addresses corporate strategy

7. Proposed steam measures

This section presents list of optimization measures that can be taken in the field of steam. Measures are split into four categories: steam generation, steam distribution, steam use and steam (condensate) recovery.

For each category, possible non-energy benefits are defined as well. The non-energy benefits are described in more detail in section 6.6. This description of non-energy benefits is included to provide general examples of possible benefits. In each company, the exact non-energy benefits have to be determined on a case by case basis.

7.1 Steam generation efficiency improvement opportunities

Table 7.1 : Common optimization opportunities in the steam generation area

Opportunity	Description
STEAM GENERATION	
Install economizer and /or air preheater	Recovers available heat from flue gases and transfers it back into the system by preheating feedwater or combustion air
Minimize excess air (oxygen rate sensor)	Reduces the amount of heat lost up the flue gas, allowing more of the fuel energy to be transferred to the steam
Clean boiler heat transfer surfaces	Promotes effective heat transfer from the combustion flue gases to the steam
Improve water treatment to minimize boiler blowdown	Reduces the amount of total dissolved solids in the boiler water, which allows less blowdown and therefore less energy loss
Install an automatic boiler blowdown controller	Reducing unnecessary energy losses
Recover energy from boiler blowdown	Transfers the available energy in a blowdown stream back into the system, thereby reducing energy loss
Add steam accumulator	Handles peak demand and increases boiler efficiency
Optimize deaerator operations	Minimizes avoidable loss of steam
Investigate fuel switching	Reducing fuel operating costs
Minimize the number of operating boilers	Minimize shell losses in hot standby
Variable speed control for fans, blowers and pumps	Reducing energy consumption
Repair or add boiler insulation	Minimize radiation and convection heat loss
Low NOx burner	Reducing energy consumption and emissions to be used by new design of the burners
Combined heat and power unit (produces heat and electricity)	Where there is continuousdemand for electricity and steam.
Install a steam generator	For small amount of steam - Easy to operate, rapid start-up, compact.

Non-energy benefits

Non-energy benefits in the field of steam generation depend in this case on the type of optimization measures. Definitely we can say that reducing energy consumption in steam generation will:

- reduce local emissions[6],
- reduce transport costs when using solid fuels(and thereby reducing the burden on transport routes)
- the possibility of lowering the contracted reserve capacity for natural gas / electricity, which can be a major cost item. In general, reduced peak usage can lead to more preferential tariffs for industrial clients.

Other benefits that can be identified are improved worker safety and health, and productivity improvements associated with steam efficiency (operational costs, maintenance costs) and reduction of unscheduled down-time.

7.1.1 Install economizer and / or air preheater

The type of heat recovery equipment found in industrial boilers will depend very heavily on the fuel being used and the corresponding boiler design. Almost all industrial boilers will (or should) have feedwater economizers. Most solid fuel boilers and fuels with significant moisture content will have air preheaters. A significant number of industrial boilers and power plant boilers will have both feedwater economizers and air preheaters. Boilers burning clean burning fuels (natural gas, methane, diesel, etc.) can benefit from condensing economizers depending on the overall system heat requirements.

There are three main kinds of flue gas heat recovery equipment that are found in industrial boilers. They are:

Feedwater economizers

A feedwater economizer is a heat exchanger installed to transfer thermal energy from the flue gas into the boiler feedwater. This is the most common energy recovery component installed on boilers. Even if the boiler design does not have a feedwater economizer configured, it maybe very feasible to install a modular feedwater economizer in the stack of an existing boiler. State-of-the-art heat exchanger design and material technologies allow for minimal flue gas side pressure drop and very good temperature approaches to maximize the heat recovery with minimal heat transfer area.

Air preheaters

A combustion air preheater heats the combustion air by transferring energy from the flue gas in the flue gas. The heat exchange is identical to the feedwater economizer except that instead of the feedwater it is the combustion air being heated. The net result is a reduction in fuel usage and hence, an increase in the boiler efficiency.

Additional care must also be taken to avoid reaching an exhaust flue gas temperature below the acid dew point. This minimum temperature limit depends on the sulfur content in the fuel. Condensation in the flue gas would form sulfuric acid which is very corrosive and would lead to metal deterioration and lower operational reliability of the boiler. In addition to sulfuric acid, further reduction in the stack gas temperature would lead to the formation of carbonic acid. This is not a major concern for short

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[6] Type of emissions depending on the fuel used

durations since carbonic acid is a weak acid but over time it will surely become an operational issue if the metallurgy is not properly configured for condensation in the stack gas.

Condensing economizers

With water vapor being a product of combustion it typically, stays in the gaseous state and exits the flue gas. Nevertheless, this water vapor contains a significant amount of energy which can be recovered if this water vapor is allowed to condense. There is commercially available heat recovery equipment which has been specifically designed for clean burning fuels (natural gas, methane gas, propane, fuel oil, etc.) to recover this latent heat of water vapor from the flue gas. These units are typically referred to as condensing economizers.

Depending on the fuel, condensing economizers can improve boiler efficiency by more than 10%. To achieve condensation in the flue gas stream, flue gas temperatures should get below the dew point. This is typically 60°C for natural gas combustion and as the flue gas temperature drops more and more water vapor condenses allowing for higher heat recovery.

7.1.2 Minimize excess air (oxygen rate sensor)

Proper combustion management requires adding enough oxygen to the combustion zone to burn all of the fuel but not adding too much air to ensure that the thermal energy loss is minimized. Combustion management evaluates the controlling methodology of the combustion process and begins with measurements.

Typically in boilers, fuel flow is controlled by steam header pressure. If steam pressure decreases the fuel flow controller will increase fuel flow for the boiler to generate more steam — restoring the steam pressure to the set point. Conversely, if steam pressure increases, fuel flow will be decreased to reduce steam production. As the fuel flow into the boiler changes combustion, air flow must correspondingly change to maintain proper combustion.

Automatic oxygen trim control

This automatic oxygen trim control is much more effective and efficient compared to the positioning control (combustion air flow control is accomplished by mechanically linking the air-flow control device (damper) to the fuel-flow control device). Combustion airflow is controlled by a combination of the fuel flow control valve and the flue gas oxygen monitor in the flue gas. Based on a burner manufacturers' combustion curve, a main air-flow control device (damper) is provided a signal based on the fuel-flow control valve. In order to estimate the potential benefit of minimizing excess air it will be necessary to evaluate the total boiler operating costs and the current and new operating boiler efficiencies.

7.1.3 Clean boiler heat transfer surfaces

Fouling on the heat transfer surfaces leads to additional heat transfer resistance which leads to higher flue gas exhaust temperatures. This leads to lower boiler efficiency because a significant amount of energy is left in the flue gases exiting the chimney. Hence, there needs to be a predictive and preventative maintenance procedure that is aimed at periodically cleaning the heat transfer surfaces in the boiler.

When heavier liquids and solid fuels (coal, wood, black liquor, etc.) are used in the boiler, there is significant ash and carbon soot build up on the tubes of the boiler. A direct indicator of fireside fouling will be an increase in the flue gas exhaust temperature and trending it will provide valuable information on the effective performance of the soot - cleaning system.

Waterside heat transfer fouling is controlled by boiler water chemistry and is a direct function of boiler pressure, feedwater quality and blowdown rate. Waterside fouling is “scale” on the tube surfaces that results in an increased heat transfer resistance. Scale has to be chemically or mechanically removed when the boiler is shutdown. Scale leads to increased tube wall temperatures and eventually a breakdown of the boiler tubes. Hence, waterside fouling has a direct impact on the reliability of boiler operations as well as the overall boiler efficiency. It is very important to perform inspections of boiler tubes for scale during the annual shutdown and undertake de-scaling of boiler tubes periodically.

Energy savings calculations using the stack loss calculator can be performed for justifying cleaning of boiler heat transfer surfaces.

7.1.4 Improve water treatment to minimise boiler blowdown

Generally, feedwater quality is impacted most by the makeup water. Condensate is commonly the cleanest water in the steam system. Makeup water must be conditioned before it is added to the system. The makeup treatment system can be improved resulting in improved makeup quality.

Boiler makeup water has to be treated appropriately based on the water chemistry requirements for reliable boiler operations. Blowdown management depends on two factors: boiler operating pressure and water treatment. Ensuring the highest quality of makeup water available will reduce the amount of blowdown required. Reduction in the amount of blowdown leads to a proportional reduction in the thermal energy lost in the blowdown stream. Nevertheless, there could be a significant cost to improve water treatment if it requires additional infrastructure and implementation of capital assets such as a demineralization system or a reverse osmosis system. In most industrial boiler systems, there will be a water chemist (or a contractor) who will be responsible for maintaining boiler water chemistry. It is best to work with them to ensure what is the optimum quality of water treatment necessary for the site. Common improvements to water treatment quality include changing from sodium-cycle softening to demineralization or to reverse osmosis conditioning.

7.1.5 Install an automatic boiler blowdown controller

In most circumstances, manual blowdown control leads to excessive blowdown and this is a large energy loss. But sometimes manual blowdown can also be not enough and that can result in very poor boiler water chemistry control leading to issues with reliable boiler operations. Installing an automatic boiler blowdown controller allows for the minimum and exact amount of blowdown that is required for reliable boiler operations thereby, reducing unnecessary energy losses. An automatic boiler blowdown controller monitors boiler water conductivity continuously, in real-time, and controls a modulating or an ON/OFF valve to maintain the required blowdown.

7.1.6 Recover energy from boiler blowdown

Blowdown thermal energy recovery takes two forms and virtually all the energy lost in the boiler blowdown can be recovered using a combination of these two methodologies:

- Flash steam recovery
- Make-up water preheating

The high-pressure blowdown stream is first flashed into a pressure vessel (flash tank) operating at low-pressure (typically slightly above deaerator pressure). Part of the blowdown liquid flashes to steam at the lower pressure. This flash-steam is clean and can feed the low-pressure steam header or supply steam to the deaerator or feedwater heating system. The liquid that remains in the flash-vessel is at the saturation temperature (> 100°C) and can still be used to preheat make-up water in the make-up heat exchanger. The blowdown water is eventually discharged from the system at a temperature very close to the make-up water (or ambient) temperature.

From an equipment perspective, the flash tank is a very simple unit and can be procured very cheap. Nevertheless, the heat exchanger has to be selected carefully. The heat exchanger applied in this service must be capable of being cleaned because the blowdown stream can foul the heat exchange surface.

7.1.7 Add steam accumulator

The purpose of a steam accumulator is to release steam when the demand is greater than the boiler's ability to supply at that time, and to accept steam when demand is low. Steam demands on any process plant are rarely steady, but the size and type of the fluctuations depend on the application and the industry. Peaks may occur once a week or even once a day during start-up. In short, peaks are responsible for loss of production, reduced product quality, increased production times, poor quality steam from the boiler, low fuel efficiency, high maintenance costs, reduced boiler life.

7.1.8 Optimize deaerator operations

The deaerator performs several functions in an industrial steam system. They include:

- Deaerating or removing dissolved oxygen from the feedwater (most important function)
- Preheating the make-up water
- May serve as a tank for mixing the returned condensate with make-up water
- Serving as a storage tank for feedwater and supplies the boiler feedwater pump

The deaerator operates at a fixed pressure. The main function of the deaerator – removal of dissolved oxygen from water – requires a stripping action. The stripping action is provided by the steam. Additionally, the steam preheats the makeup water which reduces the solubility of oxygen in the dissolved water further enhancing the stripping process. The deaerator requires a direct injection of live steam. The amount of steam used depends on:

- Deaerator pressure
- Amount of condensate returned and make-up water
- Temperature of condensate returned
- Temperature of make-up water
- Deaerator vent rate

As deaerator pressure is increased, more steam is needed and the amount of steam vented (from the vents) also increases. Nevertheless, if higher temperature condensate is being returned or if there is a waste heat recovery application that preheats the make-up water, then it may be beneficial to operate the deaerator at a higher pressure. Higher pressure operation will also require a smaller size deaerator for the same steam load. There have been several instances where processes change over time or are modified in industrial plants. This in turn may change the amount of condensate returned, temperature of condensate and make-up water preheating. Hence, it is very important to evaluate deaerator operations and ensure that it is operating at the **lowest possible pressure** and deaerating with the highest efficiency possible.

Additionally, reducing deaerator pressure will reduce the feedwater inlet temperature to a feedwater economizer and this may help to reduce flue gas temperature, which may lead to higher boiler efficiency. Care must be taken to ensure that lowering feedwater temperature doesn't reduce the flue gas temperature below its acid dew point.

7.1.9 Investigate fuel switching

Fuel selection can provide significant reductions in operating costs due to differences in energy costs and boiler efficiencies. The fuel efficiency will generally be an influencing factor when changing fuel. Sometimes energy costs and maintenance expenditures maybe offsetting but this will not be evident unless additional due diligence is done on the optimizing opportunity. Additionally, environmental issues can become a significant concern associated with fuel selection. Each application will require an independent evaluation.

7.1.10 Minimize the number of operating boilers

Typically, steam system savings opportunities and optimization in the plant may not lead to shutting down an operating boiler but this opportunity has to be investigated every time there is a change in the steam demand. There may be opportunities based on production cycles, seasonality, weekend/weekday and holiday operations, day/night operations that may all impact number of boilers operating in an industrial plant. Most often this opportunity is neglected due to the added complexity of turning ON and OFF a boiler and the amount of start-up time required. This can be an issue for large solid fuel-fired boilers but smaller boilers, especially operating with natural gas, methane gas, etc., should be much more amenable to a quick start-up.

When analyzing this as a potential optimization strategy, a thorough risk analysis should be done to identify any major issues that may result on the production end with a certain drop in steam production for a finite period of time. Additionally, the cost of additional controls or tell-tale instrumentation (alarms, temperature signals, pressure signals) should be taken into consideration when implementing this optimization strategy.

7.1.11 Install variable speed control for fans, blowers and pumps

An adjustable speed drive (ASD) is a device that controls the rotational speed of motor-driven equipment.

Variable frequency drives (VFDs), the most common type of ASD, are solid-state electronic motor controllers that efficiently meet varying process requirements by adjusting the frequency and voltage of power supplied to an alternating current (AC) motor to enable it to operate over a wide speed range. This is a much more energy efficient alternative to dampened flow, where the operating point of the motor moves down the system curve.

External sensors monitor flow, liquid levels, or pressure and then transmit a signal to a controller that adjusts the frequency and speed of the motor to match process requirements.

A change of the pump speed will bring a change of the characteristic curve, the efficiency and also of the absorbed power.

The transition from one operating condition to another can be done very smoothly bearing in mind that the flow rate Q, the head H and the power W detected at ‘n’ rpm (revolutions per minute) and the flow rate Qx, the head Hx and the power Wx, when the rpm is ‘nx’, are related by the following relations:

$$Q_x = \frac{n_x}{n} Q \; ; \quad H_x = \left(\frac{n_x}{n}\right)^2 H \; ; \quad W_x = \left(\frac{n_x}{n}\right)^3 W$$

In addition to energy benefits, VFDs adoption takes further advantages, such as: soft- starting capability; reduced voltage fluctuations that can occur in starting up large motors, and lower maintenance costs.

7.1.12 Repairing or adding boiler insulation

The walls and combustion parts of boilers are typically covered with insulating materials to reduce energy loss and to prevent leakage. There are several types of boiler insulating materials, including brick, refractory, insulation, and lagging. The selection and design of boiler insulating materials depends largely on the age and design of the boiler. Since the insulating material is exposed to high temperatures and is subject to degradation, it should be periodically inspected and repaired when necessary. New materials allow efficient insulation in tight spaces previously impossible to insulate.

Insulation used for boilers and steam distribution components (valves, expansion joints, turbines, etc.) will be of these general types:

- high density fiberglass
- blankets or batts of fiberglass or mineral wool
- calcium silicate, mineral fibre, fiberglass
- cellular glass

7.1.13 Low NO_x burner

When fossil fuels are burned, nitric oxide and nitrogen dioxide are produced. These pollutants initiate reactions which result in the production of ozone and acid rain. The nitrous oxides (NOx) come from two sources: high-temperature combustion (thermal NOx) and nitrogen bound to the fuel (fuel NOx).

NOx production is of special concern in industrial high-temperature processes because thermal NOx production increases with temperature. These processes include metal processing, glass manufacturing, pulp and paper mills and cement kilns. Although natural gas is the cleanest-burning fossil fuel, natural gas can produce NOx emissions as high as 500 ppm or more.

Low NOx burners are designed to control fuel and air mixing at each burner in order to create larger and more branched flames. Peak flame temperature is thereby reduced, and results in less NOx formation. The improved flame structure also reduces the amount of oxygen available in the hottest part of the flame thus improving burner efficiency.

Another advantage of the low NO_x burner is the reduction of excess air in the flue gas and thereby reduce the loss in the flue gas.

7.1.14 Combined heat and power unit (produces heat and electricity)

Combined heat and power - These systems direct the hot exhaust gases from a gas turbine (approximately 500°C) through a boiler, where saturated steam is generated and used as a plant utility. The electricity generated can either be used on-site or, in some circumstances, fed to the electrical grid.

Typical applications for these systems are on plant or sites where the demands for electricity and steam are in step and of proportions which can be matched to a CHP system. Efficiencies can reach 90%.

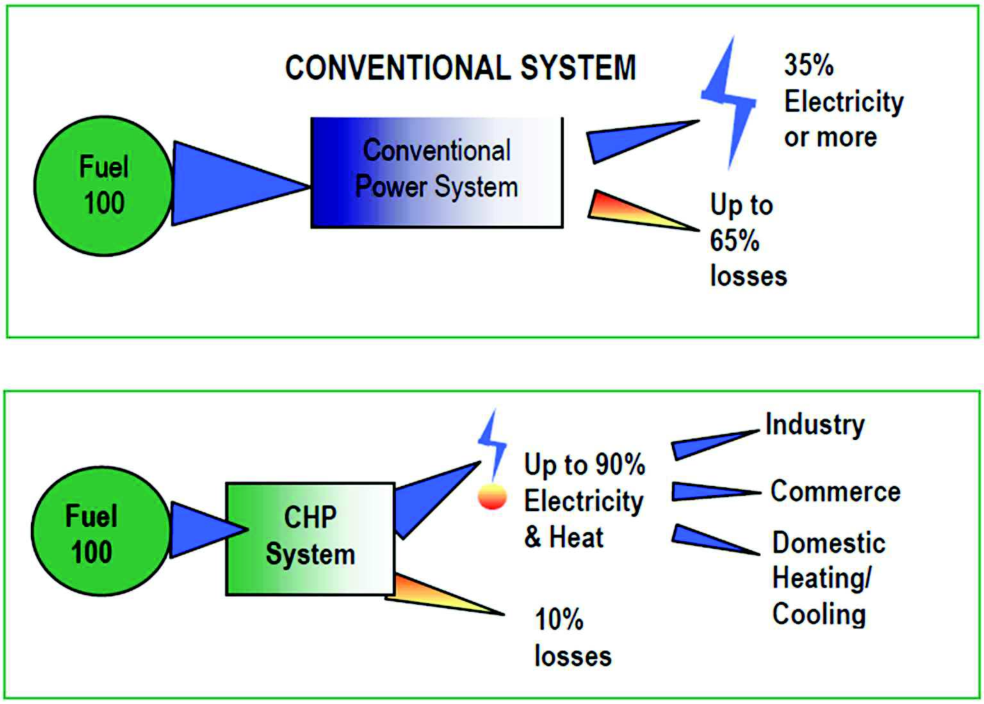


Figure 7.1: Comparison of conventional and CHP system (Source: UNEP)

The economic viability of a CHP Plant depends on the following factors: (1) the cost for the purchase and installation of the CHP plant, (2) the efficiency of the steam boiler or steam generator, (3) the cost of the fuel that powers both the steam boiler/generator and the CHP unit, (4) the cost of electricity, (5) the feed-in tariff, (6) maintenance costs for the steam boiler/generator and the CHP units.

7.1.15 Install a steam generator

Install the steam generator is preferable in these cases:

- The amount of steam required is too small to warrant a shell boiler, i.e. less than 1 000 kg/h.
- The small process requiring steam operates on a day shift only, meaning that the plant would be started every morning and shut down every night.
- The capital cost of a conventional shell boiler would adversely affect the economic viability of the process.
- The level of expertise on site, as far as boilers are concerned, is not as high as would be required on a larger steam system.

To meet these specific demands a steam generator can be used. The advantages using a steam generator compared to conventional steam boilers are:

- Easy to operate - normally no requirement for boiler authorization
- Rapid start-up and establishing full steam pressure
- Compact and easy to adapt in the existing machinery arrangement
- Price attractive - especially at low steam rates.

7.2 Steam distribution efficiency improvement opportunities

Optimizing steam distribution system in an industrial plant can focus on many different areas. These areas are fundamental in the field of energy management and generally result in attractive economics when savings opportunities are identified. These areas are also essential to the continued efficient and reliable operation of any steam system.

Table 7.2 : Common optimization opportunities in the steam distribution area

Opportunity	Description
STEAM DISTRIBUTION	
Repair steam leaks	Minimizes avoidable loss of steam
Minimize vented steam	Minimizes avoidable loss of steam
Ensure that steam system piping, valves, fittings, and vessels are well insulated	Reduces energy loss from piping and equipment surfaces
Implement an effective steam-trap maintenance program	Reduces passage of live steam into condensate system and promotes efficient operation of end-use heat transfer equipment
Isolate steam from unused lines	Minimizes avoidable loss of steam and reduces energy loss from piping and equipment surfaces
Utilize backpressure turbines instead of pressure reducing valves	Provides a more efficient method of reducing steam pressure for low-pressure services
Drain condensate from steam distribution	Avoids water hammer, ensuring the supply of dry steam
Check if distribution lines used are optimized for the current steam use	Lines may have been designed years ago and now they could be reduced or modified for a better efficiency.
Check the number and location of the stream traps and detect lack/excess of steam traps	Check if the ones installed are correct for the purpose (this last point can apply to any existing steam trap).

Non-energy benefits

Non-energy benefits in the field of steam distribution depend in this case on the type of optimization measures. In addition to energy cost savings, these benefits include environmental benefits (reduced local emissions), worker safety and health, noise reduction benefits, and financial benefits (other than energy cost savings) like reduced water consumption, reduced equipment operation and maintenance costs.

7.2.1 Repair steam leaks

Steam is an expensive utility for which significant economic losses can result when steam is lost from the system through leaks. A continuous maintenance program based on finding and eliminating steam leaks is essential to the efficient operation of a steam system. Most times, such maintenance programs are questioned in the industrial plant as regards their cost-effectiveness and overall impact to operations. But it has been observed in all instances that having a steam leaks management program can be very beneficial both economically as well as from a reliable operations perspective for an industrial plant.

7.2.2 Minimize vented steam

Steam venting happens when safety relief valves or other pressure controlling devices vent steam to the ambient from the steam header. This typically happens due to steam unbalance on the headers when more steam is being generated than needed by the end-use processes. The energy and cost savings potential can be very significant based on what the impact fuel maybe. Venting of steam most often happens automatically as steam header pressure limits are reached.

Combined Heat and Power (CHP) industrial plants that have steam turbines in operation may see steam venting more often than others, especially if there are only backpressure steam turbines driving process loads or operating under fixed power generation (or steam flow) conditions. Industrial plants having condensing turbines will almost never have steam venting unless the operating maximum capacity limits for the condensing turbine(s) has been reached. In several instances, an economic analysis based on marginal fuel and electric costs has to be done to determine the real value of vented steam.

7.2.3 Ensure that steam system piping, valves, fittings, and vessels are well insulated

Insulation is extremely important on steam systems for the following reasons:

- Plant personnel safety
- Minimizing energy losses
- Maintaining steam conditions for process end-use requirement
- Protecting equipment, piping, etc. from ambient conditions
- Preserving overall system integrity

A first-order heat transfer model can be developed and used to determine the convective (natural and/or forced) and the radiant heat transfer energy losses that exist from all the areas that are either uninsulated or poorly insulated. Nevertheless, this can be cumbersome and will require heat transfer correlations which will vary based on geometry and the modes of convective heat transfer – natural or forced. Nevertheless, an analysis must be completed to determine the energy and cost savings as well as an economic insulation thickness. Many empirical and computerized tools are available to aid in the evaluation of insulation projects.

7.2.4 Implement an effective steam trap maintenance program

Steam trap testing is highlighted separately since it is often the cause of significant steam system heat loss. It is common in steam systems that have not been maintained for several years for 15% to 50% of the installed steam traps to have failed.

Most of the energy stored in steam is in the form of latent heat. Failure to recover that latent heat, due to a faulty steam trap, results in major energy loss and often represents an opportunity for significant cost savings. To avoid large energy losses, a steam trap management programme should be put in place that:

- trains site staff or use the services of a specialist provider
- inspects every steam trap on a regular basis, with particular emphasis on critical equipment. Trap testing must be done while the plant is running, and repair can often coincide with other remedial work. Alternatively, equipment for continuous steam trap monitoring may also be used, particularly on critical plant or where potential losses are high.
- assesses its operating condition
- maintains a database of all steam traps, both operational and faulty
- identifies the suitability of traps and ancillaries
- determines the cost of energy loss from failed traps
- acts on the assessment findings.

Again, it can be difficult to assess the energy loss from faulty steam traps. Losses from steam traps can be estimated based on the condition of each trap tested, and the calculated steam flow that may result if it has failed, as determined from trap orifice size and steam pressure.

7.2.5 Isolate steam from unused lines

As industrial processes change, steam demand varies and sometimes steam is no longer required for a particular process, facility or air-handler. Nevertheless, the steam lines are still in place and contain live steam till the first block (isolation) valve of the process end-use. There are also times when certain equipment is decommissioned and will never be used again but the steam lines to that equipment are still connected to the live steam headers and are hot. This same situation can also happen during seasonal variations when the plant goes from a heating mode (in winter) to a cooling mode (in summer) where the steam lines are still running hot – adding more load to the cooling system. There are innumerable such circumstances that can exist in industrial plants and they all lead to significant energy and cost savings opportunities that a steam system optimization should capture via a systematic analysis of the distribution system in conjunction with the process end-uses.

From an energy and cost savings perspective, isolating steam from unused lines would:

- Eliminate heat transfer losses
- Eliminate steam leaks
- Eliminate any condensate formed in the headers which may lead to water hammer
- Reduce maintenance requirements of steam system components in that section.

7.2.6 Utilize backpressure turbines instead of pressure reducing valves

Typically, steam is generated at a higher pressure and distributed on different lower pressure headers or via a single pressure header. Nevertheless, there are pressure reducing stations which drop the steam pressure appropriately. As steam flows through the pressure reducing valve, it expands (with pressure reduction) and temperature reduces. Hence, steam going through a pressure reducing valve doesn’t loose its energy content (kJ/kg) because it is an “isenthalpic” process - the steam enthalpy does not change. Nevertheless, the entropy of steam does change and that implies that the steam’s ability to do shaft work reduces.

Each industrial plant should evaluate the possible use of steam turbines if there exists a continuous and significant steam flow through pressure reducing valves. The optimization opportunity has been listed in this area to ensure that steam is generated in industrial plants at the proper pressure required and there aren't any unnecessary inefficiencies due to steam expansion. A pressure reducing station will need periodic maintenance and most often it is not insulated.

7.2.7 Drain condensate from steam distribution

A steam distribution system can be extensive and there could be miles of steam piping in an industrial plant. Even when the steam lines are well insulated there is a certain amount of heat loss that exists which could lead to condensation in the steam headers especially for saturated steam systems.

Condensate that is drained from the steam headers can be flashed in a flash tank / separator vessel to a lower pressure steam header. The remainder of the condensate can either be sent back to the boiler plant directly or to a cascade condensate return system. It is very important to identify potential opportunities in the steam distribution area where condensate can and should be collected and returned back to the boiler plant.

7.2.8 Check if distribution lines used are optimized for the current steam use

The objective of any fluid distribution system is to supply the fluid at the correct pressure to the point of use. It follows, therefore, that pressure drop through the distribution system is an important feature.

Steam oversized pipework means:

- Pipes, valves, fittings, etc. will be more expensive than necessary.
- Higher installation costs will be incurred, including support work, insulation, etc.
- For steam pipes a greater volume of condensate will be formed due to the greater heat loss. This, in turn, means that either:
    - More steam trapping is required, or
    - Wet steam is delivered to the point of use.

Undersized pipework means:

- A lower pressure might be available at the point of use, which may hinder equipment performance.
- There is a risk of steam starvation due to an excessive pressure drop.
- There is a greater risk of erosion, water hammer and noise due to the inherent increase in steam velocity.

The friction factor (f) can be difficult to determine, and the calculation itself is time consuming especially for turbulent steam flow. As a result, there are numerous graphs, tables and slide rules available for relating steam pipe sizes to flowrates and pressure drops.

7.2.9 Check the number and location of the stream traps and detect lack/excess of steam traps

Many plants spend considerable effort in testing steam traps and then repairing or replacing them, usually based on a replacement strategy. This approach will re-establish the plant's steam system to its original design, with no improvement over that design, which may be many years old.

If the original design uses inappropriate or suboptimal trap technology, the full benefits of a trap-management program may not be realized. Therefore, before starting the survey, it is a good practice to check the number and location of the stream traps and detect lack/excess of steam traps.

At that point the evaluation of current steam trap practices to determine how they might be improved can be implemented. Using this approach, higher-performance traps can be selected. An effective method for assessing the existing steam trap technology involves a lifecycle cost model.

Maintaining a steam trap database is absolutely essential for an effective steam trap management program.

This database, at a minimum, should contain the following fields:

- Trap tag number; Location; Trap type; Model number; Manufacturer
- Date when the trap was last checked for performance
- Date when the trap was installed (or re-installed after failure)
- Cause of trap failure
- Potential economic loss if trap fails to open
- Potential production issues if trap fails to open/close
- Indication of trap failed to open/close

7.3 Steam end use efficiency improvement opportunities

Industrial steam end-use is very varied and even the same basic process is different from one industry to another. As a result of that it is very difficult to cover steam end-uses in a simple training manual. Nevertheless, steam end-use is the main reason for having a steam system in an industrial plant and should not be neglected. Enough due diligence should be given to study and understand end-use because optimizing steam in end-use can provide significant benefits both from a perspective of fuel energy and cost savings as well as production and yield improvements. Plant personnel working in steam systems in industrial plants should be trained to understand how steam is used in their specific plants. This will allow them to really optimize their steam systems for their specific plant operations.

Table 7.3 : Common optimization opportunities in the steam end use area

Opportunity	Description
STEAM END USE	
Eliminate or reduce the amount of steam used by process	Improves the process efficiency
Use steam at as low a pressure as possible	Improves the process efficiency
Check that heat flows in each specific process are exchanged to optimize the use of the heat.	Improves the process efficiency

Non-energy benefits

Non energy benefits in steam use depend in this case on the type of optimization measures. In addition to energy cost savings, these benefits include worker safety and health, financial benefits (other than energy cost savings) like reduced water consumption, reduced equipment operation and maintenance and productivity increases.

For any steam system optimization analysis, it is very important to understand how much steam is used by each end-user in the industrial plant. This information can be gathered on an overall steam system level or can be gathered for each individual pressure header level or by each individual area within an industrial plant. Most times it is difficult to create such a steam end-use distribution pie chart because sub-metering and flowmeters may not be available at each end-user. It is recommended that plant personnel understand operations and together with design information be able to assign steam demands (and heat duties) to the end-uses based on process load conditions. This methodology will help tremendously to develop an overview of the steam end-use and identify the major end-uses that one needs to focus attention on while undertaking an industrial steam system optimization.

7.3.1 Eliminate or reduce the amount of steam used by process

Reducing requirements for process heat and steam services can involve a number of measures.

There are also alternatives to using heat and steam, particularly in chemical processes, that could be investigated. For example:

- Replacing steam with hot water where appropriate will reduce energy consumption by lowering the boiler water output temperature and reducing losses associated with managing high pressure steam.
- Recycling content in material manufacture contributes to energy savings because recycling processes can be run at lower temperatures compared to the full-cycle processing of raw materials.
- Optimising the water content of bricks before kiln-firing has been shown to significantly reduce the amount of heat and time required for the process

7.3.2 Use steam at as low a pressure as possible

Steam pressure plays an important role when trying to maximize the energy transfer of steam. Latent heat or heat of vaporization is the energy released by steam when it condenses. Latent heat is transferred to the process as heat energy. The quantity of latent heat in steam changes as pressure changes. Latent heat quantity increases as pressure decreases. To maximize latent heat transfer, steam should be used at as low a pressure as possible.

Steam pressure also controls the saturated steam temperature. As pressure increases, so does temperature. Since temperature difference governs heat energy transfer, the higher the temperature, the easier it is to transfer heat. The ease of energy transfer can yield a smaller heat exchanger due to the improved heat transfer. The trade-off for the smaller heat exchanger could be that much more steam is consumed, due to the decrease in latent heat of the higher pressure steam.

When steam is distributed through the piping system, steam pressure drops. Steam mains and steam branch lines are sized to distribute the steam without excessive pressure drop. When steam pressure drops, the total energy content of the steam also drops. To avoid the energy loss, steam mains and branches must be sized very carefully to avoid making the energy loss even higher than normal.

7.3.3 Check that heat flows in each specific process are exchanged to optimize the use of the heat

It is typical to use better or more heat exchangers to improve the use of the heat in the process.

Examples of heat exchangers can be often found in the drinks industry, especially in milk production. After pasteurization of milk (heating up to 75ºC) it is necessary to quickly cool the milk down to maintain the quality of the milk. Instead of using a cooling medium like water, fresh (unpasteurized) milk of 5ºC can be preheated so that the waste heat is directly used in the heating process.

7.4 Condensate recovery efficiency improvement opportunities

Once steam has transferred its thermal energy it forms condensate. This condensate has to be continuously removed for the process to continue in the industrial plant. Condensate is not a waste stream but is the purest form of water (distilled) in the industrial plant. It has a significant amount of economic value because:

- Condensate is much hotter than make-up water and hence, has significant thermal energy
- Condensate doesn't need any chemical water treatment other than condensate polishing
- If collected, condensate doesn't need to be drained.

The main metric to determine how an industrial plant is performing in the area of condensate recovery is to determine how much of the available condensate is actually returned to the boiler plant. The amount of available condensate is the amount of steam that is used in indirect heat exchange processes and condensing turbines. This calculation is typically represented as a ratio of amount of condensate returned to the amount of steam produced. Depending on the industrial plant, sometimes due to multiple headers, this ratio is also calculated at each header level and then for the overall steam plant.

Table 7.4 : Common optimization opportunities in the condensate recovery area

Opportunity	Description
CONDENSATE RECOVERY	
Implement an effective steam-trap management	Reduces energy losses
Recover as much as possible of available condensate	Reduces the amount of make-up water added to the system, chemicals for water treatment, energy losses
Recover condensate at the highest possible thermal energy	Minimize energy losse
Flash high pressure condensate to make low pressure steam	Exploits the available energy in the returning condensate

Non-energy benefits

Non-energy benefits in the field of condensate recovery depend in this case on the type of optimization measures. NEBs may consist mainly of environmental benefits like reduced water consumption, reduced amount of chemicals needed for water treatment and reduced fuel consumption.

7.4.1 Implement an effective steam-trap management

It is vitally important to have an effective steam trap management and maintenance program in an industrial plant. There can be several hundreds of steam traps in large plants and this steam trap population should be checked periodically for proper operation. It is necessary to inspect every steam trap in the facility and determine how it is performing at least once a year. There are many different types of traps that function based on different principles. In order to investigate the steam traps it is important to understand how each type works. Hence, these inspections should be completed by trained personnel that understand the operation of steam traps and the steam system in general. Steam trap functionality should be assessed through the use of appropriate instruments like ultrasonic sensors and thermometers.

Steam traps fail in two major modes that have a significant economic and/or operational impact:

- Failed Open
- Failed Closed

A failed-open steam trap allows “live” steam to discharge from the system and so becomes a steam leak. A failed-closed trap does not remove condensate and it backs up in the upstream equipment. If this is a process heat exchanger, production processes will be heat duty limited. If this trap serves a steam distribution header, then it could result in water hammer and damage components. Even a well-maintained steam system will typically experience a 10% trap failure in a 1-year period. If unchecked, this can translate into significant economic losses and operational issues to the system.

The assessment results should be compiled in a database that includes results for the trap:

- Good and working properly
- Failed open and leaking steam
- Failed open and blowing to ambient
- Failed closed

Steam loss estimation for each failed leaking trap should be provided in the assessment.

7.4.2 Recover as much as possible of available condensate

Optimizing condensate recovery begins by evaluating the current amount of condensate returned. Condensate returned should be evaluated based on different header levels. In large industrial plants which have an extensive distribution of steam system and a multitude of steam end-uses, condensate recovery depends on the following factors:

- Contamination levels
- Cost of recovery equipment
- Cost of condensate piping

The cost of recovery equipment and piping will depend on the physical location of the end-use compared to the boiler plant and the distance that condensate will have to piped to get it to the boiler plant. Additionally, designs will have to consider electrically pumping condensate back versus using the steam pressure and a lift station.

Condensate receivers can serve as a local collection point and help to reduce project costs of individually pumping condensate back from each end-user. Additionally, condensate receivers and flash tanks reduce the amount of steam entering the condensate return piping and this mitigates flow restrictions in the return piping. It will also help to eliminate water hammer in condensate return systems.

7.4.3 Recover condensate at the highest possible thermal energy

The higher condensate return temperatures imply lesser heating required in the deaerator. This directly translates to steam and energy cost savings. This optimization opportunity can be evaluated in a very similar manner. But collecting and returning high temperature condensate may need significant due-diligence which if not provided, could result in operational problems. The biggest concern is the issue of flashing that could happen in the condensate return lines. The problem can be magnified in a cascade system, where condensate from different locations is mixed and there are large temperature differences between the condensate returns.

The steam system optimization strategy weighs the additional cost of dedicated high temperature condensate return compared to having a condensate receiver / flash tank (with an ambient vent) to remove this extra thermal energy. Depending on the amount of condensate, this thermal energy can be significant and every effort should be made to capture condensate and return it back to the boiler plant with the highest thermal energy possible.

7.4.4 Flash high pressure condensate to make low pressure steam

In industrial plants which have steam usage at different pressure levels, this optimization opportunity can significantly impact operating energy and costs. Condensate contains a lot of thermal energy and if it is at a higher pressure it can be collected and flashed to produce low pressure steam. Depending on the location and proximity to the headers or end-uses, this low pressure steam directly offsets “live” steam on the low pressure header that was produced by the boiler. This optimization opportunity will clearly need a solid thermodynamic steam system model to evaluate the true economic impacts and using.

Annex I - steam audit report template

STEAM UP

STEAM UP Audit Report

Template

Name of Energy Auditor, Organisation

Name of Company, Location

1 Summary

1.1 Summary of Main Findings

NACE Code		
Energy information		**Unit**
Fuel consumption (total)		
Electricity consumption (total)		
Energy consumption for production of steam (unit and energy carrier)		
Steam Use Information		
Main processes (% of steam consumption)		
Main findings (control, temperature, alternatives)		
Steam Boiler Information		
Kind of fuel [gas, oil, biomass]		
Nominal steam capacity [tons/hour]		
Size of boiler [MWth]		
Boiler pressure level [barg] (pressure referred to atmosphere (1 bar absolute)		
Boiler's operation [hours/year]		
Kind of control (CO/O2)		
Exhaust gas temperature [°C] after Economizers (if existing), Economizer yes/no		
O_2 level in exhaust gas in [%]		
Steam Distribution Information		
Rate of condensate return [%] (at which Temperature [°C])		
Rate of direct used steam [%]		
Leakage detection at steam traps: yes/no (how often per year)		
Steam Management Information		
Set targets		
Energy Performance Indicators		
Non Energy Benefits identified for steam optimization		
Main responsibilities for steam in the company		
Current trainings		
Number of participants for STEAM UP Trainings		
Special points to be mentioned (e.g. very good practice)		
Energy saving measures proposed	**Saving potential for each saving measure estimated**	

1.2 Action Plan

Saving measure	**Energy saved**	**Costs saved [€/year)**	**Investment costs [€]**	**Economic Indicator (PB, IRR, NPV,…)**	**NEBs**

Incl. monitoring actions, measures, maintenance

The measures should be ranked according to the criteria defined with the company

2 Company Information

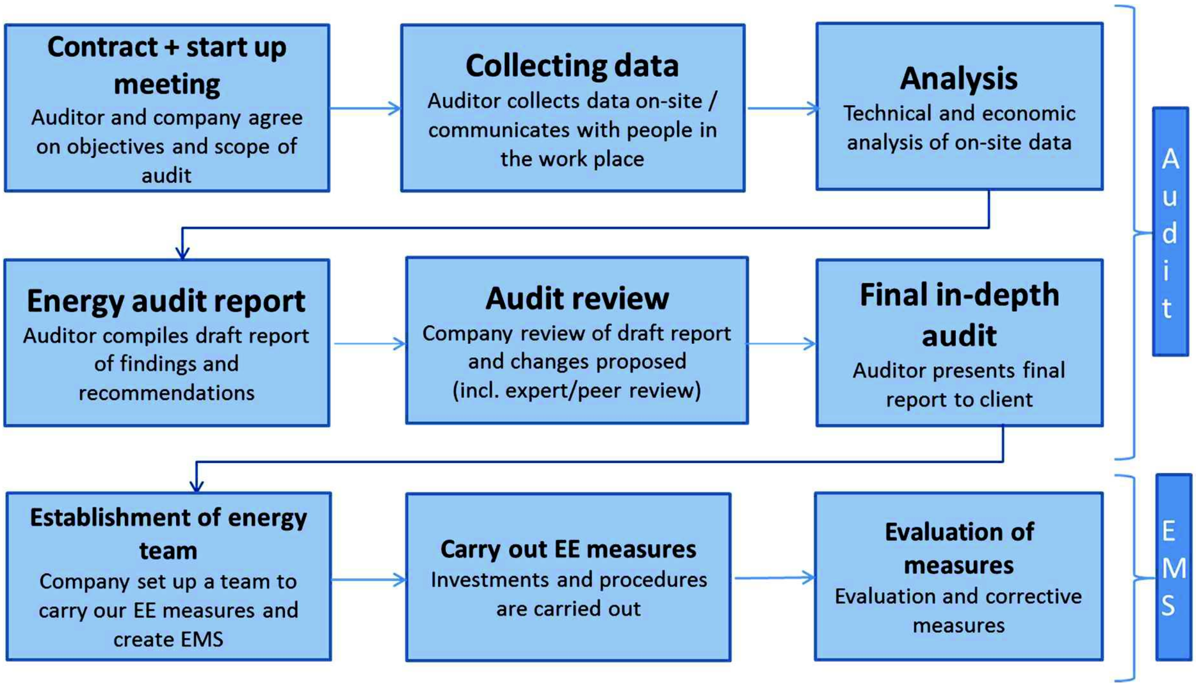
Company Information	
Branch	
Country	
Overview on processes and products on site:	
Main processes supplied by steam	
Area [m²] *(conditioned, not heated…)*	
Production data/year e.g. [t/year], [pieces]	
Number of employees [full time equivalent]	
Number of shifts Production time (hours/year), start-end per day	
Energy management system (ISO 50001?)	
other relevant information relevant	
Total yearly energy consumption and –costs	
Energy costs as percentage of the turnover	

- *Company Strategy (see also workshop results), what are the companies' long term targets:*
  - *market share, production level,*
  - *annual increase of turnover or profit*
  - *environmental policy*
  - *what is their main concern (at the moment)? This could be used to hook on the steam audit. Example from Denmark. For steam installations of a certain size and running time 24/7*
  -

3 Information on Energy Audit and Team Members

Steam Up Audits follow an comprehensive review outlined in the following figure:

Figure 1 STEAM UP Audit Approach



The main activities of some steps are explained in the following paragraph. Within the contract and the start up meeting the scope of the audit is agreed with the company. For collecting data checklists are used during the audit, different process may use different lists. For the analysis, calculations that have been made are indicated, incl. the purpose of the calculation. When establishing the energy team some members of the company management should be involved.

Audit Team Members*

List of Member **Name, function company (name and contacts for use during the audit only)**	**Telephone or Email contact (name and contacts for use during the audit only)**

**Onsite: (function: e.g. energy manager, production manager, boiler attendant, facility manager; Off-site: (consultant company, energy utility, installation company, steam system provider…);*

On-Site Visits

(Date of Kick-Off, further visits)

List of Site Visits **Date**	**Main Topics:**

Further (main) email, telephone contacts

List of Contacts Date	Main Topics:

Start Up Meeting Results

Topics discussed and decided	Result
Degrees of thoroughness required; Definition of Scope of the audit	
Timescale to complete the in-depth audit for steam;	
Criteria for evaluating energy efficiency improvement measures; only standard financial appraisal (IRR, NPV, LCC)	
The type of non-energy benefits (NEB) to take into account	
Expected deliverables and required format of the report;	
Presentation needed at the end?	
Costs and hours to be spent by employees agreed	
Information on follow up	

Further information

- *The management is informed about the method and they have expressed their willingness to participate;*
- *Analyse the steam system from a management point of view, i.e. what are its overall costs and alternatives*
- *Proposing an energy management system where steam is included*
- *Steam alternatives*
- *How does steam interact with the rest of the organization?*

4 Data on Energy consumption and Regression Analysis

This chapter summarizes data available for energy consumption in the company, on general level but also specific for the steam production. Furthermore an analysis is given to show the correlation between the steam consumption (or energy consumption for steam) in comparison to other relevant factors.

4.1 Total energy consumption

Table 4.1 : Total energy consumption of company (Delete lines, not relevant!)

For e.g. last three years and average year (mean average of last three years)					
Fuels and energy input	**Unit**	**Amount**	**Net Calorific value [GJ/unit]**	**Conversion to MWh**	**Annual costs Euro**
Electricity	MWh				
Heat	GJ				
Natural gas	m_n^3				
Other gas	MWh				
Black coal	t				
Brown coal	t				
Coke	t				
Other solid fuel	t				
Heavy fuel oil	t				
Light fuel oil	t				
Oil fuel	t				
Secondary sources	GJ				
Renewable sources	GJ				
Other fuels	GJ				
Total fuel and energy inputs					

4.2 Energy consumption for steam

Table 4.2 : Energy consumption for steam production (!Delete lines, not relevant)

For e.g. last three years and average year (mean average of last three years)					
Fuels and energy input	**Unit**	**Amount**	**Net Calorific value [GJ/unit]**	**Conversion to MWh**	**Annual costs Euro**
Electricity	MWh				
Heat	GJ				
Natural gas	m_n^3				
Other gas	MWh				
Black coal	t				
Brown coal	t				
Coke	t				
Other solid fuel	t				
Heavy fuel oil	t				
Light fuel oil	t				
Oil fuel	t				
Secondary sources	GJ				
Renewable sources	GJ				

Other fuels	GJ
Total fuel and energy inputs	

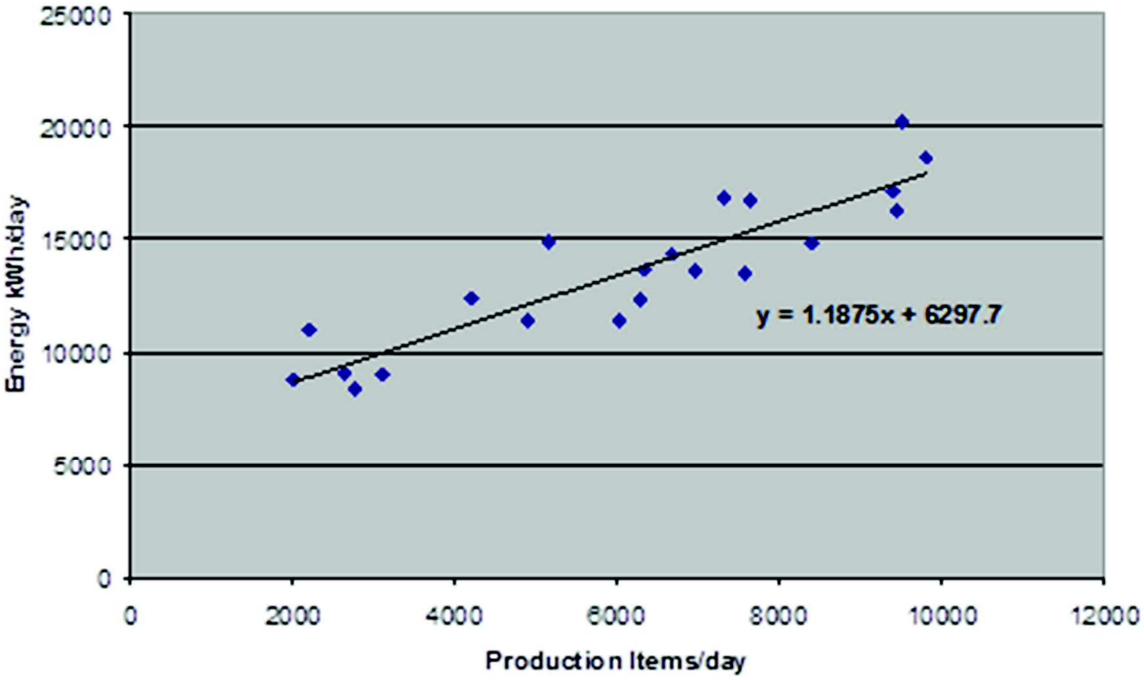
Table 4.3 : Annual balance of production from own steam source

C.	Title	Unit	2012	2013	2014	Average
1	Installed thermal power	MW				
2	Steam generation	GJ/year				
3	Steam delivery (external)	GJ/year				
4	Sale of steam	GJ/year				
5	Own consumption of heat for steam production	GJ/year				
6	Own energy consumption in fuel for steam production	GJ/year				

4.3 Regression Analysis

E.g. Monthly Steam Consumption (or gas) data vs. production data and/or outdoor temperature

Figure 2: example of regression analysis – energy consumption versus production level



5 Description of the Steam System

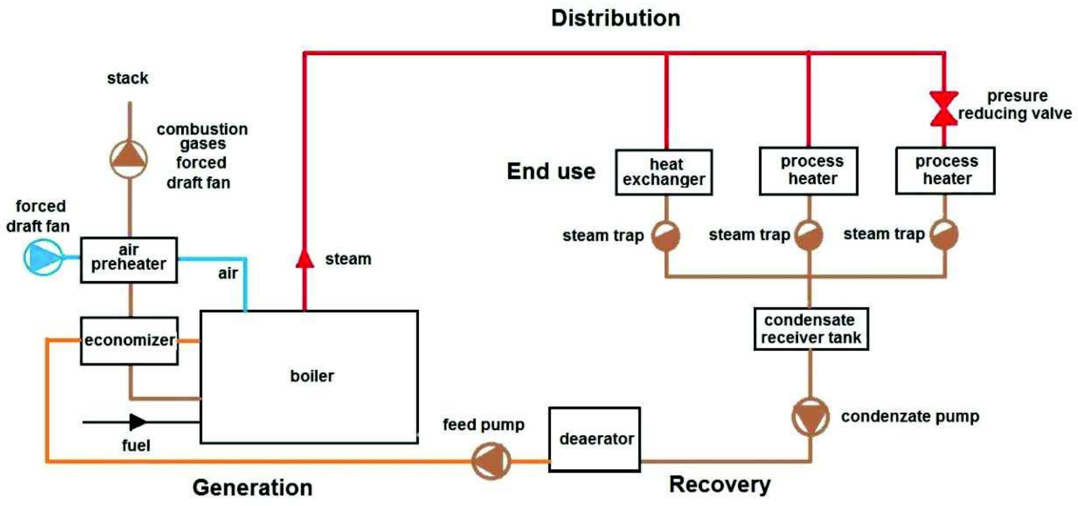
This chapter gives an overview on the steam system installed on-site.

5.1 Overview of Steam System

Table 5.1 : Basic technical characteristics of own steam source

C.	Title	Unit	2012	2013	2014	Average
1	Annual overall efficiency of steam generation (or flue gas losses)	%				
2	Fuel consumption for steam generation	GJ/year				
3	Annual operating hours of installed capacity	hours				
4	Specific cost for steam generation	€/GJ				

Simple Picture, eg



Source: ENVIROS

5.2 Steam Use

Responsible function in company:………………..

Table 5.2 Evaluation of measures already implemented

EVALUATION OF MEASURES ALREADY IMPLEMENTED	ACTUAL STATUS (example)
STEAM END USE	
Eliminate or reduce the amount of steam used by process	Done
Use steam at as low a pressure as possible	Used
Check that heat flows in each specific process are exchanged to optimize the use of the heat.	Checked

Table 5.3 : Example list of data to be collected

Steam use	
General information on the running of the company	Daily/annual production, operating times, start up and shut downs of production, shift patterns
Energy management and monitoring level	Which indicators, who monitors them?
Kind of operation	Drying, heating, cooking, sterilization, etc.
Types of machines using steam	Steam turbine, steam heat exchanger, steam dryer
Steam	Steam consumption, flow rates, pressure, temperatures, return systems, etc.
Condensates	Recovery of condensates, pipe sizing, etc.
Steam traps	Type, number and location
Operating hours	Number

5.2.1 List of Steam Consumers

Main Steam Consumers are …

Table 5.4 List of Steam Consumers

Steam Consumer description	Processes temperature [°C] Current/ needed	Steam-Pressure [barg, overpressure], Temperature	Mass flow steam [kg/h]	Running hours [h]	Other information
Eg. pasteurizer	80ºC	10 barg	1.000 kg/H	2.400	Pasteurizer designed for steam

5.3 Steam Generation

Responsible function in company:………………..

Table 5.5 : Evaluation of measures already implemented

EVALUATION OF MEASURES ALREADY IMPLEMENTED	ACTUAL STATUS (example)
Economizers and air preheaters	Installed
Minimize excess air (oxygen rate sensor)	Measured
Clean boiler heat transfer surfaces	Automatically,
Improve water treatment to minimize boiler blowdown	On high level
Install an automatic boiler blowdown controller	Installed
Recover energy from boiler blowdown	Installed
Add steam accumulator	Installed

Optimize deaerator operations	On high level
Investigate fuel switching	Fuel as waste from production
Minimize the number of operating boilers	Monitored
Variable speed control for fans, blowers and pumps	Installed
Repair or add boiler insulation	Installed

Table 5.6 : Example list of data to be collected

Steam generation	
Description of the facility	Total installed capacity, number of boilers and description of their normal use (e.g. two 3t/h boilers, one of them is stand-by of the other)
Description of operating mode	Cascade, backup, shutdown, supplementary, etc.
Generators	For each one, commissioning date, power, brand, type, kind of fluid, pressure, outgoing temperatures, nominal steam rate, thermal insulation level
Burner	Nature of fuels, age, type, power, control system (e.g. flue gas temperature, O2, ...)
Control and measurement equipment	Fuel, boiler, metering points (legal requirements for flue gas?)
Boiler efficiency equipment installed	Recuperators, superheaters, economizers, air preheaters
Power supply circuits	Feed water, temperature, pressure
Water treatment	Characteristics of water quality, treatment of boiler water
Flue gas	Exhaust flue gas temperature (after Economizer), O_2 level

Table 5.7 Information for boiler operation (Minimum information)

Kind of fuel [gas, oil, biomass]	
Nominal steam capacity [tons/hour]	
Size of boiler [MWth]	
Boiler Pressure level [barg] (pressure referred to atmosphere (1 bar absolute)	
Boiler’s operation [hours/year]	
Kind of control (CO/O2)	
Exhaust Gas Temperature [°C] after Economizers (if existing), Economizer yes/no	
O_2 Level in exhaust gas in [%]	

5.4 Steam Distribution

Responsible person:………………..

Table 5.8 : Evaluation of measures already implemented

EVALUATION OF MEASURES ALREADY IMPLEMENTED	ACTUAL STATUS (example)
STEAM DISTRIBUTION	
Repair steam leaks	Done
Minimize vented steam	Not done
Ensure that steam system piping, valves, fittings, and vessels are well insulated	Partly
Implement an effective steam-trap maintenance program	Not done
Isolate steam from unused lines	Isolated
Utilize backpressure turbines instead of pressure reducing valves	Installed
Drain condensate from steam distribution	Done
Check if distribution lines used are optimized for the current steam use	Checked
Check the number and location of the stream traps and detect lack/excess of steam traps	Checked

Table 5.9 : Example list of data to be collected

Steam distribution	
Kind of steam	Pressure, temperature, nominal flow rate, real flow rate
Type of network	Above-ground, channels, tunnel, distribution method
Characteristics	Lengths, diameters, flow rates, pressure, temperatures, return systems, etc.
Condensates	Recovery of condensates, pipe sizing, etc.
Steam traps	Type, number and location
Thermal insulation	Description, design
Losses	If it is determined
Networks	Condition and upkeep

5.4.1 Information on Leakage and Condensate Management

Table 5.10 Information on Leakage and Condensate Management

Parameter for steam distribution	
Rate of condensate return [%] (at which Temperature [°C])	
Rate of direct used steam [%]	
Leakage detection at steam traps: yes/no (how often per year)	

5.5 Data Analysis

In this chapter the main results of important calculations for analysing a steam system are given, incl. purposes

Examples of calculations are:

Calculation of stack loss:

Calculation of blow-down loss:

Calculation of degazificiation

Calculation of heat losses (boiler, network): as possible

6 Organisational Information Specific for Steam

Table 6.1 List of positions and their main responsibilities

List of positions relevant for steam use, distribution, production	Main responsibilities

Table 6.2 List of relevant energy management topics for steam

Energymanagement-Topics	Current procedure in the company
Are targets set?	
Is information on steam efficiency available in the company?, are there regular trainings	
Is top management involved in steam relevant procedures (design, optimization, monitoring)	
Are resources for steam system optimization available?	
Are trainings for relevant persons performed	
Who will participate in the Steam Up Training	
Are key characteristics of operation regularly measured, reported, analyzed? (when EnPIs defined, see point below)	
Energy Performance Indicators for steam installations, responsibilities, activities (which are reported to top-management, other employees, are there meetings, discussions on this topic...)	
Are measurement instruments properly maintained, calibrated? (Which instruments)	
Procurement of boiler components, design	
Legal Compliance	
How are events of non-conformance followed up?	
Process for Installation, commissioning	
Maintenance Information: (incl. budget of maintenance)	
Leakage detection, steam traps	
How are energy saving opportunities identified?	
Is the steam system analysed on regular basis for energy efficiency optimization?	
How is implementation measures organized?	
Which criteria are set for selecting efficiency options? (e.g. NPV)	
Are non-energy benefits accounted for?	

7 Proposed Steam Measures

Table 7.1 : Calculation of the proposed measures

Indicators	**Value**	**Unit**
Description of the measure		
Energy savings		MWh/year
Investment costs		€
Operating and maintenance costs before measure		€/year
Operating and maintenance costs after measure		€/year
Reduce costs due to measures		€/year
Simple Payback Period		year
Discounted payback period		year
Net present value (NPV) for the lifetime		€
Internal return rate (IRR) for the lifetime		%
Further indicators, e.g.: NPV for the lifetime of the technology assessed LCCA		
Non Energy Benefits considered:		